HIERARCHAL GENETIC (T-R UNIT) STRATIGRAPHY OF THE LOWER PERMIAN (GEARYAN STAGE) FORAKER FORMATION IN NORTHEASTERN KANSAS

by

FREDRICK J. BARRETT

B.S., Ft. Lewis College, 1984

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

(Geology)

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1989

Approved by:

Major Professor

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ABSTRACT

A hierarchal genetic stratigraphy approach of Busch (1984) and Busch and Rollins (1984), utilizing a series of of transgressive-regressive (T-R) units is used to define and acurrately correlate some Lower Permian strata of the Foraker Formation (Gearyan, Lower Council Grove Group) in northeastern Kansas. This approach was utilized to detect the total range of facies and facies contacts, based on its genetic time-stratigraphic principals, rather than on a single lithostratigraphic, Kansas cyclothem approach.

Based on detailed lithostratigraphic and biostratigraphic analyses of four detailed localities, the smallest recognizable units in outcrop and core are sixth-order T-R units of Busch (1984) and Busch and Rollins (1984). These are relatively thin, shallowing upward units bounded by genetic, transgressive surfaces; PACs of Goodwin and Anderson (1985). The relative extents of maximum transgression among the sixth-order T-R units define three fifth-order T-R units: the Americus, Hughes Creek, and Long Creek fifth-order T-R units. These fifth-order T-R units are distinct because they contain relatively thin, transgressive/retrogradational phases with relatively diverse faunal assemblages, and thicker regressive/progradational sequences characterized by interbedded algal-molluscan calcirudites (wackestones to packstones), relatively nondiverse to nonfossiliferous shale interbeds and laminated

calcilutite-paleosol couplets. The Americus, Hughes Creek, and Long Creek fifth-order T-R units form the basal part of a larger unit, called the Foraker fourth-order T-R unit. The Red Eagle and Burr fifth-order T-R units (Clark, 1987) form the upper part (in ascending fashion) of this T-R unit. The Foraker fourth-order T-R unit encompasses strata from the very upper Hamlin Shale Member (Janesville Formation) to the basal part of the Salem Point Shale Member (Grenola Formation).

Sixth- and fifth-order T-R units comprising the net transgressive, and the initial parts of the net regressive phase of the Foraker fourth-order T-R unit, are correlative across the study area. Autogenic deposits of a local nature occur only in the regressive phases of the Foraker fourth-order T-R unit.

Construction of sixth-order paleogeographic maps that represent maximum or near maximum transgressive conditions illustrated a non-random pattern of deposition relative to the fifth-order T-R units. During the initial transgressive/retrogradational and net regressive phases, environmental conditions were most variable across the area. During maximum fifth-order transgressions, the sixth-order paleogeographic maps illustrate that environmental conditions were essentially uniform. Isopach maps corresponded to paleogeogeographic development with the transgressive facies characteristically uniform in thickness, and the net regressive facies characteristically more variable in thickness.

Sixth-order paleogeographic and isopach maps facilitated the construction of composite paleogeographic and isopach maps. A recurrent trend of deepening and more open facies to the south and west, corresponds to recurrent thickening trends. A recurrent northwest-southeast shallowing to shoaling trend in the central part of the area corresponds to recurrent isopach thinning trends. Recurrent lagoonal-mudflat conditions in the northeastern part of the area, corresponds to a recurrent net thickening trend.

A transparent overlay of the composite paleogeographic and isopach map shows that specific sixth-order trends conform to the northeast-southwest and northwest-southeast trending structural framework of the area. Mapping on a sixth-order scale may provide the data necessary to detect subtle, local structural and stratigraphic hydrocarbon traps not otherwise detected at a larger scale. Shallowing and thinning facies correspond to isolated topographic highs along the Nemaha anticline, as well as to relatively more subtle structural highs to the east of the Nemaha anticline. Structural lows, along major synclinal axes and opposing pull-apart grabens, correspond to deeper, more open facies, as well as to the more restricted lagoonal-mudflat facies.

Fusulinids of the Foraker Formation (mainly Triticites) inhabited a wide range of environments, but commonly favored conditions associated with times of sixth-, fifth-, and fourth-order transgressive maxima. Thus, fusulinids were critically affected by extrinsic sea level changes; they do not form the central vertex about which like assemblages are disposed. Fusulinids inhabited a wide range of substrates, and occupy facies ranging from semi-restricted, nearshore _Crurithyris_ biofacies to maximum, offshore brachiopod-rich biofacies of the Foraker fourth-order T-R unit. The analysis of Foraker fusulinids relative to a hierarchy of T-R units, can be used to explain their distribution and evolution. Sixth-order fusulinid biofacies are essentially temporally, taphonomically, and spatially averaged biostratigraphic entities. Their phenotypic variation thus becomes magnified on a fifth-order scale. Because of widespread net dispersals coupled with fifth-order phenotypic variations, fusulinids on a fourth-order scale become index fossils. _Triticites ventricosus_ is an index for the Foraker fourth-order T-R unit. Radiations, extinctions, and dispersals of fusulinids at a third-, and second-order scale have resulted in the worldwide framework of fusulinid zones.

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ACKNOWLEDGEMENTS

Sincere thanks are expressed to my advisor, Richard M. Busch, for his guidance, knowledge, and suggestions in the field, laboratory, and classroom. I would like to acknowledge gratefully, Dr. Ronald R. West, for serving on my committee, for acting as thesis advisor and mentor in the final stages of this investigation, and for his invaluable assistance and suggestions during the completion of this project. Many thanks go to the other members of my committee, Dr. George Clark, and Dr. A. Paul Schwab, for reviewing this thesis.

I would especially like to thank my wife, Belinda, for having undue patience and endurance in the final year of my graduate studies, and for surviving the completion of this project. Sincere appreciation is expressed for the support and encouragement my parents have given me throughout my college career. Special thanks are also given to my brother, Terry R. Barrett, for his support, encouragement, and discussions on my study interval.

I would also like to gratefully acknowledge Jerry Hodgden, of Hodgden Oil Company for his suggestions, and the use of subsurface geologic maps in eastern Kansas. Gratitude is expressed to the Kansas Geological Survey, especially Dr. W. Lynn Watney for providing support for my summer field expenses and for supplying maps utilized in the field.

INTRODUCTION

A dichotomy of geologic thinking has surfaced in recent years, caused by a growing body of evidence that links sedimentary cycles and their depositional patterns to allocyclic, episodic sedimentation. The dichotomy arises when evidence of cyclic sedimentation based on minor eustatic sea level changes contradicts traditional models of sedimentation that are based on gradual, continuous stratigraphic accumulation (Goodwin and Anderson, 1985; Goodwin et al., 1986; Busch, 1984; Busch and Rollins, 1984; Busch and West, 1987). Sedimentologists and stratigraphers, particularly since the advent of seismic stratigraphy, have given "credence" to episodic processes and globally synchronous eustatic fluctuations that ultimately allow for intra- and interbasinal, and worldwide correlations of isochronous transgressive-regressive depositional sequences.

Cyclic sedimentation that is ascribed to intrinsic feedback mechanisms causing lateral migration of environmental elements, such as meandering channels or prograding tidal flats, is advocated by proponents of autocylicity. On the other hand, thin allocyclic units (punctuated aggradational cycles, or PACs) are considered by Goodwin and Anderson (1985) to be pervasive throughout the stratigraphic record. The pervasiveness of episodically formed, allocyclic units such as PACs, is based on cosmically driven (i.e., Milankovitch orbital perturbations), climatic variations and sea level fluctuations. According to Goodwin and Anderson (1985), autocyclic products are locally superimposed on an allocyclically formed stratigraphic record. With increased testing of their hypothesis, correlation methods and techniques have increased in recent years (e.g., Busch and Rollins, 1984; Busch and West, 1987; Grotzinger, 1986; and Van Tassel, 1987).

Utilization of the PAC hypothesis led Busch (1984), Busch and Rollins (1984), and Busch and West (1987) to develop a method of correlation whereby a nested hierarchy of transgressive-regressive (T-R) units, representing eustatically controlled deepening-shallowing events of differing scales, is used to establish a temporal-spatial framework for intra- and interbasinal paleoceanographic studies. Their time-stratigraphic, hierarchal genetic (T-R unit) stratigraphy is not only a viable method for testing the applicablility of Goodwin and Anderson's PAC hypothesis, but it may provide a wealth of new data regarding chronostratigraphic relationships, lithofacies development, and biofacies development, both vertically and laterally (Busch and Rollins, 1984).

Appalachian Carboniferous strata and Midcontinent Permo-Carboniferous strata have offered excellent opportunities for genetic, hierarchal, stratigraphic analyses based on the

PAC hypothesis (e.g., Busch, 1984; Busch and Rollins, 1984; Busch and Brezinski, 1984; Busch et al., 1985; West and Busch, 1985; Wells, 1985; Bisby, 1985a-b; Busch and West, 1987; Suchy, 1987; Bogina, 1988; Clark, 1988; Leonard, 1988; Busch, Clark, and Bogina, 1988; Busch, Bogina, and Clark, 1988; Busch, 1988; West et al., 1988). Midcontinent Permo-Carboniferous sequences have traditionally been described and interpreted relative to idealized cyclic or rhythmic vertical repetitions of lithofacies and their associations, based on what is now known as the "Kansas cyclothem" approach, defined by Heckel (1977, 1986).

Busch (1984) found the cyclothem approach impractical, because it was more feasible to define and accurately correlate widely persistent, time-stratigraphic, transgressive-regressive units themselves, including all contacts and facies. Rather than subdividing Pennsylvanian sequences in the Appalachian basin into cyclothems, Busch defined a hierarchy of genetic transgressive-regressive units (i.e., T-R units). These were delineated by carefully considering the total range of facies and facies contacts present in the sequences. Correlations among sequences were then made by aligning patterns in the hierarchy of T-R units from each locality relative to marker beds and biozones.

Although the Kansas cyclothem approach and the hierarchal (T-R unit) genetic stratigraphy of Busch (1984), Busch and Rollins (1984), and Busch and West (1987) have eustatic sea level fluctuations as a basic tenet of their stratigraphic methodology, they differ critically because: 1) the Kansas cyclothem approach invokes only gradualistic deposition based on vertical and lateral lithofacies (members) that form an irregular continuum; and 2) hierarchal genetic stratigraphy favors eposidicity and gradualism, and it does not rely on lithostratigraphic correlation, but rather on correlation of persistent, isochronous genetic surfaces that bound a nested hierarchy of T-R units. The purpose of this thesis is to demonstrate the applicability of hierarchal genetic (T-R unit) stratigraphy as a chronostratigraphic framework for understanding factors that affected deposition of some Lower Permian strata in northeastern Kansas.

Objectives

The objectives of this project are twofold. First, a punctuated aggradational cycle (PAC) approach (Goodwin and Anderson, 1985) will be used to define, and accurately correlate, a hierarchy of transgressive-regressive units (T-R units, after Busch and Rollins, 1984) in the Lower Permian Foraker Formation, Council Grove Group (Lower Gearyan), of northeastern Kansas. This study entails the analysis of the total range of biostratigraphic and lithostratigraphic units of each sequence to be studied. The hierarchy of T-R units at each location was defined by the inspection of all facies and facies contacts and their relative relationships. By utilizing a nested hierarchy of transgressive-regressive (T-R) units (after Busch and Rollins, 1984; and Busch and West, 1987), this approach differs from the traditional, cyclothemic approach (Heckel and Baeseman, 1975; Heckel 1977, 1985, 1986; Heckel *et al*., 1980).

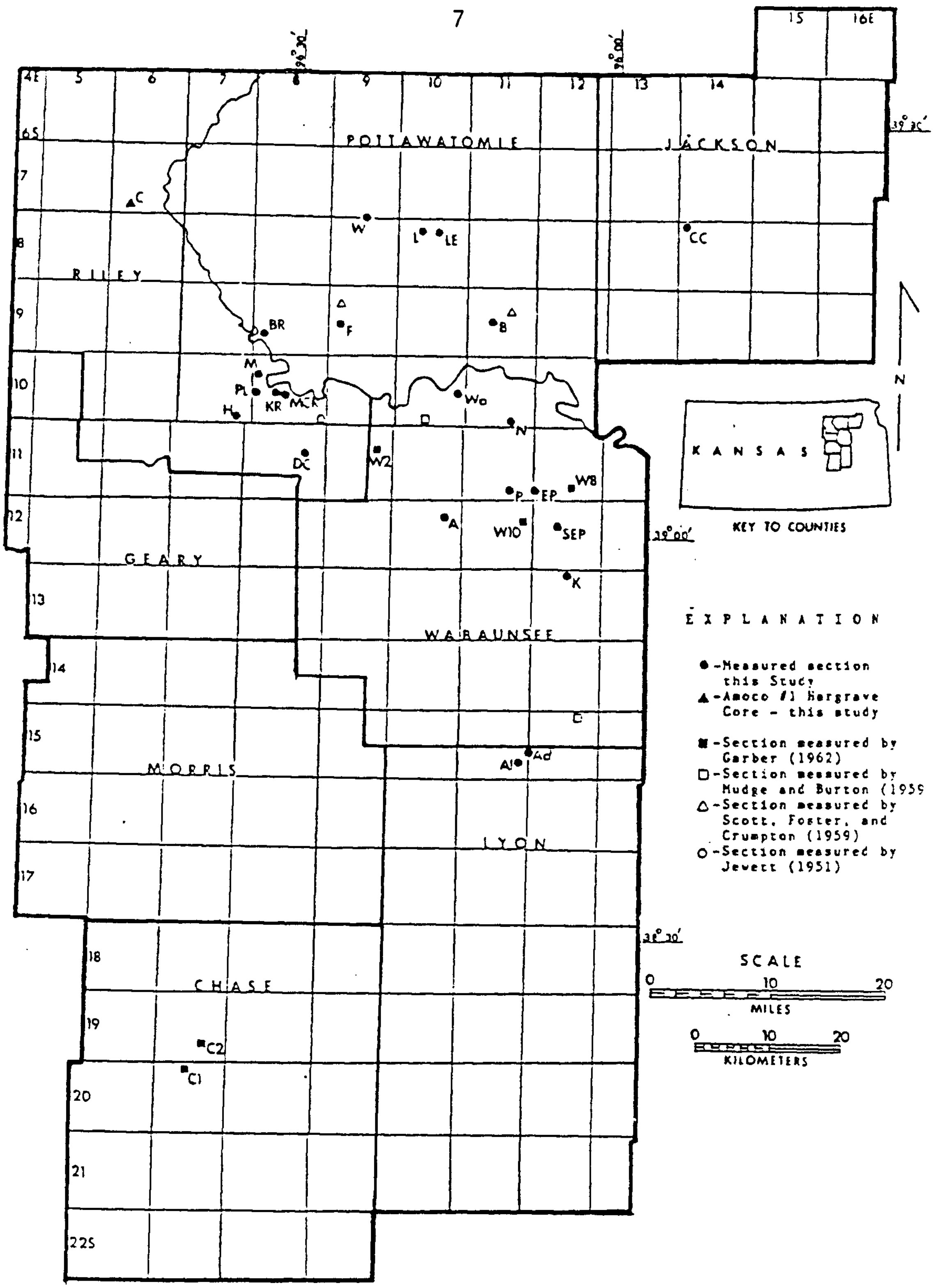
Secondly, correlation of the isochocronous, hierarchal T-R units, through marine and non-marine intervals, aids in differentiating allocyclic from autocyclic T-R units (Busch and Rollins, 1984; Busch and West, 1987). Using this stratigraphic framework, paleogeographic maps will be constructed, which will aid in understanding the controls over the development of lithofacies and biofacies in the Lower Permian Foraker Formation.

Area of Study

The Foraker Formation was studied in northeastern Kansas within the following counties: Riley, Pottawatomie, Jackson, Wabaunsee, Lyon, and Chase (Figure 1).

Physiography.--This study area is located predominately in the Great Plains Province and is adjacent to, or flanks, the western boundary of the Central Lowlands. More specifically, the southeastern part lies within the Osage Cuesta Plains subprovince, while the northeastern part lies

Figure 1. Area of study showing stratigraphic localities utilized in this study. Definition of locality abbreviations (in alphabetical order) that are included in the Appendix, are as follows: A = Alma section; Ad = Admire section; Al = Allen section; B = Belvue section; BR = Blue River section; C = Amoco #1 Hargrave core locality; CC = Crow Creek section; C1 and C2 = Garber's (1962) Chase County localities 1 and 2; DC = Deep Creek section; EP = East Paxico section; F = Flush section; H = Holidome section; K = Keene section; KR = Kansas River section; L = Louisville section; LE = Louisville East section; M = Manhattan section; MCR = McDowell Creek Road section; N = Newbury section; P = Paxico section; PL = Poliska Lane section; SEP = Southeast Paxico section; Wa = Wabaunsee section; W = Westmoreland section.


POTTAWATOMIE
JACKSON
RILEY
GEARY
WABAUNSEE
MORRIS
LYON
CHASE
KANSAS
KEY TO COUNTIES
EXPLANATION
●-Measured section this Study
▲-Amoco #1 Hergrave Core - this study
■-Section measured by Garber (1962)
□-Section measured by Mudge and Burton (1959
△-Section measured by Scott, Foster, and Crumpton (1959)
○-Section measured by Jewett (1951)
SCALE
0 10 20
MILES
0 10 20
KILOMETERS
N
39°30′
39°00′
38°30′
96°30′
96°00′

within the Dissected Till Plains subprovince. Most of the eastern part of the area is within the Flint Hills Upland subprovince, so-called because of the east facing cherty limestone escarpments that trend north-northeast.

Paleogeography.--The paleogeographic position of the study area during Foraker deposition was between 0 degrees and 10 degrees south latitude (Habicht, 1979). Therefore, Foraker deposition occurred in the southern hemisphere tradewind zone (low pressure, easterly winds).

Geologic Setting

Formal Lithostratigraphy.--The Foraker Formation represents the basal formation of the Council Grove Group, and consists of three members (Figure 2). In ascending order, these members are the Americus limestone, Hughes Creek shale, and Long Creek limestone. By formal definition, the Foraker Formation is underlain by the Janesville Shale Formation (Admire Group, Lower Permian) and is overlain by the Johnson Shale Formation (Zeller, 1968). Fisher (1980) regarded the basal boundary of the Foraker Formation as representing a regolithic (i.e., erosional) disconformity.

The Council Grove Group is underlain by the Admire Group, and is overlain by the Chase Group. The Admire, Council Grove, and Chase Groups collectively make up the Gearyan Stage. The Gearyan Stage and the

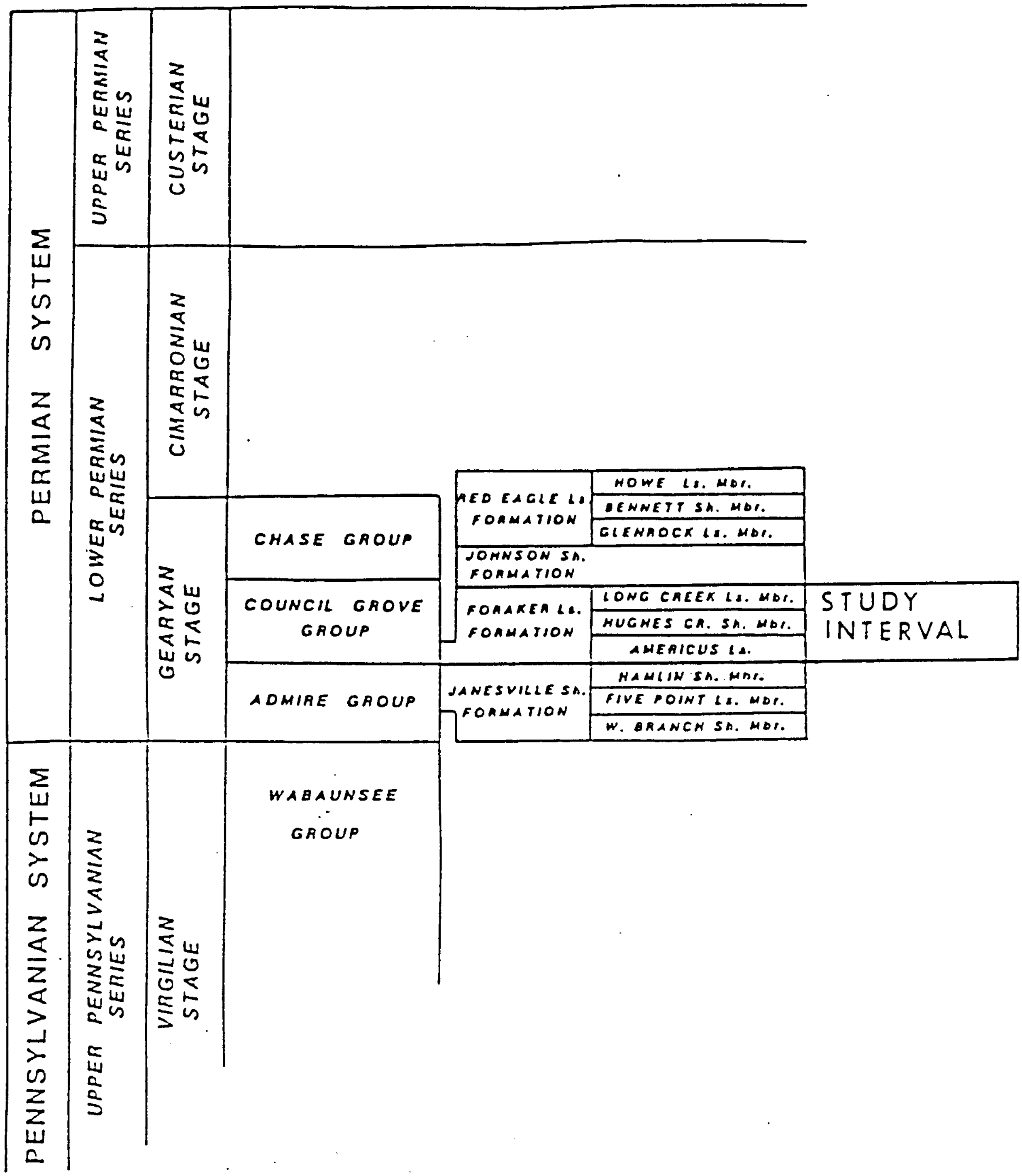


Figure 2. Stratigraphic nomenclature of Permian and upper Pennsylvanian Systems in Kansas, showing interval of study (adapted from Zeller, 1968; and O'Connor, 1963; taken from Fisher, 1980).

overlying Cimmaronian Stage form a two-fold classification that define the Lower Permian Series (O'Connor, 1963; and Zeller, 1968).

Moore (1936) discussed the revision of the Pennsylvanian System and showed that the Foraker Formation was originally placed in the upper Pennsylvanian, Missouri Series (i.e., the base of the Cottonwood limestone was considered the Pennsylvanian-Permian boundary). Moore and Moss (1934) and Moore (1940) placed the base of the Permian System at the base of the Admire Group because: 1) of an unconformable contact at the base of the Admire marked by channel fill sandstones (i.e., Indian Cave Sandstone); and 2) this boundary occured at the base of the so called "Pseudoschwagerina zone". This Pseudoschwagerina zone conforms to the Pseudoschwagerina zone of the Uralian geosyncline in Russia. According to Dunbar (1940; p. 237) "...the most natural lower limit of the Permian system is at the base of the Pseudoschwagerina zone; that is, at the base of the Sakmarian in the U.S.S.R., of the Wolfcamp in America, of the Chuanshan in South China, and of the Schwagerinakalk in the Carnic Alps."

Pertinent to this study is that the Americus limestone of the Foraker Formation is the lowest horizon to contain Schwagerina (Moore, 1940; Dunbar, 1940). Moore (1932) originally considered the base of the Americus as the Permo-Carboniferous boundary. Moore (1940) concluded that if one included all conformable beds below and above those that contain *Pseudoschwagerina*, then the Admire, Council Grove, and Chase Groups should all be considered as belonging to the *Pseudoschwagerina* zone and, therefore, were Permian. Discussion of the Pennsylvanian-Permian boundary is beyond the scope of this report, but more detailed explanations and classifications of this boundary in Kansas are provided by Moore (1940, 1949) and Mudge and Yochelson (1962).

Prosser (1895) proposed the term Big Blue for exposures along the Big Blue River in Nebraska and Kansas. The term Big Blue was considered as the lowermost series of rocks making up the Permian System by the Kansas and Nebraska State Geological Surveys. Elias (1937) regarded the Big Blue Series as the last of Late Paleozoic rocks designated as predominately marine in origin. The Kansas Geological Survey abandoned the term Big Blue, and adopted the term "Wolfcampian" based on the standard North American Permian section in the Glass Mountains of Texas, as established by Adams *et al*. (1939). Later, O'Connor (1963) abandoned the west Texas Permian stage names and replaced them with locally derived stage names for the Kansas region. O'Connor did this because Kansas Permian strata bear little resemblence to the west Texas Permian. The Wolfcampian was replaced with the term "Gearyan" (named for Geary County, Kansas), and the Leonardian and lower Guadalupian stages were replaced with the Cimarronian.

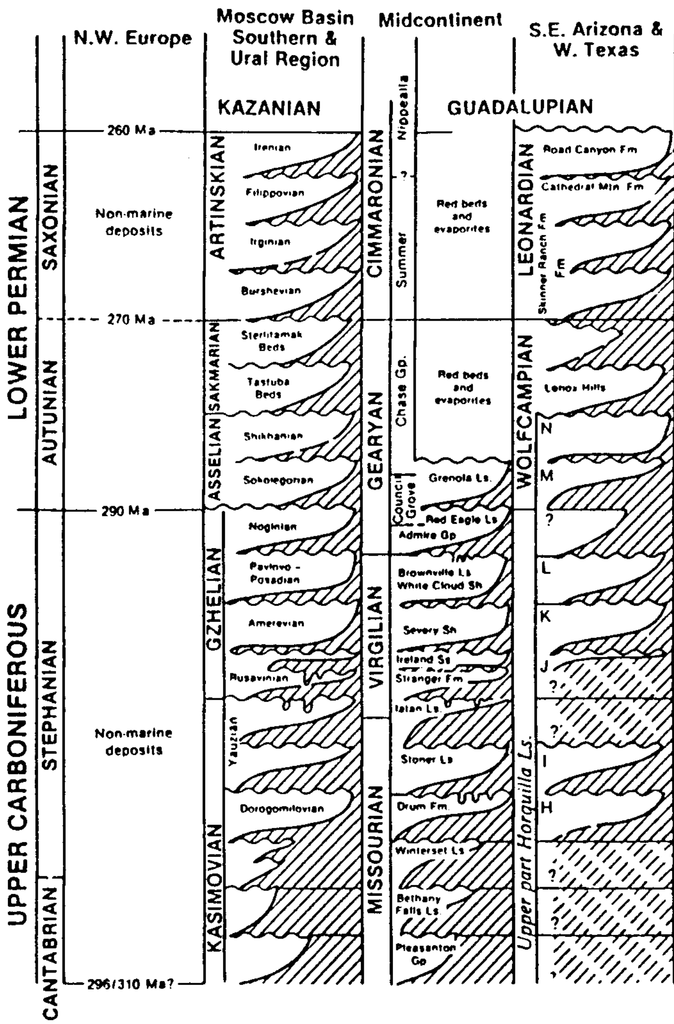
Prosser (1902) considered the Council Grove as a stage name that included the Cottonwood Limestone and "Garrison Shale". He introduced the "Elmdale Shale" for strata between the top of the Americus and the base of the Neva limestone. Moore (1932, 1936) formally changed the Council Grove Stage to the Council Grove Group with the Americus Limestone Member defining its base (Figure 2). Revision of the old classification led to the detailed application of ascending formational names, with the subdivision of the formations into members. Further reclassification of the Council Grove Group led to the present day classification of formations and their members as described by Zeller (1968) and accepted by the Kansas State Geological Survey.

Chronostratigraphy.--The Wolfcampian or Gearyan Stage of the southwestern and Midcontinent United States correlates with the Asselian (lower substage of the Sakmarian) and overlying Sakmarian (upper substage of the Sakmarian) age sediments of the Russian Urals (Figure 3; Harland *et al*., 1982). According to Harland *et al*. (1982) and Ross and Ross (1985b), the Asselian and Sakmarian together, represent a time period of approximately 18-20 my (Figures 3 and 4).

The Council Grove and Admire Groups form the lower portion of the Wolfcampian-Gearyan Stage, and thus the Council Grove Group is an Assel-equivalent (Ross, 1963, p. 43; and Elias and Condra, 1957, p. 5; Figure 3). Therefore, the Council Grove (and thus the Foraker study

Permian Period							PERMIAN SYSTEM					
Period	Epoch	Age	Chron	Biostratigraphic correlation: Fusulinid zones	Biostratigraphic correlation: Brachiopods	Ma	N.W. EUROPE (GERMANY)	U.S.S.R. EASTERN RUSSIAN PLATFORM	U.S.S.R. TIMAN	JAPAN	AUSTRALIA (QUEENSLAND)	U.S.A. (DELAWARE BASIN)
Tr	Tr1	Griesbachian				248						
Permian (P)	Late (P2)	Tatarian (Tat)		*Yabeina yasubaensis* and *Lepidolina toriyamai*		253	BUNTSANDSTEIN; OHRE 5 (ZECHSTEIN)	VYATSKIY; SEVERODVINSKIY; URZHUMSKIY	RED CLAYS AND MARLS; PYTYRYUSKIY	KUMAN	? REWAN; BARALABA; TAMAREE	DEWEY LAKE (OCHOAN; UPPER PERMIAN)
Permian (P)	Late (P2)	Kazanian (Kaz)		*Verbeekina verbeeki*	*Cancrinelloides*		ALLER 4; LEINE 3; STASSFURT EVAPORITES 2; HAUPTDOLOMIT-STINKSCHIEFER; WERRA (ZECHSTEIN)	UPPER KAZANSKIY; LOWER KAZANSKIY	VESLYANSKIY; CHEV'YNSKIY	KUMAN; AKASAKAN	U CURRA LST; ?; PELICAN CREEK; SCOTTVILLE	RUSTLER; SALADO; CASTILE (OCHOAN); CAPITAN (GUADALUPIAN)
Permian (P)	Late (P2)	Ufimian (Ufi)		*Neoschwagerina craticulifera*	? *Lissochonetes*	258	ZECHSTEINKALK 1; KUPFERSCHIEFER (ZECHSTEIN)	SHEMSHINSKIY; SOLIKAMSKY	USTKULOMSKIY; VYCHEGODSKIY	AKASAKAN	EXMOOR	WORD (GUADALUPIAN)
Permian (P)	Early (P1)	Kungurian (Kun)	Irenian	*Neoschwagerina simplex*	*Pseudosyrinx*		WEISSLIEGENDES	IREN'SKIY	IREN' SKIY	NABEYAMAN		LEONARDIAN
			Filippovian			263		FILIPPOVSKIY	VYL' SKIY			
Permian (P)	Early (P1)	Artinskian (Art)	Baigendzinian	*Parafusulina kaerimizensis*	*Sowerbina*; *Antiquatonia*		ROTLIEGENDES	IKSKIY	KOMICHANSKIY	NABEYAMAN	GEBBIE	LEONARDIAN (LOWER PERMIAN)
			Aktastinian		*Jakutoproductus*	268			NERMINSKIY		SIRIUS SHALE	
Permian (P)	Early (P1)	Sakmarian (Sak)	Sterlitamakian	*Pseudofusulina vulgaris*	*Tornquistia*; *Attenuatella*			STERLITAMAK-SKIY	PEL' SKIY	SAKAMOTOZAWAN	TIVERTON	WOLFCAMPIAN (LOWER PERMIAN)
			Tastubian		*Yakovlevia*			TASTUBSKIY	ILIBEYSKIY		LIZZIE CREEK	
Permian (P)	Early (P1)	Asselian (Ass)	Krumaian	*Pseudoschwagerina monkawai*	*Torniopsis*			KOKHANSKIY	NENETSKIY		BURNETT	
			Uskalikian		*Orthotichia*							
			Surenan		*Kochiproductus*	286		SOKOL'YEGORSKIY	INDIGSKIY		JOE JOE	
C	Gze	Noginskian		*Triticites*						HIKAWAN		

Figure 3. Permian chronostratigraphic scale, and correlation (from Harland et al., 1982)



Fusulinacean Zones: Moscow Basin & Southern Urals	Fusulinacean Zones: Southwestern United States
	Parafusulina boesei, P. apiculata
Parafusulina solidissima, Pseudofusulina? uresbajevi	*Parafusulina schucherti, P. durhami*
Parafusulina lutugini, Pseudofusulina concessa	*Parafusulina spissisepta, P. brooksensis*
Pseudofusulina? concavutas, P. schellwieni	*Robustoschwagerina stanislavi, Schwagerina crassitectoria, S. guembeli, S. hawkinsi*
Pseudofusulina callosa, P. plicatissima, P. urdalensis	*Pseudoschwagerina robusta*
Pseudofusulina verneuili Pseudofusulina moelleri	*Pseudoschwagerina convexa, Pseudofusulina nelsoni, Schwagerina diversiformis, Eoparafusulina*
Pseudoschwagerina sphaerica, Pseudofusulina firma	*Pseudoschwagerina portalensis, Triticites creekensis, Schwagerina vervillei, S. providens*
Pseudoschwagerina moelleri, Pseudofusulina fecunda	*Pseudoschwagerina uddeni, Paraschwagerina kansasensis, Leptotriticites tumida, Rugosofusulina*
Daixina sokensis	*Leptotriticites americana, Triticites ventricosus, Schwagerina cf. S. longissimoidea*
Jigulites jigulensis	*Triticites subventricosus, T. whetstonensis Schubertella whetensis*
Triticites (Rauserites) stuckenbergi	*T. callosus, T. cullomensis, T. plummeri*
Triticites rossicus / *Triticites paraarcticus*	*Triticites mcg. ewensis, Dunbarinella*
Triticites irregularis, Pseudofusulinella usvae	*Triticites iatensis, T. newelli, Kansanella (K.) joensis*
Triticites acutus	*Triticites primarius, Kansanella neglecta*
T. ohioensis (spanning both columns)	
Triticites arcticus	*Triticites collus, T. nebraskensis*
Montiparus montiparus, Quasifusulina longissima	*Kansanella (Iowanella) winterensis, T. cf. ohioensis*
Quasifusulinoides (spanning both columns)	
Protriticites pseudomontiparus	*Eowaeringella, Oketaella*
Obsoletes obsoletus	

Figure 4. Correlation of upper Carboniferous and Lower Permian transgressive-regressive sequences and fusulinacean zonations (from Ross and Ross, 1985b).

interval) is provisionally Early Permian in age. The Council Grove and Admire Groups (lower Gearyan) correlate with the lower Rotliegendes of Germany, the Sokol 'Yegorskiy and Kokhanskiy of the eastern Russian Platform, the Indigskiy and Nenetskiy of Timan, the lower Sakamotozawan of Japan and the Joe Joe and Burnett of Australia. These time stratigraphic units are all Assel-equivalent, according to Harland et al. (1982), and belong to the zone of Pseudoschwagerina.

In addition to being correlative with Wolfcampian rocks of west Texas, the Council Grove Group is also correlative with (based on the Pseudoschwagerina Zone) at least the lower portion of the Hueco Formation in the Delaware basin of Texas and the lower Wichita Series of central Texas (Dunbar, 1940). It is also correlative with at least the lower part of the Pontotoc Group along the northern flank of the Wichita uplift, according to Rascoe and Adler (1983). This is based on the unconformable position of Pontotoc rocks relative to older Paleozoic rocks.

Ross and Ross (1985b) used unconformity-bounded transgressive-regressive depositional sequences of Mitchum et al. (1977), with fusulinid, bryozoan, and ammonoid biostratigraphy, to correlate Permo-Carboniferous strata on a global scale (Figure 4). According to Ross and Ross (1985b), the interval from the base of the Admire to the top of the Red Eagle Formation (Council Grove Group), represents one depositional sequence (approximately 2 m.y.). Figure 4 shows the basal Council Grove (i.e., the Foraker) as correlative with the upper Pennsylvanian Gzhelian and Stephanian strata. This correlation is tenuous because: firstly, the Red Eagle unconformity is highly questionable, and secondly, Ross and Ross's (1985b) correlation of the remainder of the Permian in the Midcontinent (U.S.A.) region is incomplete.

Outcrop Extent and Characteristics.--Figure 5 shows the extent of outcrop, in Kansas, of the Council Grove Group and thus the outcrop contact between the Foraker Formation and the subjacent Admire Group. The Foraker Formation crops out in a linear belt and exhibits a marked thickness change from 24 feet in southeastern Nebraska to 73 feet in northeastern Oklahoma (Avers, 1968). The Foraker grades from predominately calcareous silty shales and interbedded argillaceous micritic limestones in the northern outcrop belt, to thicker, massive, cherty limestones in the southern outcrop belt (Mudge and Yochelson, 1962). In the most extreme southern outcrop (Lincoln County, Oklahoma) it consists of a few thin dolomite layers, interbedded between red silty shales and massive, lenticular, fluvial sandstones (Fritts, 1980).

The Americus Limestone Member of the Foraker Formation, as redefined by Mudge and Burton (1959) and confirmed by Mudge and Yochelson (1962), consists of two limestone benches separated by shale in northern Kansas. The lower boundary of

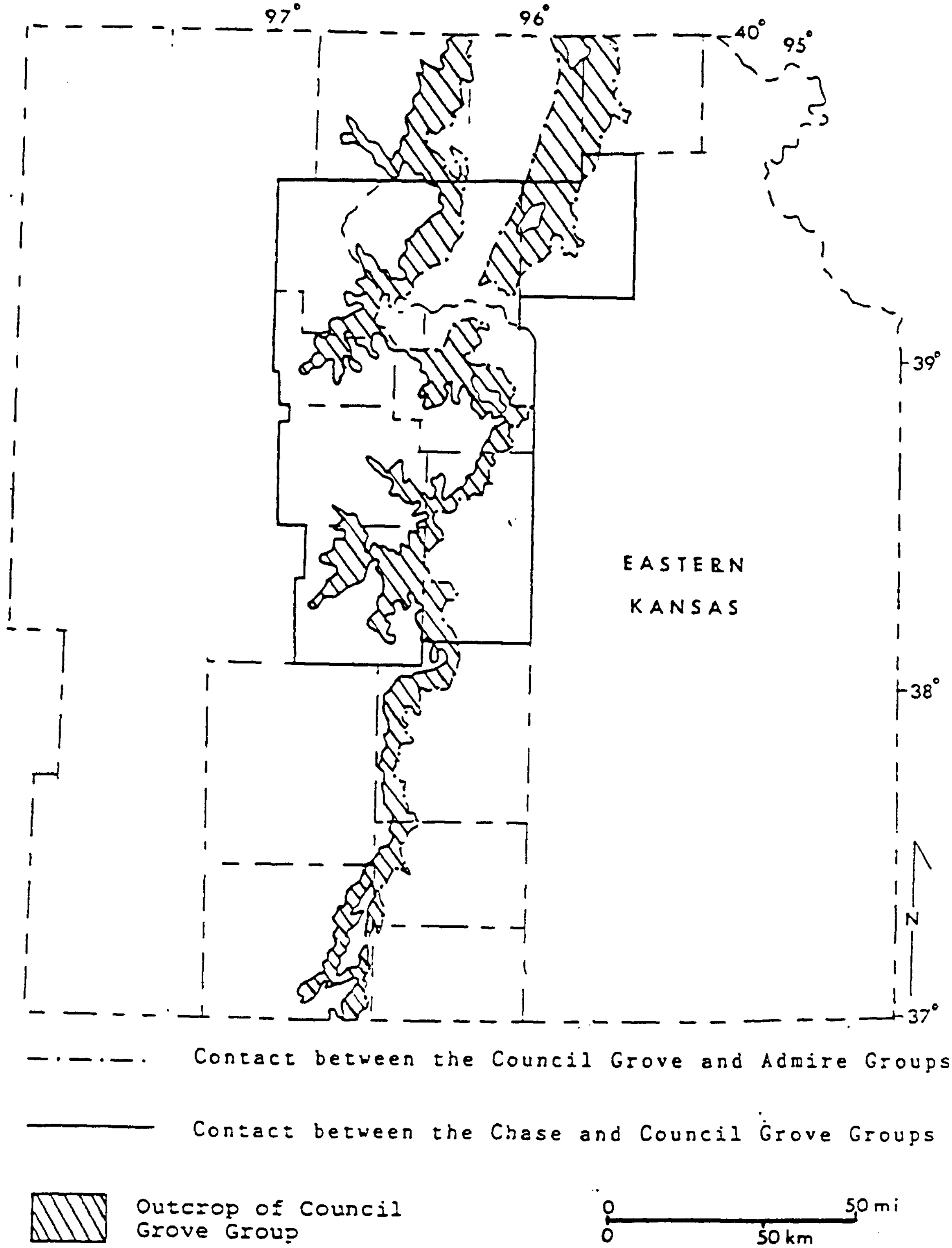


Figure 5. Map of eastern Kansas showing outcrop belt of the Council Grove Group (adapted from Aber and Grisafe, 1982).

the Americus (and thus the Foraker) is placed at the base of the massive algal stromatolites in the lower Americus limestone ledge (Mudge and Yochelson, 1962). The Americus Limestone Member thickens southward (e.g, 20 ft. in Elk County, Kansas), and there is an increase in fusulinids and chert. According to Mudge and Burton (1959) the Americus splits into three limestones, separated by two shales, near the Lyon-Wabaunsee County line. Northward the Americus thins (1.5 ft in Brown County, Kansas), and there is a decrease in fusulinids and chert. The basal algal stromatolites disappear north of central Wabaunsee County, Kansas (i.e., northern boundary of this study area; Mudge and Yochelson, 1962).

In the area studied (Figures 1 and 5) the lower Americus is characterized by a basal, massive, stromatolite facies overlain by a molluscan dominated limestone. A middle fossiliferous to non-fossiliferous, gray to gray-black shale underlies the upper Americus limestone bench, which is characterized as a crinoidal, fusulinid-bearing limestone. The lower limestone bench of the Americus can be quite variable in thickness and facies composition, while the upper bed is usually quite homogeneous in texture and composition.

The Hughes Creek Shale Member of the Foraker Limestone grades laterally from silty, calcareous to noncalcareous, black, gray, and blue-gray shales in southeastern Nebraska and northern Kansas (Condra, 1927); through progressively alternating calcareous shales and argillaceous micritic limestones in northeastern and central Kansas (this study area; Garber, 1962); to thick, massive, cherty limestones in southern Kansas and northeastern Oklahoma (Mudge and Yochelson, 1962; Fritts, 1980).

The shale to limestone ratio is 12:1 in the north and progressively changes to a ratio of 1:2 in southern Kansas and northeastern Oklahoma (Avers, 1968). Fusulinids are extremely abundant in the massive cherty limestone in the south, and decrease in number northward, accompanied by an increase in thick shelled brachiopods. In the area studied, fusulinids are locally concentrated in massive, interbedded, very calcareous shales and argillaceous limestones. According to Mudge and Yochelson (1962), chert is not present in the Hughes Creek north of Greenwood County, Kansas; and <u>Lingula</u> (a marginal marine to brackish water indicator: Wells, 1985) is not present in the Hughes Creek south of northern Greenwood County, Kansas. The Hughes Creek member ranges in thickness from approximately 20 feet in Lancaster County, Nebraska, to over 50 feet in southern Kansas and northeastern Oklahoma (Avers, 1968; Fritts, 1980).

The Long Creek Limestone Member (uppermost member of the Foraker Formation) varies in thickness from north to south, but averages 8 feet (Mudge and Yochelson, 1962). In the area studied, the Long Creek is characterized by alternating, massive, tan to gray-orange, dolomitic, argillaceous limestones with thin gray-brown shale lentils. The Long Creek limestone is usually nondescript because of its highly-weathered and brecciated nature. The brecciation includes tee-pee structures, suggesting that it is at least partly due to collapse after dissolution of evaporites. Vugs within the Long Creek member are commonly lined with celestite, calcite, and quartz. The Long Creek rarely forms a hillside bench. It is also characterized in the area of this study by its rare molluscs (e.g., Permophorus, Aviculopecten and Tainocerus), and thin algal laminations. In northeastern Oklahoma, fusulinids are abundant throughout the Long Creek Limestone Member, sometimes forming biosparudites (Fritts, 1980).

Structural Setting.--Figure 6 shows the regional structural setting during latest Pennsylvanian and earliest Permian times, in the southern Midcontinent. The geologic framework and sedimentation of Lower Permian sediments was affected by, and basically inherited from, the structural elements formed in the Pennsylvanian (Moore, G.E., 1979). From late Morrowan into early Desmoinesian time the collisional episode between the North American and South American plates was responsible for most of the southern tectonic features, such as the Ouachita foldbelt; the emergence of the Amarillo-Wichita, Apishapa, and Nemaha uplifts; and the marked subsidence of the Arkoma and Anadarko Basins (Rascoe and Adler, 1983; Moore, G.E, 1979). It was

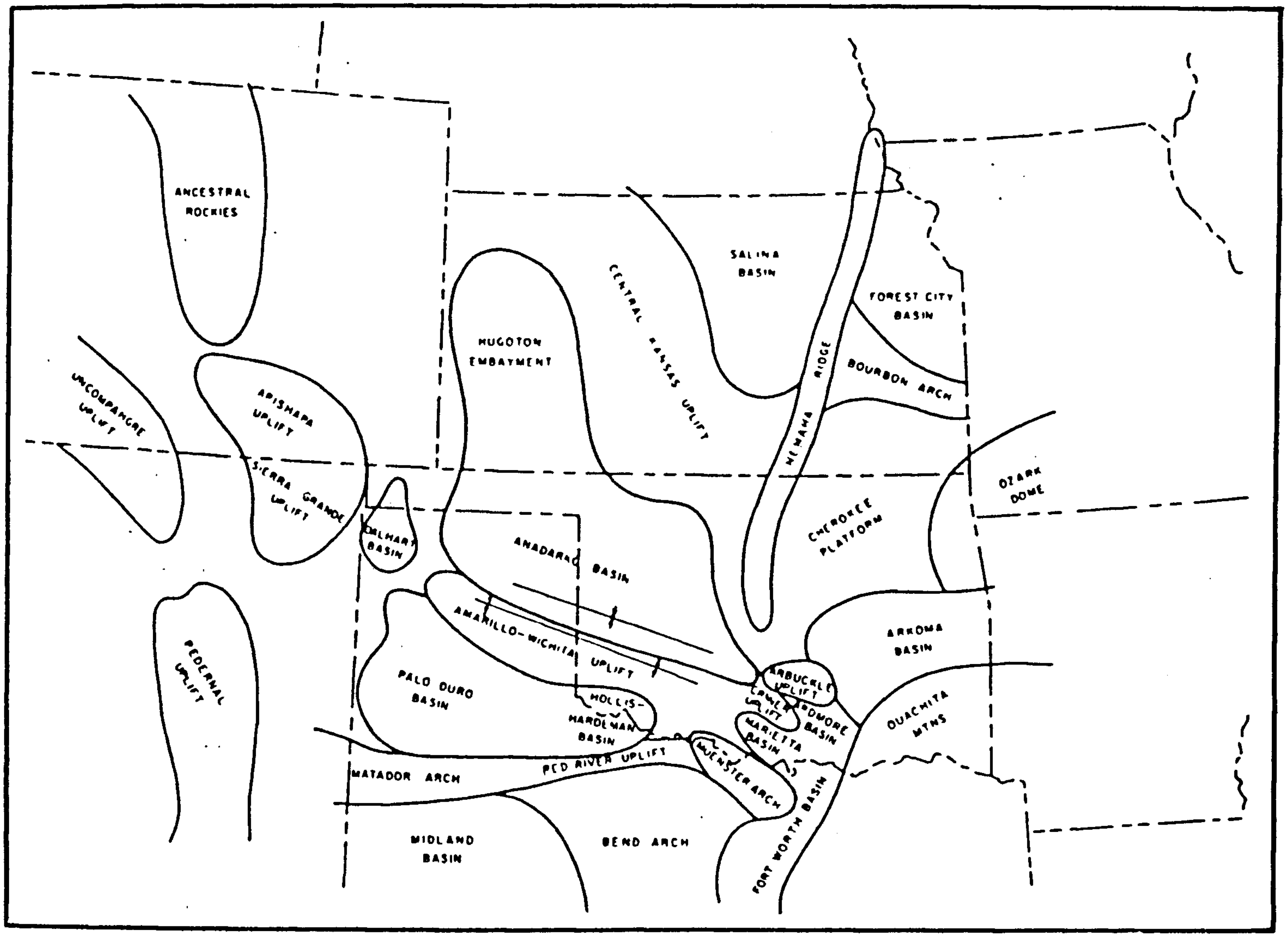


Figure 6. Principal Pennsylvanian tectonic features of the southern Mid-Continent (from Moore, G.E., 1979).

not until the Late Pennsylvanian that the Arbuckle Orogeny occurred.

The Pennsylvanian and Early Permian Midcontinent region north of the Anadarko Basin, inclusive of this study area (Figure 6), has been considered by some workers as the "Kansas Shelf" (e.g., Laporte, 1962; Moore, G.E., 1979). Most apparent across this shelf is the deposition of widespread cyclic deposits of the Pennsylvanian and Permian. Sources for these sediments were probably two-fold: a cratonic source to the north and a tectonic source to the south (e.g., Ouachita foldbelt and Arbuckle uplift). This is supported by the work of Imbrie et al.'s (1959, 1964), in which clay minerals dominated by mica and chlorite are found in the marine Florena Shale Member (Beattie Limestone Formation, Lower Permian) of northern Kansas, and clay minerals dominated by illite and montmorillonite are found in the Florena shale of southern Kansas.

The present study area is bounded on the west by the Salina Basin, on the east by the Forest City Basin, and on the southwest by the extreme northeastern flank of the Sedgwick Basin (Figure 6). Strata within the study area are part of the Prairie Plains monocline which consists of west to northwest dipping beds (30 feet per mile; Jewett, 1941). The dip of these beds is distinctly altered and sometimes reversed because of the Nemaha Anticline. In Riley and Pottawatomie Counties, the northwestern portion of Wabaunsee

County, and central Chase County, Kansas, the Foraker crops out along the north-northeast trending Nemaha Anticline (Figure 7). The Nemaha Anticline is a southward-plunging linear feature with a granitic core, that extends from near Omaha, Nebraska (i.e., Table Rock Anticline) to Oklahoma City, Oklahoma (Lee, 1943; Jewett, 1951; Merriam, 1963).

The eastern flank of the Nemaha Anticline is bounded by a steeply dipping fault zone, the Humbolt fault zone. Adjacent to the Humbolt zone, seismic exploration has shown a complex array of normal and reverse faults, and even horst and grabens (Steeples, 1982). The Nemaha structure was mainly developed in Late Mississippian to Early Pennsylvanian time, as based on the upturned and beveled Mississippian and older rocks (including Precambrian) on its flanks that are overstepped and overlapped by relatively horizontal Desmoinesian strata (Lee, 1943; Jewett, 1951).

Other secondary features within the problem area (Figure 7) include the Alma Anticline, which parallels the Nemaha axis in western Wabaunsee County (Jewett, 1951); the northeast trending Abilene Anticline and the adjacent Irving Syncline in northwestern Riley County (Shenkel, 1959; and Chelikowsky, 1972); and the Brownville Syncline in southeastern Pottawatomie County and north-central Wabaunsee County. According to Jewett (1951), the Brownville Syncline in this area is recognized as the deepest part of the Forest City Basin.

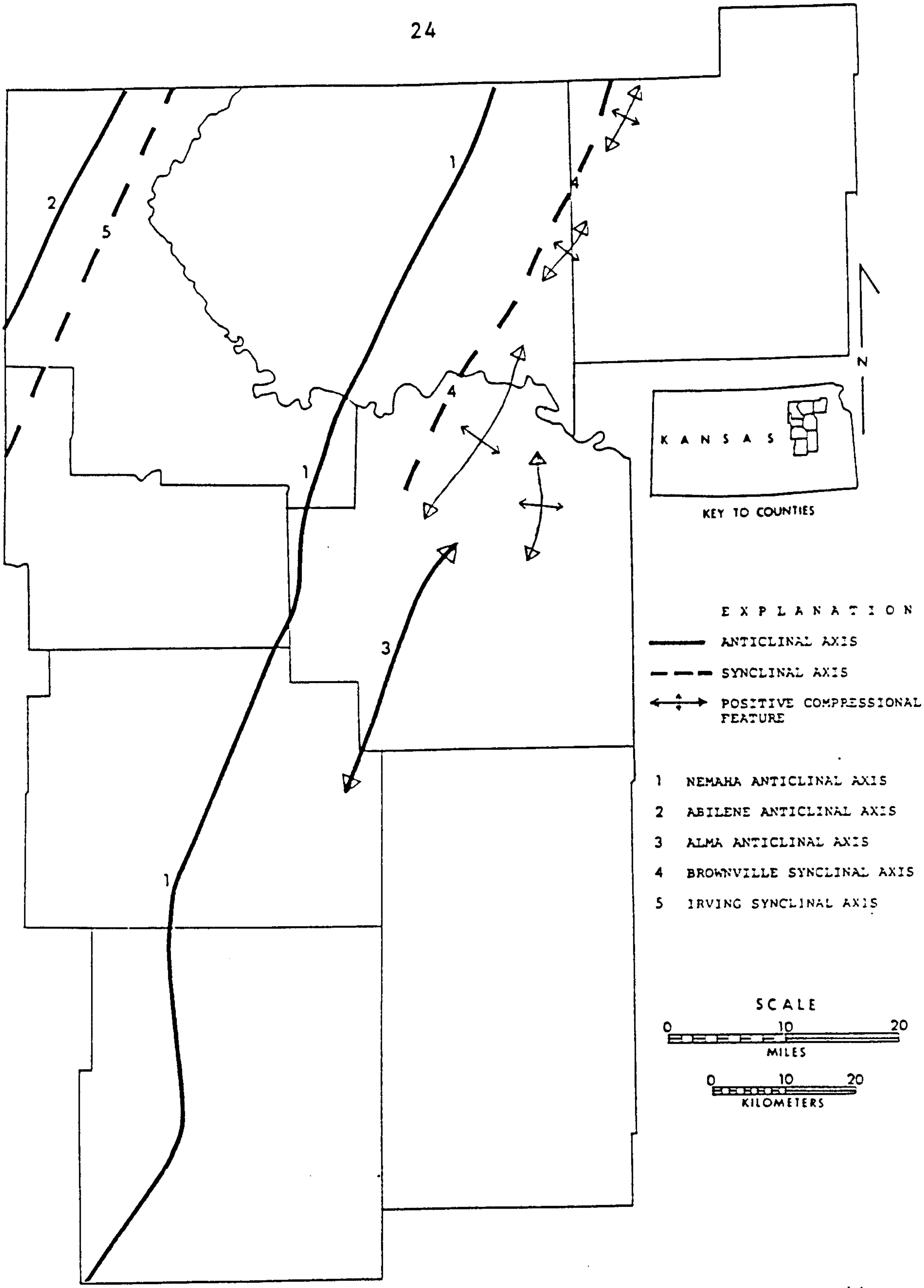


Figure 7. Major (and minor) northeast-southwest trending structural axes within study area.

Equally important are west-northwest to east-southeast trending normal faults that cut across the Nemaha Anticline. These faults have a strike-slip and a dip-slip component, and extend into the Cherokee and Forest City Basins (Berendsen and Blair, 1986; and Chelikowsky, 1972). Erosional patterns created by these faults suggest that different sections of the granitic Nemaha core have been differentially moved along its northeast-southwest tract, as discussed in a latter part of this report.

Previous Investigations.--Heald (1916) named the Foraker Formation for exposures in northwestern Osage County, Oklahoma, near the town of Foraker. Bass (1929) correlated the Foraker from Osage County, Oklahoma to outcrops in Cowley County, Kansas, and subsequently introduced the Foraker Formation into Kansas terminology. The Americus Limestone Member was named by Kirk (1896) for exposures near Americus, Lyon County, Kansas, and Condra (1927) named the Hughes Creek Shale Member for exposures along Hughes Creek in Nemaha County, Kansas. The Long Creek member was named by Condra (1927) for exposures in a bluff along Long Creek, near the town of Auburn, Nebraska; it was not until 1935 that he defined the Long Creek as the upper member of the Foraker Formation.

Other studies dealing with the Foraker Formation can be essentially grouped into three broad categories: 1) those dealing principally with the fauna (paleoecology, etc.); 2) those dealing with the stratigraphy and the petrology of the Foraker; and 3) those dealing with the cyclic nature of Foraker deposition. Although several studies deal with a combination of these, they will be discussed in the order noted above.

One of the first faunal studies was by Twenhofel (1919), who gave an analysis of the osagid "algaloid" encrusters from the Foraker Formation. In emending Twenhofel's study, Henbest (1963) discussed the paleoecology, mineralogy, and diagenesis of some sedentary foraminiferal and algal-foraminiferal colonies in some limestones from the Foraker Formation near the Kansas-Oklahoma border.

One of the first detailed classifications of fusulinid species in the Foraker Formation of Kansas was by Thompson (1954). Later fusulinid studies by Kaesler and Fisher (1969), and Fisher (1971), provided a paleoecologic interpretation, and an operational method for the study of fusulinid population characteristics. Other investigations on Foraker fusulinids are by Elias (1937), Douglass (1962), Garber (1962), Moore (1964), Lane (1964), Schmidt (1974), Fritts (1980), and Verville and Sanderson (1988).

Comprehensive paleoecologic analyses that deal with the total macro-fossil content within the Foraker Formation are by Mudge and Yochelson (1962), Yarrow (1974), Schmidt (1974), and Fritts (1980). Comprehensive studies of total micro-fossil content have been provided by Lane (1964). More specific microfossil studies include those by Little (1965), on conodonts from the Hughes Creek shale in northeastern Kansas, and Peterson (1978) and Peterson and Kaesler (1980), which reviewed the ostracode assemblages and biofacies in the upper Hamlin shale (Janesville Formation) and Americus limestone in northeastern Kansas.

Stratigraphic and petrologic investigations of the Foraker Formation can be grouped relative to their regional context. For example, Mudge and Yochelson (1962) illustrated the characteristic changes of the Foraker along the north-south outcrop belt. Harbaugh and Demirmen (1964), using factor analysis, described the lithologic and biotic changes of the upper Americus limestone, from northern Kansas to northern Oklahoma. Additional stratigraphic information, in a regional context, from southeastern Nebraska to southern Kansas, is provided by Avers (1968).

Other stratigraphic and petrologic investigations were more localized, concentrating either in northeastern Kansas or northeastern Oklahoma. For example, Garber (1962) concentrated his stratigraphic (paleoenvironmental) study of the Foraker in east central and northeastern Kansas. Work in northeastern Kansas by Schmidt (1974) provided petrologic data on an interval within the lower Hughes Creek. In addition, Fisher (1980) gave a detailed analysis of the stratigraphic and petrologic characteristics of the upper

Hamlin shale (Janesville Formation) and Americus Limestone Member in northeastern Kansas. More recently, an environmental interpretation of the lower Americus limestone in northeastern Kansas was provided by Kaesler and Denver (1985).

Studies dealing with the Foraker in northeastern Oklahoma are by Mogharabi (1966) and Fritts (1980). The former deals mostly with the carbonate petrology of the Foraker Formation in Osage and Pawnee Counties, Oklahoma, while the latter deals with the stratigraphy and paleoecology of the Foraker Formation in Osage, Pawnee, Payne, and Lincoln Counties, Oklahoma.

Detailed analyses of the cyclic nature of the Foraker Formation in Kansas have been provided by Elias (1937), Mudge and Yochelson (1962), and Avers (1968). Elias considered the Foraker Formation as a "single cycle" characterized by minor sea level fluctuations (Figure 8). He arrived at this interpretation because of the "intimately interbedded" fusulinid and brachiopod phases (i.e., phases 7 and 6 respectively), and formally termed it the "Foraker Cycle". Elias did not consider the Foraker Cycle as the result of "rapidly repeated" changes of sea level from deeper (e.g., fusulinid environments) to shallower (e.g., brachiopod-bryozoan-coral environments) marine conditions, but rather, as a "single marine invasion" representing maximum depths ranging from 110 ft. to 180 ft. (phases 6 and 7). Elias'

ELIAS (1937)

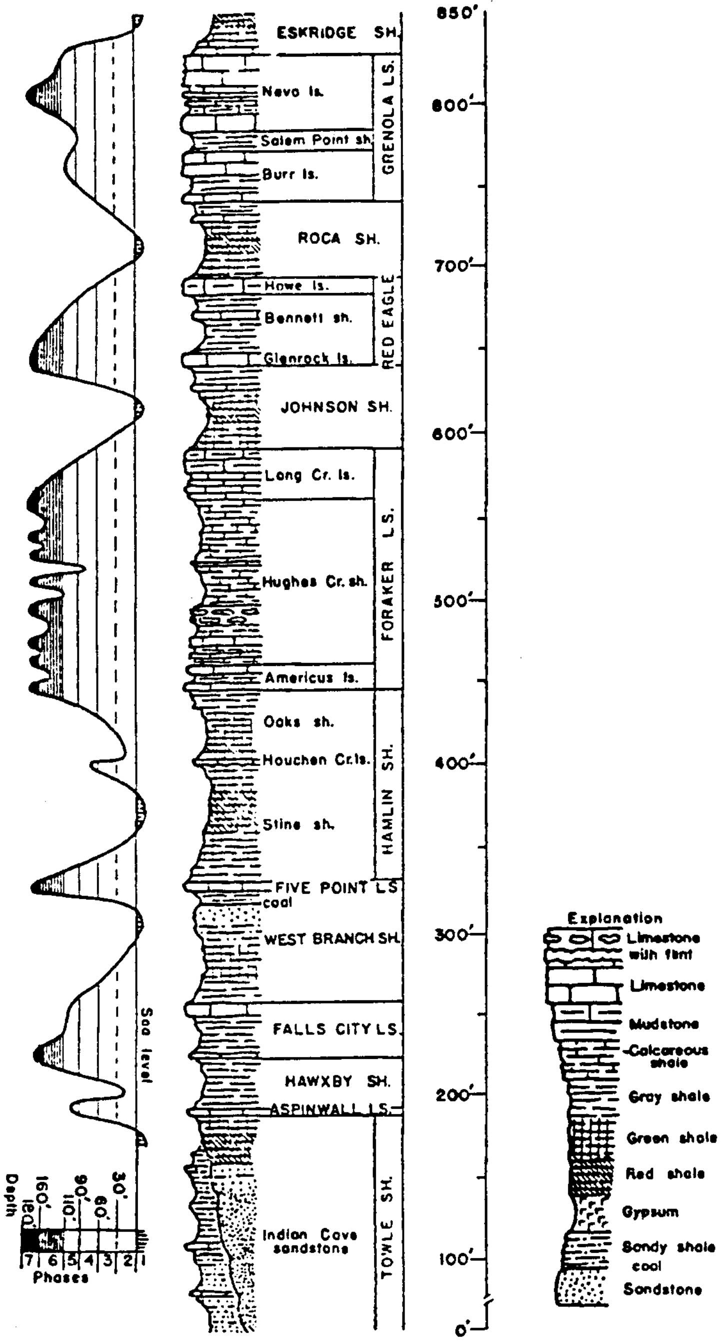


Figure 8. Elias' (1937) composite geologic section of some Lower Permian strata (inclusive of the Foraker Formation) in terms of cyclic sedimentation and depth of deposition.

complete Foraker Cycle begins in the upper Hamlin shale represented by his phase 2, and ends in the middle Johnson Shale Formation, represented by his nonmarine phase 1 (Figure 8).

Mudge and Yochelson (1962) used a modified, composite stratigraphic section to illustrate the cyclicity of the Lower Permian and upper Pennsylvanian rocks of Kansas. As seen in Figure 9, Mudge and Yochelson considered their "Foraker Cyclothem" as being similar to Elias's Foraker Cycle. However, they show two distinct Lingula phases (phase 3) interpreted as representing shallow marine conditions, thus disrupting Elias' single Foraker cycle. Their Foraker cyclothem encompasses strata from the top of the Houchen Creek limestone (Hamlin Shale Member, Lower Permian) to the middle of the Johnson Shale Formation.

Avers (1968) divided the lower Council Grove Group and upper Hamlin shale into six cyclothems (limestone-shale couplets) that define one complete megacyclothem using the terminology and methodology of Moore (1936). Aver's composite section (Figure 10) shows the Foraker encompassing one complete cyclothem (cyclothem 3) from the base of the upper Americus limestone bench to the upper part of the Hughes Creek Shale Member. The upper part of Aver's "cyclothem 2", includes the lower part of the Americus limestone, whereas the lower part of his "cyclothem 4" includes the uppermost Hughes Creek shale, all of the Long

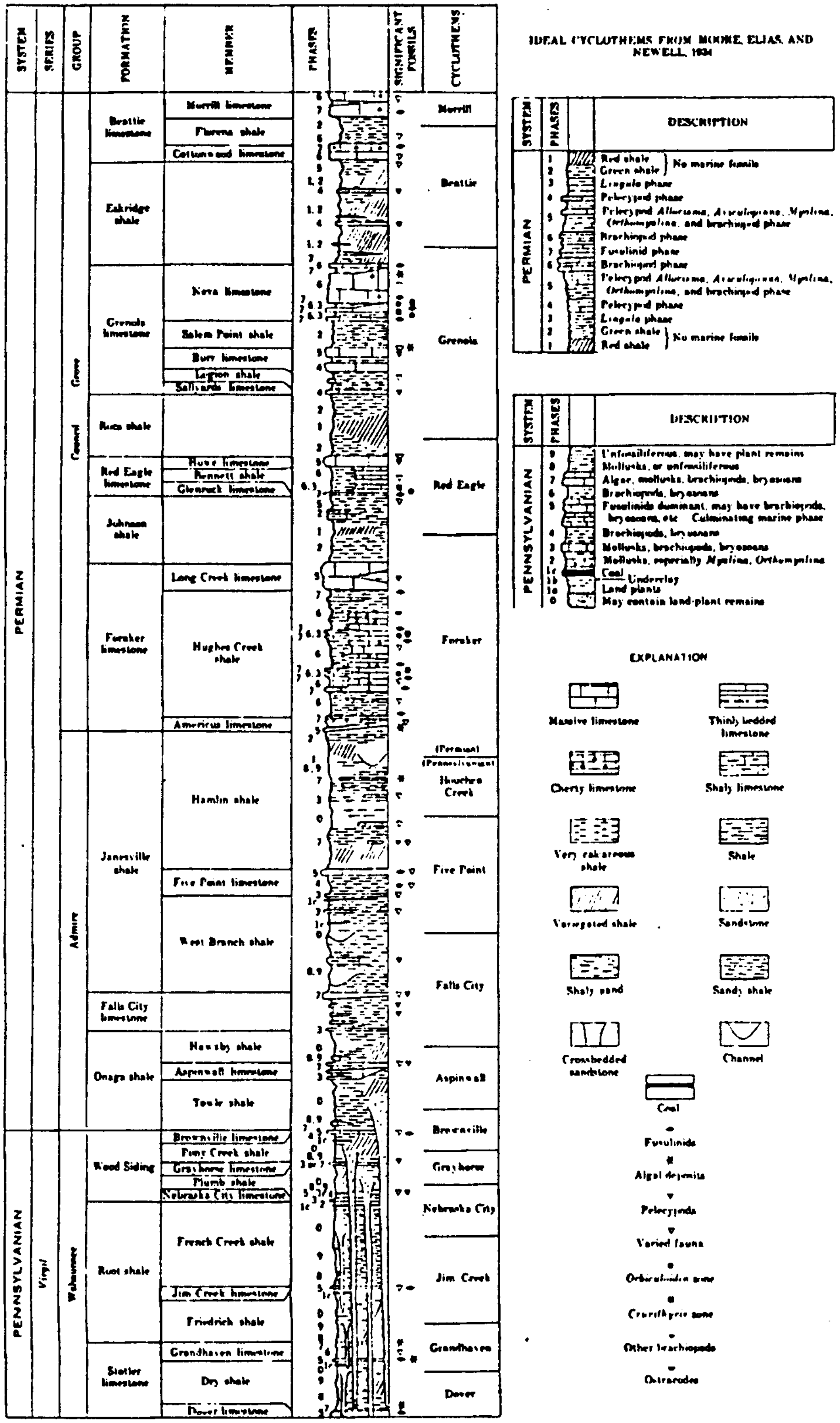


Figure 9. Mudge and Yochelson's (1962) interpretation of Lower Permian and upper-most Pennsylvanian cyclic sedimentation.

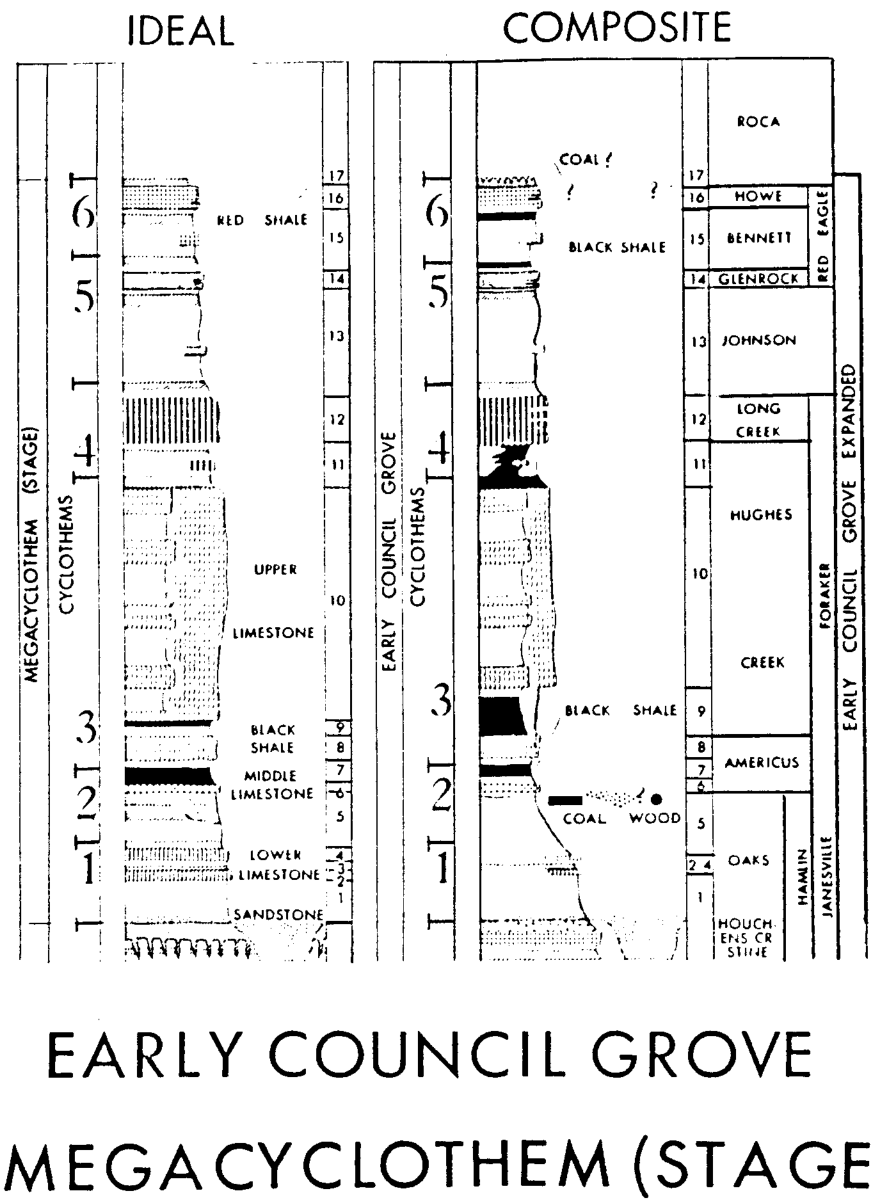


Figure 10. Relation of a composite section of the lower Council Grove Group to an idealized megacyclothem (from Avers, 1968).

Creek member, and the basal part of the Johnson Shale Formation. Aver's "ideal section" (Figure 10) shows the lower Americus limestone interpreted as a "middle limestone", and the upper Americus and most of the Hughes Creek interpreted as an "upper limestone" of Moore's megacyclothemic classification. Avers' (1968) lower Council Grove megacyclothem encompasses strata from the top of the Houchen Creek limestone to the top of the Red Eagle Formation.

Sedimentary Cycles

As early as 1888, Suess recognized 3 orders of eustatic sea level cycles in mid-Paleozoic to Late Cretaceous sequences. Suess described sea level cycles as representing larger, worldwide first-order cycles, that had second- and third-order sea level oscillations superimposed on them. Although eustacy was regarded as untenable in the early 1900's, an increase in the awareness of cyclic strata was evident. For example, Udden (1912) recognized repetitive, cyclic sequences in the Pennsylvanian strata of Illinois. Likewise, Stout (1932) observed the repetitive nature of underclays, coals, and limestones in the Ohio area.

Weller (1930) recognized repetitive Pennsylvanian strata in western Illinois, and concluded that his cyclic formations should be bounded by diastrophic indicators (e.g., channel sands, etc., indicative of unconformities). Thus, diastrophism was inherent in his concepts. His "widespread" repetitive Illinois sequences (i.e., Pennsylvanian) were bounded by unconformities, and consisted of, in ascending order: sandstones and sandy shales, underclay, coal, and marine limestones and shales. Wanless and Weller (1932, p. 1003) deemed the term "formation" (as used by Weller, 1930) inappropriate for cyclic strata, and coined the name "cyclothem" for a "...series of beds deposited during a single sedimentary cycle of the type that prevailed during the Pennsylvanian period." Wanless and Shepard (1936) subsequently proposed that sedimentary cycles, and successions of cyclothems, were caused by repeated glacial-eustatic changes.

It was not until 1933 that Jewett published the first paper on the cyclic nature of Lower Permian rocks in Kansas. His interpretations were base primarily on the lithologic variations of strata. Subsequently, Elias (1937) distinguished cyclic "phases" within the "Big Blue Series" based on a depth-related faunal scheme (Figure 8).

Moore (1936) recognized an ideal pattern of cyclothemic deposition in the Wabaunsee group (upper Virgilian), similar to that found by Weller (1930) and Wanless and Weller (1932). Wanless and Weller's (1932) Illinois cyclothem differs from Moore's ideal cyclothem in that it represents the transgressive portion ("hemicycle") of Moore's complete cycle, with the regressive portion shortened or absent. In subdividing the Pennsylvanian System in Kansas, Moore (1936) discussed the "ideal cyclothem" as recording a single marine pulsation that consisted of an emergent phase, transgressive marine phase, culminating marine phase (with fusulinids), a regressive marine phase, and a terminal emergent phase. Moore (1936) also recognized, for example in the Shawnee group (lower Virgilian), a much more complex pattern of culminating marine phases that consisted of numerous fusulinid bearing limestones (i.e., termed by Moore as lower, middle, upper, and sometimes super limestone members) and shales, thus defining a series of limestone-shale couplets. This sequence is usually underlain and overlain by terrestrial deposits, and ultimately formed what Moore referred to as a complex major cyclothem. Moore (1936) recognized alternating sequences of complex major and "ideal", or minor, cyclothems that he designated as representing "megacyclothems". He envisioned the megacyclothem as representing a large cyclic "movement" that had smaller oscillations, on a cyclothemic scale, superimposed on it. Figure 11 shows the interpreted environments and sea level curves relative to his hypothetical succesive cyclothems.

Vella (1965), in recognizing the status of sedimentary cycles at that time, re-emphasized the usefullness of "sedimentary cycles" for mapping and stratigraphic

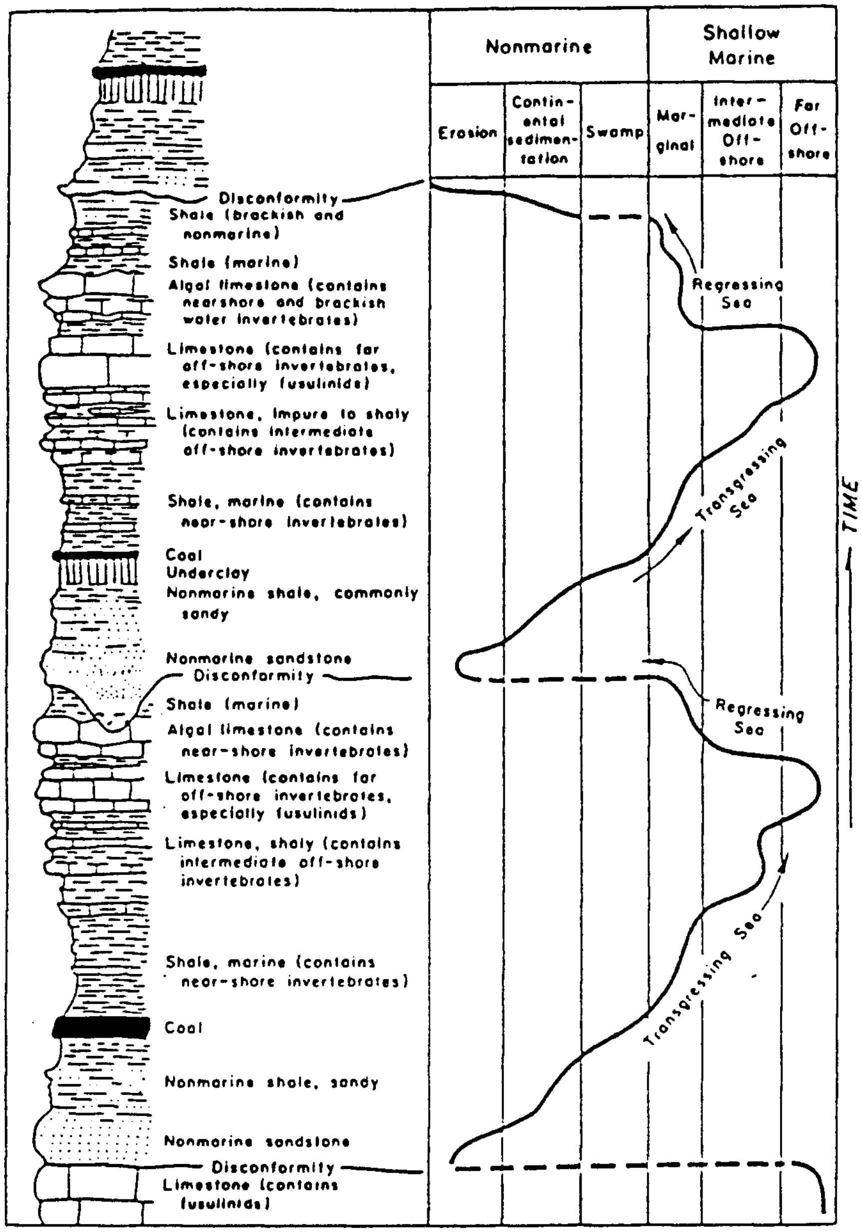


Figure 11. Diagrammatic section of the typical lithologic and biostratigraphic features of successive Pennsylvanian or Permian cyclothems, and their environmental interpretations (from Moore, 1964).

classification. He defined sedimentary cycles as time-stratigraphic units that can cut across lateral facies changes and consist of many "interdigitating" lithofacies and zones.

Vail et al. (1977) concluded that Phanerozoic history was affected by cyclic, global, sea level changes. They found, based on seismic information, well control, and other geologic data, that regional cycles of different magnitudes, and on different continental margins, are simultaneous. These regional cycles are represented by depositional sequences and the unconformities that bound them. Three major orders of depositional sequences (first-, second-, and third-order) are described by Vail et al. (1977) as representing major onlap-offlap (i.e., transgressive-regressive) sequences. These sequences are bounded by regionally and globally correlative unconformities that resulted from relative regressive offlap.

Relatively smaller cycles than those of Vail et al., were described by Ramsbottom (1979) who showed that the Carboniferous of northwestern Europe formed a single large cycle he termed a synthem, following Chang (1975). Ramsbottom proposed a hierarchal nomenclature specifically for "eustatic cycles". These included synthems (largest cycles), mesothems, and cyclothems (smallest cycles).

Heckel (1977, 1980) abandoned the term megacyclothem (after Moore, 1936) and established the "Kansas cyclothem" as a result of his work on the mid-Desmoinesian to mid-Virgilian strata in the Midcontinent. Considered by Heckel as a "basic" transgressive-regressive cyclothem, the "complete" Kansas cyclothem consists of, in ascending order: outside, nearshore shales deposited during lower stands of sea level; trangressive, typically skeletal limestones deposited in deepening water; an offshore, thin, conodont-rich, gray to black, phosphatic "core" shale formed at maximum transgression; a regressive, shoaling upward, commonly thick marine limestone; and a regressive, marine to nonmarine outside shale.

Heckel's Kansas cyclothem approach is intrinsically different from the cyclothem and megacyclothem approach of Moore (1936) based on the position of the core shale as representing maximum transgression. Moore (1936, 1964) considered the fusulinid rich limestones in his Pennsylvanian and Permian cyclothems, as representing the most offshore conditions as a result of maximum transgression. Also, Moore (1964) implicity shared the view of Zangerl and Richardson (1963) on the black shales of the "Heebner type"; namely, that these shales were representative of relatively shallow marine conditions. Figure 12 shows a typical "Kansas cyclothem" as interpreted by Heckel (1977), relative to a cyclothem as interpreted by Moore (1936, 1964).

Heckel (1985, 1986) classified complete Kansas cyclothems as "major cycles" having conodont-rich shales that

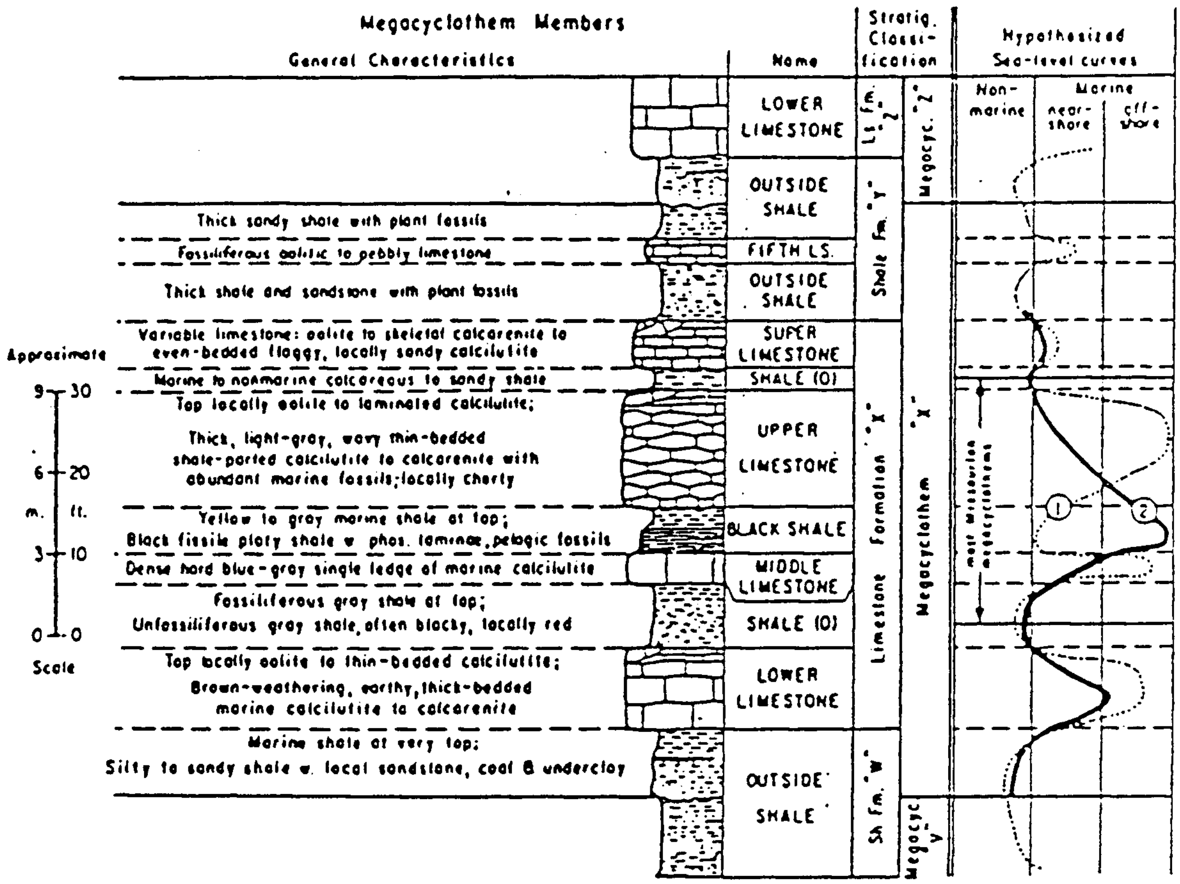


Figure 12. Typical Mid-Continent cyclothem showing various interpretations of origin of the black, fissile, phosphatic shale (from Heckel and Baesemann, 1975). Dotted line (1) represents "shallow water" interpretations of black shale (Moore, 1936, 1964). Solid line (2) represents the "deeper" water interpretation for the black shale (Heckel and Baesemann, 1975).

extend to the northern limit of outcrop in Iowa, as well as the complete development of other members in the cyclothem. His major cycles represent maximum inundation onto the shelf. Heckel also recognized "intermediate cycles", which are incomplete Kansas cyclothems because they have poorly developed core shales. They resulted from inundation of a lesser magnitude. Heckel (1985, 1986) also recognized "minor cycles" as deepening-shallowing sequences lacking the core shale, and representing minimum extent of marine inundation onto the shelf or minor reversals within major cycles. Heckel suggested that his cycles are distributed in an irregular continuum based on the rate and extent of marine inundation onto the shelf (see Heckel, 1986, Figure 2).

Goodwin and Anderson (1985) challenged the traditional model of gradual, stratigraphic accumulation, by presenting an alternative that is based on allogenic, episodic accumulation; namely, the hypothesis of punctuated aggradational cycles (PACs). According to Goodwin and Anderson, PACs are commonly thin (1-5 meters), asymmetrical, shallowing-upward units presumed to be correlative at least basinwide (Figure 13A). Each cycle is bounded by non-depositional surfaces that result from a geologically instantaneous rise in base-level. These punctuation events bound an aggradational/progradational unit that was deposited during relative base level stability.

Goodwin and Anderson (1985) coined the term PAC to be

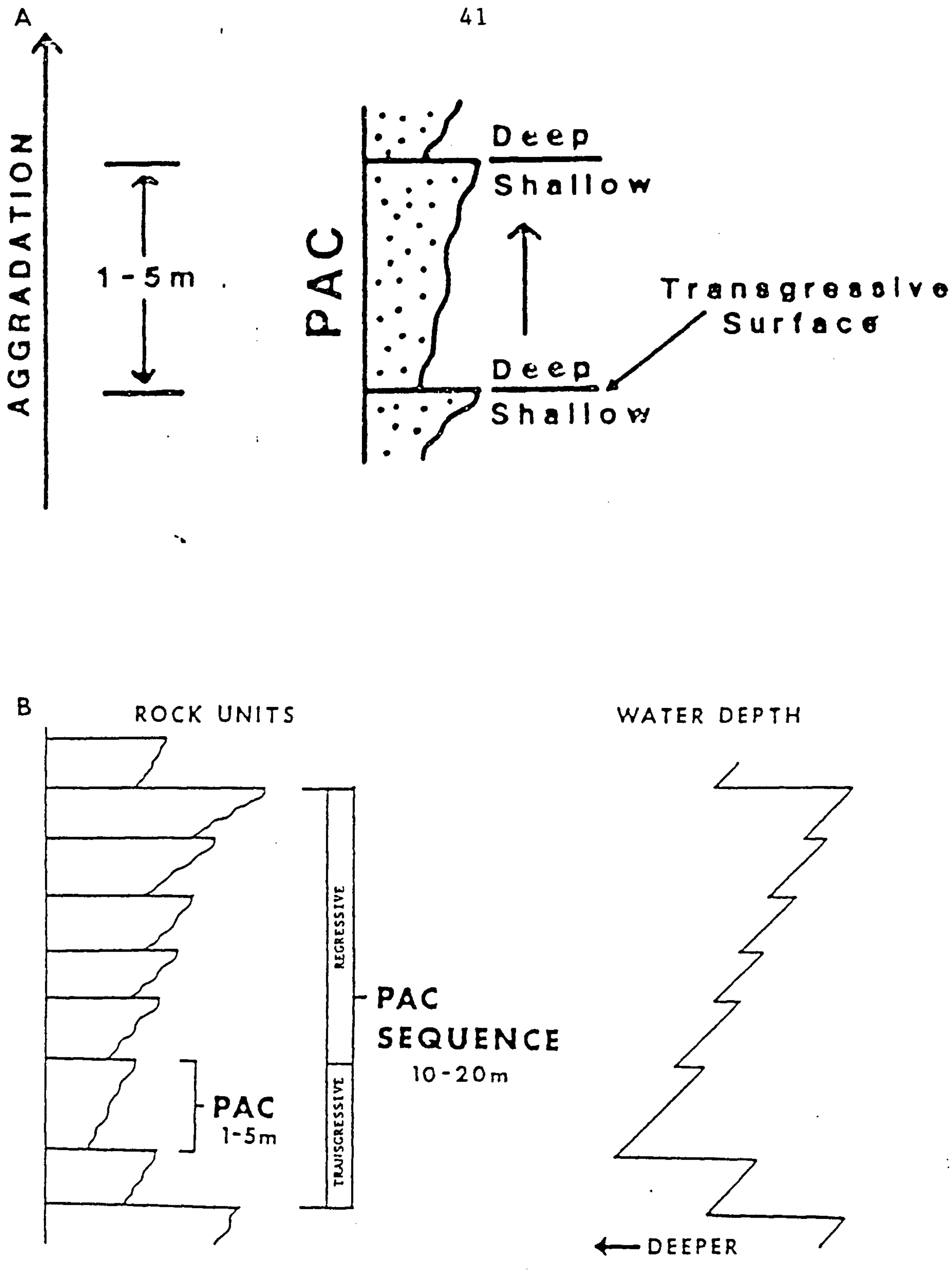


Figure 13. Characteristics of a typical PAC (A), or punctuated aggradational cycle, and characteristics of a typical PAC sequence (B) (from Goodwin and Anderson, 1985).

used as a new allostratigraphic unit, based on cyclic recurrences. Anderson *et al*. (1984) found PAC boundaries to coincide with formation boundaries that separate markedly "disparate" facies, and thus cast "serious doubt" on the conception of formations as truly representing gradual, laterally migrating mappable facies.

According to the PAC hypothesis, PACs are pervasive throughout the stratigraphic record (Goodwin and Anderson, 1985). Consequently, all environments (in general) including fluvial, deltaic, tidal flat, shelf, slope, submarine fan, basinal clastic, and marine carbonate environments are predictable with this hypothesis. Basinwide, chronostratigraphic correlation is possible because of the laterally extensive nature and isochronous boundaries of PACs. PACs are considered by Goodwin and Anderson as thin, time-stratigraphic units.

PACs can also be grouped into larger-scale transgressive-regressive sequences, about 5 to 30 meters thick, which Goodwin and Anderson (1985) termed PAC sequences (Figure 13B). These sequences are generally shallowing-upward sequences and can be isolated relative to key marker beds and horizons. This provides time-stratigraphic correlation of vertical sequences of PACs.

Hierarchal Genetic (T-R Unit) Stratigraphy

Busch (1984) and Busch and Rollins (1984) utilized field data and published data on the Carboniferous of the Appalachian Basin, to define a hierarchal classification of deepening-shallowing sequences. These sequences are at least basinwide in extent, so they were recognized as transgressive-regressive units (T-R units) of differing magnitudes, presumed to have been caused by cyclic sea level changes, operating at different rates and magnitudes. Busch and Rollins (1984) defined T-R units as being either major or minor (Figure 14). The major T-R units encompass first-, second-, and third-order T-R units, while the minor units encompass fourth-, fifth-, and sixth-order T-R units.

These major and minor units are defined on a physical basis by the inspection of all lithostratigraphic and biostratigraphic facies and facies contacts, but their periodicities are also hierarchal (Figure 14). Accordingly, Vail et al's. (1977) first-, second-, and third-order T-R units (i.e. depositional sequences) have periodicities of 225-300 m.y., 20-90 m.y., and 7-13 m.y., respectively. The Phanerozoic Eonothem is composed of two first-order T-R units with a first-order apex of transgression occurring in the Lower Ordovician and another in the Upper Cretaceous. A first-order apex of regression occurs near the Permo-Triassic boundary.

