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Stratigraphy and brachiopod genus <Composita > of the Wreford megacyclothem (Lower Permian) in Kansas and Oklahoma

STRATIGRAPHY AND
BRACHIOPOD GENUS
COMPOSITA OF THE
WREFORD MEGACYCLOTHEM
(LOWER PERMIAN) IN
KANSAS AND OKLAHOMA

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Stratigraphy and Brachiopod Genus Composita of the
Wreford Megacyclothem (Lower Permian)
in Kansas and Oklahoma

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ABSTRACT

Previous studies of the Nebraska and Kansas portions of the Wreford Megacyclothem have yielded extensive knowledge of the lithology, stratigraphic relationships, paleogeography, and paleo-environmental implications of these rocks. However, comparably detailed understanding of the Oklahoma Wreford has not been achieved until now, as presented in this paper. This thorough knowledge of Wreford stratigraphy in turn provides background for making detailed studies of the various well-preserved Wreford fossil groups.

Field tracing of the stratigraphic units of the Wreford Megacyclothem into northern Oklahoma reveals that major facies changes take place within a short distance south of the Kansas-Oklahoma border, so that all the typically marine Wreford horizons of Kansas grade laterally into interbedded red shales and red sandstones. Several units (the entire Speiser, middle and upper Havensville, upper Schroyer, and the Wymore) become red beds only a few miles south of the border. The remaining horizons comprise two marine tongues extending farther south and thus indicate shoreline fluctuations of the Wreford sea. The upper tongue, newly discovered and poorly exposed, includes algal-molluscan limestone (lower Schroyer) overlain by grayish-yellow mudstone (middle Schroyer), and extends to about 40 miles south of the state line. The lower tongue consists of two algal-molluscan limestones (lower Threemile and lower Havensville equivalent) bracketing a thin brachiopod-molluscan limestone (middle and upper Threemile), and extends to about 50 miles south of the border. Both tongues pass

through tan quartzose sandstone or red clayey molluscan limestone as they grade southward into red shale and red sandstone.

The Wreford in Oklahoma is dominated by fewer rock types than in Kansas. Red shales interbedded with red sandstones comprise the most volume of any rock type. Also important are pelecypod-burrowed algal-molluscan limestones, which change southward by an increase in molluscs, algally ("Osagia") or inorganically coated grains, and fine quartz sand, with a simultaneous decrease in brachiopods and bryozoans. These limestones may represent calcarenite shoals as well as shallow level bottoms in the Wreford sea, immediately offshore from the coastal plain to the south. Other distinctive Oklahoma Wreford rock types include tan quartzose sandstone and red clayey molluscan limestone.

Brachiopods are abundant and widely distributed in the Wreford Megacyclothem. Groups recognized include chonetids, Cleiothyridina, Composita, Derbyia, Enteletes, Lingula, Orbiculoidea, Petrocrania, productids, and Wellerella.

The abundant, well-preserved, and widely distributed Wreford Composita group was studied in detail. Because the Wreford Composita population consists of an intergradational series of individuals which cannot be separated into clearly distinct groups interpretable as separate species, these fossils are best included in a single species, Composita subtilita (Hall, 1852). Two morphologically distinct varieties can be recognized as end members of this intergrading population: Composita subtilita var. subtilita, and Composita subtilita var. ovata. These two varieties do not differ significantly in distribution and abundance, occurrence in rock types,

stratigraphic horizons, or geographic regions. The varieties thus cannot be explained as ecotypes, evolutionary populations, or subspecies, but can be regarded most appropriately as intraspecific morphotypes. Eleven numerical morphological characters were measured on each well-preserved Wreford specimen of Composita subtilita. These measurable characteristics, summarized for the entire Wreford population, aid greatly in determining that no systematic morphologic variations exist in this population attributable to ecologic, evolutionary, or clinal difference.

Paleoecologic investigation of the Wreford Composita subtilita suggests that salinity or sediment influx may have been important limiting environmental factors for this species, that Composita subtilita did not live at sites of strong currents, and that large shell beds covered the southern reaches of the sea floor at certain times during Wreford deposition.

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PART I

GENERAL INTRODUCTION

PREVIOUS WREFORD INVESTIGATIONS

The detailed stratigraphy and environments of deposition of the various rock types of the Lower Permian Wreford Megacyclothem were studied by Hattin (1957). With such excellent geographic, stratigraphic, lithologic, and ecologic backgrounds provided by the above paper, thorough studies of the various fossil groups present in the Wreford Megacyclothem could be accomplished. Cuffey (1967) began the detailed fossil work with his study of the bryozoan Tabulipora carbonaria, and other bryozoan works soon followed (Newton, 1971; Warner, 1972). The Wreford comprises only a small fraction of Early Permian time, and its regional setting is evident from summaries such as the Permian paleotectonic atlas (McKee et al, 1967).

OBJECTIVES OF PRESENT INVESTIGATION

Several brachiopod groups occur in large numbers in the Wreford, but have never been studied in detail. Autecologic studies of the various brachiopod species would bring paleontological students of the Wreford closer to the "big picture" of the life present on the Permian sea bottom and in its waters throughout the formation of the megacyclothem. These autecologic studies, when combined with stratigraphic and other paleoecologic information, will contribute to an overall synecologic synthesis, which will be an important contribution to the geology of the Mid-Continent region in Early Permian time.

I assembled a very large collection (about 10,000 specimens) of Wreford brachiopods, all precisely located, as the basis for my study. The very close control possible over these fossil collections in terms

of geographic, stratigraphic, and lithologic occurrence provides unique opportunities for detailed and accurate taxonomic and paleoecologic studies.

Because of the large numbers of specimens collected, I restrict the present paper to only one of the abundant Wreford brachiopod groups--the brachiopod genus Composita. I am examining and will report on the remaining groups at a later time.

The principal objective of studying such a large population-sized sample of fossils was to generate thorough understanding of their morphology and variability, and thereby to recognize species which closely approach paleobiologic species concepts. Moreover, taxonomic, evolutionary, stratigraphic, geographic, and paleoecologic causes of variability may well become evident through studies of such large numbers of precisely located fossils. Another purpose of the present study was to apply more extensive numerical characterization to these fossils than had previously been achieved by other investigators, because I expected that such numerical characterizations might help indicate causes of any observable morphologic variability. These numerical methods also aid in precisely describing this population of Composita, and this description can therefore serve as a focal point of comparison with other Late Paleozoic Composita species. The extensive collection studied here also provides the basis for paleoecologic conclusions concerning this interesting brachiopod group.

The single most important contribution of the present study of Wreford Composita is probably that the morphologic variability of this very large sample indicates that the sample constitutes only

one species, in contrast to the habit of previous workers of identifying different-looking specimens from their much smaller samples as representing different species. This conclusion has important implications for species-level taxonomic practice on paleobiologic populations, in that morphologic intergradation might not be obvious from small samples, which might therefore be misinterpreted as several separate species rather than as one variable species.

During the present brachiopod study, it was also necessary to determine in detail the characteristics of the southernmost extent of the stratigraphic units of the Wreford Megacyclothem in Oklahoma, since the stratigraphy of only the Kansas portion had been thoroughly studied previously (Hattin, 1957).

Consequently, I measured and studied stratigraphic sections in Oklahoma (see Appendices A and B for these measured sections) in order to trace the megacyclothem southward and determine its concomitant lithologic changes.

The primary objective of this part of the present study was to provide extensive knowledge of the southernmost portions of the megacyclothem, so that a comprehensive view of the entire Wreford throughout its total geographic extent could be obtained now for the first time. This was achieved, and thus the most important contribution of the study of the stratigraphy of the Oklahoma Wreford is the detailed view of the rock types, facies changes, fossil content, and geographic extent of these rocks, and the correlation of this information with their Kansas counterparts.

This paper is thus divided into four parts, the first of which is the present general introductory section. In the second part, I

will review the stratigraphy of the Wreford Megacyclothem in Kansas and add new information on the Wreford in northern Oklahoma. Thirdly, I will give an introduction to the various brachiopods of the Wreford, including some details about their distribution and abundance, and then treat in detail the Wreford brachiopod genus Composita. Finally, fourth, I will present certain detailed or background material supportive to parts of the second and third sections as appendices.

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INTRODUCTION

The stratigraphy and paleontology of the lower Permian Wreford Megacyclothem in Kansas were studied intensively by Harris (1971). Detailed investigations of the various fossil groups present in the Wreford Megacyclothem thus became possible on a regional, against the stratigraphic, lithologic, paleontologic, and geographic background provided by Harris's regional study.

Such detailed paleontologic investigations began with study (Coffey, 1967) of the bryozoan *Tetralopora californica*, and treatments of the Wreford spongiolites (Barton, 1971) and *Haralopora* (Coffey, 1972) were followed. Currently, in addition to several other bryozoan groups, the various brachiopod groups present in

PART 2

STRATIGRAPHY OF THE WREFORD MEGACYCLOTHEM (LOWER PERMIAN)

IN SOUTHERNMOST KANSAS AND NORTHERN OKLAHOMA

has been completed (see Coffey, in preparation).

Because Harris (1971) had worked out the detailed stratigraphy of the Wreford only within the boundaries of Kansas, a preliminary extensive understanding of the geochronologic portions of the megacyclothem did not exist until this present paper. To provide comprehensive knowledge of the Wreford Megacyclothem, in order to complete the detailed background for bryozoan and brachiopod investigations in progress, selected stratigraphic sections (Appendices A and B) of the Wreford Megacyclothem in Oklahoma were studied in detail. Results of this study are reported in this paper. In addition, this information concerning the detailed stratigraphy of the Oklahoma Wreford is presented so that it can be worked with knowledge of the Kansas Wreford.

INTRODUCTION

The stratigraphy and environments of deposition of the Lower Permian Wreford Megacyclothem in Kansas were studied intensively by Hattin (1957). Detailed investigations of the various fossil groups present in the Wreford Megacyclothem thus became possible to accomplish, against the stratigraphic, lithologic, paleoecologic, and geographic background provided by Hattin's Kansas study.

Such detailed paleontologic investigations began with study (Cuffey, 1967) of the bryozoan Tabulipora carbonaria, and treatments of the Wreford rhomboporoids (Newton, 1971) and fistuliporoids (Warner, 1972) soon followed. Currently, in addition to several other bryozoan groups, the various brachiopod groups present in the Wreford Megacyclothem are being studied. Of these, the investigation of the Wreford population of the brachiopod Composita has been completed (Lutz-Garihan, in preparation).

Because Hattin (1957) had worked out the detailed stratigraphy of the Wreford only within the boundaries of Kansas, comparably extensive understanding of the southernmost portions of the megacyclothem did not exist until the present paper. To provide comprehensive knowledge of the Oklahoma Wreford, in order to complete the detailed background for bryozoan and brachiopod investigations in progress, measured stratigraphic sections (Appendices A and B) of the Wreford Megacyclothem in Oklahoma were studied in detail. Results of this study are reported in this paper. In addition, this information concerning the detailed stratigraphy of the Oklahoma Wreford is presented so that it can be meshed with knowledge of the Kansas Wreford,

in order that a comprehensive view of the entire Wreford throughout its total geographic extent can be obtained now for the first time.

METHODS OF INVESTIGATION

As the basis for the present study, stratigraphic sections were examined and measured and rock samples (as well as brachiopods) were collected from Wreford outcrops in southernmost Kansas and northern Oklahoma. These measured sections are described in Appendices A and B.

Localities upon which is based the extension of Wreford stratigraphy into Oklahoma are briefly listed (Table 1) and mapped (Figure 1). More detailed descriptions of each may be found in previous papers (Cuffey, 1967; Newton, 1971) and in the Composita paper being submitted separately (Lutz-Garihan, in preparation), whose numbering system is continued here in order to facilitate integrated use of all these contributions.

The rock samples included bulk samples of shales for later laboratory kerosening, chips of indurated rocks (limestones and sandstones, mostly) for oriented thin-sections, and chunks of limestones, sandstones, and shales for later insoluble residue studies.

The thin-sections of key beds were examined to determine both rock type and fossil content.

Insoluble residues, determined as weight percentages of constituents for key beds, also provided information relevant to the present stratigraphic study. These percentages are indicated in Appendix A. The rock samples were crushed and weighed and then dissolved in acetic acid for two to four days; the resulting residue was dried and weighed.

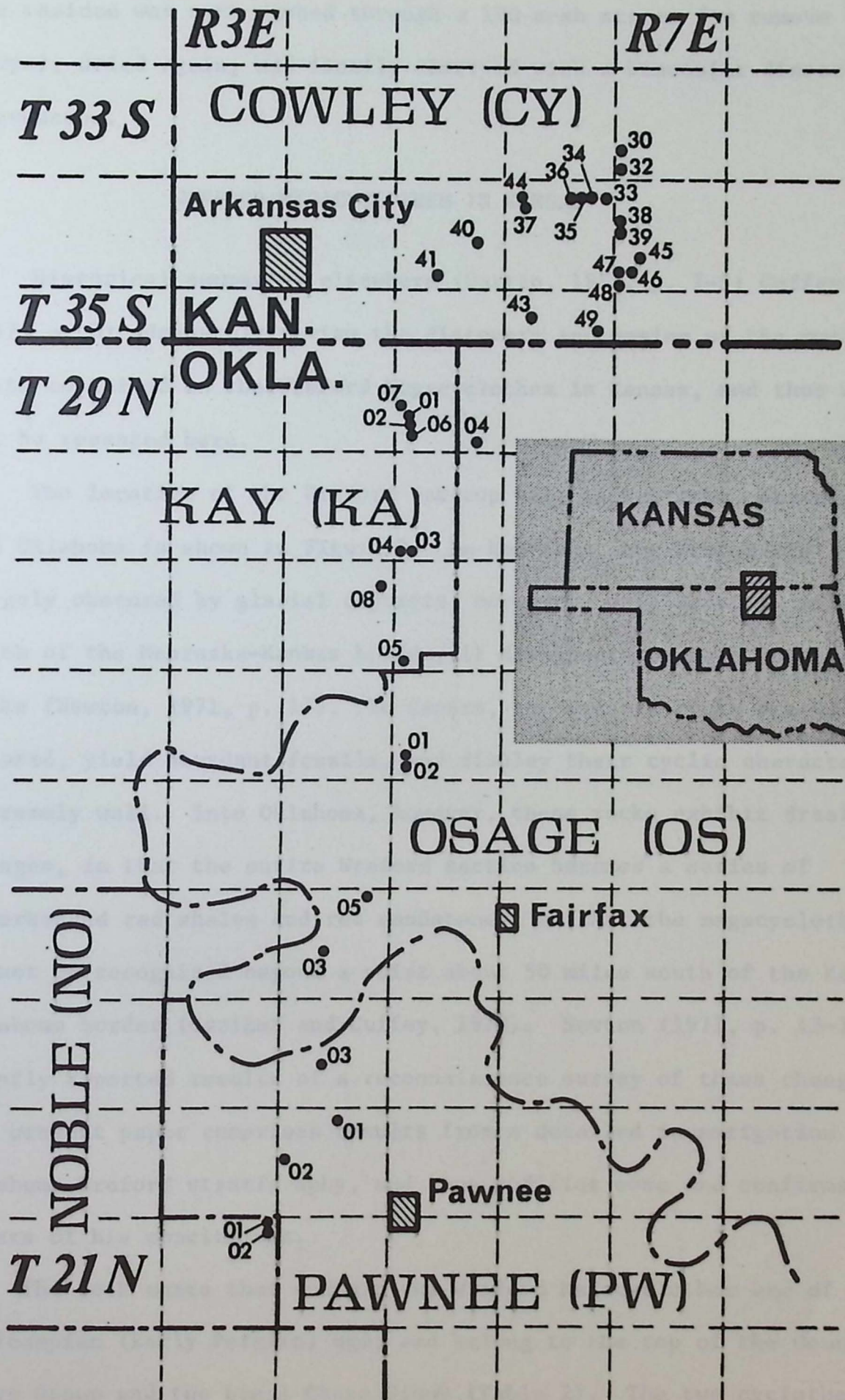
TABLE 1. Wreford localities in southernmost Kansas and northern Oklahoma.

<u>Locality Number</u>	<u>Locality Type</u>	<u>Locality Location</u>	
CY30	road cut	NW 1/4 sec. 30, T.33S., R.7E.	Cowley Co., Kansas
CY32	road cut	SW 1/4 sec. 31, T.33S., R.7E.	
CY33	road cut	NE 1/4 sec. 12, T.34S., R.6E.	
CY34	road cut	NW 1/4 sec. 11, T.34S., R.6E.	
CY35	road cut	NW 1/4 sec. 11, T.34S., R.6E.	
CY36	road cut	NE 1/4 sec. 10, T.34S., R.6E.	
CY37	spillway	SW 1/4 sec. 8, T.34S., R.6E.	
CY38	road cut	SW 1/4 sec. 18, T.34S., R.7E.	
CY39	road cut	SW 1/4 sec. 18, T.34S., R.7E.	
CY40	road cut	ctr. sec. 23, T.34S., R.5E.	
CY41	stream bed	NW 1/4 sec. 33, T.34S., R.5E.	
CY43	stream cut	SE 1/4 sec. 8, T.35S., R.6E.	
CY44	gully	SE 1/4 sec. 7, T.34S., R.6E.	
CY45	gully	NW 1/4 sec. 29, T.34S., R.7E.	
CY46	road cut	SE 1/4 sec. 30, T.34S., R.7E.	
CY47	road cut	NW 1/4 sec. 31, T.34S., R.7E.	
CY48	road ditch	SW 1/4 sec. 31, T.34S., R.7E.	
CY49	stream cut	NW 1/4 sec. 13, T.35S., R.6E.	

TABLE 1 (Continued)

<u>Locality Number</u>	<u>Locality Type</u>	<u>Locality Location</u>	
KA01	road ditch	NE 1/4 sec. 30, T.29N., R.5E.] Kay Co., Okla.
KA02	road cut	NE 1/4 sec. 30, T.29N., R.5E.	
KA03	gully	SW 1/4 sec. 31, T.28N., R.5E.	
KA04	road cut	SW 1/4 sec. 31, T.28N., R.5E.	
KA05	butte top	SW 1/4 sec. 31, T.27N., R.5E.	
KA06	road cut	SW 1/4 sec. 29, T.29N., R.5E.	
KA07	stream cut	NW 1/4 sec. 19, T.29N., R.5E.	
KA08	hillside	NW 1/4 sec. 12, T.27N., R.4E.	
OS01	road cut	SE 1/4 sec. 30, T.26N., R.5E.] Osage Co., Okla.
OS02	gully	NE 1/4 sec. 31, T.26N., R.5E.	
OS03	butte top	NW 1/4 sec. 21, T.24N., R.4E.	
OS04	road cut	SW 1/4 sec. 35, T.29N., R.5E.	
OS05	road ditch	NE 1/4 sec. 2, T.24N., R.4E.	
PW01	road cut	SW 1/4 sec. 3, T.22N., R.4E.] Pawnee Co., Okla.
PW02	road cut	SW 1/4 sec. 18, T.22N., R.4E.	
PW03	road cut	SW 1/4 sec. 21, T.23N., R.4E.	
NO01	road ditch	NE 1/4 sec. 1, T.21N., R.3E.] Noble Co., Okla.
NO02	road ditch	NE 1/4 sec. 1, T.21N., R.3E.	