HIERARCHY OF PERMO-CARBONIFEROUS T-R UNITS

BUSCH & ROLLINS, 1984 AND BUSCH, 1984	VAIL *et al*., 1977	CHANG, 1975 AND RAMSBOTTOM, 1979	MOORE, 1936	GOODWIN AND ANDERSON, 1985	HECKEL, 1977 AND HECKEL, 1986	WANLESS AND WELLER, 1932
FIRST-ORDER 225-300 Ma	FIRST ORDER DEPOSITIONAL SEQUENCES					
SECOND-ORDER 20-90 Ma	SECOND ORDER DEPOSITIONAL SEQUENCES	SYNTHEMS				
THIRD-ORDER 7-13 Ma	THIRD ORDER DEPOSITIONAL SEQUENCES					
FOURTH-ORDER 0.6-3.6 Ma		MESOTHEMS				
FIFTH-ORDER 300-500 ka		CYCLOTHEMS	MEGACYCLOTHEMS	SHALLOWING PAC SEQUENCES	KANSAS CYCLOTHEMS; MAJOR CYCLES	CYCLOTHEMS
SIXTH-ORDER 50-130 ka			CYCLOTHEMS	PUNCTUATED AGGRADATIONAL CYCLES (PACs)	MINOR CYCLES	

Figure 14. Hierarchy of Permo-Carboniferous T-R units after Busch and Rollins (1984) and Busch (1984), with average periodicities as updated by Busch and West (1987).

In terms of the Permo-Carboniferous, the Mississippian System encompasses the upper portion of a second-order T-R unit, all of the Pennsylvanian and Early Permian make up another second-order T-R unit, and the Middle-Upper Permian forms the basal part of another second-order T-R unit. According to Vail et al. (1977), cumulative sea level falls in the first-order T-R units tended to be more gradual, and the sea level curves are relatively symmetrical. However, the sea level curves of second- and third-order T-R units are asymmetrical, with a relatively gradual rise in sea level followed by a generally abrupt fall.

Fourth-order T-R units have periodicities of about 0.6-3.6 m.y., and are equivalent in scale to Ramsbottom's (1979) Carboniferous mesothems of Europe. Fifth-order T-R units have periodicities of about 300,000-500,000 years and are similar in scale to Wanless and Weller's (1932) Illinois cyclothem, Moore's (1936) megacyclothems, Heckel's (1977) Kansas cyclothems, Heckel's (1985, 1986) major and intermediate cyles, and Ramsbottom's (1979) European Carboniferous cyclothems. Sixth-order T-R units have periodicities of about 50,000-130,000 years or less, and are essentially PACs of Goodwin and Anderson (1985). Heckel's (1986) minor cycles and Moore's (1936) cyclothems are analogous in scale to sixth-order T-R units.

Methods of Study

Methods of Hierarchal Genetic Correlation.--Three distinct methods of stratigraphic correlation can be differentiated based on the following definitions:

Cyclothem stratigraphy - is defined by the correlation of rhythms (A-B-C, A-B-C, A-B-C) of sedimentation (e.g., cyclothemic limestone-shale couplets, Moore, 1936) or cycles (A-B-C-B-A, A-B-C-B-A, A-B-C-B-A) of sedimentation (e.g., Kansas cyclothem, Heckel, 1977).

Genetic stratigraphy - correlates events (deepenings, shallowings, climate changes, erosional episodes, volcanic ash falls, storms or tempestites, etc.) defined by the inspection of all facies and facies contacts and their relative relationships (e.g., Busch, 1984).

Hierarchal Genetic Stratigraphy - Correlates a nested hierarchy of correlative deepening-shallowing units (transgressive-regressive, or "T-R", units) and their terrestrial equivalents (climate-change units) defined by the inspection of all facies and facies contacts and their relative relationships (e.g., Busch and Rollins, 1984; and Busch and West, 1987).

The method of correlation used in this study was devised and fashioned by Busch (1984), and Busch and Rollins (1984), and it relies on the definition of a hierarchy of T-R units (described above). The definition of hierarchal transgressive-regressive units is based on an initial PAC approach to outcrop and cores to define the sixth-order T-R units. This calls for the investigation of the total range of facies and facies contacts. The sixth-order T-R units are then grouped into larger fifth-order T-R units, and so on. The sixth-order T-R units are thus the smallest T-R units (i.e., PAC-scale) one can define in outcrops and cores based upon a macroscopic inspection, and enhanced with laboratory data.

Sea level curves can be drawn relative to columnar sections as shown in a hypothetical example in Figure 15. The lithologic and paleoecologic relationships within each sixth-order T-R unit reveal intervals that represent the start of transgression (and/or retrogradation), maximum transgression (i.e., the transgressive apex; Busch and West, 1987), start of regression/progradation, and maximum regression/progradation. The relative extents of these events are depicted (environmentally) in the sixth-order sea-level curves (Figure 15).

The boundaries of fifth-order T-R units are determined by considering the relative extents of transgression among each of the sixth-order T-R units. For example, a fifth-order boundary is placed at the top of any sixth-order T-R

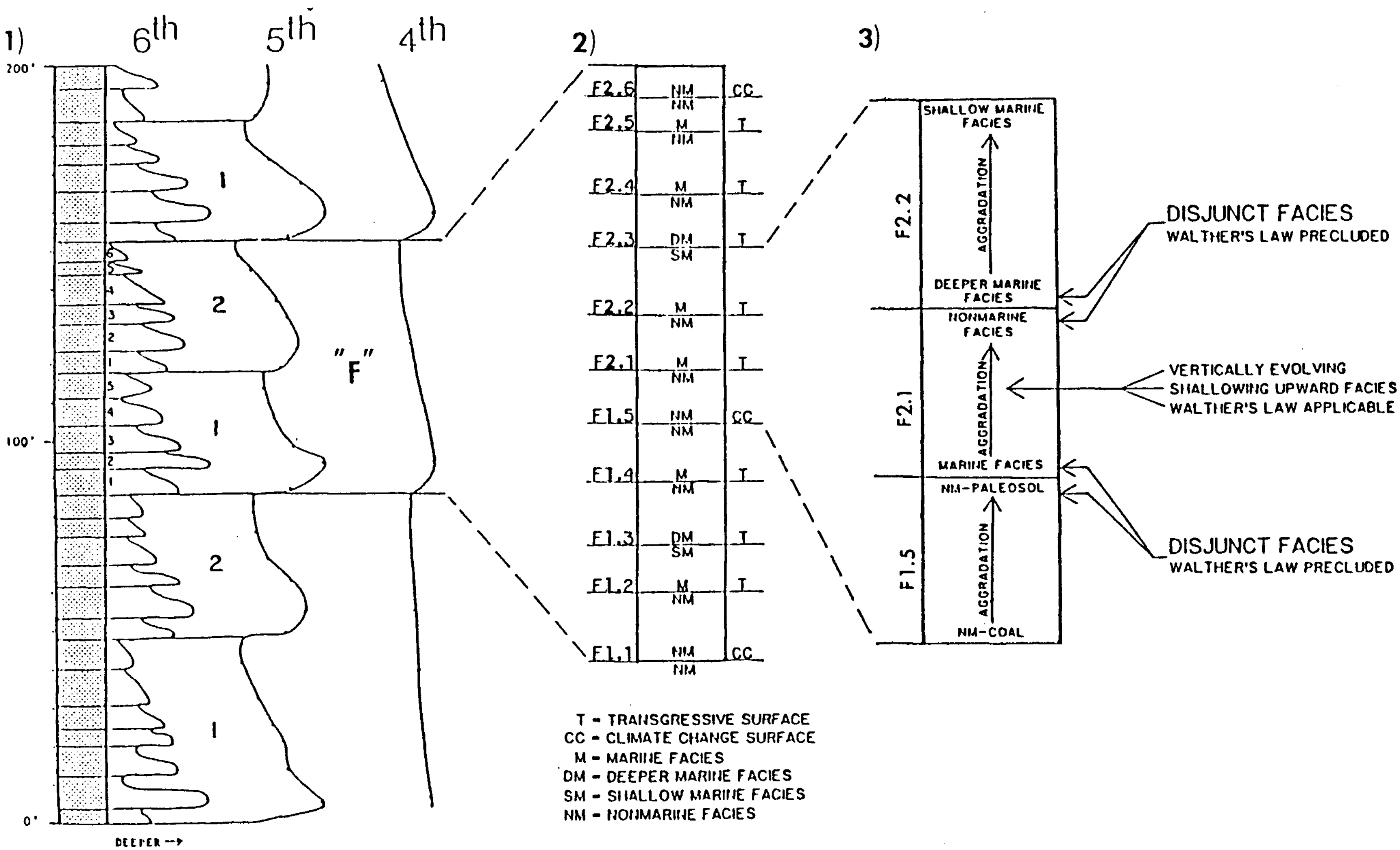


Figure 15. Schematic section showing: 1) concept of a nested hierarchy; 2) labeling of sixth-order T-R units and their climate-change and transgressive surfaces; and 3) the concept of disjunct facies.

unit representing less extensive transgression than the sixth-order T-R unit immediately above it. Conversely, a fifth-order boundary is placed below any sixth-order T-R unit representing more extensive transgression than the sixth-order T-R unit immediately below it.

Fourth-order T-R unit boundaries are identified based upon similar relationships among the fifth-order transgressions. A fourth-order T-R unit boundary is placed at the top of any fifth-order T-R unit containing a transgressive apex that represents less extensive transgression than the fifth-order T-R unit immediately above it.

Autocyclic units can be isolated using this methodology. Where the number of transgressive-regressive units are equal and correlative among localties (relative to key marker beds), then all of the T-R units are considered as allocyclic (i.e., resulting from widespread changes in sea level or climate change; Figure 16, bottom). If none of the units are correlative, and show total variability relative to the marker beds, then the units are considered as autocyclic (i.e., probably resulting from local internal feedback mechanisms; Figure 16, top). The likelihood is that locally derived, autocyclic or extra, noncorrelative units will occur "within" a stratigraphic interval of widespread allocyclic units (Busch and West, 1987; Figure 16, center).

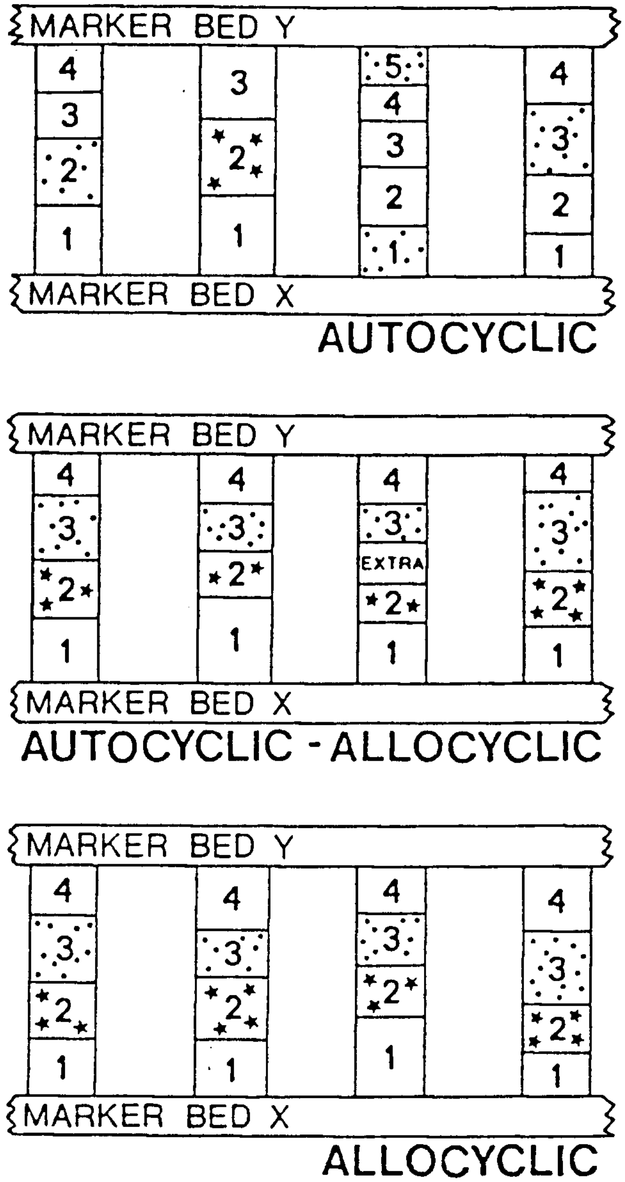


Figure 16. Schematic stratigraphic columns composed of numbered deepening-shallowing units isolated between two marker beds X and Y, and illustrating the difference between autocyclic and allocyclic T-R units (see text for discussion; from Busch and West, 1987).

Genetic Surfaces.-- Boundaries of T-R units, termed "genetic surfaces", can be transgressive surfaces or climate change surfaces (Busch and Rollins, 1984; Busch and West, 1987). Transgressive surfaces are located between either a relatively deeper marine facies overlying a relatively shallower marine facies, or between a marine facies overlying a non-marine facies. Climate change surfaces are located between non-marine units representative of relatively more humid conditions (e.g coals or lacustrine limestones) and subjacent non-marine units of a relatively less humid, or arid nature (e.g., paleosols).

The relationships between climate change surfaces, and transgressive surfaces are exemplified in Figure 17 (and discussed in detail by Busch and West, 1987). Transgressive surfaces that are located between marine facies and nonmarine facies (e.g., genetic surfaces 2 and 6, Figure 17), and climate change surfaces located between coal and paleosol developments (e.g., sixth-order genetic surface 1), are generally conspicuous. Most of the other genetic surfaces are cryptic in Figure 17, being located either between less open marine facies, and more open marine facies (e.g., transgressive genetic surfaces 7, 8, and 9, at all locations), or within, for example, coal sequences as at the base of location X (e.g., climate change surfaces 2, 3, 4, and 5). The nine sixth-order genetic surfaces define eight complete, and two incomplete (at the base and top) sixth-

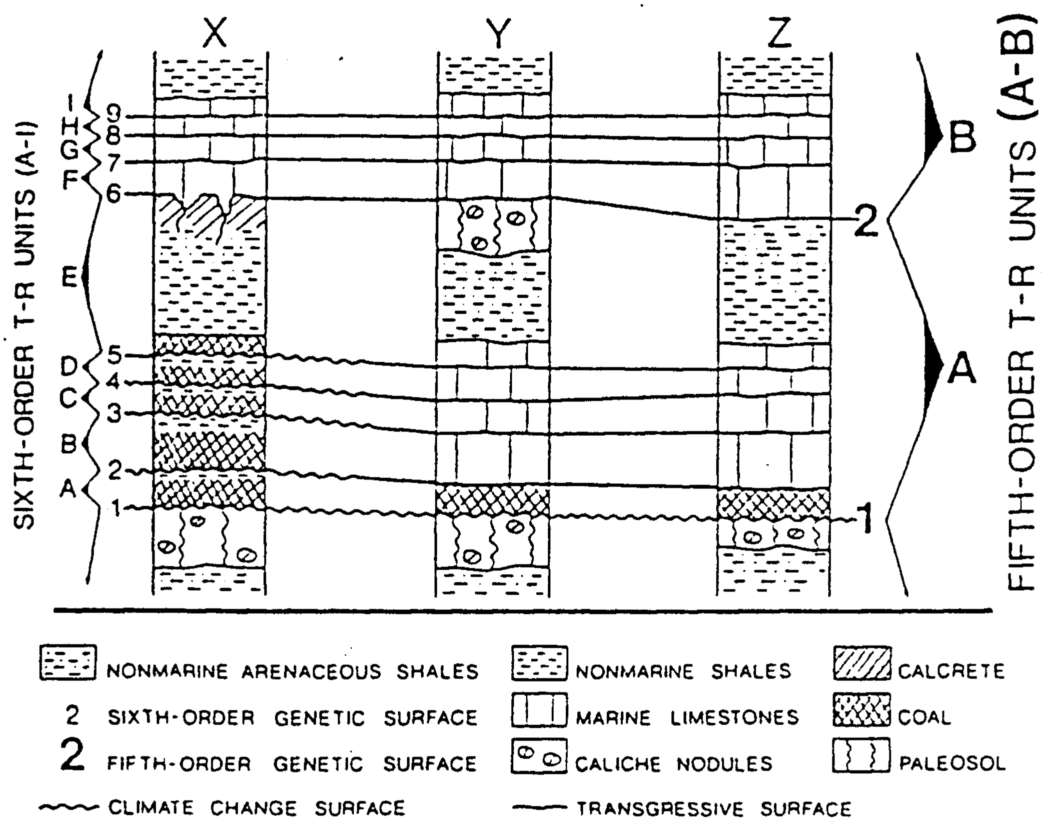


Figure 17. Schematic illustration of three hypothetical locations (X, Y and Z) to exemplify the relationship between climate change surfaces and transgressive surfaces, plus the definition of sixth- and fifth-order T-R units (from Busch and West, 1987).

order T-R units. One complete (fifth-order T-R unit A), and two incomplete (at the base and top of locations X, Y, and Z) fifth-order T-R units are defined, and correlated, based on the sequence of marine and nonmarine facies. In short, Figure 17 shows how hierarchal, genetic T-R units (and their bounding surfaces) can be correlated through widespread nonmarine intervals (e.g., sixth-order T-R unit A), through marine to nonmarine intervals (fifth-order T-R unit A), and finally, through widespread marine intervals (e.g., base of fifth-order T-R unit B).

Disjunct Facies.-- The word facies was introduced into geologic literature by Steno (1669), and was used to define rocks representative of a particular time interval. Gressly (1838) stated that a facies of a stratigraphic unit contains distinct lithological or paleontological characteristics, that are different from the characteristics of other facies of the same geological horizon. Walther (1893) continued the development of the facies concept by coining the term "faciesbezirk" (facies tract) for a conformable sequence of vertical, genetically related facies. Walther (1894) formulated what is now known as "Walther's Law", which states that a conformable vertical sequence of facies was generated by a lateral sequence of environments. Critical analyses of the facies concept led to similar facies definitions. For example, Moore (1949, p. 32) defined sedimentary facies as "...any areally restricted part of a designated stratigraphic unit which exhibits characters significantly different from those of the other parts of the unit."

Walther's Law, and thus the gradual accumulation and migration of genetically related facies, is traditionally used to explain the presence of members or formations as deposits of a diachronous nature. The concept of episodic accumulation has recently been used to challenge this traditional concept (e.g., Dott, 1983; Anderson *et al*., 1984; Goodwin and Anderson, 1985; and Goodwin *et al*., 1986). Because PACs are based on rapid base level rises and episodic accumulation, their bounding isochronous surfaces separate noncontiguous or disjunct facies (Goodwin *et al*., 1986). Therefore Walther's Law is precluded across PAC boundaries, but the law is used to explain the vertical sequence of facies within a PAC. Figure 18 illustrates the concept of disjunct facies in a series of shallowing-upward sixth-order T-R units.

Interpretive Biofacies.--The term biofacies, as used in this study, is defined as a lateral or vertical subdivision of a sixth-order T-R unit differentiated from other adjacent, subjacent, or superjacent subdivisions of the same sixth-order T-R unit by its biological characteristics. Moore (1949, 1957) and Weller (1958) used a similar definition of biofacies. Use of the term biofacies in this report is emphasizing that facies can be differentiated using biological components (i.e., versus lithologic characters). This is important to the present study because of the diverse invertebrate fossil associations within the Foraker Formation (e.g., Elias, 1937; Mudge and Yochelson, 1962; Yarrow, 1974; Schmidt, 1974).

Organisms adjust to, and exhibit the results of, environmental variations (e.g., deepening-shallowing marine conditions) that are not always reflected by lithologic differences. Analysis of the presence-absence of Foraker fauna (and thus recurrent faunal associations) and the biofacies they define (both vertically and laterally) helped invoke environmental interpretations. This, in turn, helped establish the basis for determining sixth-order genetic boundaries, and deeper versus shallower facies within each sixth-order T-R unit. Environments represented by deeper or shallower facies (biofacies) were graphically illustrated by relative sea level curves. All environmental interpretations were made subsequent to any taphonomic interpretations of biofacies. The use of biofacies and the methodology of environmental interpretations in this study are analogous to several examples as discussed below.

Brezinski (1981, 1983) and Wells (1985) analyzed the biofacies and faunal associations of some Pennsylvanian strata in the Northern Appalachian Basin that contained taxa similar to those found in the Foraker Formation. Environmental stress gradients (caused by water depth, salinity, proximity to source lands, etc.), causing differences in faunal diversities, allowed the lateral and vertical differentiation of biofacies. For example, Figure 18 illustrates Brezinski's biofacies of the Ames Limestone (Late Carboniferous, Virgilian). This figure shows that there are distinct boundaries represented by the shoreward disappearance of stenotopic biota (e.g., fusulinids, Neospirifer, and Composita) and an increase in eurytopic individuals (e.g., Crurithyris, Aviculopecten, and bellerophontaceans). Brezinski (1983, pg. 97) showed that his biofacies are also discernible in vertical stratigraphic sequence where, for example, a Neochonetes biofacies is overlain by a Neospirifer and Composita biofacies, which is overlain by a Crurithyris biofacies, which is overlain by a molluscan biofacies. This vertical sequence of biofacies defines a basal transgressive, opportunistic (Neochonetes) facies, that is overlain by a deeper or normal marine facies (Composita and Neospirifer biofacies), which grades upward into a paralic or more restricted marine facies (Crurithyris and molluscan biofacies).

Wells (1984) also demonstrated that the Woods Run "marine unit" (late Pennsylvanian, Missourian) of the Appalachian Basin, could be divided into three biofacies that represent distinct environments. Wells' first biofacies (Cavellina-rugosan-Glabrocingulum-echinoderm biofacies) represents a stable, open-marine environment that contained

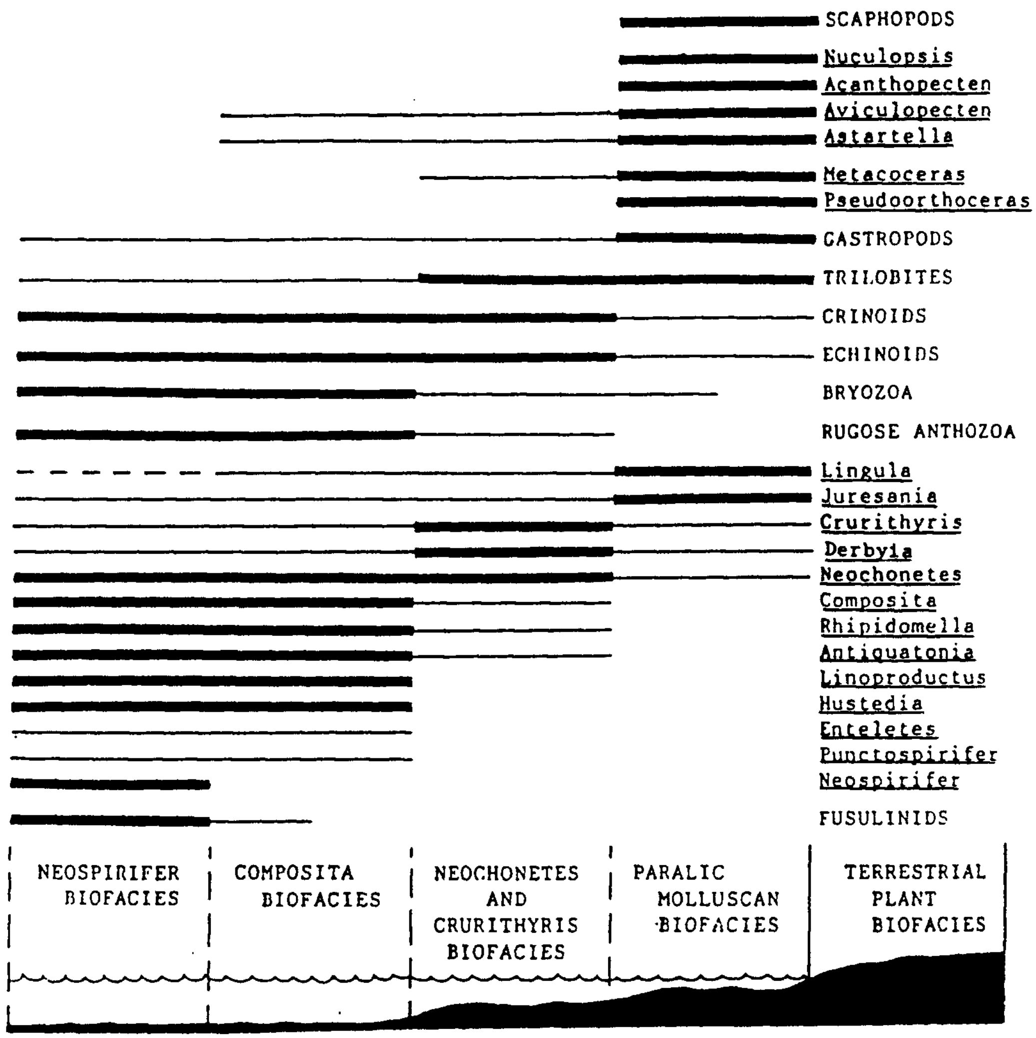


Figure 18. Biofacies distribution of the Ames Limestone (Late Missourian or Early Virgillian) of the Northern Appalachian Basin, as defined by Brezinski (1981, 1983) and modified with data from Busch (1984).

stenotopic and eurytopic individuals and is the most generically diverse assemblage. The other two biofacies (*Straparollus*-*Donaldina*-*Coryllites* biofacies and the *Lingula*-*Orbiculoidea*-*Hollinella*-bellerophontacean biofacies) are less diverse, are dominated by stenotopic individuals, and and represent shallow, nearshore environments. Studies such as these, show that stenotopic fauna are not present in nearshore, unstable environments, and that generic diversity increases toward more stable, deeper or more open-marine environments.

Fossil diversity is one of the fundamental parameters used in this study to differentiate deeper (more open) versus shallower (more restricted) marine facies. Diversity is defined as the taxonomic richness or number of species (or genera) present (Raup and Stanley, 1971). Sanders (1969), and Bretsky and Lorenz (1970) stated that species diversity increases proportionally, with an increase in environmental stability, as in the case of more normal marine conditions (e.g., during maximum transgression); and that diversity changes are discernible whether studied vertically or laterally.

Carboniferous studies by Donahue *et al*. (1972), Donahue and Rollins (1974), and Rollins *et al*. (1979) have shown that maximum fossil diversities (containing eurytopic and stenotopic individuals) occur in the more "open" and deeper marine units, representative of maximum transgression;

whereas, the less diverse biota (consisting of eurytopic individuals) occur in the regressive, shallow marine deposits. Stevens (1971) showed that fossil diversities in the Pennsylvanian Minturn Formation of central Colorado increase with increasing depth and distance from shore because of environmental stability.

Patterns illustrating onshore to offshore diversity increases have also been documented by Bretsky (1970) in the Upper Ordovician of the Central Appalachian Basin, by Walker and Laporte (1970) in Ordovician and Devonian strata of the Appalachians, and by Sutton et al. (1970) in Upper Devonian deltaic sediments of New York. Nonrandom vertical and lateral biofacies distributions, as influenced by stable (offshore) and unstable (nearshore) environments, have been documented in terms of diversity for most of the Paleozoic (Anderson, 1974).

Anomalous increased diversities in a shoreward direction have been commonly attributed to an increase in molluscan diversity, which has been termed the "molluscan reversal" by Dodin (1974). Such molluscan reversals have been documented by Stevens (1971) and Brezinski (1983); both interpreted their reversals as indicative of nearshore environments. Hattin (1957) and Anderson (1974) have also shown molluscan dominated facies as representing nearshore environments.

Most recently West and Busch (1985) have shown that the

Middle Pennsylvanian Wewoka Formation (Desmoinesian) contains at least 14 sixth-order transgressive surfaces. These were delineated by using quantitative fossil diversities. Where faunal diversities showed an abrupt increase, following a quantitatively lower diversity value, a sixth-order boundary was postulated at that position.

In this study the number of genera, and thus the diversities, are represented graphically by the presence and absence of genera. The abrupt increase or appearance in fossil diversity (as represented by a particular biofacies) was interpreted in this study as representing a deepening event, with the transgressive surface being placed at the base of this event. Decreases in fossil diversity (as represented by certain biofacies) and lithostratigraphic changes helped define the shallowing-upward nature of each sixth-order T-R unit.

Comparing the relative maximum fossil diversities of all sixth-order T-R units (and carefully considering any molluscan reversals) helped reveal the fifth-order boundaries. In so doing, the maximum extent of transgression in each fifth-order T-R unit (i.e., the fifth-order transgressive apex) was also revealed, based on the biofacies containing the maximum faunal diversity, relative to the other sixth-order T-R units. Net deepening and shallowing trends (on a fifth-order scale), based on relative net increases and relative net decreases (respectively) in fossil diversity, were also revealed.

Once the maximum extent of transgression was found at a fifth-order level, the fossil diversities of each fifth-order "transgressive apex" (e.g., Busch and West, 1987) could be compared. This helped determine where the maximum extent of transgression on a fourth-order scale occurred, as well as where the net deepening, and net shallowing phases occurred.

The presence and absence of fossils used to help delineate the deepening-shallowing trends was described in a relative sense. Namely, each genus is spoken of in terms of abundant, common, rare, or absent. Abundant refers to a fossil that is numerous or profuse enough to be readily seen (or is essentially everywhere present) in a slabbed surface, thin section, shale sieve analysis, or the weathered outcrop surface. Common refers to fossils that are numerous, but are not immediately conspicuous (or are not everywhere present). Rare refers to fossils that are very poorly represented in the sample (found only once or twice in the rock).

Labeling of T-R Units.--An alpha-numeric label was affixed to each individual sixth-order T-R unit. This label defines its hierarchal placement relative to the fifth- and fourth-order units. The labeling scheme, Fn.n, was devised for this study and is defined in the following manner: "F" arbitrarily stands for the Foraker fourth-order T-R unit; the first "n" stands for the numerical position, in ascending increasing order, of the fifth-order T-R unit within the fourth-order T-R unit; and the second "n" stands for the sixth-order T-R unit, and its relative position within the fifth-order unit. For example, F1.2 stands for the second sixth-order T-R unit above the base of the first fifth-order T-R unit within the "F" or Foraker fourth-order T-R unit (Figure 15).

The label, Fn.n, essentially has a two-fold meaning. Firstly, it represents the transgressive and/or climate change surface to which it is affixed; and secondly, it also represents the entire sixth-order T-R unit immediately above the genetic surface containing the same label, and below the next superjacent genetic surface.

The names of the fifth-order T-R units delineated in this study reflect the names of the formal lithostratigraphic "member" most completely contained within that particular fifth-order T-R unit (e.g., Americus fifth-order T-R unit, or the Hughes Creek fifth-order T-R unit). Fourth-order T-R units can named in a similar manner, using formational names.

HIERARCHAL GENETIC STRATIGRAPHY OF THE FORAKER FORMATION

The initial procedure for defining the hierarchal genetic (T-R unit) stratigraphy of the Foraker Formation consisted of a detailed bed-by-bed, stratigraphic analysis of closely spaced outcrops and one core (Amoco #1 Hargrave, Appendix). The new locations (Figure 1) described here (Appendix) were located using geologic and topographic maps. Other sections were redescribed after Jewett (1941), O'Connor (1953), Walter (1953), Scott et al. (1959), and Mudge and Burton (1959).

The measured sections and their relative locations were utilized on the basis of their completeness of the Foraker exposure, proximity to one another, and north-south and east-west location to provide three dimensional stratigraphic (and paleogeographic) control. Two additional locations described by Garber (1962), one from Mudge and Yochelson (1962), two from Mudge and Burton (1959), two from Scott et al. (1959), and one from Jewett (1941) were used to supplement those sections measured and described by this author.

Thin sections and rock slabs of more than 100 limestone samples were made, then analyzed with binocular and petrographic microscopes. Particular attention was paid to the presence-absence of fossils and lithologic features indicative of particular paleoenvironments. Thin section analysis aided in describing microfossils and fossil debris that were unrecognizable in the field.

Calcareous and non-calcareous shales were disaggregated using Quaternary-O (a dispersing agent) for the study of fossil content and general textural properties. The samples were immersed in a 2% solution of Quaternary-O for approximately 30 to 40 days (or until a texturally homogenous residue was obtained; i.e., the samples were not boiled). The shale residues were then washed through a U.S. standard 10-60-140-220 mesh screen stack. Samples were collected from each screen-size, and macrofossils were separated from microfossils. This method works exceptionally well, even for very calcareous shales.

Field and laboratory analyses of the lithologies, fossils, and sedimentary structures were used to describe in detail, the Foraker Formation at four locations to determine the presence of T-R units. These localities consist of the Paxico, Manhattan, McDowell Creek Road, and Poliska Lane sections (Figure 1; Appendix). Each distinct lithology was sampled at each of the four localities. Where limestones and shales were relatively thick and massive, multiple samples were taken to detect stratigraphic lithofacies or biofacies changes. Thin sections and washed residues were concentrated in those intervals that, from field observations, appeared to be critical in correlating the T-R units of the detailed sections with other localities.

Sixth- and fifth-order T-R units of the Paxico section will be described first, as this represents the most complete section of the Foraker. Subsequently, sixth- and fifth-order T-R units are described for the McDowell Creek Road section, Manhattan section, and lastly, for the Poliska Lane section (in that order), as these last three sections supplement each other in a stratigraphically ascending fashion, and close geographic proximity. Part of a fourth-order T-R unit will be described separate from the fifth- and sixth-order T-R units. The four detailed sections need to be discussed within the same context, and essentially simultaneously, in order to define part of the fourth-order T-R unit. Genetic correlation, based on three cross-sections (pocket enclosure), will then be discussed relative to the detailed sections.

Paxico Section

Sixth-Order T-R Units.--Based on detailed field and lab analysis of the lithostratigraphic and faunal associations, the Paxico section was divided into 14 sixth-order T-R units. The first sixth-order T-R unit, F1.1 (Figures 19 & 20a; Appendix) is present from 0.43 m below the base of the Americus Limestone Member, to 0.81 m above the base of the Americus limestone, and encompasses units 2 through 5. Unit 2 consists of an olive gray, silty, blocky and shaley claystone, that contains abundant ostracodes and macerated

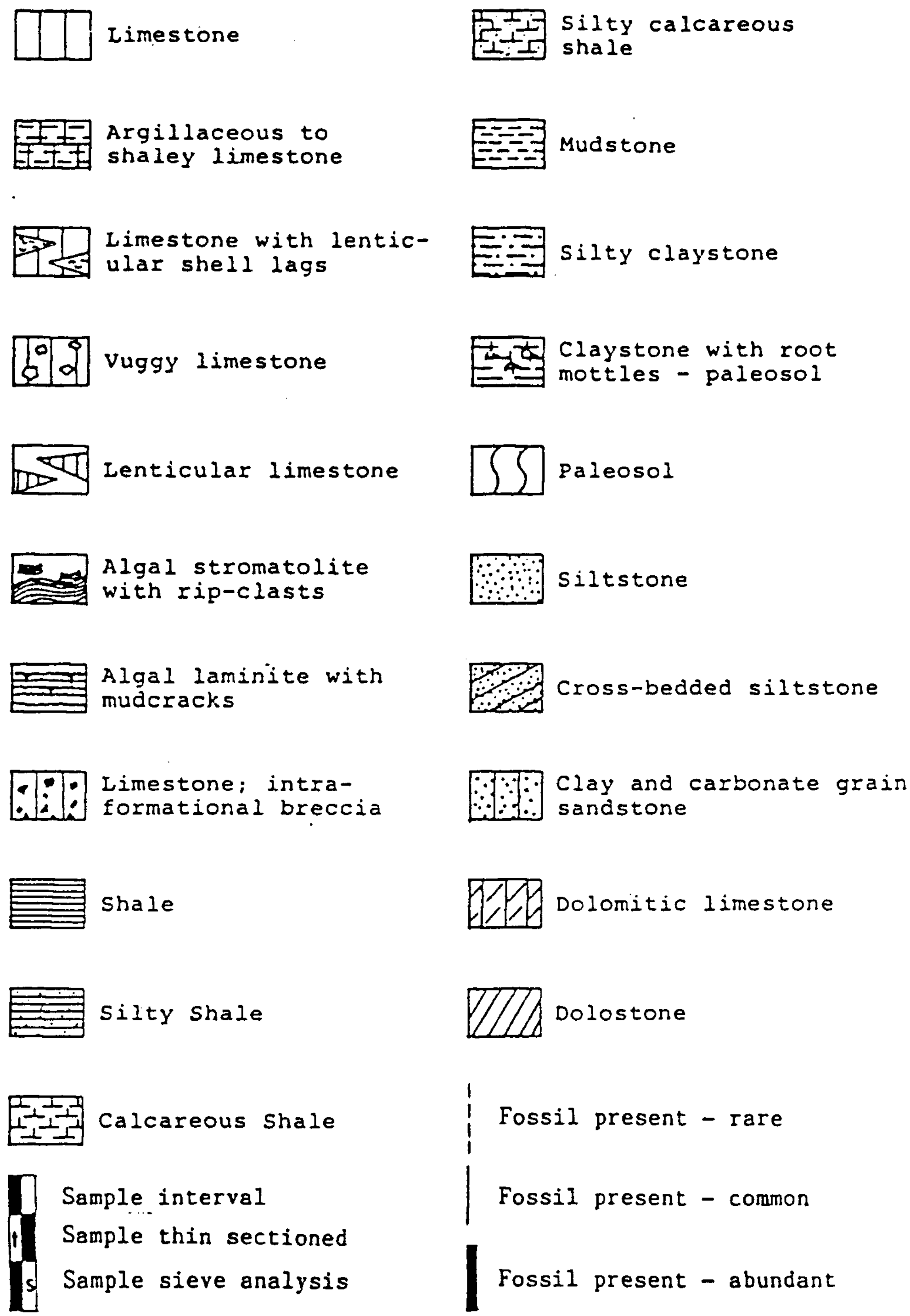


Figure 19. Lithostratigraphic symbols, sample intervals, and relative fossil abundance symbols used in Figures 20, 21, and 22.

Figure 20a-e . Graphic illustrations of the Paxico section showing the lithostratigraphic, biostratigraphic, and paleoenvironmental charateristics of each sixth- and fifth-order T-R unit, and their bounding genetic surfaces.

a. Graphic illustration of the very upper Hamlin shale, and sixth-order T-R units F1.1, F1.2, and the basal part of F1.3.

b. Graphic illustration of sixth-order T-R units F1.3, F2.1, F2.2 and the basal part of F2.3.

c. Graphic illustration of sixth-order T-R units F2.3, F2.4, and the basal part of F3.1.

d. Graphic illustration of sixth-order T-R units F3.1, F3.2, F3.3 and the basal part of F3.4.

e. Graphic illustration of F3.4, F3.5, and F3.6.

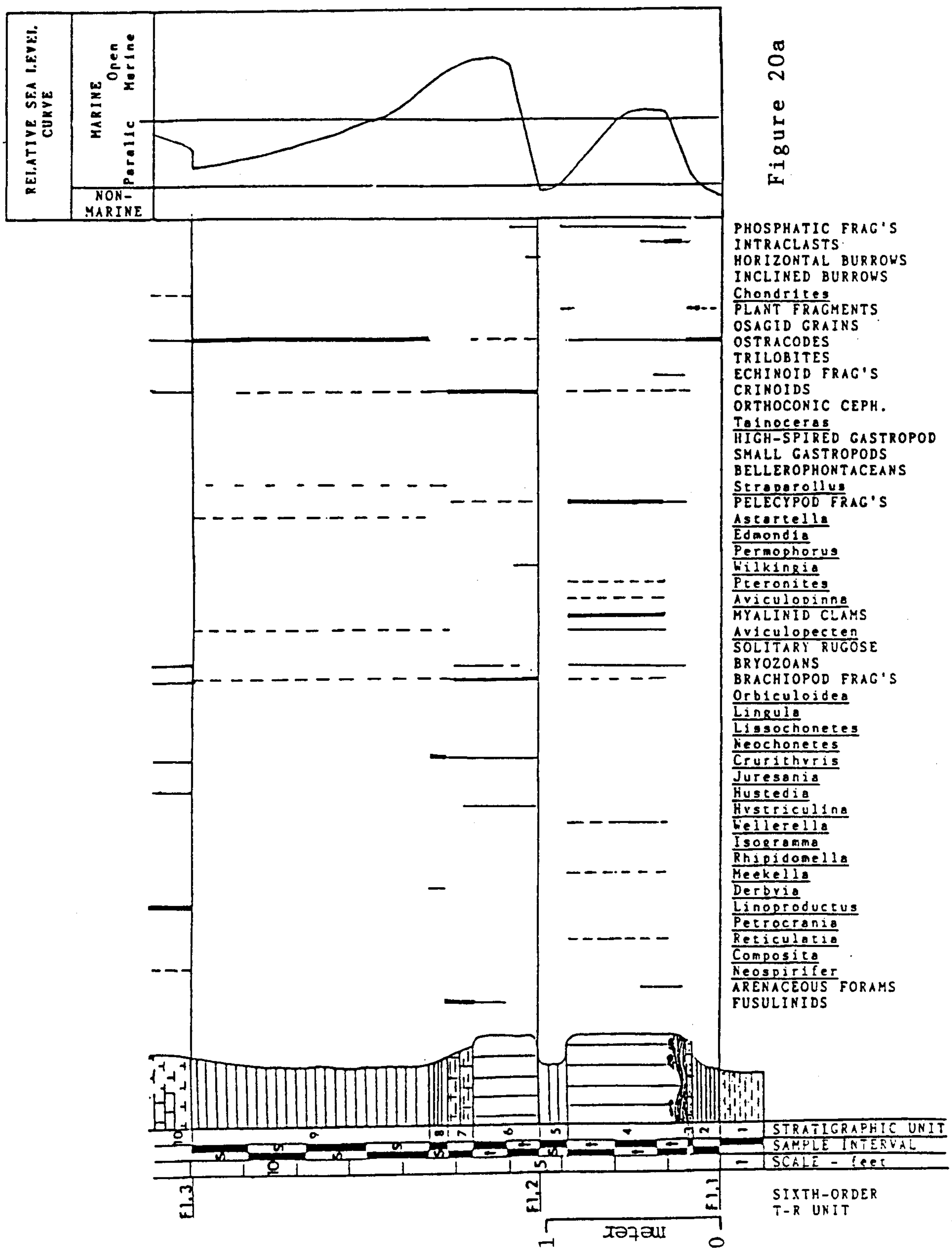

RELATIVE SEA LEVEL CURVE
MARINE
Open Marine
Paralic
NON-MARINE
PHOSPHATIC FRAG'S
INTRACLASTS
HORIZONTAL BURROWS
INCLINED BURROWS
Chondrites
PLANT FRAGMENTS
OSAGID GRAINS
OSTRACODES
TRILOBITES
ECHINOID FRAG'S
CRINOIDS
ORTHOCONIC CEPH.
Tainoceras
HIGH-SPIRED GASTROPOD
SMALL GASTROPODS
BELLEROPHONTACEANS
Straparollus
PELECYPOD FRAG'S
Astartella
Edmondia
Permophorus
Wilkingia
Pteronites
Aviculopinna
MYALINID CLAMS
Aviculopecten
SOLITARY RUGOSE
BRYOZOANS
BRACHIOPOD FRAG'S
Orbiculoidea
Lingula
Lissochonetes
Neochonetes
Crurithyris
Juresania
Hustedia
Hystriculina
Wellerella
Isogramma
Rhipidomella
Meekella
Derbyia
Linoproductus
Petrocrania
Reticulatia
Composita
Neospirifer
ARENACEOUS FORAMS
FUSULINIDS
STRATIGRAPHIC UNIT
SAMPLE INTERVAL
SCALE - feet
SIXTH-ORDER T-R UNIT
F1.3
F1.2
F1.1
1
meter
0

Figure 20a

plant fragments. Genetic surface F1.1 is placed at the base of unit 2, because unit 1 (base concealed) is a non-fossiliferous, massive, silty, slightly dolomitic mudstone that contains common calcite nodules in its upper 0.15 m. Overlying unit 2 is 0.01 m to 0.03 m of fine to medium grained, friable sandstone (unit 3). Unit 3 is composed predominately of moderately sorted, angular clay and carbonate grains (lithoclasts?; i.e., calcilithite to shale-arenite). Unit 3 also contains common ostracode carapaces, rare algal (stromatolitic in origin) intraclasts, and plant fragments. These constituents are loosely held in a clayey, calcareous limonitic matrix that is porous. This unit is overlain by, and is gradational with, a 0.10 m to 0.20 m bed of massive, planar to domal algal stromatolites (base of unit 4) averaging 0.12 m to 0.20m in diameter and 2.0 cm to 4.0 cm in height. Laterally, the algal stromatolites are brecciated, and contorted.

In between the subtle algal domes and embracing the larger algal clasts at the base of unit 3, is a medium-grained calcarenite matrix composed of poorly sorted, algal rip-up clasts, occasionally arranged edgewise. The matrix also contains ostracodes, pelecypod fragments, and forams (occasionally encrusting the algal stromatolites; e.g., Fisher, 1980); pellets, bryozoans, and echinoderm fragments are also present, but less conspicuous. The upper part of unit 4 (0.15 - 0.36 m) is an argillaceous calcarenite with common pelecypods, ostracodes, and phosphatic debris (fish debris?), and traces of brachiopod fragments. The pelecypods include common large myalinid fragments, common to rare Aviculopecten and rare pinnid fragments. This facies is identified as a molluscan biofacies. The matrix also contains thin, irregularly shaped flaser-like "clay whisps" that become common in the upper 0.15 m. These are attributed to bioturbation (possibly burrowing by pelecypods). The upper 0.15 m of F1.1 (unit 5) is represented by the middle shale unit of the Americus Limestone Member. This unit is a gray-black to gray, non-calcareous, nonfossiliferous shale with marked fissility. The lower 1 cm of this facies is carbonaceous, and abundant minute selenite crystals are found on the bedding surfaces of unit 5.

In summary, upward through T-R unit F1.1, an ostracode bearing silty shale (unit 2) is overlain by a very thin basal transgressive carbonate-clay sandstone (unit 3), which grades into massive, brecciated stromatolites (base of unit 4). There is an increase in diversity going from units 2 (1 taxon) to 4 (14 taxa), an abrupt appearance of intraclasts and stromatolites at the base of unit 4, a decrease in grain size from units 3 to 4, and a decrease in the intraclasts and fragmental debris upward into the overlying pelecypod dominated limestone (unit 4). Lastly, there is an increase in siliciclastic mud (unit 5) . Environmentally, F1.1 is represented by an initial marine inundation that trapped sediments in a possible brackish or estuarine environment conducive to ostracode and plant accumulation (unit 2). Subsequently, relatively rapid transgression produced the intertidal calcarenite-sandstone (unit 3). Continued deepening formed the laterally brecciated stromatolitic facies (base of unit 4) that probably represents a high subtidal, yet agitated environment. The most open environment (subtidal) is repesented by the molluscan biofacies (upper part of unit 4; e.g., Hattin, 1957; Lutz-Garihan and Cuffey, 1979)). The subtidal open marine environments were followed by shallow marginal marine, restricted, and possibly hypersaline lagoonal environments (unit 5).

Fisher (1980), Peterson and Kaesler (1980) and Mudge and Yochelson (1962) have noted the existence of basal "transgressive", brecciated algal stromatolites in the lower Americus. Fisher (1980) suggested that the brecciated and contorted nature of these algal stromatolites were due in part to storm and tidal currents. He described the basal limonitic clay-grain sandstone (unit 3) as a regolithic deposit, representing a disconformity, that formed under subaerial conditions at the end of Hamlin time. Based on the gradual increase in diversity from units 2 through 4, this unit is interpreted as a "transgressive lag". Fisher (1980) considered this same unit to be a regolithic deposit, but I found no evidence of subaerial exposure. Unit 3 is clearly gradational with the overlying algal stromatolites.

Sixth-order T-R unit F1.2 is present from 0.81 m to 2.05 m above the base of the Americus limestone (Figures 19 & 20a; Appendix) and encompasses units 6 thru 9. The lower 0.15 m of F1.2 (i.e., unit 6, the upper Americus Limestone) is an argillaceous, silty, crinoidal, brachiopod, intraclast, packed biomicrite (packstone) that contains detritus-filled, horizontal burrows (2.0 - 5.0 cm diameters). Fisher (1980) concluded that the semi-infaunal pelecypod, Wilkingia, formed these burrows.

The lower 0.15 m of unit 6 grades into a biomicrite (wackestone) with common fusulinids, bryozoans, pelecypods and abundant crinoids and brachiopods (upper part of unit 6). Above this is 0.15 m of argillaceous, micritic calcirudite that contains common fusulinids (approximately 10% by volume of rock), and crinoids, and rare Crurithyris, and Hystriculina (unit 7). Above unit 7 is 0.11 m of calcareous, dark-gray shale (unit 8), containing abundant Crurithyris. The upper 1.40 m of F1.2 (unit 9) is a dark gray to gray, micaceous shale with abundant smooth ostracodes, and rare productids and molluscs. In summary, upward through F1.2, there is a loss of intraclasts, an appearance and increase in brachiopod fragments, fusulinids, bryozoans, crinoids, and mud, a subsequent increase in Crurithyris, and finally, an increase in ostracodes, and more mud. The paleoenvironments represented in F1.2 range from higher energy, transgressive, nearshore intertidal conditions at the base of unit 6, to more open marine (subtidal) conditions as represented by the brachiopod, bryozoan, crinoidal and fusulinid biofacies (upper portion of unit 6, and unit 7). These were followed by intertidal, regressive/progradational conditions as represented by the Ostracode biofacies (units 8 and 9).

Sixth-order T-R unit F1.3 (Figures 19 & 20b) occurs from 2.05 m to 3.90 m above the base of the Americus limestone, and encompasses units 10 thru 13. The lower 0.71 m of F1.3 (units 10 and 11) is a silty, fossiliferous, calcareous shale with thin (2.0 - 5.0 cm) biomicrite interbeds containing abundant Linoproductus, rare to common Neospirifer, common to rare Crurithyris, Hustedia, bryozoans, crinoids and ostracodes, and ocassional horizontal burrows (Chondrites). Above this is 0.35 m of thin bedded to nodular, very argillaceous calcirudite, that is defined as a burrowed, brachiopod-molluscan-osagid packed biomicrite (packstone). The dominant constituents of this facies are osagid encrusted grains, pelecypod fragments, and gastropods; in addition to common echinoid and crinoid debris. The molluscan and echinoderm constituents are commonly encrusted, but also occur (rarely in thin section) as free of Osagia. Neospirifer, Composita, Reticulatia, Linoproductus, Neochonetes, and others (Figure 20b) occur as comminuted fossil debris (in thin section), and are commonly encrusted. At the base of unit 12, brachiopods are rarely articulated.

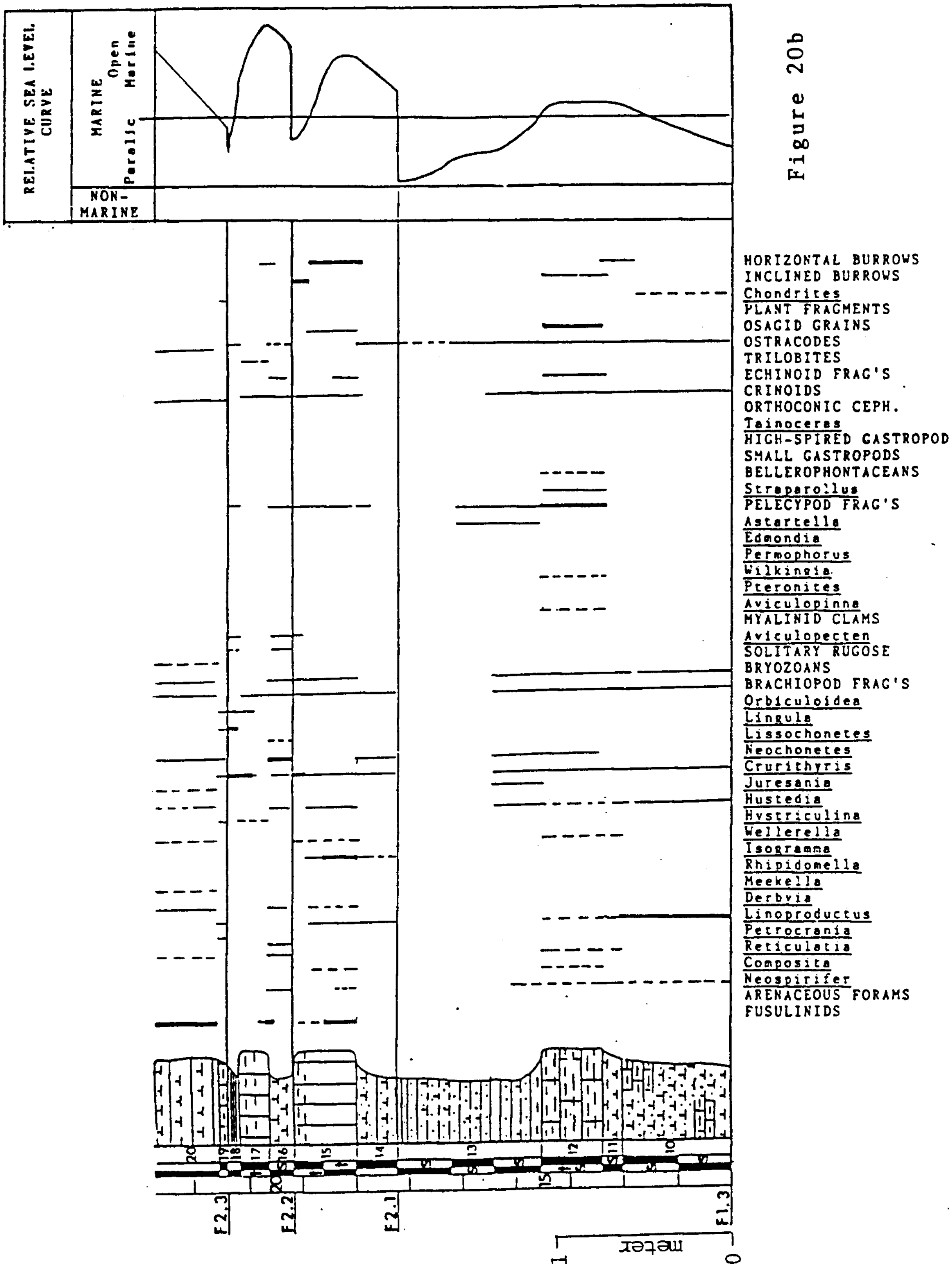

RELATIVE SEA LEVEL CURVE
MARINE
Open Marine
Paralic
NON-MARINE
HORIZONTAL BURROWS
INCLINED BURROWS
Chondrites
PLANT FRAGMENTS
OSAGID GRAINS
OSTRACODES
TRILOBITES
ECHINOID FRAG'S
CRINOIDS
ORTHOCONIC CEPH.
Tainoceras
HIGH-SPIRED GASTROPOD
SMALL GASTROPODS
BELLEROPHONTACEANS
Straparollus
PELECYPOD FRAG'S
Astartella
Edmondia
Permophorus
Wilkingia
Pteronites
Aviculopinna
MYALINID CLAMS
Aviculopecten
SOLITARY RUGOSE
BRYOZOANS
BRACHIOPOD FRAG'S
Orbiculoidea
Lingula
Lissochonetes
Neochonetes
Crurithyris
Juresania
Hustedia
Hystriculina
Wellerella
Isogramma
Rhipidomella
Meekella
Derbyia
Linoproductus
Petrocrania
Reticulatia
Composita
Neospirifer
ARENACEOUS FORAMS
FUSULINIDS
20
19
18
17
16
15
14
13
12
11
10
F2.3
F2.2
F2.1
F1.3
1
meter
0

Figure 20b

Overlying unit 12 is 0.76 m of silty, olive gray, slightly calcareous, sparsely fossiliferous shale (unit 13).

Sixth-order T-R unit F1.3 contains 8 taxa in unit 10, 10 taxa in unit 11, 20 taxa in unit 12, and only one fossil type in unit 13. Environmentally, F1.3 contains a net transgressive, retrogradational, opportunistic faunal association (dominated by Linoproductus) representing intertidal to subtidal conditions at its base (units 10 and 11). This is overlain by a more diverse, carbonate-rich, molluscan-osagid biofacies, representing turbulent conditions in a shallow, subtidal environment (unit 12). Regressive/progradational conditions are recorded by the sparsely fossiliferous siliciclastic mud (unit 13) that represents a nearshore, possibly brackish-marine, intertidal environment.

Algaloid concretions of the form genus Osagia incrustata (Twenhofel, 1919) are considered by Henbest (1963) as segregated associations of girvanellid-like algae and cornuspirid foraminifera (e.g., Hedraites and Apterinella) that form in wave- and current-prone areas within the photic zone, as the algae are considered chlorophyll-bearing plants. Toomey (1969, 1974) described in detail, algally coated grains of a similar nature in the Leavenworth limestone (upper Pennsylvanian, Virgilian). Osagid grains of unit F1.3 are similar to those studied by Toomey in that they are associated with a diverse biota.

Sixth-order T-R unit F2.1 (Figures 19 & 20b; Appendix) is present from 3.90 m to 4.54 m above the base of the Americus limestone and encompasses units 14 and 15. Unit 14 is a fossiliferous (6 taxa), silty, calcareous shale that is overlain by 0.30 m of coarse calcarenite to fine calcirudite (unit 15) compositionally referred to as an osagid-bearing, fusulinid-brachiopod biomicrite. Fossil diversity is highest in the lower half of unit 15, as represented by a total of 15 taxa. Unique to the base of unit 15 is the brachiopod Isogramma. The upper 0.05 m of unit 15 is a Crurithyris-rich, very argillaceous, fine to medium calcirudite. As seen in Figure 20b, the lower part of unit 15 contains 15 taxa, whereas the upper part contains 7 taxa. F2.1 is also biogenically stratified with horizontal burrows ("spreite") in the lower-half, and vertical and U-shaped burrows in the upper 0.05 m.

In summary, upward through F2.1, there is a decrease in Isogramma and fusulinids, an increase in diversity towards the middle of unit 15, and then a sharp decrease in fossil diversity in the Crurithyris biofacies (top of unit 15). The paleoenvironments range from a transgressive, open marine environment represented by an opportunistic fauna (Isogramma, Linoproductus), to deeper marine conditions marked by maximum diversity (lower half of unit 15). This was follow by nearshore, regressive conditions in the upper 0.05 m of unit 15. The regressive nature of the Crurithyris biofacies in the upper 0.05 m of F2.1, is supported by Brezinski's (1981, 1983) and Donahue and Rollins' (1974) interpretation of Crurithyris, as being a eurytopic form capable of withstanding nearshore environments that received large influxes of sediment.

Sixth-order T-R unit F2.2 (Figures 19 & 20b; Appendix), is present from 4.54 m to 4.90 m above the base of the Americus limestone, and encompasses units 16 through 18. Unit 16 is 0.15 m of dark gray to brown-gray, very calcareous shale (mudstone) with 17 taxa. Neochonetes is the most abundant genus in unit 16, but this unit also contains common (fragmented and articulated) Neospirifer, Reticulatia, Hustedia, Crurithyris, ramose and fenestrate bryozoans, as well as common myalinids and Aviculopecten. Unit 16 is overlain by, and is gradational with, 0.15 m of fine calcirudite (unit 17), compositionally referred to as an argillaceous, fusulinid-brachiopod biomicrite. Fusulinids occur at the top of unit 16, as well as at the base of unit 17, thus creating a gradational relationship between these two units. A Crurithyris biofacies encompasses the upper 0.10 m of unit 17 and all of unit 18. Unit 18 is 0.05 m of dark gray, very calcareous fossiliferous shale in which Lingula, Orbiculoidea, and pelecypod fragments are also present.

In F2.2 there are 16 taxa in the lower part of unit 16, 17 taxa in the upper part of unit 16, 7 taxa in unit 17, and

7 taxa unit 18. From units 16 to 17 there is a decrease in brachiopod, molluscan, and bryozoan diversity. This is followed by an appearance and disappearance of fusulinids in the middle portion of F2.2, that is accompanied by an increase in Crurithyris and calcium carbonate content (unit 17). A subsequent increase in black shale content and inarticulate brachiopod fragments occurs in unit 18. The paleoenvironments of F2.2 range from a transgressive, open marine environment (base of unit 16), to maximum, open marine conditions, as represented by the maximum diversity in the upper part of unit 16. This grades into a regressive, carbonate-rich, relatively shallow, and well lit environment (unit 17), that was replaced by a restrictive, probably lagoonal-intertidal environment (unit 18).

Sixth-order T-R unit F2.3 (Figures 19 & 20c; Appendix) is present from 4.90 m to 7.08 m. above the base of the Americus limestone, and encompasses units 19 thru 22. Unit 19 consists of 0.04 m argillaceous, fossiliferous, coarse calcarenite with abundant Chondrites on bedding plane surfaces. The abundant Chondrites is suggestive of increased oxygenation events as a result of the start of transgression (i.e., relative to the subjacent black shale reflecting nearly anoxic substrate conditions in unit 18). Unit 19 is overlain by 0.33 m of massive, very calcareous, fusulinid-rich shale (approximately 20% by volume of rock; unit 20) containing 13 taxa. Unit 20 is overlain by, and is

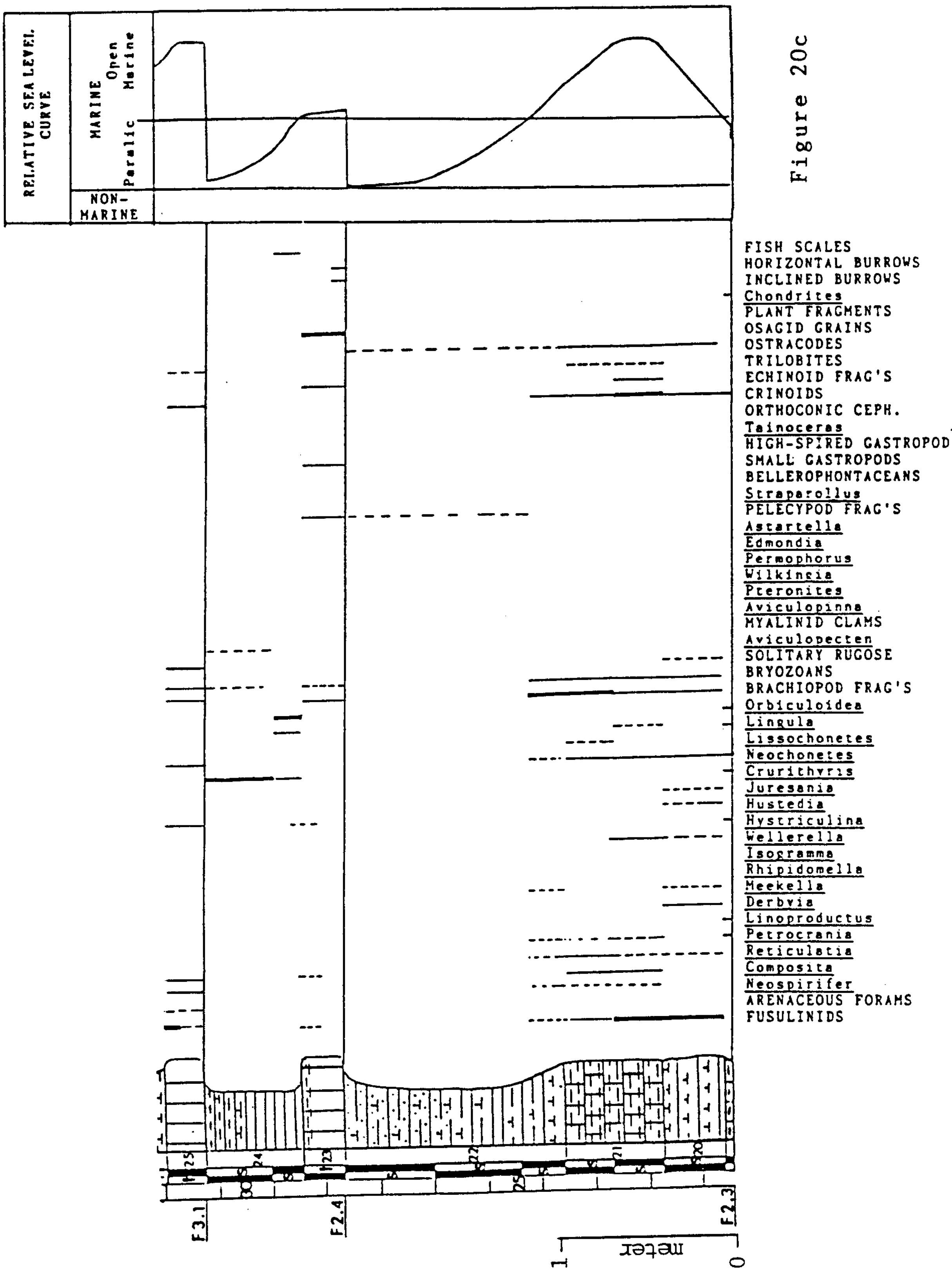

RELATIVE SEA LEVEL CURVE
MARINE
Open Marine
Paralic
NON-MARINE
FISH SCALES
HORIZONTAL BURROWS
INCLINED BURROWS
Chondrites
PLANT FRAGMENTS
OSAGID GRAINS
OSTRACODES
TRILOBITES
ECHINOID FRAG'S
CRINOIDS
ORTHOCONIC CEPH.
Tainoceras
HIGH-SPIRED GASTROPOD
SMALL GASTROPODS
BELLEROPHONTACEANS
Straparollus
PELECYPOD FRAG'S
Astartella
Edmondia
Permophorus
Wilkincia
Pteronites
Aviculopinna
MYALINID CLAMS
Aviculopecten
SOLITARY RUGOSE
BRYOZOANS
BRACHIOPOD FRAG'S
Orbiculoidea
Lingula
Lissochonetes
Neochonetes
Crurithyris
Juresania
Hustedia
Hystriculina
Wellerella
Isogramma
Rhipidomella
Meekella
Derbyia
Linoproductus
Petrocrania
Reticulatia
Composita
Neospirifer
ARENACEOUS FORAMS
FUSULINIDS
F3.1
F2.4
F2.3
1
meter
0

Figure 20c

gradational with, 0.56 m of very argillaceous to shaley, fossiliferous, fine to medium calcirudite (unit 21) with abundant to common fusulinids, crinoids, brachiopods, and bryozoans (typically ramose). The basal part of unit 21 contains 14 taxa, whereas the upper half contains 12 taxa. Unit 21 grades vertically upward into 0.15 m of fossiliferous calcareous shale (unit 22) that is dominated by brachiopods, bryozoans, and crinoids in its basal part (12 taxa). The upper part of unit 22 is a silty, micaceous, calcareous shale lacking fossils. In summary, upward through F2.3, fusulinids and clay content decrease, accompanied by an increase in bryozoans, brachiopods, crinoids and carbonate content. Finally, there is an increase in the siliciclastic fraction, rare ostracodes, and <u>Astartella</u>. Basally, F2.3 represents open, quiet, subtidal marine conditions (unit 20 and base of unit 21) that allowed accumulation of siliciclastic mud. This was followed by a less diverse, open marine environment, representing the initial phases of regression (upper part of unit 21 and base of unit 22). Lastly, nearshore-paralic conditions with increased siliciclastic deposition (upper part of unit 22) represent the regressive/progradational phase of F2.3.

Sixth-order T-R unit F2.4 (Figures 19 & 20c; Appendix) is present from 7.08 m to 7.84 m above the base of the Americus limestone and encompasses units 23 and 24. Unit 23 is a burrowed, packed biomicrite, with rare brachiopods and fusulinids, and common pelecypods and gastropods. Osagid grains are abundant in unit 23. Overlying unit 23 is 0.15 m of gray-black, non-calcareous, Orbiculoidea-rich shale (basal part of unit 24). This grades into 0.40 m of gray to dark gray shale with abundant Crurithyris (upper part of unit 24). The osagid-molluscan biofacies of unit 23, represents relatively nearshore, shallow, yet moderately agitated conditions. Intermittent open marine circulation probably helped sustain niches suitable to the rare brachiopod taxa of unit 23. This was followed by less open, semi-restricted lagoonal-intertidal conditions represented by the Orbiculoidea and Crurithyris biofacies (unit 24).

Sixth-order T-R unit F3.1 (Figures 19 & 20d; Appendix) is present from 7.84 m to 8.28 m above the base of the Americus limestone and encompasses units 25 and the basal 0.23 m of unit 26. Taxa such as fusulinids, Neospirifer, Composita, Hystriculina, Neochonetes, solitary rugose corals, bryozoans, and crinoids are present throughout unit 25. These taxa are distributed such that unit 25 grades from a brachiopod packstone (fragmented) at its base, to a fusulinid packstone at its top. The brachiopod and fusulinid-rich biofacies of unit 25 were eventually overcome by progradational-regressional deposition of clay (base of unit 26). Only two taxa, fusulinids and crinoids, were found in unit 26. The paleoenvironments of unit F3.1 range from maximum, open marine conditions represented by the brachiopod

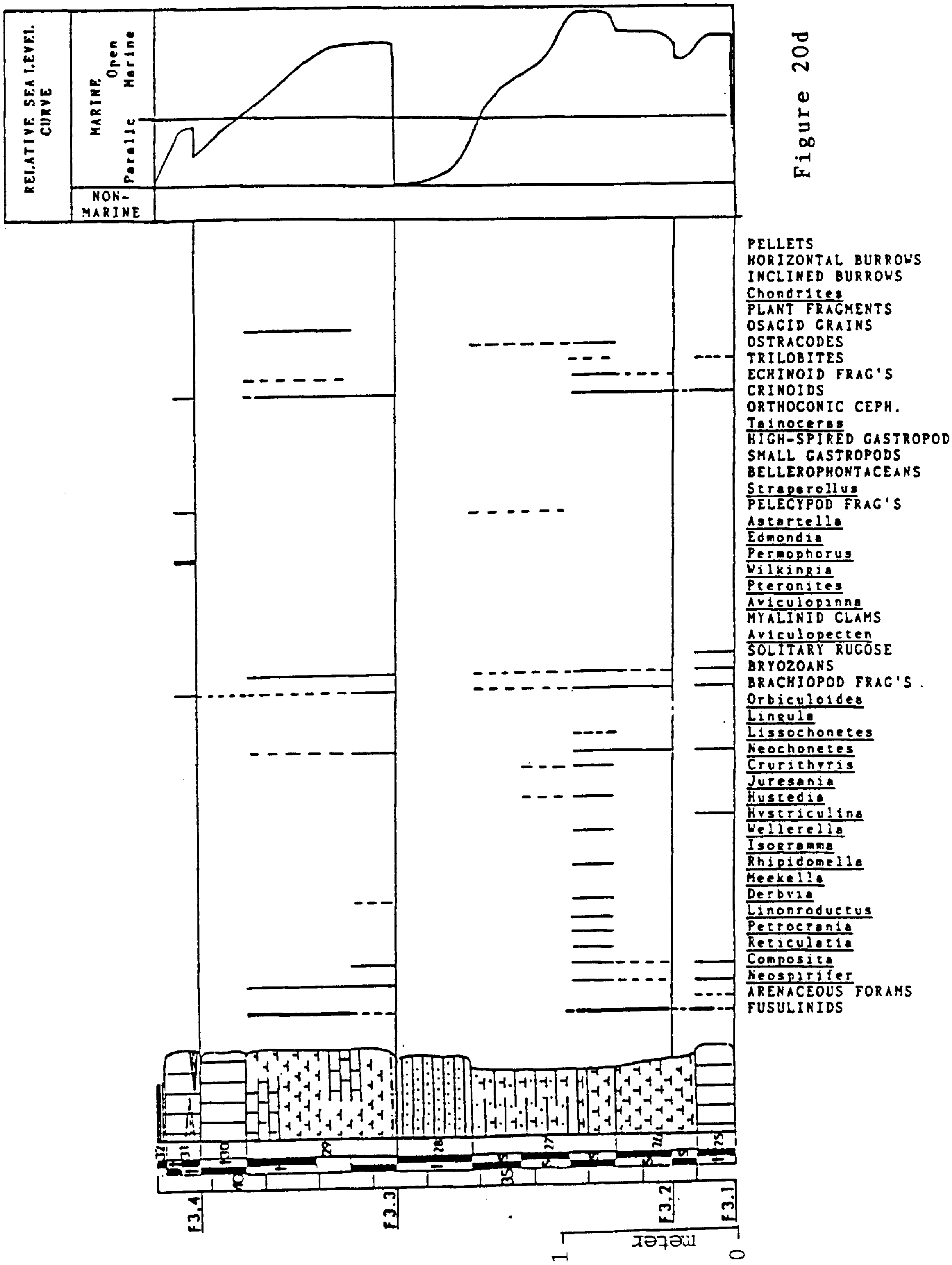

RELATIVE SEA LEVEL CURVE
MARINE
Open Marine
Paralic
NON-MARINE
PELLETS
HORIZONTAL BURROWS
INCLINED BURROWS
Chondrites
PLANT FRAGMENTS
OSAGID GRAINS
OSTRACODES
TRILOBITES
ECHINOID FRAG'S
CRINOIDS
ORTHOCONIC CEPH.
Tainoceras
HIGH-SPIRED GASTROPOD
SMALL GASTROPODS
BELLEROPHONTACEANS
Straparollus
PELECYPOD FRAG'S
Astartella
Edmondia
Permophorus
Wilkingia
Pteronites
Aviculopinna
MYALINID CLAMS
Aviculopecten
SOLITARY RUGOSE
BRYOZOANS
BRACHIOPOD FRAG'S
Orbiculoidea
Lingula
Lissochonetes
Neochonetes
Crurithyris
Juresania
Hustedia
Hystriculina
Wellerella
Isogramma
Rhipidomella
Meekella
Derbyia
Linoproductus
Petrocrania
Reticulatia
Composita
Neospirifer
ARENACEOUS FORAMS
FUSULINIDS
F3.4
F3.3
F3.2
F3.1
meter
1
0

Figure 20d

and fusulinid biofacies (of unit 25), to a regressive/progradational shallower marine environment, represented by a decrease in diversity and an increase in mud (base of unit 26).

Sixth-order T-R unit F3.2 (Figures 19 & 20d; Appendix) is present from 8.28 m to 9.80 m above the base of the Americus limestone, and encompasses strata from 0.23 m above the top of unit 25 to the top of unit 28. Genetic surface F3.2 is marked by a significant increase in the diversity of marine taxa, even though the surface (F3.2) is not a sharp lithologic contact. The lower 0.28 m of F3.2 (upper part of unit 26) is a very calcareous, massive, olive-gray shale with abundant fusulinids (approximately 45% by volume of rock) and common Neochonetes and crinoids. The unit also contains lesser amounts of Neospirifer, Composita, echinoid debris, and bryozoans, thus making a total of 9 taxa in the upper part of unit 26. This is overlain by 0.30 m of fossiliferous, dark gray, calcareous shale, with abundant brachiopods and fusulinids (base of unit 27). Fusulinids account for 10-15% of the lithology and become rare toward the top of the brachiopod biofacies. The basal part of unit 27 contains 19 different marine taxa. This grades into 0.51 m of sparsely fossiliferous (occasionally pyritized fossils), silty, calcareous shale, having only a few marine taxa (upper part of unit 27). Lastly, F3.2 is capped by 0.43 m of non-fossiliferous, blocky, massive, silty shale (unit 28). In summary, upward through F3.2, fusulinids decrease and eventually disappear (units 26 and the base of unit 27), brachiopods become abundant near the middle, and eventually the marine biota disappears completely and siliciclastic mud dominates. The paleoenvironments of F3.2 range from a transgressive, open marine, quiet environment represented by the fusulinid biofacies (upper part of unit 26), to maximum open marine conditions represented by the brachiopod biofacies (base of unit 27). These environments were followed by a nearshore, regressive/progradational environment, characterized by the nondiverse, silty-shale lithofacies (upper part of unit 27, and unit 28).

Sixth-order T-R unit F3.3 is present from 9.80 m to 10.92 m above the base of the Americus limestone, and encompasses units 29 and 30 (Figures 19 & 20d; Appendix). F3.3 represents the upper part of the Hughes Creek Shale Member. Unit 29 consists of 0.86 m of very calcareous (occasionally micritic), massive, fossiliferous shale. This is overlain by 0.25 m of sparsely fossiliferous, argillaceous calcilutite (unit 30). Fusulinids are rare to common in the lower 0.23 m of unit 29 and become abundant (approximately 30% by volume of rock; packstone) in the upper 0.63 m of unit 29. Bryozoans, crinoids, osagid grains, and brachiopods such as *Neospirifer* and *Neochonetes* also occur throughout the calcareous shale (unit 29). Fossil content decreases abruptly, however, in unit 30. The paleoenvironments of F3.3

range from initial, maximum open marine, well circulated and agitated conditions (unit 29; with oscillatory wave conditions to account for the osagid content; e.g., Henbest, 1963), back to nearshore, paralic-intertidal, possibly restricted conditions, as represented by the upper, sparsely fossiliferous calcilutite (unit 30).

Sixth-order T-R unit F3.4 (Figures 19 & 20e) is present from 10.92 m to 11.25 m above the base of the Americus limestone, and encompasses units 31 through 33. F3.4 represents the basal part of the Long Creek Limestone Member. Unit 31 is 0.18 m of cherty, argillaceous, coarse calcarenite, compositionally referred to as a pelecypod, crinoid, pelletal biomicrite. This unit is characterized by lenticular shell lags consisting of Permophorus (internal molds) and crinoids. Unit 31 is overlain by 0.10 m of gray, calcareous shale (unit 32) containing abundant plant fragments. F3.4 is capped 0.08 m of nonfossiliferous, argillaceous, calcareous dolostone (unit 33). The paleoenvironments of F3.4 range from a nearshore, agitated, intertidal to subtidal environment as represented by the Permophorus biofacies (unit 31), through a semirestricted intertidal to subtidal environment (unit 32), to a supratidal mudflat environment represented by the nonfossiliferous dolostone lithofacies (unit 33).

Sixth-order T-R unit F3.5 is present from 11.25 m to 11.83 m above the base of the Americus limestone, and

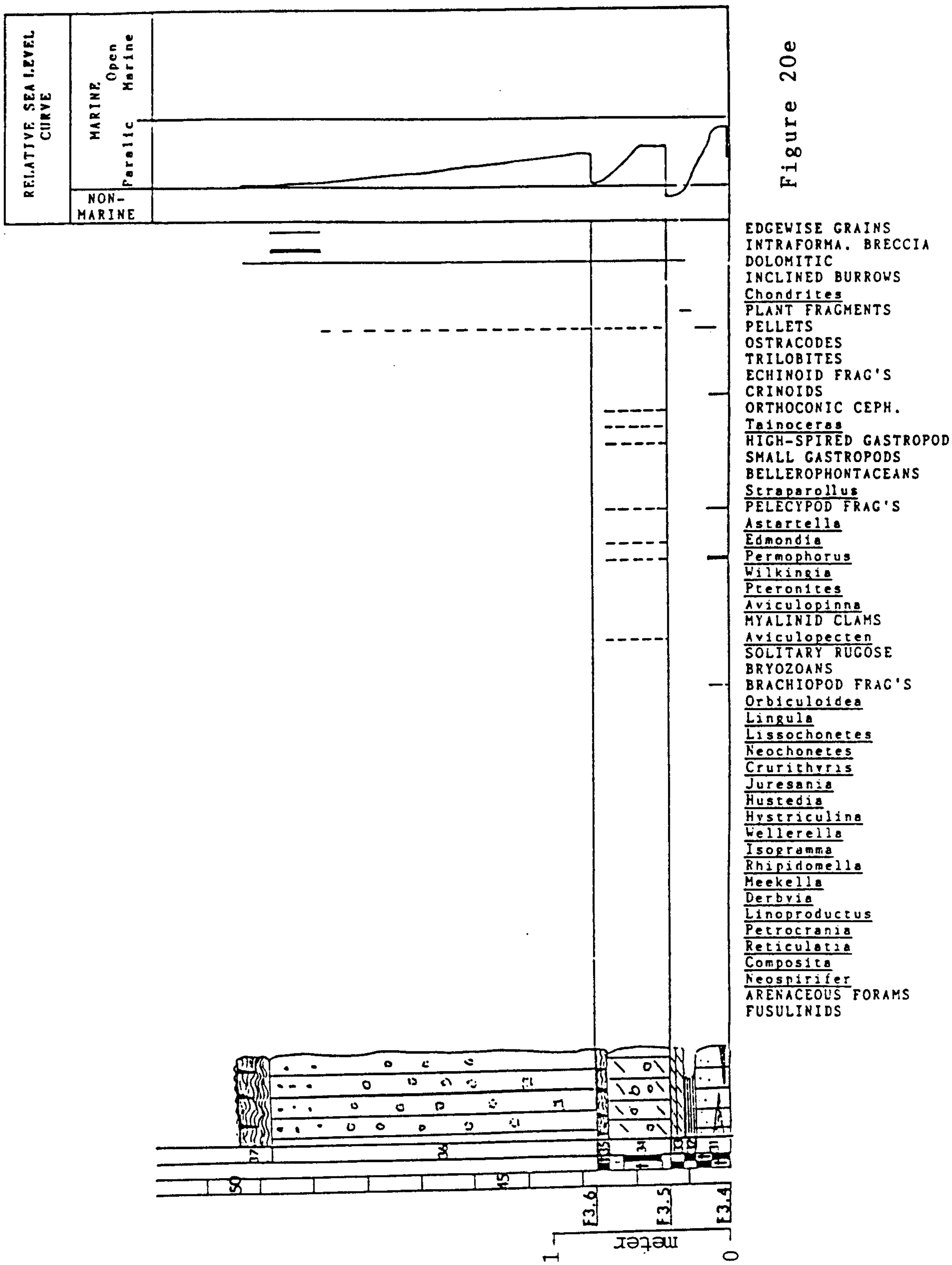

RELATIVE SEA LEVEL CURVE
MARINE
Open Marine
Paralic
NON-MARINE
EDGEWISE GRAINS
INTRAFORMA. BRECCIA
DOLOMITIC
INCLINED BURROWS
Chondrites
PLANT FRAGMENTS
PELLETS
OSTRACODES
TRILOBITES
ECHINOID FRAG'S
CRINOIDS
ORTHOCONIC CEPH.
Tainoceras
HIGH-SPIRED GASTROPOD
SMALL GASTROPODS
BELLEROPHONTACEANS
Straparollus
PELECYPOD FRAG'S
Astartella
Edmondia
Permophorus
Wilkingia
Pteronites
Aviculopinna
MYALINID CLAMS
Aviculopecten
SOLITARY RUGOSE
BRYOZOANS
BRACHIOPOD FRAG'S
Orbiculoidea
Lingula
Lissochonetes
Neochonetes
Crurithyris
Juresania
Hustedia
Hystriculina
Wellerella
Isogramma
Rhipidomella
Meekella
Derbyia
Linoproductus
Petrocrania
Reticulatia
Composita
Neospirifer
ARENACEOUS FORAMS
FUSULINIDS
37
36
35
34
33
32
31
30
50
45
F3.6
F3.5
F3.4
meter
1
0

Figure 20e

encompasses units 34 and 35 (Figures 19 & 20e; Appendix). Unit 34 consists of 0.35 m of molluscan, pelletal, argillaceous, dolomitic calcilutite, and is capped by 0.18 m of algal laminated, mudcracked, dolomitic calcilutite (unit 35). The algal laminations are very thin, mudcracked, and planar to crinkly (i.e., after Busch, 1983). In summary, there is a decrease in molluscan content and diversity up through unit F3.5, accompanied by algal laminite development. The paleoenvironments range from paralic-intertidal (unit 34), to probably high intertidal or low supratidal (unit 35).

The last sixth-order T-R unit of the Paxico section is F3.6, and is present from 11.83 m to 13.71 m above the base of the Americus limestone. F3.6 encompasses units 36 and 37 (Figures 19 & 20e; Appendix) and represents the upper part of the Long Creek limestone. Unit 36 contains 1.42 m of highly weathered, extremely vuggy, dolomitic, calcilutite. This is overlain by 0.30 m of dolomitic calcilutite that contains common intraformational, green shale clasts. The remainder of this sixth-order T-R unit is represented by an algal laminated, mudcracked, dolomitic calcilutite (unit 37), similar in nature to that of unit 35. The paleoenvironments represented by F3.6 range from nearshore, lagoonal-intertidal conditions (basal unit 36), through more agitated intertidal conditions (top of unit 36), to a progradational supratidal environment (unit 37). The highly vuggy, and collapsed-brecciated nature of unit 36 is indicative of the former presence of evaporites, that probably formed in the basal parts of F3.6 soon after deposition, as a result of hypersaline pore fluids created by ground water evaporation.

Fifth-Order T-R Units.--The relative extents of maximum transgression (i.e., the transgressive apex) among the sixth-order T-R units at the Paxico section, were used to define the boundaries of the fifth-order T-R units. The transgressive apex within each fifth-order T-R unit was also determined, which helped to define the net deepening and net shallowing phases of each fifth-order T-R unit.

Two complete and one incomplete fifth-order T-R unit are described from the Foraker Formation at the Paxico locality. These are, in ascending order: the Americus fifth-order T-R unit, which encompasses all of the Americus Limestone Member and the lower portion of the Hughes Creek Shale Member (Figures 20a and 20b); the Hughes Creek fifth-order T-R unit, which encompasses the middle portion of the Hughes Creek Shale Member (Figures 20b and 20c); and the Long Creek fifth-order T-R unit, which encompasses the upper part of the Hughes Creek Shale Member and all of the Long Creek Limestone Member (Figures 20d and 20e). The Long Creek fifth-order T-R unit is incomplete here, because strata above the Long Creek Limestone Member have been removed by modern erosion.

The Americus fifth-order unit is composed of three sixth-order units: F1.1, F1.2, and F1.3. This fifth-order unit has marine facies best developed medially, in sixth-order T-R unit F1.2, as represented by the top part of the upper Americus limestone bench (i.e., the crinoidal, brachiopod, and fusulinid facies in the upper part of unit 6 and unit 7). Maximum transgression of the Americus fifth-order T-R unit is put into perspective relative to the subjacent, shallow marine, molluscan-dominated facies of F1.1 (unit 4, lower Americus limestone bench) and the superjacent molluscan-osagid biofacies of F1.3 (unit 12). Units 4 and 12 (F1.1 and F1.3, respectively) contain a higher diversity of marine taxa, but they are predominately molluscs, and unit 12 is an argillaceous, osagid packstone in thin section. Thus, a molluscan reversal (e.g., Brezinski, 1983) is present, particularly in unit 4 of F1.1., and unit 12 of F1.3. The transgressive apex, representing maximum inundation of the Americus fifth-order T-R unit, is therefore represented by the fusulinid biofacies of F1.2. Net deepening occurs from the base of the Americus fifth-order T-R unit, to unit 7 of F1.2, and net shallowing occurs from unit 8 (i.e., the Crurithyris biofacies) of F1.2, to the top of unit 13 in F1.3.

The upper boundary of the Americus fifth-order T-R unit and thus the base of the Hughes Creek fifth-order T-R unit, is placed at the base of unit F2.1, because the maximum extent of transgression in F1.3 (unit 12) is less than F2.1 (i.e., unit 15). This is based on the occurrence of a diverse, brachiopod-dominated biofacies, namely the osagid-fusulinid-Isogramma biofacies in F2.1 (unit 15). Unit 12 of F1.3 contains a higher diversity of taxa (i.e., 20 taxa), but as previously mentioned, it is molluscan and osagid dominated indicating a more nearshore and agitated, lagoonal(?) condition.

The Hughes Creek fifth-order T-R unit contains four sixth-order T-R units: F2.1, F2.2, F2.3, and F2.4 (Figures 20b and 20c). The maximum diversities of these units are as follows: F2.1 (unit 15) contains 15 genera, F2.2 (unit 16) 17 genera, F2.3 (unit 21) 14 genera, and F2.4 (unit 23) 9 genera. Therefore unit 16 of F2.2 is the most open facies at a fifth-order scale (with a total of 17 taxa). Net deepening on a fifth-order scale occurs from unit 14 of F2.1, to unit 16 of F2.2, and net shallowing occurs from unit 17 of F2.2 to unit 24 of F2.4.

The top of the Hughes Creek fifth-order T-R unit, and thus the basal Long Creek fifth-order genetic surface, was placed at the base of unit F3.1 (Figure 20d and 20e). This is because of the more open marine fossils of F3.1 which include brachiopods (such as Neospirifer and Composita), bryozoans, crinoids, and fusulinids (unit 25). These taxa clearly represent greater transgressive extent, relative to the maximum regressive (on a fifth-order scale), paralic, molluscan-osagid dominated facies of unit 23 in sixth-order T-R unit F2.4.

The Long Creek fifth-order T-R unit at the Paxico section contains at least six sixth-order T-R units, but the top of this interval has been removed by modern erosion (Figures 20d and 20e). The maximum transgressive facies of this fifth-order T-R unit is best developed in units 26 and 27 of F3.2. Because F3.1, F3.2, and F3.3 each contain an abundance of fusulinids (i.e., mainly Triticites as confirmed by Kaesler and Fisher, 1969; and Fisher, 1971) in their transgressive facies, the fifth-order transgressive apex appears cryptic, particularly in the field. Graphic representation of the fauna (Figure 20d), however, clearly shows the base of unit 27 as representing the fifth-order transgressive apex. This facies contains a total of at least 19 taxa (predominately brachiopods, and fusulinids).

The remaining sixth-order T-R units (F3.4, F3.5, and F3.6) of the Long Creek fifth-order T-R unit clearly show an overall decrease in faunal diversity, in a shallowing-upward calcilutite sequence. This is accompanied by the presence of algal laminites at the top of the last two sixth-order T-R units. With the transgressive apex confirmed in F3.2, the complete net deepening sequence, on a fifth-order scale, occurs from the base of F3.1 (unit 25) to the base of unit 27 in F3.2, and is characterized by thin, taxonomically rich, retrogradational facies. The net fifth-order shallowing sequence occurs from unit 27 of F3.2, to at least the top of the last sixth-order T-R unit exposed, namely F3.6 (unit 37).

McDowell Creek Road Section

The McDowell Creek Road section lies within the Manhattan, Kansas area and contains F1.1, and the basal portion of F1.2 (inclusive of the upper Americus limestone bench). In addition, strata subjacent to the Foraker Formation, in the upper part of the Hamlin Shale Member (Janesville Formation; Admire Group), was measured and described at this locality. This helped establish (and confirm) where the basal sixth-order T-R unit, F1.1, occured within the Foraker hierarchy at a fifth-order scale.

The Hamlin shale will be described in ascending order starting at 4.67 m below the base of the Americus limestone (Figures 19 & 21a). Three sixth-order T-R units, labeled in ascending order as H1, H2, and H3, were discernible in the Hamlin shale, with the basal part of H1 concealed at this location. One trangressive surface (H2), and one climate change surface (H3), delineate these units (Figure 21a).

Sixth-order T-R Units.--The upper part of sixth-order T-R unit H1 is present from 4.67 m to 3.45 m below the base of the Americus limestone, and encompasses unit 1 (Figures 19 & 21a; Appendix). Unit 1 is an olive-brown, non-fossiliferous mudstone exhibiting microslickensides. The upper part of H1 (unit 1) is interpreted as representing a lithified paleosol.

Sixth-order T-R unit H2 is present from 3.45 m to 2.54 m

Figure 21a-b. Graphic illustrations of the McDowell Creek Road section showing the lithostratigraphic, biostratigraphic, and paleoenvironmental characteristics of each sixth- and fifth-order T-R unit, and their bounding genetic surfaces.

a. Graphic illustration of upper Hamlin shale and sixth-order T-R units H1, H2, and lower part of H3.

b. Graphic illustration of the upper part of H1, all of F1.1, and the basal part of F1.2.