Figure 1. Wreford localities in southernmost Kansas
and northern Oklahoma (separately numbered
in each county).



The residue was next washed through a 100 mesh screen (to remove the clays), dried again, and finally observed with a binocular dissecting microscope.

WREFORD MEGACYCLOTHEM IN KANSAS

Historical summaries elsewhere (Hattin, 1957, p. 7-9; Cuffey, 1967, p. 8) adequately review the discovery and naming of the rock units contained in the Wreford Megacyclothem in Kansas, and thus will not be repeated here.

The location of the Wreford outcrop belt in Nebraska, Kansas, and Oklahoma is shown in Figure 2. In Nebraska, the Wreford is largely obscured by glacial deposits; moreover, only about 30 miles north of the Nebraska-Kansas border, it disappears beneath Cretaceous rocks (Newton, 1971, p. 13). In Kansas, the Wreford rocks are widely exposed, yield abundant fossils, and display their cyclic character extremely well. Into Oklahoma, however, these rocks exhibit drastic changes, in that the entire Wreford section becomes a series of interbedded red shales and red sandstones, so that the megacyclothem cannot be recognized beyond a point about 50 miles south of the Kansas-Oklahoma border (Garihan and Cuffey, 1973). Newton (1971, p. 13-14) briefly reported results of a reconnaissance survey of these changes; the present paper comprises results from a detailed investigation of Oklahoma Wreford stratigraphy, and thus modifies some and confirms others of his conclusions.

The rock units that contain the Wreford Megacyclothem are of Wolfcampian (Early Permian) age, and belong to the top of the Council Grove Group and the basal Chase Group (Table 2). The two cyclothems

Figure 2. Outcrop of Wreford Limestone in Nebraska, Kansas and Oklahoma (adapted from Geologic Bedrock Map of Southeastern Nebraska, 1966; Geologic Map of Kansas, 1964; and Geologic Map of Oklahoma, 1954).

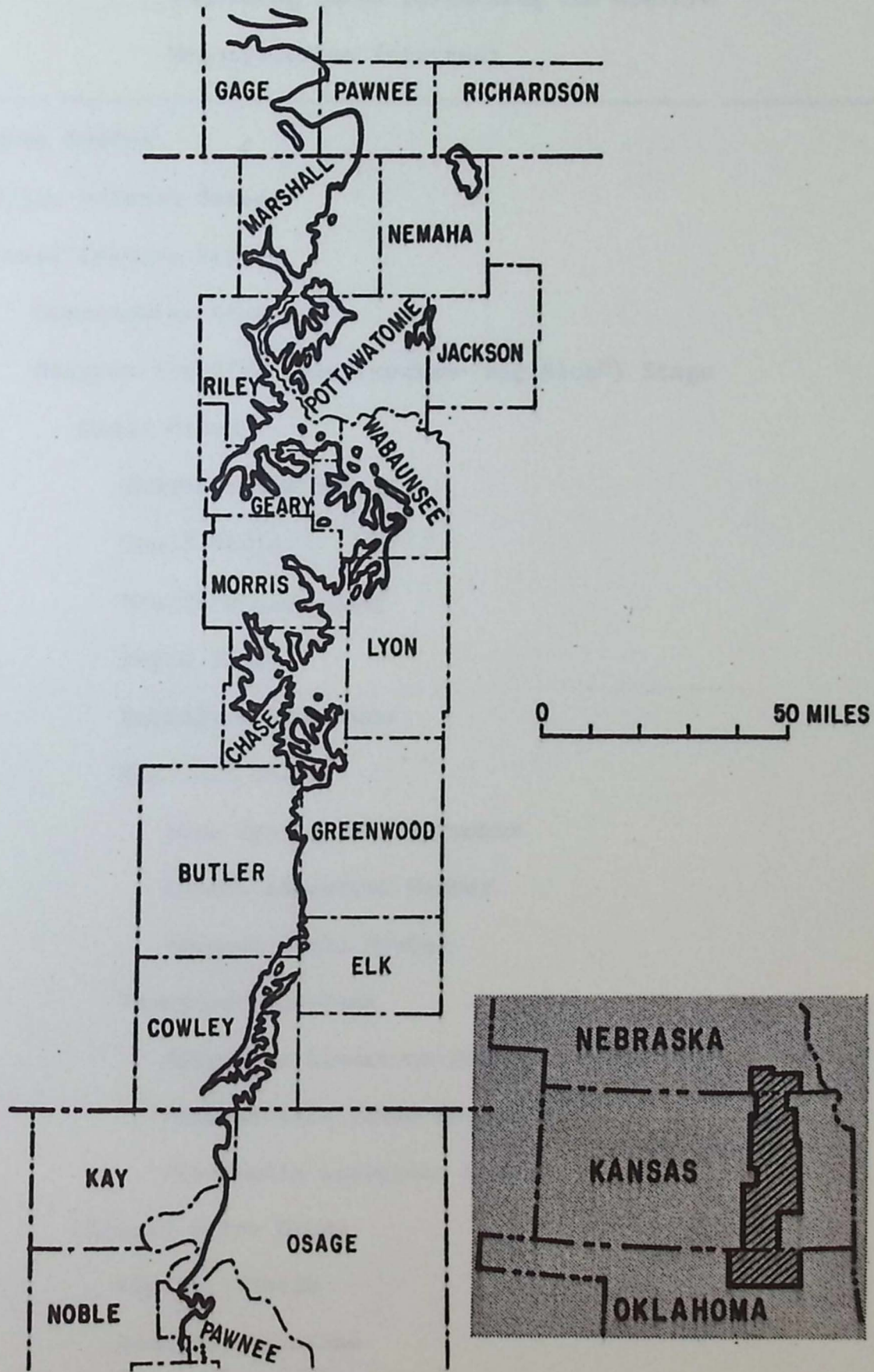


TABLE 2. Stratigraphic section of the Kansas Wolfcampian,
including units containing the Wreford
Megacyclothem (starred).

Permian System

Upper Permian Series

Lower Permian Series

Cimarronian Stage

Gearyan (=Wolfcampian=Lyonian="Big Blue") Stage

Chase Group

Nolans Limestone

Odell Shale

Winfield Limestone

Doyle Shale

Barneston Limestone

Matfield Shale

Blue Springs Shale Member

Kinney Limestone Member

*Wymore Shale Member

*Wreford Limestone

*Schroyer Limestone Member

*Havensville Shale Member

*Threemile Limestone Member

Council Grove Group

*Speiser Shale

Funston Limestone

Blue Rapids Shale

Crouse Limestone

TABLE 2 (Continued)

Easley Creek Shale
Bader Limestone
Stearns Shale
Beattie Limestone
Eskridge Shale
Grenola Limestone
Roca Shale
Red Eagle Limestone
Johnson Shale
Foraker Limestone
Admire Group

included in the Wreford (and indicated on Figure 3) are the Threemile cyclothem below and the Schroyer cyclothem above.

The detailed stratigraphy of the Wreford Megacyclothem throughout its region of outcrop can be summarized succinctly by the large cross-section (Figure 3, in pocket). This cross-section in part represents updating of preliminary versions (Cuffey, 1967, p. 14-15; Newton, 1971, p. 8-9) and in part is newly compiled, both parts depending upon new information generated by the present stratigraphic investigation and by companion Wreford brachiopod (Lutz-Garihan, in preparation) and bryozoan (Cuffey, in preparation) studies.

The many thin strata included within the Wreford Megacyclothem represent comparatively few rock types which recur in a cyclic pattern. The characteristics and paleoenvironmental interpretations of these rock types in Kansas have been treated in detail by Hattin (1957, p. 51-104), Cuffey (1967, p. 10-13), and Newton (1971, p. 7-10). This information is briefly summarized here (Tables 3 and 4; Appendix C) to provide necessary background for the present stratigraphic study.

In addition, a few papers have appeared since these detailed descriptions, which shed light on other aspects of Wreford rock types.

Rasmussen et al (1971) report that a vertebrate assemblage from an intraformational conglomerate of Upper Pennsylvanian age in Kansas includes sharks, fishes, reptiles, and amphibians. Thus, both fresh water and marine vertebrates contributed to the debris found in these channel conglomerates.

Lee (1972) found little change vertically in clay mineralogy of the Havensville Shale Member, but significant variation laterally between near-shore and offshore marine shales. Kaolinite is found

TABLE 3. Abbreviations for Wreford rock types, used in Table 4 and Figure 4 to summarize aspects of Wreford stratigraphy.

<u>Abbreviation</u>	<u>Rock Type</u>
alg ls	algal limestone
alg-moll ls	algal-molluscan limestone
argill ls	argillaceous limestone
black sh	black shale
brach-moll ls	brachiopod-molluscan limestone
calc sh	calcareous shale
chlky ls	chalky limestone
chnl cgl	channel conglomerate
chty ls	cherty limestone
coal	coal
grn sh	green shale
gr-yl mud	gray-yellow mudstone
int brecc	intraformational breccia
moll ls	molluscan limestone
red sh	red shale
red ss	red channel sandstone
resid cl	red residual clay
tan ss	tan quartzose sandstone

Table 4. Paleoenvironmental interpretations of Wreford rock types, considered in approximate cyclic order (compiled from Hattin, 1957; Cuffey, 1967; and Newton, 1971).

<u>Rock Type</u>	<u>Water Depth</u>	<u>Distance from Shore</u>	<u>Salinity</u>	<u>Water Movement</u>	<u>Substrate</u>	<u>Physiography</u>
tan ss	very shallow	near	brackish	moderate	terrigenous sand	level sea bottom or intertidal flat
alg-moll ls	very shallow to 10'? 60'?	near	brackish	moderate	carbonate mud or sand	level sea bottom or intertidal flat
alg ls	very shallow to 10'? 60'?	near	brackish? (possibly hypersaline?)	sometimes moderate	carbonate sand or mud	level sea bottom or calcarenite shoal
chlky ls	very shallow to 10'? 60'?	near to far	normal marine	weak?	carbonate mud	carbonate mud banks

Table 4 (Continued)

<u>Rock Type</u>	<u>Water Depth</u>	<u>Distance from Shore</u>	<u>Salinity</u>	<u>Water Movement</u>	<u>Substrate</u>	<u>Physiography</u>
chty ls	10' to 60'	near to far	normal marine	none	carbonate mud	level sea bottom
calc sh	10' to 30' (possibly to 60')	near to far	normal marine	none	mixed terri- genous and carbonate mud	level sea bottom
brach-moll ls	10' to 60'	near to far	normal marine or brackish	none to weak	carbonate mud	level sea bottom
moll ls	10' to 60'	near to far	normal marine or brackish	weak	carbonate mud	level sea bottom
int brecc	very shallow	near to far	normal marine or brackish	strong	mixed mud	level sea bottom
gry-yl mud	very shallow	near	brackish	weak?	terrigenous mud	level sea bottom

Table 4 (Continued)

<u>Rock Type</u>	<u>Water Depth</u>	<u>Distance from Shore</u>	<u>Salinity</u>	<u>Water Movement</u>	<u>Substrate</u>	<u>Physiography</u>
coal; black sh	very shallow	near	brackish	none?	plant debris	depressions in sea bottom
grn sh	very shallow or low intertidal	very near or on- shore	brackish	weak?	terrigenous mud	intertidal flat or level sea bottom
red sh	very shallow or high intertidal	very near or on- shore	fresh or brackish	weak?	terrigenous mud	flood plain or intertidal flat
red ss	very shallow	very near or onshore	fresh or brackish	strong	terrigenous sand	stream channel
chnl cgl	very shallow	very near or onshore	fresh or brackish	strong	terrigenous gravel	stream channel

only in near-shore facies in southern Kansas. Montmorillonite decreases northward as illite increases, although some illite was probably derived diagenetically from the montmorillonite. Mixed-layer chlorite exists at all the localities studied but decreases in abundance northward. Lee (1972) concluded that both detrital and diagenetic effects are evident in this Havensville clay-mineral assemblage.

Isotopic data were also considered for the clay minerals of the Havensville Shale (Chaudhuri and Lee, 1972). These data imply that the clay minerals (especially illite) had inherited radiogenic strontium at the time of deposition, that the illites are detrital, and that the clays from northern versus southern Kansas were derived from different sources.

Chaudhuri and Methot (1972) discussed reasons for high $\text{Sr}^{87}/\text{Sr}^{86}$ values in Permian limestones in general, because a high value may imply that this ratio was also high for the isotopic composition of the environment of deposition. They conclude merely that the strontium isotopic composition of limestones might help in reconstructing the environment in which these rocks were formed.

Turning attention again to more general matters, the distribution of the various rock types throughout the formally recognized rock-stratigraphic units containing the Wreford Megacyclothem has also been considered extensively by previous writers (Hattin, 1957, p. 24-50; Cuffey, 1967, p. 13-14). Again, this information is presented succinctly by the detailed cross-section (Figure 3), and is also summarized in Appendix D.

Inspection of the Wreford cross-section (Figure 3) indicates that many strata can be traced laterally for considerable distances. Further study has permitted the subdivision of the Wreford strata into 22 successive stratigraphic horizons (Cuffey, 1967, p. 71-72), each dominated by one or only a few rock types as it is traced laterally throughout the Wreford outcrop belt. Because these horizons have proven so useful in previous studies (as, for example, Cuffey, 1967, p. 73-78), they have been tabulated here (Table 5). The dominant rock types at each horizon in each geographic region are also briefly indicated (Figure 4), although this information could also have been presented more extendedly in the form of 22 lithofacies maps, one for each of the 22 horizons.

Each of the 22 Wreford horizons mapped is a lithologic-rock unit, rather than a chronologic-time unit. There is no firm evidence for precisely locating time lines within the sections; for example, there are no marker beds such as bentonite layers that could indicate a time plane over the whole region. Consequently, the exact time significance of the 22 horizons is uncertain. Within Kansas, most workers have assumed that a cyclothem bed of a particular lithology is essentially time-parallel, and this seems a reasonable presumption in view of the remarkable widespread geographic extent and lithologic and thickness similarities of the rock units. McCrone (1963, p. 50) believed that a knife-sharp contact between a limestone and a black shale in the Red Eagle Cyclothem reflected a sudden widespread change in conditions of deposition and thus could be considered a time line. He then assumed that the rest of the rock units in the Red Eagle Cyclothem were also contemporaneous.

Table 5. Abbreviations for stratigraphic horizons recognized within the Megacyclothem and utilized in clarifying Wreford stratigraphy in southernmost Kansas and Oklahoma.

<u>ABBREVIATION</u>	<u>STRATIGRAPHIC HORIZON</u>		
mMw-----	middle part	of Wymore Shale Member	of Matfield Shale
lMw-----	lower part		
uWs-----	upper part		
umWs-----	upper beds	of middle part	of Schroyer Limestone Member
lmWs-----	lower beds		of Wreford Limestone
lWs-----	lower part		
uuWh-----	upper beds	of upper part	
luWh-----	lower beds		
mWh-----	middle part	of Havensville Shale Member	of Wreford Limestone
ulWh-----	upper beds	of lower part	
ullWh--	upper portion		
lllWh--	lower portion	of lower beds	

Table 5 (Continued)

ABBREVIATION

STRATIGRAPHIC HORIZON

uuWt-----upper beds

muWt-----middle beds of upper part

luWt-----lower beds

mWt-----middle part of Threemile Limestone Member of
Wreford
Limestone

lWt-----lower part

uuSp-----upper beds

muSp-----middle beds
 of upper part

uluSp--upper portion of lower beds of Speiser
Shale

lluSp--lower portion

mSp-----middle part

Figure 4. Dominant rock types at each Wreford stratigraphic horizon in different geographic areas; rock-type abbreviations from Table 3, stratigraphic-horizon abbreviations from Table 5.

	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls	alg ls	alg ls	alg-moll ls	
umWs	chty ls ;calc sh	brach-moll ls	chty ls ;calc sh	calc sh	gr-yl mud
lmWs	calc sh	calc sh	calc sh	calc sh	gr-yl mud
lWs	chty ls	chty ls	chty ls	chty ls	alg-moll ls ;tan ss
uuWh	calc sh	calc sh	calc sh	calc sh	
luWh	moll ls	brach-moll ls	alg ls	alg-moll ls	
mWh	gr-yl mud	gr-yl mud ;calc sh	gr-yl mud	brach-moll ls	
ulWh	moll ls	brach-moll ls	alg ls	alg-moll ls	alg-moll ls ;moll ls
ullWh	calc sh	calc sh	alg ls	alg-moll ls	alg-moll ls
lllWh	calc sh	calc sh	alg ls	alg-moll ls	alg-moll ls ;tan ss
uuWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
muWt	chlky ls	chlky ls	chty ls	chty ls	brach-moll ls
luWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
mWt	calc sh	calc sh	calc sh	calc sh	brach-moll ls
lWt	chty ls	chty ls	chty ls	brach-moll ls	alg-moll ls ;tan ss ;moll ls
uuSp	calc sh	calc sh	calc sh ;brach-moll ls	calc sh ;brach-moll ls	
muSp	moll ls	moll ls	calc sh ;brach-moll ls	gr-yl mud	
uluSp	gr-yl mud	gr-yl mud	gr-yl mud	(ruled pattern indicates interbedded red shale and red sandstone)	
lluSp	grn sh	grn sh	gr-yl mud		
mSp	red sh	red sh	red sh		

When the Wreford is traced into Oklahoma, where most of the beds thin drastically and change lithology, the 22 stratigraphic horizons recognized in the Kansas Wreford can still be profitably followed. Thus, precise time relationships southward into Oklahoma are not certain, although it still would seem reasonable to regard these horizons as essentially synchronous planes there in the absence of evidence to the contrary.

WREFORD MEGACYCLOTHEM IN SOUTHERNMOST KANSAS AND OKLAHOMA

HISTORICAL REVIEW

The rock units cropping out in east-central Oklahoma, a series of interbedded red sandstones and red shales, presented several problems to stratigraphers in the late 1800's. These problems included the limit of their red color, their geologic age, and their relationships to rocks in the adjoining states of Kansas and Texas (Beede, 1907).

In Texas, the red beds were initially assigned ages ranging from Permian to Tertiary, but on the basis of lithostratigraphic evidence only. Paleontologic dating was first employed when Cope (1878) recognized the red beds as Permian, based on vertebrate fossils. White (1889) described the first invertebrate fossils from the same units and concurred that the rocks were Permian. In 1901, Cummins divided the Texas Permian into three divisions, and for the first time indicated upper and lower boundaries for the Permian of this region. Cummins (1897) also noted that by walking north along an outcrop belt in Texas, the gradual lithologic change of a particular unit from fossiliferous limestone to unfossiliferous calcareous sandy clay could be observed.

In Kansas, many rock units are light colored marine limestones with abundant invertebrate fossils that allowed their Permian age to be determined early by various workers. Expanding upon this evidence, Cragin (1897) also assigned a Permian age to the red beds in Kansas.