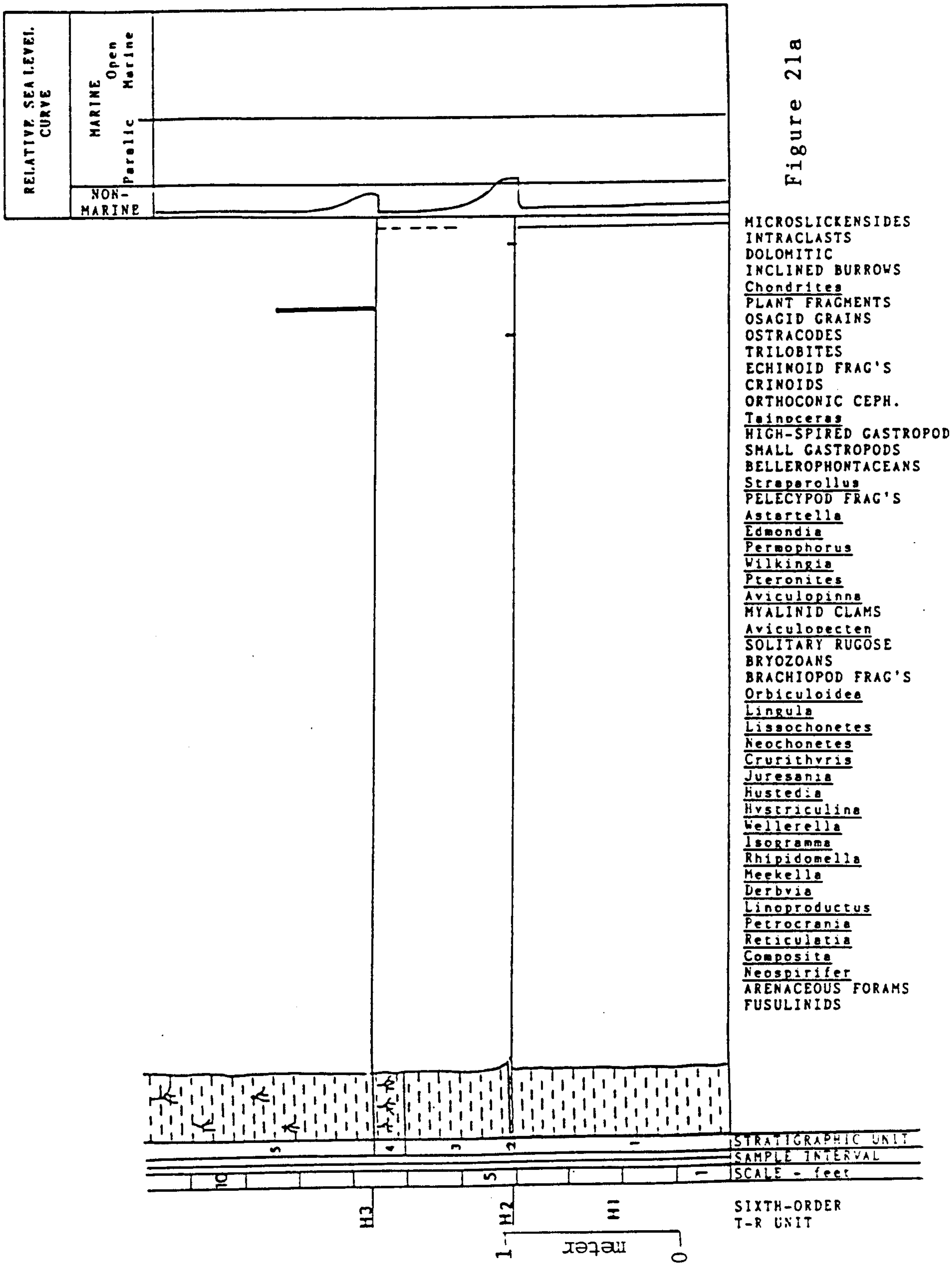

RELATIVE SEA LEVEL CURVE
MARINE
Open Marine
Paralic
NON-MARINE
MICROSLICKENSIDES
INTRACLASTS
DOLOMITIC
INCLINED BURROWS
Chondrites
PLANT FRAGMENTS
OSAGID GRAINS
OSTRACODES
TRILOBITES
ECHINOID FRAG'S
CRINOIDS
ORTHOCONIC CEPH.
Tainoceras
HIGH-SPIRED GASTROPOD
SMALL GASTROPODS
BELLEROPHONTACEANS
Straparollus
PELECYPOD FRAG'S
Astartella
Edmondia
Permophorus
Wilkingia
Pteronites
Aviculopinna
MYALINID CLAMS
Aviculopecten
SOLITARY RUGOSE
BRYOZOANS
BRACHIOPOD FRAG'S
Orbiculoidea
Lingula
Lissochonetes
Neochonetes
Crurithyris
Juresania
Hustedia
Hystriculina
Wellerella
Isogramma
Rhipidomella
Meekella
Derbyia
Linoproductus
Petrocrania
Reticulatia
Composita
Neospirifer
ARENACEOUS FORAMS
FUSULINIDS
5
4
3
2
1
STRATIGRAPHIC UNIT
SAMPLE INTERVAL
10
5
1
SCALE - feet
H3
H2
H1
SIXTH-ORDER T-R UNIT
1
meter
0

Figure 21a

below the base of the Americus limestone, and encompasses units 2 through 4 (Figures 19 & 21a; Appendix). Unit 2 is represented by 0.04 m of cross-laminated, fine-grained calcareous sandstone, with shale partings, intraclasts, and ostracodes. The base of unit 2 represents the first transgressive boundary (H2) subjacent to the Foraker hierarchy (Figure 21a). Unit 2 is overlain by 0.68 m of olive, non-calcareous mudstone (unit 3), which is overlain by 0.18 m of root mottled, maroon to brown mudstone interpreted as a lithified paleosol (unit 4; upper part of H2).
The paleoenvironments of H2 range from transgressive, marginal marine conditions (possibly brackish; unit 2), to an aggrading, nonmarine, terrestrial environment (units 3 and 4).

Sixth-order T-R unit H3 is present from 2.54 m to 0.43 m below the base of the Americus limestone, and encompasses unit 5 (Figures 21a & 21b; Appendix). Unit 5 is a massive, olive, blocky and silty mudstone (unit 5), that contains common plant fragments in the basal 0.90 m, and root trace development toward the top (i.e., paleosol development). The base of unit 5 is a climate-change surface representing a change from more arid or subaerial conditions below (unit 4), to more humid or subaqueous conditions above (unit 5).
The paleoenvironments of H3 range from possibly estuarine conditions (or more humid conditions; base of unit 5) to more arid, terrestrial-paleosol conditions (top of unit 5).

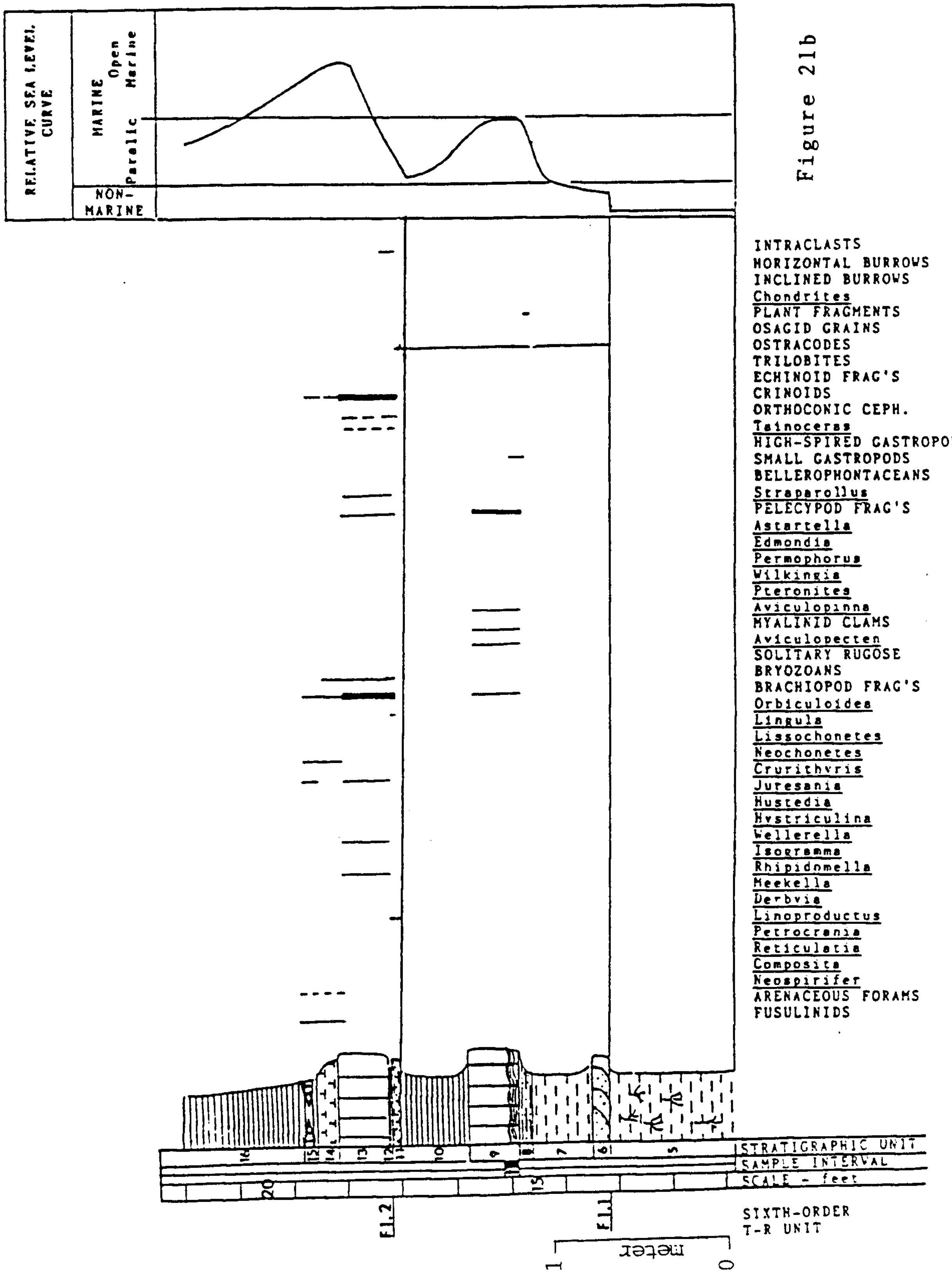

RELATIVE SEA LEVEL CURVE
MARINE
Open Marine
Paralic
NON-MARINE
INTRACLASTS
HORIZONTAL BURROWS
INCLINED BURROWS
Chondrites
PLANT FRAGMENTS
OSAGID GRAINS
OSTRACODES
TRILOBITES
ECHINOID FRAG'S
CRINOIDS
ORTHOCONIC CEPH.
Tainoceras
HIGH-SPIRED GASTROPOD
SMALL GASTROPODS
BELLEROPHONTACEANS
Straparollus
PELECYPOD FRAG'S
Astartella
Edmondia
Permophorus
Wilkingia
Pteronites
Aviculopinna
MYALINID CLAMS
Aviculopecten
SOLITARY RUGOSE
BRYOZOANS
BRACHIOPOD FRAG'S
Orbiculoidea
Lingula
Lissochonetes
Neochonetes
Crurithyris
Juresania
Hustedia
Hystriculina
Wellerella
Isogramma
Rhipidomella
Meekella
Derbyia
Linoproductus
Petrocrania
Reticulatia
Composita
Neospirifer
ARENACEOUS FORAMS
FUSULINIDS
16
15
14
13
12
11
10
9
8
7
6
5
STRATIGRAPHIC UNIT
SAMPLE INTERVAL
20
15
SCALE - feet
F1.2
F1.1
SIXTH-ORDER T-R UNIT
1
meter
0

Figure 21b

Sixth-order T-R unit F1.1 is present from 0.43 m below the base of the Americus limestone, to 0.66 m above the base of the Americus limestone, and encompasses units 6 thru 10 (Figures 19 & 21b). Units 6 and 7 represent the uppermost Hamlin shale. Unit 6 is 0.10 m of very calcareous, cross-laminated, argillaceous, ostracode bearing siltstone. This is overlain by 0.33 m of massive, ostracode bearing, shaley mudstone (unit 7), containing rare to common plant fragments. Ostracodes increase in abundance toward the top of unit 7. Unit 8 is a friable, shaley, ostracode bearing, fine-grained sandstone (calcarenite or calcilithite; i.e., Fisher's, 1980, regolithic disconformity), that contains abundant carbonate and clay clasts, as well as common plant fragments. Unit 8 grades into an intraclast, ostracode, gastropod biosparite with algal rip-up clasts (lower 1 cm of unit 9). This is overlain by, and is gradational with, an algal stromatolite facies similar in nature to the stromatolitic facies found in the basal Americus limestone at the Paxico section. The carbonate matrix between the algal stromatolites contains gastropods (and encrusting forams?), that are perhaps indicative of remnant seasonality (i.e., thin interbedded seasonal deposits). For example, in the medieval harbor basin of Geziret Fara'oun (Gulf of Aqaba), cyanobacterial layers indicative of seasonally warm periods (and indicative of high salinity and evaportion rates), alternate with exclusive gastropod and/or foraminiferal layers indicative of colder periods (when salinity values are more conducive to potential grazers; Reiss and Hottinger, 1984). The algal stromatolites are overlain by a pelecypod dominated, argillaceous calcilutite, that represents the remainder of the basal Americus limestone bench (unit 9). Overlying unit 9 is 0.41 m of dark gray, fissile shale containing lenses of ostracodes (unit 10). In terms of paleoenvironments, the lower part of F1.1 (units 6 and 7) represents an aggrading estuarine, to very nearshore marine environment (paralic). This grades into the transgressive, relatively high energy, intertidal to subtidal environments of unit 8, and the basal part of unit 9 (i.e., basal transgressive sand lag, biosparite facies, and algal stromatolites). The molluscan biofacies (unit 9) represents a more open, quieter marine environment, that is overlain by a regressive, restricted lagoonal (or possibly estuarine) environment as represented by the ostracode biofacies (unit 10).

Sixth-order T-R unit F1.2 (Figures 19 & 21b) is incomplete but is present from 0.66 m to 1.90 m above the base of the Americus limestone, and encompasses units 11 thru 16. Unit 11 is a very silty, ostracode bearing, calcareous shale that contains Linoproductus (rare). Above this unit is 0.02 m of black fissile shale with ostracodes, pelecypods, and rare brachiopod fragments (unit 12). Overlying unit 12 is 0.28 m of dark-gray, argillaceous, fossiliferous calcarenite (upper Americus limestone bench), containing brachiopods, crinoids, bryozoans, pelecypods, and cephalopods. At the base of unit 13, is a distinct bed containing intraclasts, with some showing borings. Unit 13 is overlain by 0.13 m of very calcareous, fossiliferous, dark gray shale (unit 14) containing fusulinids (< 5% by volume of rock), as well as articulated Neochonetes, ramose bryozoans, and crinoids. Unit 14 is overlain by 0.10 m of dark gray, platy shale containing calcarenite lenses with common Crurithyris, and other brachiopods and fusulinids. Overlying this last unit is 0.61 m of non-fossiliferous, silty, calcareous, olive shale. The remainder of this sixth-order T-R unit is concealed. In summary, upward through F1.2, there is a decrease in intraclasts, an increase in brachiopod fragments and carbonate mud (unit 13), and subsequently, an increase in fusulinids and clay content (units 14 and 15). Lastly, an increase in Crurithyris (units 14 and 15), is followed by the decrease and disappearance of marine taxa (unit 16). The paleoenvironments of F1.2, range from an initial transgressive, lagoonal or marginal marine environment (units 11 and 12), to a transgressive, more open and agitated marine environment (base of unit 13). Above this, maximum open marine conditions prevailed (fusulinid biofacies, top of unit 13 and unit 14), which was followed by regressive/progradational conditions (unit 16).

Fifth-Order T-R Units.--The McDowell Creek Road section is important because it confirms the existence of a fifth-order genetic surface, F1.1, in the uppermost Hamlin Shale Member of the Janesville Formation (Lower Permian, Amire Group; Figures 21a and 21b). This locality contains the upper part of what is informally termed the Hamlin fifth-order T-R unit, and the lower part of the Americus fifth-order T-R unit.

The upper part of the Hamlin fifth-order T-R unit contains sixth-order T-R units H1, H2, and H3, which are predominately a series of aggrading paleosols (alluvial). The basal ostracode bearing facies of unit 2 in sixth-order T-R unit H2, represents a greater extent of transgression, than the basal plant bearing facies of H3 (unit 5). Therefore, net shallowing at a fifth-order scale is indicated going from H2 (unit 2) to H3 (unit 3). A return to nearshore, shallow, paralic conditions, as represented by the ostracode-bearing facies at the base of F1.1 (units 6 and 7), defines the lower Americus fifth-order genetic surface at the base of unit 6 (i.e., in the very upper Hamlin shale, as it is at the Paxico section). This is justified because H3 is essentially nonfossiliferous.

The transgressive apices of sixth-order T-R units F1.1 and F1.2 (unit 9, and top of unit 13, respectively; Figure 21b) clearly show a net deepening-upward sequence, similar to that found at the Paxico section. Unit 9 of F1.1 contains at least 6 taxa, composed mainly of molluscs, and the top of unit 13 contains at least 13 taxa, composed mainly of brachiopods, bryozoans, crinoids, and fusulinids. The most open facies (i.e., the transgressive apex) is therefore represented in the top of unit 13 (upper Americus limestone bench). Unit 13 can be verified as the transgressive apex of the Americus fifth-order T-R unit, by comparing it to the transgressive apex of sixth-order T-R unit F1.3 at the Manhattan section (i.e., F1.3 is concealed at the McDowell Creek Road section). The transgressive apex of F1.3 at the Manhattan section is represented by a molluscan-osagid biofacies, suggesting relatively less open, more paralic conditions; while unit 13 of F1.2, at the McDowell Creek Road section, is represented by a relatively more open marine, diverse brachiopod, bryozoan, and fusulinid biofacies. The Paxico section, as previously discussed, also shows net shallowing, upward from F1.2 to F1.3.

Manhattan Section

Sixth-Order T-R Units.-- The Manhattan section was divided into nine complete sixth-order T-R units (F1.3 through F3.5), and two incomplete sixth-order T-R units (upper part of F1.2, and the basal part of F3.5). Sixth-order T-R units that are concealed below the base of the Manhattan section (i.e., F1.1 and F1.2) are exposed at the McDowell Creek Road section (previously described); whereas, strata concealed above F3.5, at the Manhattan section, are exposed at the Poliska Lane section (described in a following section).

The base of the first complete sixth-order T-R unit at the Manhattan section, F1.3 (Figures 19 & 22a; Appendix), will be used as a reference datum from which to describe the stratigraphic positions of the sixth-order T-R units above this level. Below F1.3 is 0.31 m (unit 1; base concealed) of sparsely fossiliferous, silty, olive-gray shale, representing the upper (regressive) part of F1.2. This shale is similar to the upper shale of F1.2 at the McDowell Creek Road and Paxico sections.

F1.3 is present from 0.0 m to 1.11 m (i.e., above its base), and encompasses units 2 through 8 (Figure 22a). Unit 2 consists of 0.10 m of very argillaceous calcirudite, that contains abundant Linoproductus (occasionally forming shell lags). This is overlain by 0.36 m (units 3 through 6) of very calcareous, silty shale with thin (2 cm to 4 cm) interbedded fossiliferous calcirudites, composed predominately of Linoproductus and Crurithyris. Unit 6 grades into 0.25 m of molluscan, crinoidal, echinoid, and Osagia dominated calcirudite, defined as an argillaceous, poorly sorted, sparse to packed, bioturbated biomicrite (unit 7). This facies also contains comminuted brachiopod and bryozoan (fenestrate and ramose) fragments. Fossil fragments in the lower half of unit 7 are commonly unevenly coated with Osagia. In the upper half (unit 7), the size of gastropods

Figure 22a-d. Graphic illustration of the Manhattan section showing the lithostratigraphic, biostratigraphic, and paleoenvironmental characteristics of each sixth- and fifth-order T-R unit, and their bounding genetic surfaces.

a. Graphic illustration of uppermost F1.2, and all of F1.3, F2.1, F2.2, and the basal part of F2.3.
b. Graphic illustration of F2.3 and F2.4.
c. Graphic illustration of F3.1, F3.2, F3.3 and the base of F3.4.
d. Graphic illustration of F3.4 and F3.5.

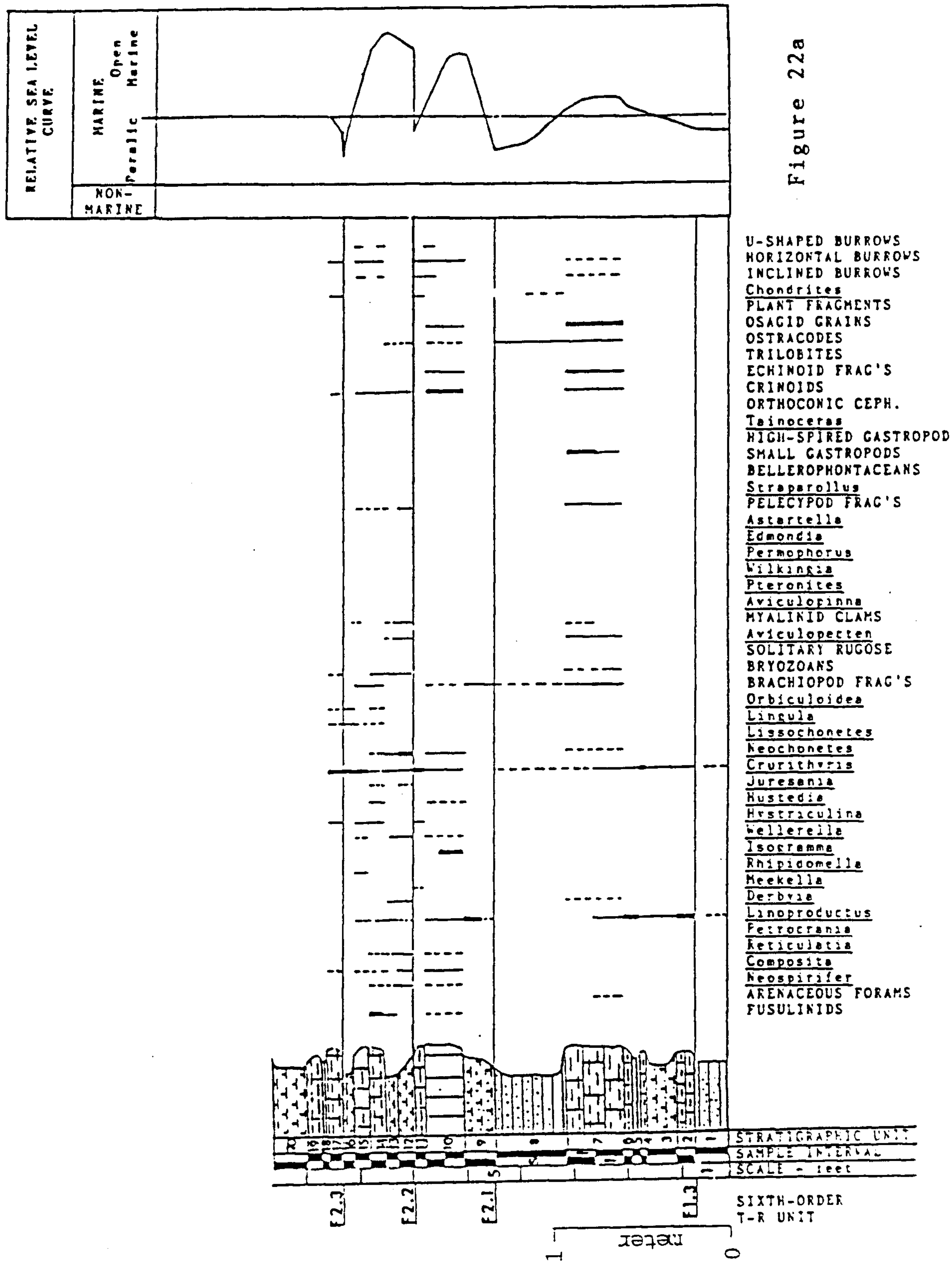

RELATIVE SEA LEVEL CURVE
MARINE
Open Marine
Peralic
NON-MARINE
U-SHAPED BURROWS
HORIZONTAL BURROWS
INCLINED BURROWS
Chondrites
PLANT FRAGMENTS
OSAGID GRAINS
OSTRACODES
TRILOBITES
ECHINOID FRAG'S
CRINOIDS
ORTHOCONIC CEPH.
Tainoceras
HIGH-SPIRED GASTROPOD
SMALL GASTROPODS
BELLEROPHONTACEANS
Straparollus
PELECYPOD FRAG'S
Astartella
Edmondia
Permophorus
Wilkingia
Pteronites
Aviculopinna
MYALINID CLAMS
Aviculopecten
SOLITARY RUGOSE
BRYOZOANS
BRACHIOPOD FRAG'S
Orbiculoidea
Lingula
Lissochonetes
Neochonetes
Crurithyris
Juresania
Hustedia
Hystriculina
Wellerella
Isogramma
Rhipidomella
Meekella
Derbyia
Linoproductus
Petrocrania
Reticulatia
Composita
Neospirifer
ARENACEOUS FORAMS
FUSULINIDS
STRATIGRAPHIC UNIT
SAMPLE INTERVAL
SCALE - feet
SIXTH-ORDER T-R UNIT
F2.3
F2.2
F2.1
F1.3
meter
1
0

Figure 22a

and their abundance increases, as do grains evenly coated with Osagia. Unit 7 is overlain by 0.41 m of quartz-silty, micaceous, ostracode and Crurithyris bearing shale (unit 8).

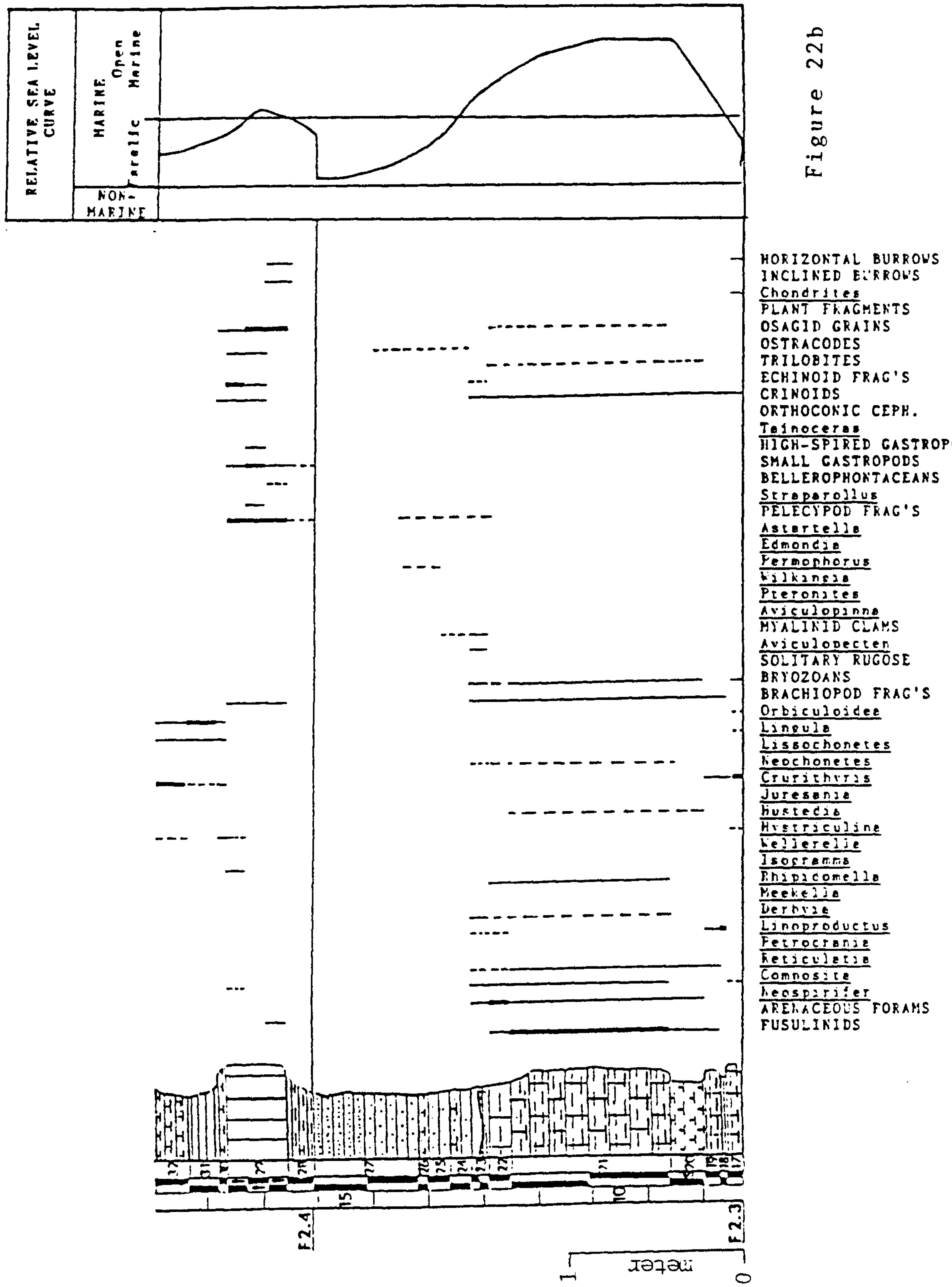
Upward through F1.3, units 2 through 6 each contain 2 taxa, the lower-half of unit 7 contains 14 taxa, the upper half of unit 7 contains 13 taxa, and unit 8 contains 3 taxa (at the very top). Accordingly, there is an abrubt increase in diversity at the base of unit 7, a net increase in molluscs and Osagia in the upper half of unit 7 (with a slight decrease in diversity), and a decrease in diversity accompanied by an increase in siliciclastic mud in unit 8. The paleoenvironments of F1.3 range from transgressive, lagoonal(?) conditions at the base, represented by the Linoproductus biofacies (units 2 through 6), to more open, better circulated, and agitated conditions in the lower half of unit 7 (based on its diversity). Relatively shallower, initial regressive conditions are represented by the upper half of unit 7, based on the increase in molluscs and Osagia. A paralic, regressive/progradational condition existed in the upper part of F1.3, based on the decrease in diversity and occurrence of quartz-silt in unit 8.

Sixth-order T-R unit F2.1 (Figures 19 and 22a; Appendix) is present from 1.11 m to 1.40 m above the base of F1.3, and encompasses units 9 through 11. Unit 9 is 0.18 m of gray, calcareous, silty shale, that marks the abrupt appearance of Linoproductus (abundant). This is overlain by 0.23 m of very fossiliferous, coarse calcarenite-biomicrite (wackestone; unit 10), that contains Isogramma and rare fusulinids. Unit 10 also contains other brachiopod fragments (Figure 22a), abundant crinoids, and rare to common Osagia. Unit 10 contains a vertically stratified lithology, resulting from large horizontal (spreite) burrows in the lower and middle parts, and U-shaped, inclined, and small horizontal burrows (Chondrites) towards the top (e.g., Schmidt, 1974). The larger burrows generally produce a mottled appearance. The upper 0.04 m of F2.1 (unit 11) is represented by a shaley, Crurithyris dominated biomicrite (unit 11).

Upward through F2.1 there is an increase in fossil diversity towards the middle (i.e, 2 taxa in unit 9, and 15 taxa in the lower half of unit 10), and an abrupt decrease in diversity at the top (unit 11, 3 taxa). The paleoenvironments of F2.1 range from a transgressive, relatively shallow, and restricted condition, as represented by the opportunistic brachiopods, Linoproductus and Isogramma (unit 9 and base of unit 10), to maximum open marine conditions, represented by the diversity of fossils in the middle of F2.1 (unit 10). This was followed by very near shore, possibly restrictive conditions, as represented by the Crurithyris biofacies (unit 11).

Sixth-order T-R unit F2.2 (Figures 19 & 22a; Appendix) is present from 1.40 m to 1.83 m above the base of F1.3 and encompasses units 12 through 16. Unit 12 is 0.10 m of gray, very calcareous, very fossiliferous, blocky shale (mudstone) that contains a diverse biota (15 taxa) of brachiopods (Neochonetes being the most abundant), bryozoans, pelecypods, crinoids, and very rare fusulinids at the top. Unit 12 grades into 0.08 m of very calcareous, fissile shale (unit 13) that is marked by an increase in fusulinids (and contains a total of at least 16 taxa). This is overlain by, and is gradational with, unit 14, which consists of 0.10 m of very argillaceous, fusulinid biomicrite (containing 16 taxa). Unit 14 is overlain (gradationally) by 0.10 m of Crurithyris-rich, less argillaceous, fine grained, calcirudite (containing at least 10 taxa; unit 15). Unit 15 is in sharp contact with, and is overlain by, 0.01 m of dark gray to black gray, very calcareous, fissile shale (unit 16) containing abundant Crurithyris, and common Orbiculoidea and Lingula (i.e., 3 taxa). The paleoenvironments of F2.2 are as follows: an initial transgressive, open marine environment (unit 12) with a relatively diverse biota (characterized by the opportunistic brachiopod Neochonetes; e.g., Brezinski, 1983; Moore, 1964), was followed by maximum open marine conditions, represented by the fusulinid biofacies (units 13 and 14). This was followed by a regressive, open marine to nearshore (paralic), carbonate-rich environment (well lit conditions, conducive to algal growth which bound the sediment), as is common in the Crurithyris biofacies (unit 15). Finally, restrictive paralic conditions (possibly lagoonal), characterized by siliciclastic-mud deposition conducive to inarticulate brachiopods and Crurithyris, represent the maximum regressive phase of F2.2 (unit 16).

Sixth-order T-R unit F2.3 is present from 1.83 m to 4.21 m above the base of F1.3, and encompasses units 17 thru 27 (Figures 19 & 22b; Appendix). Unit 17 consists of 0.10 m of fossiliferous (6 taxa), argillaceous calcirudite, with distinct clay-filled horizontal burrows (Chondrites) and Crurithyris. This underlies a 0.02 m transitional bed of Linoproductus-rich shale (unit 18; with at least 4 taxa). Unit 18 grades into 0.10 m of argillaceous, fossiliferous calcirudite (biomicrite; with 6 taxa), that marks the first appearance of fusulinids (unit 19). Above unit 19 is 0.20 m of massive, very calcareous, fossiliferous shale with fusulinids, brachiopods, and crinoids (8 taxa; unit 20). The top of Unit 20 is gradational with 0.86 m of massive, blocky, very argillaceous, fine grained micritic-calcirudite (unit 21), containing abundant fusulinids (approximately 20% by volume of rock), and common brachiopods, bryozoans and crinoids (13 taxa). Unit 22 is distinguished by a decrease in fusulinids, an increase in carbonate content, and consists of 0.10 m of limonitic, fossiliferous, medium calcirudite-biomicrite. Unit 22 contains abundant to common articulated and fragmented Neospirifer, common Composita, Reticulatia, Rhipidomella, crinoids, and other fossil fragments (making up 12 taxa). Overlying unit 22 is a dark gray, non-calcareous,



RELATIVE SEA LEVEL CURVE
MARINE
Open Marine
Paralic
NON-MARINE
HORIZONTAL BURROWS
INCLINED BURROWS
Chondrites
PLANT FRAGMENTS
OSAGID GRAINS
OSTRACODES
TRILOBITES
ECHINOID FRAG'S
CRINOIDS
ORTHOCONIC CEPH.
Tainoceras
HIGH-SPIRED GASTROPO
SMALL GASTROPODS
BELLEROPHONTACEANS
Straparollus
PELECYPOD FRAG'S
Astartella
Edmondia
Permophorus
Wilkingia
Pteronites
Aviculopinna
MYALINID CLAMS
Aviculopecten
SOLITARY RUGOSE
BRYOZOANS
BRACHIOPOD FRAG'S
Orbiculoidea
Lingula
Lissochonetes
Neochonetes
Crurithyris
Juresania
Hustedia
Hystriculina
Kellerella
Isogramma
Rhipidomella
Meekella
Derbyia
Linoproductus
Petrocrania
Reticulatia
Composita
Neospirifer
ARENACEOUS FORAMS
FUSULINIDS
F2.4
F2.3
meter
1
0

Figure 22b

silty shale, with common brachiopods, bryozoans, and crinoids (unit 23). Although unit 23 contains 12 taxa, at least 3 of those taxa consist of pelecypods including Aviculopecten, and myalinid fragments. Thinly interbedded (1 cm), lenticular, very fossiliferous calcarenite-biosparites are common in unit 23. Overlying unit 23 is 0.56 m of dark gray to gray, sparsely fossiliferous (3 taxa) shale that contains thin interbedded, very silty, non-fossiliferous shale lentils (unit 24). Unit 24 marks the first appearance of ostracodes within this T-R unit. The remaining 0.63 m of F2.3 is a brown-gray, quartz-silty shale, with a low diversity (units 25 and 26; 3 taxa). F2.3 is non-fossiliferous in the upper 0.30 m (unit 27).

In summary, upward through F2.3, Crurithyris, Chondrites, and Linoproductus decrease, and disappear. This is followed by a diverse marine fauna associated with very calcareous shale deposition and subsequent carbonate-mud deposition. Lastly, F1.1 is characterized by sparsely fossiliferous to nonfossiliferous, quartz-silty shale deposition. The paleoenvironments of F2.3 range from initial transgressive, less open (paralic) marine, restrictive conditions, as represented by the Crurithyris-Chondrites, and Linoproductus biofacies (units 17, 18, and 19; with continued deepening through unit 20); to maximum open marine conditions as represented by the massive, aggradational fusulinid, brachiopod, crinoidal and bryozoan facies (unit 21). Subsequently, initial regressive, more agitated, yet open marine conditions prevailed (represented by the carbonate production and biosparite lags of units 22 and 23). Finally, nearshore, regressive/progradational intertidal (brackish; units 25, 26, 27) conditions are indicated by the lack of fossils, and increased siliciclastic mud deposition near the top of F2.3.

Sixth-order T-R unit F2.4 is present from 4.21 m to 5.10 m above the base of F1.3, and encompasses units 28 through 32 (Figures 19 & 22b; Appendix). Unit 28 is 0.15 m of fissile, calcareous shale with rare molluscs (2 taxa). This is overlain by 0.35 m of limestone (unit 29) that is characterized as follows. The lower one-third is a burrowed, foram bearing (arenaceous), osagid, pelecypod biomicrite (with 8 taxa). The middle one-third is a crinoidal, osagid, echinoid, pelecypod, gastropod biomicrite (9 taxa; with more evenly coated osagid grains). Lastly, the upper one-third is a limonitic, brachiopod bearing, echinoid, osagid, gastropod, pelecypod biomicrite (with 10 taxa; and a slight decrease in Osagia). Unit 29 is overlain by 0.02 m of transitional, very calcareous, limonitic, and fossiliferous shale (unit 30; 5 taxa). Unit 30 grades into 0.18 m of non-calcareous, black to gray-black shale, marked by an Orbiculoidea epibole (unit 31). A Crurithyris-rich zone, in a light gray, calcareous shale, overlies unit 31, and represents the last unit of sixth-order T-R unit F2.4 (unit 32). Upward through F2.4, diversity increases to a maximum at the top of unit 29, then decreases abruptly through units 30, 31, and 32. The increase in diversity is accompanied by a net increase in *Osagia* (with a slight decrease in the top of unit 29), molluscs, echinoids, and a slight increase in brachiopods (top of unit 29). The molluscs and *Osagia* disappear, and are followed by *Orbiculoidea* and *Crurithyris* biofacies, respectively (units 31 and 32). Paleoenvironments range from transgressive, marginal marine conditions with the initial deposition of calcareous, siliciclastic mud (unit 28), to transgressive, more open, and agitated conditions (in the lower two-thirds of unit 29). This was followed by maximum open marine conditions (relatively shallow) represented by the presence of *Composita* and *Hystriculina* (and a decrease in algal content) at the top of unit 29. After maximum transgression, less open and more restrictive, lagoonal conditions (*Orbiculoidea* biofacies, unit 30) prevailed, indicating initial regression. Lastly, this was followed by maximum regression with more marginal marine conditions (*Crurithyris* biofacies, unit 31).

Sixth-order T-R unit F3.1 is present from 5.10 m to 5.71 m above the base of F1.3, and encompasses units 33 through 36 (Figures 19 & 22c; Appendix). Unit 33 is 0.20 m of gray, fossiliferous (9 taxa), very calcareous shale to very argillaceous calcirudite with common *Neospirifer*, *Composita*, *Crurithyris*, bryozoans, abundant crinoids, rare

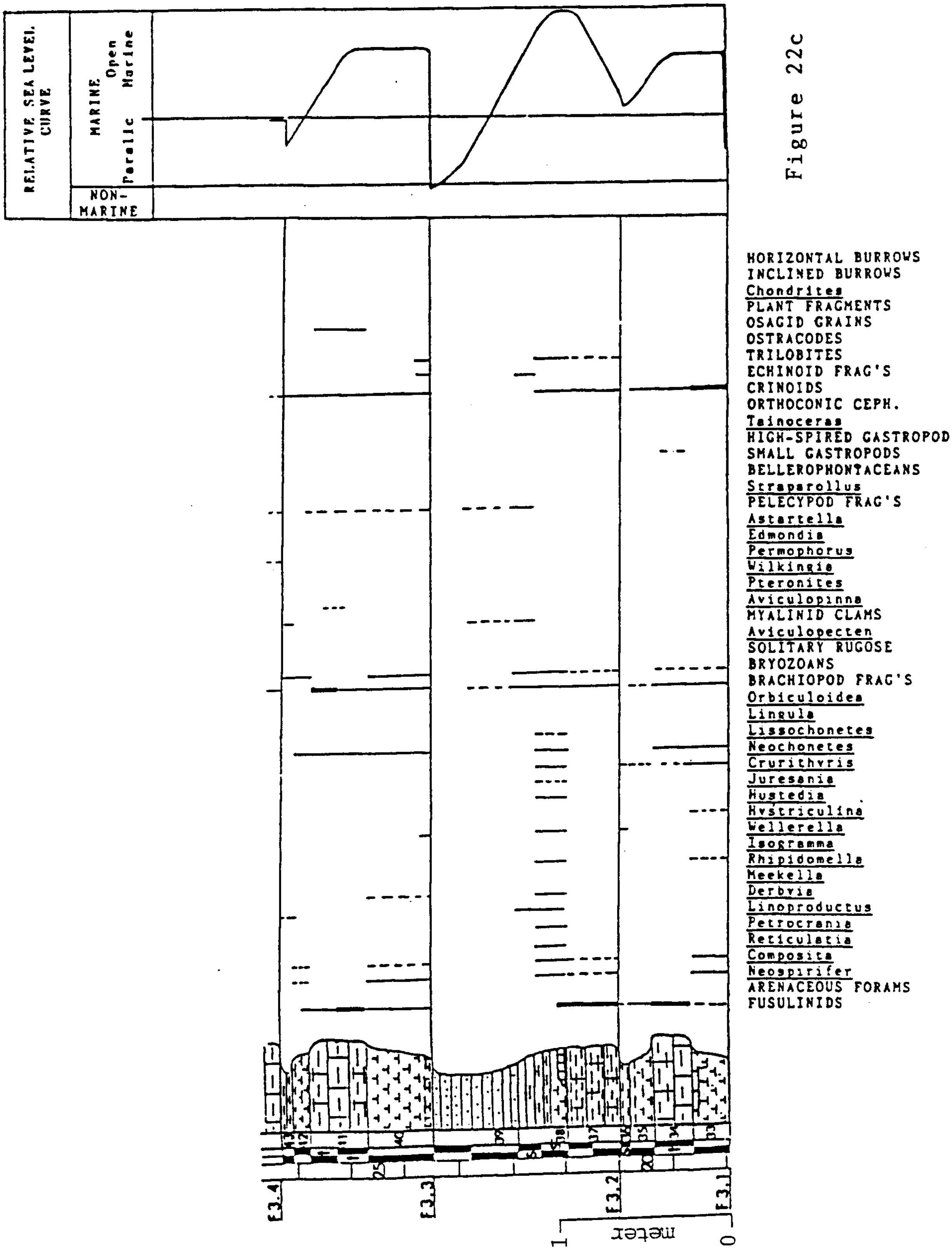

RELATIVE SEA LEVEL CURVE
MARINE
Open Marine
Paralic
NON-MARINE
HORIZONTAL BURROWS
INCLINED BURROWS
Chondrites
PLANT FRAGMENTS
OSAGID GRAINS
OSTRACODES
TRILOBITES
ECHINOID FRAG'S
CRINOIDS
ORTHOCONIC CEPH.
Tainoceras
HIGH-SPIRED GASTROPOD
SMALL GASTROPODS
BELLEROPHONTACEANS
Straparollus
PELECYPOD FRAG'S
Astartella
Edmondia
Permophorus
Wilkingia
Pteronites
Aviculopinna
MYALINID CLAMS
Aviculopecten
SOLITARY RUGOSE
BRYOZOANS
BRACHIOPOD FRAG'S
Orbiculoidea
Lingula
Lissochonetes
Neochonetes
Crurithyris
Juresania
Hustedia
Hystriculina
Wellerella
Isogramma
Rhipidomella
Meekella
Derbyia
Linoproductus
Petrocrania
Reticulatia
Composita
Neospirifer
ARENACEOUS FORAMS
FUSULINIDS
E3.4
E3.3
E3.2
E3.1
meter
1
0

Figure 22c

fusulinids and other brachiopod fragments. Unit 33 grades into 0.22 m of fossiliferous (7 taxa), fine-grained calcirudite (packstone to wackestone; unit 34), with abundant fusulinids (approximately 30% by volume of rock). Overlying unit 34 is 0.13 m of gray, fossiliferous (4 taxa), very calcareous shale, with common fusulinids and crinoids, and rare brachiopods (unit 35). Fusulinids and brachiopods become rare in the very calcareous shale at the top of F3.1 (unit 36). In summary, upward through F3.1, there is a decrease in brachiopods and crinoids towards the middle, an increase in fusulinids and carbonate mud toward the middle, and an overall decrease in diversity, accompanied by an increase in siliciclastic mud deposition toward the top of F3.1. The paleoenvironments of F3.1 range from maximum open marine conditions (basally), as signified by the maximum diversity (i.e., 9 taxa) in the crinoidal-brachiopod biofacies (unit 33), to shallower, yet well circulated marine conditions (unit 34; owing to the carbonate mud and fusulinid content). This was followed by more restricted, lagoonal conditions (units 35 and 36), as fusulinids and brachiopods become rare in the upper facies of F3.1.

Sixth-order T-R unit F3.2 is present from 5.71 m to 6.78 m above the base of F1.3, and encompasses units 37 thru 39 (Figures 19 & 22c; Appendix). The base of F3.2 is a cryptic transgressive genetic surface, in that it is bounded below and above by fusulinid-bearing strata. However, it is definable because of the abrupt increase in fusulinids, and the appearance of crinoids, bryozoans, and brachiopods at the base of sixth-order T-R unit F3.2 (unit 37). Unit 37 is a fossiliferous (with at least 7 taxa), very argillaceous, fine-grained calcirudite (to very calcareous shale) with abundant fusulinids (approximately 30-40% by volume of rock) and crinoids. Unit 37 is overlain by 0.28 m of gray to olive-gray, calcareous shale (unit 38) with a very diverse assemblage (with at least 18 taxa) of brachiopods, bryozoans, crinoids, trilobites, and fusulinids. The basal 0.10 m of unit 38 contains thin (1-2 cm) lenticular, to thin interbedded calcirudite (fine to medium) zones, with abundant brachiopod fragments and fusulinids. Unit 38 is overlain by 0.48 m of non-calcareous, silty shale, with rare productids and myalinids in its lower part, and no marine taxa in its upper part (unit 39).

In summary, F3.2 ranges from a discrete fusulinid, carbonate-rich facies (with 7 taxa; unit 37), to a diverse, thin, brachiopod epibole (with 18 taxa; unit 38), and finally to a silty shale lithofacies containing few marine taxa (3 taxa) at its base (unit 39). The paleoenvironments of F3.2 range from an initial, transgressive, open marine environment as indicated by the fusulinid biofacies, (unit 37; e.g., Stevens, 1969), to maximum open marine conditions, as indicated by the diverse brachiopod epibole (unit 38; possibly representative of a hiatus which produced a diverse, relatively thin concentration of brachiopod and fusulinid taxa). This was followed by initial regressive intertidal-paralic conditions (base of unit 39), which was followed by very nearshore (brackish?), regressive/progradational conditions (upper part of unit 39).

Sixth-order T-R unit F3.3 is present from 6.78 m to 7.70 m above the base of F1.3, and encompasses units 40 thru 43 (Figures 19 & 22c; Appendix). Unit 40 is 0.30 m of very calcareous, olive-gray, blocky to hackly, fossilifeorus shale (12 taxa). Unit 40 grades into a middle fossiliferous (7 taxa), argillaceous calcirudite, compositionally referred to as a fusulinid-brachiopod, osagid bearing biomicrite (unit 41). Fusulinids are abundant in the lower-half of unit 41, and brachiopods are abundant in the upper half. Osagid encrusted grains are common throughout unit 41, preferentially coating the brachiopod fragments, but rarely the fusulinids. Unit 41 is overlain by, and gradational with, 0.10 m of very calcareous, fossiliferous shale (5 taxa; unit 42). Unit 42 is overlain by 0.07 m of calcareous, less fossiliferous shale (4 taxa), with myalinid fragments (unit 43).

In summary, diversity is highest at the base of F3.3 and decreases upward. The decrease in diversity is accompanied by an increase in carbonate mud and fusulinids; this is followed by a reduction in the percentage (by volume) of fusulinids (i.e., from 25-30 % at the base of unit 41, to approximately 10% in the upper part; Appendix). This change in fusulinid density is accompanied by an increase in brachiopods toward the top of the unit. Lastly, there is an overall increase in clay, and a decrease in diversity (units 42 and 43). The paleoenvironments upward, range from quiet, maximum open marine conditions (unit 40), to more nearshore, regressive, yet open marine, and occasionally agitated conditions (e.g., osagid grains) in the middle (units 41 and 42). Lastly, more restrictive lagoonal(?) conditions are indicated by the decrease in diversity and pelecypods in unit 43.

Sixth-order T-R unit F3.4 is present from 7.70 m to 8.20 m above the base of F1.3, and encompasses units 44 thru 47 (Figures 19 & 22d; Appendix). Genetic surface F3.4 is a questionable transgressive boundary, because units 43 (F3.3) and 44 (F3.4) both contain 4 marine taxa, including brachiopods, pelecypods and crinoids. This surface is not questionable, however, at the Paxico section. At both localities, surface F3.4 underlies a distinct Permophorus biofacies (unit 44 of the Manhattan section).

Unit 44 is an argillaceous, limonitic, fossiliferous, cherty, fine calcilutite with rare brachiopods and crinoids, and common pelecypods (mostly Permophorus). Unit 44 is overlain by 0.33 m of olive-gray, non-fossiliferous, very silty, calcareous mudstone with rare plant fragments (unit 45), which grades into 0.10 m of light brown, very silty, non-calcareous mudstone with abundant plant fragments (unit

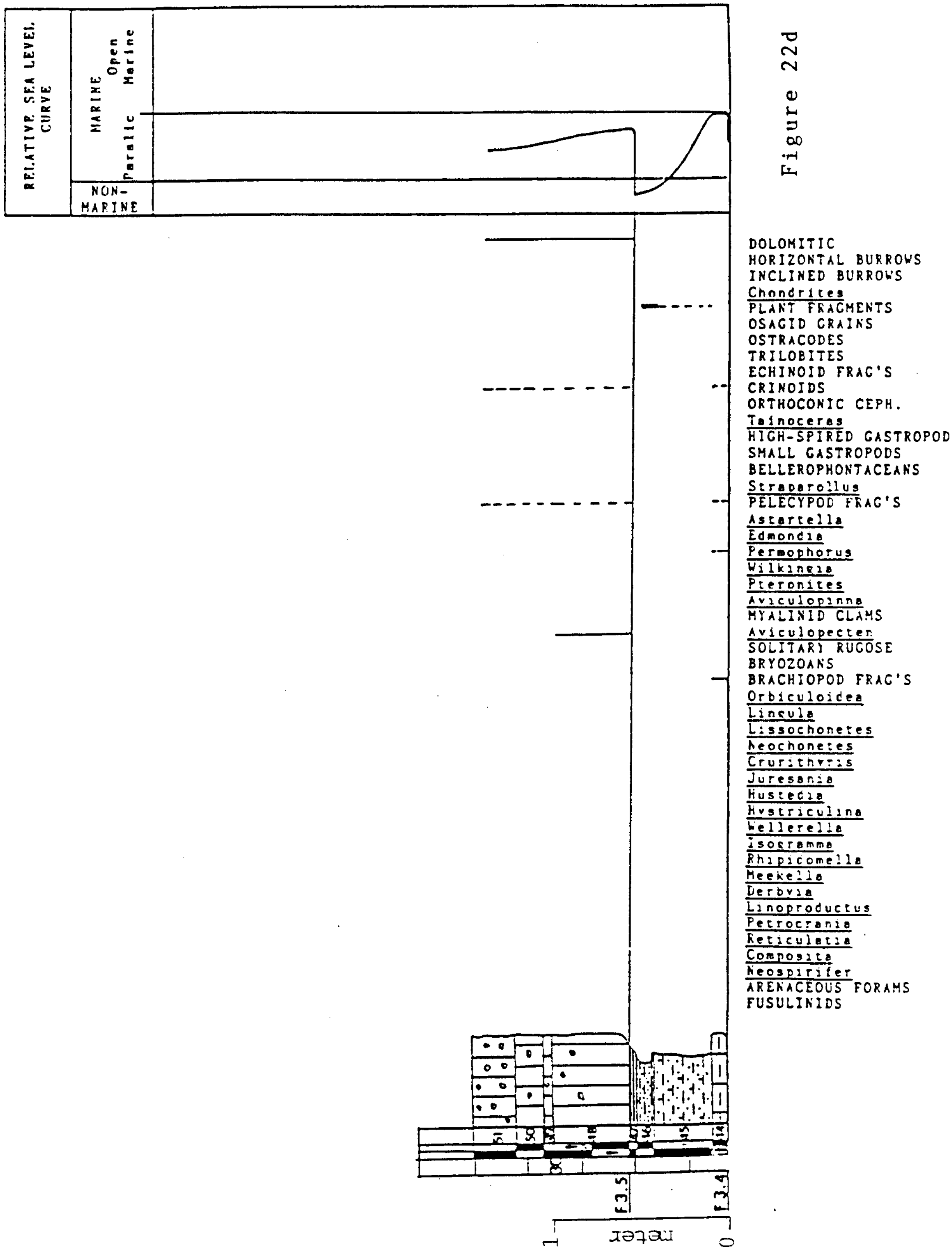

RELATIVE SEA LEVEL CURVE
MARINE
Open Marine
Paralic
NON-MARINE
DOLOMITIC
HORIZONTAL BURROWS
INCLINED BURROWS
Chondrites
PLANT FRAGMENTS
OSAGID GRAINS
OSTRACODES
TRILOBITES
ECHINOID FRAG'S
CRINOIDS
ORTHOCONIC CEPH.
Tainoceras
HIGH-SPIRED GASTROPOD
SMALL GASTROPODS
BELLEROPHONTACEANS
Straparollus
PELECYPOD FRAG'S
Astartella
Edmondia
Permophorus
Wilkingia
Pteronites
Aviculopinna
MYALINID CLAMS
Aviculopecten
SOLITARY RUGOSE
BRYOZOANS
BRACHIOPOD FRAG'S
Orbiculoidea
Lingula
Lissochonetes
Neochonetes
Crurithyris
Juresania
Hustedia
Hystriculina
Wellerella
Isogramma
Rhipidomella
Meekella
Derbyia
Linoproductus
Petrocrania
Reticulatia
Composita
Neospirifer
ARENACEOUS FORAMS
FUSULINIDS
F3.5
F3.4
1
meter
0

Figure 22d

46). Above unit 46 is a blocky, burrowed, non-fossiliferous shale (unit 47). In summary, only unit 44 contains marine fossils, and represents a paralic marine environment. The upper mudstones of F3.4 (units 45, 46, and 47) are interpreted as representing a regressive-progradational, estuarine-like (to explain the plant fragments) or shallow lagoonal environment.

The last sixth-order T-R unit of the Manhattan section, F3.5, is present from 8.20 m to 9.10 m above the base of F1.3 (Figures 19 & 22d; Appendix). The upper part of F3.5 is concealed at this locality. Strata present consist of massive, light brown-orange, argillaceous, dolomitic, fossiliferous calcilutites (units 48 through 51), with rare internal molds of Aviculopecten and other pelecypod fragments. Molluscan diversity decreases (slightly) upward. F3.5 contains vugs that are lined with calcite and celestite, suggesting post-depositional evaporite formation and dissolution. The paleoenvironments of F3.5 range from relatively shallow, subtidal conditions (base of F3.5) to intertidal lagoonal-mudflat conditions (upper part of F3.5). The homogenous, massive nature of this unit may be due in part, to bioturbation in a fluctuating subtidal to intertidal environment, as bedding commonly appears mottled in thin section.

Fifth-Order T-R Units.--The upper part of the Americus fifth-order T-R unit, the complete Hughes Creek fifth-order

T-R unit, and the lower part of the Long Creek fifth-order T-R unit were recognized at this locality. The top of the Americus fifth-order unit is recognized at the base of unit 9 (F2.1; Figure 22a). This is put into perspective when comparing the sixth-order transgressive apex of F1.3 (base of unit 7) and F2.1 (unit 10). The base of unit 7 is represented by a brachiopod, echinoid, molluscan, and osagid dominated biofacies containing 14 taxa. Unit 10 (F2.1) represents more open marine conditions based on its fusulinid and stenotopic brachiopod taxa (e.g., Composita and Neospirifer), and also contains 14 taxa. However, unit 7 of F1.3 is interpreted as a molluscan reversal that represents net regressive, less open, shallow marine conditions of the upper Americus fifth-order T-R unit.

The Hughes Creek fifth-order T-R unit at the Manhattan section contains 4 sixth-order T-R units: F2.1, F2.2, F2.3, and F2.4. In comparing the number of taxa in each sixth-order transgressive apex (units 10, 13, 21, and 29, respectively), it was found that F2.2 contains the fifth-order transgressive apex. Accordingly, F2.1 contains 14 taxa, F2.2 contains 17 taxa, F2.3 contains 11 taxa, and F2.4 (unit 29) contains 10 taxa.

With the transgressive apex defined in F2.2 (unit 13), net deepening on a fifth-order scale occurs from the base of F2.1 (unit 9) to unit 13 of F2.2. Net shallowing occurs from unit 14 of F2.2 to the top of F2.4, with the maximum fifth-order regressive deposits represented by the Orbiculoidea and Crurithyris biofacies (units 31 and 32, respectively; Figure 22b). The overall deepening-shallowing pattern of the Hughes Creek fifth-order T-R unit is asymmetrical, with thin net transgressive facies (units 9 through 13), and an overall thicker, net regressive phase (units 14 through 32).

The base of the Long Creek fifth-order T-R unit was recognized at the base of F3.1 (Figure 22c). The brachiopod and fusulinid biofacies of F3.1 (units 33 and 34) represent more open, stable marine conditions relative to the paralic, molluscan-osagid facies of F2.4. The Long Creek fifth-order T-R unit is composed of at least five sixth-order T-R units, that define a complete net-transgressive phase, and the basal part of a net regressive phase. The maximum extent of transgression, at a fifth-order scale, is represented by unit 38 of F3.2, which contains at least 18 taxa. The "brachiopod epibole" (unit 38; Figure 22c) clearly marks the Hughes Creek fifth-order transgressive apex, relative to the less diverse, brachiopod, fusulinid, bryozoan, and Osagia bearing facies of F3.1 (with 9 taxa in unit 31) and F3.3 (with 12 taxa in unit 40). Net deepening therefore occurs from the base of F3.1 to unit 38, and an incomplete net shallowing phase, at a fifth-order scale, occurs from the base of unit 39, to the top of F3.5 (upper part concealed). The net shallowing phase is confirmed by the relatively low molluscan diversities in the transgressive apices of F3.4 and F3.5 (units 44 and 48, respectively).

Poliska Lane Section

The Poliska Lane section completes the detailed examination of the Foraker Formation from the upper Hughes Creek shale into the Johnson shale. Sixth-order T-R units that define the entire Long Creek fifth-order T-R unit, also encompass strata in the lower half of the Johnson Shale. There are at least 11 sixth-order T-R units (i.e., sixth-order T-R units F3.1 through F3.11) that form the Long Creek fifth-order T-R unit. Descriptions of sixth-order T-R units F3.3 through F3.11, in addition to the strata above the Long Creek fifth-order T-R unit in the lower Red Eagle fifth-order T-R unit (Clark, personal communication), will be given to substantiate the placement of the upper Long Creek fifth-order genetic surface.

Sixth-Order T-R Units.-- Sixth-order T-R unit F3.3 is the first complete sixth-order T-R unit at the Poliska Lane section, which contains the first massive fusulinid biofacies below the base of the Long Creek limestone (as at the Paxico and Manhattan sections, Figures 20e and 22c). Subjacent to F3.3 is 0.15 m of non-fossiliferous, silty, dark gray shale, interpreted as the upper regressive facies of F3.2 (unit 1).

F3.3 contains 0.53 m of massive, fusulinid-rich calcirudite (packstone; unit 2) at its base, which is overlain by 0.15 m of brachiopod-rich, calcareous shale (unit 3; Appendix). Unit 3 is overlain by a pelecypod and crinoidal calcilutite (unit 4), the base of which correlates with genetic surface F3.4 at the Paxico and Manhattan sections. As at the other detailed sections, unit 4 (characterized by a Permophorus biofacies) is overlain by a quartz-sandy, nonfossiliferous calcareous shale, with rare to common plant fragments representing regressive lagoonal or estuarine conditions (unit 5; Appendix).

Sixth-order T-R unit F3.5 (Appendix) contains a basal 0.20 m pelecypod, crinoidal, brachiopod biomicrite (calcilutite, unit 6), that is overlain by 0.99 m of cross laminated (current), sparsely fossiliferous (crinoids and pelecypods), argillaceous, massive calcilutites (units 7 and 8: Appendix). Overlying unit 8 is 0.38 m of mudcracked calcilutite (unit 9) with thin shale lentils. Unit 9 is capped by 0.23 m of massive, iron stained, intensely root mottled, argillaceous dolomite (unit 10) marking the maximum regression of F3.5. Paleoenvironments represented in F3.1 range from subtidal to intertidal (units 6,7, and 8), to a (prograding) supratidal mudflat (units 9 and 10).

A 0.91 m non-fossiliferous calcilutite (unit 11) with an uneven basal contact marked by intraclasts, characterizes the base of sixth-order T-R unit F3.6. The upper part of F3.5 (units 12 and 13) is a non-fossiliferous, silty shale that is capped by a root mottled, iron stained claystone (paleosol). Units 12 and 13 represent the basal part of the Johnson shale. F3.6 ranges from a subtidal to intertidal carbonate environment, to a terrestrial paleosol facies.

The next three sixth-order T-R units F3.7, F3.8, and F3.9, are each characterized, at the base, by thin, flaggy, argillaceous, non-fossiliferous calcilutites that are overlain by olive-green, root mottled claystones. These claystones are interpreted as lithified paleosols.

The remaining two sixth-order T-R units F3.10 and F3.11 (Appendix), are each characterized by intertidal to supratidal dolostones (basally) that are capped by minor root mottled claystones (paleosols). F3.11 represents the uppermost sixth-order T-R unit of the Long Creek fifth-order T-R unit. The next four sixth-order T-R units, above F3.11, support this interpretation. These include, in ascending order, sixth-order T-R units F4.1, F4.2, F4.3, and F4.4, (Appendix). These sixth-order T-R units have been described in detail by Clark (personal communication), and represent the initial facies of the Red Eagle fifth-order T-R unit. F4.1 and F4.2 encompass the uppermost Johnson Shale Formation, F4.3 encompasses the Glenrock Limestone Member, and F4.4 encompasses the lower part of the Bennett Shale Member (Appendix).

At the base of sixth-order T-R unit F4.1 is 0.08 m of ostracodal calcilutite (unit 24) capped by 0.33 m of non-fossiliferous claystone (paleosol). The lower 0.51 m of F4.2 is an ostracodal, laminated calcilutite (units 26 and 27) overlain by a distinct, black, fissile, silty, carbonaceous shale with plant fragments and ostracodes (unit 28). Unit 28 is also burrowed, and may represent very shallow, restricted lagoonal (or estuarine) conditions. Overlying unit 28 is a paleosol characterized by a slightly root mottled claystone with caliche nodules (unit 29). The maximum transgressive facies of F4.1 and F4.2 range from subtidal to intertidal environments that were followed by nonmarine terrestrial environments (their maximum regressive facies).

Sixth-order T-R unit F4.3 (Glenrock Limestone) is 0.41 m of massive, molluscan, osagid, intraclast biomicrite (unit 30). Above it, in the upper 0.02 m of the Glenrock limestone (unit 31), is a thin massive fusulinid calcirudite (packstone) representing the initial transgressive facies of F4.4 (unit 31). Unit 31 of F4.4 contains a very diverse marine biota including Neospirifer, Composita, and bryozoans (Clark, personal communication). According to Clark, unit 31 (F4.4) represents the transgressive apex of the Red Eagle fifth-order T-R unit.

Overlying the transgressive facies of F4.4 is a thin (0.05 m) black shale (unit 32) with a distinct Orbiculoidea biofacies. This grades upward into 0.07 m of silty, platy shale (with few marine taxa) that represents maximum regression of unit 33.

Fifth-Order T-R Units.--The Poliska Lane section contains most of the net shallowing phase of the Long Creek fifth-order T-R unit, and the basal part of Clark's Red Eagle fifth-order T-R unit. In the Long Creek fifth-order T-R unit it is obvious that F3.3 contains the most diverse assemblage of marine taxa including brachiopods, bryozoans, echinoderms, and fusulinids (Appendix). The incomplete net-shallowing phase at a fifth-order scale, thus occurs from F3.2 through the molluscan-bearing argillaceous calcilutites of F3.4 and F3.5. The remainder of the net-shallowing phase is represented by the subtidal to intertidal, non-fossiliferous calcilutites of F3.6 through F3.9, and the supratidal dolostones of F3.10 and F3.11.

The top of the Long Creek fifth-order T-R unit, and thus the lower boundary of Clark's Red Eagle fifth-order T-R unit, is recognized because of the fossiliferous facies in F4.1, relative to the subjacent, non-fossiliferous, "stacked" supratidal-paleosol facies of F3.10, and F3.11. Clark's Red Eagle fifth-order T-R unit shows a continued net deepening through the massive calcilutite and overlying black, fissile, ostracodal shale of F4.2 (unit 28: Appendix). Maximum transgression at a fifth-order scale, is represented by the richely diverse facies of F4.4 (unit 31; Clark, personal communication), above the transgressive algal-molluscan facies of F4.3.

Foraker Fourth-Order T-R Unit

Based on the relative extents of maximum transgression among the Americus, Hughes Creek, and Long Creek fifth-order T-R units, the upper part of the net transgressive phase of a fourth-order T-R unit can be defined (Figure 23). The lower part of the regressive phase can be recognized with additional information on the superjacent Red Eagle and Burr fifth-order T-R units (Clark, personal communication; Figure 24). Data on rocks above and below the intervals analyzed in this study is needed to determine the exact positions of the upper and lower boundaries of this fourth-order T-R unit, which I will refer to as the "Foraker fourth-order T-R unit."

The fourth-order net deepening phase was determined using fossil diversities. For example, at the Paxico section the Americus fifth-order transgressive apex, or TA, (Figure 20b, upper part of unit 6 and unit 7) contains at least 8 taxa, the Hughes Creek fifth-order TA (Figure 20c; unit 16) contains 17 taxa, and the Long Creek fifth-order TA contains 19 taxa (Figure 20e, basal part of unit 27). The net increase in diversity from the Americus to the Long Creek fifth-order TAs, is interpreted as reflecting net deepening, at a fourth-order scale. This pattern is consistent with the McDowell Creek Road and Manhattan sections, where the Americus fifth-order TA contains 12 taxa (at the McDowell

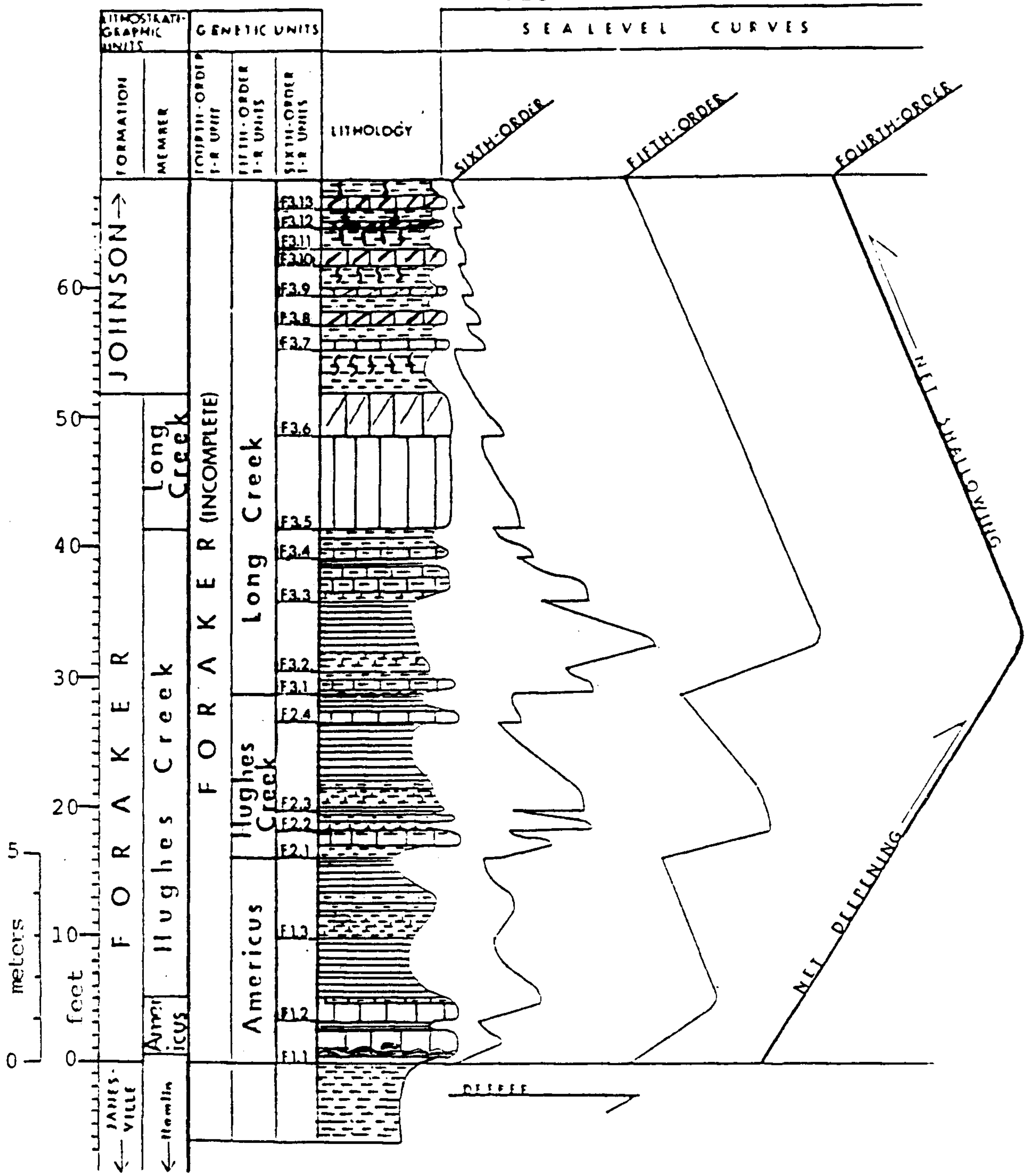
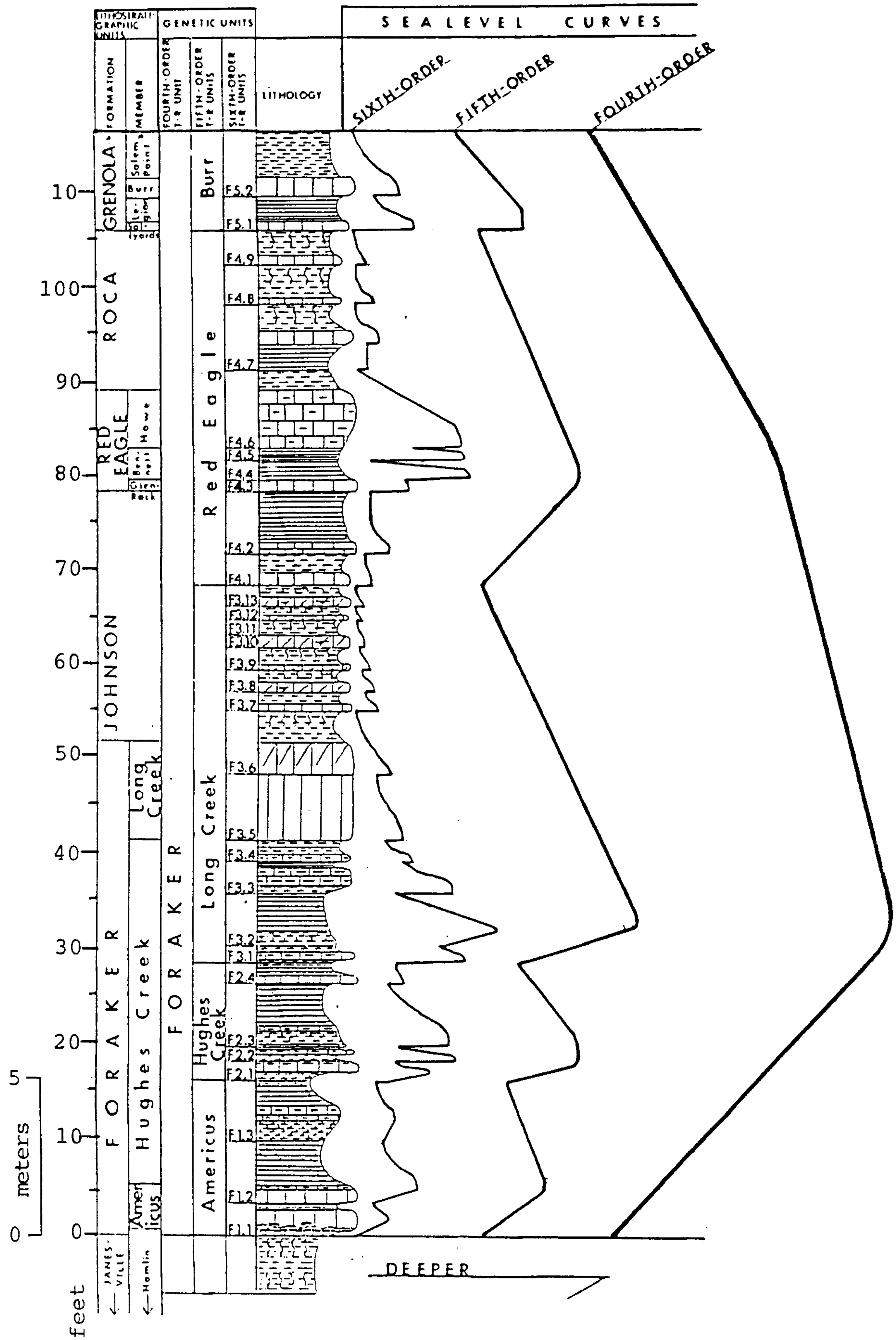


Figure 23. Standard hierarchal genetic (T-R unit) stratigraphy of the Foraker Formation illustrating the nested hierarchal pattern of sixth-, fifth-, and fourth-order T-R units (see text for discussion).

Figure 24. Standard hierarchal genetic stratigraphy of the Foraker fourth-order T-R unit, illustrating the internal nesting of fifth- and sixth-order T-R units. Information on the Red Eagle and Burr fifth-order T-R units provided by Clark (personal communication).



LITHOSTRATIGRAPHIC UNITS
GENETIC UNITS
FORMATION
MEMBER
FOURTH-ORDER T-R UNIT
FIFTH-ORDER T-R UNITS
SIXTH-ORDER T-R UNITS
LITHOLOGY
SEA LEVEL CURVES
SIXTH-ORDER
FIFTH-ORDER
FOURTH-ORDER
GRENOLA
ROCA
RED EAGLE
JOHNSON
FORAKER
JANES-VILLE
Salem Point
Burr
Legion
Sallyards
Howe
Bennett
Glenrock
Long Creek
Hughes Creek
Americus
Hamlin
FORAKER
Burr
Red Eagle
Long Creek
Hughes Creek
Americus
F5.2
F5.1
F4.9
F4.8
F4.7
F4.6
F4.5
F4.4
F4.3
F4.2
F4.1
F3.13
F3.12
F3.11
F3.10
F3.9
F3.8
F3.7
F3.6
F3.5
F3.4
F3.3
F3.2
F3.1
F2.4
F2.3
F2.2
F2.1
F1.3
F1.2
F1.1
DEEPER
feet
meters
0
10
20
30
40
50
60
70
80
90
100
10
0
5

Creek Road section), the Hughes Creek fifth-order TA contains 16 taxa (at the Manhattan section), and the Long Creek TA contains 18 taxa (at the Manhattan section); here again, defining a net transgressive phase based on fossil diversity.

A net decrease in diversity occurs going from the Long Creek fifth-order TA (18 taxa), to the Red Eagle fifth-order TA (F4.3, 11 taxa; Appendix). This is interpreted as reflecting net shallowing at a fourth-order scale. Fourth-order regression continues through the Burr fifth-order T-R unit (Figure 24; Clark, personal communication). Net regression at a fourth-order scale is reflected in the development of algal bearing facies, a concomitant decrease in brachiopods and bryozoans, and the lack of fusulinids in the Burr fifth-order T-R unit (Busch, personal communication).

Correlation Methods and Results

Correlation of Foraker T-R units was genetically achieved relative to key marker beds, hierarchal deepening-shallowing patterns, and biozones. Three cross-sections, A-A', B-B', and C-C' (pocket enclosures), show that sixth- and fifth-order T-R units are correlative in a north-south and east-west direction.

The Americus fifth-order T-R unit is easily correlated, because the upper Americus limestone bench is a key marker bed in sixth-order T-R unit F1.2, that is genetically central to F1.1 and F1.3. Sixth-order T-R units F1.1 and F1.3 are more variable in their geographic extent (discussed later in more detail). Where the Americus Limestone Member is concealed (or absent), the fusulinid-*Isogramma* biofacies in the basal part of F2.1 can be used as a unique biologic marker in the basal part of the Hughes Creek fifth-order T-R unit (in the present study area). However, *Isogramma* as a key biostratigraphic horizon for the Hughes Creek fifth-order T-R unit (outside the present study area) should be used carefully, because Fritts (1980) recognized *Isogramma* in the Long Creek Limestone Member in northeastern Oklahoma. The correlative hierarchal pattern of the Hughes Creek fifth-order T-R unit is reflected in the thin lateral persistence of F2.1 and F2.2. There is a distinct increase in fusulinids going from F2.1 to F2.3 across the study area at all sections, revealing that part of the hierarchy.

Sixth-order T-R unit F2.4 is distinctly correlative across the study area using the osagid-molluscan content at the base and the superjacent *Orbiculoidea* and *Crurithyris* biofacies. The distinct *Orbiculoidea* and *Crurithyris* zones of F2.4 must be carefully correlated, because they thin drastically to the south and southeast, and actually disappears in Lyon and Chase Counties (Mudge and Yochelson 1962; Garber, 1954). Hierarchal patterned increases and decreases in fusulinid content will probably prove to be the genetic, correlative arbiter of the Hughes Creek fifth- and sixth-order T-R units, as it is a very useful tool in Wabaunsee, Pottawatomie, and Riley Counties.

The basal three sixth-order T-R units of the Long Creek fifth-order T-R unit, F3.1, F3.2, and F3.3, are genetically useful based on their massive, fusulinid-rich biofacies. The fusulinid biofacies form three distinct zones (one in each sixth-order T-R unit) that are consistently found across the area. These zones are always subjacent to the massive, dolomitic, calcilutite lithofacies of the Long Creek limestone. Equally distinctive in correlation is the Foraker fourth-order TA, as represented by the brachiopod epibole that is superjacent to the massive fusulinid biofacies of F3.2. This zone is concealed at the Admire (Ad) and Allen (Al) sections in Lyon County, and is not detectable at the C1 and C2 sections using Garber's (1962) descriptions (Appendix I). Correlation of the Foraker fourth-order TA can be made as far south as the Keene (K) section.

The base of F3.2 is questionable at the Paxico (P), Amoco #1 Hargrave Core (C), Alma (A), and Louisville (L) locations. At these locations a massive fusulinid zone (of F3.2) overlies another fusulinid zone (of F3.1), with no distinct stratigraphic separation. At all other sections, the fusulinid biofacies of F3.1 and F3.2 are separated by a thin (2-4 cm), sparsely fossiliferous, calcareous shale. This raises the question of whether or not there may actually be cryptic "diastemic" surfaces (representing regressive phases and transgressive events on a sixth-order scale) within the massive fusulinid zones of the Foraker Formation (e.g., F2.3, F3.1, F3.2, and F3.3). If this is true, other sixth-order genetic surfaces may exist, that are not otherwise defined by a distinctly less diverse, or sparsely fossiliferous, subjacent, sixth-order regressive facies. Within the massive fusulinid zones there may exist disjunct facies of a nondisparate nature. Continued correlation to the south, past Chase County, and into the extreme southern part of Kansas using a genetic approach, may define such cryptic, genetic surfaces as fusulinids become ubiquitous throughout the Foraker Formation in these areas (e.g., Garber, 1962; Mudge and Yochelson, 1962; Ávers, 1968; Fritts, 1980).

Sixth-order T-R unit F3.3 marks the last correlative fusulinid biofacies, and is genetically distinctive in this sense because the superjacent Long Creek limestone does not contain fusulinids. Fusulinids only occur in the Long Creek Limestone Member near the Kansas-Oklahoma border, and become abundant in northern Oklahoma (Fritts, 1980). The upper boundary of F3.3, and thus genetic surface F3.4, is cryptic at the Manhattan (M), Holidome (H), Southeast Paxico (SEP), Kansas River (KR), and Flush (F) sections, because no clear faunal or lithologic, genetic distinction exists, but it is distinguishable at the other sections. The fact that this boundary (F3.4) is questionable at a number of sections does not disrupt the correlative, continued, net-shallowing phase at a fifth-order scale through the remainder of the Long Creek fifth-order T-R unit, at all sections exposing this sequence. In addition, the basal part of F3.4 at all localities (inclusive of those with a questionable F3.4 surface) is marked by a *Permophorus* biofacies.

Sixth-order T-R unit F3.5 is correlative based on the occurrence of a subjacent, plant-bearing silty shale in the regressive part of F3.4, and an overlying massive, sparsely fossiliferous, molluscan calcilutite in F3.5 at all locations. However, the upper part of F3.5 is variable because at some localities there is a single, prominent, mudcracked algal laminite facies (e.g., #1 Hargrave Core, Deep Creek, Admire, Alma, and East Paxico sections: Appendix I) at the top of F3.5. At other localities, F3.5 contains multiple, thinnly interbedded, non-fossiliferous calcilutites and algal laminites (e.g., Southeast Paxico, and Keene sections). This may indicate the presence of autogenic "noise", in this case deepening events. At the same time, the upper part of F3.5 at the Poliska Lane (PL), Blue River (BR), Kansas River (KR), and Holidome (H) sections contain no algal laminites. It is evident, for example, that the algal laminites of the #1 Hargrave Core (C; in F3.5) and Deep Creek (DC) sections (in F3.5) are correlative with the intensely root mottled, iron stained dolomites of the Poliska Lane and Kansas River sections (Cross Section B-B'; Appendix). This part of the Foraker hierarchy (F3.5) represents concomittant fourth-order net regression. Therefore the extra algal laminites (e.g., Keene and Southeast Paxico sections) probably represent autogenic events. Better stratigraphic control and more complete sections are needed to test this idea.

Sixth-order T-R unit F3.6 was only described at the #1 Hargrave core (C), Holidome (H), Alma (A), Paxico (P), Blue River (BR), Poliska Lane (PL), and Kansas River (KR) sections. More field data is needed to complete sixth-order correlation above F3.6. However, in the #1 Hargrave Core, Holidome, and East Paxico sections, regressive (on a fifth- and fourth-order scale) algal-bearing, flaggy calcilutites and paleosols of the Johnson Shale Formation consistently occur above the Long Creek limestone.

Standard Hierarchal Genetic (T-R Unit) Stratigraphy of the Foraker Formation

By the analysis of all facies and facies contacts a discrete, physically nested hierarchy of sixth-, fifth-, and and part of a fourth-order T-R unit encompasses the Foraker Formation. The sixth-order T-R units (Figures 23 and 24) are relatively thin (0.50 m to 3.00 m), asymmetrical, shallowing-upward units that are correlative across the area of study.

The fifth-order T-R units are also characteristically asymmetrical with relatively thin transgressive phases, and thicker net regressive phases.

According to Busch and West (1987) the periodicities of Permo-Carboniferous T-R units are also hierarchal (Figure 14). Based on their estimate of Permo-Carboniferous fifth-order T-R units, each fifth-order T-R unit recognized in this study probably represents 300,000 to 500,000 years of deposition. The interval from the base of the Americus to the top of the Long Creek fifth-order T-R unit would therefore represent approximately 900,000 years to 1.5 my of deposition. Dividing this range by the total number of sixth-order T-R units in this interval (18) results in a sixth-order periodicity range of approximately 50,000 years to 83,000 years.

PALEOGEOGRAPHIC DEVELOPMENT OF THE FORAKER FORMATION

Methods

Paleogeographic maps were constructed for correlative facies representing maximum transgression within each sixth-order T-R unit, thus establishing both paleoecologic and lithologic changes across the study area. The only exception to this is that a map for early transgression, and a map for initial regression, rather than maximum transgression, was constructed for F1.1 and F1.3, respectively. This approach (i.e., mapping the TA) was utilized by Busch (1984), and is useful for understanding the controls over the development of lithofacies and biofacies in rock sequences. Sixth-order T-R units F1.1 thru F3.2 of this study were mapped for discussion on the Foraker paleogeography. These sixth-order T-R units were mapped because they encompass all three fifth-order T-R units, and thus, the upper net deepening phase of the Foraker fourth-order T-R unit.

Development of the Foraker paleogeographic maps is based on the premise that each sixth-order transgressive facies is affected by, and potentially inherits, the topography that existed prior to the punctuation event (i.e., transgression). This is a reasonable postulate, because according to the PAC hypothesis, punctuation events are commonly marked by non-deposition (or very thin transgressive facies). Thus, the sixth-order transgressive facies was being deposited on a previously formed topography that (presumably) resulted from an entirely different set of environmental conditions. Isopach maps of the thickness of each sixth-order T-R unit were used to help delineate corresponding topographic highs and lows that may be inferred from the paleogeographic maps.

After completion of the paleogeographic maps, all boundaries, whether biofacies or lithofacies boundaries, were overlain and superimposed onto a single base map of the study area. This "composite paleogeographic map" was used to detect any recurrent sixth-order facies trends. Likewise, a "composite isopach map" was constructed to show the recurrent sixth-order isopach "thins" and "thicks".

Paleoecologic and Lithologic Trends

Sixth-order T-R Unit Fl.1.--The transgressive apex of Fl.1 is a laterally uniform mudstone to wackestone (calcarenite-biomicrite) lithofacies that represents the upper part of the lower Americus limestone bench. Within the TA of Fl.1, molluscs are the dominant marine taxa throughout the area, with fewer ostracodes, crinoids and brachiopods (Appendix). Although brachiopods appear to increase in abundance toward Garber's (1962) Cl and C2 sections, as well as the #1 Hargrave Core (C; Appendix), there is no discrete biofacies or lithofacies differentiation in the TA of Fl.l. Therefore the intitial transgressive facies of Fl.l (rather than the TA of Fl.l) that encompasses the basal part of the lower Americus limestone bench, was used to construct a paleogeographic map (Figure 25; Appendix). This was done because there are discrete lithofacies changes in the initial transgressive phase of Fl.l across the study area, which may provide more information on the controls over deposition of the Foraker Formation. Another more detailed paleogeographic map representing the entire lower Americus interval (Figure 26) is provided by Fisher (1980), and will be disscused in support of this study.

Figure 25 has been differentiated into three general, primary environments. These environments include: 1) a shoaling, intertidal to subtidal environment located in the northern and central portions of the study area, as represented by the molluscan-algal packstone lithofacies; 2) a "deeper", quieter marine environment located in the western, southwestern, and southern parts of the area, as represented by the calcareous shale lithofacies; and 3) an intertidal-subtidal mudflat environment located in the eastern and northeastern part of the area, as represented by the nonfossiliferous mudstone-calcilutite lithofacies.

The shoal area (molluscan-algal packstone lithofacies) is typified by reworked, brecciated, and contorted algal stromatolites (Collenia?). Although not all of the

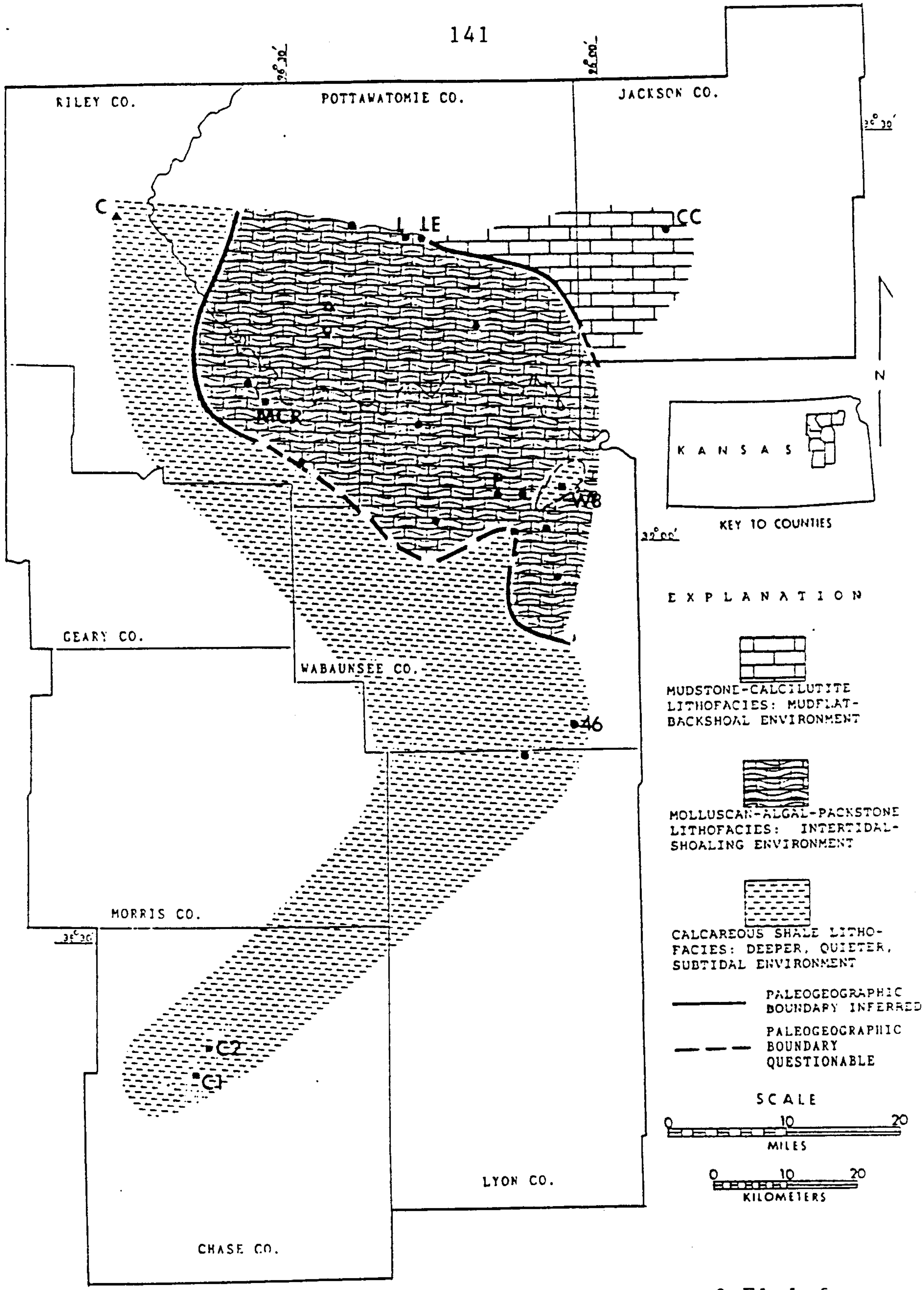


Figure 25. Paleogeographic lithofacies map of F1.1 for early transgression. See text for discussion.

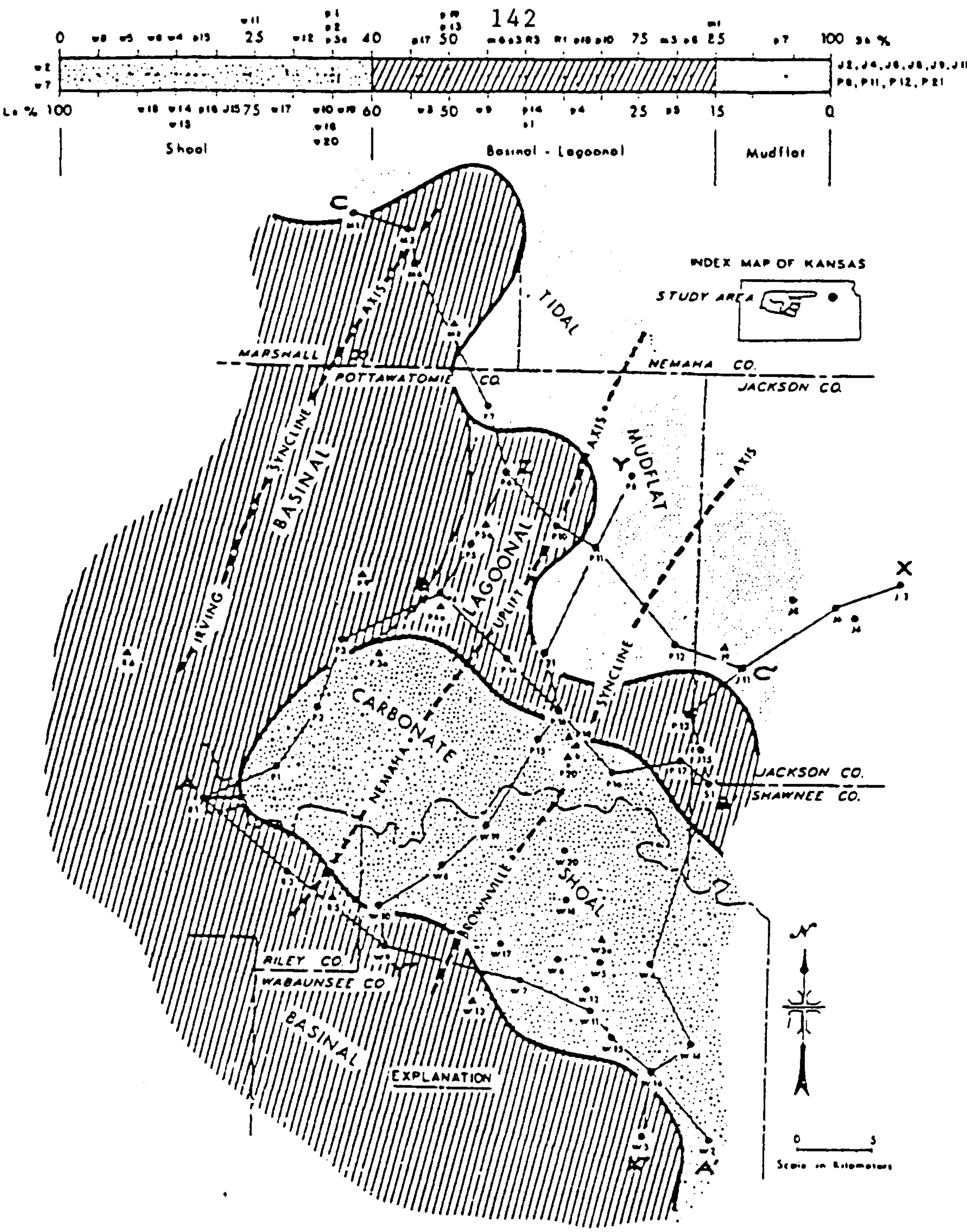


Figure 26. Fisher's (1980) paleogeographic map of the basal Americus Limestone bench, as interpreted from limestone and shale percentages.

stromatolitic facies show this characteristic, it is common within the confines of the lithofacies. Encasing the algal stromatolites and their rip-up clasts (e.g., Paxico, P, section; Appendix) is an intraclast biomicrite (skeletal packstone) that grades upward into a molluscan (myalinids and pinnids), occasionally burrowed, biofacies.