In Oklahoma, Adams (1898) described the red beds, and later (1901) dated these rocks as Carboniferous and Permian and also solved the problem of the color line (that is, the northeastern boundary of the geographic area underlain by red beds). He resolved both problems by tracing units along strike from Kansas, where the rocks were known to be Carboniferous and Permian, into Oklahoma. He studied particularly one Pennsylvanian limestone and one Mississippian limestone, both of which began as gray limestones in Kansas and changed to red beds as they were traced into Oklahoma. Adams was thereby able to map a line of color change, which surprisingly was "diagonal to the strike of the Carboniferous and Permian formations" (Adams, 1901, p. 386). Workers before Adams had thus confused the stratigraphic picture by assuming that the color line was parallel to the strike of the rocks. Adams (1901) also determined the age of the Oklahoma rocks by tracing these Carboniferous units along strike. Although he did not actually trace any Permian units, he also inferred that one would also be able to follow Permian marine beds from Kansas into red beds in Oklahoma; these red beds are thus also Permian in age. Finally, Adams (1901, p. 386) predicted that "From what is known of the Permian limestones of Kansas, they will be found, when followed southward, to diminish in thickness, and this change will be accompanied by a transition to more sandy beds." Gould (1902)

also discussed the tracing of light colored rocks in Kansas into red beds in Oklahoma; in 1905, he presented a geologic map of Oklahoma, in part based upon this practice.

Knowing that the Permian rocks of Kansas have their equivalents in Oklahoma red beds, the next problem became the correlation of specific units.

In particular, Kirk (1905) tried to trace the Wreford Limestone across Oklahoma, and concluded that the Wreford is replaced by two coalescing layers of sandstone, the Payne, which in turn could be traced as far south as Norman, Oklahoma. Beede, in his thorough review of Mid-Continent red bed stratigraphic problems (1907, p. 135), mentioned Kirk's work, and expressed the hope that this unit could be traced on into Texas to provide "an unimpeachable connecting link between the Kansas and Texas Permian." However, this correlation of the Wreford Limestone is not confirmed by the present detailed stratigraphic investigations. The red sandstones observed in the Oklahoma Wreford are lenticular, do not extend laterally for more than short distances, and can be interpreted paleoenvironmentally as stream channel deposits on a wide alluvial coastal plain; therefore it is highly unlikely that any sandstone unit would be continuous enough to trace across much or all of Oklahoma. Moreover, Kirk in 1905 had access to only a few rock exposures, and no detailed studies of the sequence of Wreford rock units had yet been made; both factors would greatly magnify the difficulty of accurately correlating a particular unit. For these reasons, Kirk's correlation of the Wreford Limestone is rejected here, and the improbability of Beede's hopes ever being realized is suggested.

Several papers (Heald, 1916; White et al, 1922; Aurin, Officer, and Gould, 1926; Beckwith, 1928; Patterson, 1933; Grieg, 1959) are concerned with Permian rocks in Oklahoma. Their information concerning measured sections and regional geologic maps was valuable to the present study by indicating localities where the Wreford Megacyclothem units might be examined in outcrop.

LITHOLOGIC CHANGES IN WREFORD STRATIGRAPHIC HORIZONS IN OKLAHOMA

The 22 stratigraphic horizons recognized informally within the five formations or members containing the Wreford Megacyclothem change lithologically from gray shales and limestones to red beds within a few miles south into Oklahoma from Kansas. These changes are summarized in the detailed Wreford cross-section (Figure 3) and the chart of dominant lithofacies at each Wreford horizon (Figure 4). The evidence supporting these conclusions may be examined on the correlation chart of measured sections of the Wreford Megacyclothem in southernmost Kansas and Oklahoma (Figure 5, in pocket); these measured sections are also described in detail in Appendices A and B.

The changes that occur in the lithology of the various Wreford horizons can be considered in three groups (Garihan and Cuffey, 1973): 1) units that become interbedded red shales and red sandstones about 10 miles south of the state line; 2) a newly discovered but poorly exposed marine tongue that extends to about 40 miles south of the state line; and 3) a previously recognized and well exposed marine tongue extending to about 50 miles south of the state line.

Many Wreford horizons become interbedded red shales and red sandstones a few miles south of the Kansas-Oklahoma border. These

include the middle and upper parts of the Speiser Shale, the middle and upper parts of the Havensville Shale Member, the upper part of the Schroyer Limestone Member, and the lower and middle parts of the Wymore Shale Member. The middle Speiser red shales grade into interbedded red shale and red sandstone just north of the state line, while the various non-cherty limestones and shales of the upper Speiser become red beds about 10 miles south of the state line. This red bed sequence thickens rapidly to the south. The middle and upper Havensville and the upper Schroyer likewise change from shales and non-cherty limestones to red beds a few miles south of the border. Finally, the lower and middle Wymore, red shale in southernmost Kansas, also grades into a thick sequence of interbedded red sandstones and shales at about the same latitude.

The second group of changes to be considered involve those in a newly discovered but poorly exposed upper marine tongue that extends to about 40 miles south of the state line. This marine tongue includes the horizons of the lower and middle parts of the Schroyer Limestone Member. The lower Schroyer is cherty limestone in Kansas, but changes to algal-molluscan limestone approximately at the state line. Farther south, this limestone grades into tan quartzose sandstone, and that in turn into red beds. The middle Schroyer is a thin calcareous shale up to 10 miles south of the state boundary, and then passes through grayish-yellow mudstone before being replaced by interbedded red shales and red sandstones.

The third group of changes is found within a lower marine tongue that extends somewhat beyond the upper tongue for a total of 50 miles

down into Oklahoma. This tongue was recognized previously (Grieg, 1959; Newton, 1971) because it is much better exposed than the one just discussed. This lower tongue includes all of the horizons of the Threemile Limestone Member and of the lower part of the Havensville Shale Member. Throughout most of the extent of this tongue, the lower Threemile and lower Havensville are represented by algal-molluscan limestones that bracket a thin brachiopod-molluscan limestone equivalent to the middle and upper Threemile farther north. At the northern end of this tongue, approximately at the Kansas-Oklahoma border, the lower Threemile grades from the cherty limestone facies found throughout Kansas into brachiopod-molluscan limestone; a few miles farther south that grades in turn into algal-molluscan limestone. The lower Havensville has already passed from algal limestone into algal-molluscan limestone a few miles north of the border. At the southern end of this lower tongue, the middle brachiopod-molluscan limestone (the middle and upper Threemile equivalent) changes to red beds about 10 miles farther north than the algal-molluscan limestones above and below it. These two algal-molluscan limestones thus become separate subtongues. Each grades into tan quartzose sandstone and then a short distance farther into red clayey molluscan limestone before finally disappearing into the red beds.

ROCK TYPES PROMINENT IN OKLAHOMA WREFORD

Generalities

For those rock types important in the Oklahoma Wreford, their petrologic features and inferred paleoenvironments are described here,

and information concerning their characteristics as developed in southernmost Kansas and Oklahoma are stressed.

The Wreford Megacyclothem in Oklahoma is dominated by fewer rock types than in Kansas, where a variety of rock types are all abundantly represented (see Figure 3).

Virtually all of the rock types for which insoluble residues were examined contain quartz and either hematite or limonite. In most samples, quartz is the dominant constituent, either as sub-hedral or rounded grains, or as fine-grained masses. Limonite and hematite are present in lesser quantities as distinct grains, or else are encrusting on other grains. A few samples yield small rhombs, many of which are clear, which might be carbonate rhombs secondarily replaced by silica. Also, many samples contain sili-cified fragments of organisms secreting originally calcareous shells.

During Wreford deposition, Kansas was covered by a shallow sea, while much of Oklahoma was low-lying coastal plain. Changes in shoreline position are suggested by observing the northernmost occurrences of red beds (Figure 3). In particular, the shoreline, as inferred from the northern limit of red beds, seems to have been in approximately the same position throughout deposition of the Speiser, middle and upper Havensville, and upper Schroyer and Wymore. This lack of shoreline fluctuation confirms that factors other than simply changing water depth alone determined the depositional environments (Cuffey, 1967, p. 10-13, 87; Newton, 1971, p.14). Twice during Wreford time, the shoreline apparently migrated southward significant distances, thus resulting in deposition of the two marine tongues discussed above.

Red Sandstone and Red Shale

Interbedded red sandstones and red shales comprise the greatest volume of rock in the Wreford section in Oklahoma. They tend to be relatively poorly exposed, however, because they mostly form vegetated slopes; only at a few localities do massive sandstones form ledges which crop out.

The sandstones are red or reddish-purple; they range from shaly-bedded to massive, are fine-grained, quartzose, and friable. The shales are red, moderately calcareous, lack primary features such as graded beds or ripple marks, and fossils are completely absent.

The sand grains of the red sandstones are mostly quartz and are well sorted and angular, probably due to secondary crystal growth; thus they can be petrographically classified as ortho-quartzites. Thin sections of the red shales show a predominance of quartz sand and silt and the presence of hematite or limonite.

Insoluble residues of the red sandstones and red shales are composed mainly of subhedral pink and clear quartz grains, with a substantial amount of hematite coating the quartz and existing as distinct grains. Mica flakes also occur in many of these samples. Amounts of insoluble residues of these rocks, as indicated in Appendix A, range from 87 to 100%.

The environmental interpretation of the red sandstones and red shales has been discussed by Hattin (1957, p. 82-85), Cuffey (1967, p. 11), and Newton (1971, p. 7). The sandstones probably represent stream channel deposits, and it seems likely that the red shales represent subaerial coastal plain deposits.

Algal-Molluscan Limestone

Algal-molluscan limestones are the most conspicuously and extensively exposed rock type in the Oklahoma Wreford.