It is evident that the molluscan-algal packstone lithofacies was formed by relatively higher energy conditions. For example, Fisher (1980) found evidence of algal "roll" structures attributed to storm currents, and imbricated rip-up clasts that were attributed to tidal reworking. The eastern and western limits of the shoal area are defined by the disappearance of the basal, massive algal stromatolites as seen in the Amoco #1 Hargrave Core (C) in the northwestern part of the study area, and the Crow Creek (CC) section (Appendix) in the northeastern part of the area. The southern and western limits of the shoal area are interpreted as representing the boundary between higher energy conditions of the shoaling environment, and more stable energy conditions that allowed the deposition and accumulation of fine siliciclastic sediments to the south. Deposition of siliciclastic mud to the south formed the calcareous shale lithofacies (Figure 25).

The calcareous shale lithofacies separates the basal algal stromatolite facies from the lower Americus limestone bench at the Keene (K) section and at Mudge and Burton's

(1959) section 43 (Figure 25; Cross Section A-A', pocket enclosure). Mudge and Burton (1959), and Mudge and Yochelson (1962) confirmed the existence of a very calcareous, silty, gray to dark gray shale between the lower Americus limestone and the basal Americus stromatolite facies (originally referred to as the Houchen Creek Limestone). The intervening calcareous shale lithofacies, originally termed the Oaks Shale Member of the Janesville Formation (Admire Group), is prevalent in Lyon and Chase Counties (Moore, Jewett and O'Connor, 1951; and O'Connor, 1953). The calcareous shale lithofacies pinches out in northern Wabaunsee county. Garber's (1956) data shows the exsistence of productid brachiopods and foraminiferids in the calcareous shale lithofacies at his "C1" section in Chase County (Figure 25: Appendix).

The calcareous shale lithofacies is also present in the form of thin interbedded shales and shale lentils at the #1 Hargrave Core (C) in the northeastern part of the study area, and is also present in northern Wabaunsee County. The isolated calcareous shale lithofacies at Garber's W8 locality is interpreted as representing a quieter, "ponded" area within the shoaling environment of the molluscan-algal packstone lithofacies. Based on Fisher's (1980) discussion, other such "ponded" areas probably existed within the shoaling environment. In addition to the disappearance of the stromatolite facies at the #1 Hargrave core (C), the initial, shaley transgressive deposits of F1.1 contain an assemblage of brachiopods, pelecypods, crinoids, and ostracodes. The basal 0.01 m to 0.15 m of F1.1, at the core site, also contains carbonate intraclasts that may actually be allochthonous rip-up clasts transported seaward from the shoaling environment(?). The calcareous shale lithofacies is indicative of quieter, more stable, level bottom conditions (e.g., Anderson, 1974) in a "deeper marine?" environment, as indicated by its siliciclastic mud and brachiopods.

The mudstone-calcilutite lithofacies in the northeastern part of the area is characterized by the disappearance of stromatolites at the Crow Creek (CC) section. The algal stromatolite facies begins to pinch out near the Louisville East (LE) section, where it is a very thin (<2cm) and laterally impersistent facies (Fisher's Ottonosia facies?). The basal part of sixth-order T-R unit F1.1 at the Crow Creek (CC) section is a non-fossiliferous calcilutite (mudstone) with occasional non-fossiliferous clay lentils (e.g., Mudge and Yochelson, 1962: Appendix). This facies represents a semirestricted, intertidal mudflat environment. A more detailed, and probably less tenuous picture of this portion of the study area is given by Fisher (1980), and is based on more stratigraphic control of the Americus limestone in this area.

Fisher (1980) recognized four lithofacies in the lower Americus limestone interval based on carbonate:shale ratios and petrologic data (Figure 26). These include: 1) a tidal mudflat lithofacies in the northeastern part of his area; 2) a northwest-southeast trending lagoonal facies tract in eastern Pottawatomie County; 3) a similar trending carbonate shoal facies in southern Pottawatomie and northern Wabaunsee Counties; and 4) a "basinal" facies tract along the western and southwestern part of his area. The basinal facies is analogous, lithostratigraphically and paleogeographically, to the deeper marine, calcareous shale lithofacies recognized in this study. Likewise, Fisher's carbonate shoal is analogous to the intertidal to subtidal shoal of this study.

Good stratigraphic control in eastern Pottawatomie and southeastern Jackson Counties enabled Fisher (1980) to recognize a back-shoal lagoonal facies seaward of the mudflat facies (Figure 26). This facies contains thinly interbedded osagid-bearing packstones, *Orbiculoidea*-bearing black shales, and gray and green calcareous shales with brachiopods, crinoids and pelecypods. The mudflat area is differentiated from the lagoonal facies by its pustular to tufted, algal stromatolitic crusts (i.e., *Ottonosia*) found in eastern Pottawatomie and western Jackson Counties. Fisher (1980) compared these rocks to the high intertidal to low supratidal mudflat facies of Shark Bay, Australia (described by Logan *et al.*, 1974). Fisher's northern tidal mudflat and basinal facies are questionable, as they are immediately adjacent to one another in Marshall County (Figure 26).

The shoaling facies interpreted and preferred in this study (Figure 25) is expanded and covers a slightly broader area. Fisher's carbonate shoal facies essentially coincides with, and lies within, the molluscan-algal packstone lithofacies of the present study. The larger shoaling area of this study is based mainly on the fact that a distinct molluscan-algal packstone lithofacies is found at the Louisville (L) and McDowell Creek Road (MCR) sections. The former locality coincides with Fisher's shaley lagoonal tract, and the latter location coincides with his basinal facies. Neither of these localities contain a basal, intervening calcareous shale lithofacies. At the same time there is no indication, lithologically or paleoecologically, for placing these two sections in a deeper basinal or lagoonal facies (e.g., see lower Americus interval, F1.1, at Louisville East and McDowell Creek Road sections: Appendix).

Sixth-Order T-R Unit F1.2.--The transgressive apex of sixth-order T-R unit F1.2, throughout the area, occurs in the upper 0.10 to 0.15 m of the upper Americus limestone bench. It includes the fusulinid biofacies (recognized at the Paxico (P) and McDowell Creek Road (MCR) sections, Figures 20a and 21b), above which lies the regressive *Crurithyris* biofacies. The remarkable persistence of the lithology, biotic diversity, and thickness of the upper Americus limestone bench supports the interpretation that it is a maximum fifth-order transgressive event. The homogeneousness of the upper Americus limestone bench, and its fusulinid biofacies (Figure 27), makes it difficult to discern any lateral changes in lithofacies or biofacies (e.g, Harbaugh and Demirmen, 1964; Fisher, 1980).

The TA of Fl.2 is a fine calcirudite, compositionally referred to as a poorly sorted, pelecypod, brachiopod, crinoid, fusulinid biomicrite (wackestone). This facies contains varying amounts of clay, and glauconite is rare to common. A relatively diverse assemblage of articulated, and well preserved fossils such as Neospirifer, Neochonetes, Reticulatia, Derbyia, and Lophopyllidium (e.g., Westmoreland section, W; Appendix I), occur within the fusulinid biofacies. No clear lateral facies change, faunally or lithologically, exists in the fusulinid biofacies (Figure 27); however, there appears to be a slight increase in fusulinids (from north to south), and crinoids and clay (from south to north), across the area. At all localities, fusulinids are rare or nonexistent in the base of the upper Americus limestone bench, and become common to abundant at the top (i.e., in the TA of Fl.2). Subjacent to the TA of Fl.2 (in the lower half of the Americus limestone bench) the lithology is similar, except for the occurrence of intraclasts and the disappearance of fusulinids.

Throughout the study area, horizontal burrows (epirelief, detritus filled) occur on the undersides, as well

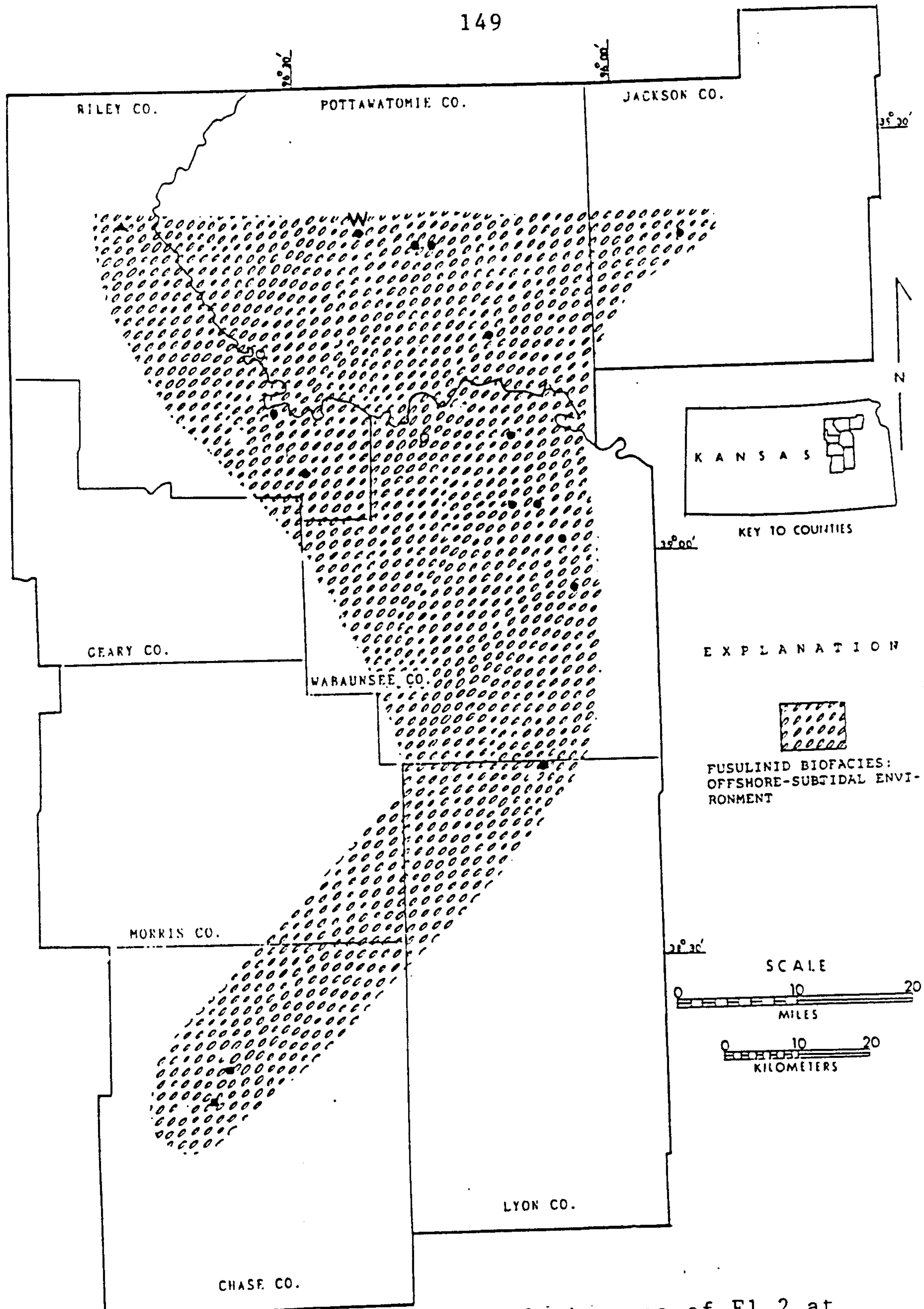


Figure 27. Paleogeographic biofacies map of F1.2 at maximum transgression. See text for discussion.

as the upper bedding planes, of the upper Americus limestone (characterized by 2 to 4 cm diameters). It is recognized in this study, and also by Fisher (1980), that burrowing by pelecypods (Wilkingia?) may have had some effect on the vertical and lateral facies differentiation. In addition, it was recognized by Fisher (1980) and this author, that currents may have enhanced the "mixed", poorly sorted, homogeneousness of the upper Americus limestone bench (particulary subjacent to the TA of F1.2). Fisher (1980) has documented inclined bedding surfaces, and graded bedding. Commonly found in this study were edgewise grains of intraclasts and crinoids (below the TA of F1.2). This suggests "more-than-normal" agitation by waves and currents (e.g., Friedman and Sanders, 1978). The abundance of carbonate mud in the upper Americus limestone bench (inclusive of the TA) suggests that such agitation was discontinous or that carbonate-sediment bafflers existed. Because crinoids are particularly abundant (even in the TA of F1.2) they may have been these carbonate - sediment bafflers.

Harbaugh and Demirmen (1964) quantitatively differentiated depositional regimes of the upper Americus limestone bench using petrologic data from 27 localities, extending from Lincoln County, Oklahoma to northern Pottawatomie County, Kansas (Figure 28). They recognized four paleogeographic "phases" (or facies areas): phase A, coincident with the northern part of this study area, is

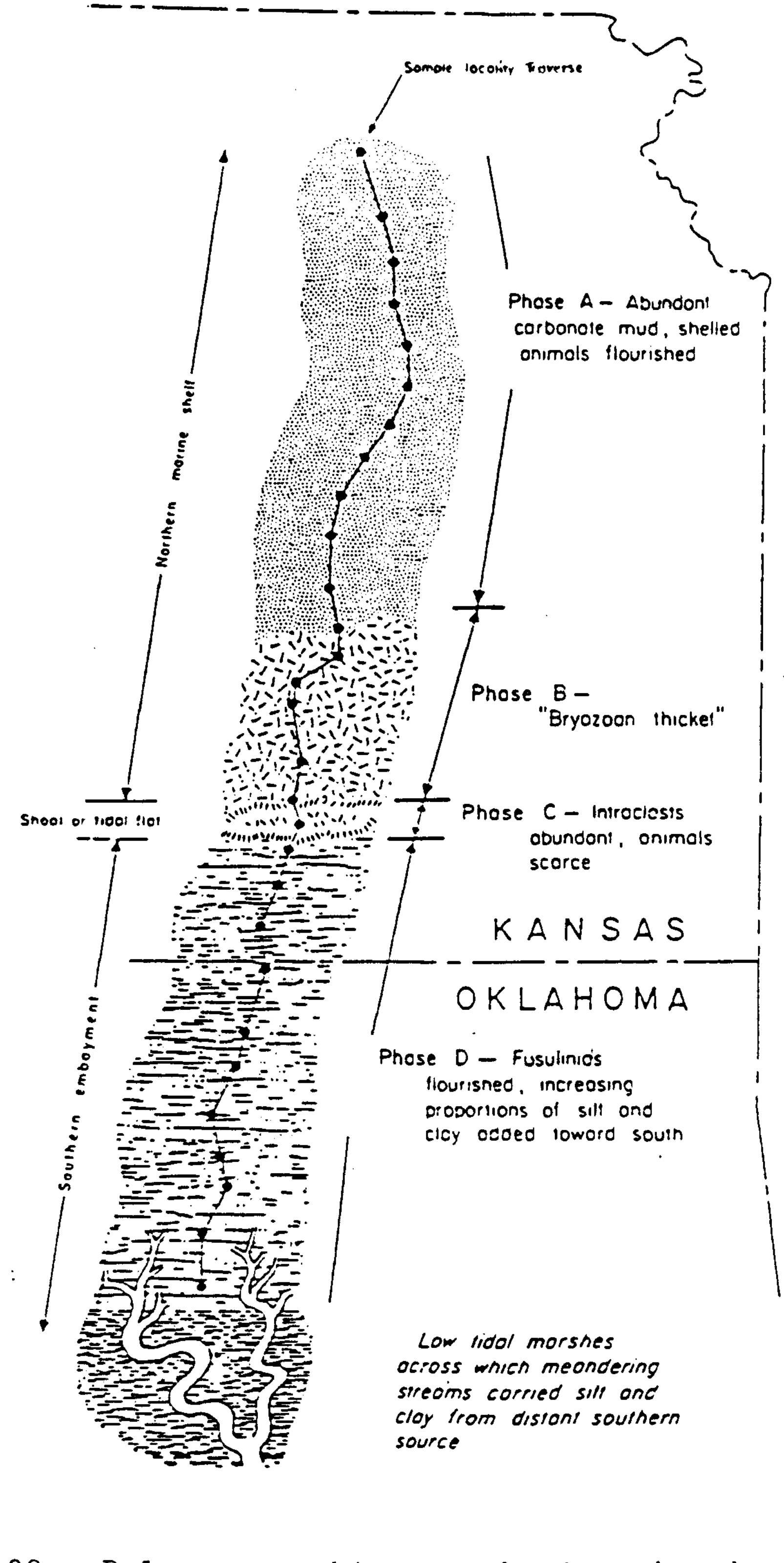


Figure 28. Paleogeographic map showing the phases of depositional environments of the upper Americus limestone bench (from Harbaugh and Demirmen, 1964).

typified by abundant "shelled" animals (i.e., brachiopods and pelecypods) and abundant carbonate mud; phase B, typified by bryozoans ("bryozoan thicket") and crinoids; phase C, a shoaling phase dominated by intraclasts; and phase D, a southern phase that is typically thicker and contains abundant fusulinids associated with increased silt and clay. They concluded that their northern phase A (coincident with the present area of study) represents a single depositional phase (or facies) of the upper Americus limestone bench, formed far from shore with little effect by waves and currents as indicated by the abundant carbonate mud. This study provides a slightly different interpretation for the same area. At least 3 different facies (gradational in nature, and consistently found across the area of study), rather than a single "phase", are represented in the upper Americus limestone bench: 1) an initial transgressive facies, representing more agitated conditions, is marked by the basal intraclast bearing facies; 2) a maximum transgressive facies that represents a more open, less agitated environment is marked by the fusulinid and brachiopod biofacies in the upper part of the Americus limestone; and 3) an initial regressive facies representing more restricted, less open conditions is indicated by the *Crurithyris* biofacies (e.g., Brezinski, 1983), superjacent to the fusulinid biofacies.

Sixth-order T-R unit F1.3.--Two paleogeographic maps were constructed for the maximum transgressive facies of

F1.3, to show variations in both lithofacies and biofacies (Figures 29 and 30). Both maps represent a return to shallowing conditions at a fifth-order scale, as F1.3 represents the upper regressive phase of the Americus fifth-order T-R unit.

Figure 29 is the lithofacies map of the transgressive apex of F1.3. Two lithofacies are distinguished in this map: 1) a sparry calcirudite lithofacies in the northeastern part of the study area; and 2) an argillaceous calcirudite - calcareous shale lithofacies in the southern, central, and western areas of study.

The sparry calcirudite lithofacies (Figure 29) is dominated by osagid grains, commonly in grain-to-grain contact. Consequently, sparry calcite cement is common throughout this lithofacies. The osagid-type grains are also occasionally supported by argillaceous, carbonate mud, thus resulting in a flaggy, and sometimes thin bedded appearance in the field. There is a mixture of fragmented and worn fossil allochems, as well as articulated brachiopods such as Wellerella and Neospirifer. This rock is poorly to moderately sorted, and reverse-graded bedding was occasionally observed. For example, at the Westmoreland (W) section the upper 0.10 m of the sparry calcirudite facies, shows a size grading of the osagid grains, from .35 mm (long diameter) near the base, to approximately 8.0 mm (long diameter) near the top (Appendix). Associated with the

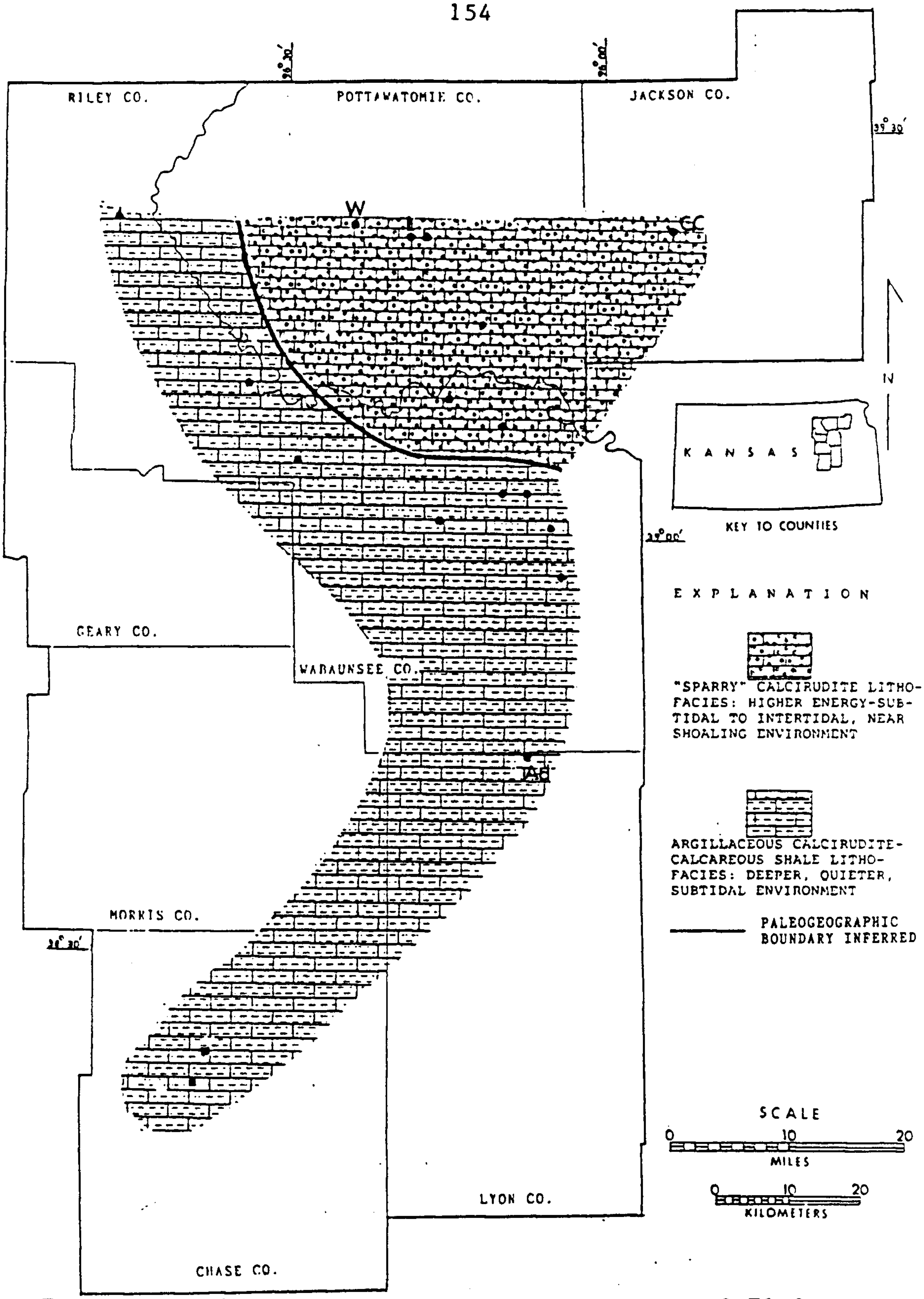


Figure 29. Paleogeographic lithofacies map of Fl.3 at maximum transgression. See text for discussion.

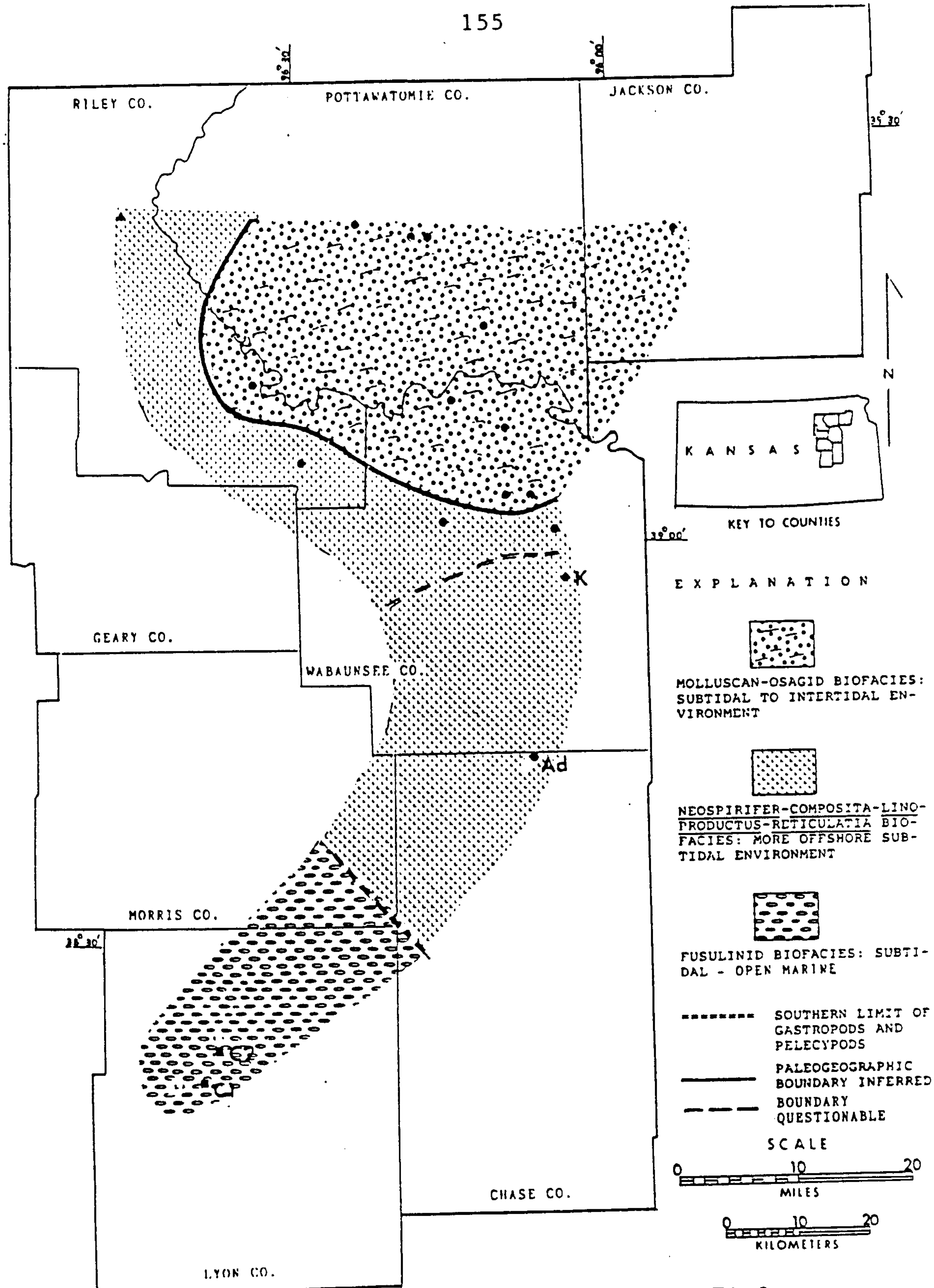


Figure 30. Paleogeographic biofacies map of F1.3 at maximum transgression. See text for discussion.

larger grains at the top is an increase in sparry calcite cement, suggesting an increase in current washing. Low angle, inclined bedding is rarely found in the sparry calcirudite facies and is usually accompanied by edgewise, bean-shaped, osagid grains, and other fossil fragments. Environmentally, the mixture of osagid grains, sparry calcite cement, and micritic mud is suggestive of a relatively shallow environment, that was intermittently agitated. Agitation was probably provided by both current oscillations and storms.

The sparry calcirudite lithofacies becomes silty and sandy (quartz) at the Crow Creek (CC) section, in the northeastern area of study. In the initial deepening phases of F1.3 (subjacent to and gradational with the sparry calcirudite facies) at the Crow Creek section (CC) are thin interbedded, sandy calcilutites (sparsely fossiliferous) and sandy calcareous shales. Symmetrical ripples occur on the upper bedding planes of the sandy calcilutite facies. The direction of current motion, perpendicular to the ripple axes, is north-30 degrees-east to south-30 degrees-west (Appendix). Shoaling or oscillation waves in a shallow water environment typically form oscillation ripples. The very thin interbedded shale that occurs in the sandy calcilutite lithofacies may be flaser bedding(?), but the minimal lateral exposure at the Crow Creek section makes this difficult to determine.

The argillaceous calcirudite - calcareous shale lithofacies (Figure 30) is so named because of the increasing amounts of clay, particulary to the south. For example, at the Admire (Ad) section the transgressive apex of F1.3 is essentially intermediate between a very calcareous shale and a very argillaceous calcirudite. The TA of the sections just south and west of the sparry calcirudite facies are represented by a very argillaceous (shaley), fine-grained calcirudite, compositionally referred to as a pelecypod, gastropod, bryozoan, crinoid, brachiopod biomicrite. Basally, at nearly all sections, in the initial net deepening phase, F1.3 is characterized by thin interbedded, Linoproductus-rich calcareous shales and micritic-calcirudites (wackestones to packstones).

The sparry calcirudite facies may have approached shoaling conditions (owing to the indicators of agitated waters aforementioned) relative to the argillaceous calcirudite - calcareous shale lithofacies to the south and west. Consequently the sparry calcirudite facies may reflect a well washed sediment bypass system. Allochthonous, siliciclastic, fine sediment was being transported across this facies seaward into more offshore waters of the argillaceous calcirudite -calcareous shale lithofacies to the south, southwest, and west.

The three maximum transgressive biofacies of F1.3 (Figure 30) are: 1) a molluscan-osagid biofacies in the northeastern area of study that corresponds to the sparry calcirudite lithofacies; 2) a Neospirifer-Composita-Linoproductus-Reticulatia biofacies that corresponds with the northern part of the argillaceous calcirudite - calcareous shale lithofacies; and 3) a fusulinid biofacies that corresponds to the southern part of the argillaceous calcirudite - calcareous shale lithofacies.

The molluscan-osagid biofacies is characterized by abundant osagid encrusted grains where fragments of molluscs, echinoderms, brachiopods, bryozoans, and dasyclad algae are coated with the foraminiferal consortium, Osagia incrustata, as recognized by Henbest (1963). The grains are evenly coated, creating a bean or kidney shaped coated grain (in the weathered outcrops) similar to those described in the Hughes Creek shale of southern Kansas by Twenhofel (1919), and in the upper Pennsylvanian Leavenworth limestone of eastern Kansas (Toomey, 1969, 1974).

Associated with the molluscan-osagid biofacies are bellerophontaceans, Straparollus, and other small gastropods (Pseudozygopleura?); as well as Aviculopecten, Edmondia, Pteronites, and other unidentified dimunitive mollusc fragments. The molluscs are commonly algal coated. Encrusting bryozoans are also characteristic of the molluscan-osagid biofacies, and commonly encrust brachiopods, pelecypods, echinoid spines, and other fossil fragments. Encrusting bryozoans do not occur south of the osagid-molluscan biofacies. Cuffey (1967) also found encrusting bryozoans (in the Wreford Formation) in his molluscan and osagid-bearing facies that were indicative of shallow, nearshore, and hypersaline environments.

Brachiopods such as Neospirifer, Wellerella, and Neochonetes exist within the molluscan-osagid biofacies. Where they are associated with the osagid grains without being encrusted, they occasionally show signs of wear, and commonly have acrothoracian borings. Accordingly, niches suitable to high level suspension feeders in a shallow, agitated environment must have existed in the molluscan-osagid biofacies, as evidenced by the diversity of molluscs, brachiopods, and bryozoans. The brachiopod taxa probably indicate that this facies was exposed to open marine circulation, but was probably shallower (topographically higher and more restricted) than the biofacies to the south (discussed below), owing to its dominant algal-molluscan content. Toomey (1969, 1974) attributed the association of a diverse biota with abundant osagid-type grains (in the Leavenworth limestone) to shallow marine conditions within the photic zone, on a slowly subsiding carbonate platform. It is also possible, that diverse osagid facies may represent topographically higher areas that are intermittently (seasonally?) exposed to open marine circulation.

To the west, southwest, and south of the molluscan-osagid biofacies their existed topographically lower(?), more open and stable marine conditions (Figure 30). This is represented by the Neospirifer-Composita-Linoproductus-Reticulatia biofacies. This biofacies is clearly associated with the argillaceous calcirudite - calcareous shale lithofacies (Figure 29). The biofacies is characterized by an increase in well preserved spiriferid, productid, and chonetid brachiopods. In some instances, these can be found in "life-position". Composita, Reticulatia (not found in the molluscan-osagid biofacies) and Neochonetes become increasingly more common to the south (e.g., Admire, Ad, and Keene, K, sections). Most characteristic of this facies is the marked decrease in Osagia and molluscs. In fact, the Keene (K) and Admire (Ad) sections contain no osagid encrusted grains, or molluscs. Where osagid-encrusted grains do occur, they do not completely envelop the fossil fragments. Commonly, the Osagia encrusts only the concave part of the brachiopod or pelecypod shells. This, in addition to the diversity of stenotopic individuals, is a positive indication of quieter, more stable marine conditions.

In the extreme southern part of the area (Figure 30), a fusulinid biofacies is discernible in the correlative part of Fl.3 at Garber's (1962) C1 and C2 sections (Appendix). Geographically, the fusulinid biofacies corresponds with the southern-most part of the argillaceous calcirudite - calcareous shale lithofacies, which suggests that the fusulinid biofacies may represent topographically lower, more offshore conditions. This is supported by the absence of molluscs, algae, and sparry calcite cement. The brachiopod and fusulinid biofacies were formed relative to a topographically higher, more agitated, shallower marine environment represented by the molluscan-osagid biofacies and sparry calcirudite lithofacies. In summary, this facies mosaic reflects a return to shallower, regressive conditions at a fifth-order scale. The regressive conditions restricted fusulinid and brachiopod development to the southwestern part of the area, in a more offshore position relative to the osagid-molluscan biofacies.

Sixth-order T-R unit F2.1.--The genetically correlative interval representing maximum transgression in F2.1 occurs in the lower half of the basal limestone in F2.1. Figure 31 represents the biofacies development at the time of maximum transgression. The lithofacies deposited during maximum transgression of F2.1 are remarkably similar throughout the area, and are generally glauconite-bearing, brachiopod, fusulinid biomicrites. Therefore, no lithofacies boundaries are shown on Figure 31.

Two boundaries have been tentatively drawn on Figure 34 to delineate the extent of the three main biofacies that developed in F2.1 during maximum transgression. The three biofacies are: 1) an osagid-brachiopod-*Isogramma* biofacies in the north and northeast part of the study area; 2) an

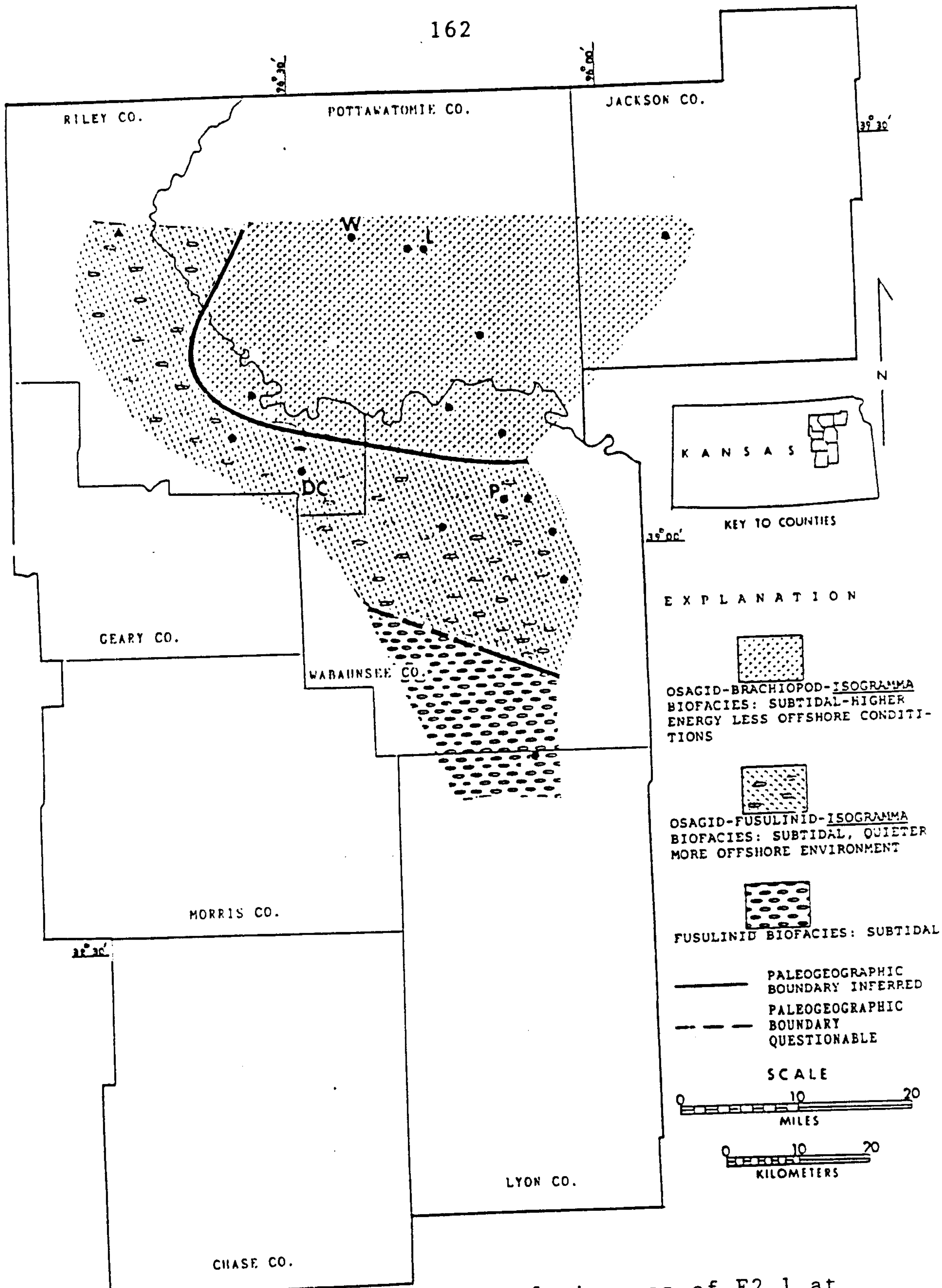


Figure 31. Paleogeographic biofacies map of F2.1 at maximum transgression. See text for discussion.

osagid-fusulinid-*Isogramma* biofacies to the south and west of the former biofacies; and 3) a fusulinid biofacies in southern Wabaunsee, and northern Lyon Counties. There is also an increase in fusulinid abundance, a decrease and eventual loss of osagid grains, and the loss of *Isogramma* from north to south across the area. The latter of these trends is tentative, because field control is lacking in the extreme southern part of the study area (i.e., Lyon and Chase Counties).

The osagid-brachiopod-*Isogramma* biofacies is characterized by an assortment of brachiopods such as *Neochonetes*, *Composita*, *Neospirifer*, *Linoproductus* and *Derbyia*, and also common osagid encrusted fragments. This biofacies also contains molluscs such as bellerophontaceans and other small gastropods, *Edmondia*, *Aviculopecten*, and *Wilkingia*. Fusulinids are rare in this biofacies.

The osagid-fusulinid-*Isogramma* biofacies is similar to the latter facies in brachiopod content but characteristically has rare osagid encrusted grains. Fusulinids are common throughout the limestone in F2.1, as well as upwards in the overlying *Crurithyris* biofacies at the top of F2.1. Pelecypods are less common in this biofacies.

Characteristic to the osagid-brachiopod-*Isogramma* and osagid-fusulinid-*Isogramma* biofacies is the punctate brachiopod *Isogramma*. Schmidt (1974) interpreted *Isogramma* as an opportunistic, sessile, epifaunal, high-level suspension feeder that may be related to the orthid or terebratulid brachiopods. As pointed out by Fritts (1980), its relatively large mantle area and wide hinge line was (probably) effectively adapted for harsher conditions (oxygen poor?) on a soft substrate. Isogramma has also been reported in the Rock Bluff Limestone Member of the Deer Creek Formation (Upper Pennsylvanian Series; Moore, 1964). Moore recognized a "Leavenworth-type Isogramma assemblage", but did not offer any paleoecological interpretation of Isogramma. In this study, Isogramma is considered as a brachiopod that preferred the shallower, less offshore conditions of the initial transgressive (F2.1) and net regressive phases (F2.4) of the Hughes Creek fifth-order T-R unit.

The southernmost biofacies of F2.1 (Figure 34) is dominated by fusulinids (e.g., Admire section, Ad; Appendix). No Isogramma or osagid grains were found in thin section or hand sample, and pelecypods are rare (none were found in thin section). At the Admire (Ad) section this facies contains a diverse biota including Neospirifer, Composita, Wellerella, Neochonetes, ostracodes, arenaceous foraminiferids, crinoids, and fenestrate bryozoans. Approximately 30% of the rock, by volume, are fusulinids.

The osagid-brachiopod-Isogramma biofacies and the osagid-fusulinid-Isogramma biofacies were deposited in relatively well lit, subtidal environments that were mildly agitated. This is based on their micritic matrix, relatively high diversities, and osagid grains. In the northeastern part of the area, waters were more agitated, and less open (shallower) to account for the increase in *Osagia*, and molluscs (Figure 31). Conditions were less agitated and relatively more open in the osagid-fusulinid-*Isogramma* biofacies, to account for the decrease in *Osagia* and molluscs. The fusulinid biofacies is considered the most open facies because it lacks osagid grains and a discrete molluscan biota.

Sixth-Order T-R Unit F2.2.--The sixth-order transgressive apex of F2.2 is characterized by a fusulinid - brachiopod biofacies (Figure 32). This biofacies occurs within the thin (0.15 m to 0.2 m), basal, laterally persistent, dark gray, calcareous shale lithofacies of F2.2 (Appendix). The fusulinid - brachiopod biofacies contains a "mixed" but diverse biota including brachiopods (most abundant), pelecypods (e.g., myalinids), bryozoans, echinoderms, and fusulinids (rare to common). The litho- and biofacies during the maximum transgression of F2.2 appear to be laterally persistent across the area, and therefore no lithofacies or biofacies changes are shown on Figure 35. The fusulinid-brachiopod biofacies of F2.2 also represents the transgressive apex of the Hughes Creek fifth-order T-R unit. Environmentally uniform open marine conditions prevailed across the area during this time.

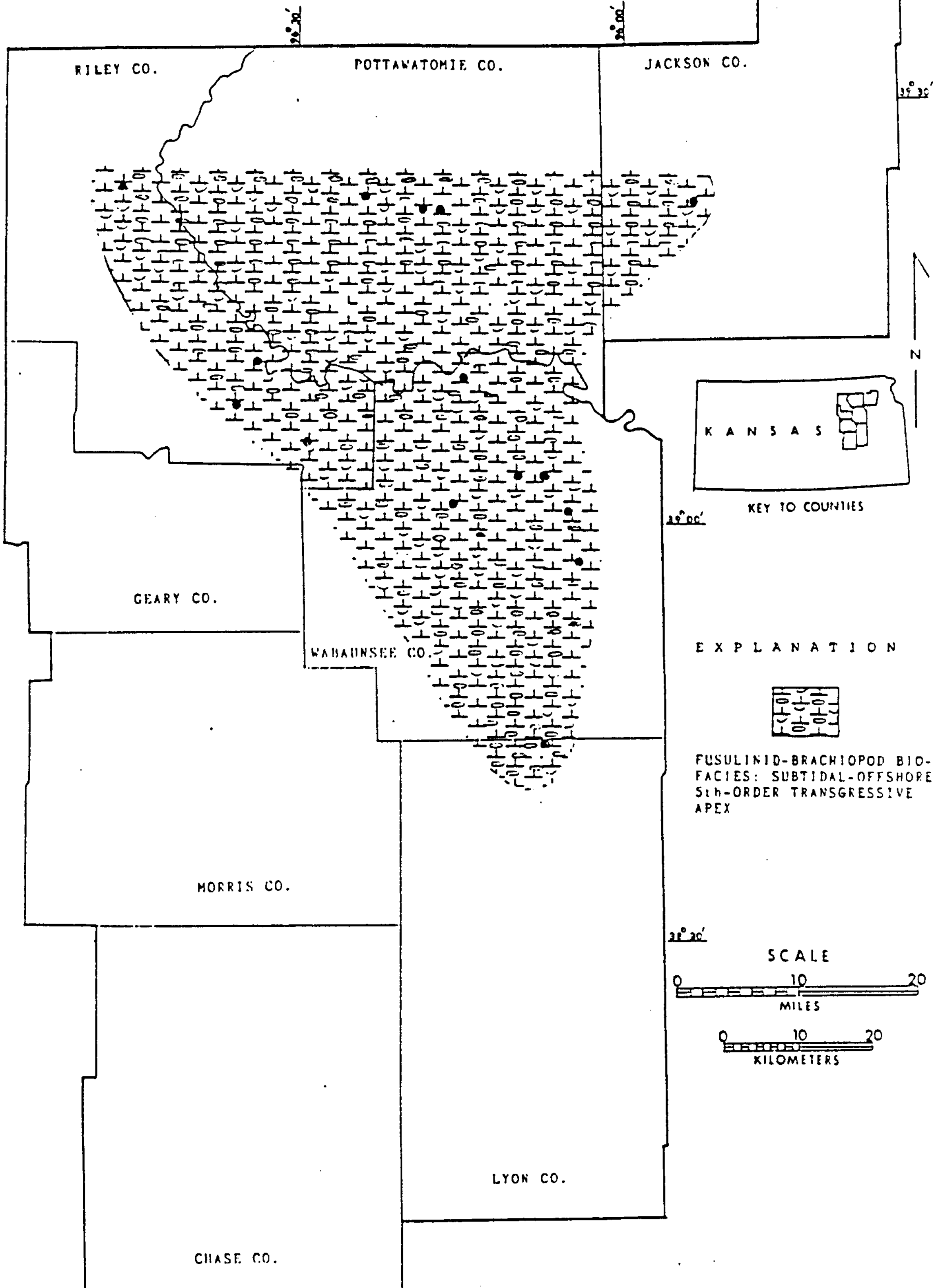


Figure 32. Paleogeographic biofacies map of F2.2 at maximum transgression. See text for discussion.

Sixth-order T-R unit F2.3.--The transgressive apex of sixth-order T-R unit F2.3 is represented by a laterally persistent fusulinid biofacies across the study area (Figure 33). This biofacies marks the only laterally persistent, massive accumulation of fusulinids in the Hughes Creek fifth-order T-R unit (of this study area). The fusulinid biofacies contains lesser amounts of other marine taxa such as ramose bryozoans, crinoids, and brachiopods. Brachiopods within this biofacies include well preserved, articulated Composita, Neospirifer, Reticulatia, Neochonetes, Wellerella, Hustedia, and Linoproductus. The lithofacies representing the TA of F2.3 is intermediate between a very calcareous shale, and a very argillaceous, fine-grained calcirudite (wackestone to packstone). Environmentally, open marine and relatively quiet conditions conducive to siliciclastic and carbonate mud deposition prevailed across the area.

The fusulinid biofacies of F2.3 extends into Chase County, and includes Garber's sections C1 and C2 (Figure 33). His descriptions of these sections do not reveal sixth-order T-R unit F2.3, but the interval in which it should occur is essentially fusulinid-rich.

Sixth-order T-R unit F2.4.--The transgressive apex of F2.4 represents a part of the upper net regressive sequence of the Hughes Creek fifth-order T-R unit. The TA of F2.4 indicates a return to a less open, molluscan-dominated facies mosaic, similar to that seen in the upper regressive phase of

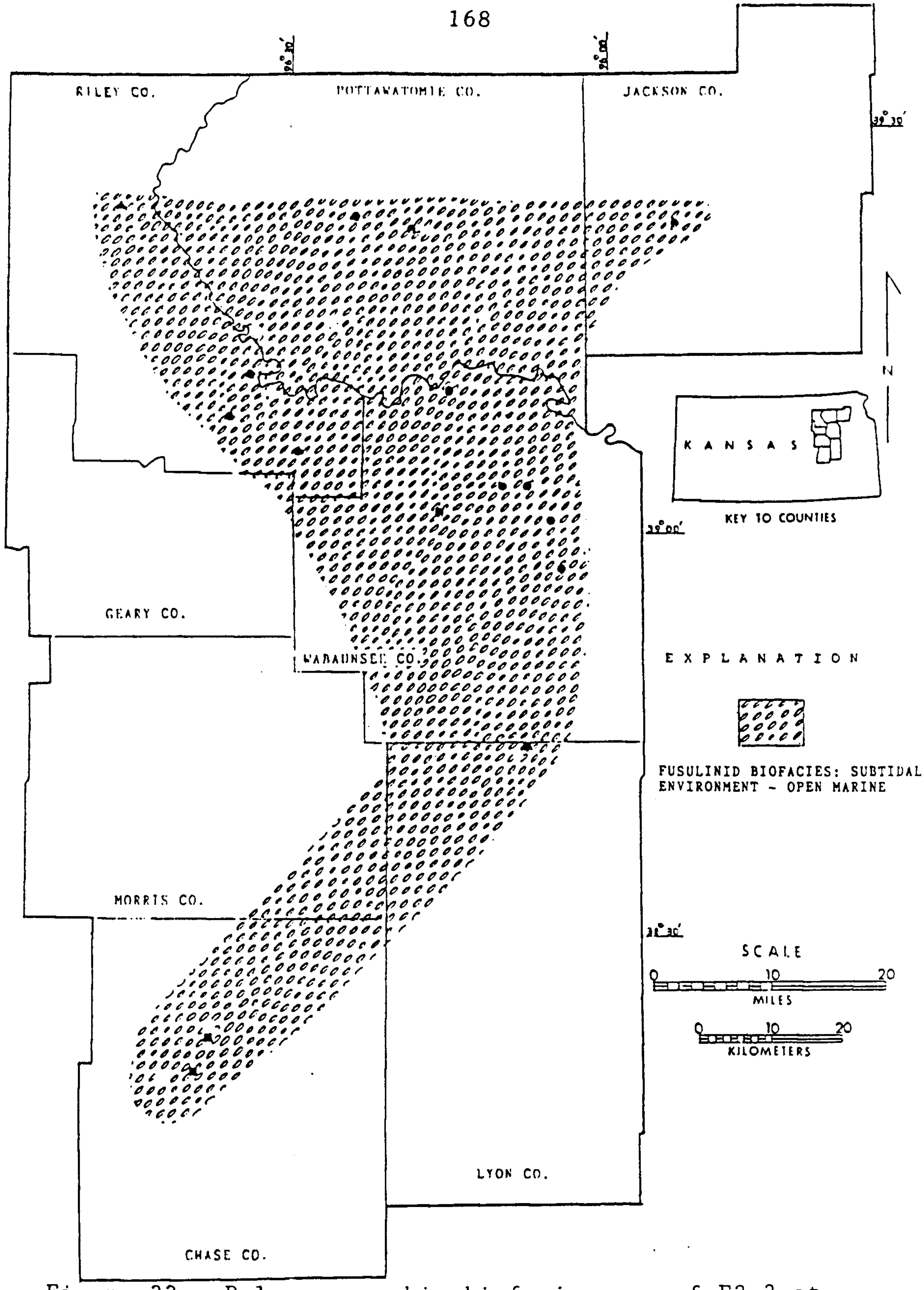


Figure 33. Paleogeographic biofacies map of F2.3 at maximum transgression. See text for discussion.

the Americus fifth-order T-R unit (F1.3). Niches suitable to gastropods, pelecypods, echinoderms, Osagia, and rarely brachiopods (Crurithyris, Hystriculina, Composita and inarticulates) were present across the area, and no lateral differentiation of biofacies was possible.

Two boundaries have been drawn on Figure 34 to delineate the extent of the three main lithofacies that developed in F2.4 during maximum transgression. The three lithofacies are: 1) an argillaceous mudstone-wackestone lithofacies in the southern and western parts of the study area; 2) a wackestone-packstone lithofacies in the central part of the area; and 3) a stromatolitic(?) lithofacies (boundstone?) in the northeastern part of the area. The three lithofacies are texturally and compositionally differentiated by an increase in argillaceous content, a decrease in Osagia, and a decrease in comminuted shell debris, accompanied by better preserved articulated pelecypods going from north (northwest) to south (southwest) across the area.

The argillaceous mudstone-wackestone lithofacies is distinct because of its argillaceous content. Thin interbedded, slightly fossiliferous (e.g., Hystriculina) shale lentils, and "flaser-like" shale "whisps" are common in this lithofacies. Osagid encrusted grains are rare to common. At the Admire (Ad) section osagid grains are absent.

The wackestone-packstone lithofacies is characterized by

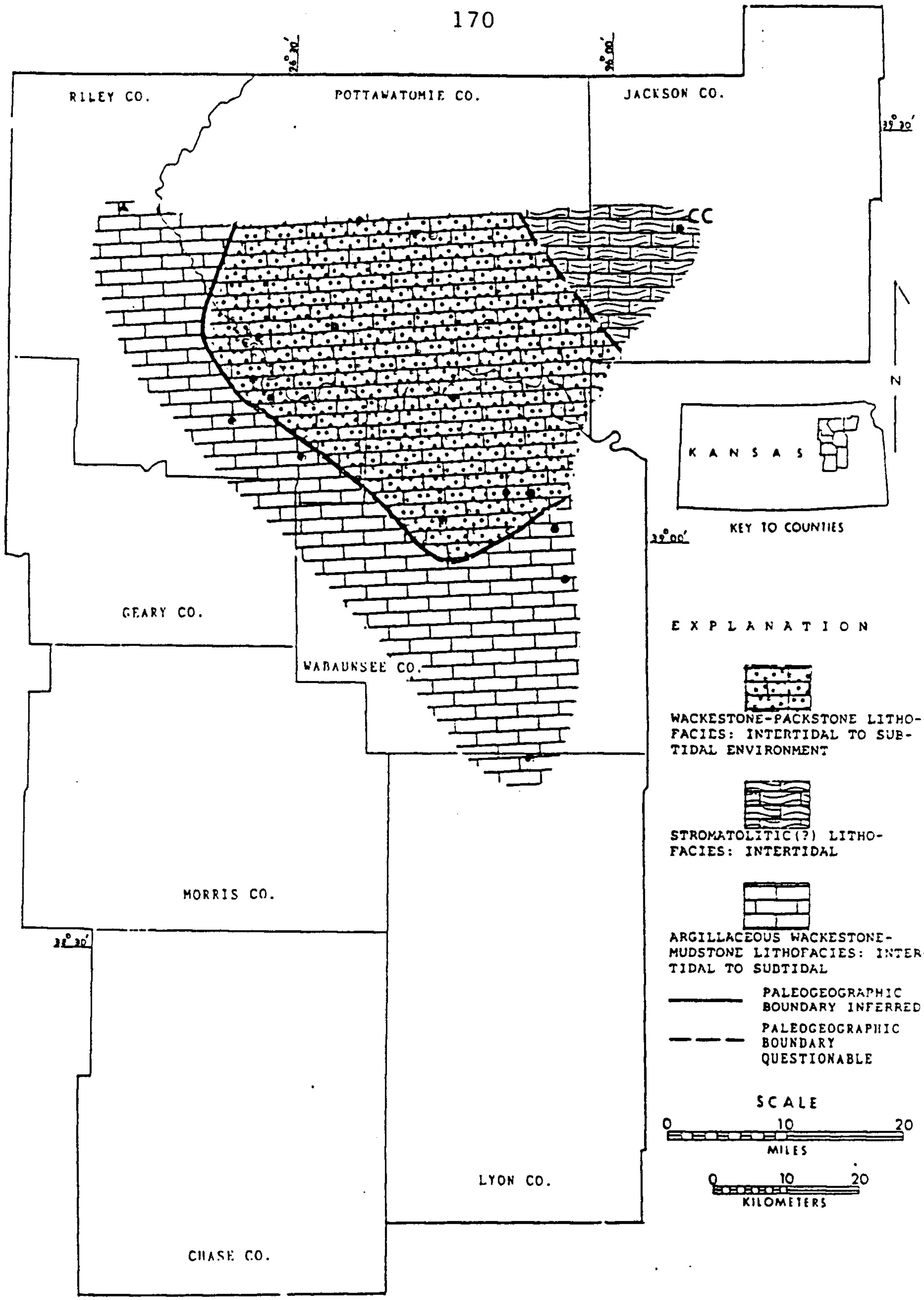


Figure 34. Paleogeographic lithofacies map of F2.4 at maximum transgression. See text for discussion.

molluscs, and osagid encrusted, comminuted fossil debris. The increased osagid content and comminuted shell debris of this lithofacies suggests deposition in a shallower, more agitated enviroment. The mudstone-wackestone facies (to the south) was deposited in a quieter, less agitated environment that lacked Osagia.

Data for the northeastern stromatolitic lithofacies was obtained from Mudge and Yochelson's (1962) field descriptions of the Crow Creek (CC) section (Appendix). Mudge and Yochelson (1962) described stromatolitic encrusted fossil fragments in the genetically correlative TA of F2.4. Whether or not their stromatolitic facies is Ottonosia (a stromatolitic-like form genus of Osagia; Henbest, 1963) is unclear, because this part of the Crow Creek section is presently concealed. Stromatolitic structures are not present in any of the other sections exposing this interval. Thus, the northeastern part of the study area is designated as a possible (and questionable) stromatolitic lithofacies, indicative of intertidal mudflat conditions.

Sixth-order T-R unit F3.1.--The transgressive apex of F3.1 could not be differentiated lithologically or paleoecologically. Rather, the initial regressive deposits of F3.1 were used to illustrate a discernible variation in facies (Figure 35). The transgressive apex of F3.1, at all localities where it is exposed, is a fusulinid-brachiopod biofacies commonly occurring in the basal part of F3.1. The

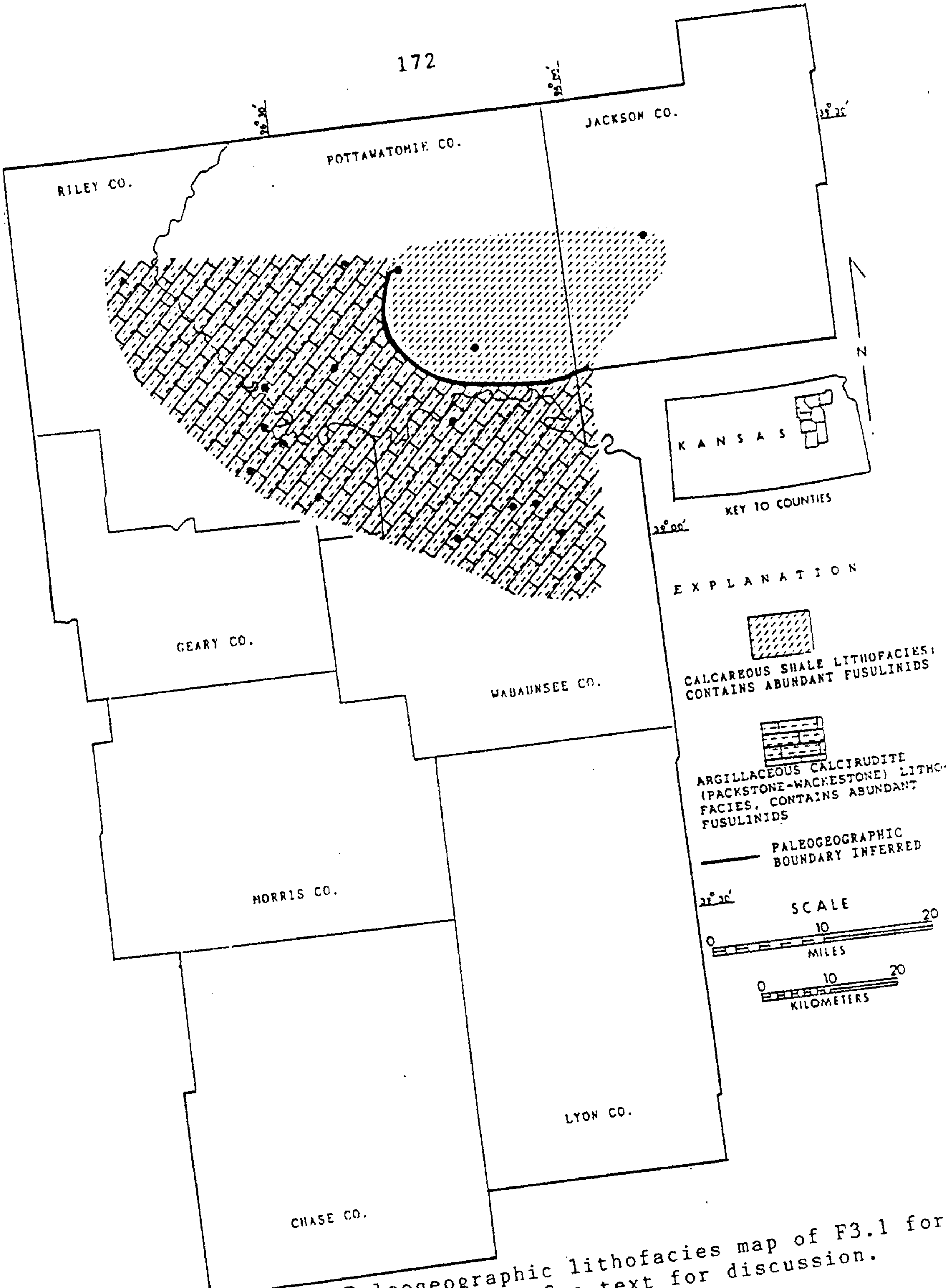


Figure 35. Paleogeographic lithofacies map of F3.1 for initial regression. See text for discussion.

fusulinid-brachiopod biofacies is characterized by well preserved *Composita*, *Neospirifer*, *Hystriculina*, *Neochonetes*, *Lophophyllidium*, bryozoans, and crinoids. Fusulinids are rare at the base, and become common to abundant toward the top of the biofacies. Lithologically, the transgressive apex is intermediate between a very calcareous shale and a very argillaceous, fine-grained calcirudite (packstone to wackestone) throughout the area.

Overlying the fusulinid-brachiopod biofacies, at all localities, are the initial regressive deposits of F3.1. This interval is marked by a massive (but relatively thin) fusulinid biofacies. The fusulinid biofacies occurs throughout the study area, but the lithology containing this biofacies is variable. Lithologically, the area at the time of initial regression can be divided into a fusulinid-rich, calcareous shale lithofacies in the northeast, and a fusulinid-rich packstone (calcirudite) lithofacies to the west, southwest, and south of the former lithofacies (Figure 35). The fusulinid-rich packstone lithofacies probably represents higher energy conditions, conducive to algal binding, in a topographically higher position. The fusulinid-rich, calcareous shale lithofacies probably represents quieter (more restrictive lagoonal) conditions, in a topographically lower position, because of the siliciclastic mud.

Sixth-Order T-R Unit F3.2.--No paleogeographic boundaries were detected in the initial transgressive or maximum transgressive facies of sixth-order T-R unit F3.2. The initial transgressive facies are massive, fusulinid-rich biofacies (analogous to Moore's, 1964, Tarkio type, Triticites assemblage). The fauna is composed almost entirely of fusulinids (and lesser brachiopods and crinoids) that thrived on a very calcareous, mud substrate throughout the area. Maximum transgressive conditions of F3.2 resulted in the replacement of the transgressive (opportunistic) fusulinid biofacies with a fusulinid-bearing, brachiopod-rich biofacies (i.e., the "brachiopod epibole"; Figure 36). This biofacies is equally uniform in its diversity at all sections exposing the TA of F3.2 (e.g., Figure 20c, base of unit 27, and Figure 22c, unit 28). The fusulinid-bearing, brachiopod biofacies also represents the transgressive apex of the Long Creek fifth-order T-R unit, and the Foraker fourth-order T-R unit. The brachiopod epibole is concentrated in a relatively thin zone (averaging 0.15 m to 0.20 m) across the area, so sedimentation rates were probably at a minimum (i.e., near diastemic conditions may have existed during the TA of F3.2). The TA of F3.2 is concealed at the Allen (Al) and Admire (Ad) sections in northern Lyon County, and is not distinguishable at Garber's (1962) C1 and C2 sections (Appendix). Therefore this facies is not shown south of the Keene (K) section (Figure 36).

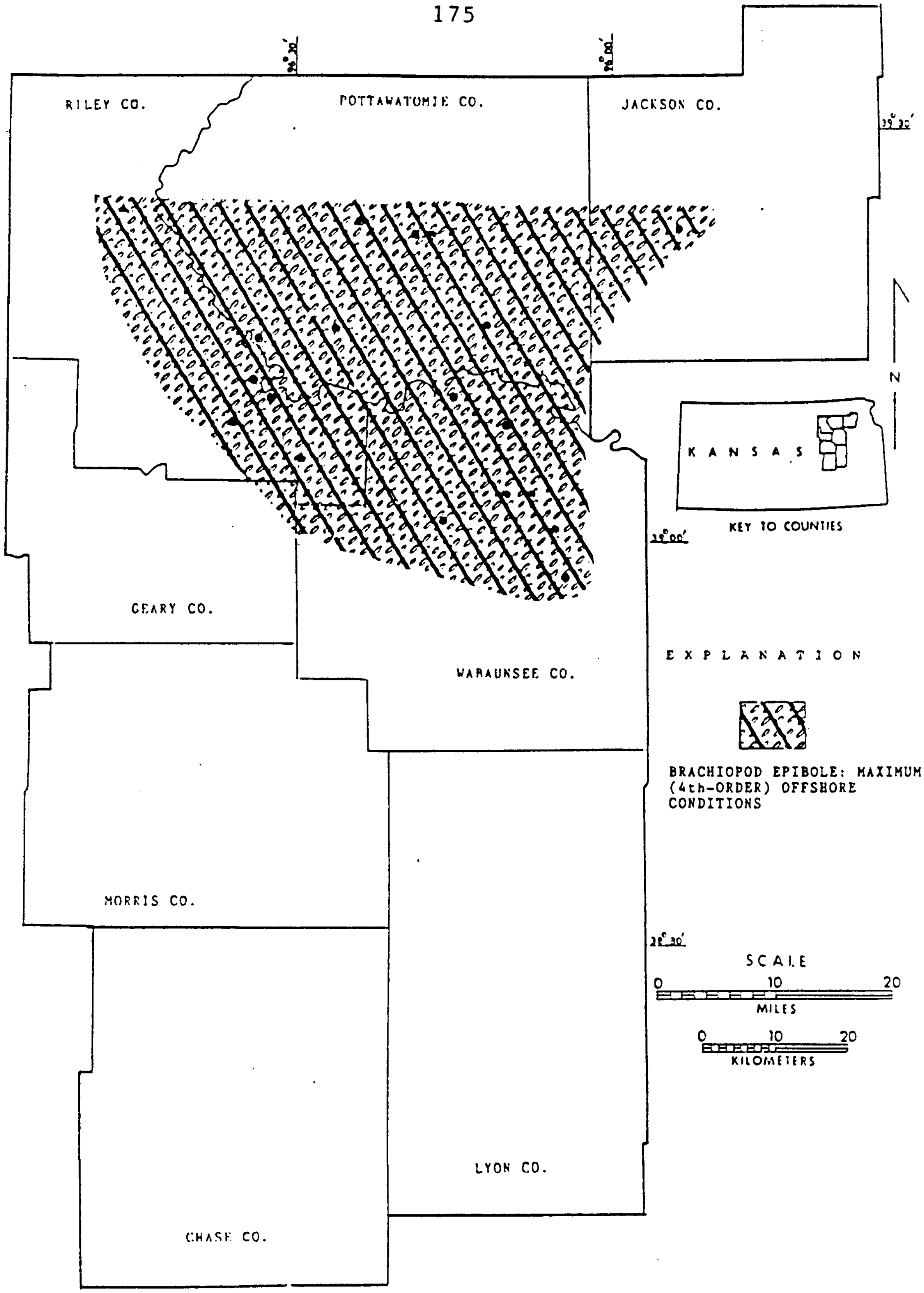


Figure 36. Paleogeographic biofacies map of F3.2 at maximum transgression. See text for discussion.

Interpretation of Isopach Maps

Isopach maps are used in conjunction with the paleogeographic maps and stratigraphic cross-sections to aid in understanding the paleoceanographic history of the Foraker Formation. It will be shown that sixth-order isopach maps support the validity of the paleogeographic interpretations of the Foraker Formation. On the isopach maps the letters A,B,C denote spatially recurring highs (isopach thins), and the letters W,X,Y,Z denote spatially recurring lows (isopach thicks). These highs (thins) and lows (thicks) were initially recognized in the isopach map of F1.1 (Figure 37).

Sixth-Order T-R Unit F1.1.--The isopach map of sixth-order T-R unit F1.1 (Figure 37) depicts three areas of deposition that coincide with the paleogeographic map of F1.1 (Figure 25). The first area is conspicuous in that it contains thin isopachous closures in southern Pottawatomie (A) and northern Wabaunsee County (B and C). This area corresponds to the shoaling molluscan-algal packstone facies of F1.1. The thin isolated nature of the F1.1 sediments in this area can be attributed to a lack of shale deposition during transgression over a topographic high (see Figures 25, 26). The general trend of isopachous lines suggests a northwest to southeast trend of this high. Slight anomalous thickenings within this same area (e.g., X in the northern portion of Wabaunsee County) may be suggestive of less

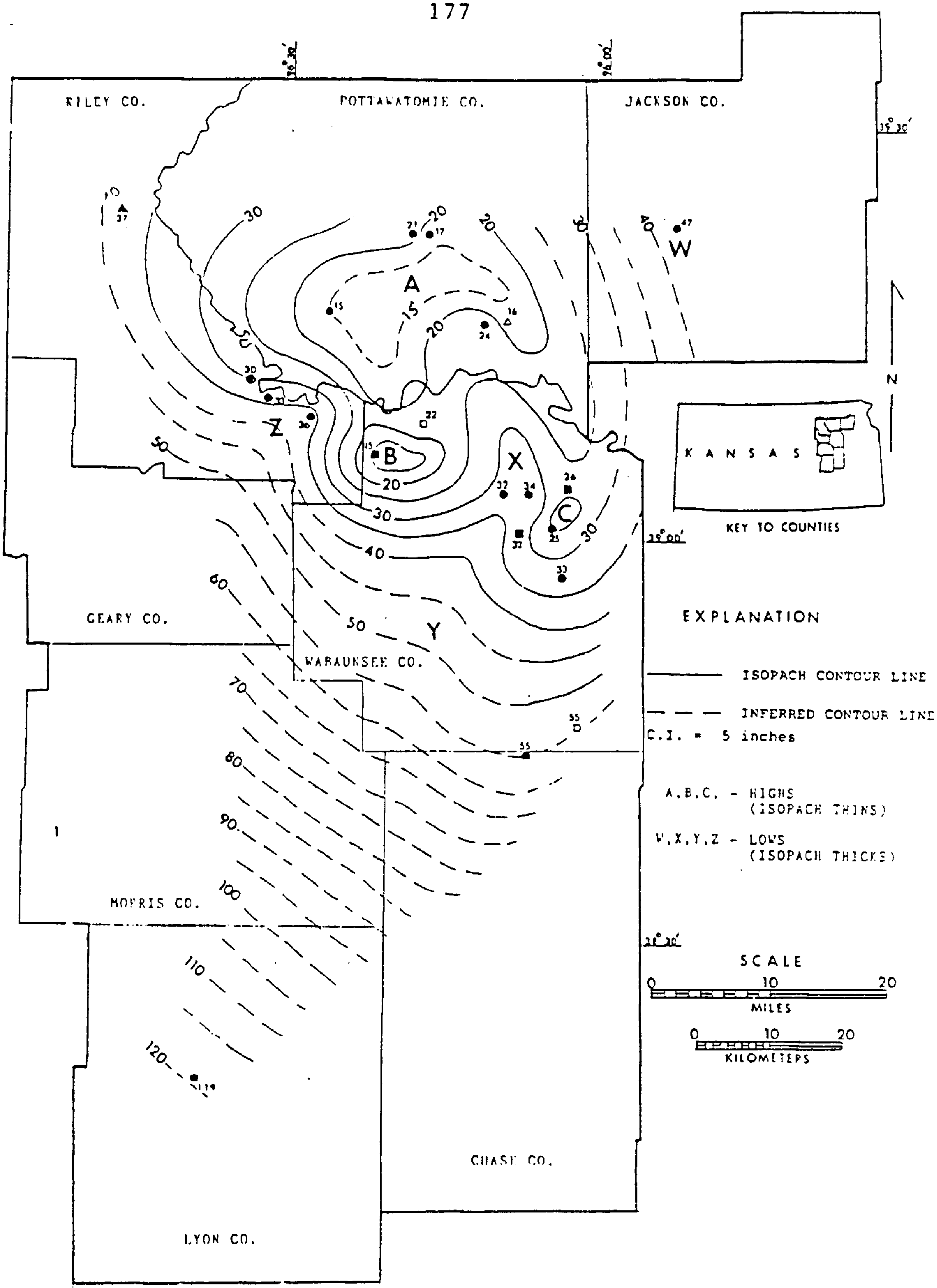


Figure 37. Isopach map, in inches, of Fl.1.
See text for discussion.

agitated, "ponded" areas within the overall topographic high, where shale accumulated.

A second area is represented by an overall thickening of Fl.1 sediments to the west, southwest, and south of the thin isopachous closures (A,B,C). This is illustrated by the closeness of isopach lines in southern Wabaunsee County, northern Lyon County (Y), and southeastern Riley County (Z). These areas correspond to topographically lower (Y and Z), deeper marine areas where thicker sequences of siliciclastic and carbonate muds were being deposited. The thicker part of Fl.1 geographically corresponds to the brachiopod-bearing calcareous shale lithofacies of Fl.1 (Figure 25), and to Fishers' (1980) basinal shale lithofacies (Figure 26).

A third area represents the thickening trend towards the Crow Creek section (CC) in Jackson County. This trend (W) corresponds to the quieter marine conditions of the mudflat environment (Figure 25), where stromatolitic facies are absent. Fisher's (1980) lagoonal and mudflat facies in northeastern Pottawatomie and eastern Jackson Counties (Figure 26) also coincide with this thickening trend (W). Cross-section C-C' shows subtle thinning of Fl.1 sediments across the north-central part of the study area (central Pottawatomie County). Concomitant thickening toward the Amoco #1 Hargrave core (C) to the west, and Crow Creek section (CC) to the east coincides with the absence of stromatolitic facies at these localities.

Sixth-Order T-R Unit F1.2.--The isopach map of sixth-order T-R unit F1.2 (Figure 38), in general, shows a reversal of thickening-thinning trends when compared to the isopach of F1.1 (Figure 37). Exceptions to this are the recurrent thickening trends of W, X and Z, and the thinning trend of C. In eastern Riley, all of Pottawatomie, western Jackson, and northern Wabaunsee Counties the sediments are the thickest and the trends most uniform. South of northern Wabaunsee County the contour lines show a distinct thinning of F1.2 sediments, just the opposite of what is seen on the F1.1 isopach (except at C and X; cross-section A-A').

The basal lithofacies of F1.2 is the Lower Americus limestone bench. It is essentially uniform in thickness throughout the study area (e.g., Harbaugh and Demirmen, 1964; Mudge and Yochelson, 1962; and this study, Appendix). Thus, it is the thickness of the regressive shale sequence in F1.2 that is controlling the general isopach trends in Figure 41. During aggradation/progradation of F1.2, sediment input and accumulation was greatest in the northern regions of the study area, even over the topographic "high" represented by the shoaling facies of F1.1. Lithologically, the regressive shales in the northern part of the study area (e.g., Amoco #1 Hargrave core, C, Westmoreland, W, Louisville, L, Louisville east, LE, and the Crow Creek sections, CC) contain thin (2 to 4 cm), interbedded, non-fossiliferous, shaley siltstones and sandy (very fine quartz) shales. These silty-sandy interbeds

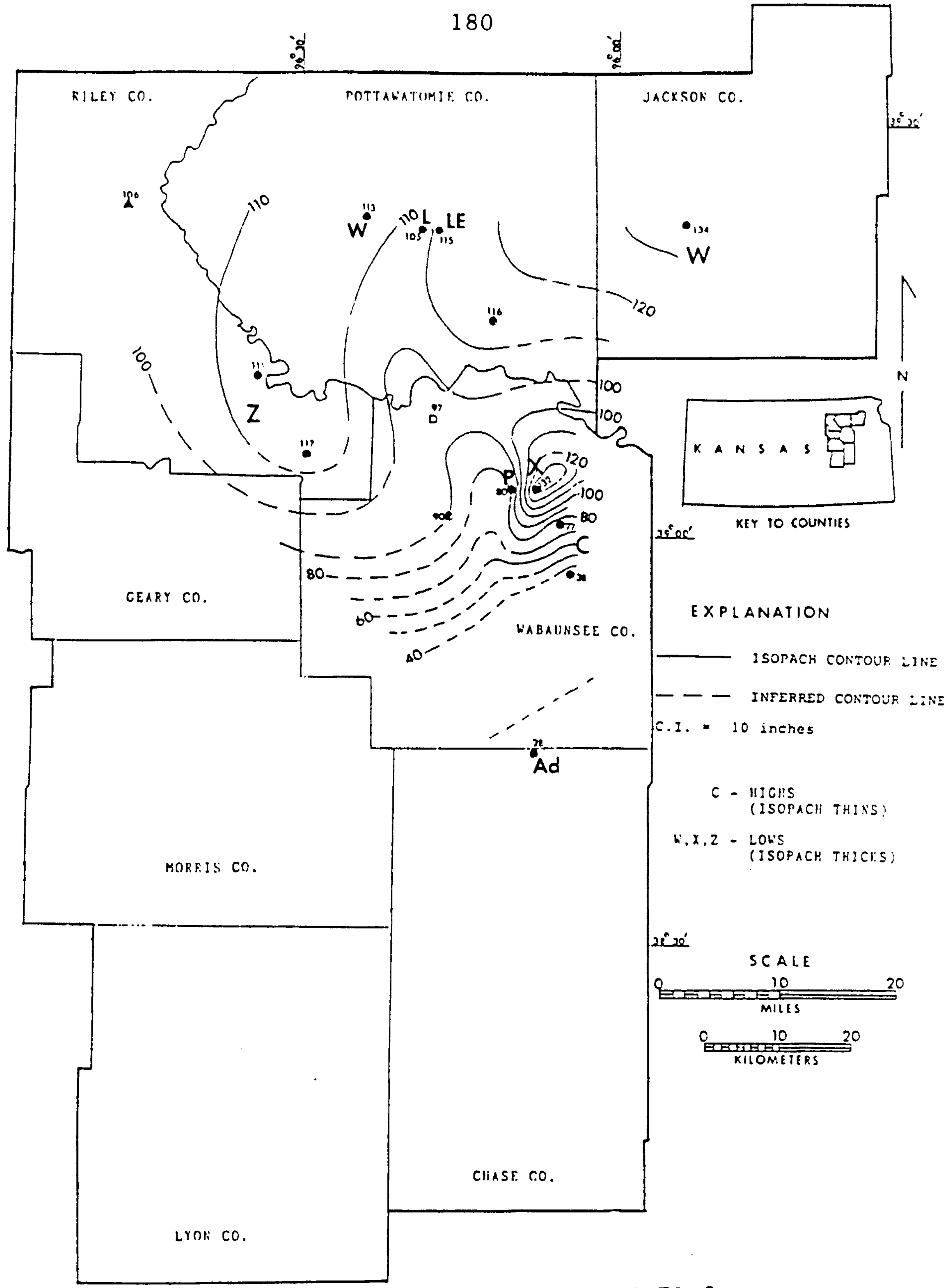


Figure 38. Isopach map, in inches, of F1.2.
See text for discussion.

are virtually nonexistant at the Paxico and Admire sections, between which the regressive shale of F1.2 thins discernibly (Figure 38). The texturally coarser and "thicker" shale was probably deposited in more intermittently agitated waters (more proximal to the source of the sediments), in the northern regions of the study area. The finer clay was deposited as a thinner sequence to the south.

Sixth-Order T-R Unit F1.3.--The isopach map of F1.3 (Figure 39) shows another reversal of thickening-thinning trends relative to the isopach map of F1.2 (Figure 38; cross-sections A-A', B-B'). The recurrent thinning trends of A,B, and C, however, are present as are the thickening trends of Y and W. The thickening trends of Z and X are absent. The isopach map (Figure 39) of F1.3 shows that rocks thin in a northwest-southeast trend (e.g, A, C respectively), coinciding with the shallower "sparry" calcirudite and molluscan-osagid facies of F1.3 (e.g., Figures 29 & 30). These facies developed over the thickest part of the underlying sixth-order T-R unit, F1.2 (i.e., in the northern part of the study area; cross-section A-A'). Development of osagid bearing rocks in this area reflects the shallowing to shoaling conditions over a topographic high.

A thickening trend of F1.3 to the south-southeast (Y) (Figure 39) corresponds with the deeper marine, calcareous shale lithofacies (Neospirifer-Composita-Linoproductus-Reticulatia biofacies). Thickening of F1.3 to the northeast

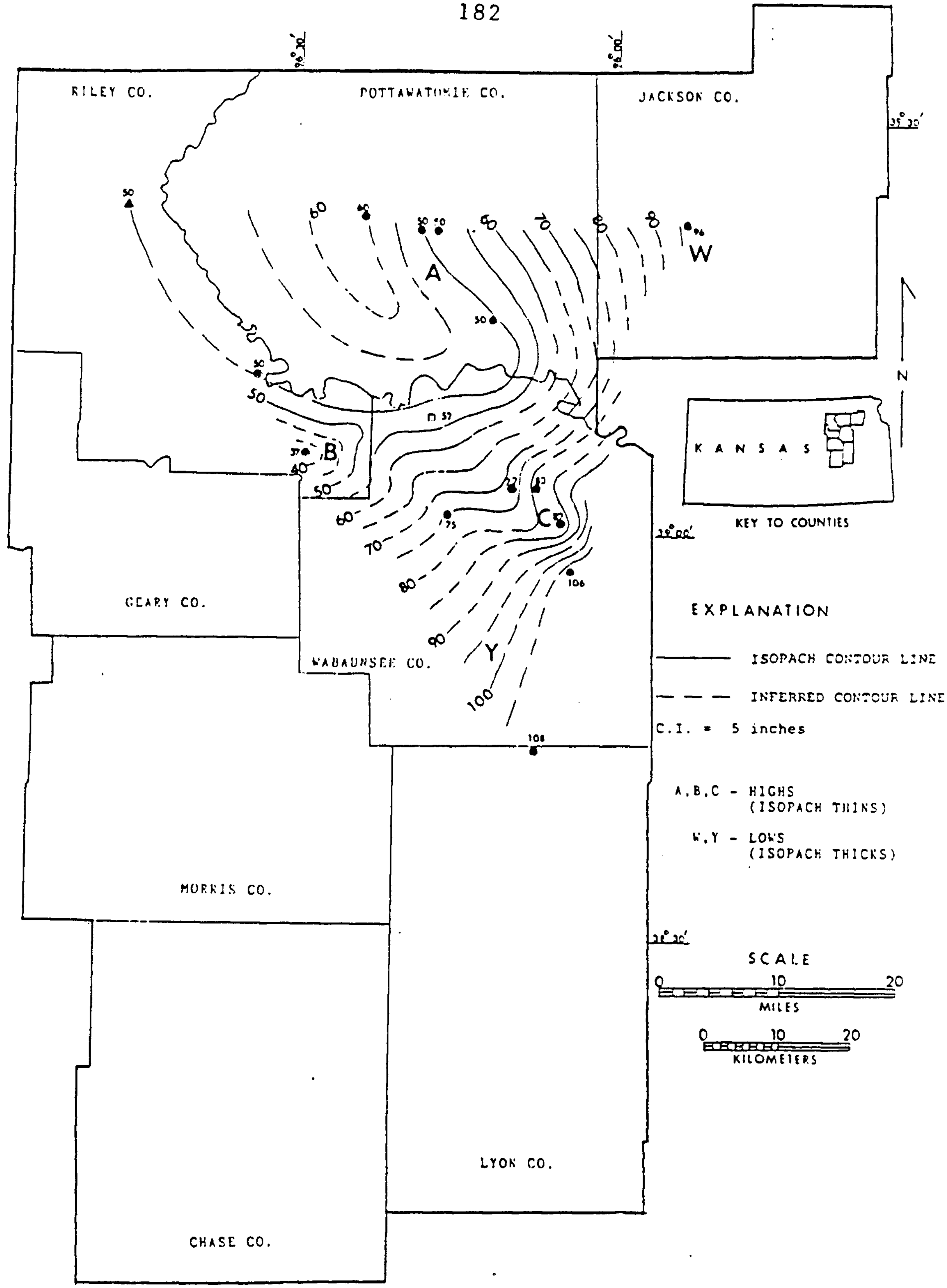


Figure 39. Isopach map, in inches, of Fl.3. See text for discussion.

(area W) coincides with the increase in thin interbedded, finer carbonate (i.e., calcilutite versus calcirudite) fractions and the concomitant coarser siliciclastics (quartz sand) of the transgressive phase of F1.3, at the Crow Creek (CC) section. Therefore the deposition of sixth-order T-R unit F1.3 at the Crow Creek (CC) section probably occurred in a shoreward position, more proximal to coarser siliciclastic accumulation.

The depositional pattern of F1.3 is similar to that seen in the initial transgressive phase of F1.1. The thicker deposits of F1.1 and F1.3 accumulated in a slightly deeper, topographically lower environment to the south (Y), southwest (Z), and also northeast (W). On the other hand, massive silty shales of F1.2 were deposited to the north, as part of an aggradational/progradational sequence. Therefore a sort of "see-saw" stratigraphic pattern (see cross-section A-A', Appendix) is recognized when integrating the paleogeographic, stratigraphic cross-section, and isopach data for the Americus fifth-order T-R unit.

Sixth-Order T-R Units F2.1 and F2.2.--The isopach maps of sixth-order T-R units F2.1 and F2.2 (Figures 40 and 41), both illustrate relatively uniform thicknesses throughout the study area. This signifies their retrogradational-transgressive nature in which regressive (progradational) shales are very thin or absent. Recurrent thinning trends (A,C in F2.1, and A,B in F2.2) and thickening trends (X,Y,Z

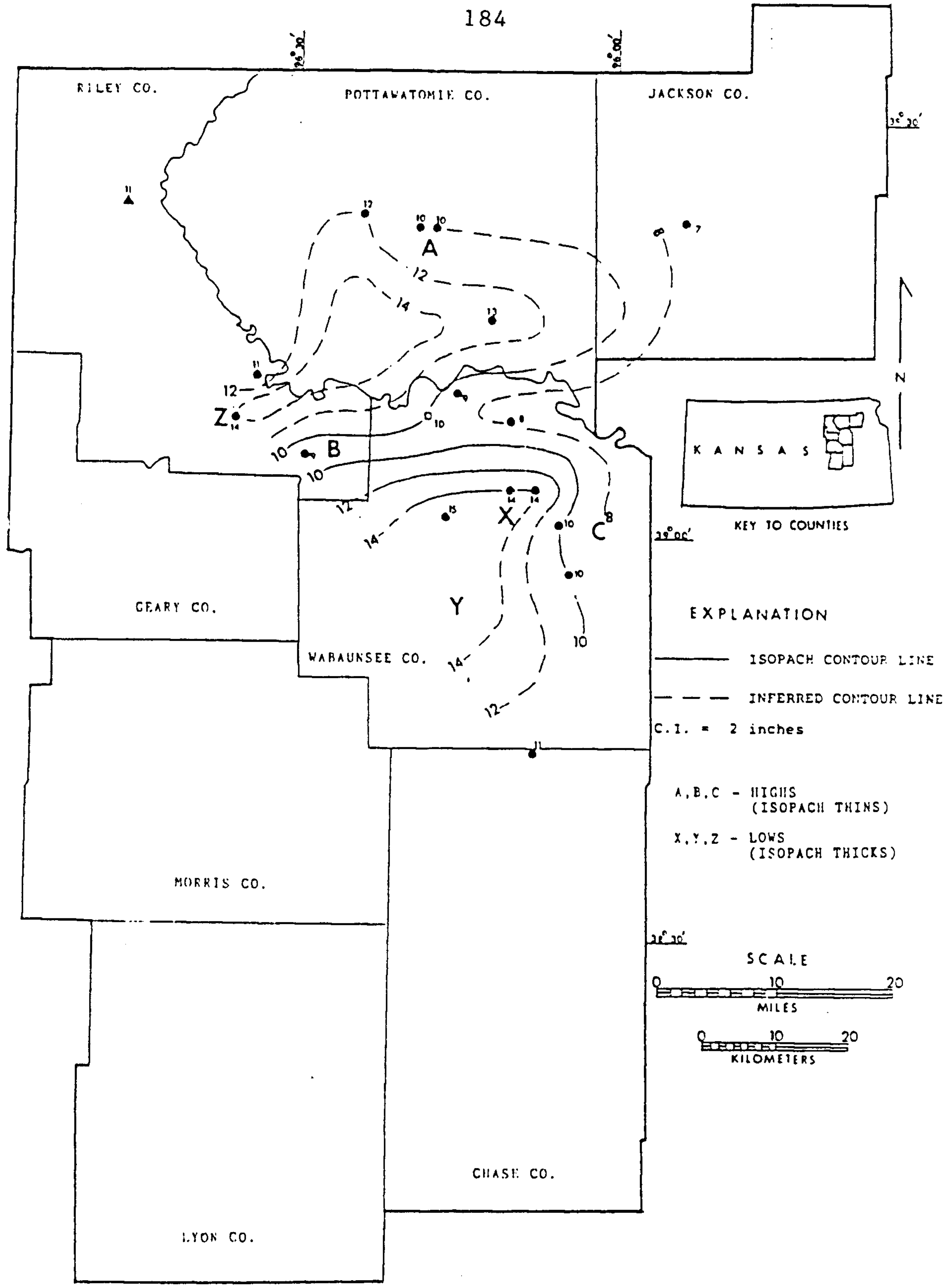


Figure 40. Isopach map, in inches, of F2.1.
See text for discussion.

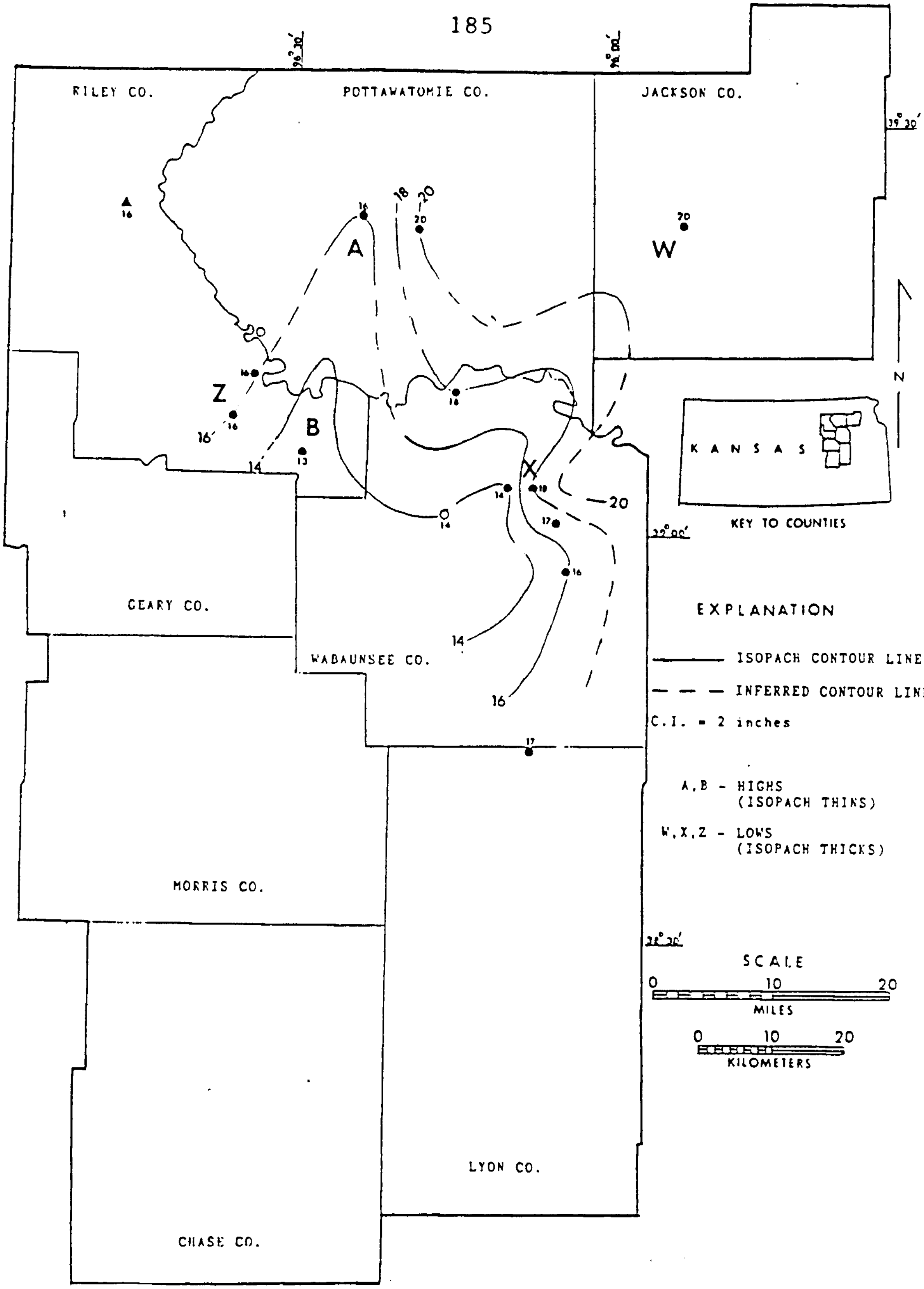


Figure 41. Isopach map, in inches, of F2.2.
See text for discussion.

in F2.1, and X,B in F2.2) however, still exist.

The shallow marine osagid-brachiopod-*Isogramma* biofacies of F2.1 (Figure 31) lies in the same area as the topographically high, molluscan-osagid biofacies of F1.3. (Figure 30). The isopach of F2.1 (Figure 40) does show a slight thickening of limestone in southern Pottawatomie County. This may have resulted from increased algal-osagid production because of a shallower, more agitated environment of deposition (over a topographic high).

The isopach map of F2.2 reflects only very subtle topographic changes. Thick areas existed mainly in the eastern part of the study area (e.g., W,X), and thin areas occurred west of these lows. The subtle thicks and thins essentially had no direct affect on the formation of the fusulinid-brachiopod biofacies (Figure 32) of F2.2. The relative lateral uniformity of F2.2 reflects a maximum transgression that occurred at a fifth-order scale.

Sixth-Order T-R Unit F2.3.--The isopach map of sixth-order T-R unit F2.3 (Figure 42) shows a slightly different isopach pattern, than those of F2.1 (Figure 40) and F2.2 (Figure 41). The thicknesses of F2.3 are much more variable, but the thinning trends (A,B,C) and thickening trends (X,Y,Z) are still present. The W (low) thick trend is absent.

The isopach of F2.3 (Figure 42) shows an overall thinning trend southward. The northeast-southwest trending "thin" in the central part of the map is a linear trend that

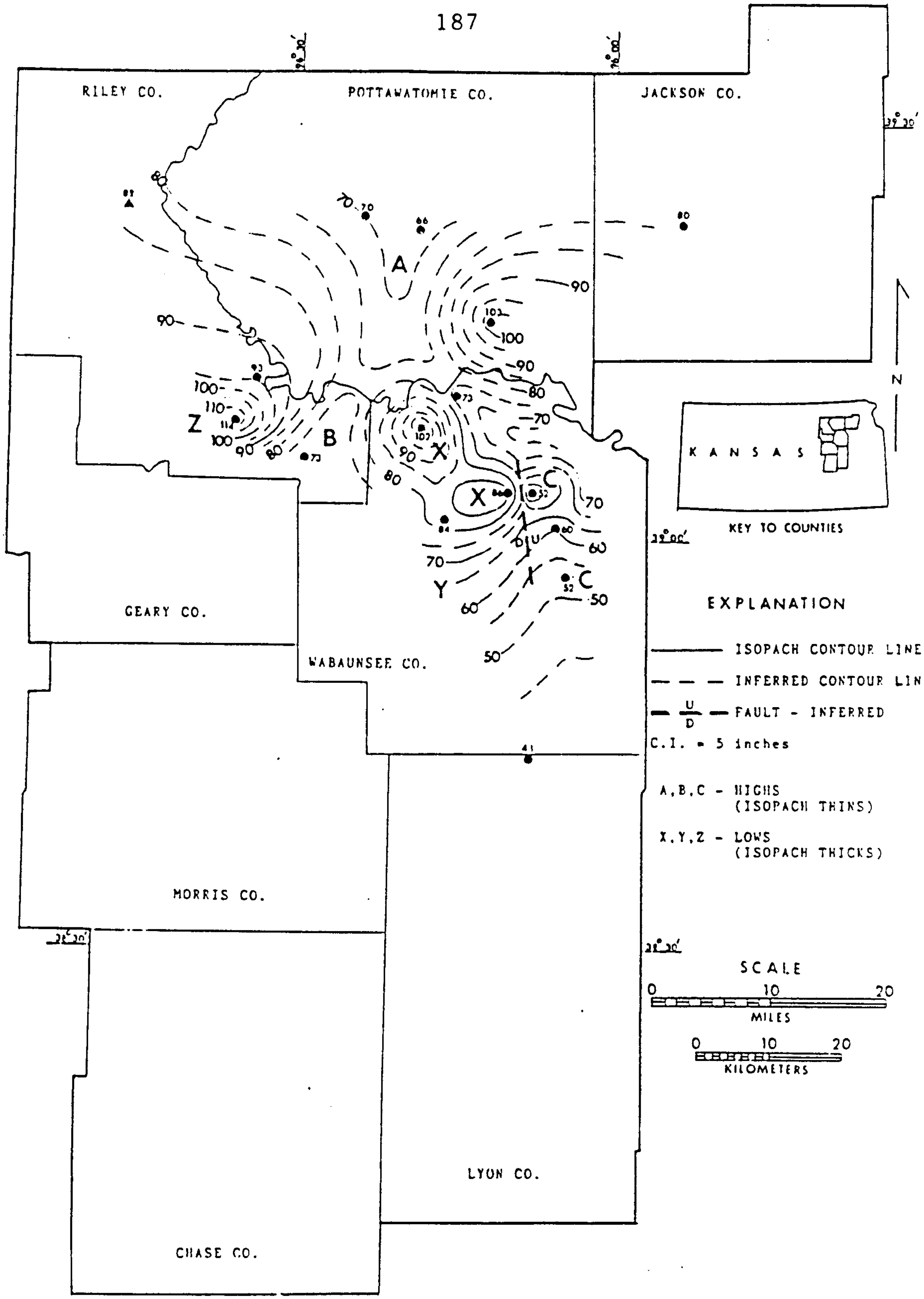


Figure 42. Isopach map, in inches, of F2.3. See text for discussion.

encompasses A and B (highs). Another linear "thin" occurs in a northwest-southeast direction in northern Wabaunsee County. This trend probably represents most of the thinning labelled C. Isopach "thicks" reflecting local depocenters, flank the isopach "thins", and exhibit closure (e.g., X,Y,Z). In this map, X covers a large part of northern Pottawatomie County. A fault (down to the west-southwest, and up to the east-northeast) is inferred between C (high) and X (low). The most conspicuous correlation between this map, and the regional setting, is the linear-trending thins (A, B, and C) that parallel the northeast-southwest, and northwest-southeast structural elements (i.e., Nemaha Anticline, northwesterly trending fractures, and pull-apart grabens). The topography of F2.3, and its influence on deposition, may have been structurally controlled, but it did not affect the lateral uniformity of the massive fusulinid biofacies during maximum transgression of F2.3.

Sixth-Order T-R Unit F2.4.--The basal limestone of F2.4 was isopached (Figure 43) to see if "thickenings" were associated with the *Osagia* dominated wackestone-packstone lithofacies of Figure 34. A subtle northeasterly "thickening" parallels the northeast-southwest "thinning" (A,B) of F2.3. It coincides, in part, with the *Osagia* dominated wackestone to packstone facies of F2.4. This might be evidence of increased algal production on a topographic high. The W "thick" is present and corresponds to the

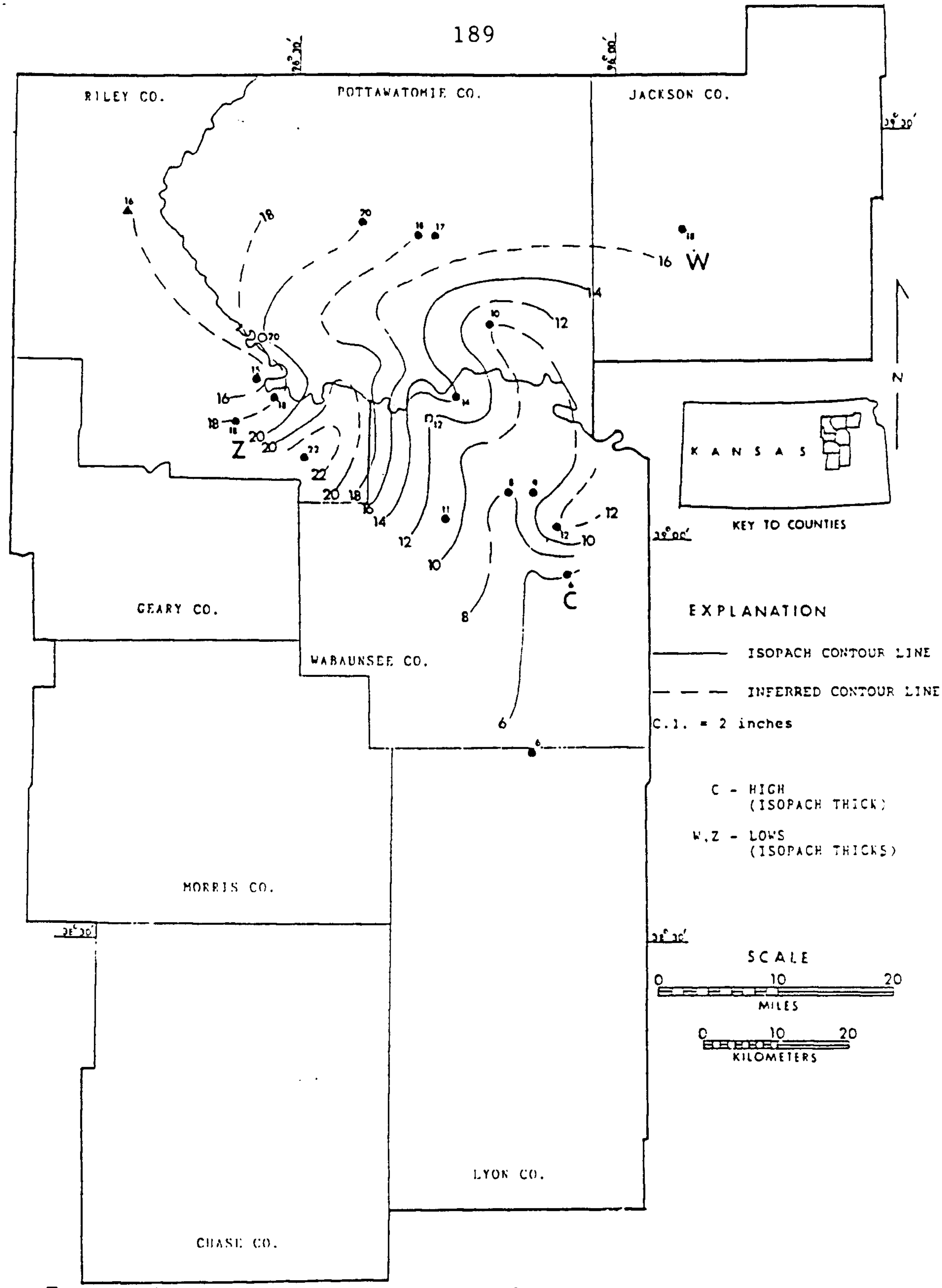


Figure 43. Isopach map of the basal limestone in F2.4, in inches. See text for discussion.

occurence of the stromatolitic(?) facies (Figure 34). Net thinning to the south, where the argillaceous, wackestone-mudstone lithofacies is prevalent may correspond to the absence of osagid-algal production in this area.

Sixth-Order T-R Units F3.1 and F3.2.--The thicknesses of sixth-order T-R unit F3.1 and F3.2 were combined because genetic surface F3.2 is questionable at several locations (discussed previously). However, this combination will illustrate the depositional trend of the overall net deepening sequence of the Long Creek fifth-order T-R unit (Figure 44).

The combined isopach map of F3.1 and F3.2 (Figure 44) shows a definite isopachous closure representing a "thinning" (high) of rocks in southwestern Pottawatomie and southeastern Riley Counties. This trend might be part of the northeast-southwest A-B linear high (e.g, Figure 43). This recurrent thinning trend (A-B), over this same general area, has been a conspicuous feature revealed by the isopach maps throughout the Foraker hierarchy.

Composite Facies Trends

Boundaries from the paleogeographic reconstructions were overlayed and put onto a single base map of the study area. On this "composite paleogeographic map" (Figure 45) the gray, "stippled tracts" represent areas where sixth-order facies

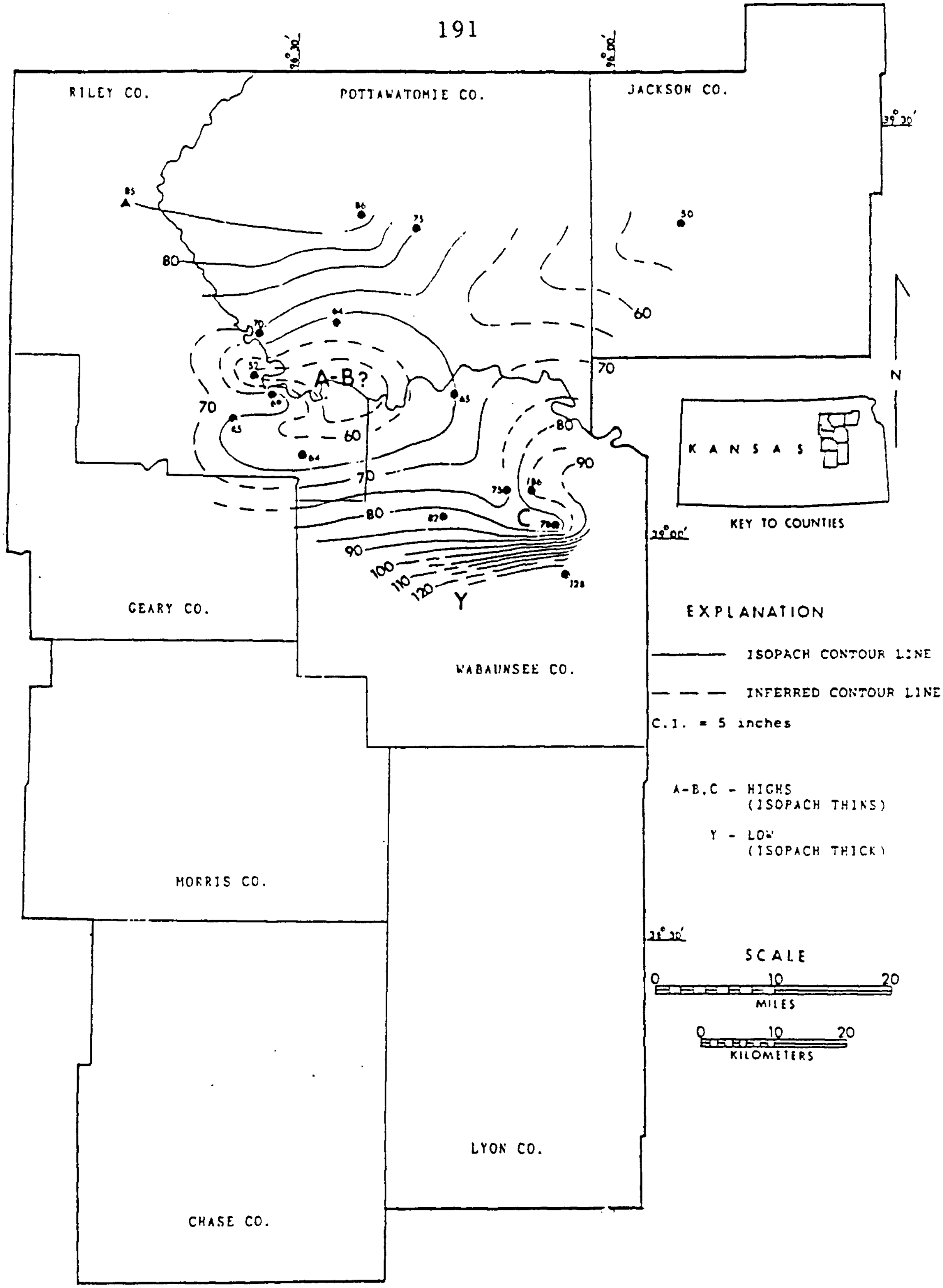


Figure 44. Isopach map of F3.1 and F3.2 combined, in inches. See text for discussion.

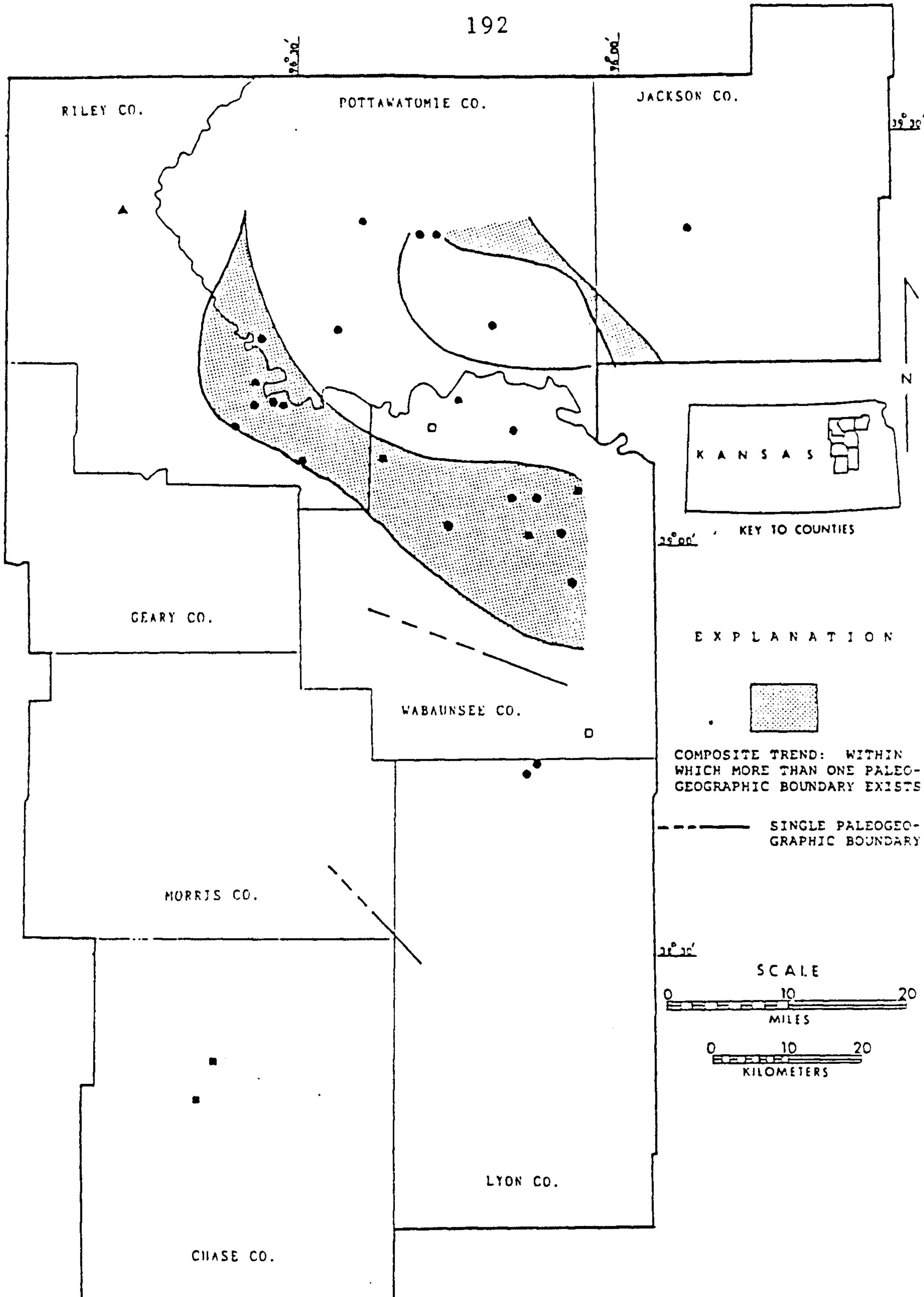


Figure 45. Composite sixth-order paleogeographic map. See text for discussion.

changes (paleogeographic boundaries) commonly occurred. These areas are referred to as composite paleogeographic tracts.

In Figure 45 a larger, more conspicuous composite tract covers most of northern Wabaunsee, southeastern Riley, and southwestern Pottawatomie counties. Another less conspicuous, smaller composite tract occurs in eastern Pottawatomie and southwestern Jackson counties. Between these two composite tracts in southern Pottawatomie and northern Wabaunsee counties, the rocks commonly reflected shallower marine and shoaling conditions (e.g., F1.1 and F1.3). To the southwest of the larger composite tract, recurrent facies commonly reflected more open (deeper), and quieter marine conditions, whereas northeast of the smaller composite tract, the rocks commonly reflected intertidal-lagoonal to supratidal conditions.

Sixth-order isopach "thins" (A, B, C) that represent temporally recurring highs, and sixth-order isopach "thicks" (W, X, Y, Z) representing recurrent lows, were assembled and labeled on the composite paleogeographic map (Figure 46). Contouring between the highs and lows differentiates larger areas of recurrent isopach thinning (northwest-southeast diagonal lines in Figure 46), and thickening (northeast-southwest diagonal lines in Figure 46).

The area of recurrent sixth-order highs (A, B, C) (Figure 46) coincides mostly with the area of recurrent

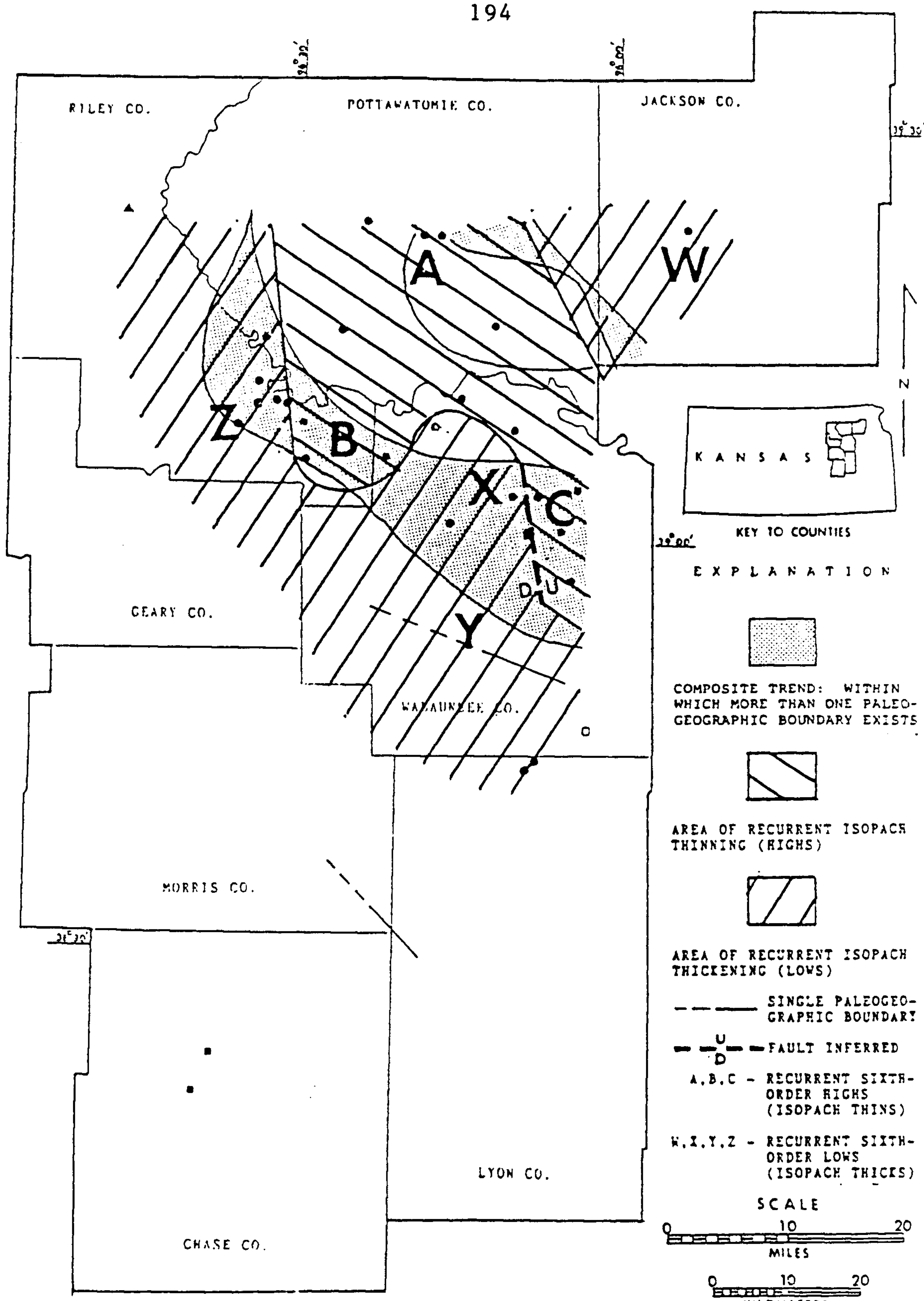


Figure 46. Composite sixth-order isopach map relative to paleogeographic trends. See text for discussion.

shallowing (and shoaling), between the two composite tracts. At the same time, the area of recurrent lows (X, Y, Z) southwest of the larger composite tract, corresponds with the area of recurrent deepening, and more open marine facies. To the northeast of the smaller composite tract, recurrent topographic lows (W) correspond with the recurrent lagoonal-intertidal facies. Recurrent facies trends, such as these, may reflect some underlying structural control that was affecting local sedimentation.

STRUCTURAL CONTROLS OVER FORAKER DEPOSITION

Structural Overview

Major structural features within the study area that may have affected deposition of Foraker sediments are the Nemaha Anticline, Abilene Anticline, Irving Syncline, and the Brownville Syncline (Figure 7). Secondary structural features are common east of the Nemaha axis including the Alma Anticline, Zeandale Dome, and others (e.g., Figure 7; Figure 46).

The northeast-trending Nemaha Anticline defines a tectonic zone that is complexly deformed. The Nemaha tectonic zone contains high-angle reverse, normal, and strike-slip faults, basement-cored domal anticlines (e.g., Zeandale Dome), and conspicuous "pull-apart" grabens (e.g., Berendsen and Blair, 1986; Steeples, 1982). The Nemaha tectonic zone and its associated structures form part of the eastern boundary of the 1100-m.y.-old Central North American rift system (CNARS; e.g., Berendsen and Blair, 1986; Van Schmus and Hinze, 1985; Serpa _et al_., 1984). Reactivation of this rift system occurred at the end of the Mississippian. Berendsen and Blair (1986) consider the reactivation of the CNARS a direct result of foreland deformation from the Pennsylvanian Ouachita orogeny to the south.

Figure 7 shows the major structural features trending northeast-southwest, but a better representation of local structure style can be seen in a structure map of the top of the Precambrian basement rocks (Figure 47; Cole, 1976). On this map, the Nemaha Anticline consists of localized structural highs that are cross-cut by northwest-southeast trending faults, thus forming pull-apart basins in an en echelon fashion. This is well illustrated in southeastern Riley County, and eastern Chase County (Figure 47).

The en echelon pattern probably resulted from foreland, sinistral, wrench style (i.e, strike slip) tectonics (Berendsen and Blair, 1986). The northeast-southwest and northwest-southeast trends of the structures were reactivated from similar-trending faults that were formed in the Proterozoic (Chelikowsky, 1972; and Berendsen and Blair, 1986). These trends can be seen in the fracture patterns which have affected the regional drainage pattern. In particular, the Big Blue River parallels the northwest-southeast and northeast-southwest fracture trends, forming a "dog leg" on the eastern side of Pottawatomie County (Chelikowsky, 1972).

Pertinent to this study are several minor structural highs (labeled A,B,C on Figure 47). These are: 1) the localized structural high known as the Zeandale Dome, which can be located where Wabaunsee, Pottawatomie, and Riley Counties meet (B); 2) the structurally high area to the north

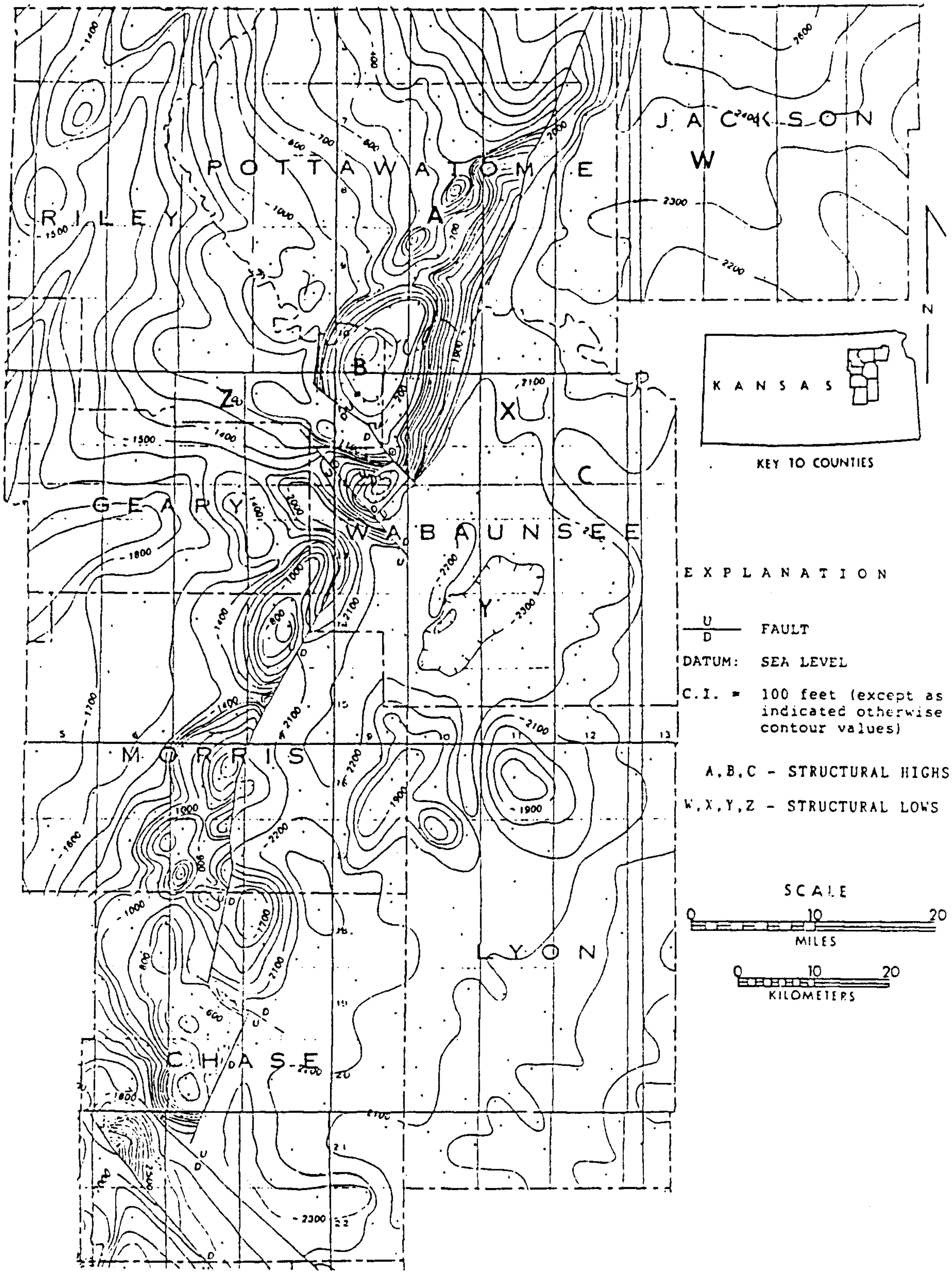


Figure 47. Structural contour map of the top of the Pre-Cambrian basement within the area of study (from Cole, 1976).

in Pottawatomie County (A), along the Nemaha Anticline; and 3) the very subtle structural high (reentrant, C) in northeastern Wabaunsee County. There are also several pertinent, structural lows (W,X,Y,Z). These are: 1) the northwest-southeast trending structural graben (pull-apart graben) that bounds the south edge of the Zeandale Dome (B) in southeastern Riley and eastern Wabaunsee counties; 2) the structural "lows" in southeastern and north central Wabaunsee County (Y and X respectively); 3) the structural low (Z) to the west and northwest of the Zeandale Dome (B); and 4) the structurally low area east of the Nemaha Anticline in eastern Pottawatomie and western Jackson Counties (W).

Present day structural configurations of the base of the Upper Pennsylvanian Kansas City Group (Missourian, Figure 48), and the top of the Lower Permian Americus limestone (Figure 49), show that the Zeandale Dome (B) and northern structural highs (e.g., A) of the Nemaha Anticline, were still active even after Permian time. The structural "highs" east of the Nemaha Anticline (e.g., C, Figure 47; and Figure 7) have been interpreted by Hodgden (personal communication) as representing local compressional features that resulted from the reactivation of the midcontinent rift system. The offset, discontinous nature of these local "highs" (Figure 7) may have resulted from northwest-southeast trending strike-slip faulting that originated in the Nemaha tectonic zone (e.g., the pull-apart grabens). The

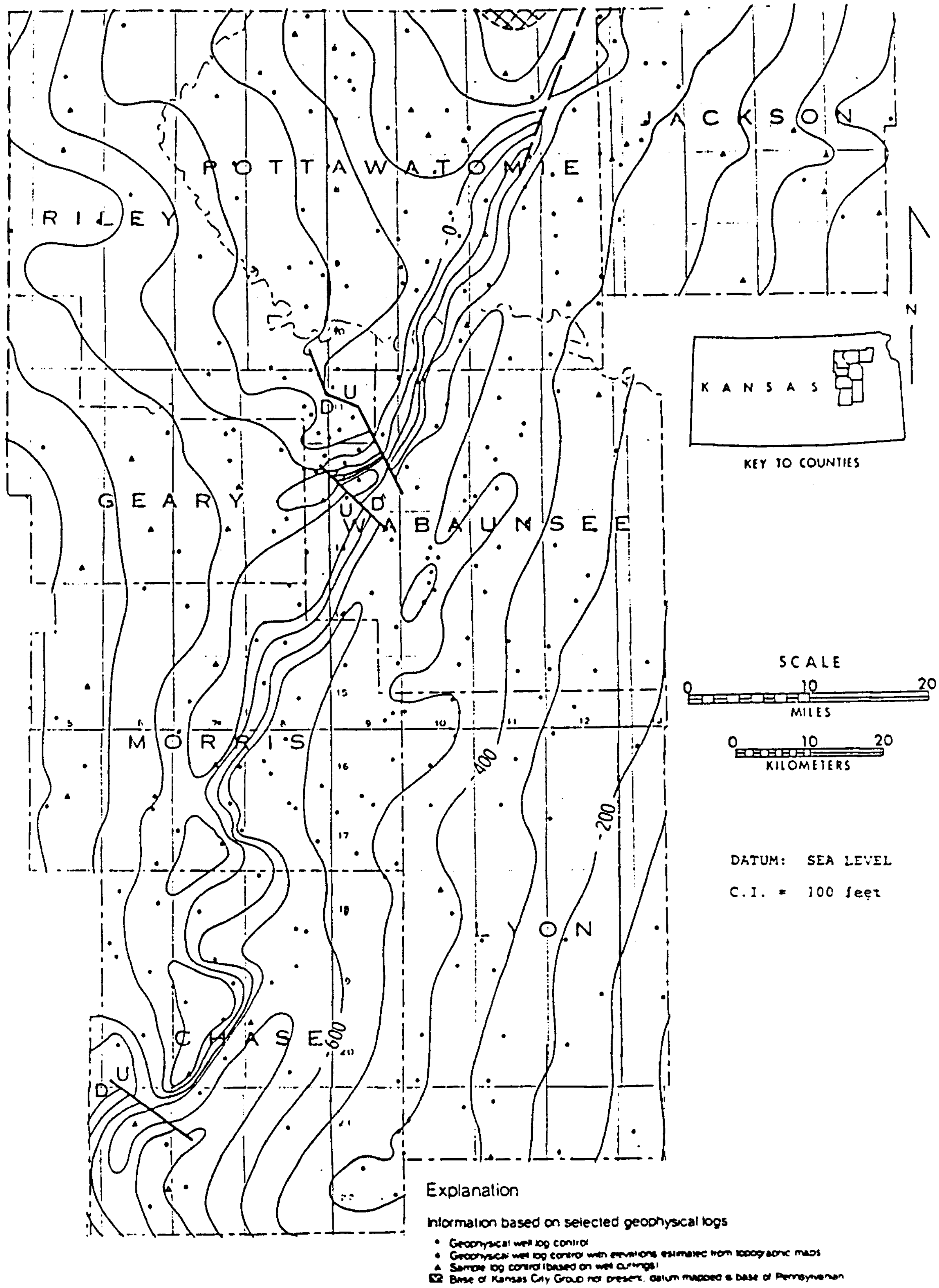


Figure 48. Structural contour map of the base of the Kansas City Group within the area of study (Missourian; from Watney, 1978).

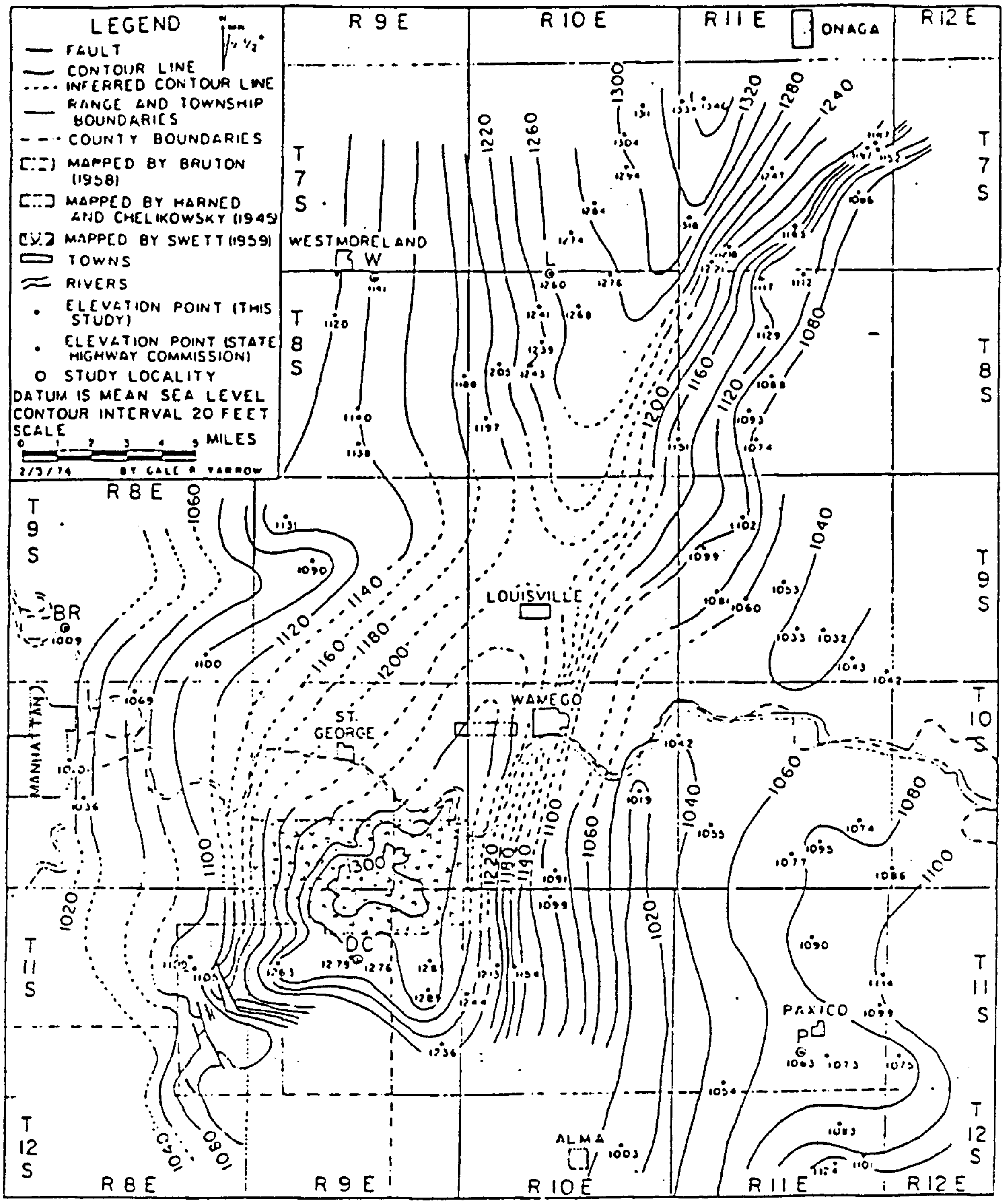


Figure 49. Structural contour map of the top of the Americus limestone (Foraker Formation, Lower Permian) in northern Wabaunsee, southern Pottawatomie, and southeastern Riley Counties (from Yarrow, 1974).

strike-slip faults may have been an avenue for the release of compressional stresses that were forming the local structural highs to the east of the Nemaha Anticline (Hodgden, personal communication). Repetition of strata in bore hole data has indicated the presence of reverse faults along the eastern flanks of these structural highs, thus suggesting a compressional origin (e.g., Alma Anticline, Figure 7). It is these structural highs flanking the Nemaha Anticline that have been the subject and target of extensive oil and gas exploration in the Kansas region (e.g., Davis Ranch oil field production from the Alma Anticline, Smith and Anders, 1951). Detailed mapping of sixth-order facies relationships should aid in targeting such prospects, and enhance in-fill drilling of existing fields. For example, a prospect investigation may be warranted for potential hydrocarbon entrapment along the inferred north-northwest to south-southeast trending fault (Figure 47) in the topographically high area of C.

Composite Paleogeographic and Structural Trends

Recurrent paleogeographic and isopach trends may reflect structures that repeatedly influenced the depositional pattern of the sixth-order T-R units. Therefore, a transparent overlay of the composite paleogeographic and isopach map is used in conjunction with the Precambrian structure map (Figure 50) to see where the recurrent trends

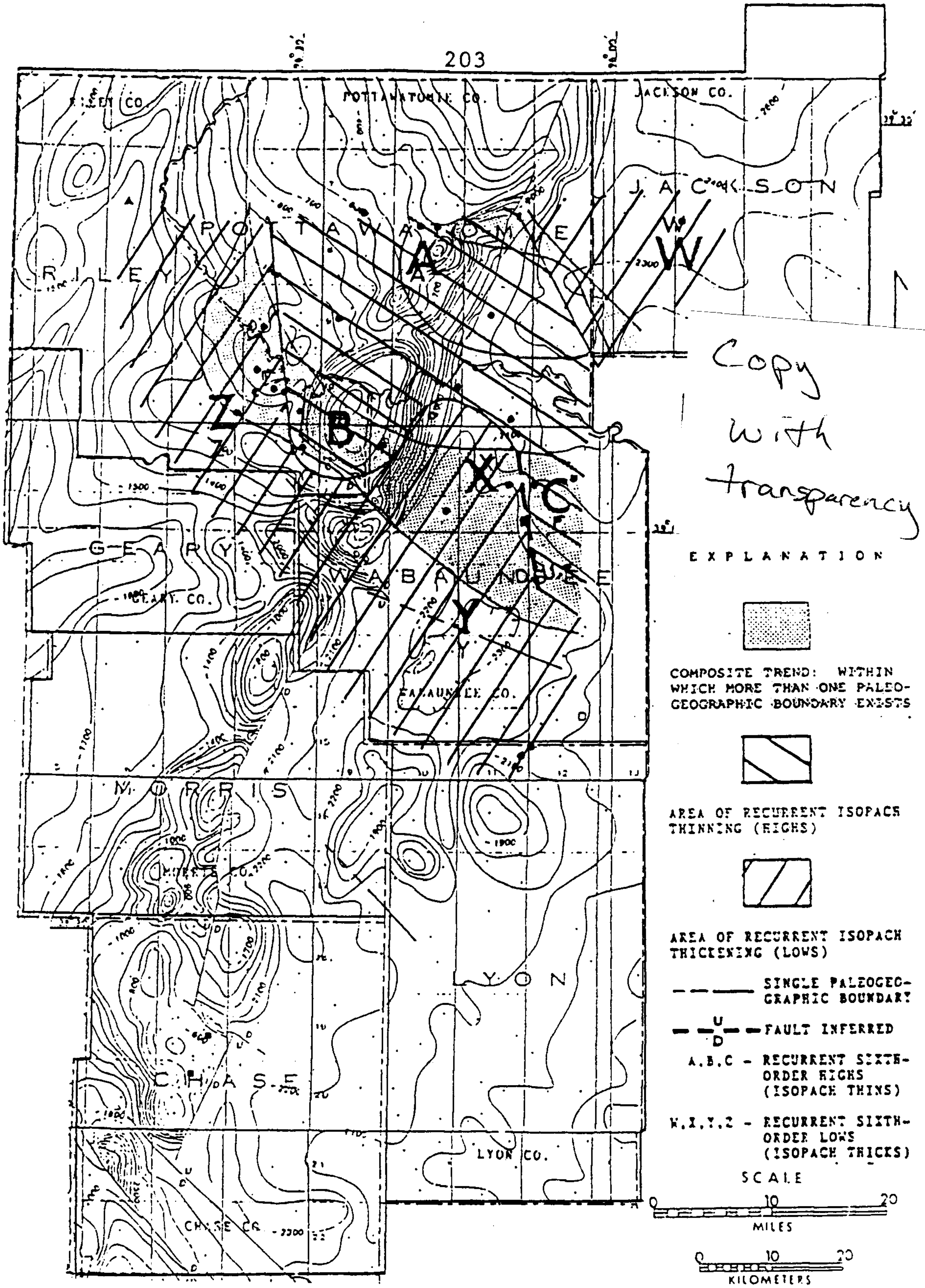


Figure 50. Relation of sixth-order composite paleogeographic and isopach trends (overlay) to the structural configuration of the top of the Pre-Cambrian basement (from Cole, 1976; see Figure 47 for explanation).

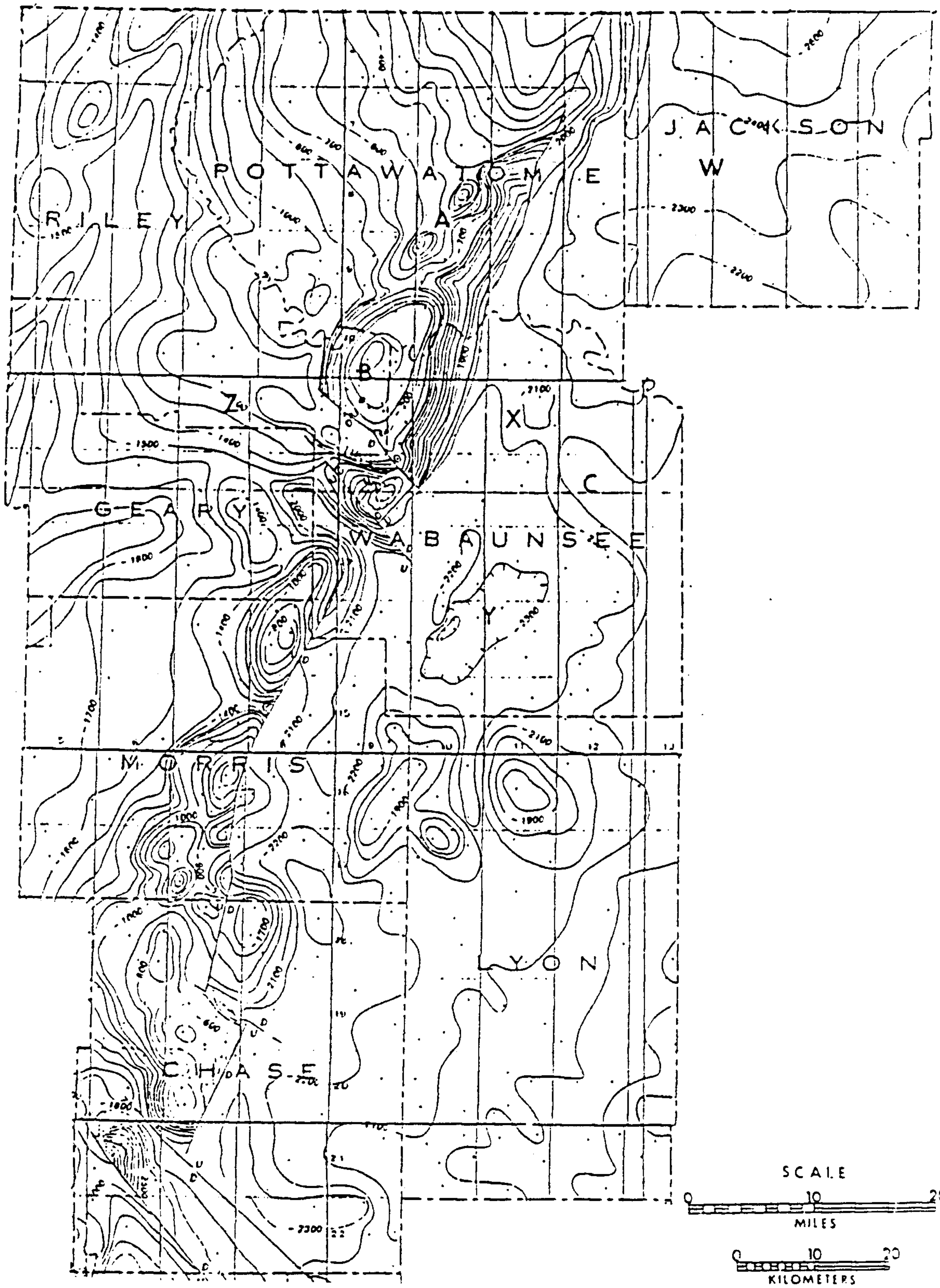


Figure 50. Relation of sixth-order composite paleogeographic and isopach trends (overlay) to the structural configuration of the top of the Pre-Cambrian basement (from Cole, 1976; see Figure 47 for explanation).

occur relative to known structural features.

Overlaying the composite paleogeographic and isopach map on the Precambrian basement configuration (Figure 50) reveals several structural, paleogeographic, and isopach correlations. South and west of the larger, conspicuous composite tract the structural contours indicate synclinal (negative) features (X,Y,Z). These features coincide with the recurrent offshore, deeper facies trends, as well as the recurrent isopach thicks of X, Y, and Z. The larger composite tract subparallels, and in part coincides with, the trend of the structural pull-apart graben immediately south of the Zeandale Dome (B). The larger composite tract then changes direction (at Z), paralleling the axis of the Irving Syncline (Figures 50 & 7) in Riley County. The more open facies to the west, thus coincide with the eastern flank of the Irving Syncline.

Between the two composite tracts there is an increase in structural elevation (Figure 50). This area coincides with the recurrent shallower, and more paralic facies trends, as well as with the topographic highs (isopach thins) of A and B (inclusive of the Zeandale Dome). The structural highs of A and B (along the Nemaha Anticline) were affecting deposition by causing near shoaling conditions, for example, in sixth-order T-R units F1.1, F1.3, and F2.4 (Figures 25, 26, 29, 30, 34). Structural highs east of the Nemaha Anticline (e.g., C, Figure 50; Figure 7) may have been affecting deposition in a similar manner. This would explain why the recurrent shallowing and shoaling trends (F1.1, F1.3, and F2.4) extend to the eastern part of Pottawatomie and Wabaunsee Counties.

Structurally low areas northeast of the smaller composite tract coincide with the recurrent, shoreward, lagoonal, and intertidal facies (Figure 50); they also correspond with the recurrent isopach "thick" W. This supports Fisher's (1980) conclusions that a deeper, more restricted, back-shoal lagoonal area may have existed northeast of his shoaling environment (e.g., Figure 26).

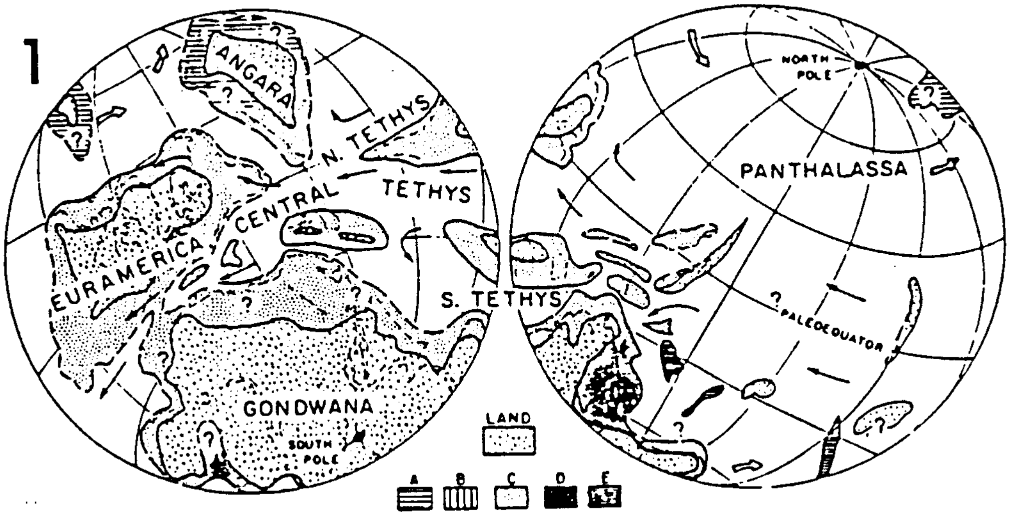
FUSULINIDS OF THE FORAKER FORMATION

Overview

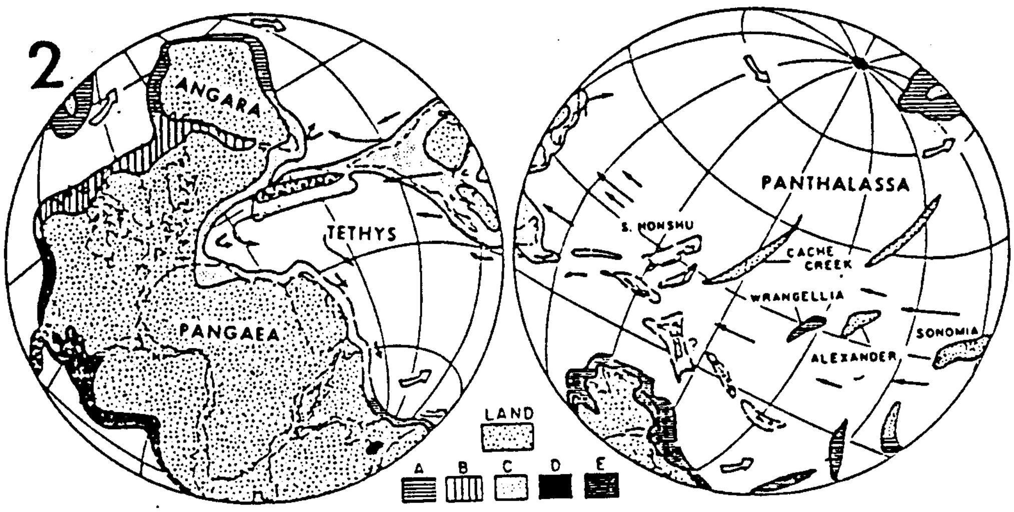
Fusulinids exhibited remarkable, widespread, evolutionary radiations during the Late Paleozoic. Therefore, I feel it is necessary to give a brief synopsis of fusulinid faunal realms and paleogeographic distribution to better place the fusulinids of the Foraker Formation in a hierarchal, temporal, and spatial perspective. Fusulinid extinctions will also be discussed. Finally, a brief review of previous ecologic interpretations of fusulinids will be given for comparison to the interpretations made in this study.

During an interval of about 100 million years, fusulinids were widely distributed in tectonically evolving geosynclines and associated marine shelf (epicontinental) areas, throughout the world (Ross, 1967; Haynes, 1981). From late Early Carboniferous to the end of the Permian, fusulinids underwent major evolutionary changes (Ross, 1967; Ross and Ross, 1985a). These changes took place in essentially three major, biogeographical faunal realms (Figure 51): 1) a Tethyan-Boreal realm which included Eurasia and the Uralian and Franklian geosynclines, and which extended across the Arctic into the northern Cordilleran geosyncline; 2) an American Midcontinent and Andean

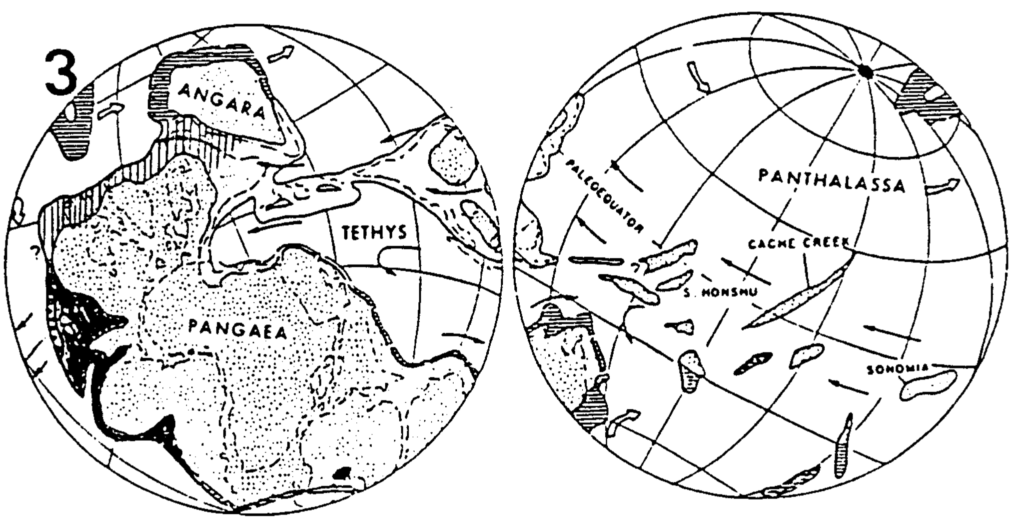
Figure 51. Global paleogeographic maps for Early Carboniferous through Middle Permian times (1-3). Patterns A and E are north and south, cold to cool faunal regions; B is Franklinian - Ural subtropical to warm temperate area; C is the tropical cosmopolitan regions that form Tethyan faunas; and D is the southwestern North American (and Mid-Continent) and Andean faunas. Solid arrows indicate warm-water surface currents; open arrows indicate cool-water surface currents (from Ross and Ross, 1985a).



Early to early Middle Carboniferous



late Middle to Late Carboniferous



Mid-Permian

geosyncline realm; and 3) a worldwide realm that is distinguished by its biostratigraphically correlative, cosmopolitan fusulinids (Haynes, 1981). The first two realms are best distinguished by their endemic genera and species lineages; the Tethyan realm was the main origin of new forms (Haynes, 1981). Four phylogenetic lineages of fusulinid families were established in Early to Middle Carboniferous times (the Ozawainellidae, Staffelidae, Schubertellidae, and Fusulinidae) and two lineages were established in Early Permian times (the Verbeekinidae and Scwagerinidae) (Ross, 1967).

During late Early Carboniferous (Visean-Mississippian) time there existed unrestricted, circumequatorial tropical waters between Gondwana and Euramerica (i.e., Laurasia: Strahler, 1981; Figure 51-1). This allowed habitation of both realms by cosmopolitan fusulinid faunas, and by Middle Carboniferous (Early-Middle Pennsylvanian) time, the worldwide evolution of fusulinids had resulted in a great number of genera, with the Fusulinidae being the most diverse family (Ross, 1967; and Haynes,1981). During this time a net transgressive phase at a second-order scale (Figure 52) was also occurring (Vail et al., 1977); however, as a result of continental suturing between Gondwana and Euramerica (e.g., Hercynian-Appalachian, Ouachita, and Marathon orogenic belts), the equatorial circulation was cut off (Figure 51-2). Cosmopolitan fusulinid diversity dwindled by the end of

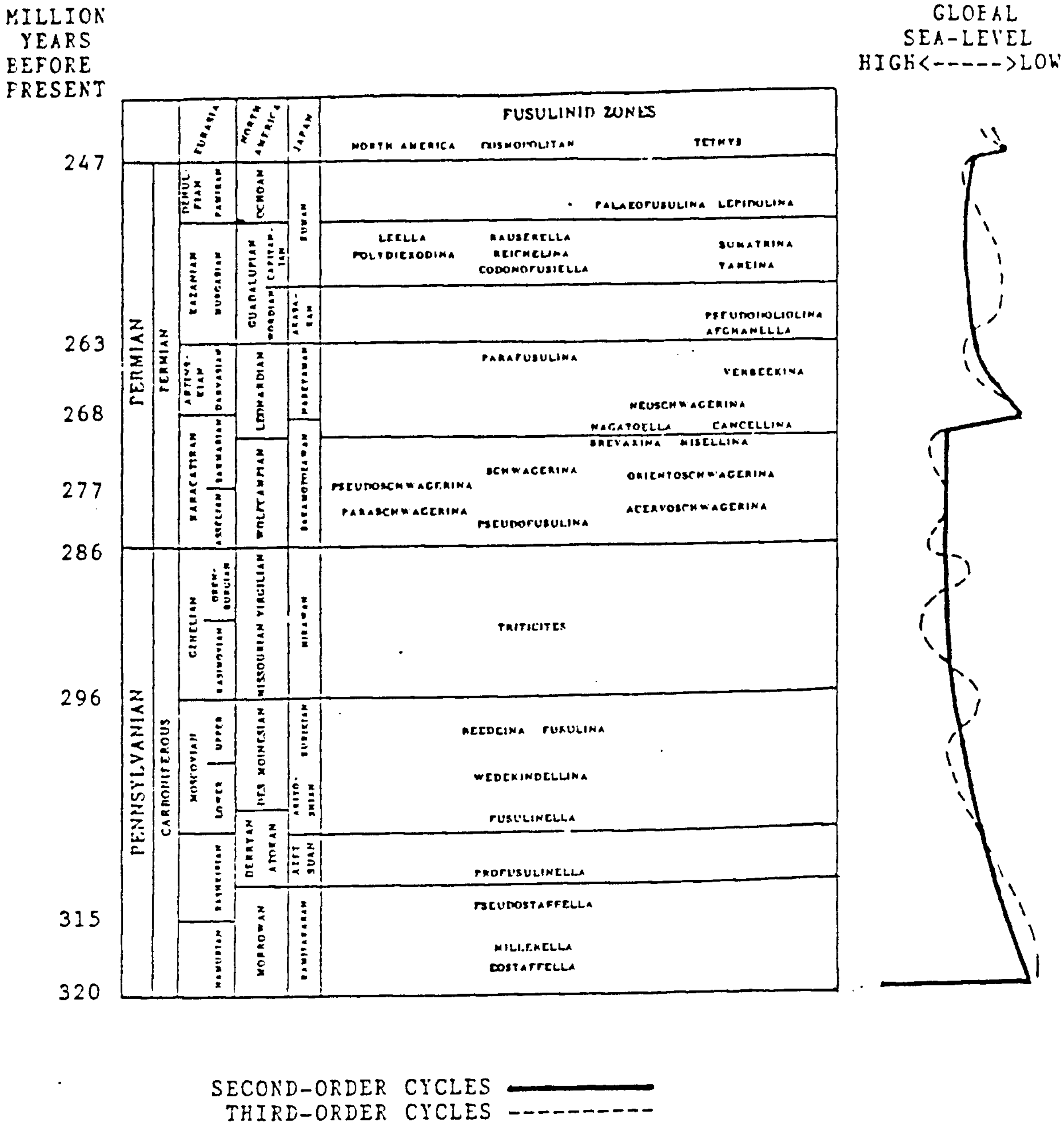


Figure 52. Pennsylvanian-Permian chronostratigraphy and fusulinid zones (from Douglass, 1977) relative to absolute geochronology (Veevers and Powell, 1987) and best estimation of second-order and third-order cycles of global sea-level change. Data on sea-level changes adapted from Vail et al. (1977), Busch (1984), Busch and Rollins (1984), Veevers and Powell (1987), and Busch (1988 - personal communication).

Middle Carboniferous time (Ross and Ross, 1985a; Figure 52). Triticites (the dominant genus of the Hughes Creek shale: Kaesler and Fisher, 1969; Fisher, 1971) appeared and invaded the American Midcontinent during this time (Haynes, 1981). A "zone of Triticites" is also recognized worldwide, thereby establishing a correlation, for example, of the Gzehlian of Eurasia with the Missourian and Virgilian of North America (Figure 52).

The extinction of many fusulinid genera in the Late Pennsylvanian (i.e., Missourian and Virgilian) may coincide with a net third-order regressive phase. Indeed, Busch and Rollins (1984) show a net regressive third-order phase at the end of the Pennsylvanian and during very earliest Permian (Figure 52). Also, Crowell (1978) noted, based on American cratonic sea level curves, a discrete regressive phase in the Late Pennsylvanian (Figure 53). Rascoe and Adler (1983) also indicated a widespread regression in the Late Pennsylvanian of the Midcontinent. Thus, the two times of rapid evolutionary diversification of fusulinids, the Middle Carboniferous and Lower Permian, may represent net third-order transgressive apices that are separated on a global scale, by a third-order regressive apex in the Upper Pennsylvanian (Figure 52). This third-order trend occurred at a second-order transgressive apex (Figure 52).

During the Early Permian, relatively rapid evolutionary diversification of fusulinids occurred for the second and

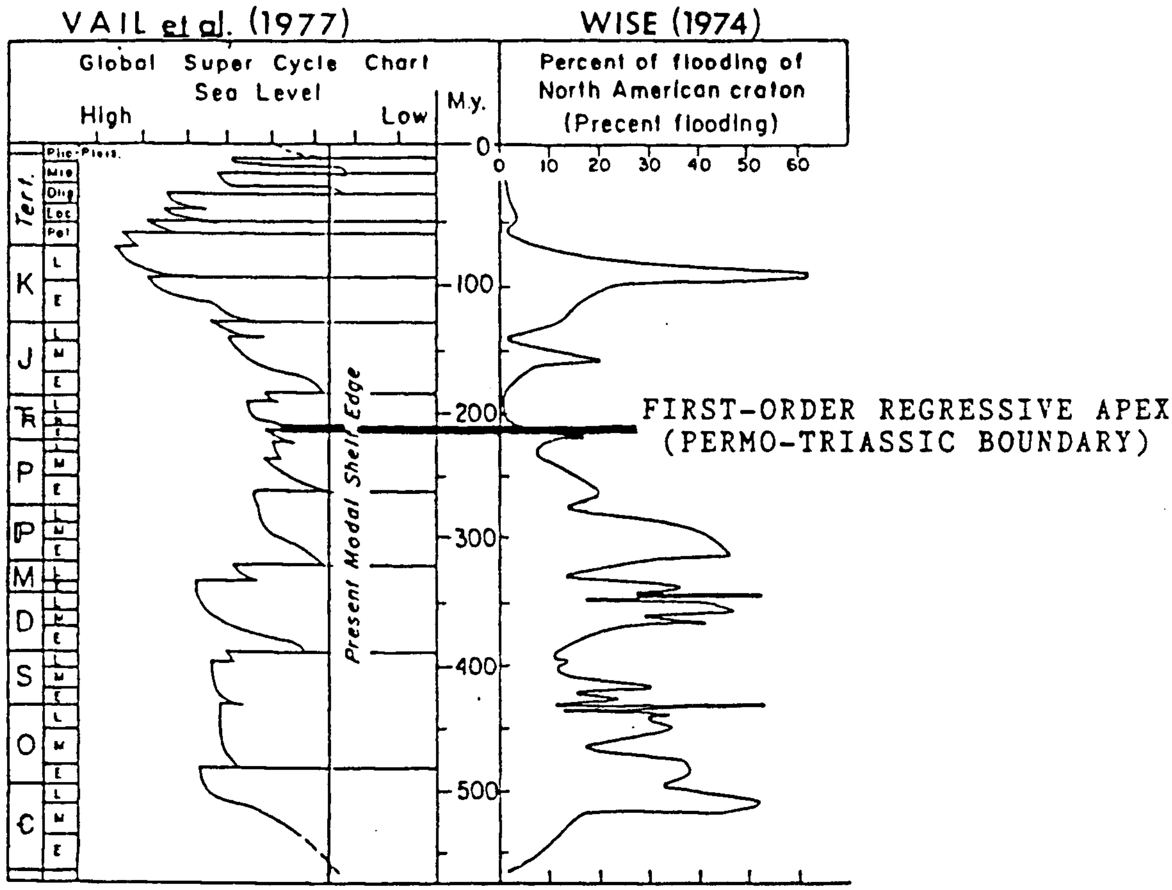


Figure 53. Global sea-level (Vail et al., 1977) and North American free board curves (showing percent of flooding of the craton; from Wise, 1974; and Crowell, 1978) as they correspond to the first-order regressive apex that coincides with the Permo-Triassic boundary.

last time in geologic history (Ross, 1967; and Ross and Ross, 1985a), despite the effects of Pangaea. Recall that there was general climatic warming and several episodes of sea level change during the Early Permian (Figure 52). During Asselian and Sakmarian time (i.e., Gearyan-Wolfcampian), largely cosmopolitan faunas developed, one of which arose from Triticites, namely the Schwagerinidae (Figure 54). Consequently, schwagerinid genera such as Pseudoschwagerina, and Schwagerina were cosmopolitan during the Asselian and Sakmarian, and now characterize (along with many others) the worldwide correlative "zone of Pseudoschwagerina" (e.g., Douglass, 1977; Figure 52). According to Ross (1967), the family Schwagerinidae arose from the Fusulinidae, a once very diverse fusulinid family of the Middle Carboniferous (Figure 54).

Moore (1940) placed the Permo-Carboniferous boundary at the base of the Admire Group in Kansas, because such placement conformably underlies the limestone containing what he thought was the first occurrence of Pseudofusulina (i.e, start of the Pseudoschwagerina zone); namely, the Americus Limestone Member of the Foraker Formation. Mudge and Yochelson (1962) have since noted that Pseudofusulina also occurs in the middle of the Admire Group (Five Point limestone), but that lower Admire beds (i.e., below the Five Point limestone) could be assigned to the zone of Triticites (i.e., Pennsylvanian). Thus, this study

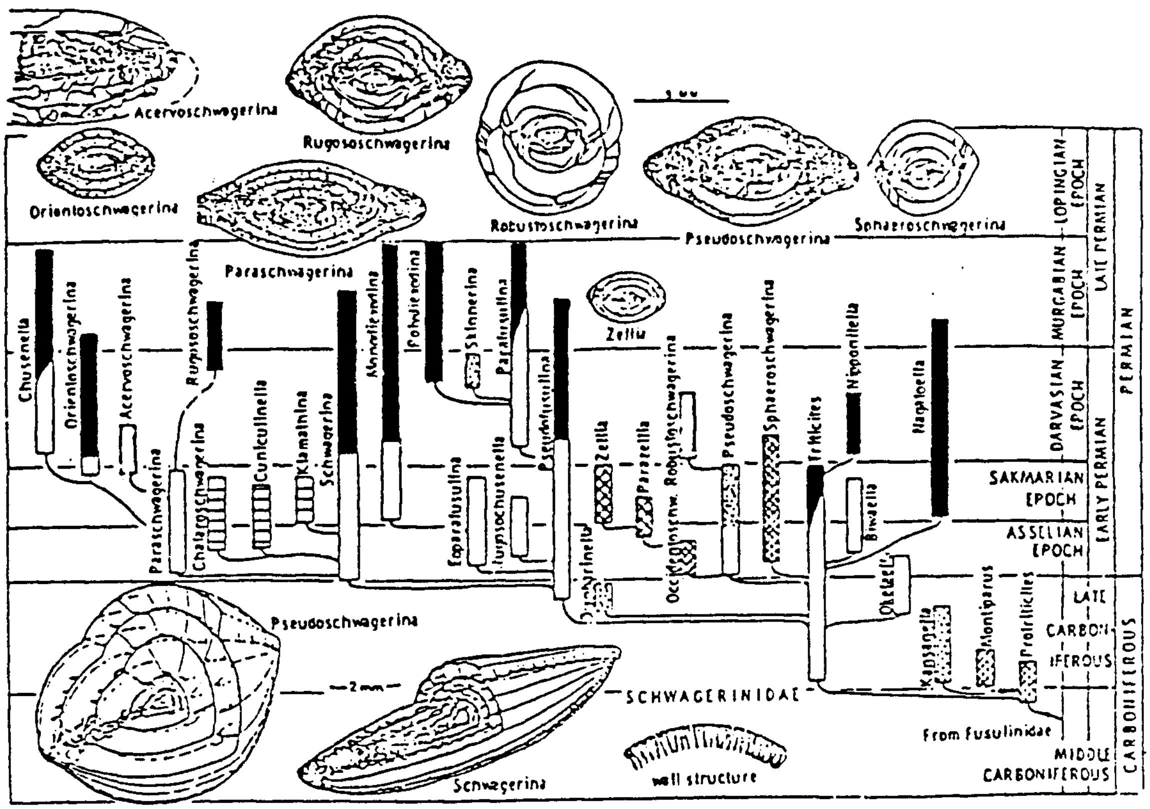


Figure 54. Phylogeny of the family Schwagerinidae and the distribution of genera in fusulinid biogeographic realms. Cross-hatched branches occur in the Eurasian-Arctic (Boreal) fusulinid realms, black branches occur in the Tethyan fusulinid realm, open branches are cosmopolitan, and stippled branches occur in the Mid-Continent - Andean faunal realm (from Ross, 1967).

encompasses strata containing fusulinids that by definition belong to the "zone of Pseudoschwagerina". That is, all rocks studied herein are of Early Permian age and are probably Assel equivalents (Douglass, 1977; and Harland et al., 1982).

The Zone of Pseudoschwagerina is one of the most widely recognized and diverse fusulinid zones of the Late Paleozoic (Figures 52 and 54). It typifies the evolutionary development of the Paleozoic fusulinids as more structurally advanced forms appeared in the Permian (Figure 54). According to Thompson (1964), several distinct changes took place at this time: 1) fusulinids became larger (although not a regularly progressive attribute); 2) shell shape changed from discoidal (in the late early Carboniferous) to spherical fusiform, and elongate subcylindrical in the Permian; 3) more complex shell walls developed; and 4) the antetheca and septa became fluted.

By early Middle Permian time (Leonardian, Figures 52, 54) two fusulinid realms, with characteristic endemic genera, were re-established in the Tethyan and Midcontinent areas. It is reasonable to suggest that this was related to net sea level regression at second- and third-order scales (Figure 52). Thus the zone of Parafusulina-Neoschwagerina was established in Leonardian and Lower Guadalupian time. In late Middle Permian (upper Guadalupian, Capatanian) the Polydiexodina-Yabeina zone was established. This probably corresponds to the initial phases of a third-order transgression (Figure 52). By late Middle Permian time (Capatanian) fusulinids had disappeared from the Boreal subprovince, and at the end of Middle Permian (Guadalupian) time the schwagerinids and another family of fusulinids, the verbeekinids, became extinct (e.g., Ross, 1967; and Haynes, 1981).

Fusulinid diversity decreased during the Late Permian (Ochoan) with only small fusulinids (ozawainellid and schubertellid genera) inhabiting only the central and eastern Tethys realm (Figure 52). Not surprisingly, the extinction of fusulinids at the end of the Permian coincided with the apex of regression at a first-, second-, and third-order scale. This also marks the end of the Paleozoic Era (Figures 52 and 53).

Fusulinids Versus Foraker Hierarchal Genetic Stratigraphy

Fusulinids of the Foraker Formation occur in distinct zones (i.e., biofacies) representing indigenous accumulations (i.e., Model II of Johnson, 1960; fossil communities of Fagerstrom, 1964), rather than accumulations of allochthonous biological grains. This view is also shared by other authors (e.g., Fisher, 1971; Kaesler and Fisher, 1969), because fusulinids show no signs of size sorting, are preserved in random orientation, and show few signs of physical abrasion.

The distribution of fusulinid zones within the Foraker Formation is considered relative to the previously determined hierarchal genetic stratigraphy of this Foraker Formation.

Fusulinid zones of the Foraker Formation occur in sixth-order T-R units F1.2, F2.1, F2.2, F2.3, F2.4, F3.1, F3.2, and F3.3. They are typically massive accumulations of fusulinids at the bases of the sixth-order T-R units (i.e., immediately superjacent to the transgressive surface). The biofacies of which these fusulinid zones are a part, thus represent part of the sixth-order T-R units that were deduced as transgressive facies in earlier parts of this study. Some of the fusulinids inhabited environments representing the initial phases of sixth-order transgressions; however, they also typically inhabited environments representing maximum sixth-order transgression. They occasionally inhabited environments representing initial phases of sixth-order regressions, but only in greatly reduced abundances. In fact, fusulinids become absent towards the top of every sixth-order T-R unit of this study except one, F3.1, which underlies the Foraker fourth-order transgressive apex. Therefore, fusulinids of the Foraker Formation typically did not inhabit environments representing late phases of early regressions, or maximum phases of regressions, of sixth-order scale. At the sixth-order scale, fusulinids do not form the central vertex about which other "like" assemblages of taxa are symmetrically disposed; a view popularized by

Elias (1937) and Moore (1936, 1964).

Fusulinids of the Foraker Formation are mainly *Triticites*. For example, Fisher (1971) found abundant *Triticites* and rare *Pseudofusulina* in the Hughes Creek units that I recognize as sixth-order T-R units F2.3, F3.1, F3.2, and F3.3. Kaesler and Fisher (1969) also studied *Triticites* from my units F3.1 and F3.2, and regarded them as *Triticites ventricosus*. Later studies of fusulinids (Schmidt, 1974), from my units F2.1 and F2.2 of the Hughes Creek shale, revealed the common presence of *Triticites* and *Pseudofusulina*, in association with less common *Pseudoschwagerina*. *Dunbarinella* has been reported from the Hughes Creek shale by Thompson (1954), as has the rare *Millerella* (Douglass, 1962). The Americus limestone (i.e, sixth-order T-R unit F1.2) contains a variety of fusulinid genera including common *Triticites* and *Dunbarinella* (Thompson, 1954), plus less common *Millerella* (Douglass, 1962).

Therefore, *Triticites* occurs in all fusulinid zones of the Foraker fourth-order T-R unit and is also the most common fusulinid genus of the Foraker fourth-order T-R unit. While *Triticites* occurs in all fifth-order T-R units of the Foraker fourth-order T-R unit, there are fusulinid genera which are unique to each fifth-order T-R unit. The Americus fifth-order T-R unit (F1) contains *Millerella*, *Triticites*, and *Dunbarinella*; the Hughes Creek fifth-order T-R unit (F2) contains Triticites, Dunbarinella, Pseudoschwagerina, and Pseudofusulina; and the Long Creek fifth-order T-R unit (F3) contains Triticites and Pseudofusulina. The Red Eagle fifth-order T-R unit (F4) contains only Triticites (McCrone, 1963), and no fusulinids have been reported from the Burr fifth-order T-R unit (F5). Douglass (1962) has noted that genera (e.g., Triticites, Pseudofusulina, Millerella) and species (e.g., Triticites eoextenta, Millerella inflata) of fusulinids found in the Foraker Formation actually range through at least one other formation. Fusulinid genera and species range through many sixth-order T-R units, as components of biofacies. They also range through many fifth-order T-R units; that is, through biofacies sequences. As some fusulinid species are common to individual fourth-order T-R units, they provide biostratigraphic resolution of individual fourth-order T-R units (e.g., Ross and Ross, 1985b). The Foraker fourth-order T-R unit contains the zone of Triticites ventricosus. This zone is found throughout the North American Midcontinent (e.g., Kauffman and Roth, 1966; Kaesler and Fisher, 1969). Most recently, Verville and Sanderson (1988) have noted that Triticites ventricosus occurs in outcrops mapped as the Late Pennsylvanian Brownville Limestone Member (Virgilian, Wood Siding Formation) in northern Oklahoma. Enhanced biostratigraphic correlation of the Foraker fourth-order T-R unit into northern Oklahoma, may result in lithostratigraphic and biostratigraphic changes concerning the Brownville limestone of that area.

Figure 55 shows the average percentages (taken from visual estimation charts) of fusulinids in zones of each sixth-order T-R unit at the Manhattan, Paxico, and Poliska Lane sections. These percentages are based on thin section, washed residues, and hand sample examinations (Appendix). They are also quantitatively supported by data from Fisher (1971). What is immediately apparent in Figure 55 (with overlay) is that fusulinids are most abundant (in terms of percentages) near or within the transgressive apices (TAs) of the Americus, Hughes Creek, Long Creek, and Red Eagle fifth-order T-R units. Even more interesting is the fact that fusulinids become increasingly more abundant from the Americus fifth-order TA to about the Long Creek fifth-order TA. There is then a net decrease in abundance (upward), from the Red Eagle fifth-order TA to the Burr fifth-order TA. The zone (biofacies) containing the most abundant fusulinids, is immediately below, and gradational with, the brachiopod epibole of F3.2. This interval has been interpreted not only as a fifth-order TA, but also as the Foraker fourth-order TA. The maximum abundance of fusulinids in F3.2 does not coincide exactly with the fourth-order TA (i.e., the brachiopod epibole); however, fusulinids did occupy intermediate to most offshore conditions because they are still common to abundant in the brachiopod epibole that does represent the exact

Figure 55. Standard section of the Foraker hierarchy showing approximate, maximum percentages of fusulinids in each biofacies, relative to sixth-, fifth-, and fourth-order sea level curves (overlay). Fusulinid percentages based on field and laboratory observations (visual estimation charts) of the Paxico, Manhattan, and Poliska Lane sections.

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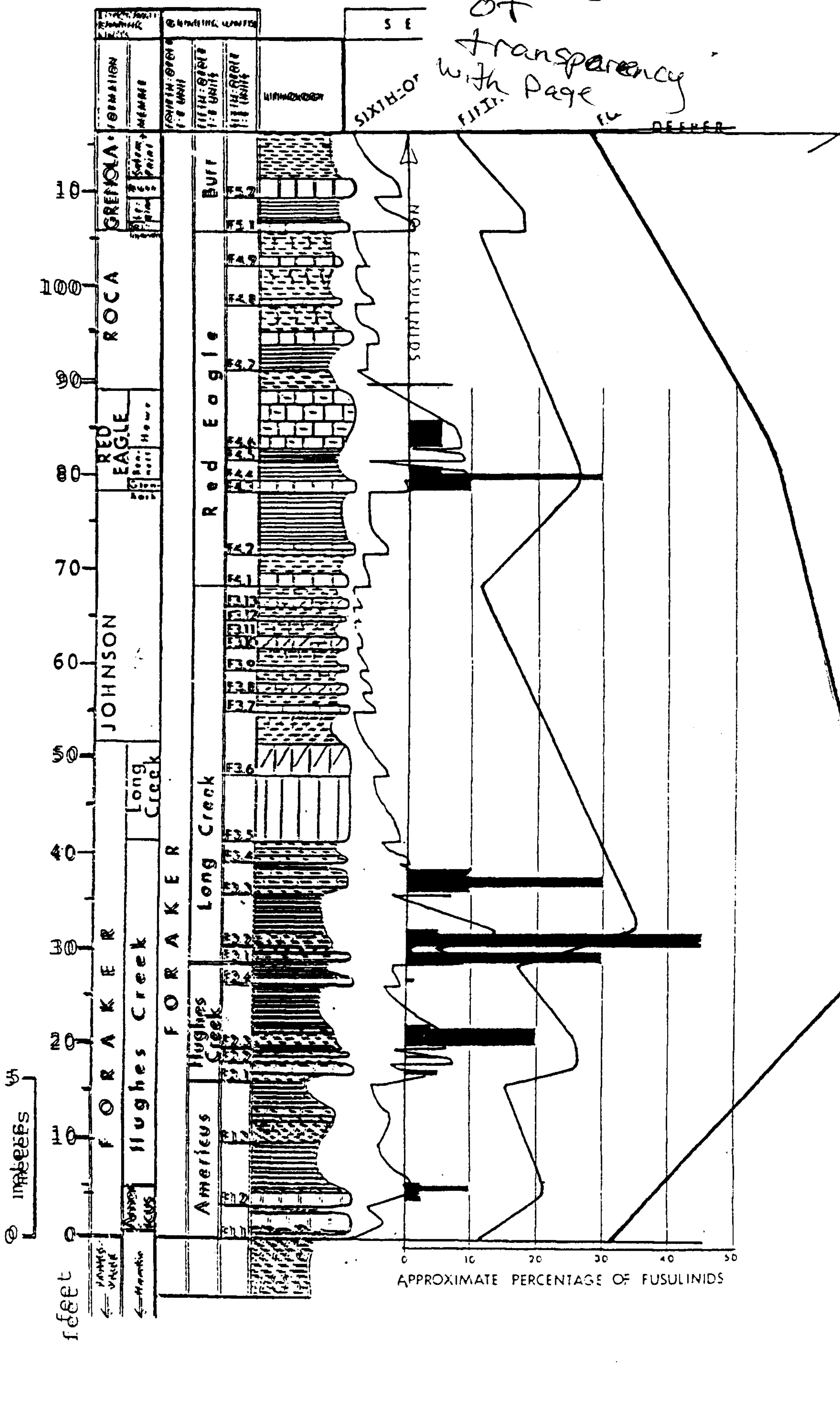

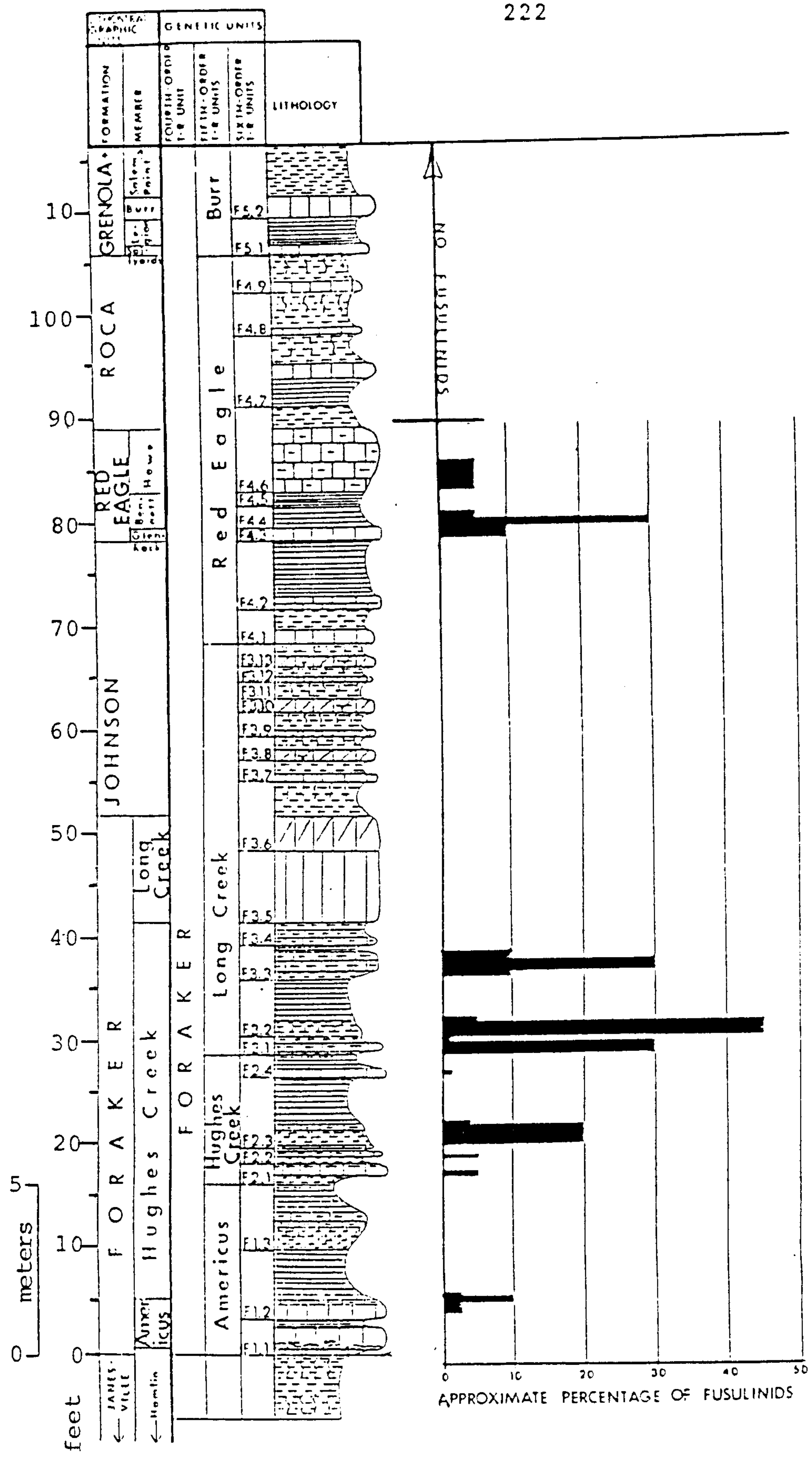
GENETIC UNITS
FORMATION
MEMBER
FOURTH-ORDER T-R UNIT
FIFTH-ORDER T-R UNITS
SIXTH-ORDER T-R UNITS
LITHOLOGY
GRENOLA
ROCA
RED EAGLE
JOHNSON
FORAKER
Long Creek
Hughes Creek
Americus
Burr
Red Eagle
Long Creek
Hughes Creek
Americus
F5.2
F5.1
F4.9
F4.8
F4.7
F4.6
F4.4
F4.2
F4.1
F3.7
F3.6
F3.5
F3.4
F3.3
F3.2
F3.1
F2.4
F2.3
F2.2
F2.1
F1.3
F1.2
F1.1
NO FUSULINIDS
APPROXIMATE PERCENTAGE OF FUSULINIDS
0
10
20
30
40
50
meters
feet
JANESVILLE
Hamlin

fourth-order transgressive apex.

It is very evident from the above information that fusulinid occurrences of this study tend to correspond with transgressive apices on a sixth-, fifth-, and fourth-order scale. The increase in fusulinid percentages toward the Foraker fourth-order transgressive apex is also supported by Fisher's (1971) work on the population dynamics of fusulinid "zones" in my units F2.3, F3.1, F3.2, and F3.3 at the Paxico and East Paxico localities. For example, at the Paxico locality he quantitatively calculated that the fusulinid density of the main zone in my F3.1 (Figure 55) was approximately 5,500 fusulinids per 1000 cubic cm.; whereas, the main zone corresponding to F3.2 (the zone below the fourth-order transgressive apex) contained an average 36,000 fusulinids per 1000 cubic cm. Above the transgressive apex in F3.3 the fusulinid biofacies contained approximately 6,600 fusulinids per 1000 cubic cm.

Ecological Interpretations of Fusulinids

Ecological interpretations of fusulinids are essentially hampered because fusulinids are extinct. As noted by Ross (1969, p. 298), "In studying the paleoecology of fusulinids, we are not only studying an extinct suborder of Foraminiferida but most of the other associated organisms, such as rugose and tabulate corals, trepostome and cryptostome bryozoans, orthid, rhynchoporacean, productacean, and spiriferid brachiopods, and inadunate, flexible, and camerate crinoids, are representatives of subclasses, orders, and families that are also extinct". A number of studies have utilized the stratigraphic positions of fusulinids relative to other faunal assemblages, lithostratigraphic and sedimentological features, and morphologic characteristics of fusulinids, to make ecological interpretations.

Fusulinids were utilized by Elias (1937; 1964) as paleoecologic depth indicators of culminating marine conditions in the Permian strata of Kansas (e.g., Figure 8). Elias ascribed a depth of 160 to 180 feet to fusulinids based primarily on three factors: 1) comparison to modern foraminiferids; 2) the central position of fusulinids between diverse brachiopod assemblages; and 3) comparison to similar depth estimates of Uralian fusulinids by Rauser-Chernousova (e.g., Elias, 1964). Moore (1936, 1964) also agreed that fusulinids represented maximum marine conditions but regarded fusulinid facies as being representative of "maximum offshore" conditions, rather than "maximum water depth". This conclusion is advocated by Thompson (1964) who suggested that fusulinids penetrated continental basins most extensively during times of maximum marine inundation.