In outcrop in southernmost Kansas and northern Oklahoma, these limestones are light gray, light yellowish-gray, or grayish-brown, and they weather medium gray to orangish-gray; they are thin-, medium-, or thick-bedded, hard, burrowed, weather rounded, and contain some rust or dark brown spots about 1 mm in diameter. Many "osagites" (rocks containing abundant algally coated grains) (McCrone, 1963, p. 66-67) are included in this rock type. As in Kansas, typical for algal-molluscan limestones are large burrows (up to 5 cm in diameter), formed by large burrowing clams (Allorisma or Aviculopinna) which are found in place at the bottoms of the burrows at some localities (such as OS02). The algal-molluscan limestones change southward; in that direction they have more coated grains ("Osagia"), more molluscs, and fewer brachiopods and bryozoans (these latter are usually absent from the southernmost exposures of these limestones). Also obvious, not only in hand specimens, but also in thin sections and insoluble residues, is the increasing abundance of fine quartz sand to the south.

Algal-molluscan limestones, in thin sections, are sparse to packed biomicrites (using the terminology of Folk, 1959; 1962); where there are many coated grains, they may even be classified as biosparites. These rocks often contain intraclasts and oolites. Brachiopod and pelecypod fragments are common in the algal-molluscan limestones. The algal structures are Osagia, which is made up of intergrowths of algae and various encrusting forams, and this gives

the name to osagite texture (Lane, 1958, p. 146, 147; McCrone, 1963, p. 64-67) and Osagia facies (Imbrie, Laporte, and Merriam, 1959, p. 72, 77). However, in many specimens, only laminated micrite is visible surrounding the nucleus; it is possible that such grains may be coated with inorganic micritic crusts, as Boyer (1972) has observed in the modern Florida reef tract.

Algal-molluscan limestone insoluble residues are quite varied. Again, abundant quartz and chert, and common hematite and limonite, are found in these samples. Many samples also contain silicified fossils, rare vertebrate fragments, and rare to common arenaceous forams; a few samples have mica flakes, sponge spicules, conodonts, and rhombs (probably silica replacing carbonate). The amount of insoluble residue is usually well below 25%.

The micritic algal-molluscan limestones were deposited in near-shore, at least sometimes agitated, shallow or very shallow, brackish, marine water (Hattin, 1957, p. 96-97; Cuffey, 1967, p. 12). The presence of burrowing clams has been taken to indicate that the water was brackish, probably due to freshening of sea water from runoff from the nearby shore (which also contributed some sand and silt grains) (Hattin, 1957, p. 98). Algae are thought to have thrived in both hypersaline and brackish water; thus their presence can also be explained with this model. The osagite-type rocks (especially where intergrain spaces are spar-filled rather than micrite-filled) may represent more turbulent water over calcarenite shoals rising slightly above the surrounding carbonate mud level bottoms.

Tan Quartzose Sandstone

Prominent because it replaces algal-molluscan limestones at the southernmost Wreford exposures, tan quartzose sandstone is also an interesting rock type because it does not occur farther north in the Kansas Wreford (Newton, 1971, p. 10).

Tan quartzose sandstones are white, light tan, or dark brown, weathering dark gray or brown, thin-bedded to massive, somewhat calcareous rocks. At some localities, there are burrows similar to those made by clams in the algal-molluscan limestones. The surfaces of this rock type frequently have dark brown blotches, thought by Grieg (1959, p. 106, 109) to be limonitized Osagia. Nodules or lenses of molluscan or algal-molluscan limestones occur in several places within this sandstone. Fossil pelecypods are present at many exposures of tan quartzose sandstone.

These rocks in thin section are orthoquartzites. They are composed of well-sorted, subangular, fine to medium sized quartz grains. They contain a small amount (less than 5%) of calcareous cement.

The insoluble residues show that the tan quartzose sandstones contain subhedral, clear, quartz grains, which may be coated with limonite. Individual limonite grains are also present and furnish the tan color of these rocks. Mica flakes are common in most samples; one sample also contained a few arenaceous forams. The insoluble residue amounts are usually near 100%.

The tan quartzose sandstones might represent shallow, loose shifting quartz sand bottoms just offshore. Or, from their occurrences only as the southern lateral equivalents of increasingly

sandy algal-molluscan limestones, they may actually represent very sandy algal-molluscan limestones whose calcareous material has largely been removed by leaching during Late Cenozoic weathering (Newton, 1971, p. 10).

Molluscan Limestone

Molluscan limestone, of character quite different from typical Kansas molluscan limestones, is also noticeable because it is found only at the most southern Oklahoma Wreford exposures.

These northern Oklahoma molluscan limestones are red to red mottled with yellow, very hard, dense limestones, occurring in thin to medium beds; they contain some pelecypods and crinoid columnals.

In thin sections, the Oklahoma molluscan limestones are sparse biomicrites or even calcareous sandstones. Intraclasts are occasionally present. These rocks contain numerous fossils, especially pelecypods, gastropods, crinoid debris, and some ostracods. Other groups are noticeably absent, especially bryozoans and brachiopods.

The insoluble residues of molluscan limestones have quartz and hematite in about equal amounts. Hematite casts of gastropods, pelecypods, crinoid columnals, ostracods, and some small bryozoan fragments occur in the insoluble residues. They also have clear rhombs (possibly silica replacing carbonate) and rare arenaceous forams. The amount of insoluble residue for these samples is about 40%.

Typical Kansas molluscan limestones represent deposition in shallow, brackish to normal marine waters (Hattin, 1957, p. 86-89;

Cuffey, 1967, p. 11; Newton, 1971, p. 8, 10). The Oklahoma molluscan limestones were probably deposited in similar environments. The mix of fossils implies brackish water; and the red color, as well as their extreme southern position, implies a position very close to shore. It may be that there were brackish lagoons between the red bed coastal plain and regions of purer quartz sand bottoms (possibly including bars) just offshore.

Brachiopod-Molluscan Limestone

The Wreford section in Oklahoma exposes some brachiopod-molluscan limestone, which there is much like similar rocks found in the Kansas Wreford.

In outcrop and hand specimen, the southern Kansas and Oklahoma brachiopod-molluscan limestones are light gray rocks, weathering light yellowish-gray or light brownish-gray; they are thin-bedded to massive, hard, burrowed, and have some small (about 1 mm) yellowish-brown stains which, as mentioned above, are probably limonitized Osagia. As their name suggests, they contain both molluscs (especially pelecypods) and brachiopods as common or abundant constituents. Some beds contain noticeably abundant Derbyia and Composita.

Thin sections of these limestones show that they are sparse to packed biomicrites. They sometimes contain intraclasts, and numerous fossils are present, especially brachiopods and pelecypods, as well as some bryozoans, forams, gastropods, algae, and crinoid and echinoid debris.

Most insoluble residues of brachiopod-molluscan limestones have quartz and detrital angular chert as the most abundant elements,

and also rare to common vertebrate fragments. Some samples contain in addition silicified fossils and limonite and hematite, and a few have rare arenaceous forams or conodonts. One bed (the brachiopod-molluscan limestone of the lower Threemile at locality KA02) contains abundant clear rhombs, apparently silica replacing carbonate. The amount of insoluble residue is usually under 25%.

Because the lithology and faunal content of brachiopod-molluscan limestones are intermediate to those of molluscan limestones and calcareous shales, it was presumed by Cuffey (1967, p. 12) that their environment of deposition was also intermediate. This environment was probably shallow and of normal marine salinity. The localities where abundant Derbyia and Composita shells are found may have been large shell beds in the Wreford sea.

Cherty Limestone

Some cherty limestone occurs in the Wreford rocks of extreme northern Oklahoma; this rock type is essentially like the Wreford cherty limestones in southernmost Kansas, and trends such as continuing decrease in chert quantity (Hattin, 1957, p. 29, 31, 45) are maintained southward across the border.

In outcrop and hand specimen, cherty limestone is light gray, thin- to thick-bedded, hard, and sometimes has dark brown spots (limonitized Osagia). The chert is noncalcareous light to dark gray or calcareous bluish-to brownish-gray and concentrically layered.

Cherty limestone thin sections indicate that these rocks in northern Oklahoma are micrites or sparse biomicrites. The dominant fossils are bryozoans, brachiopods, and crinoid and echinoid fragments.

Quartz and chert are the primary components in insoluble residues of most cherty limestone samples, as well as common to abundant silicified fossils, rare to common vertebrate fragments, and minor limonite and hematite. A few samples also include rare sponge spicules, many silicified productid? or echinoid? spines, and small rhombohedral grains (some attached to the spines) which may be silica replacing carbonates. One sample contains mainly vertebrate fragments, along with minor quartz and hematite. Amounts of insoluble residues are usually less than 20%.

The environment of cherty limestone deposition (Hattin, 1957, p. 91-92; Cuffey, 1967, p. 12) was probably quiet, normal marine water, deeper than the zone of intense wave action.

Calcareous Shale

Minor calcareous shale, much like that seen throughout Kansas in the Wreford Megacyclothem, accompanies cherty limestone in the Wreford of northern Oklahoma.

The calcareous shales are light grayish-yellow, medium hard, and silty (Hattin, 1957, p. 61-63; Cuffey, 1967, p. 12; Newton, 1971, p. 10). They do not seem to be as fossiliferous as those found in Kansas. Thin sections of these rocks from Oklahoma are fossiliferous micrites or sparse biomicrites containing bryozoans, brachiopod and pelecypod shell fragments, and echinoid and crinoid debris.

The most abundant constituents of the calcareous shale insoluble residues are quartz and chert as discrete grains and as fine-grained masses. Most samples also contain common or abundant silicified

fossils, such as crinoid columnals, brachiopod and pelecypod shell fragments, and productid and echinoid spines. Most samples also have hematite and limonite. Vertebrate fragments occur in many calcareous shales; some may also have rare conodonts, sponge spicules, arenaceous forams, mica flakes, and pyrite grains. The amounts of insoluble residues vary between 30 and 60%, mostly.

The environment of deposition of calcareous shales was described by Hattin (1957, p. 90), Cuffey (1967, p. 12), and Newton (1971, p. 10) as being fairly quiet, normal marine water. The less fossiliferous nature of the beds in Oklahoma perhaps reflects less favorable conditions than in Kansas, possibly a brackish near-shore salinity.