Imbrie *et al*. (1959, 1964), and Laporte (1962) asserted that fusulinids of the Beattie Formation (Lower Permian, Council Grove Group) reflect deposition in agitated waters less than 30 feet deep. They based their estimates on the association of fusulinids with osagid grains, and the occurrence of conspicuous scour-and-fill structures, and cross-bedding in their "fusuline facies". They considered their "*Chonetes* facies" of the Florena Shale Member as representing maximum depth of deposition. This was based on the lack of fusulinids in their geographically "deeper" facies tracts in southern Kansas. However, Moore (1964) considered their stratigraphy as improperly correlated and incomplete, and noted that there are indeed fusulinid facies in the Beattie Formation of southern Kansas that could potentially represent deeper marine conditions. McCrone (1963, 1964) also recognized the association of algae with fusulinids, and estimated depths of fusulinid accumulation at approximately 70 feet. He agreed with Elias (1937) that fusulinid assemblages represent culminating marine conditions; also the opinion of Hattin (1957).

Work on fusulinids outside Kansas (e.g., Ross, 1961, 1965, 1969; Stevens, 1969, 1971) has shown that fusulinids probably inhabited a wide depth range in a variety of habitats. For example, when Ross (1961) plotted the occurrence of fusulinids (from the Leonard Formation in the Glass Mountains of Texas) on a grid, with carbonate grain-size plotted against quartz-silt and clay percentages, he found discrete groupings of certain species of *Parafusulina* and *Schwagerina*. Ross (1965) also recognized that different species of fusulinids, with similar morphologies, were associated with distinct lithologic facies of the Gaptank Formation in west Texas. On a more regional scale including central, northern, and western Texas, Ross (1969) found that fusulinids were restricted to the shallow carbonate and clastic depositional shelves, and were essentially absent in the "starved" basins. He also found that elongate species of Triticites were found in impure silty limestones and fine to medium sandstone, indicative of shallow interdistributary bays, lagoons, wave-built bars and wave-built terraces. Larger fusiform specimens were predominately found in shallow water "algal meadows", banks of crinoidal fragments, and coarse calcarenites suggestive of an environment similar to that of the present day Florida Bay. Smaller fusiform species of Triticites were found in poorly sorted limestones which Ross (1969) interpreted as representing deeper-water shelf areas that extended down to effective wave base. Most recently, Ross (1983) has suggested that most fusulinids were restricted to depths less than 15 to 20 meters.

Fusulinids from the Pennsylvanian Minturn Formation of central Colorado occur in calcareous facies that represent outer shelf environments (Stevens, 1969, 1971). Stevens (1969, 1971) calculated that Minturn fusulinids lived in water depths ranging from 20 to 70 meters, an interpretation similar to that of Elias' (1937).

Perhaps one of the more significant paleoecologic attributes of fusulinids is their relatively large size, compared to other foraminiferids. They also have external morphologies that are similar to the isomorphic modern miliolinids, the Alveolinidae. Ross (1979, 1983) pointed out that most of the larger tropical, living foraminiferids have zooxanthellae as a photosynthetic, symbiotic partner, and that most Fusulinaceans probably hosted similar symbiotic relationships. Thus, fusulinids would have been restricted to the photic zone. A direct comparison of living and dead alveolinids versus fusulinids was made by Severin and Lipps (1987). They concluded that fusulinids may have accumulated in much the same manner as alveolinids as a result of the following conditions: 1) ocassionally disturbed but rather stable substrates; 2) slow test production; 3) long test endurance; and 4) low effective test densities which caused test concentration near the sediment-water interface. Reiss and Hottinger (1984) have shown that alveolinids are actually capable of buring themselves in coral sands of the Gulf of Aqaba with the aid of polar pseudopodia. The alveolinids also use the pseudopodia to "fix" or attach themselves to hard bottom substrates, and plants. Environmentally, extant alveolinids have a "clear provincial distribution", going back to Miocene times, ranging from coastal areas several meters deep (e.g., East Africa) to open ocean environments that are tens-of-meters deep (e.g., Red Sea, Caribbean, and the Indian Ocean; Reiss and Hottinger, 1984).

It was observed in the field and laboratory that each fusulinid biofacies of the Foraker Formation contained a diversity of fusulinid morphologies. For example, in F2.3, F3.1, F3.2, and F3.3 large ventricose, fusiform, elongate fusiform, and globose forms of fusulinids were observed in each biofacies. Fisher (1971) recognized this also. Although these differences in fusulinid morphologies may be different growth stages, or different species, there appears to be a discrete difference in fusulinid morphology between F3.3 and the other fusulinid biofacies. In F3.3 the fusulinids are discretely of a larger (e.g., 7mm axial length) ventricose form, whereas the fusulinids of F3.2 are predominately smaller and fusiform (e.g., 4mm axial length). Ross (1969), found that larger ventricose forms were indicative of shallower, more highly agitated conditions; whereas, the smaller fusiform types were found in facies interpreted as representing deeper, more offshore environments. Indeed, the larger fusulinids of F3.3 are occasionally encrusted with Osagia, indicating well lit, highly agitated conditions.

Fusulinids of the Foraker Formation also inhabited a wide range of substrates, including pure micritic mud (e.g., in F1.2, F2.1, and F2.4), argillaceous carbonate mud (e.g., F1.2, F2.2, 2.3, 3.1, 3.2, 3.3) and very calcareous shales (e.g., F2.3, F3.2). Thus, fusulinids do not appear to have been substrate controlled. Fusulinid populations probably developed best in environments where nutrients readily accumulated, and/or in well lit environments, where symbiotic algae could be produced (e.g., see Ross, 1983). Ross (1969) pointed out that fusulinids were probably adapted to variations such as salinity, temperature, Eh, pH, turbidity, currents, and associated biota, instead of slight differences in water depth. It appears that fusulinids were effected by extrinsic factors, the most important of which was eustatic sea level changes (Figure 55 and overlay).

Fusulinids of the Foraker Formation inhabited a wide range of environments. For example, the fusulinid biofacies of F1.2 grades and shallows upward into a Crurithyris biofacies (a relatively nearshore, eurytopic indicator, e.g., Brezinski, 1983; Wells 1984). On the other hand, the most discrete fusulinid biofacies of the Hughes Creek fifth-order T-R unit (F2.3) contains a diverse, open marine fauna with Reticulatia, Composita, Neospirifer, crinoids, and ramose bryozoans. It is overlain by a diverse, open marine Neospirifer-Composita-Reticulatia biofacies. Accordingly, fusulinids of F1.2 lived in a relatively nearshore environment, that was adjacent to, and seaward of, the more restricted Crurithyris-rich environment in which only rare fusulinids can be found. The fusulinid biofacies of F2.3 accumulated in a more normal marine environment that was more conducive to open marine brachiopod taxa (high-level suspension feeders).

Fusulinid zones can be characterized as massive zones or relatively thin, underdeveloped zones. Where fusulinid zones (biofacies) are most massive (i.e., F2.2, F2.3, F3.2, and F3.3) they tend to be associated with (i.e., are conformably overlain or underlain by) a relatively diverse brachiopod biofacies. Where fusulinid zones are least massive and most underdeveloped (e.g., F1.2, F2.1, F2.4), they are characteristically associated with a nondiverse *Crurithyris* biofacies. Massive fusulinid zones associated with the more open, offshore marine conditions are geographically widespread, and make good marker beds. This indicates that they represent environmentally uniform conditions across the study area for those times (e.g., Figures 27, 32, 33, 36). During less open, initial transgressive and net regressive conditions, fusulinids are restricted in their geographic extent. For example, during the maximum transgressive conditions of F2.1 (Figure 31), fusulinids were most abundant in the southern part of the area, in a seaward direction away from the shallower, osagid-brachiopod-*Isogramma* biofacies. This decrease in algal content and shallow molluscan taxa, accompanied by an increase in fusulinid abundance, is a common phenomenon that has been documented by other workers. In particular, Stevens (1969) has documented an increase in faunal diversity and fusulinid abundance away from his "loferitic facies" in the Pennsylvanian Minturn Formation of central Colorado. Moore (1949, 1964) documented a gradual decrease and eventual loss of osagid-algal and *Ottonosia* biofacies that was accompanied by an increase in abundance of fusulinids in the Wakarusa limestone (Upper Pennsylvanian), from northern Oklahoma to central Kansas.

This report is in disagreement with Elias (1937, 1964) who regarded all fusulinid biofacies of the Foraker Formation as representative of maximum offshore marine conditions and depths of 160-180 feet (48-55 meters). Fusulinids of the Foraker Formation are clearly associated with a variety of biofacies that occupied a wide range of marine environments and depths from relatively nearshore (a few meters deep?), to intermediate, to most offshore (10-20 meters deep?).

Hierarchal Paleoecology/Evolution of Fusulinids

The foregoing information clearly indicates that hierarchal genetic (T-R unit) stratigraphy can be used to explain the distribution and evolution of fusulinids, including those of the Foraker Formation. That is, fusulinids evolved, dispersed, interacted, and declined relative to sea level changes that caused the development of the Busch and Rollins (1984), and Busch and West (1987) hierarchy of Permo-Carboniferous T-R units. This relationship is summarized in Table 1.

Sixth-order T-R units defined in this study are actually conformably-stacked lithofacies/biofacies tracts (Table 1), as previously noted. The lithofacies/biofacies of each

TABLE 1: HIERARCHAL PALEOECOLOGY/EVOLUTION OF FUSULINIDS

SCALE OF T-R UNIT OR CYCLE OF SEA-LEVEL CHANGE	BIOLOGICAL PROCESSES	RESULTS
Second-Order	Radiations/declines of fusulinid superfamilies, families, subfamilies, and some genera.	Fusulinid Biostratigraphy based mainly on superfamilies, families, and subfamilies; Fusulinid Biogeographic Realms (Ross and Ross, 1985a).
Third-Order	Radiations/extinctions of fusulinid genera and some species.	Fusulinid Biostratigraphy using genus and some species zones.
Fourth-Order	Origin/extinctions of some fusulinid species; extinctions, ecological displacements, and dispersals between provinces for many shallow marine species (Ross and Ross, 1985b).	Fusulinid Biostratigraphy using some species; i.e., lowest (most) detailed) level of fusulinid biostratigraphy. Fusulinid Provinces (Ross and Ross, 1985b)
Fifth-Order	Ecological displacements and dispersals of species within provinces. Most significant and obvious phenotypic variation.	Unconformably stacked sequences (i.e., fifth-order T-R units) of conformably stacked biofacies that may contain fusulinids (i.e., sequences of biofacies tracts, or sixth-order T-R units): Fusulinid Ecostratigraphy
Sixth-Order	Ecological migration and dispersal of species within provinces (as members of biofacies with or without ecotones) in response to allogenic changes of sea-level; Phenotypic variation; Colonization of new areas and community succesions/replacements.	Conformably stacked biofacies that may contain fusulinids (i.e., sequences of biofacies tracts, or sixth-order T-R units);that are bounded by transgressive surfaces; Fusulinid Ecostratigraphy.

sixth-order T-R unit represent environmental areas that migrated in Walther's Law fashion relative to allogenic sixth-order changes of sea-level. The boundary between any two of these facies is typically ecotonal (gradational); however, there are exceptions to this (e.g., current-scoured contacts overlain by contrasting facies). As sixth-order T-R units accumulated, fusulinids interacted with other taxa in particular environments; which led to their dispersal, decline, or demise, within limited areas of provinces. In this sense, biofacies are the net accumulation of repeated community successions (seres), community replacements, ecotones between communities, migrations of taxa, and declines of taxa, that have been temporally, taphonomically, and spatially averaged as a stratigraphic entity. Rarely, however, single events may be preserved within a particular biofacies. For example, storm disruptions and seral development of reefs could produce sorted storm deposits (tempestites) and patch reefs, respectively.

The boundaries of sixth-order T-R units are commonly disjunct (unconformable) contacts between lithofacies/biofacies that formed at maximum regression, and overlying lithofacies/biofacies that formed during an ensuing sixth-order transgression. Such surfaces are commonly sharp, because they represent displacements of lithofacies/biofacies at nondepositional (omission) or erosional surfaces. On the other hand, not every sixth-order genetic surface (boundary) is a disjunct (unconformable) contact. In some cases it is simply the surface marking the end of a sixth-order regression (i.e., base of an overlying, relatively deeper lithofacies/biofacies). Such a sixth-order genetic surface is actually conformable, but still marks the exact positions in the stratigraphic record where sixth-order regression/progradation ended and sixth-order transgression/retrogradation began. As previously noted, such surfaces are often manifested as the contact between a series of biofacies in which fusulinids decline in abundance, and a series of biofacies in which fusulinids dramatically increase in abundance (e.g., surface F3.2 at Paxico, and Manhattan sections; Figure 55).

Each fifth-order T-R unit of the Foraker and associated formations is essentially a T-R unit composed of nested sixth-order T-R units that have been grouped into a larger T-R unit, based on the relative extent of sixth-order transgression. As such, fifth-order T-R units are unconformably-stacked (i.e., at sixth-order genetic surfaces) sequences of conformably-stacked lithofacies/biofacies tracts (i.e., sixth-order T-R units). The sixth-order T-R units, and their bounding genetic surfaces, are thus temporally and spatially averaged into what is regarded as a fifth-order T-R unit bounded by fifth-order genetic surfaces. Variation in the extent of biofacies displacements and faunal migrations among the temporally averaged sixth-order T-R units, within each fifth-order T-R unit, has produced a fifth-order record of variable dispersals/declines of fusulinid species within provinces. Furthermore, phenotypic variation from base to top of a fifth-order T-R unit can be dramatic for any taxon, a factor that undoubtedly plays a role in the evolution of new species.

Fourth-order T-R units are composed of nested fifth-order T-R units that have been temporally and spatially averaged on the basis of the relative extent of the fifth-order transgressive apices. Therefore, when the effects of fifth-order processes are averaged to a fourth-order scale, they become more obvious (magnified). For example, the ecological displacements of fusulinids become temporally averaged as even more widespread net dispersals and declines between provinces (Ross and Ross, 1985a). The combination of this factor and the long term (i.e., fourth-order) effects of fifth-order phenotypic variations cited above, apparently led to the evolution and extinction of fusulinid species. Some fusulinid species are indeed index fossils for specific fourth-order T-R units (e.g., Triticites ventricosus of the Foraker fourth-order T-R unit). The fourth-order scale is thus the smallest scale at which fusulinid biostratigraphy is effective (e.g., Ross and Ross, 1985b).

Fourth-order processes and effects are, in turn, more obvious and magnified when temporally averaged at the third-order scale. Radiations and extinctions of fusulinid genera (and some species) at the third-order scale provide a biostratigraphic framework for this scale that is based mainly on genera (Figure 52). The dispersal of genera between provinces at this scale, has also resulted in a worldwide framework of fusulinid zones based on genera (Figure 52). Temporal/spatial averaging of these third-order phenomena has also resulted in the worldwide framework of fusulinid biostratigraphy that is mainly based on temporal ranges of subfamilies, families, and superfamilies (e.g., Figure 56).

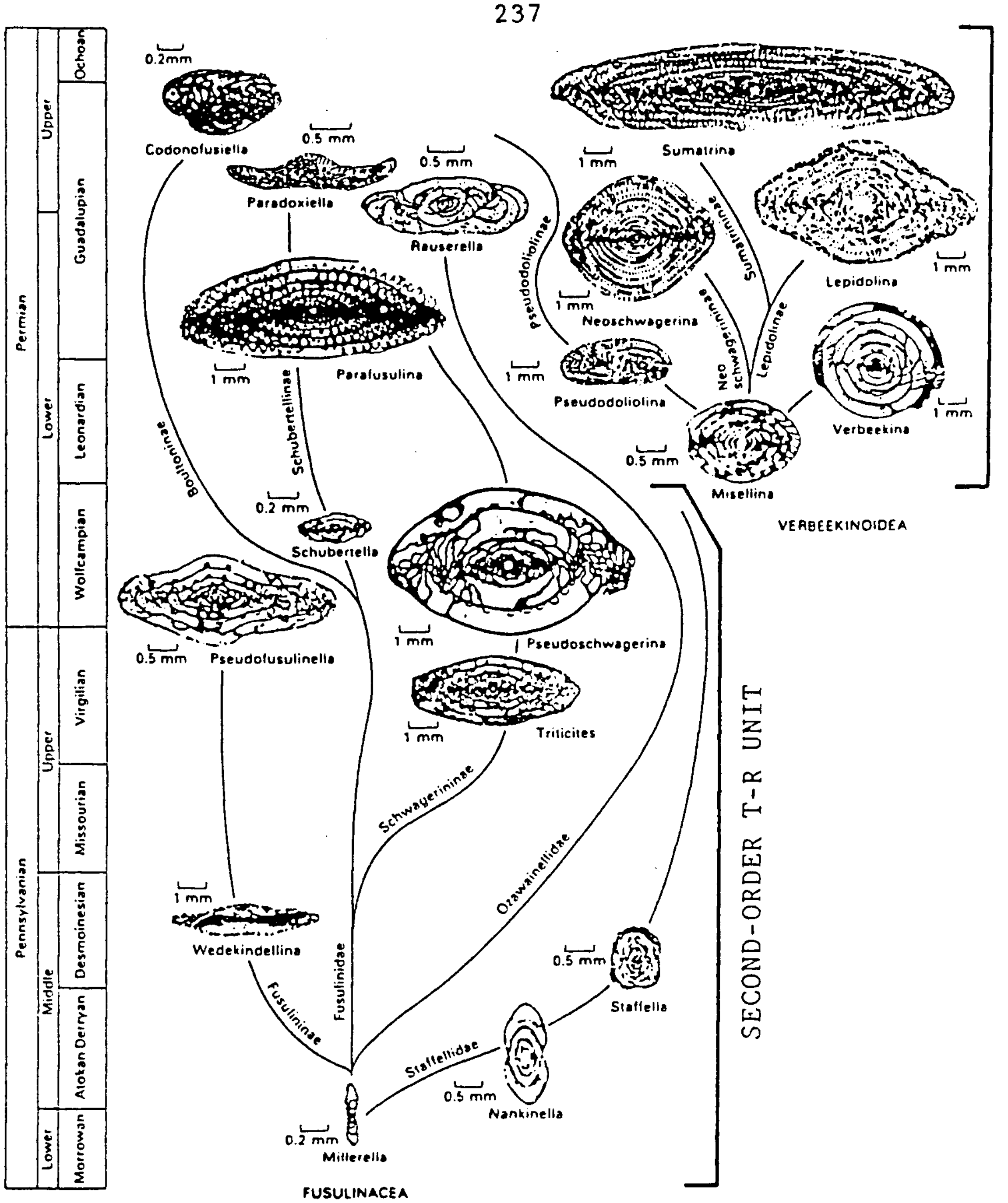

Figure 56. Simplified phylogeny of two superfamilies (with a few representative genera shown in axial section) of fusulinids (adapted from Douglass, 1987) modified to show its relationship to second-order T-R units (see Figure 51). The Verbeekinoidea evolved and diversified entirely within the Leonardian-Ochoan second-order T-R unit. The Fusulinacea evolved and diversified within the Morrowan-Wolfcampian second-order T-R unit, but they declined within the Leonardian-Ochoan second-order T-R unit.

CONCLUSIONS

This study has provided detailed analyses of the lithostratigraphic, biostratigraphic, paleogeographic, and structural development of the Foraker Formation by utilizing hierarchal genetic (T-R unit) stratigraphy. The establishment of a hierarchy of T-R units in the Foraker Formation has provided a wealth of detailed, new data concerning facies and facies contacts that were not provided by other methods. Establishing a viable correlation of sixth-, fifth-, and fourth-order T-R units that are associated with the Foraker Formation, provides a valid paleoceanographic framework. Transgressive-regressive units (inclusive of PACs) are pervasive throughout the study area.

Detailed stratigraphic analysis of each sixth-order T-R unit, provided the necessary data to construct sixth-order paleogeographic maps. Sixth-order paleogeographic and isopach maps, when viewed separately and in combination, help provide an understanding of depositional controls during Foraker deposition, as they are intimately associated with the structural framework of the area. Depositional features that are detected at a sixth-order scale, might otherwise be masked by mapping at larger scales. The Busch (1984), Busch and Rollins (1984), and Busch and West (1987) method of hierarchal genetic (T-R unit) stratigraphy should provide new data concerning more regional chronostratigraphic relationships and additional controls on Foraker facies development, particulary in Nebraska, southern Kansas, and northern Oklahoma. Additional data on community successions, community replacements, ecotonal characteristics, migrations and declines of taxa, and hierarchal evolutionary aspects, for example of fusulinids, will be provided by this method of genetic stratigraphy.

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A P P E N D I X

Locality descriptions based on field and laboratory analysis. "TA" at the end of a unit description refers to the facies representing the transgressive apex within each sixth-order T-R unit. Those units that were either thin sectioned or analyzed by sieve analysis are listed at the end of the locality descriptions. The locality descriptions occur in alphabetical order as listed below.

Page No.

State: Kansas County: Lyon Quadrangle: Allen

Locality Description:

Admire Locality (Ad)
Section exposed in road ditches on both sides of road, immediately south of the Wabaunsee-Lyon county line.

Section measured from the middle of the Hughes Creek Shale of the Foraker Formation, down into the Americus Limestone.

Interval measured August, 1986

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— - - - Climate Change Surface	Unit Thicknesses ft	in	m
F2 (HUGHES CREEK)	F2.4	22. Hughes Creek Shale: limestone, light gray, weathers tan-orange; blocky; hard; argillaceous; calcarenite, medium, slightly silty, pelecypod, gastropod, biomicrite; wackestone to mudstone; unit also contains bellerophont gastropods, high-spired gastropods, echinoid fragments, bryozoans, and crinoids; top of unit concealed.	0	7	.18
	F2.3	21. Hughes Creek Shale: shale, olive to gray olive; weathers light gray; micaceous; contains trace amounts of productid spines and shell fragments.	1	0	.30
		20. Hughes Creek Shale: limestone, gray, weathers light tan-gray; very argillaceous; the lower 8" is intermediate between a very argillaceous calcirudite, and a very calcareous shale; blocky to slightly nodular; unit contains large articulated Neospirifer, common Composita, Wellerella, Hustedia, ramose, fenestrate, and incrusting bryozoa, common Neochonetes, echinoid fragments, fusulinids which are abundant in the lower 8" (25%), and decrease up the unit; and crinoids. unit is considered a shaley, calcirudite, fine, brachiopod, bryozoan, fusulinid, crinoidal, biomicrite; wackestone to packstone; TA	1	4	.41
		19. Hughes Creek Shale: shale, olive-gray; blocky, very calcareous; micaceous; contains abundant large and small fusulinids (approximately 20-30% of the lithology), crinoids, rare Hustedia, bryozoa fragments, and other lesser brachiopod fragments.	0	5	.13
		18. Hughes Creek Shale: limestone, light gray, weathers gray-tan; very argillaceous; massive; flaggy to platy in part; calcirudite, fine, fusulinid, biomicrite; unit also contains Neospirifer, Composita, broyozoa fragments, crinoids, echinoid fragments; fusulinids are approximately 20% of the lithology.	0	8	.20
	F2.2	17. Hughes Creek Shale: shale, gray to olive, weathers gray to orange-olive; fissile to blocky, calcareous; contains rare fusulinids, Crurithyris, Linoproductus, and productid spines.	0	3	.08
		16. Hughes Creek Shale: limestone, gray, weathers light gray; flaggy to platy; very argillaceous; calcarenite, medium, Crurithyris, fusulinid bearing, biomicrite.	0	3	.08
		15. Hughes Creek Shale: limestone, gray, weathers yellow-gray; hard; blocky; argillaceous; calcirudite, fine, brachiopod, fusulinid bearing, biomicrite; contains abundant overlapping Crurithyris, crinoids, and other brachiopod fragments; fusulinids rare.	0	5	.13
		14. Hughes Creek Shale: shale, olive to gray-olive; weathers light gray; fissile to blocky; calcareous; contains common to abundant Neochonetes, Crurithyris, Reticulatia, rare echinoid fragments, bryozoans, Neospirifer, and Composita; TA.	0	6	.15
	F2.1	13. Hughes Creek Shale: limestone, dark gray, to blue-gray, weathers light tan-gray; blocky to slabby; argillaceous; calcirudite, fine, Crurithyris, biomicrite; also contains rare bryozoan fragments; echinoid plates and spines; the upper 1/2" contains thinnly interbedded calcareous shale lentils.	0	3	.08

Admire section continued

12.	Hughes Creek Shale: limestone, olive-gray; weathers light yellow-gray; very argillaceous; blocky to hackly; in thin-section is a calcirudite, fine, clayey, slightly silty, brachiopod, fusulinid, biomicrite; fusulinids are abundant and account for approximately 30% of the lithology; contains abundant brachiopod fragments including Composita, Wellerella Neochonetes, and Crurithyris; unit also contains arenaceous forams (biserial), crinoids, fenestrate bryozoa fragments; also contains rare Aviculopecten; TA.	0	8	.20
11.	Hughes Creek Shale: shale, olive to gray-olive; weathers light olive; blocky to fissile; noncalcareous; silty; micaceous; contains common ostracodes.	2	0	.61
10.	Hughes Creek Shale: shale, orange to brown, blocky, limonitic; contains common ostracodes.	0	1	.02
9.	Hughes Creek Shale: shale, dark gray, weathers light olive-gray; blocky to fissile; noncalcareous; contains rare to common ostracodes, and nuculoid bivalves.	2	2	.66
8.	Hughes Creek Shale: shale, dark gray, weathers light gray, contains thinnly interbedded brown shale, noncalcareous; limonitic; fissile, contains common Lingula, lying parallel to bedding.	0	6	.15
7.	Hughes Creek Shale: shale, olive to olive-gray, weathers light olive; fissile to blocky; calcareous; micaceous; non-silty; contains rare Crurithyris, and productid fragments.	0	6	.15
6.	Hughes Creek Shale: shale, gray-olive, weathers olive; blocky; to fissile; micaceous, calcareous, and limonitic; contains common Neochonetes, Crurithyris, and productid fragments.	0	6	.15
5.	Hughes Creek Shale: shale, dark gray, weathers light gray; very calcareous; hackly to platy; massive; contains common, articulated, Reticulatia, Composita, Neospirifer, rare Neochonetes, crinoids, and Crurithyris.	1	11	.58
4.	Hughes Creek Shale: shale, olive to olive gray, weathers light gray; very calcareous (more than unit above); hackly; micaceous; unit contains common, articulated and fragmented Composita, Hustedia, Neochonetes, Reticulatia, Neospirifer, Derbyia, Crurithyris, Linoproductus, crinoids, ramose and fenestrate bryozoa, and rare Juresania, and Lissochonetes; unit contains common argillaceous, immature, calcarenite-biosparite lenses containing brachiopod fragments aforementioned; (sieve analysis); TA.	1	4	.41
3.	Hughes Creek Shale: shale, gray-olive; blocky to fissile; slightly micaceous, slightly calcareous; contains common productid fragments in the lower 2" and rare to common fusulinids in the lower 1-2"; Crurithyris throughout. fossils decrease in abundance up the unit.	1	0	.30
2.	Hughes Creek Shale: limestone, gray to dark gray; weathers light gray; hackly, argillaceous; calcirudite, fine, fusulinid, biomicrite; fusulinids account for approximately 15-20% of the lithology; unit also contains common crinoids, and rare brachiopod fragments.	0	2	.05
1.	Americus Limestone: limestone, gray, weathers yellow-gray; massive; blocky; hard; poorly exposed; in thin section is a calcirudite, fine, slightly argillaceous, crinoidal, brachiopod, fusulinid, biomicrite; fusulinids account for approximately 10% of the lithology, and decrease in abundance toward the base (accompanied by an increase in brachiopod fragments); crinoids abundant throughout (20%); unit also contains rugose corralites; rare to common pelecypod fragments, bryozoan fragments, Neochonetes, and ostracodes; TA.	1	2	.35

Thin section data was used to supplement descriptions of the following units: 1, 4, 12, 15, 18, 20, 22.

State: Kansas County: Lyon Quadrangle: Allen

Locality Description:

Allen locality (Al)
C N½ SE¼ sec. 26, T15S, R11F
Section measured in a roadcut, just to the west of One Hundred and Fortytwo Mile Creek
Section measured from the Long Creek Limestone of the Foraker Formation down into the upper Hughes Creek Shale.

Interval measured August, 1986

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— - - - Climate Change Surface	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.5	14. Long Creek Limestone: algal laminite, gray, thinnly laminated, planar to slightly wavey and mudcracked; dolomitic, with very thin interbedded, nonfossiliferous, argiliaceous calcilutites.	0	4	.10
		13. Long Creek Limestone: limestone, light tan-yellow, weathers tan; blocky, medium hard; argillaceous; massive; dolomitic; calcilutite, fossiliferous micrite; contains common Aviculopecten, and rare gastropods.	1	1	.33
		12. Long Creek Limestone: limestone, light tan-yellow, weathers tan-gray; blocky, hard, argillaceous, dolomitic, massive; calcilutite, fossiliferous micrite; vuggy with calcite and celestite linings; contains rare to common bellerophont gastropods; rare Aviculopecten, and Permophorus.	1	0	.30
		11. Long Creek Limestone: limestone, light tan, weathers tan-yellow; blocky; medium hard; argillaceos; linomitic, and dolomitic; calcilutite, fossiliferous, micrite; contains rare Aviculopecten, gastropods, Permophorus, and rare crinoids; chert bearing; TA.	1	7	.48
	F3.4	10. Hughes Creek Shale:. shale, tan-olive, weathers light tan-gray; blocky; silty; noncalcareous; micaceous; contains common plant fragmets that become abundant in the upper 1"; fissility increases up the unit.	0	8	.20
		9. Hughes Creek Shale: limestone, tan-gray, weathers tan-yellow; argillaceosu, micaceous; silty; dolomitic; calcilutite, Permophorus and crinoidal (?) micrite; chert bearing; TA.	0	2	.05
		——?——————?——————?——			
	F3.3	8. Hughes Creek Shale: shale, olive, gray-olive; weathers light gray; blocky to fissile; noncalcareous, micaceous; slightly silty; contains rare inarticulate brachiopod fragments.	1	0	.30
		7. Hughes Creek Shale: shale, light olive to gray-olive, weathers light tan-gray; fissile, very calcareous; slightly micaceous; lower 1-2" contains abundant crinoids columnals, rare fusulinids, ramose and fenestrate bryozoan fragments, rare Composita, and rare Neospirifer.	0	5	.13
		6. Hughes Creek Shale: limestone, gray, weathers tan-gray; blocky, to hackly; argillaceous; massive; calcirudite, fine, osagid bearing, brachiopod, fusulinid biomicrite; fusulinids account for approximately 30-35% of the lithology (thin section estimate); and are rarely incrusted with Osagia; also contains rare fenestrate bryozoans, crinoids, rare Neospirifer, Composita, crinoids, and other brachiopod fragments.	1	0	.30
		5. Hughes Creek Shale: limestone, gray, weathers light gray; very argillaceous; hackly to platy; massive; calcirudite, fine, shaley, brachiopod, fusulinid, crinoidal, biomicrite; contains abundant fusulinids (15%), common articulated Neospirifer, Reticulatia fragments, rare Meekella, echinoid fragments, large, well preserved crinoid stems (1-2"); unit grades to a very calcareous shale in the basal 2"; TA.	0	7	.18
		4. Hughes Creek Shale: shale, olive-gray; fissile, blocky; silty; micaceous; contains abundant Derbyia, Linoproductus, crinoids and other brachiopod fragments.	0	5	.13
		3. Hughes Creek Shale: limestone, gray to dark gray, weathers tan-gray; very argillaceous (grades to very calcareous shale); blocky; silty, micaceous; calcarenite, coarse, brachiopod, biomicrite; contains common fragmented Linoproductus, Spirorbis, Meekella, Derbyia, and Chondrites.	0	9	.23

Allen section continued

F3 (LONG CREEK)	F3.3	2. Hughes Creek Shale: shale, gray-olive; weathers light gray; blocky, slightly fissile; silty; micaceous; calcareous; contains common productid fragments.	0	8	.20
	F3.2	1. Hughes Creek Shale: shale, olive-gray, to dark gray; blocky to fissile; silty; noncalcareous; nonfossiliferous base of unit concealed. -Thin section data was used to supplement descriptions of the following units: 6, 9, 11, 12, 13, and 14.	0	7+	.18

State: Kansas County: Wabaunsee Quadrangle: Alma

Locality Description:

Alma Section (A)
SW¼ SW¼ NE¼ sec. 11, T12S, R10E
Section measured in a stream cut, along tributary that feeds into Mill Creek, at the west end of Clapboard Canyon; approximately 3/4 of a mile east of the town of Alma.

Section measured from the Long Creek Limestone of the Foraker Formation down into the lower portion of the Hughes Creek Shale.

Interval measured July, 1986

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— ---Climate Change Surface	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.9	33. Long Creek Limestone: limestone, tan-orange, weathers light tan-orange; argillaceous; blocky to flaggy; contains brown laminations throughout (algal origin?); calcilutite.	1	8	.51
		32. Long Creek Limestone: limestone, orange-brown, weathers orange-tan; flaggy; limonitic; dolomitic; hard; contains numerous vugs that are calcite and celestite filled; rare mudcracks; fossiliferous, calcilutite; contains fragmented (reworked, and probably transported) pelecypods; TA.	0	7	.18
	F3.8	31. Long Creek Limestone: algal-laminite, gray-brown; blocky to platy; thinnly laminated with thin interlaminated, non-fossiliferous, argillaceous calcilutite; dolomitic and mudcracked.	0	4	.10
		30. Long Creek Limestone: limestone, light tan, weathers gray-yellow; blocky to slabby; argillaceous; calcilutite, algal beraing micrite; contains dark brown algal laminations that become prominent in the upper 6"; dolomitic and bioturbated throughout causing mottled bedding.	1	2	.36
		29. Long Creek Limestone: limestone, huff-tan, weathers light yellow-tan; massive; laminated; dolomitic; argillaceous calcilutite.	1	4	.41
		28. Long Creek Limestone: limestone, buff-tan, weathers tan; platy to flaggy; argillaceous; fossiliferous, calcilutite. contains common Permophorus, horizontal burrows, and rare macerated plant fragments; TA.	0	8	.20
	F3.7	27. Long Creek Limestone: shale, gray, brown, weathers tan; argillaceous; calcareous; fractures hackly; contains abundant clay-filled .andomly oriented burrows.	0	3	.08
		26. Long Creek Limestone: limestone, tan-orange; weathers gray-gronw, blocky; argillaceous, limonitic, fo siliferous calcilutite; contains common Permophorus, and other pelecypod fragments; also contains orange clay-filled burrows toward the top of unit; TA.	1	2	.36
	F3.6	25. Long Creek Limestone: shale, gray-brown, weathers light tan; fissile; calcareous; silty; contains abundant plant fragments; and rare Aviculopecten in the lower 1".	0	3	.08
		24. Long Creek Limestone: limestone, tan-orange; weahters light tan; argillaceous; blocky toslabby; fossiliferous, calcilutite; contaisn common Permophorus, brachiopod fragments, crinoids; TA.	0	7	.18
	F3.5	23. Hughes Creek Shale: limestone, light tan-gray, weathers tan; very argillaceous; blocky; limonitic, nonfossiliferous calcilutite.	0	5	.13
		22. Hughes Creek Shale: limestone, tan-gray, weathers brown-gray; argillaceous; hard; blokcy; massive; contains abundant fusulinids (20-30%); also contains minor amounts of disarticulatid Neochonetes, Neospirifer, productid fragments; and crinoids; calcirudite, fine, fusulinid, biomicrite; TA.	3	0	.91
	F3.4	21. Hughes Creek Shale: interval con ealed, shale?	3	6	1.06
		20. Hughes Creek Shale: shale, olive-gray, fissile; calcareous; limonitic, contains sparse amounts of Crurithyris.	0	6	.15
		19. Hughes Creek Shale: claystone, olive, weathers gray-brown; hackly to blocky; calcareous; contains abundant fusulinids; also contains Neochonetes, crinoids, ramose and fenestrate bryozoans; fusulinids account for approximately 40% of lithology. TA.	2	0	.61

Alma section continued

F3	F3.1	18. Hughes Creek Shale: limestone, tan-gray, weathers olive-tan; blocky; hard; argillaceous; calcirudite, brachiopod, fusulinid, biomicrite; contains abundant fusulinids (30%); also contains Neochonetes, crinoids, Neospirifer, Composita, Crurithyris, and other brachiopod fragments; TA.	0	10	.25
F2 (HUGHES CREEK)	F2.4	17. Hughes Creek Shael: shale, gray-black; fissile; noncalcareous; contains abundant Orbiculoidea in the lower 4-6"; also contains abundant Crurithyris concentrated in bedding lags, and isolated individuals; unit also contains Lingula.	1	0	.30
		16. Hughes Creek Shale: limestone, orange-gray; weathers brown-orange; blocky; argillaceous; lower-half in thin section is a coarse calcarenite, osagid, crinoidal, brachiopod, gastorpod, pelecypod, echinoid, biomicrite; upper-half in thin section is a fine calcirudite, osagid (becomes thicker and more rounded grains), pelecypod (increase in abundance), gastropod, crinoidal, ostracode, brachiopod, biomicrite; packstone to wackestone; unit also contains Derbyia, Neochonetes, Crurithyris, and other brachiopod fragments; TA.	0	11	.28
	F2.3	15. Hughes Creek Shale: shale, gray-black to gray; weathers light gray; platy to fissile; slightly calcareous; contains light tan, thin interbedded, silty shales.	2	11	.89
		14. Hughes Creek Shale: limestone, gray, weathers olive; hackly to blocky; massive; shaley; calcirudite, brachiopod biomicrite; contains common Linoproductus, Neospirifer, Ditymopyge fragments, Composita, crinoids, myalinid bivalve fragments; unit contains rare fusulinids; TA.	0	11	.28
		13. Hughes Creek Shale: shale, olive-gray, weathers light tan; very calcareous, argillaceous; fractures blocky to hackly; contains abundant fusulinids (approximately 25%) that are poorly sorted, and well preserved, in random orientation; lower 4" contains rare productid fragments, and common crinoids.	3	0	.91
		12. Hughes Creek Shale: limestone, tan-gray, weathers yellow-gray; slabby to flaggy, very argillaceous to shaley; calcarenite; coarse, Crurithyris, Chondrites biomicrite; unit also contains rare Lingula fragments (reworked from unit below?), and crinoids.	0	2	.05
	F2.2	11. Hughes Creek Shale: shale, black-gray; weathers light gray; fissile; soft; slightly cacareous; contains rare Orbiculoidea; and common Crurithyris.	0	3	.08
		10. Hughes Creek Shale: limestone, gray, weathers yellow-gray; blocky; slabby; calcirudite, fine, clayey, brachiopod, fusulinid, recrystallized biomicrite; contains common articulated Hystriculina, Neospirifer, rare Composita, and other brachiopod fragments; Crurithyris is abundant in the upper 1"; common crinoids; fusulinids are rare to common in the lower-half of unit (less than 5%); unit also contains detritus-filled burrows (bifurcated) that are horizontal and conspicuous on the basal surface.	0	6	.15
		9. Hughes Creek Shale: shale, gray-black; weathers brown-gray; fissile; very calcareous; contains abundant Neochonetes, also contains large, well preserved ramos broyozoans, and small fragments of fenestrate bryozoans, crinoids, Neospirifer, Reticulatia, and other brachiopod fragments; TA	0	5	.13
	F2.1	8. Hughes Creek Shale: limestone, gray, weathers tan-yellow; blocky; hard; calcirudite, fine, brachiopod, fusulinid, Isogramma, biomicrite (thin section); fusulinids, Isogramma, and brachiopods are abundant in thin section; also contains common to rare echinoid spines, ostracodes, crinoids, and rare osagid incrusted grains; unit also contains articulated Reticulatia, Crurithyris, Wellerella; contains abundant Crurithyris in the upper 2" (accompanied by an increase in argillaceous content) and lower 2"; diversity of fauna is greatest in the middle of unit; TA.	1	3	.38

Alma section continued

F2	F2.1	7. Hughes Creek Shale: shale, olive-gray, blocky; fissile; calcareous; contains common amounts of Linoproductus (one in life position); rare articulated Crurithyris, and minor occurence of Chondrites.	0	8	.20
F1 (AMERICUS)	F1.3	6. Hughes Creek Shale: shale, dar olive-gray, weathers light gray; blocky; slightly cacareous to noncalcareous; nonfossiliferous; silty.	2	5	.74
		5. Hughes Creek Shale: shale, gray-black; blocky; slightly calcareous; contains common productid fragments; and ramose bryozoans.	0	2	.05
		4. Hughes Creek Shale: limestone, gray, weathers buff-tan; blocky, argillaceous; calcarenite, coarse, to fine calcirudite, pelecypod, crinoid, brachiopod biosparite; contains common Linoproductus fragments, Edmondia, common crinoids, and other pelecypod fragments (Aviculopecten); fossils highly fragmented forming packed biosparite (grainstone); poorly sorted in thin section.	0	3	.08
		3. Hughes Creek Shale: shale, gray-black, weathers tan-gray; blocky to fissile; contaisn large articulated Neospirifer, Reticulatia, Neochonetes, Wellerella, crinoid columnals, and bryozoan fragments.	0	6	.15
		2. Hughes Creek Shale: limestone, gray, weathers tan-gray; blocky; to platy; argillaceous (shaley); calcarenite, fine to medium, shaley, pelecypod bearing, osagid bearing, brachiopod, crinoidal biomicrite; contains common articulated Neospirifer, Reticulatia, Hustedia, Wellerella, Neochonetes, Wilkingia, crinoid columnals, Ditymopyge fragments, rare Straparolus; approximate percentage of argillaceous or shale content is 30-40% ; TA.	1	5	.43
		1. Hughes Creek Shale: shale, gray-black, to dark gray; weathers gray; blocky to fissile; very calcareous; contains thin interbedded, shaley, fossiliferous, calcilutite lenses throughout and contain common articulated Linoproductus; unit also contains Wilkingia (one in life position), Composita, and nuculoid bivalves; base concealed.	1	7	.48

-Thin section data was used to supplement descriptions of the the following units: 2, 4, 17, and 19.

State: Kansas County: Pottawatomie Quadrangle: Laclede

Locality Description:

Belvue locality (B)
NE¼ NE¼ sec. 20, T9S, R11E
Section measured in a roadcut (poorly exposed), starting approximately 3 miles north of Highway 24 in southern Pottawatomie County.

Section measured from the Hughes Creek Shale of the Foraker Formation down into the Hamlin Shale of the Johnson Shale Formation. Interval measured August, 1986; complete Foraker interval was measured at the same locality, in a fresh roadcut by Scott, Foster, and Crumpton, 1959.

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— - - - Climate Change Surface	ft	in	m
F1 (AMERICUS)	F1.3	12. Hughes Creek Shale: limestone, tan-gray, to red-gray; weathers tan; flaggy to blocky; limonitic; slightly nodular in the lower 6"; argillaceous; in thin section, lower and upper halves are calcirudites, fine to medium, immature, poorly washed, osagid, biosparites; osagid grains are bean-shaped and rounded, and most of the fragments (nuculei) are recrystallized beyond recognition; osagid grains account for approximately 60-70% of the lithology; other disarticulated and fragmented fossils include Wellerella, Neospirifer, Neochonetes, Straparolus, echinoid spines, incrusting bryozoa (incrusting echinoid spines and larger brachiopod fragments); fenestrate bryozoa fragments; crinoids; and other pelecypod fragments; unit is moderately to poorly sorted; packstone to grainstone; TA.	1	7	.48
		11. Hughes Creek Shale: shale, olive to gray-olive; blocky, very silty; calcareous; contains productid fragments.	0	6	.15
	F1.2	10. Hughes Creek Shale: shale, olive, gray; blocky; noncalcareous; silty; nonfossiliferous; poorly exposed; base concealed.	0	10+	.25
		9. Hughes Creek Shale: interval concealed; shale as above?	7	1	2.16
		8. Americus Limestone: limestone, gray to tan-gray; weathers tan; blocky; massive; hard; calcirudite, fine to medium; crinoidal, fusulinid bearing, brachiopod biomicrite; contains rare to common fusulinids toward the top of unit; crinoids are abundant throughout; unit also contains echinoid and pelecypod debris; TA.	1	0	.30
		7. Americus Limestone: shale, light tan-brown; calcareous; blocky; contains thinnly interbedded calcarenite lenses with common crinoids and brachiopod fragments (productids); sharp contact with unit below.	0	3	.08
	F1.1	6. Americus Limestone: shale, light tan, to olive; blocky; very calcareous; contains clay nodules throughout; nonfossiliferous.	0	4	.10
		5. Americus Limestone: limestone, light tan-gray to tan-yellow, weathers dull gray; hard; blocky; the lower 2"-4" contains cryptalgal structures (Collenia?); the algal structures average 6" in diameter, and approximately 4" in height; inbetween algal domes is an calcarenite, coarse to medium, ostracode, pelecypod, brachiopod, crinoidal, intraclast, biomicrite (packstone); contains large, common disarticulated myalinid bivalves; rare Meekella, fenestrate bryozoan fragments; crinoids and ostracodes; unit also contains common edgewise grains and thinnly interbedded flaser-like shale lentils; the larger myalinid bivalves occur mostly in the upper 6", which becomes a wackestone; TA.	1	8	.51
		4. Americus Limestone: limestone, tan-orange; massive; very argillaceous; contains abundant carbonate and clay grains, angular and moderately to poorly sorted in a micritic matrix; coarse calcarenite (calclithite to shale-arenite); also contains rare plant fragments and ostracodes.	0	3	.08
		3. Hamlin Shale: claystone, light tan to olive tan; blocky; massive; contains common ostracodes.	0	5	.13
		2. Hamlin Shale: shale, gray to olive; weathers light olive; blocky; calcareous; contains abundant ostracodes; and small calcareous clay nodules throughout.	0	7	.18

Belvue section continued

HAMLIN	1. Hamlin Shale: shale, olive to light olive-gray; weathers tan-olive; blocky; calcareous; silty; nonfossiliferous; base concealed. Unit 5 supplemented by thin section data.	0	10	.25

State: Kansas County: Pottowatomie Quadrangle: Manhattan

Locality Description:

Blue River Locality (BR)
NE¼ SW¼ SE¼ sec. 30, T9S, R9E
Section measured in a road cut along the north bank of Blue River.

Section measured from the lower Johnson Shale down into the Hughes Creek Shale of the Foraker Formation.

Interval measured July, 1985

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— ---Climate Change Surface)	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.7	23. Johnson Shale: limestone, tan, to gray; platy; bioturbated; nonfossiliferous calcilutite; top eroded.	0	8	.20
	F3.6	22. Jonnson Shale: shale, olive, flaggy, silty; nonfossiliferous sharp contact with unit below.	2	2	.66
		21. Long Creek Limestone: limestone, tan-gray; weathers tan-orange; massive; blocky; dolomitic, nonfossiliferous calcilutite. contains common celestite filled vugs in the top 2 feet. basal 1" is a pelecypod, crinoidal, biomicrite; considered as transgressive lag; TA.	4	0	1.23
	F3.5	20. Long Creek Limestone: limestone, tan-gray, weathers tan-orange; very vuggy with celestite and calcite linings; nonfossiliferous calcilutite; very dolomitic (grades to dolostone).	1	7	.48
		19. Long Creek Limestone: limestone, tan-gray, weathers tan-orange; massive; blocky; argillaceous; vuggy with celestite linings; calcilutite, fossiliferous, dolomitic, biomicrite. contains common Aviculopecten, Permophorus, rare crinoids, and rare gastropods; TA	1	7	.48
	F3.4	18. Hughes Creek Shale: shale, gray to brown; weathers light gray; blocky, well indurated; silty; contains common macerated plant fragments.	0	10	.25
		17. Hughes Creek Shale: limestone, gray, weathers tan, argillaceous; calcilutite, Permophorus, crinoidal, biomicrite; unit also contains rare plant fragments.	1	0	.30
		16. Hughes Creek Shale: shale, gray to tan; weathers light gray; fissile to platy; very calcareous; contains common Aviculopecten, Neospirifer, Meekella, Derbyia, Straparolus, crinoids, and Dunbarelia; TA.	0	7	.18
		——?——————?——————?——			
	F3.3	15. Hughes Creek Shale: limestone, tan-gray, weathers tan-orange; massive; blocky and hard; argillaceous; clacirudite, fine, fusulinid biomicrite; unit also contains other brachiopod fragments and crinoids; fusulinids account for approximately 30-40% of the lithology, are randomly oriented, and consist of large and small fusulinids.	1	3	.38
		14. Hughes Creek Shale: shale, gray-olive, weathers light gray; splintery to hackly; very calcareous; contains whole articulated Composita, Derbyia, Neospirifer, crinoid colmnals, productid fragments; and common to rare fusulinids (less than 3%);	1	10	.56
		13. Hughes Creek Shale: Shale, dark gray to olive; platy to fissile; contains abundant fragments of Composita, Wellerella, Neospirifer, productids, Aviculopecten, bryozoans, crinoids, echinoids, and trilobites; fossils from lag, transgressive; fossils are occasionally articulated; TA.	0	4	.10
	F3.2	12. Hughes Creek Shale: shale, gray to gray-black; weathers gray; indurated, medium-hard; fissile; calcareous; contains rare to common productids, Aviculopecten, Astartella, and Planolites.	1	6	.46
		11. Hughes Creek Shale: shale, dark gray, to gray-black, weahters gray; blocky; calcareous; contains abundance of fauna including articulated, well preserved Composita, Neospirifer, Punctospirifer, Hustedia, Reticulatia, Neochonetes, Crurithyris, Derbyia, Juresania, Petrocrania (incrusting Reticulatia)	0	9	.23

(continued next page)

Blue River section continued

F3 (LONG CREEK)	F3.2	11. Hughes Creek Shale: continued; ramose, fenestrate, and incrusting bryozoa (incrusting Derbyia and other brachiopod fragments); unit also contains fusulinids in the lower 3-5" (fusulinids are larger and less abundant than in unit below); also contains trilobite "hash" layers; the fossils occur either as clay-supported, or in densely packed thin interbedded calcirudite lags; Composita, Reticulatia, and Neospirifer are concentrated in the basal portion of unit, and Composita can be found in life position; TA.	0	9	.23
		10. Hughes Creek Shale: limestone, tan-gray; weathers tan; massive; blocky; very argillaceous (grades to very calcareous shale); calcirudite, fine, fusulinid, biomicrite; fusulinids are randomly oriented and non-sorted, and account for approximately 30%-40% of the lithology; unit also contains rare Neochonetes, Derbyia, Reticulatia, crinoid columnals, bryozoa fragments, trilobites, and other fragments.	0	11	.28
	F3.1	9. Hughes Creek Shale: shale, gray, to dark gray; fissile to platy; contains rare pelecypod fragments, and productid fragments.	0	3	.08
		8. Hughes Creek Shale: limestone, dark gray, weathers tan; very argillaceous, hackly; calcarenite, coarse, brachiopod, fusulinids (basally), biomicrite; contains common fusulinids (approximately 5%), Composita, Crurithyris, Hystriculina, Neochonetes, Neospirifer, crinoids.	0	3	.08
		7. Hughes Creek Shale: limestone, gray, weathers tan; blocky and very argillaceous; calcirudite, fine, fusulinid, brachiopod biomicrite; fusulinids account for approximately 20-30% of the lithology; unit also contains rare Neochonetes, Derbyia, Reticulatia, Crurithyris, Composita, crinoids, and bryozoa fragments.	0	7	.18
		6. Hughes Creek Shale: limestone, gray, weathers tan; very argillaceous to shaley; hackly; transitional between unit above and below; calcirudite- fusulinid, brachiopod, biomicrite, fine grained; contains fusulinids (not as abundant as unit above; approximately 10%); Neochonetes, Composita, productids, Crurithyris, crinoids, and other brachiopod fragments, make up the dominant fauna.	0	7	.18
		5. Hughes Creek Shale: shale, gray, weathers yellow-tan; very calcareous; hackly; contains common Composita, Neochonetes, Hystriculina, Crurithyris, Hustedia, Wilkingia, crinoids, and rare fusulinids; TA.	0	7	.18
F2 (HUGHES CREEK)	F2.4	4. Hughes Creek Shale: shale, black to gray-black; fissile to platy; calcareous; contains abundant Orbiculoidea, and less abundant Crurithyris and Lingula in the lower 6"; contains abundant Crurithyris (occuring in overlapping fashion) in the upper 6"; Crurithyris zones are occasionally Fe-oxidized, lenticular, and orange suggesting fresh-water influx.	0	5	.13
		3. Hughes Creek Shale: limestone, tan-buff, weathers tan-yellow; blocky, hard, massive; calcarenite, coarse, osagid, molluscan, brachiopod, echinoid, biomicrite; contains rounded, elongate osagid-incrusted grains (incrusting brachiopod and pelecypod fragments, and other recrystallized fragments); also contains small (high-spired) gastropods, echinoid spines and plates, crinoids, bryozoans, and common pelecypod fragments; fossils commonly fragmented and poorly to moderately sorted; upper 2" is very argillaceous and contains Crurithyris, Composita, Hystriculina, Orbiculoidea fragments, and osagid grains ; TA.	1	4	.41
		2. Hughes Creek Shale: shale, olive, fissile, calcareous; contains fragments of fenestrate bryozoa, Aviculopecten, ostracodes, Astartella, and Planolites.	0	6	.15
	F2.3	1. Hughes Creek Shale: shale, gray to gray-black; weathers gray; blocky to hackly; calcareous; silty; contains rare macerated plant fragments; and rare Chondrites toward the base of unit; base of unit concealed.	3+		.91+

State: Kansas **County:** Riley **Quadrangle:** Randolph

Locality Description:

Amoco Production Company #1 Hargrave Core (C)
NE¼ NE¼ NE¼ NE¼ sec. 32, T7S, R6E

Interval measured and described from the Johnson Shale, down into the Hamlin Shale of the Janesville Formation.

Interval measured October, 1986.

UNIT DESCRIPTIONS

Transgressive Surface —— – – – Climate Change Surface

5th order T-R units/boundaries	6th order T-R units/boundaries	Unit Descriptions	ft	in	m
F3 (LONG CREEK)	F3.8	50. Johnson Shale: gypsum, clear-gray; to white; coarsely crystalline; bedding mottled and contorted; basal 4" contains 1"-2" algal band, dark gray; with interbedded calcilutite.	1	5	.43
	F3.7	49. Johnson Shale: mudstone, gray-olive; blocky; silty, contains light tan to dark gray laminae; root traces?; nonfossiliferous; and noncalcareous; paleosol	8	6	2.59
		48. Johnson Shale: claystone, olive; blocky; noncalcareous; nonfossiliferous; lower 1" contains reworked carbonate clasts from limestone below; lower contact uneven and wavy.	0	10	.25
		47. Long Creek Limestone: calcilutite, light tan-olive; finely laminated; nonfossiliferous, argillaceous micrite; upper 2" contains abundant intraclasts that create transitional zone with unit above; TA.	0	10	.25
	F3.6	46. Long Creek Limestone: algal-laminite, gray to gray-olive; hard; contains abundant brecciated algal bands throughout; mudcracked; algal bands are micro-faulted, and bedding is non-distinct; lower ½" contains intraclasts from unit below; may contain possible tee-pee structures as a result of dissolution of gypsum.	0	7	.18
		45. Long Creek Limestone: limestone, light gray-olive; thinnly bedded with dark gray laminae that increase in the upper 3"; dolomitic; nonfossiliferous, calcilutite; TA.	1	1	.33
	F3.5	44. Long Creek Limestone: algal-laminite; dark gray; wavy to planar algal laminae; also contains 1"-2" wide algal domes with thinnly interbedded argillaceous calcilutite; upper 2" contains abundant algal rip-clasts, and carbonate intraclasts between algal domes; also contains small scour structures throughout.	1	3	.38
		43. Long Creek Limestone: limestone, olive-tan; very thin-bedded; argillaceous; vuggy (celestite lined); contains rare to common dark colored laminae (algal?); nonfossiliferous, dolomitic calcilutite.	0	6	.15
		42. Long Creek Limestone: limestone, tan-gray; massive; blocky; lower 4" contains shell "hash" with poorly sorted crinoids, pelecypod fragments; carbonate intraclasts, forming, medium to coarse calcarenite-biomicrite; the remaining 30" is a pelecypod bearing, crinoid bearing (small 1-2mm), bioturbated, calcilutite, with rare dark gray, thin shale lentils; the upper 4" is nonfossiliferous and dolomitic; TA.	2	11	.89
	F3.4	41. Hughes Creek Shale: mudstone, gray-olive; blocky; calcareous with very thin light tan laminae throughout; also contains common black, macerated plant fragments throughout, and rare crinoids toward the base; the upper 2" contains abundant, random, clay-filled, burrows, horizontal and inclined.	1	4	.41
		40. Hughes Creek Shale: limestone, gray, argillaceous, very thin-bedded with thin planar light tan laminae; intraclast bearing, crinoidal, pelecypod bearing calcilutite.	0	11	.28
		39. Hughes Creek Shale: limestone, light gray; hard; slightly argillaceous; massive; bedding mottled; contains wavy, thin interbedded crinoidal, pelecypod, brachiopod, biomicrites, and sparsely fossiliferous lenticular argillaceous micrites-calcilutites; TA.	0	6	.15

Core description continued

F3 (LONG CREEK)	F3.3	38. Hughes Creek Shale: shale, dark gray; slightly laminated; fissile; calcareous; contains rare crinoids.	0	3	.08
		37. Hughes Creek Shale: limestone, gray-olive; hackly; very argillaceous; massive; calcirudite, fine, fusulinid, brachiopod, biomicrite; fusulinids are most abundant in the middle portion of unit (approximately 25-30% of the lithology), and are less abundant in the upper and lower 6" (approximately 10-15% of the lithology); uni also contains rare Reticulatia, Neospirifer, Composita (most abundant in the upper 3"); fusulinids are locally clustered in lenticular and irregular shaped cluster throughout, are poorly sorted, and radomly oriented; unit contains common crinoids throughout;TA.	2	10	.86
		36. Hughes Creek Shale: olive to olive gray; calcareous; becomes very calcareous in the upper 8" (i.e. gradational with unit above); contains common Linoproductus, articulated well preserved Derbyia; rare Neospirifer, and Neochonetes; crinoids, and rare fusulinids in the upper 3".	1	4	.41
	F3.2	35. Hughes Creek Shale: gray, blocky, noncalcareous, micaceous; contains sparse Orbiculoidea, Crurithyris, and Linoproductus fragments in the lower 20"; unit contains rare Lingula, Orbiculoidea, and Crurithyris in the upper 20"; becomes silty in the upper 20".	3	5	1.04
		34. Hughes Creek Shale: shale, gray, calcareous; fissile; to blocky; contains common myalinid bivalve fragments, and rare Crurithyris, Hystriculina, and crinoids; upper 1" contains shell "hash" of myalinid bivalve fragments.	0	3	.08
		33. Hughes Creek Shale: shale, gray, fissile to blocky; very calcareous; contains common well preserved, articulated Reticulatia, Neospirifer, Composita, Neochonetes, and other unidentified brachiopod fragments; also contains rare large fusulinids in the lower 2"; also contains rare to common Hustedia and myalinid bivalve fragments; TA.	0	4	.10
		32. Hughes Creek Shale: limestone, gray-olive; very argillaceous; massive; calcirudite, fine, fusulinid, biomicrite (grades to very calcareous shale); consists of large (7mm) and small (3mm) fusulinids (i.e. no size sorting) that are randomly oriented (approximately 30% of the lithology).	1	4	.41
	F3.1	31. Hughes Creek Shale: shale, gray-olive; very calcareous; massive; blocky; contains common productid fragments, and rare fusulinids.	0	3	.08
		30. Hughes Creek Shale: limestone, gray to light gray; very argillaceous; massive; calcirudite, fusulinid and brachiopod, biomicrite; contain abundant fusulinids, crinoids, and brachiopod fragments; fusulinids are approximately 25% of the lithology ; TA.	0	8	.20
		29. Hughes Creek Shale: shale, gray to dark gray; very argillaceous; hackly; common to abundant Crurithyris, common Hystriculina, crinoid columnals; contains rare fusulinids in the upper 3" (i.e. gradational with unit above).	0	9	.23
F2 (HUGHES CREEK)	F2.4	28. Hughes Creek Shale: shale, dark gray; calcareous; blocky; contains common Crurithyris; and rare inarticulate brachiopod fragments; rare productid fragments.	0	5	.13
		27. Hughes Creek Shale, dark gray; fissile, to blocky; noncalcareous; contains abundant Orbiculoidea, locally overlapping; also contains rare Crurithyris and Lingula.	0	8	.20
		26. Hughes Creek Shale: limestone, gray, hackly; argillaceous; calcarenite, coarse, crinoidal, osagid, brachiopod biomicrite; contains Crurithyris, Linoproductus, and a productid shell hash in the upper ½".	0	3	.08
		25. Hughes Creek Shale: limestone, gray to light gray; blocky; hard; contains thin wavy dark gray interbedded shale lentils in the basal 3-5"; the lower 5" contains common fragments of Isogramma; osagid grains appear toward the middle of unit, and commonly become evenly coated toward the top of unit; unit also contains common brachiopod fragments, crinoids, gastropods, and pelecypod fragments; calcirudite, fine, argillaceous, brachiopod, crinoid, molluscan, osagid biomicrite (wackestone); basal 3-5" is considered a calcarenite, coarse, brachiopod biomicrite (wackestone to mudstone, argillaceous); TA.	1	4	.41

Core description continued

F2 (HUGHES CREEK)	F2.3	24. Hughes Creek Shale: gray; fissile to blocky; slightly calcareous; contains sparse Lingula in the lower ½ of unit; unit also contains light tan laminae throughout.	3	6	1.06
		23. Hughes Creek Shale: limestone, gray to olive gray; very argillaceous with clay partings and wavy shale lentils throughout; calcarenite, coarse to fine calcirudite, crinoidal, brachiopod, bryozoan, biomicrite; the lower 2" is darker gray and contains common Linoproductus and Crurithyris; common crinoids and rare Neospirifer: the remainder of the unit continas common to abundant crinoids, common articulated Neospirifer; Reticulatia; and common ramose bryozoans; unit also contains rare to common fusulinids (large, approximately 9mm axial length); contains equal amounts of fragmented fossils and disarticulated whole fossils ; TA.	3	2	.96
		22. Hughes Creek Shale: limestone, gray; argillaceous, blocky; calcarenite, medium, brachiopod biomicrite; contains common Crurithyris; crinoids, Hystriculina, and other brachiopod fragments.	0	2	.05
	F2.2	21. Hughes Creek Shale: shale, dark gray; very calcareous; micaceous; contains common Crurithyris, sparse crinoids, and inarticulate brachiopod fragments.	0	2	.05
		20. Hughes Creek Shale: limestone, gray to dark gray; argillaceous; calcirudite, fine, brachiopod, crinoid, fusulinid bearing biomicrite; contians small (1-3mm) fusulinids in the lower 2"; unit also contains Reticulatia; crinoids; Crurithyris becomes abundant in the upper 4" of the unit; the upper ½" is a Crurithyris fossil hash.	0	7	.18
		19. Hughes Creek Shale: mudstone, gray-olive; very argillaceous; grades to a very calcareous shale; lower 3" contains common well preserved articulated Neospirifer, Reticulatia, Crurithyris, Neochonetes, and crinoids, and other unidentified brachiopod fragments; upper 4" contains common large and small fusulinids, that increase in abundance to approximately 5-10% of the lithology in the upper ½"; TA.	0	7	.18
	F2.1	18. Hughes Creek Shale: limestone, dark gray; argillaceous; blocky; calcirudite, fine, Crurithyris, biomicrite; also contains rare fusulinids, crinoids, and other unidentified brachiopod fragments.	0	2	.05
		17. Hughes Creek Shale: limestone, gray to light gray; blocky hard; argillaceous in the lower 1"; calcarenite, coarse, osagid bearing, brachiopod, fusulinid, biomicrite; lower 2" contains sparse to common fusulinids, which are rare in the upper ½ of unit. lower 1/3 contains common Isogramma; contains common brachiopod fragments throughout; TA.	0	10	.25
F1 (AMERICUS)	F1.3	16. Hughes Creek Shale: shale, gray, hard; massive; silty; micaceous; noncalcareous; rare to common ostracodes.	0	9	.23
		15. Hughes Creek Shale: shale, gray to dark gray; fissile; noncalcareous; contains rare Lingula throughout (common in the lower 2-3"); rare Aviculopecten; common ostracodes; upper 15" becomes silty and micaceous.	1	7	.48
		14. Hughes Creek Shale: limestone, gray to olive; very argillaceous; massive but mottled; calcirudite, fine, osagid brachiopod, biomicrite; upper 12" contains irregular, discontinous "pockets" of less argillaceous, light gray limestone consisting primarily of osagid-type grains and fragments of brachiopods and crinoids; contains no spherical or ovoid type osagid grains; most fragments are thinnly coated; unit consists predominately of brachiopod fragments; also contains rare pelecypod fragments; common Linoproductus. average osagid grain size is approximately 1-2mm (long dimension); TA.	1	5	.43
		13. Hughes Creek Shale: shale, olive; very calcareous; silty; contains common Linoproductus, and other unidentified brachiopod fragments.	0	6	.15
	F1.2	12. Hughes Creek Shale: shale, gray; fissile to blocky; very silty; micaceous; contains very silty, light tan laminae throughout; unit contains rare ostracodes.	4	4	1.32

Core description continued

F1 (AMERICUS)	F1.2	11. Hughes Creek Shale: shale, gray; blocky; hard to fissile; contains rare Crurithvris fragments in the lower half of unit; upper 4" contains lighter tan, silty laminae in the upper 4", nonfossiliferous.	3	1	.94
		10. Hughes Creek Shale: shale, gray; blocky to fissile; calcareous; becomes noncalcareous in the upper 1/2"; contains common Crurithvris, other unidentified brachiopod fragments, and rare pelecypod fragments.	0	2	.05
		9. Americus Limestone: limestone, gray, hard, massive; calcirudite, fine, brachiopod, fusulinid, crinoidal biomicrite (wackestone to packstone); contains flaser-like shale lentils throughout; contains abundant crinoids; fusulinids are common (approximately 5% of lithology); fossils highly fragmented in the upper 5-6"; TA.	1	4	.41
	F1.1	8. Americus Limestone: shale, dark gray, fissile, brittle, micaceous; noncalcareous; contains common Orbiculoidea in in the ower 1", with rare Lingula.	0	5	.13
		7. Americus Limestone: shale, gray to dark gray; calcareous; contains common to rare crinoids; and Crurithvris.	0	4	.10
		6. Americus Limestone: shale, gray; fissile; noncalcareous; contains rare Crurithyris fragments, myalinid fragments, crinoids and rare ostracodes.	1	1	.33
		5. Americus Limestone: shale, gray to dark gray, calcareous; fissile; contains common Crurithvris, and fossils as above.	0	1	.02
		4. Americus Limestone: limestone, gray, blocky, hard; lower 2" contains common light tan carbonate intraclasts; lower 6" contains common, thin interbedded dark gray, shale lentils; upper 8" is more massive, with common green, clay-filled, randomly oriented burrows; calcarenite, medium to coarse, brachiopod, ostracode, crinoidal biomicrite; unit contains rare pelecypod fragments; brachiopod fragments are predominate; unit lacks stromatolitic facies; TA.	1	2	.36
		3. Hamlin Shale: shale, gray, to dark gray, fissile; silty; contains productid fragments, and ostracodes.	0	2	.05
HAMLIN		2. Hamlin Shale: mudstone, olive, blocky, slightly calcareous; nonfossiliferous; undifferentiated	8	2	2.49
		1. Hamlin Shale: mudstone, olive; blocky; calcareous; contains rare crinoids; rare ostracodes	2	0	.61

5th order T-R units/boundaries | 6th order T-R units/boundaries

State: Kansas County: Jackson Quadrangle: Soldier Creek SW

Locality Description:

Crow Creek Locality (CC)
SW¼ NW¼ sec. 8, T8S, R14E
Section measured in a road cut adjacent to Crow Creek; poorly exposed.

Section measured from the Long Creek Limestone of the Foraker Formation, down into the Hamlin Shale of the Janesville Formation.

Interval measured and described by Mudge and Yochelson (1962); units 7,8,9, and 10 measured and described in this study; rest of section concealed.

UNIT DESCRIPTIONS

Transgressive Surface —— ---Climate Change Surface

Unit Descriptions	Unit Thicknesses ft	in	m
19. Long Creek Limestone: limestone, soft, tan, massive, weathers shaly.	5	0	1.52
18. Hughes Creek Shale: shale, silty, calcareous, tan-gray to tan, thin-bedded; fusulinids and brachiopods.	3	5	1.04
17. Hughes Creek Shale: shale, clayey, noncalcareous, gray, grades to dark gray in middle part, blocky to thin-bedded; middle part contains fragments of brachiopods. A mixed *Composita* and *Marginifera* zone overlies a *Crurithvris* zone, which, in turn, overlies *Orbiculoidea* and *Lingula* zone; TA.	2	2	.66
16. Hughes Creek Shale: limestone, medium-hard, tan-gray, weathers blocky and to irregular chips and blocks; fossil fragments with encrusted stromatolites (?); TA.	1	6	.46
15. Hughes Creek Shale: shale, silty, calcareous, gray-brown to gray, thin-bedded to blocky; very calcareous and fossiliferous in middle and lower part; thin lens in upper part contains gastropods, *Reticulatia*, *Crurithvris*, and *Hustedia*; fusulinids abundant in lower part, brachiopods abundant in middle part; TA.	6	7	2.00
14. Hughes Creek Shale: limestone, medium-hard, gray-brown, blocky; fossil fragments.	0	4	.10
13. Hughes Creek Shale: shale, silty, calcareous, tan-gray, thin-bedded; brachiopods and bryozoans; TA.	1	5	.43
12. Hughes Creek Shale: limestone, medium-hard, gray, weathers shaly to blocky; fossil fragments; TA.	0	7	.18
11. Hughes Creek Shale: shale, clayey, noncalcareous, gray, thin-bedded to blocky.	5	0	1.52
10. Hughes Creek Shale: limestone, gray-red to brown, weathers tan; platy, argillaceous, thin bedded; calcirudite, fine, brachiopod, pelecypod, osagid biomicrite; contains common pelecypod fragments including *Aviculopecten*, nuculoids; also contains *Wellerella*, productids, *Neospirifer*, and other brachiopods; also contains echinoids and crinoids; fossils highly fragmented and commonly incrusted with *Osagia*; unit is silty and contains fossiliferous, thin interbedded, calcareous shales and calcilutites ; TA.	1	7	.48
9. Hughes Creek Shale: shale, olive to gray, blocky, silty to sandy (quartz); contains common productid fragments.	0	7	.18
8. Hughes Creek Shale: limestone, tan-gray, weahters tan; blocky to slabby and platy; calcilutite, argillaceous, sandy (quartz), fossiliferous, micrite; contains rare productid fragments; and also contains horizontal burrows (epirelief) on upper bedding surfaces; symmetrical ripples on upper bedding surface indicate paleocurrent direction of N30E - S30W.	0	10	.25
7. Hughes Creek Shale: shlae, clayey, gray to olive-gray, silty, noncalcareous, blocky; nonfossiliferous in the upper half of unit; contains fossiliferous lentils in the lower part.	10	0	3.04
6. Americus Limestone: limestone, hard, gray, to tan-gray, weathers blocky; crinoid columnals abundant; fusulinids common ; TA.	0	10	.25

Crow Creek section continued

F1	F1.1	5. Americus Limestone: shale, silty, xome clay, calcareous, gray, thin-bedded.	2	6	.76
		4. Americus Limestone: limestone, hard, crystalline, gray, weathers blocky; few clay balls and lentils, clay zone in lower and upper parts; TA.	0	7	.18
HAMLIN		3. Hamlin Shale: shale, silty to clayey, calcareous, gray-green, blocky; cavernous zone in upper part; iron stains abundant of fracture planes and in cavernous zone.	5	0	1.52
		2. Hamlin Shale: shale, cavernous, gray-brown, irregular bedding; some calcium carbonate.	2	4	.71
		1. Hamlin Shale: shale, clayey, calcareous, gray-green, blocky.	10	0	3.05

State: Kansas County: Chase Quadrangle: Elmdale

Locality Description:

Cl Locality
NW¼ NW¼ sec. 3, T20S, R7E
Section measured at Camp Wood, YMCA; from water level below spillway to top of lake road.
Section measured from the Long Creek Limestone of the Foraker Formation, down into the Hamlin Shale of the Janesville Formation.

Interval measured and described by M.S. Garber (1962).

UNIT DESCRIPTIONS

Transgressive Surface —— - - - Climate Change Surface

5th order T-R units/boundaries	6th order T-R units/boundaries	Unit Descriptions	Unit Thicknesses ft	in	m
F1 (AMERICUS) — F3 (LONG CREEK)	F3.5 —	15. Long Creek Limestone: limestone, massive, moderately soft, silty with limonite specks; yellowish gray fresh surface, tan weathered surface; few crinoid fragments, brachiopod and arenaceous foraminifera.	3	9	1.16
		14. Hughes Creek Shale: shale, gray to dark gray, highly calcareous with indurated layers; abundant fusulinids.; TA.	1	2	.37
		——?——?——?——			
		13. Hughes Creek Shale: limestone, soft, silty; yellowish gray, weathers buff; finely crystalline, highly fusulinid, small amount of limonite; lower part is composed almost entirely of fusulinids.	2	1	.63
		12. Hughes Creek Shale: shale, calcareous, mottled yellowish brown and gray with indurated layers; highly fusulinid (principally Triticites); TA.	8	2	2.50
	F1.3	11. Hughes Creek Shale: limestone; yellowish gray fresh surface weathers olive gray; contains large amounts of organic debris chiefly crinoid fragments and gastropods, sparite filling in gastropods, crinoid fragments are silicified, few arenaceous foraminifera and some glauconite and limonite	1	5	.43
		10. Hughes Creek Shale: shale? covered.	8	0	2.44
		9. Hughes Creek Shale: shale, highly calcareous; olive gray fresh surface, weathers dull gray; contains rounded quartz and abundant fusulinids.	1	0	.30
	F1.2	8. Hughes Creek Shale: limestone, shaley; light gray fresh surface, duller gray weathered surgace; finely crystalline, sparite in fossils; fossils are mostly gastropods (high spired) and arenaceous foraminifera; small amount of glauconite and limonite.	0	4	.10
		7. Hughes Creek Shale: shale, calcareous, highly weathered; brown fresh surface, weathers gray; abundant fusulinids, small brachiopods (Composita) and some algae, abundant quartz grains ; TA?	0	2	.05
		6. Americus Limestone: limestone, hard, massive; brownish gray fresh surface, weathers yellowish brown; silty, finely crystalline with sparite filling in brachiopods, some algae, large amounts of conodonts and phosphatic fragments; small amount of glauconite, quartz grains, crinoid columnals.	0	11	.28
	F1.1	5. Americus Limestone: shale, slightly calcareous, dark gray fresh surface, weathers tannish gray, abundant dictyoclostids, trace of crinoid fragments.	11	5	3.48
		4. Americus Limestone: limestone, platy; grayish tan, microcrystalline, silty; contains brachiopods (dictyoclostids and Neospirifer), arenaceous foraminifera, conodonts and fusulinids ; TA.	1	4	.41
		3. Americus Limestone: shale; dark gray fresh surface, tan to buff weathered surface; non calcareous, fissile, contains a few thin ferrugenous partings and trace of rounded quartz grains, brachiopod spines and trace of arenaceous foraminifera.	3	1	.95
		2. Americus Limestone: limestone, moderately hard, algal appearance in part, wavy bedding; tan fresh surface, weathers medium gray; finely crystalline, contains arenaceous foraminifera, ostracodes, small brachiopods and trace of limonite; thin fissile shale in middle.	0	5	.13
		1. Hamlin Shale: siltstone, calcareous, buff to gray; soft; no fossils, exposed above water level.	8	0	2.44

State: Kansas County: Chase Quadrangle: Hymer

Locality Description:

C2 Locality
NW¼ SE¼ sec. 26, T19S, R7E
Section measured at Elmdale Hill from river level to road.

Section measured from the Long Creek Limestone of the Foraker Formation, down into the Americus Limestone.

Interval measured and described by M.S. Garber (1962).

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	ft	in	m
F2 (HUGHES CREEK) — F3 (LONG CREEK)		16. Long Creek Limestone: limestone, massive, bedding plane in middle; buff fresh surface, tannish gray weathered surface; contains crinoid columnals, arenaceous foraminifera, ostrocodes?, and osagia?, in a finely crystalline silty matrix; trace of limonite.	2	2	.66
		15. Long Creek Limestone: limestone, argillaceous, non-resistant; tannish gray; bedding not well defined; composed largely of silt in a finely crystalline matrix; some red quartz nodules, crinoid fragments and arenaceous foraminifera.	0	7	.18
		14. Long Creek Limestone: limestone, yellowish tan argillaceous fresh surface, weathers yellowish gray with limonite specks; upper part is massive, lower 0.5 feet is platy; contains crinoid and brachiopod fragments, arenaceous foraminifera, matrix is argillaceous and ferrugenous with some limonite on bedding planes.	1	5	.43
	F2.1 — F3.5?	13. Hughes Creek Shale: shale, mostly covered, mottled gray, calcareous.	4	0	1.22
		12. Hughes Creek Shale: limestone, platy; light tan fresh surface, weathers tannish gray; contains sparite pellets and fossil fragments (brachiopods, crinoids, fusulinids, and arenaceous foraminifera) in a ferrugenous, silty microcrystalline matrix.	0	10	.25
		11. Hughes Creek Shale: limestone, shaley; tan fresh surface, yellowish gray weathered surface; numerous crinoid and brachiopod fragments, and fusulinids; matrix is silty, microcrystalline with some small quartz-filled veins in lower part.	1	2	.36
		10. Hughes Creek Shale: shale?, covered.	4	0	1.22
		9. Hughes Creek Shale: limestone, shaley, non-resistant, fusulinid; light gray weathered surface, fresh surface is light tannish gray; composed of fusulinids (90%) in a finely crystalline silty matrix containing trace amounts of limonite.	2	8	.81
		8. Hughes Creek Shale: limestone, massive; tan fresh surface, grayish tan weathered surface; composed primarily of gastropods and fragmental brachiopods in microcrystalline matrix; with subordinate amounts of arenaceous foraminifera and phosphatic "teeth", trace of limonite.	1	5	.43
		?——————?——————?			
F1 (AMERICUS)	F1.3	7. Hughes Creek Shale: shale, calcareous, (with 0.2 foot of fissile noncalcareous, unfossiliferous, black shale at top); medium gray, composed largely of fusulinids (mostly *Triticites*).	6	0	1.83
		6. Hughes Creek Shale: limestone, fusulinid, yellowish gray fresh surface, weathers nearly same color; composed of fusulinids (60%) and a few arenaceous foraminifera in a microcrystalline silty matrix ; TA?.	0	8	.20
	F1.2	5. Hughes Creek Shale: shale, highly weathered, slightly calcareous; medium gray to yellowish tan; numerous small *Composita*, a few fusulinids and phosphatic fragments, trace of rounded quartz grains	0	1	.02
		4. Americus Limestone: limestone, hard, massive; dark bluish gray fresh surface, weathers yellowish tan; numerous fragmental fossils (brachiopods, algae and crinoids) with minor amounts of oolite, glauconite and limonite; matrix is sparry with pockets of microcrystalline material ; TA?	1	4	.41

Garber's C2 section continued

F1	F1.1	3. Americus Limestone: shale, highly calcareous, mottled gray and olive; abundant small brachiopods, ostrocodes, bryozoan fragments and echinoid spines.	8	4	2.54
		2. Americus Limestone: limestone, moderately hard, jointed, thin bedded; light bluish gray fresh surface, weathers tannish gray; composed almost entirely of fossil debris (brachiopod, crinoid, fusulinid) with some glauconite and limonite; TA.	1	0	.30
		1. Americus Limestone: shale, fissile, moderately calcareous, variegated, almost black to rust color in thin layers, unfossiliferous; exposed above water level.	0	7	.18

State: Kansas County: Riley Quadrangle: Wamego SW

Locality Description: Deep Creek (DC) Section

NE¼ SE¼ NW¼ sec. 14, T11S, R8E
Section measured in a stream bank cut, just to the south of where Deep Creek changes direction from north to east.

Measured from the Long Creek Limestone of the Foraker Formation, down into the lower portion of the Hughes Creek Shale.

Interval measured July, 1986

UNIT DESCRIPTIONS

Transgressive Surface —— - - - Climate Change Surface

5th order T-R units/boundaries	6th order T-R units/boundaries	Unit Descriptions	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.7	43. Long Creek Limestone: limestone, tan-orange, weathers light tan; blocky; slabby to flaggy; medium hard, argillaceous; limonitic; calcarenite, medium, pelecypod, gastropod, biomicrite; contains common Permophorus, and other nuculoid bivalves, small bellerophonts; sharp contact with unit below.	0	6	.15
	F3.6	42. Long Creek Limestone: limestone, reddish tan-gray; very vuggy; sucrosic texture; contains abundant, calcite and celestite crystals.	0	3	.08
		41. Long Creek Limestone: shale, gray olive gray; very fissile; noncalcareous; slightly silty and micaceous; contains sulphate films on bedding laminae; lower ¼" is laminated, hard, recrystallized, algal laminite.	0	3	.08
		40. Long Creek Limestone: limestone, light tan; hackly to platy; medium hard; very argillaceous; dolomitic; intraclast bearing calcilutite; contains mudcracked, algal laminite in upper 2".	0	6	.15
		39. Long Creek Limestone: limestone, light tan; weathers buff-tan; hackly to blocky; very argillaceous, contains rare pelecypod fragments (internal molds?), and rare crinoids; TA.	0	3	.08
	F3.5	38. Long Creek Limestone: shale, gray, dark gray, noncalcareous, fissile; contains uneven upper contact; contains small 3" diameter structures similar to scour channels; thickens and thins laterally.	0	1	.02
		37. Long Creek Limestone: dolostone; tan-buff; blocky, hard; sharp contact with unit below; vuggy, calcite filled; nonfossiliferous; and argillaceous; unit contains cryptic, dark gray laminae (possible algal laminae).	0	6	.15
		36. Long Creek Limestone: limesteon, light tan-brown; weathers light tan; blocky; slabby; medium hard; argillaceous; nonfossiliferous; fenestrate porosity (?); dolomitic, calcilutite.	0	5	.13
		35. Long Creek Limestone: light tan-brown; weathers light tan-yellow; massive; argillaceous; blocky; comatins small vugs (1-2" diameter); rare fragments of Permophorus; dolomitic, calcilutite.	2	2	.66
		34. Long Creek Limestone: limestone, buff-tan; weathers light tan, argillaceous; dolomitic, slightly vuggy-calcite lined; calcilutite, fossiliferous, micrite; contains common Aviculopecten; and rare bellerophont gastropods.	1	1	.33
		33. Long Creek Limestone: limestone, tan-orange; weathers light tan; massive; blocky; medium hard; dolomitic; argillaceous; calcilutite, limonitic, molluscan, biomicrite; contains common Aviculopecten (internal molds); gastropods, Tainocerus; and orthoconic cephalopod fragments; (wackestone to mudstone) ; TA.	1	3	.38
	F3.4	32. Hughes Creek Shale: shale, light tan-brown; weathers light tan; fissile to blocky; silty; noncalcareous; contains abundant macerated plant fragments, and thinnly interlaminated dark gray shale streaks.	0	5	.13
		31. Hughes Creek Shale: mudstone, light tan brown, weathers tan-gray; blocky; calcareous; silty; nonfossiliferous except for rare minute plant fragments.	0	6	.15
		30. Hughes Creek Shale: limestone, light tan-brown to tan-orange; very argillaceous; slabby to flaggy; contains rare pelecypod fragments; calcilutite; TA.	0	2	.05

Deep Creek section continued

F3 (LONG CREEK)	F3.3	29. Hughes Creek Shale: shale, light tan-brown; blocky to fissile; calcareous; slightly silty; micaceous; nonfossiliferous.	0	1	.02
		28. Hughes Creek Shale: limestone, tan-orange, weathers light tan-buff; very argillaceous; calcarenite, medium to coarse; Permophorus, crinoidal, brachiopod, biomicrite.; Permophorus occurs in lenticular fashion; with disarticulated valves (commonly internal molds) both convex-up and down; unit also contains rare gastropods.	0	6	.15
		27. Hughes Creek Shale: limestone, light tan, to gray-tan; very argillaceous; very thin bedded; calcarenite, coarse, brachiopod, pelecypod, bryozoan, crinoidal, biomicrite; unit contains common Aviculopecten, myalinid bivalve fragments; crinoids; erect branching bryozoans; and rare Neochonetes.	0	1	.02
		26. Hughes Creek Shale: limestone, gray-olive; weathers to light tan-yellow; blocky to hackly; very argillaceous; calcirudite, fine, massive, fusulinid, biomicrite; contains abundant fusulinids large and small (approximately 25-30%) the lower 20" is very argillaceous to shaley, and contains common Linoproductus, bryozoans, Neospirifer, crinoids, and other brachiopod fragments; TA.	4	1	1.24
	F3.2	25. Hughes Creek Shale: shale, gray, to dark gray, noncalcareous; blocky; micaceous; contains rare productid fragments, and rare trilobite fragments.	1	0	.30
		24. Hughes Creek Shale: shale, dark gray, weathers light gray; blocky, hackly; slightly micaceous; contains large, articulated Neospirifer, Composita, Hustedia, Derybia, Crurithyris; trilobite fragments; and myalinid fragments; lowermost 6" is most diverse, with diversity decreasing up the unit; rare fusulinids (larger than unit below) in the lower 3" (i.e. gradational with unit below; TA.	0	8	.20
		23. Hughes Creek Shale: shale, tan-gray, very valcareous; blocky to hackly; contains abundant robust fusulinids (approximately 40-50% of the lithology), large and small individuals (i.e. 3mm to 7mm long), common crinoids, rare to common Composita, and bryozoan fragments; becomes less calcareous up the unit.	1	3	.38
	F3.1	22. Hughes Creek Shale: shale, olive, to gray, weathers light gray; very calcareous; blocky to hackly; silty; micaceous; contains rare productid fragments; lacks fusulinids.	0	2	.05
		21. Hughes Creek Shale: shale, gray, dark gray, weathers light gray; very calcareous; blocky to hackly; abundant fusulinids that decrease in the upper 2" (from approximately 35% to less than 5%); contains other rare brachiopod fragments.	0	4	.10
		20. Hughes Creek Shale: limestone, light gray, weathers light gray-yellow; blocky, hard, argillaceous, transitional with unit below; calcirudite, fine, fusulinid, brachiopod, biomicrite; contains abundant fusulinids that increase in abundance toward the top of the unit (i.e. gradational with unit above); brachiopods are most common in the base of the unit, consisting predominately of Composita, Crurithyris, and productid fragments; also rare rugose corralite; TA basaly	0	8	.20
		19. Hughes Creek Shale: shale, gray, dark gray, very calcareous, blocky to platy; contains Composita, common Crurithyris, and productid fragments (Hystriculina).	0	6	.15
F2 (HUGHES CREEK)	F2.4	18. Hughes Creek Shale: shale, gray-black, blocky to fissile; slightly carbonaceous; limonitic; slightly carbonaceous; slightly calcareous; contaibs abundant Orbiculoidea in the lower 6", and abundant Crurithyris in the upper 6"; unit also contains Lingula in the lower 6".	1	0	.30
		17. Hughes Creek Shale: limestone, light gray, weahters tan-yellow; hard; blocky; massive; calcirudite, fine, clayey, Isogramma, molluscan, osagid, brachiopod biomicrite; poorly sorted; osagid type grains, Isogramma, and gastropods are the most abundant allochems in thin section; unit also contains common brachiopod fragments, ostracodes, pelecypods, echinoderm fragments; argillaceous wackestone; the pelecypod fragments are commonly articulated and well preserved.; TA.	1	10	.56

Deep Creek section continued

F2 (HUGHES CREEK)	F2.3	16. Hughes Creek Shale: shale, dark gray; fissile, micaceous; silty; slightly calcareous; contains sparse thin interbedded gray, silty calcareous, nonfossiliferous shale lentils.	2	5	.74
		15. Hughes Creek Shale: limestone, gray, to dark gray, hackly; thin bedded; calcirudite, fine, brachiopod, bryozoan, crinoidal, biomicrite; shaley; contains common Reticulatia, Composita, fenestrate bryozoans, crinoids; most fossils appear fragmented; upper 1" is a biosparite shell lag containing fossils aforementioned; unit also contains.common Neospirifer.	0	6	.15
		14. Hughes Creek Shale: limestone, gray, dark gray, weathers light tan yellow, blocky; calcirudite, shaley, fine, crinoidal, brachiopod, biomicrite; contains large, articulated Reticulatia, Neospirifer, Hustedia, Neochonetes, and crinoids; gradational with unit below.	0	5	.13
		13. Hughes Creek Shale: shale, gray to dark gray, weathers light tan-yellow; blocky to nodular; very calcareous; lower 12" contains common to abundant fusulinids (approximately 25%), that become rare in the upper 15"; approximately 8" up the unit, an increase in brachiopod and bryozoan diversity occurs, including large articulated Reticulatia, Composita, Petrocrania (incrusting Reticulatia); Wellerella, Neospirifer, Neochonetes; common rameose bryozoans; well preserved crinoid stems, and columnals; and Wilkingia (one found in life position); contains fossiliferous calcarenite lenses in the upper 20" causing nodular bedded appearance; base of unit contains common articulated Linoproductus; and rare Crurithyris ; TA.	2	6	.76
		12. Hughes Creek Shale: limestone, dark gray, weathers light gray; blocky to slabby; calcarenite, medium, brachiopod, Chondrites, biomicrite; contains common horizontal clay-filled, burrows; and abundant Crurithyris; common Orbiculoidea fragments; and Lingula fragments (reworked from unit below?).	0	2	.05
	F2.2	11. Hughes Creek Shale: shale, gray-black; fissile; carbonaceous; very calcareous; contains abundant Crurithyris, rare Orbiculoidea fragments, and Lingula.	0	3	.08
		10. Hughes Creek Shale: limestone, gray to dark gray, weathers yellow-gray; hard; blocky to slabby; common calcirudite, fine, Crurithyris, biomicrite; unit also contains inarticulate brachiopod fragments; Hystriculina, crinoids.	0	4	.10
		9. Hughes Creek Shale: shale, dark gray, weathers light gray; blocky to fissile; very calcareous; sharp contact with unit below; contains abundant Neochonetes in the lower half; and common fusulinids (2-3%) in the upper 2"; unit also contains common Reticulatia, Derbyia, Neospirifer, Hustedia, Crurithyris, Wellerella, Composita, ramose bryozoans; common Wilkingia, Aviculopecten, and myalinid bivalve fragments, and crinoids; most fossils are fragmented and poorly sorted; TA.	0	6	.15
	F2.1	8. Hughes Creek Shale: limestone, dark gray, slabby, very argillaceous; calcirudite, fine, argillaceous, Crurithyris, biomicrite; unit also contains productid fragments.	0	2	.05
		7. Hughes Creek Shale: shale, gray, fissile; very calcareous; common Crurithyris, bryozoans, and crinoids.	0	1	.02
		6. Hughes Creek Shale: limestone, gray, dark gray; becomes darker gray up the unit; blocky argillaceous; calcirudite, fine to medium, clayey, fusulinid, brachiopod, Isogramma, biomicrite; contains common Crurithyris throughout; fusulinids are common to abundant in the middle to basal portions, as is Isogramma; unit also contains lesser, rare, Composita, Linoproductus, Composita, Neospirifer, and Neochonetes, as well as crinoids; contains sparse osagid incrusted grains; TA.	0	9	.23
		5. Hughes Creek Shale: shale, light gray-brown; calcareous; slightly silty; blocky to silty; contains common articulated Linoproductus.	0	5	.13
F1	F1.3	4. Hughes Creek Shale: shale, gray, olive gray, slightly calcareous and silty; micaceous; blocky, fissile, and contains rare ostracodes.	1	0	.30

Deep Creek section continued

F1 (AMERICUS)	F1.3	3. Hughes Creek Shale: limestone, gray, dark gray, weathers light tan-orange; blocky, flaggy, and platy in the upper 3"; very argillaceous; lower half of unit in thin section is a shaley calcirudite, fine, Linoproductus, Crurithyris, and crinoidal biomicrite; and contains uneven wavy, shale streaks lenticular in nature; lower half also contains common brachiopod fragments, unidentified; upper half in thin section is a calcarenite, coarse, very argillaceous, to shaley, pelecypod, brachiopod, osagid, biomicrite; contains common Linoproductus and other brachiopod fragments; also contains common pelecypod fragments including Aviculopecten, Astartella, also common gastropods; rare echinoid spines; and rare algal-dasyclad fragments; rare Neospirifer; Osagia incrusts only about 3% of the allochems, and commonly incrusts only 1 side of shell fragments (approximately .073mm thick, average), usually in the concave portion; unit is poorly sorted, and contains shaley lentils in the upper half also.	1	3	.38
		2. Hughes Creek Shale: shale, dark gray, weathers light tan-gray calcareous; silty; micaceous; contains abundant Linoproductus; and Crurithyris; unit also contains thinnly interbedded calcareous, very silty interbeds; TA.	0	10	.25
	F1.2	1. Hughes Creek Shale: shale, dark gray, weathers light gray; blocky; fissile; silty; micaceous; noncalcareous, nonfossiliferous ; base of Foraker Formation concealed.	0	6	.15

		Thin section data was used to supplement descriptions of the following units: 3, 17, 20, 27, 28, 33, 34, 35, 37, 40, and and 43.			