Grayish-Yellow Mudstone

Some grayish-yellow mudstone, generally not exposed, is present in the Oklahoma Wreford section. In characteristics, the Oklahoma rocks of this type are essentially the same as those in Kansas.

These rocks are grayish-yellow, silty, calcareous rocks, which are sparsely fossiliferous, containing productid spines, ostracods, and forams.

Quartz grains are abundant, and limonite and hematite rare, in insoluble residues of grayish-yellow mudstones analyzed. Some arenaceous forams, a few silicified shell fragments, and a few vertebrate fragments may also be encountered. Insoluble residue amounts are usually near 80%.

The environment of deposition of grayish-yellow mudstones was probably very shallow, nearshore, slightly brackish marine water (Hattin, 1957, p. 85-86; Cuffey, 1967, p. 11).

SUMMARY AND CONCLUSIONS

1) Major facies changes in the units of the Wreford Megacyclothem occur within short distances south of the Kansas-Oklahoma border. These changes are evident from measured stratigraphic sections, and can also be summarized diagrammatically by a cross-section (Figure 5).

2) One facies change involves the middle and upper Speiser Shale, the middle and upper Havensville Shale Member, the upper Schroyer Limestone Member, and the lower and middle Wymore Shale Member, all of which become interbedded red shales and red sandstones about ten miles south of the state line.

3) Other facies changes involve two marine tongues. The upper tongue, newly discovered but poorly exposed, and extending some 40 miles south of the state line, includes the horizons of the lower and middle parts of the Schroyer Limestone Member. The lower marine tongue, extending for 50 miles down into Oklahoma, includes all of the horizons of the Threemile Limestone Member and the equivalents of the lower part of the Havensville Shale Member.

4) Rock types prominent in the southernmost Kansas and Oklahoma part of the Wreford are interbedded red sandstone and red shale, algal-molluscan limestone, tan quartzose sandstone, and molluscan limestone. Other rock types present there are similar to those found in the Kansas Wreford, such as brachiopod-molluscan limestone, cherty limestone, calcareous shale, and grayish-yellow mudstone.

5) The prominent Oklahoma Wreford rock types indicate paleo-environments of deposition that differ from those of the typical marine units of the megacyclothem in Kansas. Molluscan limestones, algal-molluscan limestones, and tan quartzose sandstones all seemingly

imply deposition in shallow, near-shore, normal marine to brackish waters, while interbedded red shale and red sandstone represent deposits of a subaerial coastal plain traversed by stream channels.

6) The shoreline of the Wreford sea was apparently near the Kansas-Oklahoma border throughout much of the time of deposition of the Wreford Megacyclothem. However, the shoreline migrated noticeably southward during deposition of the two marine tongues discussed here.

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INTRODUCTION, BACKGROUND, AND OBJECTIVES

The stratigraphy and environments of deposition of the Lower Permian Wreford Megacyclothem in Kansas were originally studied in detail by Hattin (1957). Concurrently with the brachiopod investigation reported in the present paper, comparably detailed understanding has been developed on the southward extension of the Wreford into north-central Oklahoma (Lutz-Garihan and Cuffey, in preparation). Various aspects of the Wreford Megacyclothem--its regional setting, stratigraphic relationships, paleoenvironmental implications, and lithologies--have been thoroughly described elsewhere (Hattin, 1957; Cuffey, 1967; Newton, 1971; Lutz-Garihan and Cuffey, in preparation), and thus need not be treated here. The Wreford Megacyclothem crops out in a north-south belt extending from southernmost Nebraska, through Kansas, into northern Oklahoma (Newton, 1971, p. 11).

The extensive stratigraphic, lithologic, paleoecologic, and paleogeographic background obtained from these detailed stratigraphic studies makes possible unusually thorough studies of the various fossil groups present in the Wreford Megacyclothem. Such studies began with the bryozoan Tabulipora carbonaria by Cuffey (1967), and other bryozoan investigations soon followed (Newton, 1971; Warner and Cuffey, in press).

Because the Wreford biota includes abundant and diversified brachiopods, and because the several brachiopod groups present there have not been studied via the detailed approaches profitably applied to the Wreford bryozoans, I chose to investigate the

Wreford brachiopods. Consequently, I collected large numbers (over 10,000) of brachiopods throughout the Wreford outcrop belt, each specimen very precisely located in terms of its geographic locality, stratigraphic horizon, and lithologic occurrence. Such large population-sized samples make possible thorough study of the morphology and variability exhibited by these brachiopods, and thus enable the paleontologist to reliably recognize among them species which more closely approach paleobiologic species concepts than has often been the case in paleontologic practice. Moreover, the extremely refined knowledge of the circumstances of occurrence of the Wreford brachiopods may well permit conclusions concerning possible interrelationships among variability induced by taxonomic, evolutionary, stratigraphic, geographic, and paleoecologic causes--conclusions which will contribute to an unusually thorough comprehension of the lives of these brachiopod species at this particular point in space and time. Ultimately, the detailed autecologic studies of these brachiopod species will be integrated with similar studies of the other Wreford fossil groups, in order to lead to a thorough synecologic synthesis of the total ecosystem recorded in the Wreford rocks. Such a synecologic synthesis would be an important contribution to understanding the Late Paleozoic geology of the Mid-Continent region.

The large number of Wreford brachiopod specimens available, while permitting intensive study of each species, also prevented timely completion of such studies for all species present.

Consequently, part of this paper constitutes a brief introduction to the various Wreford brachiopod groups and includes

generalities concerning their distribution and abundance. This information will serve as background material for future reports concerning intensive and detailed investigations of the various Wreford brachiopod species (currently under study by the author).

Moreover, as another consequence stemming from the abundance of material available, the remaining portion of this paper treats one of the Wreford brachiopod groups, Composita, in such detailed fashion. When the magnitude of the Wreford brachiopod project became apparent, that particular group was selected as the first for intensive study because its members within the Wreford Megacyclothem are quite abundant, well-preserved, taxonomically challenging, and lithologically and geographically highly non-uniform in their occurrence.

The Wreford specimens of Composita form a large population-sized sample, composed of many well preserved and whole specimens. This is exactly the kind of sample that is needed to study a fossil population in order to determine the relationships among variant forms previously thought by some workers to be different species (but which, at least in Wreford Composita, this study suggests are morphotypes within a single species, Composita subtilita). Both published and personal communications from brachiopod specialists seemed to suggest that Composita constituted an extremely difficult (if not impossible) group to treat taxonomically at species level. However, the Wreford forms comprise a very large sample, and such samples when studied by the methods contemplated for this investigation have significantly advanced paleobiologic understanding of various Wreford bryozoan groups. Consequently, I believed that such techniques

might be similarly productive when applied to Composita in the Wreford.

Moreover, even though these animals are morphologically rather simple, significantly more extensive numerical characterization of their features could be (and was) accomplished than had been achieved by previous investigators. I expected that such characterizations, especially when coupled with distribution and abundance data, would not only help resolve taxonomic problems but also indicate to what causes--stratigraphic or evolutionary, lithologic or paleoecologic, geographic or clinal--observable morphologic variability might be attributable. In addition, use of numerical as well as qualitative methods yields a very thoroughly described Early Permian population of Composita subtilita, one which can serve as a point of comparison for investigators concerned with evolutionary pathways among Late Paleozoic Composita species. Such studies, which would involve extensive examination of all relevant type specimens as well as new collections of large numbers of specimens, are much beyond the scope of the present paper, but will obviously be highly desirable to provide the comprehensive evolutionary setting in which the Wreford Composita subtilita population must be viewed.

Composita is encountered only in some of the lithologic types developed in the Wreford Megacyclothem. Moreover, its distribution within these rocks varies from north to south; to the collector in the field, Composita seems noticeably more abundant in the southern reaches of some of the Wreford units. Thus, it was originally thought (although this did not eventually prove to be the case) that both

paleoecologic and clinal variability would appear clearly within the Wreford Composita population. Nonetheless, the collection does provide the basis for paleoecologic conclusions which furnish insight into the paleobiology of this interesting species.