State: Kansas County: Wabaunsee Quadrangle:

Locality Description:

East Paxico Locality (EP)
SW¼ SW¼ sec. 30, T11S, R12E
Section measured in a road cut on the south side of I-70, ¼ mile west of rest area

Section from the Long Creek Limestone of the Foraker Formation, down into the Hamlin Shale of the Janesville Formation

Interval measured July, 1986

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.7	54. Long Creek Limestone: limestone-intraformational breccia; tan-orange; massive, hard; blocky; argillaceous calcirudite; contains abundant noncalcareous, claystone clasts (possibly dolomitic) that are poorly sorted and angular, ranging in size from 1mm to 40mm; basal 1"-2" is algal-laminite, planar and mudcracked; intraformational breccia considered as transgressive lag.	1	3	.38
	F3.6	53. Long Creek Limestone: limestone, gray-tan, to tan-orange; hard; argillaceous; dolomitic; non-fossiliferous calcilutite-micrite.	1	1	.33
		52. Long Creek Limestone: limestone, tan-orange, weathers light tan-orange; argillaceous, dolomitic; blocky; contains very rare pelecypod fragments (internal molds); calcilutite micrite; TA.	0	6	.15
		51. Long Creek Limestone: limestone, tan-orange, very argillaceous, dolomitic; blocky; to hackly; limonitic; intraclast bearing calcilutite-micrite. (possible transgressive lag)	0	6	.15
		——?——————?——————?——			
	F3.5	50. Long Creek Limestone: limestone, gray-tan, weathers massive; very vuggy; calcite lined; blocky, argillaceous; contains rare *Tainocerus*; and *Aviculopecten*; calcilutite, dolomitic micrite; TA.	1	1	.33
	F3.4	49. Long Creek Limestone: shale, light gray-olive; fissile; to blocky; silty; noncalcareous, nonfossiliferous.	0	2	.05
		48. Long Creek Limestone: limestone, tan-orange to gray-orange; weathers massive; hard; calcarenite, medium to coarse, pelecypod bearing, gastropod bearing, crinoid bearing, brachiopod bearing biomicrite; vuggy, with calcite and celestite linings; TA.	1	1	.33
	F3.3	47. Long Creek Limestone: limestone, tan-brown, nodular, very vuggy, calcite-lined; argillaceous; nonfossiliferous calcilutite; dolomitic.	0	3	.08
		46. Hughes Creek Shale: mudstone; light tan-yellow, weathers light tan; massive, blocky; limonitic, silty; contains Fe-oxidized fusiform structures (may be diagenetically altered fusulinids, transported); also contains rare plant fragments in upper 2-3".	1	1	.33
		45. Hughes Creek Shale: limestone, gray-orange, weathers light tan-yellow; blocky; hard; becomes dark-gray in the upper 6"; calcarenite-shaley, coarse, fusulinid biomicrite; contains common Fe-oxidized fusulinid casts (diagenetically altered) and common fusulinids (approximately 10% of the lithology); TA.	1	1	.33
		44. Hughes Creek Shale: shale, gray, to blue-gray; blocky; hard; massive; noncalcareous; contains lenticular fusulinid lags in the upper 6" in a calcareous shaley matrix.	1	0	.30
	F3.2	43. Hughes Creek Shale; shale, tan-buff, weathers light tan; blocky; hard; noncalcareous, nonfossiliferous; upper 2" becomes green with brown Fe-films.	0	6	.15

East Paxico locality continued

F3 (LONG CREEK)	F3.2	42. Hughes Creek Shale: shale, gray, dark gray; blocky; hard; massive; nonfossiliferous; slightly micaceous; slightly silty.	1	0	.30
		41. Hughes Creek Shale: claystone, brown, to gray; contains thin interlaminated, Fe-oxidized shale lentils; also contains abundant celestite crystals throughout; and rare unidentified brachiopod fragments.	0	2	.05
		40. Hughes Creek Shale: shale, gray-black, slightly calcareous, blocky and fissile; contains rare brachiopod fragments, and rare myalinid pelecypod fragments.	2	6	.76
		39. Hughes Creek Shale: shale, gray-black; blocky to fissile; calcareous, contains common large Reticulatia, Neospirifer, crinoids, and sparse bryozoans; gradational with unit below and above.	0	6	.15
		38. Hughes Creek Shale: shale, orange to brown-gray, weathers light gray; fissile to blocky; calcareous, contains common Fe-oxide stains throughout; very divers assemblage including common Neospirifer, Composita, Hustedia, Reticulatia, Derbyia, Neochonetes, Lissochonetes, Crurithyris, Linoproductus, common crinoid stems and columnals, fenestrate and ramose bryozoans; incrusting bryozoans, trilobite fragments (Ditymopyge) and common fusulinids; fossils exhibit articulated, disarticulated and fragmented remains (angular) that are very poorly sorted; TA.	0	5	.13
		37. Hughes Creek Shale: shale, gray, dark gray, weathers light gray; very calcareous; blocky, massive, well indurated; contains abundant fusulinids (approximately 40 to 50%) both large and small fusiform type, randomly oriented; rare to common fenestrate bryozoans, rare Hustedia, rare Neochonetes, and Neospirifer; also contians rare to common well preserved crinoid stems and columnals; fenestrate bryozoans are also large and fragmented but in a well preserved nature.	0	5	.13
		36. Hughes Creek Shale: limestone, gray-orange, weathers yellow-tan; very argillaceous (grades to very calcareous shale); massive, blocky; calcirudite, fine, fusulinid biomicrite; (packstone); contains abundant fusulinids as above, randomly oriented with no sized sorting; also contains common Composita, fenestrate bryozoans, crinoids, and other brachiopod fragments; gradational with unit above.	0	8	.20
	F3.1	35. Hughes Creek Shale: shale, dark gray; hackly to fissile; very calcareous; rare productid fragments; note lack of fusulinids.	0	3	.08
		34. Hughes Creek Shale: limestone, gray, weathers yellow-tan; blocky to platy, very argillaceous; calcarenite, coarse, brachiopod, fusulinid, crinoidal biomicrite; contains common fusulinids that become common in the upper 4"; also contains common Composita, Neospirifer (in the lower 2"), and crinoids. grades from brachiopod wackestone at the base to a fusulinid packstone toward the top; TA.	0	8	.20
		33. Hughes Creek Shale: limestone, gray; hackly, thin bedded, contains rare fusulinids; common Crurithyris fragments forming lag; calcarenite, coarse, immature, biosparite (transgressive lag).	0	1	.02
F2 (HUGHES CREEK)	F2.4	32. Hughes Creek Shale: shale, dark gray, to black-gray; contains common to abundant Crurithyris in the upper 6" forming overlapping shell lags; contains common to abundant Orbiculoidea in the lower 6", as well as Lingula.	2	0	.61
		31. Hughes Creek Shale: shale, gray, to dark gray, very calcareous, contains common Crurithyris, rare Hystriculina, and rare osagid grains.	0	1	.02
		30. Hughes Creek Shale: limestone, gray to dark gray, hackly, to blocky; argillaceous; calcarenite, coarse, poorly sorted, osagid, molluscan, brachiopod bearing, biomicrite (wackestone to packstone); fossils highly fragmented and commonly incrusted with Osagia; TA.	0	9	.23
		29. Hughes Creek Shale: claystone, olive-gray, nonbedded, soft, calcareous, contains ostracodes and rare productid fragments.	0	1	.02
	F2.3	28. Hughes Creek Shale: shale, dark gray, to gray-tan, weathers tan; fissile to platy; consists of thin, interbedded, silty calcareous shale and noncalcareous shale; contains rare Chondrites.	1	3	.38

East Paxico locality continued

F2 (HUGHES CREEK)	F2.3	27. Hughes Creek Shale: shaley limestone, gray, weat-ers light gray, blocky to hackly, massive; calcarenite, coarse, fusulinid bearing, brachiopod biomicrite; contains common large Reticulatia (articulated), Composita, Linoproductus, and rare fusulinids; transitional with unit below;	1	6	.46
		26. Hughes Creek Shale: shale, gray-brown, to orangish brown; blocky to fissile; very calcareous, massive; contains common fusulinids large and small, Crurithyris, large Reticulatia, rare Neospirifer; TA.	1	0	.30
		25. Hughes Creek Shale: limestone, gray, orange brown, hackly to blocky; massive; hard; shaley calcarenite; coarse to fine calcirudite, brachiopod bearing, fusulinid biomicrite; con-abundant fusulinids (approximately 10-15%); rare Wellerella and crinoids; (shaley packstone to wackestone).	0	3	.08
		24. Hughes Creek Shale: shale, gray, brown, soft, calcareous, fissile; contains common productid fragments and rare Fe-oxidized osagid grains; also contains rare fusulinids.	0	2	.05
		23. Hughes Creek Shale: limestone, gray-black, slabby; hard, shaley calcarenite, coarse, Chondrites, Crurithyris, biomicrite; unit also contains rare Orbiculoidea (at the base reworked from unit below), and crinoids.	0	2	.05
	F2.2	22. Hughes Creek Shale: shale, gray-black, soft, fissile; calcareous; contains abundant Crurithyris, rare Lingula, and rare Orbiculoidea.	0	2	.05
		21. Hughes Creek Shale: limestone, gray, weathers tan-yellow, argillaceous; blocky; slabby; calcarenite, coarse, brachiopod bearing, pelecypod bearing, crinoidal biomicrite; contains common Crurithyris and bivalve fragments; becomes shaley up the unit.	0	7	.18
		20. Hughes Creek Shale: claystone, orange-brown; calcareous, contains common productid fragments, bryozoan fragments, Crurithyris, and crinoids.	0	1	.02
		19. Hughes Creek Shale: shale, gray-brown, blocky, very calcareous; contains abundant to common articulated Neochonetes; Crurithyris, Derbyia, rare Neospirifer, Reticulutia, fenestrate bryozoans; faunal diversity decreases up unit; gradational with unit above; TA.	0	8	.20
	F2.1	18. Hughes Creek Shale: limestone, gray, weathers yellow-gray; blocky; hard, argillaceous; calcarenite, coarse, fusulinid bearing, brachiopod, Isogramma, osagid bearing biomicrite; also contains rare Edmondia; contains abundant Crurithyris in the upper 3"; TA.	1	2	.36
F1 (AMERICUS)	F1.3	17. Hughes Creek Shale: shale, olive to olive-gray; slightly calcareous, blocky to fissile; slightly silty; contains rare myalinid fragments; rare Rhipidomella, Crurithyris; and Linoproductus.	3	3	.99
		16. Hughes Creek Shale: shale, brown, to gray-black; weathers light gray; hackly; contains common Reticulatia (articulated), Neospirifer fragments; fenestrate brayozoans, Neochonetes, Crurithyris, Hustedia, and crinoids; lower 4" contains common calcilutite with similar faunal content; upper 4" is sparsely fossiliferous.	0	8	.20
		15. Hughes Creek Shale: limestone, gray-tan, weathers orange-gray; hard, blocky, contaisn common productid fragments, common Neopspirifer, rare Hustedia, Neochonetes, fenestrate bryozoan fragments; all fossils are highly fragmented and common incrusted with Osagia; also contains Wilkincia, rare bellerophont gastropods and other unidentified pelecypod fragments; calcirudite, fine, osagid, brachiopod, pelecypod very argillaceous biomicrite; TA.	1	4	.41
		14. Hughes Creek Shale: shale, brown-gray, weathers gray-yellow; blocky; very calcareous; contains thinnly interbedded fossiliferous calcarenites, coarse, containing abundant Linoproductus, rare Hustedia, Meekella, Neospirifer, Derbyia, crinoids, and Crurithyris; gradational with unit below.	1	6	.51

East Paxico section continued

F1 (AMERICUS)	F1.2	13. Hughes Creek Shale: shale, olive-gray, weathers light gray; blocky, fissile, slightly calcareous; slightly silty and micaceous; contains common to rare Crurithyris, Linoproductus fragments, and myalinid bivalve fragments.	4	6	1.37
		12. Hughes Creek Shale: shale, olive-gray, weathers light gray; blocky, noncalcareous, slightly silty; contains rare to common Crurithyris, Linoproductus fragments, nuculoid pelecypods articulated, and rare Rhipidomella; becomes slightly calcareous up the unit; gradational with unit above and below.	4	4	1.32
		11. Hughes Creek Shale: shale, olive-gray; blocky to fissile; slightly calcareous and silty; contains abundant Crurithyris forming lag-type deposit; also contains Derbyia; Composita, and Linoproductus fragments.	0	6	.15
		10. Hughes Creek Shale: shale, gray black, fissile to blocky, very calcareous; contains common Crurithyris, articulated and disarticulated Neochonetes, common crinoids, Linoproductus, and other fauna as in unit above; also contains common Chondrites.	0	1	.02
		9. Hughes Creek Shale: limestone, dark gray to olive-gray; blocky to hackly; very argillaceous to shaley; calcirudite, fine, fusulinid biomicrite; also contains common brachiopod fragments and crinoids; fusulinids account for approximately 10%-15% of the lithology.	0	5	.13
		8. Americus Limestone: limestone, gray, weathers light yellow-tan; blocky, and hard; calcarenite, coarse to fine calcirudite, brachiopod, pelecypod bearing, crinoidal, fusulinid biomicrite; contains common intraclasts at the base of unit; fusulinids become common in the upper 6", brachiopods and pelecypod debris most common at the base of this unit; TA.	1	2	.36
	F1.1	7. Americus Limestone: shale, gray-brown to orange; fissile; limonite stains throughout; contains black carbonaceous fragments throughout (plant fragments?); rare productid fragments.	0	3	.08
		6. Americus Limestone: limestone, tan-gray, weathers gray-yellow; contains abundant large, disarticulated myalinid valves, lying parallel to bedding; also rare to common Pteronites, fragmented; common ostracodes, rare brachiopod fragments (Reticulatia); calcarenite, coarse, ostracodal, molluscan biomicrite; TA.	1	3	.36
		5. Americus Limestone: limestone, gray, weathers yellow-tan; platy to hackly; contains common fossils as above unit; also contains reworked, angular, stromatolitic rip-clasts; also contains common flaser-like shale lentils (due to bioturbation); calcarenite as above.	0	5	.13
		4. Americus Limestone: limestone, light brown, weathers tan-yellow; laminated, contains common phosphatic debris, fossils as above; and common intraclasts; calcarenite, medium to coarse, ostracodal, pelecypod, intraclast biomicrite.	0	3	.08
		3. Americus Limestone: algal-stromatolite, gray, wavy bedding; lower 4" is predominately dark gray algal bands (Collenia?) forming subtle dome structures; inbetween and above the algal bands is a light gray, ostracode bearing, pelecypod bearing, crinoid bearing calcarenite-micrite; lower 1" contains algal rip-clasts laterally.	0	8	.20
		2. Americus Limestone: limestone, orange-brown, massive, composed almost wholly of carbonate and clay grains, angular, moderately sorted, fine calcirudite-micrite; also contains common ostracode fragments, and macerated plant fragments.	0	2	.05
		1. Hamlin Shale: shale, light gray-brown, weathers tan-brown; blocky to fissile; calcareous; silty; contains common ostracodes, and plant fragments.	0	8	.20
HAMLIN	H1	-1. Hamlin Shale: claystone, olive-brown to olive, weathers light tan; blocky, noncalcareous, nonfossiliferous, silty, trace of calcite nodules (paleosol); base concealed.	1+		.30+

Thin section data was used to supplement description of the following unit: 54.

State: Kansas County: Pottawatomie Quadrangle: Flush

Locality Description:

Flush locality (F)
NW¼ SW¼ .
Section measured in a road ditch, approximately 2¼ miles from the town of Flush.

Section measured from the Long Creek Limestone, down into the Hughes Creek Shale of the Foraker Formation.

Interval measured August, 1986

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— - - - Climate Change Surface	ft	in	m
F3 (LONG CREEK)	F3.9	24. Long Creek Limestone: algal-laminite; gray-brown; limonitic; planar to brecciated; and mudcracked; contains abundant celestite crystals on weathered surface.	0	6	.15
		———?———?———			
	F3.8	23. Long Creek Limestone: shale, tan, weathers light olive-orange; blocky, noncalcareous; nonfossiliferous; slightly silty; trace of root mottling (?); paleosol.	0	2	.05
		22. Long Creek Limestone: algal-laminite; gray-olive, weathers orange-gray; platty to flaggy; laminations planar, wavey, and slightly brecciated; contains common pseudo-birdseye structures, formed by the preferential weathering of thin, interlaminated, lenticular calcilutites between algal laminations.	0	10	.25
		21. Long Creek Limestone: limestone, tan-orange, blocky to flaggy; argillaceous; dolomitic; rare pelecypod fragments; fossiliferous calcilutite; TA.	1	2	.36
	F3.7	20. Long Creek Limestone: mudstone, tan-yellow; weathers dull tan-yellow; blocky; silty; noncalcareous; nonfossiliferous.	0	2	.05
		19. Long Creek Limestone: limestone, tan-orange; flaggy to platy; brecciated from weathering; argillaceous; vuggy with celestite linings; dolomitic; lower contact uneven and wavy; TA.	0	6	.15
		———?———?———?———			
	F3.6	18. Long Creek Limestone: claystone, light tan-yellow; blocky; limonitic; nonfossiliferous.	0	5	.13
		17. Long Creek Limestone: limestone, tan-orange; weathers light tan-orange; platty to flaggy; argillaceous; dolomitic; mudcracked. nonfossiliferous calcilutite; TA.	0	6	.15
	F3.5	16. Long Creek Limestone: algal laminite, gray-brown; limonitic; dolomitic; planar to wavy, mudcracked; with thin interbedded nonfossiliferous calcilutite.	0	2	.05
		15. Long Creek Limestone: claystone; tan-orange, slightly fissile to blocky; noncalcareous; rare plant fragments; and thinnly interbedded green claystone lentils.	0	7	.18
		14. Long Creek Limestone: limestone, tan-orange; weathers dull tan-orange; brecciated; vuggy with celestite and calcite linings; limonitic; dolomitic; and rare pelecypod fragments (internal molds); TA.	0	7	.18
	F3.4	13. Long Creek Limestone: shale, olive, light olive-gray; noncalcareous; nonfossiliferous; slightly silty.	0	5	.13
		12. Long Creek Limestone: limestone, tan-gray, orange-gray; blocky, flaggy to slabby; argillaceosu; slightly vuggy with calcite linings; calcarenite, medium to coarse; pelecypod, gastropod, crinoidal, biomicrite; fossils occur in lenticular fashion; becomes nonfossiliferous in the upper 2"; TA.	0	8	.20
		———?———?———?———			
	F3.3	11. Hughes Creek Shale: shale, gray, weathers light gray; very calcareous; hackly to blocky; contains rare pelecypod fragments, crinoids, and rare brachiopod fragments.	0	6	.15
		10. Hughes Creek Shale: limestone, light gray; weathers orange-gray; massive; very argillaceous; calcirudite, fine, fusulinid, biomicrite; fusulinids are abundant (30%) in the upper 24", but decrease in abundance in the lower 6"; unit also contains productid fragments; crinoids; bryozoa fragments.	2	6	.76

Flush section continued

Unit	Subunit	Description	ft	in	m
F3 (LONG CREEK)	F3.3	9. Hughes Creek Shale: shale, olive-tan; blocky to fissile, calcareous; contains common Meekella; common productid fragments; articulated Linoproductus; contains thin lenticular calcarenite lenses containing fossils aforementioned; gradational with unit above.	0	7	.18
		8. Hughes Creek Shale: limestone, gray, shaley, mottled; calcarenite, coarse, brachiopod, pelecypod, biomicrite; contains common Linoproductus, Dunbarella, Derbyia, and rare Meekella, fragmented and forming lag-type deposit; TA.	0	1	.02
	F3.2	7. Hughes Creek Shale: shale, dark gray; weathers olive-gray; blocky to fissile; slightly calcareous towards the base; contains rare Chondrites; rare productid fragments, rare Orbiculoidea.	1	6	.46
		6. Hughes Creek Shale: shale, olive gray to orange gray; blocky to fissile; calcareous; contains common fragmented and articulated Neospirifer, Reticulatia, Neochonetes, rare Meekella, Composita, Derbyia, ramose, incrusting, fenestrate bryozoa; rare Spirorbis and Petrocrania, large well preserved crinoid stems; the lower 2-3" contains abundant to common large fusulinids (6-7mm length), that decrease to very rare toward the top of unit; faunal diversity decreases toward the top ; TA	0	11	.28
		5. Hughes Creek Shale: limestone, tan-gray, weathers light buff-gray; blocky; to nodular; becomes shaley up the unit (i.e. gradational with unit above); calcirudite, fine, shaley, fusulinid, biomicrite; unit also contains crinoids, productids, and rare Neospirifer; fusulinids account for approximately 10-20% of the lithology.	1	3	.38
	F3.1	4. Hughes Creek Shale: shale, gray to olive, very calcareous; blocky to slightly fissile; contains Derbyia, common Neochonetes, and rare Neochonetes.	0	2	.05
		3. Hughes Creek Shale: shale, light olive-gray, weathers red-tan and gray; blocky; slightly fissile; limonitic; very calcareous; contains rare fusulinids (less than 1%); rare Neochonetes and rare crinoids.	0	4	.10
		2. Hughes Creek Shale: limestone, gray-olive; weathers light buff; blocky, hackly, very argillaceous, to shaley; massive; calcirudite, fine, brachiopod, fusulinid bearing, biomicrite; lower 2" contains common Composita, large articulated Neospirifer, rare Hystriculina, rare Crurithyris, crinoids, and other brachiopod fragments; fusulinids are common in the lower half, and become abundant in the upper 4" (approximately 20%). lower 3-4" contain thin lenticular, biosparite lags containing brachiopod fragments aforementioned; TA.	0	8	.20
		?			
F2 (HUGHES CREEK)	F2.4	1. Hughes Creek Shale: shale, olive-gray; to orange-olive; blocky to fissile; becomes more calcareous up the unit; fissile in the lower 10"; contains abundant Crurithyris, large and small; rare Orbiculoidea fragments, and productid fragments; base concealed.	1	6	.46

State: Kansas County: Riley Quadrangle: Manhattan

Locality Description: Holidome Locality (H)

C N½ sec. 25, T10S, R7E
In a roadcut on the west side of road, approximately 1 mile south-southwest of where railroad tracks turn south-southwest from and east-west direction; and approximately 1 mile south of the Holiday Inn, Holidome.

Section measured from the Johnson Shale, down into the Hughes Creek Shale of the Foraker Formation.
Interval measured July, 1986

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— ; – – – Climate Change Surface)	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.5	35. Johnson Shale: limestone, light gray, argillaceous, laminated, and mudcracked; nonfossiliferous calcilutite; top of section eroded away.	3	0	.91
		34. Johnson Shale: limestone, light gray, weathers tan; platy; to flaggy; argillaceous; nonfossiliferous calcilutite; TA.	1	2	.35
	F3.4	33. Johnson Shale: shale, pale olive, weathers gray-olive; flaggy silty, nonfossiliferous.	4	0	1.23
		32. Long Creek Limestone: limestone, tan, weathers light tan; argillaceous; thinnly laminated; weathers massive; contains large gastropods (high-spired), and rare productid spines; fossiliferous, dolomitic, calcilutite; TA.	1	10	.56
	F3.3	31. Long Creek Limestone: limestone, tan-orange, weathers buff-tan; argillaceous; massive; nonfossiliferous, dolomitic, calcilutite.	3	6	1.06
		30. Long Creek Limestone: limestone, tan-orange, weathers buff-tan; argillaceous; calcilutite; contains common lenticular, cross-bedded, crinoidal, calcarenites, that are intraclast bearing, and contain rare pelecypod fragments.	2	8	.81
		29. Long Creek Limestone: limestone, tan, weathers tan-orange; argillaceous; blocky to flaggy; cross-laminated calcilutite; contains abundant Permophorus, and rare crinoids; dolomitic.	0	8	.20
		28. Hughes Creek Shale: shale, gray-tan; fissile, calcareous; contains common crinoids, fenestrate bryozoans; Derbyia, rare Straparolus, Neochonetes, and rare Chondrites.	0	3	.07
		27. Hughes Creek Shale: limestone, tan-gray, weathers tan-yellow; blocky; argillaceous; calcirudite, fine, fusulinid, biomicrite; also contains rare Neospirifer, and crinoids; fusulinids represent approximately 35% of the lithology.	2	11	.89
		26. Hughes Creek Shale: shale, olive; weathers tan-gray; blocky; very calcareous; gradational with unit above; contains fenestrate bryozoans; osagid incrusted grains; productids (Linoproductus and others); basal 2" contains Meekella, Derbyia, Composita, large Neospirifer; fossils are fragmented and articulated; TA.	0	9	.23
	F3.2	25. Hughes Creek Shale: shale, gray-black, weathers gray; blocky to flaggy; silty; contains rare Linoproductus, rare Juresania, fenestrate bryozoan fragments and Crurithyris.	1	6	.46
		24. Hughes Creek Shale: shale, gray-black; weathers gray; flaggy to platy; calcareous; contains rare Crurithyris, Orbiculoidea fragments; Aviculopecten; productids, large fragments of fenestrate bryozoan, and rare Straparolus.	0	6	.15
		23. Hughes Creek Shale: shale, gray-green; blocky to fissile; very calcareous; contains thinnly interbedded lenticular calcarenites-biomicrites which contain ramose bryozoans, Linoproductus, Neospirifer (fragments), Hustedia, abundant fusulinids; Neochonetes, crinoids, and the upper ½ of unit contains rare trilobite pygidiums and free cheeks; unit contains other unidentified brachiopod fragments; fusulinids account for approximately 35% of lithology ; TA.	1	8	.51
	F3.1	22. Hughes Creek Shale: shale, tan-olive; weathers brown; very calcareous; flaggy to platy; contains rare Crurithyris, and bryozoan fragments.	0	6	.15

Holidome section continued

F3	F3.1	21. Hughes Creek Shale: limestone, gray-tan, weathers pale brown; blocky; argillaceous; calcirudite, gine, argillaceous, brachiopod, fusulinid biomicrite; contains Neochonetes, Composita, Crurithyris, and productids; fusulinids increase in abundance up the unit (approximately 20-30%); TA basally.	0	9	.23
		20. Hughes Creek Shale: shale, olive, weathers light olive; very calcareous, fissile to blocky; very calcareous; contains common Neospirifer, Composita, productids, and minor amounts of Crurithyris.	0	6	.15
F2 (HUGHES CREEK)	F2.4	19. Hughes Creek Shale: shale, gray-black, weathers light gray; fissile, papery; noncalcareous; contains sulfate-rich films on bedding laminae and partings; contains abundant Crurithyris in the upper 7", and abundant Orbiculoidea in the lower 7".	1	3	.38
		18. Hughes Creek Shale: limestone, light brown-yellow; weathers light tan-yellow; blocky, hard, argillaceous; calcarenite, coarse, osagid, molluscan, brachiopod, biomicrite; contains common pelecypod fragments, rare gastropods, osagid-type grains rare; upper 1" of unit contains common Hystriculina, other brachiopod fragments; unit contains common large vertical burrows (1/2" diameter) in the lower 6"; pelecypods articulated and disarticulated ; TA.	1	6	.46
		17. Hughes Creek Shale: shale, dark gray to brown-orange, weathers brown; fissile to blocky, slightly calcareous; contains common Aviculopecten; Derbyia, productid spines, fenestrate bryozoans, and Orbiculoidea and Lingula fragments.	0	7	.18
	F2.3	16. Hughes Creek Shale: shale, gray, fissile to platy; contains common, thinnly interbedded, argillaceous, and micaceous siltstones; nonfossiliferous.	3	3	.99
		15. Hughes Creek Shale: shale, olive to gray; weathers light gray; blocky to fissile; silty; contains rare Straparolus; Astartella, crinoid columnals; bryozoan fragments, Derbyia fragments, and Lingula in the lower 6"; the upper 9" shows evidence of burrowing (Chondrites); becomes more silty up the unit.	1	3	.38
		14. Hughes Creek Shale: shale, gray to olive; fissile to hackly, very calcareous; contains common Neospirifer and productid fragments; upper 1/2 inch contains lag of productid fragments.	0	6	.15
		13. Hughes Creek Shale: shale, gray-tan, weathers tan-gray; platy to flaggy; argillaceous; very calcareous; contains abundant Neospirifer, and common Linoproductus, Neochonetes, and Composita; crinoids common to abundant.	0	7	.18
		12. Hughes Creek Shale: shale, brown, gray, weathers tan-gray; abundant fusulinids (approximately 10-20%); common Hustedia, bryozoans, well preserved productid spines, Reticulatia, Derbyia, Ditymopyge fragments; Composita; fusulinids decrease in abundance toward the top; TA.	2	8	.81
		11. Hughes Creek Shale: limestone, gray-tan, weathers light yellow-tan; blocky; argillaceous; calcirudite, fine, fusulinid biomicrite; contains lesser Orbiculoidea and Lingula fragments, crinoids and productid fragments.	0	11	.28
		10. Hughes Creek Shale: shale, gray-brown, to yellow; calcareous contains productids (Linoproductus fragments), common Crurithyris, and Orbiculoidea (rare).	0	1	.02
		9. Hughes Creek Shale: shale, brown, fissile, very thinnly bedded, contains abundant Crurithyris and productids.	0	1	.02
		8. Hughes Creek Shale: limestone, dark gray, weathers light gray; argillaceous, slabby to blocky; calcarenite, coarse, Crurithyris, crinoidal, Chondrites, biomicrite; unit also contains fragments of Orbiculoidea and Lingula.	0	2	.05
	F2.2	7. Hughes Creek Shale: shale, brown, fissile, very calcareous; contains common Crurithyris, and inarticulate, brachiopod fragments.	0	2	.05
		6. Hughes Creek Shale: limestone, tan-brown; weathers light tan; argillaceous, blocky and thin bedded; contains common Neospirifer, Crurithyris, Orbiculoidea, and Hystriculina.	0	3	.08
		5. Hughes Creek Shale: shale, brown, argillaceous, very calcareous; contains common fusulinids (less than 3%); Crurithyris (increase in abundance up the unit); and Wilkingia.	0	3	.08

Holidome section continued

Formation	Member	Unit description			
F2 (HUGHES CREEK)	F2.2	4. Hughes Creek Shale: limestone, tan-gray; blocky to flaggy; very argillaceous; calcarenite, coarse, to fine calcirudite, brachiopod, crinoidal, fusulinid bearing, biomicrite; contains common Neospirifer, Crurithyris, Lingula fragments, and Orbiculoidea fragments.	0	3	.08
		3. Hughes Creek Shale: shale, dark gray-green; calcareous; fissile and soft; contains crinoids, fenestrate bryozoans, Neospirifer, Crurithyris, Wellerella, Neochonetes, and productids; also contains common Aviculopecten and myalinid bivalve fragments ; TA.	0	5	.13
	F2.1	2. Hughes Creek Shale: limestone, light gray; weathers gray-tan; thin bedded; blocky; hard, argillaceous; in thin section unit is a calcirudite, fine to medium, Isogramma, fusulinid, brachiopod, biomicrite; contains common echinoid spines, fenestrate bryozoans, common Crurithyris, rare to common Neospirifer, Hystriculina, and crinoids; the upper 2" contains common to abundant Crurithyris, and common Composita; faunal diversity decreases up the unit, and Isogramma and fusulinids are common in the lower and middle portion of unit ; TA.	1	2	.36
		1. Hughes Creek Shale: shale, gray-green; weathers light gray; calcareous, fissile, soft; contains Derbyia, Hystriculina, and common Linoproductus; fossils become more abundant up the unit.	0	8	.20

Thin section data was used to supplement descriptions of the following units: 18, and 21.

State: Kansas County: Riley Quadrangle: Manhattan

Locality Description:

Kansas River Locality (KR)
SW¼ NE¼ NW¼ sec. 20, T10S, R8E
Section measured in an exposure, cut approximately 1/8 mile to the southeast of where Highway 177 crosses the Kansas River in south-eastern Manhattan, Kansas; the exposure can be found behind business establishment.
Section measured from the Long Creek Limestone of the Foraker Formation, down into the Hughes Creek Shale (middle) of the Foraker Formation.
Interval measured July, 1986

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— – – – Climate Change Surface	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.6	18. Long Creek Limestone: limestone, buff-tan; weathers tan-orange; thin bedded, flaggy to platy; laminated with alternating dark gray and light tan calcilutites, recrystallized; possibly algal in origin; sharp contact with unit below.	0	6	.15
		17. Long Creek Limestone: limestone, light brown-gray; weathers orange-gray; weathers massive; blocky; argillaceous; fossiliferous calcilutite; contains Aviculopecten, bellerophont gastropods, Permophorus; also contains horizontal burrows (epirelief), and trails; dolomitic; contains thin (1") shale partings in the base ; TA.	1	9	.53
	F3.5	16. Long Creek Limestone: limestone, tan, weathers yellow-buff; hard, nodular to hackly fracture; calcilutite characterized by abundant celestite vugs and root traces; nonfossiliferous.	0	7	.18
		15. Long Creek Limestone: limestone, tan, weathers tan-yellow; contains less vugs than unit above; blocky to slabby; argillaceous; dolomitic; fossiliferous calcilutite; contains common to rare pelecypod fragments ; TA.	0	6	.15
	F3.4	14. Long Creek Shale: shale, brown to tan, weathers gray-yellow; massive; well indurated; blocky; silty; contains common plant fragments, that increase in abundance up the unit; unit also contains bioturbated zone in the upper 1"; basal 3" is very calcareous and contains common crinoids and Permophorous, as well as rare brachiopod fragments	2	3	.69
		13. Hughes Creek Shale: shale, tan-gray, weathers buff; calcareous, fissile to blocky; contains common crinoid columnals, Neochonetes, Derbyia, Aviculopecten, and other brachiopod fragments; TA.	0	4	.10
	?	——?————?————?——			
	F3.3	12. Hughes Creek Shale: limestone, light tan-gray; weathers tan-orange; argillaceous; massive; blocky; calcirudite, fine, fusulinid biomicrite; contains rare osagid incrusted brachiopod fragments (not incrusting fusulinids), rare Aviculopinna, crinoid stems and columnals, Neochonetes, and other brachiopod fragments.	1	8	.51
		11. Hughes Creek Shale: shale, light tan-brown, weathers tan; blocky, very calcareous; contains abundant Derbyia, lesser Composita, Meekella, crinoids (stems), fenestrate bryozoans, diversity decreases up the unit, accompanied by increase in fusulinids; TA.	1	5	.43
	F3.2	10. Hughes Creek Shale: Shale, gray-black, weathers gray; blocky to fissile; calcareous; silty; contains rare Crurithyris, Aviculopecten; and productid fragments.	2	5	.74
		9. Hughes Creek Shale: shale, gray-black, weathers gray; blocky to fissile; very calcareous; gradational with unit below and above; contains articulated and disarticulated Neochonetes, Derbyia, Hustedia, Reticulatia, Rhipidomella, Composita, Neospirifer, crinoid stems and columnals, ramose and fenestrate bryozoans, myalinid bivalve fragments; fossils are clay-supported and occur in lenticular calcirudites; unit also contains rare sharks teeth; TA.	2	1	.63
		8. Hughes Creek Shale: limestone, gray, weathers yellow-gray; clayey to shaley (grades to very calcareous shale), blocky and massive; calcirudite, fine, fusulinid (40-50%) biomicrite; also contains crinoids, and brachiopod fragments.	0	8	.38

Kansas River section continued

F3 (LONG CREEK)	F3.1	7. Hughes Creek Shale: shale, brown-tan, weathers gray-yellow; hackly to blocky, very calcareous; rare productid fragments.	0	5	.13
		6. Hughes Creek Shale: limestone, limestone, gray, weathers yellow-gray; massive; very argillaceous; calcirudite, fine, brachiopod, fusulinid, biomicrite; contains whole Hustedia, Composita, Crurithyris, and crinoids; fusulinids are rare in the lower 3", but become abundant (20-30%) in the upper 4" (accompanied by a decrease in brachiopod fragments aforementioned) ; TA basaly	0	7	.18
		5. Hughes Creek Shale: shale, gray, weathers tan-gray; blocky to hackly, very calcareous; contains common Hystriculina, Neochonetes, Crurthyris, and Composita.	0	6	.15
F2 (HUGHES CREEK)	F2.4	4. Hughes Creek Shale: shale, gray-black, weathers light gray; fissile; calcareous; contains abundant Orbiculoidea in the lower 10"; valves are parallel to bedding laminae; the lower 10" also contains rare Crurithyris and Lingula; the upper 6" contains abundant Crurithyris and Lingula, occuring in overlapping fashion; unit contains common orange Fe-oxidized, lenticular zones.	1	4	.41
		3. Hughes Creek Shale: limestone, tan-gray, weathers yellow-gray; blocky, hard, massive; calcirudite, fine to medium, osagid, pelecypod, gastropod, brachiopod, biomicrite; unit also contains rare Isogramma, and small (high-spired) gastropods; as well as echinoid debris; wackstone to packstone; the upper 2" of unit is very argillaceous to shaley, and contains Crurithyris, and Reticulatia; TA.	1	3	.38
	F2.3	2. Hughes Creek Shale: shale, bray-black; calcareous; splintery to fissile; nonfossiliferous; contains thin interlaminated, silty, light gray shales.	4	3	1.29
		1. Hughes Creek Shale: shale, gray-black, weathers light gray; blocky; very calcareous; contains common Derbyia, Reticulatia, Neospirifer, Linoproductus, and Meekella; fossils are articulated and fragmented; base of unit concealed.	0	6+	.15+

-Thin section data was used to supplement descriptions of the following units: 3, 6, 8, 12.

State: Kansas County: Wabaunsee Quadrangle: Keene

Locality Description:

Keene Section (K)
SW¼ NW¼ sec. 3, T13S, R12E
Section measured in a road cut, on the east side of the road, approximately ¼ mile south of where Highway 4 turns east.

Section measured from the Long Creek Limestone of the Foraker Formation, down into the Americus Limestone of the Foraker.

Interval measured July, 1986

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— - - - Climate Change Surface	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.5	46. Long Creek Limestone: limestone; tan to orange; weathers brown-orange; laminated to very thin bedded; weathers massive; limonitic; argillaceous; and dolomitic; calcilutite algal laminite; contains prominent algal laminations (1-5mm thick), planar to wavy; with common mudcracks; also consists of thinnly interbedded, clayey, micirite (nonfossiliferous); lower contact gradational with unit below.	1	4	.41
		45. Long Creek Limestone: limestone, light gray; weathers tan-gray; laminated to very thin bedded; platy to flaggy, hard; dolomitic; argillaceous; calcilutite, nonfossiliferous micrite.	0	10	.25
		44. Long Creek Limestone: limestone, light tan-gray; flaggy to platy; slightly laminated, argillaceous calcilutite, nonfossiliferous.	0	1	.02
		43. Long Creek Limestone: claystone, light yellow-tan; blocky, soft and poorly indurated; very calcareous; nonfossiliferous.	0	1	.02
		42. Long Creek Limestone: limestone, light tan-orange; weathers tan; blocky; massive; slightly vuggy; calcilutite, fossiliferous, micrite; contains inclined burrows, rare Permophorus, and rare crinoid columnals; TA.	1	0	.30
	F3.4	41. Hughes Creek Shale: shale, light brown, to tan; fissile; slightly blocky; calcareous; containsn abundant macerated plant fragments on bedding plane surfaces.	0	6	.15
		40. Hughes Creek Shale: limestone, light tan-buff; weathers orange-tan; blocky; slabby; hard; argillaceous; sharp contact with unit below; calcarenite, coarse, pelecypod, crinoid bearing, cherty, biomicrite; contains abundant articulated and disarticulated Permophorus (commonly internal molds), rare Edmondia (possibly Schizodus) and sparse fragments of Tainocerus., and orthoconic cephalopod fragments.	0	5	.13
		39. Hughes Creek Shale: limestone, light tan yellow, weathers tan; flaggy; hard, argillaceous; calcarenite, coarse, pelecypod, bryozoan, crinoid biomicrite; common Aviculopecten myalinid bivalve fragments, fenestrate bryozoans; sharp contact with unit below; TA.	0	1	.02
	F3.3	38. Hughes Creek Shale: shale, brown gray, fissile to blocky, very calcareous; contains rare crinoid fragments; productids, and other comminuted brachiopod fragments (rare).	0	4	.10
		37. Hughes Creek Shale: limestone, gray, weathers light gray-yellow; massive; hackly; very argillaceous; limonitic; calcirudite, fine, fusulinid, brachiopod, crinoidal, biomicrite; contains large and small robust, ventricose fusulinids (15-20%), also lesser amounts of fenestrate bryozoans, common Neochonetes, Neospirifer, and crinoids; TA.	0	7	.18
		36. Hughes Creek Shale: limestone, gray, weathers tan-yellow; massive; hard; calcirudite, fine, fusulinid, brachiopod bearing, crinoid bearing, argillaceous biomicrite; fusulinids are randomly oriented throughout; limonitic; fusulinids-30%	1	1	.33
		35. Hughes Creek Shale: shale, olive-tan to gray, weathers light tan-gray; very calcareous; blocky; hackly, hard; contains very thin bedded fossiliferous calcarenites; contains abundant robust fusulinids which gradually increase up the unit (i.e. gradational with unit above); also large Reticulatia fragments, fenestrate bryozoans, crinoids, and productid fragments.	1	7	.48
		34. Hughes Creek Shale: shale, gray, olive, weathers light tan-olive; blocky; fissile; very calcareous; transitional between units 33 and 35; contains common Linoproductus, crinoids, and productid fragments; bryozoans.	0	3	.08

Keene section continued

F3 (LONG CREEK)	F3.3	33. Hughes Creek Shale: limestone, gray, weathers light tan; hackly, to platy; very argillaceous; calcarenite, coarse, brachiopod, pelecypod, biomicrite; contains common Derbyia, Crurithyris, myalinid bivalve fragments, rare bryozoan fragments, forming shell lag; unit also contains thin shale lentils; basal 1" is shell hash composed of Derbyia and bryozoans.	0	7	.18
	F3.2	32. Hughes Creek Shale: shale, gray weathers light brown-gray; blocky to hackly; calcareous; micaceous; contains thinnly interbedded light tan brown, silty, calcareous shales; contains rare to common Linoproductus.	1	6	.46
		31. Hughes Creek Shale: shale, dark gray, weathers light gray; blocky; slightly calcareous; micaceous; slightly silty; contains common Crurithyris, rare Hustedia, Neochonetes, and Derbyia, in the lower 20"; also common Linoproductus throughout; contains rare Chondrites; the upper 20" contains sparse thin silty shale lentils.	4	3	1.30
		30. Hughes Creek Shale: shale, dark gray, weathers light gray; fissile to blocky; calcareous, micaceous; contains common Hustedia, abundant Neochonetes, articulated Neospirifer, Reticulatia fragments, Derbyia, Hystriculina, Linoproductus, rare to common Crurithyris, incrusting bryozoans, fenestrate bryozoans; and ramos bryozoans; Meekella, rare Lissochonetes, Wellerella, and Juresania; unit also contains common Composita and rare to common fusulinids in the lower 4-6"; fusulinids are very rare in the upper half of unit, TA.	0	8	.20
		29. Hughes Creek Shale: shale, gray, weathers light gray, blocky to nodular; very calcareous; contains abundant robust fusulinids (40-50%), also occuring in lenticular calcirudites (packstones), thinnly interbedded in unit; also contains Wellerella, crinoids, trace of other brachiopod fragments; gradational with unit above.	1	5	.43
	F3.1	28. Hughes Creek Shale: shale, gray, to dark tan-gray; weathers tan; blocky, slightly fissile, calcareous, slightly micaceous; contains common Crurithyris, common fusulinids, rare Hustedia, common Neospirifer, rare Composita, Linoproductus, and Juresania fragments; unit contains rare fusulinids in the upper 2", and fossil fragments are rare.	1	1	.33
		27. Hughes Creek Shale: limestone, gray, weathers light tan-gray; blocky; to platy; hard; argillaceous; lower 3-4" becomes shaley; calcarenite, coarse, brachipod, fusulinid, biomicrite; contains abundant Crurithyris in the lower portion of unit; diversity increases up the unit with common to abundant fusulinids (20-30%); common articulated Composita, sparse Aviculopecten, Hystriculina, Neospirifer, rare biserial forams (arenaceous, in thin section), rare Lophophyllidium; and large cincid stems (3-4" in length); TA.	0	11	.28
F2 (HUGHES CREEK)	F2.4	26. Hughes Creek Shale: shale, gray, dark gray, weathers light gray; slightly fissile to blocky; calcareous; micaceous; sharp contact with unit below; contains abundant Crurithyris, articulated (large and small), rare Orbiculoidea and Lingula fragments.	0	2.5	.06
		25. Hughes Creek Shale: shale, black-gray; blocky, hard, micaceous; very calcareous; contains abundant Orbiculoidea forming lenticular hash type deposits; also contains rare Crurithyris and Lingula.	0	2.5	.06
		24. Hughes Creek Shale: shale, tan, weathers gray-tan; fissile to blocky; limonitic, very calcareous, common Crurithyris, and sparse osagid type grains; Hystriculina (rare).	0	2	.05
		23. Hughes Creek Shale: limestone, light tan-gray, blocky to slabby; argillaceous; massive; calcirudite, fine, brachiopod, pelecypod biomicrite (mudstone to wackestone); contains common Crurithyris, inarticulate brachiopod fragments; thin section shows very rare osagid grains; pelecypod fragments, fenestrate bryozoans, brachiopod fragments, and crinoids; unit also contains common thinnly interbedded, light olive-gray shale lentils; TA.	0	3.5	.09

Keene section continued

F2 (HUGHES CREEK)	F2.4	22. Hughes Creek Shale: shale, gray; very calcareous; blocky; micaceous, contains common productid fragments, crinoids, and Crurithyris.	0	2	.05
		21. Hughes Creek Shale: limestone, tan-gray to red-gray; blocky to flaggy; argillaceous; calcirudite, fine, silty, recrystallized, brachiopod, ostracode, biomicrite; thin section also shows common gastropod, crinoids and pelecypod fragments.	0	2	.05
	F2.3	20. Hughes Creek Shale: shale, dark gray, weathers light gray; fissile, noncalcareous; very micaceous; slightly silty; contains rare to common Aviculopecten on bedding plane surfaces; sharp contact with unit above and below.	0	5	.13
		19. Hughes Creek Shale: shale, gray, to dark gray, blocky; fissile; calcareous; slightly micaceous; conatins common Neospirifer (articulated); Composita (ariculated), and common Linoproductus; common productid spines and fragments; bryozoan fragments; crinoid; and rare Ditymopyge fragments.	0	5	.13
		18. Hughes Creek Shale: limestone, gray, to dark gray, blocky; hackly, to slightly nodular; very argillaceous; calcirudite, fine, brachiopod, crinoid, fusulinid, biomicrite; contains common fusulinids throughout, but most abundant in the lower 9", and decreasing upwards; contains common Neospirifer, Neochonetes, Composita, bryozoan fragments, crinoids, and productid fragments; lower contact gradational with unit below.	1	6	.46
		17. Hughes Creek Shale: shale, tan-gray, weathers light tan-gray; blocky; slightly hackly; calcareous; becomes very calcareous in the upper 6"; contains abundant robust fusulinids (small and large individuals ranging from 3mm to 9mm in length; approximately 20-25% of the lithology); unit also contains ramose, incrusting, and fenestrate bryozoans; also contains lesser fragments of Neochonetes, Reticulatia, Neospirifer, crinoids, Juresania, rare Wellerella, Hustedia, echinoid plates and spines, and rare Composita fragments; TA.	1	3	.38
		16. Hughes Creek Shale: limestone, gray, weathers light gray; hackly, to blocky, very argillaceous; calcirudite, fine, clayey, osagid, brachiopod, fusulinid, biomicrite; contains abundant robust fusulinids (approximately 20-25%); also contains common bryozoans (ramose and fenestrate; one with a rugose corrallite attached to it); incrusting bryozoans; also contains rare brachiopods including Neochonetes, Reticulatia, Neospirifer, and crinoids; brachiopod fragments commonly, unevenly incrusted with osagia (i.e. incrusting concave portion of shells); no fusulinids are incrusted; unit also contains thin, wavy, interbedded, dark gray shale lentils.	0	6	.15
		15. Hughes Creek Shale: shale, dark gray, weathers gray; very calcareous; blocky; contains common articulated and disarticulated Crurithyris, common Linoproductus fragments, Neochonetes; crinoids.	0	2	.05
		14. Hughes Creek Shale: limestone, dark gray, weathers gray; blocky; slabby; argillaceous; calcirudite, fine, brachiopod, biomicrite; common horizontal burrows throughout (Chondrites) also abundant Crurithyris, rare Orbiculoidea fragments, Lingula fragments, and rare crinoids.	0	2	.05
	F2.2	13. Hughes Creek Shale: shale, gray-black; fissile; very calcareous; contains abundant Crurithyris; common Lingula, and rare Orbiculoidea.	0	2	.05
		12. Hughes Creek Shale: limestone, light gray, weathers yellow-gray; slabby to blocky; hard; calcirudite, fine, recrystallized, crinoid, brachiopod, packed biomicrite; lower half of unit in thin section shows common crinoids, Crurithyris, and rare osagid incrusted grains and sparse gastropods; upper half of unit contains common Neospirifer (one in life position), crinoids, broyozoan fragments, rare fusulinids, Hustedia, Hystriculina, and Neochonetes; most fossils are fragmented and lie parallel to bedding; lower bedding surface contains horizontal burrows (2-3" diameter), and also contains thin interbedded, fossiliferous shale streaks with fragments of brachiopods aforementioned; sharp contact with unit below.	0	6	.15

Keene section continued

F2 (HUGHES CREEK)	F2.2	11. Hughes Creek Shale: shale, dark gray, weathers light gray; very calcareous; blocky to hackly; lower 3" contains common Crurithyris; abundant Neochonetes, small and large, articulated; Derbyia fragments; common articulated Linoproductus; rare Juresania fragments; fenestrate, ramose bryozoan fragments; the upper half of the unit is same lithology, but contains common Neospirifer fragments, crinoid columnals and anchors, common fusulinids (approximately 5% in the upper 1-2"); Crurithyris; Neochonetes, and rare smooth ostracodes; (sieve analyses); TA.	0	8	.20
	F2.1	10. Hughes Creek Shale: limestone, gray, weathers light tan-gray; blocky; hard; upper 2-3" becomes platy to slabby and very argillaceous; calcirudite, fine, brachiopod, crinoid, Isogramma, fusulinid bearing biomicrite; in thin section lower half contains common to abundant Isogramma (approximately 50% of the fauna), crinoids, and Crurithyris; also rare Composita, and rare fusulinids; this grades into a more argillaceous calcirudite in the upper half of unit, with abundant Crurithyris (articulated, disarticulated, and fragmented), common crinoids and Chondrites, sparse bryozoan fragments, rare Aviculopecten; and inarticulate brachiopod fragments; the upper 2" is composed predominately of Crurithyris; TA.	0	10	.25
F1 (AMERICUS)	F1.3	9. Hughes Creek Shale: shale, dark gray, weathers light gray; calcareous; blocky, contains common Crurithyris, and rare productid fragments; unit also contains common celestite fractures.	1	6	.46
		8. Hughes Creek Shale: interval concealed- shale?	3	8	1.12
		7. Hughes Creek Shale: shale, gray, weathers gray-brown; calcareous; fissile; blocky; rare productid fragments; Neochonetes, rare Neospirifer fragments; and upper portion of unit concealed.	0	3	.08
		6. Hughes Creek Shale: limestone, gray, weathers light gray; very argillaceous; nodular to slightly platy; calcirudite, fine, silty, brachiopod, echinoiderm, biomicrite; contains abundant Neochonetes, Neospirifer (articulated), common Reticulatia, common Composita, rare Meekella, crinoid columnals; common Crurithyris, and Linoproductus, productid spines, and rare Juresania; thin section also show rare ostracodes, and bryozoan fragments; upper 12" is shaley; TA.	2	9	.84
		5. Hughes Creek Shale: shale, gray to dark gray, weathers light gray; blocky, calcareous; contains abundant Linoproductus; and Crurithyris, forming shell lags (¼-½") throughout; also contains common Neochonetes (large and small) in the upper 4"; fossils decrease toward base of exposed interval.	0	8	.20
		——?——	——?——	——?——	
	F1.2	4. Hughes Creek Shale: interval concealed- shale?	1	4	.41
		3. Americus Limestone: limestone, dark gray, weathers tan-gray, blocky, hard, massive; calcirudite; fusulinid, brachiopod, crinoid, biomicrite; fusulinids common to abundant in the upper 3-4", brachiopods most common in the lower half of unit; crinoids abundant throughout; TA.	1	7	.48
	F1.1	2. Americus Limestone: shale, dark gray, to gray black; noncalcareous, blocky to fissile; contains rare productid fragments, and Crurithyris.	1	0	.30
		1. Americus Limestone: limestone, tan-brown; massive; blocky; calcarenite, medium to coarse, ostracodal, molluscan, biomicrite; with common large myalinid bivalve fragments; basal 6" contains dark gray, algal stromatolites, domal, and laterally discontinous; TA.	2	0	.61

		-Thin section data was used to supplement descriptions of the following units: 6, 10, 12, 14, 18, 21, 23, 27, 33, 39, 42, and 46.			
		-Disaggregated shale data was used to supplement descriptions of the following units: 11, 28, and 30.			

State: Kansas County: Pottawatomie Quadrangle: Westmoreland NE

Locality Description:

Louisville Section (L)
NW¼ NW¼ NW¼ sec. 9, T8S, R10E
Section **measured** in a road cut, starting 1/8 mile east of intersection of Federal-aid secondary highway roads 543 and 1212.

Section measured from the Hughes Creek Shale of the Foraker Formation, down into the Hamlin Shale of the Janesville Formation.

Interval measured July, 1986.

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— – – – Climate Change Surface	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.3	39. Hughes Creek Shale: tan olive; weathers tan-yellow; blocky massive, very calcareous (grades to very argillaceous calcirudite) ; contains abundant ventricose fusulinids (30-35%), with no preferred orientation or preferred size sorting also contains common Neochonetes, Neospirifer, ramose and incrusting bryozoans; well preserved crinoid stems and columnals; TA.	3	1	.93
		38. Hughes Creek Shale: shale, olive; blocky, very calcareous; contains common productid fragments, Linoproductus, common **Derbyia**, and sparse crinoids; rare Neochonetes.	0	3	.08
		37. Hughes Creek Shale: claystone, tan-yellow, silty; calcareous; abundant Linoproductus , crinoids, Derbyia, and other brachio-fragments; highly weathered.	0	3	.08
		36. Hughes Creek Shale: limestone, red-gray; weathers tan; blocky flaggy; hard; calcarentite, coarse, Derbyia, Neochonetes, immature, biosparite (transgressive lag).	0	5	.13
	F3.2	35. Hughes Creek Shale: shale, olive-gray, gray, blocky; fissile; calcareous; contains rare productid fragments.	0	3	.08
		34. Hughes Creek Shale: shale, gray to dark gray; blocky to fissile; silty; noncalcareous; contains rare productid fragments, and myalinid bivalve fragments.	1	7	.48
		33. Hughes Creek Shale: shale, dark gray; blocky; fissile; slightly silty; contains abundant Neospirifer, common Reticulatia, Linoproductus, common to abundant Neochonetes, common to rare Cruruithyris, ramose, fenestrate, and incrusting bryozoans; robust fusulinids in the lower 3", Wellerella; abundant productid spines; sparse myalinid fragments; contains thin (¼ to ½") calcarenite lenses, argillaceous and sparry, in the basal 5" containing common incrusting bryozoans, Derbyia, Reticulatia, productid spines, and Crurithyris; TA.	0	10	.25
		32. Hughes Creek Shale: shale, gray, weathers olive tan; very calcareous; blocky; contains abundant fusulinids, poorly sorted, large and small inidividuals; fusulinids commonly found in thin calcarenitic lenses forming fusulinid-packed biomicrites (packstones); unit also contains rare Neospirifer, Neochonetes; bryozoans (fenestrate and ramose).	2	11	.89
	F3.1	31. Hughes Creek Shale: shale, gray, weahters olive; blocky, to fissile; very calcareous; contains rare to common Hustedia, Crurithyris, Rhipidomella, Crurithyris, crinoids; lacks fusulinids.	0	5	.13
		30. Hughes Creek Shale: limestone, gray-orange, weathers yellow-gray; slabby to hackly; hard, argillaceous; calcarenite, coarse, brachiopod, fusulinid, crinoidal, biomicrosparite; contains common to abundant fusulinids, common Neospirifer, Composita, and productid fragments; Derbyia and Hystriculina, TA basally.	0	2	.05
F2	F2.4	29. Hughes Creek Shale: shale, gray, weathers orange-brown; blocky, slightly calcareous; contains aundant Orbiculoidea in the lower 6"-8", and abundant Crurithyris in the upper 10"; upper 8" also contains rare Hystriculina, horizontal and inclined burrows; and rare Derbyia.	1	6	.46
		28. Hughes Creek Shale: limestone, light tan-gray, weathers yellow-tan; blocky, hard; argillaceous; in thin section the lower ½ of unit is calcirudite, fine, argillaceous, brachiopod osagid, bryozoan, pelecypod, gastropod, biomicrite (wackestone to packstone); also contains common Isocramma and bryozoan (continue next page)	1	5	.43

Louisville section continued

F2 (HUGHES CREEK)	F2.4	28. Hughes Creek Shale: continued; fragments; pelecypod and osagid incrusted grains are most common in lower half; lower ½ of unit in thin section is a calcirudite, fine, fusulinid, brachiopod, osagid, pelecypod, gastropod, crinodal biomicrite (packstone to wackestone); osagid incrusted grains increase in upper half of unit; TA.	1	5	.43
		27. Hughes Creek Shale: shale, olive to brownish gray; blocky to fissile, contains common Aviculopecten; Orbiculoidea fragments and productid fragments; base of unit concealed.	1	0	.30
		——?——————?——————?——			
	F2.3	26. Hughes Creek Shale: interval concealed- shale?	3	6	1.06
		25. Hughes Creek Shale: shale, olive gray, weathers light gray; blocky; very calcareous; contains common articulated Reticulatia, common articulated well preserved Composita, common large (7mm) fusulinids; rare Hustedia, incrusting Petrocrania, and Neospirifer (some with cirripid borings); top of unit concealed; TA.	0	5	.13
		24. Hughes Creek Shale: shale, gray-tan, weathers tan; hackly to nodular; very calcareous; contains calcarenite lenses with aundant Linoproductus, crinoids, and other brachiopod fragments, forming biosparite; unit also contains small (1-2mm) fusulinids.	0	4	.10
		23. Hughes Creek Shale: limestone, light gray, platy, blocky, to hackly; calcilutite, Crurithyris, Chondrites, biomicrite; unit also contains common Hystriculina.	0	3	.08
	F2.2	22. Hughes Creek Shale: shale, gray, light brown; fissile, very calcareous; contains common Crurithyris; and inarticulate brachiopod fragments, Orbiculoidea and Lingula.	0	3	.08
		21. Hughes Creek Shale: limestone, dark gray; weathers light tan-gray; blocky to slabby; contains large randomly oriented burrows, (i.e. bedding is mottled), calcilutite, Crurithyris, crinoidal biomicrite (mudstone to wackestone); contains common Crurithyris, and Hystriculina.	0	3	.08
		20. Hughes Creek Shale: limestone, gray, weathers light gray; hackly to blocky; calcarenite, fusulinid, Crurithyris, biomicrite; fusulinid are common in the lower 3"; Crurithyris becomes abundant in the upper 3" accompanied by an increase in argillaceous content.	0	8	.20
		19. Hughes Creek Shale: shale, tan-gray, weathers tan; blocky to fissile; very calcareous; contains common to abundant Neochonetes; rare to common Neospirifer, Reticulatia, rare Wellerella, rare Orbiculoidea, Crurithyris, Derbyia, and ramose bryozoans; TA.	0	6	.15
	F2.1	18. Hughes Creek Shale: limestone, yellow gray; weathers dark gray-yellow; blocky, platy; becomes very argillaceous to shaley in the upper 2"; calcarenite, osagid bearing, brachiopod, pelecypod bearing, crinoidal, Isogramma, biomicrite; unit contains Reticulatia, Hystriculina, Crurithyris, and other brachiopod fragments; including rare Composita, Neospirifer, Linoproductus, Derbyia, and Rhipidomella; unit also contains Wilkingia and other unidentified pelecypod fragments; lacks fusulinids; Crurithyris becomes abundant in in the upper 2"; TA.	0	10	.25
		17. Hughes Creek Shale: shale, light tan-olive to gray, becomes lighter up the unit; blocky; to fissile; micaceous; very calcareous; contains common Linoproductus framents.	0	11	.28
F1	F1.3	16. Hughes Creek Shale: shale, olive, weathers olive-gray; calcareous; micaceous, blocky to fissile; rare ostracodes;	2	11	.89
		15. Hughes Creek Shale: shale, gray, weathers light gray; fissile; limonitic; calcareous, contains rare fragmented Orbiculoidea, common Reticulatia, Hystriculina, and rare Aviculopecten.	0	1	.02
		14. Hughes Creek Shale: limestone, gray-orange, weahters yellow-tan; blocky, to flaggy and platy; in thin section unit is a calcirudite, medium to coarse, immature, echinoid, brachiopod, pelecypod, crinoidal, bryozoan, gastropod, osagid biosparite; poorly sorted; osagid grains most abundant; unit contains distinguishable abundant echinoid spines occasionally incrusted with bryozoans, osagid coated pelecypod fragments, (continue next page)	0	7	.18

Louisville section continued

Formation	Unit	Description	ft	in	m
F1 (AMERICUS)	F1.3	14. Hughes Creek Shale: continued; abundant gastropods, commonly not incrusted with Osagia; unit also contains Straparolus, Wellerella (not incrusted), and Neochonetes; unit also contains edgewise grains, and slight imbrication with echiniod spines showing, slightly preferred orientation, N35E, dipping to the southwest (i.e. low angle inclined bedding); osagid type grains account for approximately 80-90% of the allochems.	0	7	.17
		13. Hughes Creek Shale: limestone, gray to orange-brown; weathers light tan; massive to nodular bedding; contains thin interbedded shale lentils; in thin section unit is described as a calcirudite, fine, to medium, immature, brachiopod, ostracode, gastropod, pelecypod, echinoid, osagid, poorly washed biosparite; gastropods, pelecypods, and osagid-type grains are the most abundant allochems, with osagid incrusted fragments accounting for approximately 80% of the allochems; TA.	0	7	.17
	F1.2	12. Hughes Creek Shale: shale, olive-gray, weathers light brown-gray; silty, blocky to fissile in the lower 24"; becomes more fissile and platy in the upper 48" and contains thin light brown to tan very silty interbeds; unit contains rare Astartella.	5	10	1.78
		11. Hughes Creek Shale: shale, olive, blocky to fissile, calcareous; contains rare Astartella, rare Chondrites.	1	1	.33
		10. Hughes Creek Shale: shale, gray, blocky; contains rare to common Crurithyris, articulated.	0	6	.15
		9. Hughes Creek Shale: shale, olive gray, to orange gray; fissile and brittle; very calcareous; limonitic; contains common Neochonetes, small crinoids; and common fusulinids.	0	5	.13
		8. Americus Limestone: limestone, gray to yellow-gray; weathers dark gray to yellow-gray; calcirudite, fine, brachiopod, bryozoan bearing, fusulinid, biomicrite; fusulinids become common in the upper 3"-4"; brachiopods include Neospirifer, Composita, Neochonetes, Wellerella, Derbyia, and other unidentified brachiopod fragments; unit is composed predominately of crinoids ; TA.	1	0	.30
	F1.1	7. Americus Limestone: shale, light olive-gray; weahters light brown-gray; blocky; calcareous; contains rare disarticulated Crurithyris; rare Juresania; rare crinoids; and Neochonetes; fossils most abundat in the lower 6", and is nonfossiliferous in the upper2"	0	8	.20
		6. Americus Limestone: limestone, tan-gray; weathers light tan; flaggy to platy; argillaceous; calcarenite, medium to coarse, intraclast bearing, ostracodal, pelecypod, gastropod, brachiopod bearing, crinoidal biomicrite; upper 4" contains common large, disarticulated myalinid bivalve shells; high spired gastropods, bellerophont gastropods, rare crinoids, rare Wellerella; the basal 2" contains slightly wavy to subtle dome structures, consisting of stromatolites (Collenia); inbetween algal structures matrix consists of algal ripclasts, gastropods, ostracodes, and other fossil debris, comminuted; algal stromatolites are laterally discontinuous, and occasionally brecciated; TA.	0	6	.15
		5. Americus Limestone: limestone, gray to tan-orange; platy to hackly; argillaceous; thin bedded; calcarenite, intraclast, ostracode, pelecypod, biomicrite; gradational with unit below.	0	7	.17
		4. Americus Limestone: limestone, tan-orange, argillaceous, massive; calcarenite to coarse grained sandstone, composed predominately of carbonate and clay grains (autochthonous); that are poorly sorted and angular; unit also contains common ostracodes, and macerated, black, plant fragments.	0	5	.13
		3. Hamlin Shale: shale, gray- light gray, to olive; blocky; brittle; contains abundant ostracodes, and rare macerated plant fragments.	0	4	.10
HAMLIN	H1	2. Hamlin Shale: claystone, olive, blocky, slightly micaceous; silty; calcareous; rare root traces, and contains calcareous nodules in the upper 24" (paleosol).	4	0	1.22
		1. Hamlin Shale: claystone, olive to gray, blocky, silty, noncalcareous, nonfossiliferous; base of unit concealed.	0	6	.15

		-Thin section data was used to supplement descriptions of the following units: 13, 28, 30, 32, and 39.			

State: Kansas County: Pottawatomie Quadrangle: Westmoreland NE

Locality Description:

Louisville East Locality (LE)
SW¼ SW¼ sec. 3, T8S, R10E
Section located approximately ¼ mile east of where county road crosses East Fork Adams Creek on Federal-Aid Secondary road 543.

Section measured from the Hughes Creek Shale of the Foraker Formation, down into the Hamlin Shale of the Janesville Formation.

Interval measured July, 1986

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
F2 (HUGHES CREEK)	F2.1	16. Hughes Creek Shale: limestone, gray to light orange; weathers light orange-tan; blocky to platy; argillaceous, contains flaser-like shale lentils throughout; calcirudite, fine, brachiopod, Isogramma, osagid bearing, pelecypod, biomicrite; unit contains common articulated, Wilkingia (one found in life position); articulated and fragmented Composita, Crurithyris, Neochonetes, Derbyia; Aviculopecten, Edmondia, crinoids, echinoid spines, fenestrate, and ramose bryozoa, and osagid incrusted grains (pelecypod and brachiopod fragments, recrystallized); Isogramma is common and found in the basal 5"; faunal diversity decreases up the unit; this is accompanied by an increase in argillaceous content, and abundant Crurithyris in the upper 2"; TA.	0	10	.25
		15. Hughes Creek Shale: shale, olive to gray; weathers gray-olive; blocky to fissile; calcareous; micaceous; contains common Linoproductus; rare Neochonetes; becomes limonitic in the upper 1".	0	7	.18
F1 (AMERICUS)	F1.3	14. Hughes Creek Shale: shale, light olive-gray; weathers light gray; limonitic, blocky to fissile; noncalcareous; silty; micaceous; contains Astartella, and rare ostracodes.	2	5	.74
		13. Hughes Creek Shale: shale, gray-olive; weathers light gray; blocky; calcareous; slightly silty and micaceous; contains common Orbiculoidea, and rare productid fragments.	0	3	.08
		12. Hughes Creek Shale: limestone, gray-orange, weathers buff-tan; flaggy to platy; argillaceous; limonitic; micaceous; silty; calcirudite, fine to medium, immature, clayey, osagid, brachiopod, molluscan biosparite (poorly washed); unit consists predominately of comminuted, osagid incrusted fossil debris; other articulated and fragmented fossils (not incrusted) include Neospirifer, Reticulatia, Wellerella, Aviculopinna, Straparolus, bellerophont gastropods, crinoids, fenestrate, and ramose bryozoa fragments, incrusting bryozoa; upper 2" becomes shaley; Linoproductus in basal 2"; TA.	1	5	.43
	F1.2	11. Hughes Creek Shale: claystone, olive-gray; weathers brown-gray; fissile and blocky; noncalcareous; becomes very silty in the upper 24", and contains common oscillatory ripples (showing south-southwest to north-northeast direction of water movement, exact measurement with Brunton was difficult because bedding surface poorly exposed); contains rare (epirelief) tracks and trails on silty bedding surfaces; basal 5 feet contains rare Astartella.	0	2	.05
		10. Hughes Creek Shale: shale, olive, to orange-gray; weathers buff-gray; blocky; hackly; calcareous; contains common Crurithyris, and other productid fragments.	8	2	2.49
		9. Hughes Creek Shale: shale, olive to gray; weathers gray-buff; hackly to blocky; very calcareous; limonitic; rare fusulinids, common crinoid columnals, and ramose bryozoa.	0	2	.05
		8. Americus Limestone: limestone, gray, weathers light tan-gray; blocky hard, and massive; calcirudite, fine, crinoidal, brachiopod, fusulinid bearing (less than 2%), biomicrite; crinoids most abundant allochem (25%); unit also contains articulated and fragmented Neospirifer, Hystriculina, Neochonetes, Derbyia, and other common to abundant brachiopod fragments; also contains solitary rugose corallites (Lophophyllidium?); and rare pelecypod fragments; TA.	0	4	.10
	F1.1	7. Americus Limestone: shale, gray, olive-gray, calcareous; fissile; common Lingula; and common horizontal and inclined burrows.	0	11	.28

Louisville East section continued

F1 (AMERICUS)	F1.1	6. Americus Limestone: shale, light olive-gray; calcareous, blocky to fissile; slightly limonitic; contains common to rare productid fragments and spines; Linoproductus.	0	7	.18
		5. Americus Limestone: limestone, buff-gray, weathers tan-buff-gray; flaggy to platy; thin bedded; calcarenite, medium to coarse, brachiopod, echinoid, ostracode, recrystallized biomicrite; contains rare to common pelecypod fragments (myalinid), and rare brachiopod and echinoid fragments; middle 2" contains lenticular shell lag containing crinoidal and pelecypod and brachiopod fragments; the basal 1-2" contains poorly developed (laterally discontinuous) algal structures; stromatolitic; slightly pustular (possibly Ottonosia); wackestone to mudstone; TA.	0	7	.18
		4. Americus Limestone: limestone, tan-orange; massive; very argillaceous; contains abundant carbonate and clay grains, angular, and poorly to moderately sorted; micritic matrix; contains common macerated plant fragments and ostracodes; unit is gradational with unit above.	0	2	.05
		3. Hamlin Shale: shale, gray, weathers olive-gray; blocky to fissile; cacareous; silty; contains abundant ostracodes; and rare horizontal burrows.	0	3	.08
HAMLIN		2. Hamlin Shale: shale, light olive, gray, blocky; limonitic; nonfossiliferous; calcareous;	1	0	.30
		1. Hamlin Shale: shale, light olive, gray, blocky; silty; non-fossiliferous; noncalcareous; trace root mottling.	0	4+	.10

State: Kansas **County:** Riley **Quadrangle:** Manhattan

Locality Description:

Manhattan Locality (M)
NW1/4 SW1/4 SE1/4 SE1/4, sec. 7, T10S, R8E.
Measured outcrop approximately 30 yarrds west-northwest of the old Manhattan Water Treatment Center.

Section from the Long Creek Limestone of the Foraker Formation down into the Hughes Creek Shale of th Foraker Formation

Interval measured September, 1985

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— ---Climate Change Surface)	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.5	51. Long Creek Limestone: limestone, light tan-orange, weathers light gray-yellow, blocky to flaggy, thin bedded to medium bedded, argillaceous, dolomitic, limonitic, slightly vuggy (calcite and celestite lined); calcilutite, pelecypod bearing crinoid bearing, micrite; pelecypods unidentified in thin section(*Permophorus*?).	0	10	.25
		50. Long Creek Limestone: limestone: light tan-orange, weathers dull gray-orange, blocky, very argillaceous, dolomitic; calcilutite, pelecypod bearing, crinoid bearing micrite.	0	6	.15
		49. Long Creek Limestone: limestone, light tan orange, weathers dull gray-orange, very argillaceous, dolomitic; calcilutite, limonitic, pelecypod and crinoid bearing micrite; contains light brown argillaceous laminae throughout(thin section).	0	2	.05
		48. Long Creek Limestone: limestone, light tan-orange, weathers gray-orange, blocky, massive, very argillaceous, limonitic, dolomitic; calcilutite, fossiliferous, micrite; contains common internal molds of *Aviculopecten*, other rare pelecypod fragments and rare crinoids ; TA.	1	5	.44
	F3.4	47. Hughes Creek Shale: shale, light oliv-gray, blocky, to fissile, noncalcareous, silty, characterized by burrow structures infilled with argillaceous limestone matrix from above; contains sparse to common plant fragments.	0	1	.025
		46. Hughes Creek Shale: mudstone, light tan-brwon, weathers light tan, blocky, to slightly hackly, noncalcareous, very silty, micaceous; contains thinnly interbedded dark gray shale whisps; also contains common to abundant black and Fe-oxidized macerated plant fragments that are acicular in nature.	0	4	.10
		45. Hughes Creek Shale: mudstone, gray, gray-olive, weathers lighttan, blocky, hard, very silty, calcareous, nonfossiliferous except for very sparse trace of plant fragments; sharp contact with unit below.	1	1	.33
		44. Hughes Creek Shale: limestone, light tan-orange; blocky slabby; very argillaceous; calcilutite, fine, limonitic, fossiliferous, chert bearing, biomicrite; in thin section contains sparse pelecypod fragments, crinoids and brachiopod fragments; contains conspicuous *Permophorus* ; (mudstone); TA. ——— ? ——— ? ———	0	3	.08
	F3.3	43. Hughes Creek Shale: shale, gray-olive, weathers light tan-gray, fissile, slightly hackly, calcareous; contains common *Linoproductus*, crinoids (calyx), rare fenestrate bryozoan fragments, and common myalinid bivalve fragments.	0	3	.08
		42. Hughes Creek Shale: shale, gray-olive, weathers light tan-gray, hckly, very calcareous; contains common crinoid columnals, common fusulinids in the lower 2", fenestrate and incrusting bryozoans, *Neochonetes*, rare *Composita*, and rare *Neospirifer*; brachiopods articulated and well preserved.	0	4	.10
		41. Hughes Creek Shale: limestone, gray, weathers light tan to yellow-gray; very hackly, to slightly blocky; very argillaceous, limonitic; calcirudite, fine, algal bearing, pelecypod bearing, brachiopod, fusulinid biomicrite; contains abundant large (7mm axial length) and small (3mm axial length) fusulinids, common crinoids, productid fragments, *Neochonetes*, common to rare osagid incrusted brachiopod fragments (rarely are fusulinids incrusted); fusulinids account for approximately 25%-30% of the lithology in the lower 7"; in the upper 5"-6" there is a gradual increase in brachiopod fragments (approximately 25% of the lithology) and a decrease in fusulinids; this is accompanied by an increase in argillaceous content; brachiopod and bryozoans are fragmented and poorly sorted and angular; fusulinids are well preserved and poorly sorted. (fossil gradations seen in thin sections)	1	1	.33

Manhattan locality continued

Unit	Subunit	Description			
F3 (LONG CREEK)	F3.3	40. Hughes Creek Shale: shale, gray to olive-gray, weathers light gray-olive; hackly, very calcareous; contains common fusulinids, common Neochonetes, common Neospirifer, rare Derbyia, fenestrate and ramose bryozoans, crinoids, rare pelecypod fragments, and common productid fragments; the lower 2"-3" contains fossils aforementioned concentrated with other fossils such as Wellerella, echinoid debris, and Ditymopyge fragments, forming transgressive lag, contains rare Composita throughout; TA.	1	3	.38
	F3.2	39. Hughes Creek Shale: shale, gray, olive-gray; blocky to fissile; silty, micaceous, noncalcareous; contains rare productid fragments and myalinid bivalve fragments in the lower 12" (sieve analysis), and is nonfossiliferous in the upper 7" (sieve analysis).	1	7	.48
		38. Hughes Creek Shale:shale, gray to olive-gray weathers light gray, becomes more olive up the unit; calcareous (very calcareous in the lower 4"); blocky to fissile, micaceous, slightly silty; contains common to abundant fusulinid (in the basal 3"); contains common Neospirifer, Composita, Reticulatia with incrusting Petrocrania, Linoproductus, Derbyia, Rhipidomella, Wellerella, Hustedia, rare Juresania, common Crurithyris, Neochonetes, rare Lissochonetes, and other unidentified brachiopod fragments, fenestrate and ramose bryozoans, common crinoids and Ditymopyge; the faunal diversity gradually decreases upward, with the upper 6" containing common productid fragments, large echinoid fragments, fenestrate bryozoans, Linoproductus fragments, and myalinid fragments; unit also contains thin (1/4" to 1/2") interbedded, lenticular, calcirudite lenses in the lower 4" composed of fossils aforementioned; fossils also clay supported; fossil fragments such as Composita, Reticulatia, Neospirifer, Meekella and Wellerella, are commonly articulated and well preserved; one Composita found in life position; fenestrate bryozoans well preserved ; TA.	0	11	.28
		37. Hughes Creek Shale: limestone, very argillaceous to very calcareous shale, gray, to light brown-gray, weathers light tan-gray; very hackly; very argillaceous; becomes shaley in the upper 4"; calcirudite (packstone), fine, limonitic, crinoid, brachiopod bearing, fusulinid shaley biomicrite; contains abundant large and small fusulinids (approximately 35%-45% of the lithology) but contains predominately smaller fusiform (4mm-5mm) fusulinids; also contains rare Composita, Neospirifer, bryozoan fragments, crinoids, rare trilobite fragments, and other lesser unidentified brachiopod fragments.	1	0	.30
	F3.1	36. Hughes Creek Shale: shale, olive-gray, weathers light gray; fissile, very calcareous, slightly silty; micaceous; contains rare fusulinids, Crurithyris, and Wellerella.	0	2.5	.06
		35. Hughes Creek Shale: shale, light tan-gray, weathers light yellow-gray; hackly; very calcareous; transitional with unit below and above; contains common fusulinids, rare Crurithyris, crinoids, and other brachiopod fragments.	0	5	.13
		34. Hughes Creek Shale: limestone, gray, to tan-gray, weathers light tan-yellow; blocky, hackly, hard, very argillaceous; calcirudite, fine, crinoidal, brachiopod bearing, fusulinid biomicrite; in thin section contains common crinoids, rare gastropod, rare Crurithyris, abundant fusulinids (approximately 20%-30% of lithology), Neochonetes, and other unidentified brachiopod fragments, as well as rare bryozoan fragments, (packstone).	0	9	.23
		33. Hughes Creek Shale: shale, olive to olive-gray, weathers light yellow-gray; hard; blocky to hackly;, very calcareous; contains common Neospirifer, Composita, rare Rhipidomella, Crurithyris, Neochonetes, other brachiopod fragments, rare bryozoans, and abundant crinoids; rare fusulinids; TA.	0	8	.20
F2	F2.4	32. Hughes Creek Shale: shale, gray, weathers light tan-gray; caclareous, blocky, argillaceous; contains abundant overlapping Crurithyris shells; rare to common Orbiculoidea and Lingula; rare Hystriculina; and other productid fragments; gradational with unit below.	0	7	.18

Manhattan locality continued

F2 (HUGHES CREEK)	F2.4	31. Hughes Creek Shale: shale, black, to gray-black, weathers gray; fissile to blocky, noncalcareous; slightly silty, micaceous; contains abundant Orbiculoidea throughout (large and small), common Lingula, and rare to common Crurithyris.	0	7	.18
		30. Shale, light tan-orange, weathers gray-olive; fissile to blocky, very limonitic, contains common Orbiculoidea, common Lingula, rare Crurithyris, sparse Hystriculina, crinoids, and sparse osagid incrusted grains, transitional with units 31-29.	0	1	.025
		29. Hughes Creek Shale: limestone, reddish-gray, to olive-gray, weathers tan-yellow; blocky; hard; in thin section the lower 1/3 of this unit is a calcirudite, fine, slightly clayey, osagid, pelecypod, biomicrite; the basal portion also contains small gastropods, and bellerophonts, rare Fe-oxidized arenaceous forams (biserial), fecal (?) pellets, and sparse brachiopod fragments; Osagia is thickest in concave portion of shells (i.e. uneven coatings of algae); the middle 1/3 of this unit (in thin section) is a calcirudite, fine, slightly clayey, osagid, pelecypod, gastropod, biomicrite; also contains ostracodes and there is an increase in gastropods - both high spired and planispiral (one Straparolus was found), and echinoderm fragments; pelecypod fragments are more evenly coated with Osagia, than in the lower portion; the upper 1/3 of this unit (in thin section) is a calcarenite, coarse, limonitic, slightly clayey, echinoderm, pelecypod, biomicrite; contains brachiopod fragments inclu- sparse Composita, rare Hystriculina, and rare Isogramma fragments; also contains common gastropods and ostracodes, as well as common osagid incrusted brachiopod and pelecypod fragments; fossil content throughout unit is approximately 13%; gastropods throughoutthe unit are commonly not coated; sharp contact with unit below. (wackestone); TA.	1	2	.36
		28. Hughes Creek Shale: shale, light gray-brown, weathers gray-tan; contains very thinnly interbedded dark gray shale lentils; calcareous; contains rare small gastropods, rare pelecypod fragments; lower contact gradtional with unit below.	0	6	.15
	F2.3	27. Hughes Creek Shale: shale, dark gray, weathers light gray; silty; micaceous; slightly calcareous; very thin bedded; blocky to fissile; nonfossiliferous (sieve analysis); contains very thinnly interbedded light tan-gray, silty, shales.	1	11	.58
		26. Hughes Creek Shale: shale, light tan, weathers light yellow-tan; blocky; platy; slightly fissile; silty, micaceous; contains rare smooth ostracodes and pelecypod fragments.	0	2	.05
		25. Hughes Creek Shale: shale, gray, weathers light tan-gray; silty; micaceous; slightly calcareous; fissile; very thinnly dedded, contains rare to common , thinnly interbedded, very argillaceous, light tan-brown siltstones containing rare Permophorus and smooth ostracodes, as well as other unidentified pelecypod fragments (sieve analysis).	1	1	.33
		24. Hughes Creek Shale: shale, dark gray, weathers light gray; blocky, to fissile; slightly nodular; calcareous; silty; micaceous; contains sparse amounts of myalinids bivalve fragments, ostracodes, and other sparse pelceypod fragments.	0	9	.23
		23. Hughes Creek Shale: shale, dark gray, weathers light gray; noncalcareous; blocky to fissile; silty, micaceous; contains thinnly interbedded, argillaceous, calcirudite-biosparite (poorly washed; and poorly sorted) consisting of articulated and fragmental pieces of Neospirifer, Composita, Derbyia, Reticulatia, Linoproductus, Meekella, Neochonetes, fenestrate and ramose bryozoans; also contains myalinid bivalve fragments which become common in the upper 2"; unit also contains rare Aviculopecten, echinoid fragments, and common crinoids (sieve analysis).	0	4	.10
		22. Hughes Creek Shale: limestone, gray, to tan-orange-gray, weathers light tan-gray; very argillaceous, limonitic; blocky to hackly; calcirudite, medium, crinoidal, brachiopod, fusulinid biomicrite; contains well preserved, articulated abundant to common Neospirifer, common Composita, rare Reticulatia, Rhipidomella, crinoids, rare Ditymopyge fragments, and abundant to common fusulinids (approximately 10-15% of lithology) randomly oriented. (wackestone-packstone)	0	4	.10

Manhattan locality continued

F2 (HUGHES CREEK)	F2.3	21. Hughes Creek Shale: limestone, gray, weathers light gray; hackly, blocky, very argillaceous-grades to very calcareous shale; forms subdued ledge; indistinct bedding, massive; calcirudite (wackestone-packstone), fine, brachiopod, crinoid, bryozoan, fusulinid shaley biomicrite; contains abundant fusulinids (approximately 15-20% of the lithology), randomly oriented and poorly sorted; common Neospirifer, Composita, Reticulatia, rare to common Rhipidomella, rare Hustedia, common ramose and fenestrate bryozoans, common crinoids, and rare trilobite (Ditymopyge?) fragments, and very rare osagid incrusted grains; TA.	1	10	.56
		20. Hughes Creek Shale: shale, dark olive-gray, weathers light olive-gray; very calcareous; blocky; to hackly; slightly micaceous; contains common fusulinids, articulated well preserved Neospirifer, articulated Reticulatia, rare Hustedia; ramose and fenestrate bryozoans, incrusting bryozoans, common crinoids, and rare trilobite fragments.	0	8	.20
		19. Hughes Creek Shale: limestone, light gray, weathers light tan-gray; blocky; very argillaceous; calcirudite, fine, brachiopod, fusulinid, bryozoan, crinoidal, biomicrite; contains common Crurithyris, large articulated Reticulatia, common Linoproductus, common fusulinids, and crinoids.	0	4	.10
		18. Hughes Creek Shale: shale, dark gray, weathers light gray; very calcareous; fissile to blocky; contains abundant Linoproductus throughout, productid spines, crinoids, and common Crurithyris.	0	1	.025
		17. Hughes Creek Shale: limestone, dark gray, weathers gray; blocky to slabby; hard; argillaceous; calcirudite, fine brachiopod-Chondrites biomicrite; contins common to abundant Crurithyris, abundant clay-filled burrows (Chondrites), and large irregular clay filled burrows ("spreite"), also contains rare Lingula and Orbiculoidea fragments (reworked from unit below) as well as rare erect-ramose bryozoans and rare Composita.	0	3.5	.09
	F2.2	16. Hughes Creek Shale: shale, dark gray, to black-gray; slightly silty; very calcareous; fissile to splintery; contains abundant Crurithyris, rare to common Lingula and Orbiculoidea (articulated and fragmented).	0	2	.05
		15. Hughes Creek Shale: limestone, gray, to dark gray, weathers light tan-gray; blocky to slabby; argillaceous; calcirudite, fine, brachiopod, crinoidal, biomicrite; contains abundant Crurithyris, Rhipidomella, rare Composita, rare Linoproductus, Hystriculina, Wellerella, common Lingula, myalinid bivalve fragments and other unidentified pelecypod fragments, crinoids, also contains common to rare Chondrites, U-shaped burrows, and large irregular "spreite" burrows.	0	3.5	.09
		14. Hughes Creek Shale: limestone, gray, weathers light tan-gray; blocky; to slightly nodular in texture; nonbedded, massive; very argillaceous; contains common to abundant fusulinids (approximately 5% of lithology); contains rare articulated Neospirifer, Composita, Reticulatia, Linoproductus, common Hystriculina, Hustedia, Juresania, common Crurithyris, rare Neochonetes, Orbiculoidea, and Lingula, ramose bryozoans, rare pelecypod fragments, common crinoids and also contains common Chondrites, large horizontal "spreite" burrows, and U-shaped burrows; calcirudite, fine, fusulinid, brachiopod biomicrite; bedding mottled due to burrowing.	0	4	.10
		13. Hughes Creek Shale: shale, gray, weathers light gray; calcareous; fissile; micaceous; slightly-silty; contains rare fusulinids; rare Neospirifer; rare Reticulatia; common Linoproductus; and Crurithyris; rare Neochonetes; Petrocrania, fenestrate bryozoans, and crinoids.	0	3	.08
		12. Hughes Creek Shale: shale, gray, weathers light gray; to tan; fissile to blocky (grades to mudstone); very calcareous; micaceous; limonitic; contains common Neospirifer (articulated), Composita, Reticulatia, rare Linoproductus, common Derbyia, Wellerella, rare Juresania, common Crurithyris, characteristically contains abundant to common Neochonetes; ramose, incrusting, and fenestrate bryozoans, common Aviculopecten, and myalinid bivalve fragments, as well as other unidentified brachiopod fragments (sieve analysis), common crinoids, and rare ostracodes; bryozoans well preserved and intact (parallel to bedding). Neochonetes has small (juvenilte) and large (adult?) whole-disarticulated valves in this unit; TA.	0	4	.10

Manhattan locality continued

F2 (HUGHES CREEK)	F2.1	11. Hughes Creek Shale: limestone, dark gray, gray, weathers tan-gray; slabby to blocky; very argillaceous; calcirudite, fine, brachiopod-Crurithyris biomicrite; contains abundant articulated and fragmented Crurithyris, rare Meekella and Hystriculina; common Chondrites, as well as large irregular "spreite" burrows, and rare U-shaped burrows.	0	2.5	.06
		10. Hughes Creek Shale: limestone, gray, weathers tan-yellow; blocky, hard, non-bedded to mottled bedding (burrowing); calcarenite, coarse to fine calcirudite, fusulinid bearing, algal, crinoidal, brachiopod, biomicrite; unit contains rare fusulinids (less than 3%-visual estimation in thin section); rare Composita, rare Neospirifer, rare Reticulatia, common Linoproductus, common to abundant Isogramma, rare Wellerella, and Hustedia, common Crurithyris, Neochonetes, and other brachiopod fragments in thin section; abundant to common crinoids; common echinoid fragments, rare ostracodes, common osagid incrusted grains; characteristically contains large irregular "spreite" burrows causing mottled bedding, as well as U-shaped burrows in the upper 1"-2"; TA.	0	9	.23
		9. Hughes Creek Shale: shale, gray, olive, weathers light gray; fissile to blocky; calcareous, becomes very calcareous in the upper 3"; silty; micaceous; contains rare productid fragments, abundant Linoproductus in the upper 3" (common in the lower 4").	0	7	.18
F1 (AMERICUS)	F1.3	8. Hughes Creek Shale: shale, gray, olive, weathers light gray, silty; micaceous; slightly calcareous; contains rare productid fragments; rare Crurithyris fragments and ostracodes, in sieve analysis; unit also contains rare Chondrites.	1	4	.41
		7. Hughes Creek Shale: limestone, gray, weathers tan-gray; very argillaceous; blocky to hackly; thin bedded; calcirudite, fine, brachiopod bearing, ostracode bearing, foram bearing, bryozoan bearing, echinoid, molluscan, osagid argillaceous biomicrite; the lower half (in thin section) the lower half of the unit contains common crinoids, abundant osagid incrusted grains (commonly incrusting only one side) common to abundant echinoid fragmenst, common small gastropods, pelecypod fragments including Aviculopecten, common bryozoans and brachiopod fragments; rare Neochonetes, Crurithyris, rare Derbyia, common Linoproductus, and rare forams; the upper half of the unit shows (in thin section) shows an an increase in size and abundance of gastropods, and an increase in size and abundance of gastropods, and an increase in osagid incrusted grains that are more evenly coated; echinoid fragments are commonly not incrusted with Osagia; upper half contains rare brachiopod fragments aforementioned; there is an increase in pelecypod fragments including Aviculopecten and myalinid bivalve fragments; upper 3" also contains rare patchy distribution of sparry calcite where allochems are in grain to grain contact. (wackestone-packstone); TA.	0	10	.25
		6. Hughes Creek Shale: limestone, gray, weathers light tan; blocky, very argillaceous, silty, micaceous; calcirudite, fine, brachiopod, biomicrite; contains abundant Linoproductus throughout, and common Crurithyris.	0	5	.13
		5. Hughes Creek Shale: shale, dark gray, blocky, calcareous; silty; micaceous; contains abundant Linoproductus, and common Crurithyris.	0	1	.02
		4. Hughes Creek Shale: limestone, gray, platy, very argillaceous; calcirudite, fine, immature, brachiopod, biosparite; contains abundant Crurithyris, and rare to common Linoproductus.	0	1	.02
		3. Hughes Creek Shale: shale, dark gray, blocky, hard; very micaceous; silty, calcareous; contaisn common Linoproductus fragments.	0	7	.18
		2. Hughes Creek Shale: limestone, gray, to blue-gray; very hackly; thinnly bedded with thin shale lentils; calcirudite, fine, immature, very argillaceous, brachiopod biosparite; contains aubndant Linoproductus, convex up on bedding planes forming shell pavement; also contains abundant productid spines, and common Crurithyris fragments.	0	4	.10
	F1.2	1. Hughes Creek Shale: shale, gray, dark gray, weathers light gray; blocky, micaceous; silty; slightly calcareous; contains rare Crurithyris (one was found) and rare Linoproductus; no no fossils found at the base of this unit; unit incomplete interval concealed below.	0	7	.18

Continue Manhattan locality

-Thin section data was used to supplement descriptions of the following units: 7, 29, 34, 41, 44, and 48.

-Dissagregated shale data was used to supplement descriptions of the following units: 8, 20, 36, and 38.

State: Kansas County: Riley Quadrangle: Manhattan

Locality Description:

McDowell Creek Road section (MCR)
NE¼ NW¼ sec. 20, T10S, R8E
Section measured in a stream cut approximately 100 feet south of the intersection of McDowell Creek road and K-177, behind car dealership.

Section measured from the Hughes Creek Shale of the Foraker Formation, down into the Hamlin Shale of the Janesville Formation. Interval measured Fall,1987 by Busch, R.M. and Barrett, F.J.

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— / - - - Climate Change Surface)	Unit Thicknesses ft	in	m
F1 (AMERICUS)	F1.2	16. Hughes Creek Shale: shale, olive, weathers light gray; platy; silty, noncalcareous; nonfossiliferous; upper portion of unit concealed.	3+		.91+
		15. Hughes Creek Shale: shale, dark gray to black, weathers light gray; platy to nodular with thin interbedded calcarenite lenses; unit contains common Crurithyris, Neochonetes, productids, fusulinids, and crinoids.	0	4	.10
		14. Hughes Creek Shale: shale, olive, dark gray, weathers light gray; mottled, very calcareous, blocky; contains rare crinoids, Neochonetes, bryozoa fragments (ramose and fenestrate) fusulinids (common), and other brachiopod fragments.	0	5	.13
		13. Americus Limestone: limestone, gray to dark gray, weathers tan gray; blocky, hard, massive, bench former; calcirudite, fine, brachiopod, crinoid, molluscan, fusulinid biomicrite; (wackestone); contains Crurithyris, Straparolus, Tainocerus, Wellerella, Rhipidomella, Hystriculina, Neochonetes; brachiopod fragments are abundant in the lower 2/3; fusulinids become common in the upper half; intraclasts with signs of borings are common in the basal half of unit; crinoids most abundant allochem; TA.	0	11	.28
		12. Americus Limestone: shale, black-gray; fissile; contains common ostracodes, bivalves, and brachiopod fragments including Orbiculoidea.	0	1	.02
		11. Americus Limestone: shale, olive; massive, very silty, calcareous; contains thin lenticular Fe-oxidized zones; contains rare ostracodes and Linoproductus.	0	4	.10
	F1.1	10. Americus Limestone: shale, dark gray, weathers light gray; fissile to platy; contains ostracode lenses.	1	4	.41
		9. Americus Limestone: limestone, gray to dark gray, weathers tan gray; massive, block to platy; wavy bedded in basal 3 to 4 inches; calcilutite, brachiopod bearing, pelecypod, crinoid biomicrite; upper 8 inches contains large disarticulated myalinid bivalve shells and pinnids; lower 3 to 4 inches is algal boundstone (stromatolitic-Collenia?); basal 1 inch stromatolitic facies is a calcarenite, gastropod, intraclast, ostracodes, foram bearing(?) biosparite (transgressive lag?); stromatolites contain thin interbedded calcilutite with ostracodes, gastropods, and forams; TA.	0	11	.28
		8. Hamlin Shale: shale, orange gray; very sandy to silty; massive; contains abundant carbonate and clay grain clasts (calclithite or shale-arenite); contains ostracodes and common macerated plant fragments.	0	3	.08
		7. Hamlin Shale: claystone, olive, weathers gray-olive; massive; silty; contains common to abundant ostracodes, and rare plant fragments.	1	1	.33
HAMLIN	H3	6. Hamlin Shale: siltstone, gray-olive; very argillaceous; cross-laminated; contains common root traces	0	4	.10
		5. Hamlin Shale: mudstone, olive, weathers gray-olive; massive; blocky; silty; upper 5 to 6 feet contains common root traces throughout (paleosol); basally unit contains common plant fragments (lower 2 feet) and is flaggy; TA.	6	8	2.03
	H2	4. Hamlin Shale: mudstone, maroon to dark brown; crumbly; blocky; massive; contains root traces throughout (paleosol).	0	7	.18
		3. Hamlin Shale: mudstone, olive; flaggy to platy; basally grades upward to nonbedded, blocky, crumbly, brown, silty claystone with root traces (paleosol).	2	3	.68

McDowell Creek Road section continued

HAMLIN	H2	2. Hamlin Shale: siltstone, tan gray; sandy; cross-laminated; contains green shale partings, ostracodes, and intraclasts; TA.	0	2	.05
	H1	1. Hamlin Shale: mudstone, olive to brown and orange; massive; crumbly; granular, with microslickensides (paleosol); base unit concealed.	4+		1.22+

State: Kansas County: Wabaunsee Quadrangle: Eskridge

Locality Description:

Mudge and Burton's (1959) section 46
SW¼ NW¼ sec. 1, T15S, R12E
Section from the Hughes Creek Shale of the Foraker Formation, down into the Hamlin Shale of the Janesville Formation.

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
F1 (AMERICUS)	F1.2	9. Hughes Creek Shale: shale, silty, calcareous, dark-gray, thin-bedded; weathers tan; very fossiliferous; fossils include brachiopods, pelecypods, bryozoans, and crinoid columnals.	5	8	1.73
		8. Americus Limestone: limestone, hard, dark-gray, massive; weathers gray and blocky; fusulinids abundant; brachiopods and crinoid columnals common; TA.	1	2	.36
	F1.1	7. Americus Limestone: shale, clayey, noncalcareous, gray to gray-green, thin-bedded; weathers tan to gray; some limonite stains.	2	0	.61
		6. Americus Limestone: limestone, soft, gray to dark-gray; weathers shaly; crinoid columnals and echinoid spines; TA?	0	6	.15
		5. Americus Limestone: shale, silty, very calcareous, gray to dark-gray, thin-bedded.	0	7	.18
		4. Americus Limestone: limestone, hard, partly dense, massive, gray; weathers tan gray and from blocky to platy; large massive algae gives wavy bedded appearance.	0	8	.20
		3. Hamlin Shale: sandstone (calcarenite), tan; composed of minute limestone fragments.	0	5	.13
HAMLIN		2. Hamlin Shale: shale, silty, calcareous, tan-gray, thin-bedded; weathers tan; calcareous lens in lower part.	2	10	.86
		1. Hamlin Shale: shale, silty, calcareous, gray-green, thin-bedded.	10	0	3.05

State: Kansas County: Wabaunsee Quadrangle: Belvue

Locality Description:

Newbury Locality (N)
SE¼ SE¼ sec. 27, T10S, R11E

Section measured in a roadcut, approximately 4 miles north of the town of Newbury.

Section measured is from the lower part of the Hughes Creek Shale of the Foraker Formation.

Interval measured July, 1986

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
F2 (HUGHES CREEK)	F2.1	7. Hughes Creek Shale: limestone, tan to gray, weathers light tan-yellow; blocky to slightly flaggy; hard; slightly argillaceous; limonitic; calcirudite, fine, brachiopod, Isogramma, osagid, biomicrite; unit contains common to abundant Isogramma, occasionally incrusted by Osagia; also contains rare Derbyia, Crurithyris, crinoids, and common to abundant brachiopod fragments; also contains common Edmondia; and other pelecypod fragments in hand specimen; faunal diversity appears highest toward middle of the unit; diversity dereases toward the top of unit, accompanied by increased argillaceous content, and an abundance of Crurithyris in the upper 2"; TA.	0	8	.20
		6. Hughes Creek Shale: shale, olive, weathers light gray; blocky, fissile, calcareous; slightly silty and micaceous; contains common Linoproductus fragments forming lag in the upper 2".	0	6	.15
F1 (AMERICUS)	F1.3	5. Hughes Creek Shale: shale, olive to olive-gray; micaceous; blocky; noncalareous; contains common ostracodes.	2	5	.74
		4. Hughes Creek Shale: shale, orange-gray to olive; blocky; fissile; micaceous; calcareous; slightly silty; rare productids; rare nuculoid bivalves.	0	7	.18
		3. Hughes Creek Shale: limestone, orange-gray, weathers light tan-yellow; fractures platy to hackly; hard; argillaceous; lower 1/3 of unit is an argillaceous, poorly washed, calcirudite; fine; Linoproductus; osagid, biosparite; contains common Linoproductus forming poorly developed lag deposit; osagid grains are most abundant, incrusting unidentified brachiopod and pelecypod fragments; also incrusting bryozoa, and crinoids; the middle 1/3 is same lithology as lower portion, but also contains Neospirifer, and evidence of biomoldic porosity; also contains Wellerella, rare Reticulatia, Straparolus (common), high-spired gastropods; myalinid fragments, and fauna as at the base; upper 1/3 of unit is a calcirudite, fine, poorly washed, molluscan, osagid, brachiopod, biomicrosparite; contains common Aviculopecten, myalinid fragments, gastropods, crinoids, Neospirifer (fragments incrusted with Osagia), and fragments of incrusting bryozoa; fossils throughout the unit are mostly fragmented, and poorly sorted; TA.	1	10	.56
		2. Hughes Creek Shale: shale, gray to olive, weathers gray-tan; blocky; slightly fissile; silty; and micaceous; slightly calcareous; contains common Linoproductus, abundant in the upper 2" forming shell pavement; also rare Neochonetes, and Crurithyris.	1	5	.43
	F1.2	1. Hughes Creek Shale: shale, olive-gray; weathers light gray; blocky; micaceous; silty; noncalcareous; contains thinnly interbedded, tan, calcareous, silty shales; nonfossiliferous. base concealed.	2	8	.81+

State: Kansas County: Wabaunsee Quadrangle: McFarland

Locality Description:

Paxico Locality (P)
SE1/4 NE1/4 SW1/4 sec. 27, T11S, R11E
Roadcut on north side of I-70, southeast of the town of Paxico

Section from the Long Creek Limestone of the Foraker Limestone down into the very upper Hamlin Shale of the Janesville Shale

Interval measured June, 1985.

UNIT DESCRIPTIONS

Transgressive Surface —— - - - Climate Change Surface

5th order T-R units/boundaries	6th order T-R units/boundaries	Unit Descriptions	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.6	37. Long Creek Limestone: calcilutite, light gray, weathers tan-yellow, contains algal laminations- planar to wavy, mud-cracked, dolomitic, limonitic, and argillaceous; total thickness unknown, upper portion weathered away.	0	6	.15
		36. Long Creek Limestone: calcilutite, tan-orange, weathers tan-yellow, platy to slabby, very vuggy (calcite and celestite lined); dolomitic; nonfossiliferous; upper 12" contains green shale clasts; highly weathered and brecciated with cryptic "tee-pee" structures; (pelletiferous?); TA.	5	8	1.72
	F3.5	35. Long Creek Limestone: calcilutite, light orange to gray, weathers tan-orange, collapsed brecciated; algal laminations planar to wavy, mudcracked; limonitic, argillaceous; (pelletiferous?).	0	7	.17
		34. Long Creek Limestone: calcilutite, tan orange, weathers tan yellow, blocky, hard to medium, vuggy (calcite and celestite lined), limonitic, argillaceous, fossiliferous micrite; contains rare _Tainocerus_, and orthoconic cephalopod fragments, _Aviculopecten_, _Edmondia_, _Permophorus_, bellerophont gastropods, and high-spired gastropods; all fossils preserved as internal molds; TA.	1	2	.35
	F3.4	33. Long Creek Limestone: dolostone, buff-tan to light gray, calcareous, argillaceous, mottled to non-descript bedding, vuggy; nonfossiliferous.	0	3	.07
		32. Hughes Creek Shale: shale, gray-brown, weathers light orange-tan, fissile to blocky, silty; contains abundant macerated plant fragments; sharp contact with unit below.	0	2.5	.06
		31. Hughes Creek Shale: limestone-calcarenite, gray, weathers whitish-tan-gray, fractures slabby to blocky, argillaceous, chert bearing; calcarenite, coarse to fine, crinoid bearing, pelecypod, recrystallized, biomicrite (Wackestone to mudstone); contains lenticular shell lags (in lower 4") composed of _Permophorus_, and rare crinoids (in thin section) that have been partially replaced by chert; the upper half has no pelecypods, but contains rare to common fecal(?) pellets, trace of chert, and the appearance of silt grains (thin section); TA.	0	7.5	.19
	F3.3	30. Hughes Creek Shale: limestone-calcilutite, gray, weathers buff, hackly, argillaceous, nonfossiliferous micrite.	0	10	.25
		29. Hughes Creek Shale: shale, gray, weathers light gray, very calcareous, massive, fractures hackly, lower 9" contains rare fusulinids, common _Neospirifer_, _Neochonetes_, _Composita_, _Derbyia_, ramose bryozoans, and crinoids; the upper 25" becomes more calcareous (occasionally grading to a very argillaceous calcirudite), and contains abundant fusulinids (approximately 25%-30% of lithology) randomly oriented; also contains lesser amounts of fauna aforementioned, as well as rare to common osagid incrusted grains (fusulinids rarely incrusted- as seen in thin section), and echinoid fragments; TA.	2	10	.86

Paxico locality continued

F3 (LONG CREEK)	F3.2	28. Hughes Creek Shale: shale (gradational between shale and mudstone), olive-gray, weathers light gray; blocky to hackly, massive; silty; nonfossiliferous (thin section).	1	5	.43
		27. Hughes Creek Shale: shale, gray, to gray-black, weathers light gray; predominately fissile; calcareous, slightly micaceous; the upper 23" is silty, less calcareous, and contains rare ostracodes, bryozoans, productid spines and fragments, and rare pyritized Hustedia; faunal diversity is highest in the lower 12" and includes common fusulinids, as well as common Derbyia, Wellerella, Hustedia, Neochonetes, Composita, Neospirifer, Reticulatia, Rhipidomella, Lissochonetes, Linoproductus, Meekella, Crurithyris, incrusting Petrocrania, ramose bryozoans, fenestrate bryozoans, crinoids, echinoid fragments, rare trilobites (Ditymopyge), and ostracodes; the upper 23" contains rare pelecypod fragments; TA.	2	8	.81
		26. Hughes Creek Shale: shale, olive-gray, weathers light tan-gray, fractures hackly, very calcareous, characterized by abundant fusulinids (making up approximately 35% to 45% of the lithology), also contains common to rare Neochonetes, rare Neospirifer and Composita, and common crinoids and rare bryozoans; the lower 6"-8" contains less than 2% fusulinids, no brachiopods and rare crinoids, and is considered as belonging to the upper regressive phase of F3.1.	1	5	.43
	F3.1	25. Hughes Creek Shale: limestone, gray, weathers tan-gray, hard, slightley argillaceous, blocky to slabby, bench former; calcirudite, fine, fusulinid, brachiopod, biomicrite (occassionally recrystallized); contains predominately brachiopods in lower 2"-3" consisting of Composita, Neospirifer, Neochonetes, Hystriculina, rare Lophophyllidium(?), rare Ditymopyge, agglutinated forams, bryozoans, productid spines, and common crinoids, forming packstone; this grades into a brachiopod and fusulinid wackestone in the middle4"-5"; fusulinids become abundant in the upper 2"-3" forming packstone; all brachiopods are either articulated, disarticulated, or fragmented; fusulinids approximately 25%-30% in upper 2"-3"; TA.	0	9	.23
F2 (HUGHES CREEK)	F2.4	24. Hughes Creek Shale: shale, gray-black, weathers gray, fissile, to papery and brittle, limonitic with rare thin (1/4") interbedded Fe-oxidized shale lentils, lower 4"-6" contains common to abundant Orbiculoidea, rare to common Lingula, rare Crurithyris, and rare fish scales; upper 12"-14" contains abundant Crurithyris (articulated, and disarticulated), also contains rare pectenoid bivalve (Aviculopecten?), rare fenestrate bryozoans, and rare productid spines.	1	10	.56
		23. Hughes Creek Shale: limestone, gray to tan-gray, weathers yellowtan, blocky, hard, bench former; calcirudite, fine, argillaceous, limonitic, poorly sorted, brachiopod bearing, pelecypod,gastropod, algal (Osagia), biomicrite; locally is a packed biomicrite with patchy distribution of sparry calcite; all fossils appear fragmented, randomly oriented, and commonly incrusted with algae (approximately 70%) of fossil fragments; also contains rare bryozoan fragments, echinoid spines, fecal(?) pellets, and sparse ostracodes; also contains burrow casts at base of limestone (inclined and horizontal) and as float below limestone bench;(wackestone to packstone). Unit has rare fusulinids, Composita, Hystriculina; TA.	0	8	.20
	F2.3	22. Hughes Creek Shale: shale, gray, to dark gray, weathers light gray, fissile, silty, micaceous, calcareous; lower 6"-8" is less silty, more clayey, and transitional with unit below; also the lower 6"-8" contains rare but well preserved Neospirifer, large Reticulatia with incrusting Petrocrania, rare ostracodes, crinoids, productid spines, and bryozoan fragments, as well as common brachiopod fragments, common crinoids, and rare fusulinids, Composita, Meekella, and Neochonetes; the upper 41" is sparsely fossiliferous containg rare ostracodes and unidentified pelecypod fragments; also contains thinnly interlaminated to interbedded, light tan, silty, micaceous, nonfossiliferous shale in upper 41".	4	1	1.24

Paxico locality continued

F2 (HUGHES CREEK)	F2.3	21. Hughes Creek Shale: limestone, very argillaceous to very calcareous shale; olive, weathers tan; fractures nodular to hackly, crumbly, forms subdued ledge; lower 10" contains (from sieve analysis) abundant fusulinids, common to rare Composita, rare Reticulatia and Petrocrania, Wellerella, Neochonetes, very rare Lingula, bryozoans (ramose), abundant crinoids, common echinoid fragments, rare trilobites and ostracodes (fossils articulated and fragmented); upper 12" contains common fusulinids (i.e. decrease in fusulinids up the unit), abundant brachiopod fragments (i.e. increase in brachiopod content up the unit) including rare Neospirifer, common Composita, Reticulatia, Petrocrania, Neochonetes, and Lissochonetes; as well as ramose bryozoans, common crinoids, and ostracodes, and rare Ditymopyge (brachiopods commonly articulated and well preserved); gradational with unit below in terms of fusulinid content and lithology; TA in lower half.	1	10	.56
		20. Hughes Creek Shale: shale, gray to olive, weathers light gray, medium hard, very calcareous, fractures hackly; contains abundant fusulinids (approximately 20% of lithology, and ranging in length from 9mm to 3mm) that are randomly oriented and poorly sorted; also contains rare Reticulatia, common Derbyia, rare Meekella, rare Wellerella, rare Hustedia and Juresania, common Neochonetes, bryozoans, and productid fragments, common crinoids, and ostracodes (larger fossil fragments articulated and fragmented in sieve analysis); also rare Lophophyllidium (?).	1	1	.33
		19. Hughes Creek Shale: limestone, gray to dark gray, weathers light gray, slabby to blocky; calcarenite, med.-coarse, argillaceous to shaley, brachiopod biomicrite; contains common Chondrites, Linoproductus, Hystriculina, Crurithyris, Neochonetes, and fragmental pieces of Orbiculoidea and Lingula (reworked from unit below during transgression). (wackestone)	0	2	.05
	F2.2	18. Hughes Creek Shale: shale, dark gray, very fissile, very calcareous; contains common to abundant articulated Crurithyris, common Orbiculoidea, common Lingula, Rhipidomella, Aviculopecten, myalinid bivalve fragments, and rare to common ostracodes.	0	2	.05
		17. Hughes Creek Shale: limestone, gray, weathers tan-gray, thin bedded, blocky, to slabbly, argillaceous; calcirudite fine, brachiopod, trilobite bearing, fusulinid bearing biomicrite; contains common fusulinids (5%) in basal 2" of unit; also contains abundant Crurithyris in the upper 4" (thin section), as well lesser Rhipidomella, Orbiculoidea, crinoids, and Ditymopyge fragments; (wackestone).	0	6	.15
		16. Hughes Creek Shale: shale, dark gray to brown-gray, weathers light gray, soft, blocky (grades to mudstone), very calcareous; contains common fusulinids in the upper 1"-2" (fusulinids absent in basal 4"), unit also contains throughout, common Neospirifer, Reticulatia, Petrocrania, Derbyia, Hustedia, Crurithyris; characterized by abundant Neochonetes; also contains rare Lingula, common other brachiopod fragments; common Aviculopecten and myalinid bivalve fragments, as well as other pelecypod fragments (in sieve analysis), crinoids, echinoid fragments, rare ostracodes, as well as Chondrites and other larger horizontal burrows; TA.	0	6	.15
	F2.1	15. Hughes Creek Shale: limestone, gray, weathers light gray, blocky, hard; calcirudite, fine, to coarse calcarenite, argillaceous, algal, brachiopod, fusulinid, biomicrite; basal 10" (in thin section) characterized by common to abundant Isogramma, and common fusulinids (approximately 5%); lower 10" also contains rare Composita, Neospirifer, common Linoproductus, Derbyia, rare Wellerella, Hustedia, common Crurithyris, and other brachiopod fragments; also contains bryozoans, common pelecypod fragments, crinoids trilobite fragments, common osagid incrusted grains and large horizontal "spreite" burrows; the upper 2" (in thin section) is characterized by abundant Crurithyris, and an increase in argillaceous content (darker gray); Crurithyris forms lag deposits on bedding plane surfaces (shells commonly disarticulated and convex down); upper 2" also contains inclined burrows; TA.	1	2	.36

Paxico locality continued

F2	F2.1	14. Hughes Creek Shale: dark gray, to olive-gray; blocky to nodular, calcareous, silty, and micaceous; unit characterized by common Linoproductus, Crurithyris, Neochonetes, bryozoans, ostracodes, and rare Isogramma,	1	0	.30
F1 (AMERICUS)	F1.3	13. Hughes Creek Shale: shale gray to olive-gray; weathers light gray; blocky to nodular, silty, micaceous, slightly calcareous; lower 10" is characterized (in sieve analysis) by common pelecypod fragments, distinct Astartella, ostracodes, crinoids, bryozoans, Neochonetes, Crurithyris, Juresania, Hustedia, and rare Neospirifer; upper 20" (sieve analyses) is characterized by rare to common ostracodes.	2	24	.76
		12. Hughes Creek Shale: limestone, tan-gray, weathers tan-buff, nodular to hackly fracturing, very argillaceous; calcirudite, fine, poorly sorted, limonitic, brachiopod, molluscan, osagid-biomicrite; bedding mottled by inclined(?) burrows; contains abundant osagid incrusted grains, abundant pelecypod fragments (in thin section), including Wilkingia, and Aviculopinna; also contains common Straparolus, bellerophont gastropods, echinoid fragments, crinoids, ostracodes, bryozoans, Neochonetes, and Crurithyris; also contains rare Neospirifer, Composita, Reticulatia, Linoproductus, and Wellerella; gradational with unit below; Osagia preferentially incrusts the larger pelecypod and brachiopod fragments; contains burrow casts inclined to bedding; TA.	1	2	.35
		11. Hughes Creek Shale: shale, gray, olive, weathers light gray, hackly, very calcareous; contains articulated rare Neospirifer, Crurithyris, Wellerella, and Linoproductus; also contains rare horizontal burrows (Chondrites?).	0	4	.10
		10. Hughes Creek Shale: shale, gray, to olive, weathers buff-tan, hackly, very calcareous, silty; contains abundant Linoproductus (in thin 1-2" calcirudite lags, thinnly interbedded, as well as clay supported); also contains rare Neospirifer, Crurithyris, Hustedia, crinoids, and ostracodes.	2	0	.61
	F1.2	9. Hughes Creek Shale: shale, gray to dark gray, weathers light gray, fractures nodular to blocky; contains in sieve analysis, rare brachiopod fragments, Aviculopecten, Astartella, Straparolus, crinoids, and abundant ostracodes (smooth shelled).	4	7	1.40
		8. Hughes Creek Shale: shale, dark gray, weathers gray, fractures hackly, very calcareous; contains abundant articulated Crurithyris; also contains Derbyia fragments, rare Straparolus, and common crinoids.	0	4.5	.11
		7. Americus Limestone: limestone, gray, weathers light gray; fractures hackly, limonitic, argillaceous; calcirudite, fine, fusulinid (abundant-approximately 10% of lithology), crinoidal, biomicrite; also contains other common brachiopod fragments, and ramose bryozoans, as well as rare Crurithyris.	0	6	.15
		6. Americus Limestone: limestone, light gray, weathers tan-gray, fractures blocky, hard, massive, slightly argillaceous; thin section data shows upper and lower 7" to be a calcarenite, coarse, crinoidal, fusulinid, brachiopod, biomicrite; upper 7" contains common fusulinids, abundant crinoids, common to abundant brachiopod fragments, and common bryozoans; in thin section the basal 7" is packed biomicrite with abun- brachiopod fragments and crinoids, and rare fusulinids; also contains intraclasts in basal 2"-3", as well as rare pelecypod fragments throughout; unit contains throughout rare to common Hystriculina, Crurithyris, and bryozoans, and Neochonetes; unit also contains rare fragments of Neospirifer, Composita, and Straparolus; unit also contains large (1"-2") detritus-filled burrows that occur randomly and sparsely, and as float on the outcrop; unit also contains thinnly interbedded, dark brown, clayey "flaser-like whisps" (probably due to burrowing, Wilkingia?); unit grades from brachiopod-crinoidal-intraclast packstone at the base, to a brachiopod-crinoidal-fusulinid wackestone at the top; TA.	1	3	.38

Paxico locality continued

F1 (AMERICUS)	F1.1	5. Americus Limestone: shale, gray-black, soft, weathers papery fissile, noncalcareous, limonitic, contains abundant minute selenite crystals on bedding laminae; basal 2mm is carbonaceous shale with abundant selenite crystals; non-fossiliferous upper 2-3" becomes very clayey with indistinct bedding (due to bioturbation); sharp contact with unit below.	0	6	.15
		4. Americus Limestone: limestone, gray weathers tan gray, fractures blocky in thelower 12" and slabby to flaggy in the upper 14"; the upper 20" is characterized in thin section as a calcarenite, coarse, pelecypod, brachiopod, ostracode, biomicrite; contains disarticulated <u>Myalina</u>, <u>Reticulatia</u>, rare <u>Aviculopinna</u> fragments, sparse crinoids, <u>Aviculopecten</u>, <u>Pteronites</u>(?), as well as rare <u>Reticulatia</u>, <u>Meekella</u>, and <u>Wellerella</u>; matrix also contains thin interbedded, flaser-like clay whisps throughout; the lower 6"-8" is characterized by stromatolitic (Collenia?) subtle dome structures, averaging 5-6" in diameter, and 1-2" in height; algal strucutures are laterally contorted and breciatted; matrix between algal domes (in thin section) consists of reworked algal chunks or rip-clasts of algal stromatolites; as well as ostracodes, pelecypods, intraclasts, sparse bryozoans, crinoids, fecal(?) pellets, phosphatic macerated fragments, and echinoid debris; unit also contains common edge-wise grains; matrix between and surrounding algal domes and ripclasts is calcarenite, coarse, packed biomicrite; (packstone);TA is upper 20".	2	2	.66
		3. Americus Limestone: limestone, tan orange, very argillaceous, limonitic; calcarenite, (sandstone) coarse, composed predominately of moderately sorted, angular clay and carbonate grains (dolomitic?), common ostracode carapaces, rare stromatolitic intraclasts, common macerated plant fragments; constituents held loosely in a clayey-calcareous matrix.	0	1.5	.04
		2. Hamlin Shale: shale, olive-brown, weathers gray-brown; calcareous, blocky to hackly, silty; contains common ostracodes in the basal 4", and become abundant in the upper 4"; unit also contains rare to common plant fragments throughout; the very upper bedding surface contains abundant macerated plant fragments.	0	10	.25
HAMLIN	H1	1. Hamlin Shale: mudstone, light tan to tan-orange, weathers light buff; blocky, massive, non-calcareous, dolomitic (dolostone?); nonfossiliferous; the lower 6" becomes more olive-gray, and contains minute calcite nodules (caliche?); probable paleosol.	1	2	.36

-Thin section data was used to supplement descriptions of the following units: 4, 6, 12, 15, 17, 23, 25, 27, 28, 29, 30, 31, 34, and 35.

-Disaggragated shale data was used to supplement descriptions of the following units: 5, 8, 9, 10, 11, 12, 13, 16, 20, 21, 22, 24, and 26.

State: Kansas County: Riley Quadrangle: Manhattan

Locality Description:

Poliska Lane Section
NW¼ NE¼ and C N line of section 24, T10S, R7E
Section measured along north side of railroad cut, adjacent to Poliska Lane, and 100 yards west of railroad over-pass for K-18. Section also located approximately 60 yards north-northwest of Country Gift Shop store.
Interval measured September, 1985 by Fred Barrett; Interval also measured by Busch, R. and Clark M., summer of 1987; descriptions combined.
From the Bennett shale of the Red Eagle Fm. into the Hughes Creek shale.

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS Transgressive Surface —— - - - Climate Change Surface	Unit Thicknesses ft	in	m
F4 (RED EAGLE)	F4.4	33. Bennett Shale (basal portion): shale, brown, to brown-black; platy to flaggy; silty; contains rare Crurithyris and macerated plant fragments.	0	3	.08
		32. Bennett Shale: shale, black, black-gray; platy to fissile; contains thinnly interbedded, tannish orange (Fe-oxidized) shale streaks; contains abundant Orbiculoidea, rare Crurithyris, and productid fragments.	0	2	.05
		31. Glenrock Limestone: limestone, gray-brown; very argillaceous; hackly fracture; calcirudite, fine, brachiopod, fusulinid biomicrite; contains abundant fusulinids (approximately 40%), also contains articulated Neospirifer, Composita, Neochonetes, Wellerella, Crurithyris, Orbiculoidea fragments, productid fragments, bryozoans, Straparolus, Aviculopinna fragments, also contains horizontal and u-shaped burrows;TA.	0	2	.05
		——?——————?——————?——			
	F4.3	30. Glenrock Limestone: limestone, tan-gray, weathers tan-yellow; blocky; hard; massive; calcarenite, coarse to fine calcirudite, intraclast bearing, molluscan, osagid, recrystallized biomicrite; contains common gastropods, pelecypods, intraclasts, and abundant osagid incrusted grains; also contains lesser ostracodes; osagid-type grains increase towards base; unit is poorly sorted with no preferred orientation of allochems; packstone to grainstone; commonly poorly washed sparite; TA.	1	4	.41
	F4.2	29. Johnson Shale: claystone, gray-green, weathers light olive; blocky; massive; indistinct bedding; upper 8"-7" contains common caliche nodules and rare to common root traces; unit also contains minute black macerated carbonaceous fragments (possibly reworked from unit below); paleosol.	2	5	.74
		28. Johnson Shale: shale, black to black-brown, weathers light brown; consists of thinnly interbedded, brown silty shale, that is calcareous; and black (carbonaceous), non-silty, calcareous shale with common to rare ostracodes and rare to common tracks and trails; ostracodes occur basally; TA.	2	4	.71
		27. Johnson Shale: limestone, light gray to tan, weathers orange-gray; blocky to platy; wavy bedding; contains nondescript wavy laminations throughout (algal laminations?); calcilutite. mudcracked.	1	8	.51
		26. Johnson Shale: limestone, gray-yellow, weathers orange-gray; brecciated calcilutite clasts; argillaceous; ostracode bearing calcilutite (transgressive lag or possible storm deposit); TA.	0	7	.18
	F4.1	25. Johnson Shale: shale, gray-olive, weathers light olive; blocky, slightly unindurated; silty; calcareous; contains common root traces throughout; contains thinnly interbedded Fe-oxidized claystone lentils; unit becomes more blocky up the unit; paleosol.	1	1	.33
		24. Johnson Shale: limestone, buff gray to brown; argillaceous; soft to medium hard; blocky; calcilutite,?); contains celestitecrystals at the base; ostracode bearing; basal 1" contains thin interbedded shale lentils ; TA.	0	3	.08
F3	F3.11	23. Johnson Shale: claystone, olive; blocky, unindurated, silty; trace of root traces; paleosol.	0	6	.15

Continue Poliska Lane locality

F3 (LONG CREEK)	F3.11	22. Johnson Shale: dolostone, gray-green; massive; mottled; very argillaceous; gypsiferous; celestite crystals, pink at base; nonfossiliferous.	0	3	.08
	F3.10	21. Johnson Shale: claystone, gray-green, weathers light olive; argullaceous; contains pink celestite crystals at base; nonfossiliferous; contains sparse root mottles; paleosol.	1	3	.38
		20. Johnson Shale: dololutite, tan to gray; very argillaceous; massive; nonfossiliferous; trace of root mottles; TA.	1	3	.38
	F3.9	19. Johnson Shale: claystone, olive-green; weathers light olive; blocky; unindurated; minor root traces; Fe-oxide mottling; paleosol.	1	5	.43
		18. Johnson Shale: limestone, gray-green; weathers tan-gray; hard; blocky; very argillaceous; contains sparse laminae of green claystone; displays thin to wavy bedding by interlaminated cryptic structures (algal laminations?); calcilutite; TA.	0	8	.20
	F3.8	17. Johnson Shale: claystone, olive-green, weathers gray-green; unidurated-crumbly; blocky; nonfossiliferous; noncalcareous; minor amounts of root mottling; paleosol.	0	9	.23
		16. Johnson Shale: limestone, light gray, weathers yellow-tan; flaggy to platy; wavy bedding; cryptic mudcracks; upper bedding surface uneven and wavy; weathered; nonfossiliferous; TA.	1	3	.38
	F3.7	15. Johnson Shale: claystone, light green; weathers gray-green; silty; very calcareous; nonfossiliferous.	0	6	.15
		14. Johnson Shale: limestone, light gray, weathers tan yellow; nodular to flaggy bedding; argillaceous; contains intraclasts basally; contains cryptic mudcracks(?); calcilutite; TA.	0	7	.18
	F3.6	13. Johnson Shale: claystone, orange to light gray-green; highly Fe-oxidized; silty; blocky; common caliche nodules; paleosol.	1	1	.33
		12. Johnson Shale: shale, olive-green, weathers brown-green; silty; very thinnly bedded; noncalcareous; nonfossiliferous; consists of thinnly interlaminated black-gray and Fe-oxidized layers; carbonate and clay intraclasts occur basally; uneven contact at the base	2	0	.61
		11. Long Creek Limestone: Calcilutite, tan, massive, laminated; calcilutite; nonfossiliferous; with basal intraclasts ; TA.	3	0	.91
	F3.5	10. Long Creek Limestone: dolomite, tan-orange, weathers maroon to tan; hard; massive; argillaceous; contains abundant root traces throughout; also contains cryptic laminations (algal?).	0	10	.25
		9. Long Creek Limestone: limestone, light tan-orange, weathers light tan-yellow; massive; argillaceous; blocky; dolomitic; upper 8" becomes flaggy to platy and contains cryptic laminations (algal?) as well as mudcracks; calcilutite.	1	3	.38
		8. Long Creek Limestone: limestone, light orange-gray to tan; weathers tan-yellow; blocky; argillaceous; massive; calcilutite, pelecypod bearing, crinoid bearing, intraclast bearing, argillaceous micrite; contains rare pelecypod fragments and crinoids in the lower 3/4 of the unit (nonfossiliferous in upper 1/4); also shows evidence of low angle cross laminations; a 1" crinoidal calcarenite occurs near the base of the unit.	2	5	.74
		7. Long Creek Limestone: limestone, tan, weathers yellow-tan; argillaceous; blocky; contains common pelecypod and crinoid fragments; and trace of brachiopod fragments(?); calcilutite.	0	10	.25
		6. Long Creek Limestone: limestone, tan; weathers light tan; argillaceous; slabby to blocky; hard; calcilutite, pelecypod, brachiopod bearing, crinoid bearing, Fe-oxidized biomicrite; contains common Permophorus, as well as crinoids and brachiopod fragments, and plant fragments at the base of the unit (reworked from unit below?); TA.	0	8	.20

Continue Poliska Lane locality

F3 (LONG CREEK)	F3.4	5. Hughes Creek Shale: shale, gray to gray-brown; silty; blocky; massive; contains quartz-sandy lenses and rare to common plant fragments, that become common in the upper portion of unit.	1	0	.30
		4. Hughes Creek Shale: limestone, tan-orange, weathers tan-yellow; argillaceous; slabby; to blocky; contains common pelecypods (*Permophorus*), brachiopod fragments, and crinoids ; TA.	0	5	.13
		?——————————?——			
	F3.3	3. Hughes Creek Shale: shale, gray to brown-gray; platy to fissile; contains *Neospirifer*, *Composita*, *Neochonetes*, *Crurithyris*, bryozoans, *Straparolus*, echinoid fragments, myalinid bivalve fragments; becomes nonfossiliferous toward the top of unit.	0	6	.15
		2. Hughes Creek Shale: limestone, tan, weathers tan-yellow; very argillaceous; massive; hackly; calcirudite, fine, fusulinid biomicrite; contains abundant, randomly oriented ventricose fusulinids; also contains lesser fossil fragments such as *Neochonetes*, *Neospirifer*, *Derbyia*, bryozoans and crinoids; the basal 12"-14" becomes shaley with an increase in brachiopod content (fusulinids still abundant) ; TA.	2	6	.76
	F3.2	1. Hughes Creek Shale: shale, gray to dark gray; weathers light gray; silty; platy to fissile; nonfossiliferous; base of unit concealed.	1+		.30+

State: Kansas County: Wabaunsee Quadrangle: Maple Hill

Locality Description:

South East Paxico Section (SEP)
SW¼ NW¼ sec. 9, T12S, R12E
Section measured in a road cut beginning approximately 2¼ miles south of I-70.

Section measured from the Long Creek Limestone of the Foraker Formation down into the Hamlin Shale of the Janesville Formation.

Interval measured July, 1986.

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— - - - Climate Change Surface)	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.7	53. Long Creek Limestone: algal-laminite, gray brown, weathers light tan-gray; platy; consists of thinnly interbedded nonfossiliferous, dolomitic, argillaceous calcilutites and algal laminations.	0	8	.20
		52. Long Creek Limestone: limestone-calcilutite, yellow-gray, weathers tan; blocky, argillaceous, hard; limonitic; calcilutite; contains common celestite lined vugs; dolomitic; TA.	0	5	.13
		?——————?——			
	F3.6	51. Long Creek Limestone: algal-laminite, gray-brown, hard, limonitic; wavy to planar and mudcracked, with thin interlaminated nonfossiliferous calcilutites.	0	1	.02
		50. Long Creek Limestone: shale, tan, blocky, to fissile, very calcareous; nonfossiliferous; slightly micaceous.	0	2	.05
		49. Long Creek Limestone: limestone-calcilutite, light tan-brown, weahters light tan; very argillaceous, blocky, dolomitic, contains rare pelecypod fragments (reworked or allochthonous?) TA.	0	7	.18
	F3.5	48. Long Creek Limestone: claystone, light tan-buff; silty; blocky, nonfossiliferous, rare cubic halite(?) molds; very calcareous.	0	1	.02
		47. Long Creek Limestone: limestone, tan-brown, weathers gray-yellow, slabby to flaggy; contains common mudcracks on upper bedding surface; basal 1" contains rare _Aviculopecten_; dolomitic calcilutite.	0	2	.05
		46. Long Creek Limestone: limestone, tan-gray, weathers gray-yellow; argillaceous, pelecypod bearing, crinoid bearing, gastropod bearing, medium to coarse calcarenite-biomicrite; dolomitic, and recrystallized with sparry calcite.	0	2	.05
		45. Long Creek Limestone: limestone, tan-gray, weathers light orange-tan; platy to slabby; argillaceous; thin-bedded; calcilutite, crinoid, _Aviculopecten_, gastropod, biomicrite; recrystallized; vuggy with calcite linings.	0	3	.08
		44. Long Creek Limestone: limestone, light tan-brown, weathers light tan-orange; blocky to platy; very argillaceous; moderately hard; calcilutite, pelecypod bearing, gastropod bearing, dolomitic, micrite; TA.	1	0	.30
	F3.4	43. Hughes Creek Shale: shale, light tan-brown; fissile; calcareous; contains common to abundant macerated plant fragments and trace of ostracodes (?).	0	5	.13
		42. Hughes Creek Shale: limestone, tan orange; weathers light tan-yellow; blocky, slabby; hard; very argillaceous; limonitic; clacarenite, medium, pelecypod, brachiopod, crinoidal biomicrite; basal 1" contains lenticular brachiopod, crincidal biosparite; pelecypods consist of _Permophorus_, _Aviculopecten_, and myalinid fragments; sharp contact with unit below; TA.	0	5	.13
		?——————?——————?——			
	F3.3	41. Hughes Creek Shale: shale, light tan-brown; slightly blocky to fissile; massive; very calcareous; contains common _Neochonetes_, disarticulated _Neospirifer_; crinoids, and rare fusulinids; contains common burrows throughout-horizontal and inclined.	0	4	.10
		40. Hughes Creek Shale: limestone, tan-gray, weathers light tan-yellow to gray; blocky, hard, massive; argillaceous; contains abundant fusulinids (approximately 20-30%); sparse to common brachiopod fragments, crinoids, and bryozoans; calcirudite, fine, fusulinid biomicrite (packstone); unit also			

(continue next page)

Southeast Paxico locality continued

F3 (LONG CREEK)	F3.3	40. continued- contains Neochonetes, Neospirifer, and other brachiopod fragments, as well as osagid incrusted grains, rarely incrusting the fusulinids; upper 3" becomes more argillaceous.	1	7	.48
		39. Hughes Creek Shale: shale, gray, to olive gray, weathers light tan-gray; fractures hackly to blocky; very calcareous; lower 3" is less calcareous; contains fusulinids that increase in abundance up the unit, from less than 5% to approximately 20% in the upper 6"; unit also contains articulated Neospirifer, Neochonetes, crinoids, bryozoans, and productid fragments.; TA.	1	2	.36
		38. Hughes Creek Shale: shale, tan-olive to gray, weathers light tan-gray; blocky; calcareous; silty; contains common to abundant Linoproductus occuring in lags on bedding plane surface (articulated and fragmented); the upper 2" becomes very calcareous with an increase in abundance of Linoproductus; base of unit concealed.	0	11	.28
		——?——————?——————?——			
	F3.2	37. Hughes Creek Shale: interval concealed- shale?	3	0	.91
		36. Hughes Creek Shale: shale, gray-olive, weathers light gray; to orange-gray; blocky; very calcareous; slightly silty and micaceous; contains common to abundant articulated Neospirifer; Reticulatia with incrusting Petrocrania, Neochonetes, Wellerella, large, ventricose fusulinids that decrease up the unit, rare Crurithyris, fenestrate bryozoans, ramose bryozoans, incrusting bryozoans on larger fossil fragments; large articulated Derbyia, Lissochonetes, Meekella, Hustedia; well preserved crinoid stems; unit also contains fusulinid-rich calcirudites, nodular to lenticular in nature, and thinnly interbedded within the lower 1/2 of this unit.	1	10	.56
		35. Hughes Creek Shale: shale, olive, to light olive-gray; weathers light gray; blocky, hackly, very calcareous; contains abundant fusulinid (approximately 30-40% of the lithology); fusulinids also occur in lenticular, argillalaceous, fine, calcirudites; fusulinids are poorly sorted and consist of large (e.g. 7mm axial length) and small (e.g. 3mm axial length) individuals; unit also contains large and small Neochonetes, Reticulatia, Neospirifer, Crurithyris, Rhipidomella, fragmented Composita, incrusting Petrocrania, common crinoids, and incrusting and fenestrate bryozoans; TA.	1	5	.43
	F3.1	34. Hughes Creek Shale: shale, light orange-olive to gray-olive; blocky, very calcareous; contains rare to common Crurithyris, lacks fusulinids.	0	2	.05
		33. Hughes Creek Shale: limestone, reddish-gray, weathers light tan-gray; blocky, hard, thin to medium bedded; argillaceous; contains abundant fusulinids in the upper 3" (approximately 20-30%); brachiopods are more abundant in the lower 6" and consist of well preserved Neospirifer, rare Wellerella, common Reticulatia, Neochonetes, bryozoan fragments, well preserved crinoid stems and columnals, common to abundant Crurithyris; Composita occurs in life-position in the upper 3"; calcirudite, fine, biomicrite (wackestone); TA.	0	11	.28
		32. Hughes Creek Shale: shale, olive-gray, weathers light gray; fissile to blocky; very calcareous; contains small and large Crurithyris; and common productud fragments.	0	3	.08
F2	F2.4	31. Hughes Creek Shale; shale, gray to gray-blacke; blocky; fissile; slightly calcareous to noncalcareous; slightly carbonacesou; contains abundant Crurithyris forming shell lags on bedding surfaces (poorly sorted); Orbiculoidea is common in the lower 6"; and contains rare Lingula.	1	5	.43
		30. Hughes Creek Shale: limestone, orange-gray, weathers light tan-gray; fractures platy to hackly; and blocky; argillaceous; calcarenite, medium to coarse, brachiopod, pelecypod, osagid, poorly to moderately sorted biomicrite; contains common comminuted fossile debris of Reticulatia, Hystriculina, productid spines, and echinoid spines; gastropods, pelecypods, and crinoids, and rare osagid incrusted grains (wackstone); upper 2" is very limonitic; TA.	1	0	.30

Southeast Paxico locality continued

F2 (HUGHES CREEK)	F2.3	29. Hughes Creek Shale; shale, brown-olive, to gray olive, weathers light gray; very silty; micaceous; fissile; non-fossiliferous.	0	6	.15
		28. Hughes Creek Shale: shale, olive gray, weathers light gray blocky; fissile; slightly calcareous; micaceous; contains fish scales, rare Derybia fragments.	0	7	.18
		27. Hughes Creek Shale: shale, olive-gray; weathers light tan-gray; hackly to blocky; massive; contains abundant ventricose fusulinids in the lower 15" and decrease up the unit (from approximately 25% in the lower 10" to less than 5% in the upper 10"); unit also contains lesser amounts of Hystriculina, crinoid columnals, fragmented Neospirifer, rare to common Composita, trilobite fragments; bryozoan fragments (fenestrate and ramose); unit is very calcareous occasionally grades into very argillaceous calcirudites-lenticular in nature; TA.	3	5	1.04
		26. Hughes Creek Shale: limestone, dark gray to light gray; very thin bedded; hackly fracture; very argillaceous; contains rare to common Fe-oxidized fusulinid tests; common productid fragments; calcirudite, fine, argillaceous, fusulinid, osagid bearing, brachiopod biomicrite (wackestone)	0	3	.08
		25. Hughes Creek Shale: gray-olive; very calcareous; slightly fissile; rare osagid-type grains (Fe-oxidized), productid fragments (Linoproductus), and Crurithyris.	0	1	.02
		24. Hughes Creek Shale: limesteone, dark gray; flaggy, to blocky massive; calcirudite, fine, Crurithyris, Linoproductus, and Chondrites biomicrite (wackestone).	0	2	.05
	F2.2	23. Hughes Creek Shale: shale, gray, olive-brown; fissile; slightly calcareous; contains abundant Crurithyris, forming shell lags on bedding surface; also contains rare to common Lingula (articulated) and Orbiculoidea (fragmented); unit is also limonitic with very thin (¼") Fe-oxidized, orange lentils).	0	2	.05
		22. Hughes Creek Shale: limestone, light gray, weathers yellow gray; hard; blocky to slabby; calcarenite, coarse, Crurithyris, crinoidal, fusulinid, biomicrite; Crurithyris increases up the unit and fusulinids are most abundant (approximately 5%) in the basal portion of the limestone; also contains rare to common productid fragments.	0	6	.15
		21. Hughes Creek Shale: shale, olive-gray, weathers light gray; very calcareous; fissile; slightly silty; contains common to abundant articulated and disarticulated Neochonetes, both large and small individuals; common Neospirifer; abundant Crurithyris in the lower 2-3", Reticulatia, and large articulated Derbyia, common ramose bryozoans; fenestrate bryozoans and crinoids ; TA.	0	9	.23
	F2.1	20. Hughes Creek Shale: limestone, dark gray, gray, slabby to flaggy; very argillaceous; gradational with unit below; calcirudite, fine, Crurithyris, biomicrite (wackstone to packstone); also contains rare Chondrites, and Hystriculina.	0	2	.05
		19. Hughes Creek Shale: limestone, light yellow-gray; weathers orange gray; blocky, hard; argillaceous; limonitic; calcarenite, brachiopod, osagid bearing, fusulinid bearing, Isogramma biomicrite; also contains rare pelecypod fragments, crinoids, and fenestrate bryozoans; Isogramma is most abundant in the lower 6"; faunal diversity decreases up unit; TA.	0	8	.20
		18. Hughes Creek Shale: shale, orange-olive to gray; weathers light gray; blocky; silty; micaceous; calcareous; becomes more calcareous up the unit; contains common Linoproductus, Neochonetes; rare ostracodes; unit also contains celestite filled fractures.	0	8	.20
F1	F1.3	17. Hughes Creek Shale: shale, olive-gray; blocky; very clayey; slightly silty; micaceous; rare ostracodes.	1	8	.51
		16. Hughes Creek Shale: interval covered- shale? as above	1	0	.30
		15. Hughes Creek Shale: shale, olive-gray, blocky, very clayey; slightly silty; rare ostracodes.	0	6	.15

Southeast Paxico locality continued

F1 (AMERICUS)	F1.3	14. Hughes Creek Shale: shale, light orange-olive; blocky, to fissile; very calcareous; limonitic; contains common Neochonetes, rare Lissochonetes, rare Neospirifer, fenestrate bryozoan fragments; also contains rare to common argilla-calcarenite nodules containing fossils aforementioned; gradational with unit above and below.	0	6	.15
		13. Hughes Creek Shale: limestone, very argillaceous to very calcareous shale; gray, weathers light tan-gray, blocky to hackly; with irregular to nodular to very thin bedding; very argillaceous to shaley; contains abundant Neochonetes, Neospirifer, Reticulatia, rare Linoproductus, Derbyia, Meekella, Hustedia, and Wellerella; unit also contains fenestrate, incrusting and ramose bryozoans; common crinoids; unit also contains rare pelecypod fragments; unit contains no gastropods or osagid type grains in thin-section; Crurithyris, Linoproductus, and Neospirifer are most abundant in the basal 15"; basal 15" is considered as a very calcareous shale; and the upper 19" is considered as a calcirudite, fine, argillaceous, Neospirifer, crinoidal, biomicrite ; TA.	2	10	.86
		12. Hughes Creek Shale: shale, gray, olive, blocky, fissile, calcareous; contains abundant Linoproductus, and common Crurithyris; these fossils decrease toward the base, and become rare or absent toward the base; base concealed.	0	6	.15
		——?——?——?——			
	F1.2	11. Hughes Creek Shale: interval concealed- shale?	5	10	1.78
		10. Americus Limestone: limestone, gray, weathers yellow-gray; massive; hard; blocky; calcarenite, coarse, brachiopod, pelecypod bearing, crionid rich, biomicrite (wackestone to packstone); fusulinids become common to abundant at the top of unit; also contains rare rugose corallites ; TA.	1	0	.30
	F1.1	9. Americus Limestone: shale, gray, fissile, calcareous to noncalcareous; contains rare productid fragments.	0	7	.18
		8. Americus Limestone: limestone, light gray, weathers white-gray; flaggy to blocky; hard; calcarenite, medium, pelecypod, biomicrite; consists of common large disarticulated myalinid bivalves, Aviculopecten, Wilkingia, rare Aviculopinna; ostracodes, rare gastropods, and Petrocrania incrusting larger pelecypod shells; unit also contains large inclined burrows; basal portion contains thin interbedded dark gray shales with productid fragments; and also flaser-like shale lentils, probably due to burrowing(?); TA.	1	2	.36
		7. Americus Limestone: algal stromatolites (Collenia?); gray, weathers light yellow-gray; consists of abundant algal bands that are laterally discontinuous and average ¼ to ½" in thickness; some appear reworked and contorted; as well as domal in shape; inbetween algal structures is matrix described as calcarenite, medium to coarse, ostracode bearing pelecypod bearing, intraclast (containing algal rip-clasts and carbonate clasts), argillaceous biomicrite (wackestone to packstone); gradational with unit above.	0	4	.10
		6. Americus Limestone: calcarenite, orange-tan, weathers gray-orange; coarse grained to fine calcirudite; composed predominately of clay, carbonate, and algal stromatolite intraclasts; limonitic, poorly sorted, intramicrite; basal surface of unit contains black, macerated plant fragments; unit also contains rare ostracode carapaces; gradational with algal stromatolites above.	0	7	.18
		5. Hamlin Shale: limestone, gray, flaggy; calcarenite, coarse, intraclast, ostracode bearing, argillaceous intramicrite; contains common macerated plant fragments.	0	1	.02
		4. Hamlin Shale: shale, gray-green, weathers gray; fissile; blocky; calcareous; contains abundant ostracodes; sharp contact with unit below.	0	2	.05
HAMLIN	H1	3. Hamlin Shale: limestone-calcilutite, gray, weathers light tan; blocky to slabby, hard; dolomitic (dolostone), non-fossiliferous.	0	4	.10
		2. Hamlin Shale: shale, olive, weathers gray-olive, fissile, to blocky; calcareous, contains abundant ostracodes; also contains sparse plant fragments; lower 2" consists of lenticular, argillaceous, calcareous, dolostones.	1	0	.30
		1. Hamlin Shale: claystone, light tan-brown; blocky; massive; silty; noncalcareous; nonfossiliferous.	0	6	.15

Southeast Paxico locality continued

-Thin section data was used to supplement descriptions of the following units: 13, 30, and 40.

State: Kansas County: Wabaunsee Quadrangle: Wamego

Locality Description:

Wabaunsee Section (Wa)
SE¼ SW¼ SW¼ sec. 13, T10S, R10E
Section measured in a fresh road cut, approximately 2 3/4 miles east of Highway 99, on Federal-aid secondary road 652.

Section measured from the Long Creek Limestone of the Foraker Formation down into the Hughes Creek Shale of the Foraker Formation.

Interval measured July, 1986

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— ; - - - Climate Change Surface)	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.5	33. Long Creek Limestone: limestone, orange-gray; weahters light tan-yellow; dolomitic, hard, blocky; platy; and flaggy; laminated, rare algal laminations ; mudcracked.	1	0	.30
		32. Long Creek Limestone: limestone; gray-orange; weathers tan-orange; flaggy to hackly; hard, dolomitic; nonfossiliferous, calcilutite.	0	2	.05
		31. Long Creek Limestone: limestone, gray-orange, weathers yellow-orange and tan; argillaceous; hard; dolomitic; calcilutite; rare pelecypod fragments; also contains abundant vugs calcite and celestite lined; TA.	1	2	.36
	F3.4	30. Hughes Creek Shale: shale, light tan brown, slightly silty; micaceous; calcreous; contains *Permophorous* molds in basal portion; unit contains common plant fragments.	0	6	.15
		29. Bughes Creek Limestone: limestone, tan-orange, weathers light tan-maroon; blocky; flaggy and platy; argillaceous; hard; dolomitic; calcarenite, coarse, *Permophorus*. gastropod, crinoidal, biomicrite; TA.	0	9	.23
	F3.3	28. Hughes Creek Shale: limestone, gray, weathers light gray, blocky; slightly limonitic; abundant vugs, calcite and celestite lined; nonfossiliferous.	0	8	.20
		27. Hughes Creek Shale: mudstone, gray to olive gray, weathers light gray; blocky, hard; silty; calcareous; rare fusulinids and brachiopod fragments.	0	7	.18
		26. Hughes Creek Shale: shale, olive-orange and gray; weathers tan-gray; blocky; very calcareous; contadn abundant large ventricose fusulinids throughout (approximately 20%); also contains lesser *Neospirifer*, *Neochonetes*; crinoids; and other brachiopod fragments; also contains large, inclined, sinuous burrows, detritus filled (¼-½" diameter).	1	2	.35
		25. Hughes Creek Shale: shale, olive-gray, to orange-gray, weathers light orange-gray; blocky, very calcareous; blocky; contains abundant productid fragments, *Linoproductus*, *Neospirifer*, *Neochonetes*, incrusting, ramose, and fenestrate bryozoans; upper 4" contains sparse fusulinids; fossils found commonly in thin calcarenite lenses, micritic; TA.	0	9	.23
		24. Hughes Creek Shale: shale, gray, light gray-olive; blocky, hard; noncalcareous; silty; becomes very calcareous in the basal half, containing common *Aviculopecten*; productid fragments; and fenestrate and ramose bryozoans.	0	6	.15
	F3.2	23. Hughes Creek Shale: shale, dark gray to olive-gray; weathers light gray; blocky; solty; noncalcareous; rare productid fragments; trace of trilobites.	1	10	.56
		22. Hughes Creek Shale: shale, gray, olive, weathers light tan-gray; calcareous, fissile; blocky, contains abundant *Neochonetes*; *Reticulatia*, *Neospirifer*, *Wellerella*, *Hustedia*, *Meekella*, incrusting *Petrocrania*, *Composita*, rare *Juresania*, common crinoid columnals, echinoid plates and spines; common large fusulinids in the lower 4"; also contains fenestrate, incrusting bryozoans, and phosphatic fragments (fish bones?) diversity decreases up the unit: TA.	0	11	.28
		21. Hughes Creek Shale: shale, olive-gray, weathers light tan-olive, blocky to hackly, very calcareous; contains abundant fusulinids (25-35%); unit also contains common *Neochonetes*, *Reticulatia*, crinoids, and other brachiopod fragments; lower 3" contains no fusulinids, and rare brachiopod fragments, and is considered regressive portion of F3.1.	1	5	.43

Wabaunsee section continued

F3 (LONG CREEK)	F3.1	20. Hughes Creek Shale: limestone, gray, blue gray, weathers light tan-gray, blocky; to hackly; lower 5" is shaley; calcirudite, fine, clayey, brachiopods, fusulinid, limonitic, biomicrite; brachiopods are highly fragmented; contains common crinoids, Wellerella, Crurithyris, Composita-rare, Neospirifer; unit also contains rare gastropods in thin section; fusulinids account for approximately 25% of lithology, and brachiopods are approximately 30% of lithology; TA basally.	0	11	.28
		19. Hughes Creek Shale: shale, olive, orange olive; blocky to slightly fissile; very calcareous; argillaceous; contains common to abundant Hystriculina, abundant Crurithyris; and common productid spines and other brachiopod fragments.	0	4	.10
F2 (HUGHES CREEK)	F2.4	18. Hughes Creek Shale: shale, gray, gray-black; fissile to blocky; slightly calcareous; contains abundant large and small Orbiculoidea in the lower 6", and abundant Crurithyris in the upper 10"; uni also contains common Lingula lying parallel to bedding; also contains rare Aviculopecten.	1	5	.43
		17. Hughes Creek Shale: shale, olive to orange; fissile to hackly; very calcareous; very limonitic; contains common Hystriculina; common productid spoines, common to rare Crurithyris, and rare Orbiculoidea fragments.	0	2	.05
		16. Hughes Creek Shale: limestone, blue gray, dark gray, weathers tan-yellow; blocky; hard; massive; upper ½ of unit in thin section is a calcirudite, fine, osagid, gastropod, pelecypod, echinoid, crinoidal, brachiopod, fusulinid bearing biomicrite; osagid-type grains, gastropods, and brachiopod fragments are the most abundant allochems; locally is a packed biomicrite (wackestone to packstone); the lower ½ is an calcirudite, fine, limonitic, poor to moderately sorted (same as upper half), osagid, gastropod, pelecypod, brachiopod, crinoidal, ostracode, packed biomicrite (packstone). fossil fragments highly comminuted, and 50-60% are incrusted with Osagia; gastropods are commonly high-spired; the upper 2" of unit is very argillaceous, and contains Hystriculina ; TA.	1	0	.30
	F2.3	15. Hughes Creek Shale: shlae, light olive, to tan; weathers light gray; fissile to blocky; slightly silty; calcareous; nonfossiliferous; contains common to abundant thinnly interbedded, to interlaminated very calcareous; argillaceous, siltstones; base of siltstones are highly mottled and epirelief horizontal burrows.	2	3	.69
		14. Hughes Creek Shale: shale, gray-olive; gray, blocky, to fissile; very calcareous; silty; contains common productid fragments; common Derbyia fragments.	0	10	.25
		13. Hughes Creek Shale: limestone, olive-tan, weathers light buff-gray; hackly, massive; very argillaceous; shaley calcarenite, coarse, to fine calcirudite; brachiopod, bryozoan, crinoidal, fusulinid, biomicrite; contains common fenestrate bryozoans, ramose bryozoans, incrusting bryozoans, large articulated and fragmented Reticulatia, Neospirifer, Punctospirifer? common articulated Derbyia, Hustedia, Wellerella, crinoid columnals and stems; common fusulinids, and abundant productid spines ; TA.	2	3	.69
		12. Hughes Creek Shale: shale, olive to tan-gray; olive; weathers light tan-gray; blocky, slightly fissile; very calcareous; lower 2" contains common productid fragments (spines and shell fragments); sparse Crurithyris; rare osagid incrusted grains, fusulinids; above the lower 2" fusulinids increase (approximately 20%); and also contains trilobites (Ditymopyge), common Reticulatia, incrusting bryozoans, disarticulated Neochonetes, and Neospirifer fragments.	0	7	.18
		11. Hughes Creek Shale: limestone, dark gray, weathers light gray; blocky, to slightly slabby and hackly; indistinct bedding; contains abundant horizontal clay filled burrows, Chondrites; also contains common to abundant Crurithyris; and Lingula fragments, reworked from unit below (?); calcarenite, coarse, fine, brachiopod, Chondrites, Crurithyris, biomicrite.	0	2	.05

Wabaunsee section continued

F2 (HUGHES CREEK)	F2.2	10. Hughes Creek Shale: shale, light brown-gray; olive; weathers light tan-gray; blocky; fissile; calcareous; contains thinnly interlaminated black shale lentils; contains abundant Crurithyris; common Lingula, rare Chondrites, and rare Orbiculoidea.	0	5	.13
		9. Hughes Creek Shale: limestone, dark gray to blue-gray; weathers light tan-gray; blocky to slabby; hard; very argillaceous; sharp contact below and above; calcirudite, fine, fusulinid bearing, Crurithyris, biomicrite; locally packed; and occasionally recrystallized (sparry calcite); Crurithyris is abundant, contains rare fusulinids at the base of unit (i.e. Crurithyris increases up unit); also contains rare ostracodes, common to abundant crinoids, and fragments of Neochonetes; and inarticulate brachiopod fragments.	0	6	.15
		8. Hughes Creek Shale: shale, tan-olive to gray; weathers light gray; fissile to blocky; very calcareous; contains common fusulinids (less than 5%) in the upper 4"; rare Neospirifer fragments; Derbyia fragments, common Crurithyris, Petrocrania, Hustedia, common Neochonetes, crinoids, fenestrate and ramose bryozoans, smooth ostracode carapaces, common myalinid bivalve fragments; upper 2" contains large (1/2" diameter) horizontal, detritus filled burrows, at base of overlying limestone; TA.	0	7	.18
	F2.1	7. Hughes Creek Shale: limestone, gray, dark gray, blocky, slabby; hard; argillaceous; calcirudite, fine, Crurithyris, biomicrite; also contains inarticulate brachiopods.	0	2	.05
		6. Hughes Creek Shale: shale, tan-olive, fissile, very calcareous; contains common Crurithyris, crinoids, and Hystriculina.	0	1	.03
		5. Hughes Creek Shale: limestone, gray, weathers light tan-gray, blocky to slabby; hard; argillaceous; in thin section is a calcarenite coarse to medium, Isogramma, osagid, brachiopod, crinoidal, foram, biomicrite; arenaceous forams common (biserial, and ferruginous), Isogramma found commonly at the base of limestone; also contains common whole Straparolus, echinoid spines, and Linoproductus; TA.	0	9	.23
		4. Hughes Creek Shale: shale, orange-olive to gray; weathers light olive-gray; blocky to fissile; calcareous; limonitic; slightly silty; contains common large Linoproductus fragments; also common Neochonetes, rare crinoids; becomes more calcareous toward the top of unit.	0	4	.10
F1 (AMERICUS)	F1.3	3. Hughes Creek Shale: shale, olive, gray, weathers light gray, bedding indistinct; calcareous, contains common ostracodes, and rare Astartella.	1	6	.46
		2. Hughes Creek Shale: shale, light olive-gray; weathers light gray; indistinct bedding; blocky; silty; slightly calcareous; contains rare Aviculopecten, and rare osagid grains.	0	4	.10
		1. Hughes Creek Shale: limestone, gray, to red-gray, weathers light tan; blocky, hard, argillaceous; calcirudite, fine, osagid, molluscan, biosparite (packed); fragments incrusted include echinoid spines, crinoids, brachiopod fragments, pelecypod fragments, gastropods (rarely); some grains have up to 2mm osagia coatings and occasionally Ottonosia-like incrustations of more than one grain occur; contains mostly fragmented and comminuted debris; but also common Aviculopecten, Straparolus, Pteronites (one articulated), and other mollusc fragments; unit also contains fragmented and worn Neospirifer, Wellerella, and in thin section, rare dasyclad algal fragments, thinnly incrusted; allochems poorly sorted, osagid-type grains are well rounded and bean shaped; upper 1/2 of unit contains thin shale lenils containing rare osagid grains ; TA? basal portion concealed	0	8	.20

-Thin section data was used to supplement descriptions of the following units: 1, 5, 7, 9, 16, 20, 21, 26,

-Disaggregated shale data was used to supplement descriptions of the following units: 8, and 22.

State: Kansas County: Pottawatomie Quadrangle: Westmoreland

Locality Description:

Westmoreland Section (W)
NW¼ NE¼ NW¼ section 3, T8S, R9E
In a stream cut on the south side of Rock Creek. Rock Creek flowing on top of upper bedding plane of the Americus Limestone.

Section from the base of the Johnson Shale down into the Americus Limestone of the Foraker Formation.

Interval measured July, 1986.

5th order T-R units/boundaries	6th order T-R units/boundaries	UNIT DESCRIPTIONS (Transgressive Surface —— ; - - - Climate Change Surface)	Unit Thicknesses ft	in	m
F3 (LONG CREEK)	F3.5	42. Johnson Shale: claystone, gray-green; blocky; calcareous; nonfossiliferous; very silty.	3	0	.91
		41. Long Creek Limestone: limestone, tan to tan-orange; massive; soft, argillaceous; porous; contains common calcite-lined vugs; blocky to platy; contains rare occurence of pelecypod molds; TA.	4	2	1.24
	F3.4	40. Hughes Creek Shale: shale, tan to brown; very silty; calcareous; contains common macerated plant fragments.	0	4	.10
		39. Hughes Creek Shale: limestone, tan, weathers light tan; argillaceous; blocky; calcilutite, pelecypod and crinoidal biomicrite; contains common Permophorus; TA.	0	6	.15
		——?—— ——?——			
	F3.3	38. Hughes Creek Shale: shale, gray to gray-brown, blocky to fissile; slightly silty; contains common crinoids; rare to common brachiopod fragments; and rare myalinid bivalve fragments.	0	4	.10
		37. Hughes Creek Shale: limestone, gray-tan; weathers tan-yellow; massive; very argillaceous (grades to a very calcareous shale toward the base); hackly; contains abundant fusulinids (approximately 30%-35% of the lithology), as well as common crinoids; Neochonetes; and other brachiopod fragments; rare bryozoan fragments; TA.	2	1	.63
	F3.2	36. Hughes Creek Shale: shale, dark gray, weathers light gray; noncalcareous; slightly silty; fissile; contains rare to common Derbyia in lower 6"-8", and other sparse brachiopod fragments.	3	0	.91
		35. Hughes Creek Shale: shale, dark gray; calcareous; non-silty; contains common Hustedia, Lissochonetes, Neochonetes, Neospirifer, Linoproductus, Derbyia, common large robust fusulinids, crinoid stems and columnals; also contains Reticulatia, Hystriculina, Wellerella, Crurithyris, Composita, and rare myalinid bivalve fragments; contains very thinnly interbedded ¼-½" highly fossiliferous shell lags-biosparudites that are lenticular in nature; one occurs in the upper 2"; another occurs in the middle and also one at the base; TA.	0	9	.23
		34. Hughes Creek Shale: shale, olive gray, weathers light gray; very calcareous; contains abundant fusulinids (approximately 30%-40%); also contains crinoids, rare productid fragments; Neospirifer, and Reticulatia; unit also contains lenticular argillaceous, micritic-calcirudites containing abundant fusulinids (packstone).	1	4	.41
	F3.1	33. Hughes Creek Shale: shale, olive-gray, weathers light gray; blocky, very calcareous; lacks fusulinids.	0	6	.15
		32. Hughes Creek Shale: limestone, gray, weathers tan-gray; blocky; argillaceous; contains thin interbedded shaley lentils.; contains common to abundant fusulinids (approximately 30%); Composita, Neospirifer, Crurithyris, and other productid fragments and crinoids; calcirudite, fine, argillaceous, brachiopod, crinoidal, fusulinid biomicrite. TA.	0	8	.20
		31. Hughes Creek Shale: shale, olive gray, very calcareous; blocky; contains common to abundant Crurithyris, Hystriculina, Composita, crinoids and other brachiopod fragments; gradational with unit above and below.	0	7	.18

Westmoreland locality continued

F2 (HUGHES CREEK)	F2.4	30. Hughes Creek Shale: shale, gray, dark gray, weathers light gray; blocky to fissile; calcareous; contains abundant artic. Crurithyris throughout; also contains rare to common Lingula, rare Orbiculoidea fragments, and rare Hystriculina.	0	7	.18
		29. Hughes Creek Shale: shale, gray-black, weathers gray; fissile to blocky; contains abundant Orbiculoidea (small and large articulated individuals in lenticular aggregated masses as well as isolated individuals), sparse to common Linglua, Hystriculina and rare Crurithyris; slightly carbonaceous.	0	6	.15
		28. Hughes Creek Shale: shale, light orange gray, hackly; blocky very calcareous; contains common whole and fragmented pieces of Hystriculina, rare Orbiculoidea, Crurithyris, crinoids, sparse osagid incrusted grains and other brachiopod fragments.	0	2	.05
		27. Hughes Creek Shale: limestone, gray, weathers yellow gray; blocky; massive; hard; slightly argillaceous; Calcarenite, coarse, osagid, molluscan biomicrite; contains common osagid incrusted pelecypod fragments, common gastropods, rare to common brachiopod fragments such as Crurithyris and Hystriculina and other productid fragments (Wackestone). TA	1	5	.43
		26. Hughes Creek Shale: shale, tan-gray, orange-gray; blocky to fissile; bedding slightly mottled (bioturbation) to laminated contains common Aviculopecten, and other unidentifiable pelecypod fragments.	0	2	.05
	F2.3	25. Hughes Creek Shale: shale, dark gray, fissile, blocky, calcareous; contains very thin interbedded to interlaminated silty, calcareous shale containing rar to common Astartella.	2	8	.81
		24. Hughes Creek Shale: limestone, gray, gray-olive, weathers light gray; blocky to hackly; very argillaceous, grades to very calcareous shale; contains common large Reticulatia, rare Neospirifer, abundant crinoids, echinoid fragments, rare Neochonetes, and sparse fusulinids; calcirudite, fine, shaley, brachiopod, fusulinid bearing, crinoidal biomicrite (wackestone).	1	11	.58
		23. Hughes Creek Shale: shale, olive-gray, weathers light gray; very calcareous; blocky; contains abundant crinoid columnals and large ventricose fusulinids; sparse Neochonetes and Neospirifer, and bryozoan fragments.	0	9	.23
		22. Hughes Creek Shale: limestone, olive-gray, blocky to slabby, hackly; argillaceous to shaley; contains abundant fusulinids; rare Linoproductus, Neochonetes (fragments), with incrusting Spirorbis, very abundant crinoid columnals, rare Aviculopinna; upper 1" becomes very shaley; calcirudite, fine, brachiopod, fusulinid, crinoidal biomicrite (wackestone to packstone); TA.	0	3	.08
		21. Hughes Creek Shale: shaley calcirudite, gray, very thin bedded; fractures hackly; contains abundant Linoproductus forming lag; also contains rare Neochonetes fragments; rare Hustedia.	0	.5	.01
		20. Hughes Creek Shale: limestone, tan-gray, weathers brown-gray; blocky to slabby; contains abundant inclined and horizontal clay filled (lighter) burrows (Chondrites), abundant Crurithyris, and sparse Hystriculina; calcarenite, coarse, Crurithyris, Chondrites, biomicrite. (wackestone)	0	2	.05
	F2.2	19. Hughes Creek Shale: shale, bray-black; papery fissile; calcareous; contians sparse amounts of minute selenite crystals on bedding surfaces; contains abundant Crurithyris forming lag on bedding surfaces, some in life position; rare Lingula; and Orbiculoidea fragments, and rare Chondrites.	0	3	.08
		18. Hughes Creek Shale: limestone, gray, to dark gray, weathers tan-gray; blocky to slabby; contains large Neospirifer, common Crurithyris, Reticulatia, crinoids and other productid fragments; gradational with unit below; calcarenite, coarse, brachiopod biomicrite; also contains rare fusulinids.	0	5	.13
		17. Hughes Creek Shale: limestone, brown-gray to dark gray; weathers tan-gray; blocky, very argillaceous; calcarenite-calcirudite, crinoidal, brachiopod, fusulinid, biomicrite; contains common to abundant fusulinids (5%-10%), common Crurithyris fragments which become abundant in the upper 1/2" (i.e. gradational with unit above), Orbiculoidea fragments, common Neospirifer, and common crinoids.	0	2	.05

Westmoreland section continued

F2 (HUGHES CREEK)	F2.2	16. Hughes Creek Shale: limestone, gray, weathers light gray, blocky; hackly; hard; argillaceous; calcarenite, coarse to fine calcirudite, fusulinid, brachiopod, crinoidal biomicrite; contains common fusulinids (5%), common Neospirifer, rare Orbiculoidea fragments, common crinoids, and other brachiopod fragments; gradational with unit below.	0	2	.05
		15. Hughes Creek Shale: shale, gray, to tan-gray, weathers tan-yellow; blocky, very calcareous; contains common well preserved, articulated Neospirifer, well preserved Neochonetes, articulated Reticulatia, common Linoproductus, lesser Crurithyris, Rhipidomella, Derbyia; unit also contains common myalinid bivalve fragments, Aviculopecten, common fenestrate and ramose bryozoans, and crinoids; Neochonetes and Linoproductus are most abundant toward the base of this unit, and Neospirifer is more common toward the top of this unit; TA.	0	4	.10
	F2.1	14. Hughes Creek Limestone: limestone, gray, tan-gray, weathers tan-yellow; blocky, hard, argillaceous; calcarenite, coarse to fine calcirudite, osagid bearing, brachiopod biomicrite; contains common Crurithyris, common Isogramma fragments most abundant in the lower 1/2 of unit, lesser Neospirifer, Linoproductus, Derbyia, Nechonetes, crinoids and Hustedia; faunal diversity decreases abruptly in the upper 2" which is accompanied by very argillaceous content and abundant Crurithyris; unit also contains throughout, flaser-like shale lentils; unit also contains rare pelecypod fragments; TA	1	0	.30
		13. Hughes Creek Shale: shale, light olive-gray, blocky; hard; calcareous; contains common, articulated, Linoproductus, myalinid bivalve fragments, and rare clay-filled burrows-inclined.	0	6	.15
F1 (AMERICUS)	F1.3	12. Hughes Creek Shale: shale,olive-gray, weathers light olive-gray; blocky, silty, micaceous; calcareous; contains common ostracodes and rare myalinid bivalve fragments.	2	2	.66
		11. Hughes Creek Shale: shale, gray-olive, blocky, calcareous, slightly silty; contains rare osagid incrusted grains, abundant Aviculopecten?, rare fenestrate bryozoans, nuculoid bivalves (Astartella?), and myalinid bivalve fragments.	0	2	.05
		10. Hughes Creek Shale: limestone, gray, weathers tan-yellow; massive, blocky to slabby, argillaceous; upper 1/2 of unit in thin section is a calcirudite, medium, mature to submature, osagid-biosparite; and contains abundant "bean shaped" osagid grains that show reverse grading where .35mm size grains grades into 8mm sized grains toward the top of the unit; upper portion of unit also contains abundant gastropods, and pelecypod fragments including Aviculopecten; also contains lesser echinoid spines, crinoids and brachiopod fragments; the lower 1/2 of this unit in thin section is a calcirudite, fine to medium, poorly washed, brachiopod, molluscan, osagid biosparite to sparry biomicrite; the lower ½ contains abundant osagid incrusted grains with Osagia thickest in the concave portion of valves; lower 1/2 also contains common Aviculopecten, echinoid plates, rare Neospirifer fragments, bellerophont gastropods, large Derbyia fragments, fragments of fenestrate and ramose bryozoans, and rare to common nuculoid bivalves.; overall, unit is poorly sorted with osagid grains and sparry content increasing up the unit TA.	1	5	.43
		9. Hughes Creek Shale: limestone, tan-gray, weathers yellow-gray; argillaceous-shaley, slabby to blocky; contains rare to common Neospirifer fragments, Neochonetes, Crurithyris, common productid fragments.	0	2	.05
		8. Hughes Creek Shale: shale, olive-gray, blocky, siltly; slightly calcareous; common articulated Linoproductus, common Crurithyris; basal 1" is a fossil lag (transgressive) containing abundant Linoproductus, Aviculopecten; sharp contact with unit below.	0	6	.15

Westmoreland locality continued

F1 (AMERICUS)	F1.2	7. Hughes Creek Shale: shale, gray-black, dark gray, weathers light gray; fissile; micaceous, noncalcareous; contains thin interbedded, tan-gray, micaceous, noncalcareous, nonfossiliferous, siltstones; lower 12" contains patchy distribution of Crurithyris and Chondrites.	7	11	2.4
		6. Hughes Creek Shale: shale, gray, to gray-black, fissile to platy; very calcareous; contains abundant Crurithyris- articulated large and small individuals; and rare Neochonetes.	0	2	.05
		5. Americus Limestone: limestone, gray, to dark gray; weathers light gray; platy to hackly; very argillaceous to shaley; contains abundant to common fusulinids (approximately 10 to 15%, of large and small fusulinids) that become rare in the upper 2"; also contains large and small Neospirifer; common crinoids that increase upward (i.e. accompanied by decrease in fusulinids); upper 1" contains common Crurithryis (i.e. gradational with unit above); and Chondrites; unit consists of thinnly interbedded, lenticular, sparry, micritic-calarenites and shaley calcarenites containing fossils aforementioned.	0	6	.15
		4. Americus Limestone: limestone, gray to blue-gray, weathers yellow-gray; slightly argillaceosu, blocky, hard; calcirudite, fine, crinoidal, pellet bearing, brachiopod, fusulinid bearing biomicrosparite (thin section); unit contains abundant crinoids, and brachiopod fragments in thin section (randomly oriented and poorly sorted); consists of Neochonetes, common toward the top of unit, common Composita, Derbyia, Wellerella, Reticulatia, Neospirifer, rare rugose corallites (Lophophyllidium?), echinoid spines and other fragments, rare Straparolus, and rare Crurithyris; unit also contains fusulinids that are common toward the top and rare toward the base; also contains rare carbonate and clay intraclasts toward the base; allochems are occasionally in "edgewise fashion"; TA.	0	9	.23
	F1.1	3. Americus Limestone: shale, dark gray, fissile, slightly silty calcareous; contains abundant Crurthyris.	0	6	.15
		2. Americus Limestone: limestone, dark gray, very thinnly bedded; very argillaceous to shaley; contains common Crurithyris, articulated and disarticulated Neochonetes, and other brachiopod fragments; calcarenite, coarse, brachiopod, biomicrite (wackestone); TA.	0	6	.15
		1. Americus Limestone: limestone-algal stromatolite; gray to dark gray; uneven to hummocky algal bands that appear bioturbated (possibly grazed on) and contorted; inbetween algal bands and encasing stromatolites (in thin section) is an argillaceous, fine, calcarenite; pellet bearing, gastropod, intraclast, ostracodal, biomicrite (packstone); base of unit concealed.	0	4	.10

-Thin section data was used to supplement descriptions of the following units: 1, 2, 4, 10, and 32.

-Dissagregated shale data was used to supplement descriptions of the following unit: 35.

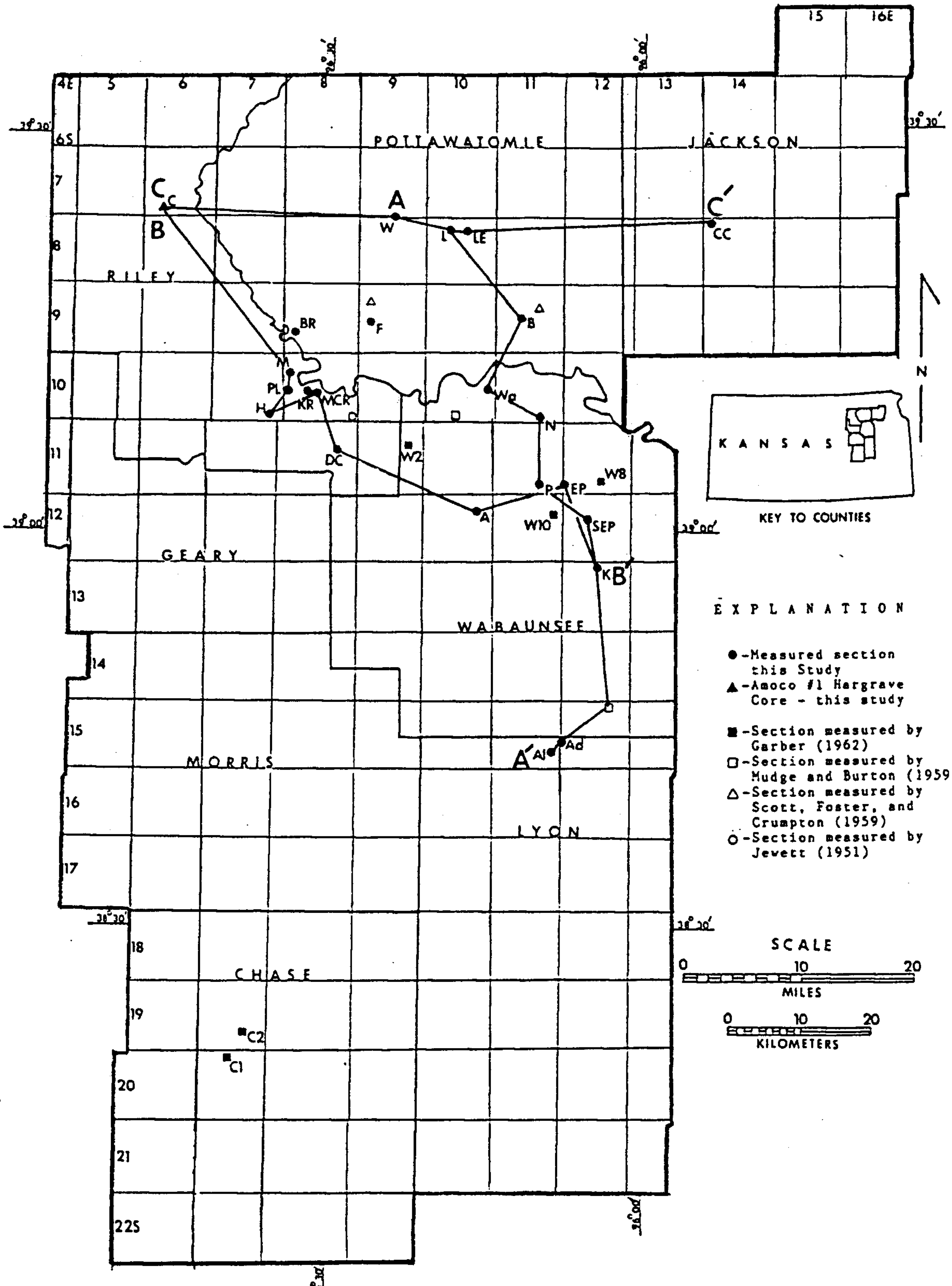

Plate 1: Area of study showing locations of cross sections A-A', B-B', and C-C'.

Plate 2
NORTH-SOUTH STRATIGRAPHIC CROSS-SECTION, A-A', FROM CENTRAL POTTAWATOMIE COUNTY TO NORTHERN LYON COUNTY, SHOWING EXTENT OF SIXTH-ORDER T-R UNITS OF THE FORAKER FOURTH-ORDER T-R UNIT

EXPLANATION

Limestone
Argillaceous to shaley limestone
Limestone with osagid grains
Limestone with mudcracks
Lenticular limestone
Siltstone
Carbonate and clay-grain sandstone
Paleosol
Dolomitic limestone
Dolostone
Algal stromatolite with rip-clasts
Algal laminite with mudcracks
Calcareous shale
Shale or claystone
Fusulinid biofacies-abundant fusulinids
Less abundant fusulinids
Concealed interval
Limestone- intraformational breccia

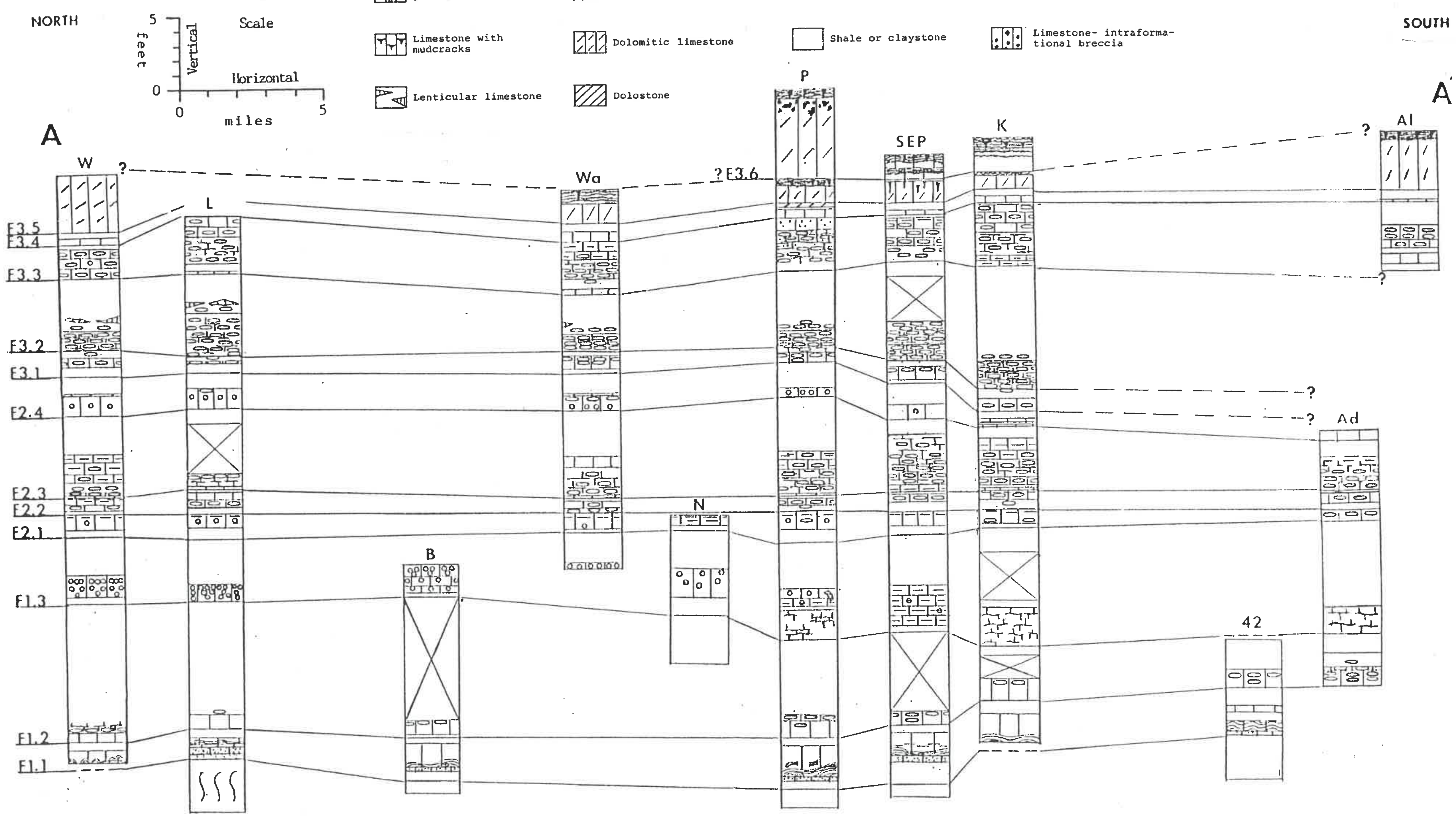

Plate 3

NORTHWEST-SOUTHEAST STRATIGRAPHIC CROSS-SECTION, B-B', FROM CENTRAL RILEY COUNTY TO EASTERN WABAUNSEE COUNTY, SHOWING EXTENT OF SIXTH-ORDER T-R UNITS OF THE FORAKER FOURTH-ORDER T-R UNIT

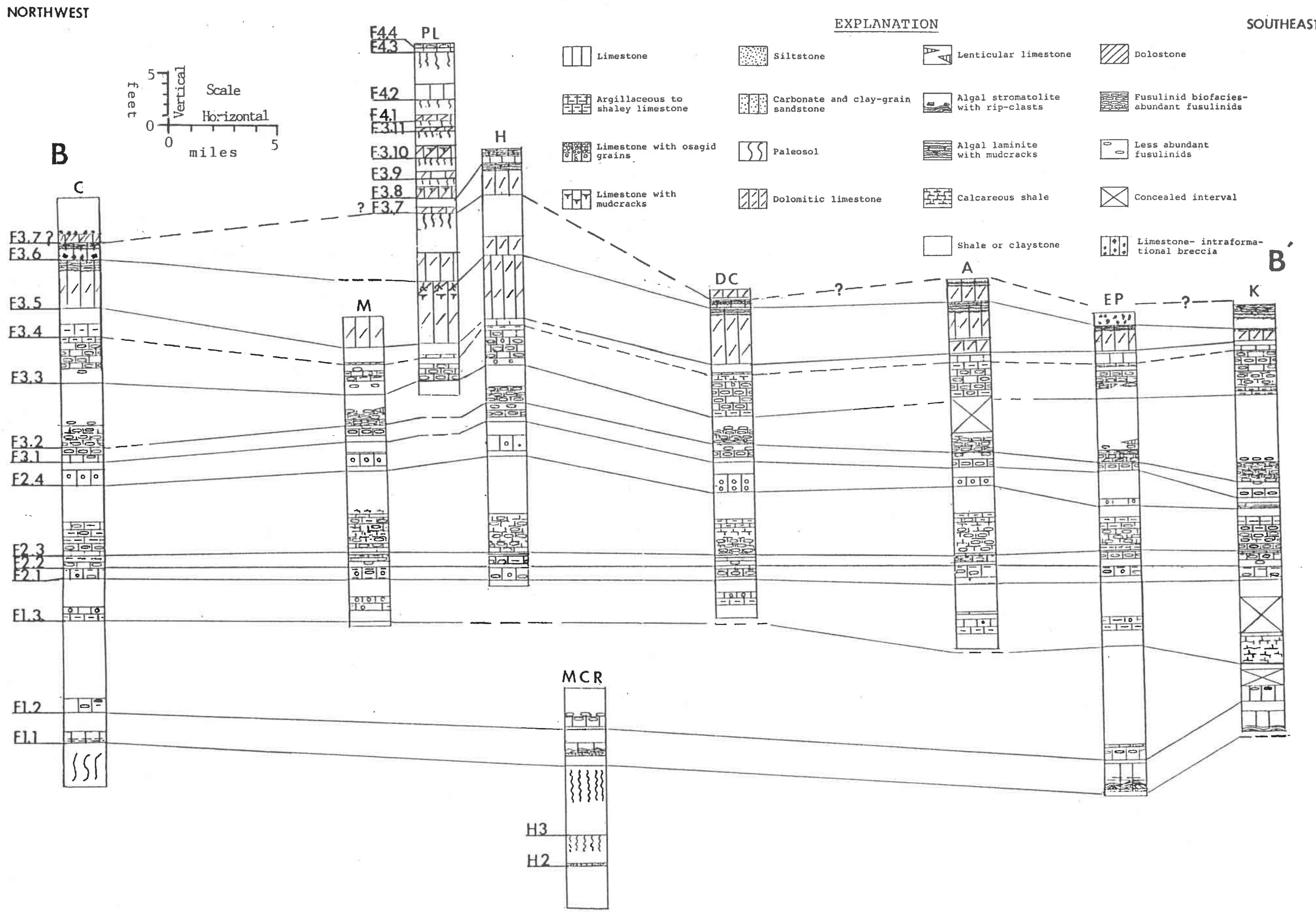

Plate 4

EAST-WEST STRATIGRAPHIC CROSS-SECTION, C-C', FROM CENTRAL RILEY COUNTY TO EASTERN JACKSON COUNTY, SHOWING EXTENT OF SIXTH-ORDER T-R UNITS OF THE FORAKER FOURTH-ORDER T-R UNIT