METHODS OF INVESTIGATION OF THE WREFORD BRACHIOPODS

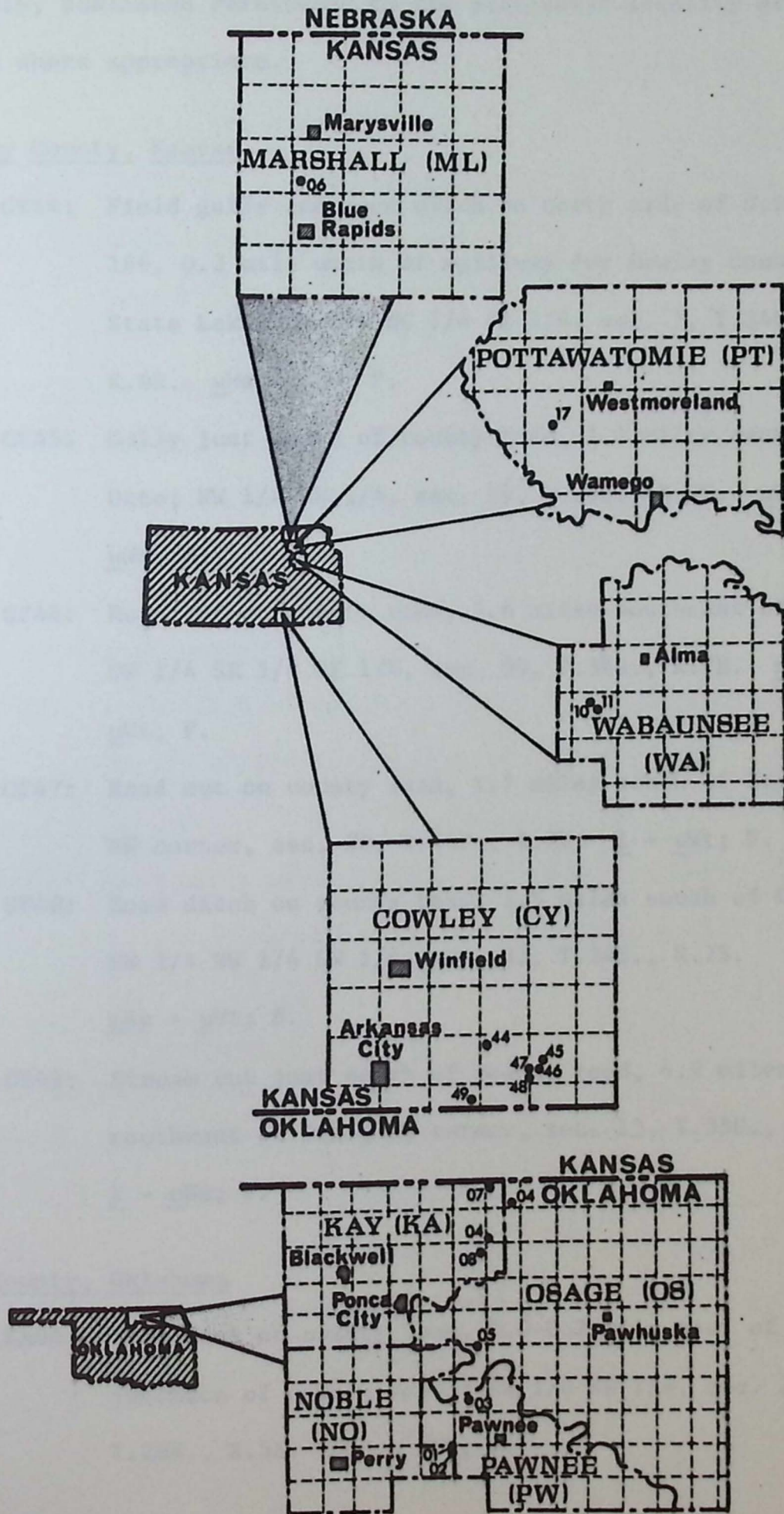
COLLECTING LOCALITIES

Outcrops of the Wreford Megacyclothem in Kansas, Nebraska, and Oklahoma are mostly road cuts, few natural exposures being encountered because the shales weather easily and quickly to become vegetated slopes. I collected brachiopods during the summer of 1971, from Wreford outcrops in Kansas, southern Nebraska, and northern Oklahoma, and also made use of samples collected in a similar manner previously by Cuffey and Newton.

Most of the brachiopods used in this study were collected from localities already adequately described by Cuffey (1967, p. 18-20, 89-94) and Newton (1971, p. 15-16). The following list therefore includes only those additional localities not given by those authors.

To maintain consistency with their system, I have continued their format and nomenclature. Locations are indicated in Figure 6. In the list, after the number and description of each locality, the stratigraphic units exposed there are indicated, in terms of the informal divisions - lower (l), middle (m), and upper (u) - of the units containing the Wreford Megacyclothem - Speiser Shale (Sp), Threemile Limestone Member (Wt), Havensville Shale Member (Wh), Schroyer Limestone Member (Ws), and Wymore Shale Member (Mw). Next is indicated whether the exposures at the locality are very good (VG), good (G), fair (F), poor (P), or very poor (VP).

Figure 6. Wreford localities in Kansas and northern Oklahoma
described in text.



Finally, published references to the particular locality are cited where appropriate.

Cowley County, Kansas

- CY44: Field gully and road ditch on north side of U.S. Hwy. 166, 0.3 mile north of spillway for Cowley County State Lake; SE 1/4 NE 1/4 SE 1/4, sec. 7, T.34S., R.6E. uWs - uMw; P.
- CY45: Gully just south of county road, 1.1 miles east of Otto; NW 1/4 NW 1/4, sec. 29, T.34S., R.7E. mSp - uWt; G.
- CY46: Road cut on county road, 1.6 miles southeast of Otto; SW 1/4 SE 1/4 SE 1/4, sec. 30, T.34S., R.7E. mSp - uWt; F.
- CY47: Road cut on county road, 1.1 miles south of Otto; NW corner, sec. 31, T.34S., R.7E. 1 - uWt; F.
- CY48: Road ditch on county road, 1.5 miles south of Otto; NW 1/4 NW 1/4 SW 1/4, sec. 31, T.34S., R.7E. mSp - uWt; F.
- CY49: Stream cut just north of county road, 4.2 miles southwest of Otto; NW corner, sec. 13, T.35S., R.6E. 1 - uWt; F.

Kay County, Oklahoma

- KA04: Road cuts on county road, 0.0-0.2 mile east of junction of county roads; SW 1/4 SW 1/4, sec. 21, T.28N., R.5E. mSp - mMw; F.

KA07: Stream cut, just south of county road, 0.8 mile northwest of Hardy; NE 1/4 NW 1/4 NW 1/4, sec. 19, T.29N., R.5E. uWt - mWs; G.

KA08: Hillside, 0.7 mile southwest of junction of county roads; SE 1/4 NE 1/4, sec. 12, T.27N., R.4E. lSp - uWt; F.

Marshall County, Kansas

ML06: Hillside just east of county road, 1.0 mile south of Schroyer; SE corner, sec. 30, T.3S., R.7E. lWs - uMw; P. Hattin, 1957, p. 145 (loc. 10).

Noble County, Oklahoma

NO01: Road ditch along county road, 0.9 mile north of Lela; NE 1/4 NE 1/4 NE 1/4, sec. 1, T.21N., R.3E. mSp and mMw; P.

NO02: Road ditch along county road, 0.8 mile north of Lela; SE 1/4 NE 1/4 NE 1/r, sec. 1, T.21N., R.3E. mSp and mMw; P.

Osage County, Oklahoma

OS04: Road cut on county road, 4.1 miles west of Grainola; SW corner, sec. 35, T.29N., R.5E. l - uWt; G.

OS05: Road ditch along county road, 0.7 mile east of junction of county roads; NE 1/4 NW 1/4 NE 1/4, sec. 2, T.24N., R.4E. mSp, lWt, and mMw.

Pawnee County, Oklahoma

PW03: Road cut on county road, 0.1 mile west of bridge over Walker Creek; SE corner SW 1/4, sec. 21, T.23N., R.4E. 1 - mSp; F. Greig, 1959, p. 101-105.

Pottawatomie County, Kansas

PT17: Road cut on Kan. Hwy. 13, 0.1 mile north of junction with county road; NW 1/4 NW 1/4 SW 1/4, sec. 22, T.8S., R.8E. 1 - uMw; VG.

Wabaunsee County, Kansas

WA10: Road cut on county road, 1 mile southeast of Volland; NE 1/4 SW 1/4, sec. 10, T.13S., R.9E. 1Sp - 1Ws; VP. Hattin, 1957, p. 146 (loc. 42).

WA11: Stream bed, 1.5 miles southeast of Volland; NE 1/4 NE 1/4, sec. 15, T.13S., R.9E. mWs; VP. Hattin, 1957, p. 146 (loc. 43).

COLLECTING PROCEDURES

Brachiopods were collected from the various limestone units by chiseling out specimens found along the exposed faces of the beds. The well-indurated character of these limestones prevented much sampling for any horizontal distance into the outcrop face. Similarly, brachiopods were collected from shales by picking them from the faces of the units; collecting was extended a few centimeters into the outcrop face by removing the outermost shale with a pick. Bulk samples of the shales were also taken (for later

laboratory processing), by digging a trench in the shale until unweathered shale was exposed, and then taking a sample weighing approximately four pounds.

The above two collecting methods supply fossils whose stratigraphic positions are precisely and certainly known. However, at many of the Wreford outcrops there were also quantities of fossils that had weathered out and were lying free on the surfaces of the talus piles. The particular unit which was the source of such specimens could be recognized with confidence in many instances. At some localities, moreover, a bench has been formed by road grading or erosion so that the outcrop above the unit forming the bench is several feet away from the edge of the bench; fossils have since weathered out of the bench and lie on its surface to comprise a large and easily collectable sample. These and other float-picked samples provide fossils which may furnish important information for a morphological study of the organisms, even if they cannot be assigned to a particular rock unit.

SEPARATION TECHNIQUES

The fossils collected by chiseling of limestone beds could only be removed from the rock matrix by physically hammering them out. I was unable to use an acid-removal technique because of the identical composition (calcareous) of both the rocks and the fossils. The brachiopods that had been picked directly from shale were merely washed, as were the fossils that had been weathered out of the outcrop as float specimens. The bulk samples of shale were disaggregated with a kerosene treatment, and the samples were subsequently washed through a series of sieves.

After drying, sorting of the samples was performed by picking out the brachiopods from the sample and separating them according to major groups (described later).

ACETATE PEELS

Serial acetate peels were made of some specimens of Composita, in order to determine the internal features of these brachiopods. The peels are made by grinding the specimen from the posterior end and orienting the ground surface perpendicular to the greatest length of the shell. After etching the surface in hydrochloric acid for about ten seconds, rinsing with water, and drying, acetone is applied; the etched surface of the brachiopod is then quickly placed on a piece of 1/8-inch-thick acetate, and allowed to dry for thirty minutes. When the dried specimen is later snapped off the acetate, the resulting impression reveals the structures and provides a permanent record of them.

A series of peels made parallel to each other at regular intervals on the same brachiopod provides a three-dimensional view of the internal features of that specimen.

THIN SECTIONS

A few oriented thin-sections were also made according to standard methods in order to supplement information derived from acetate peels.

MEASUREMENTS OF COMPOSITA SUBTILITA

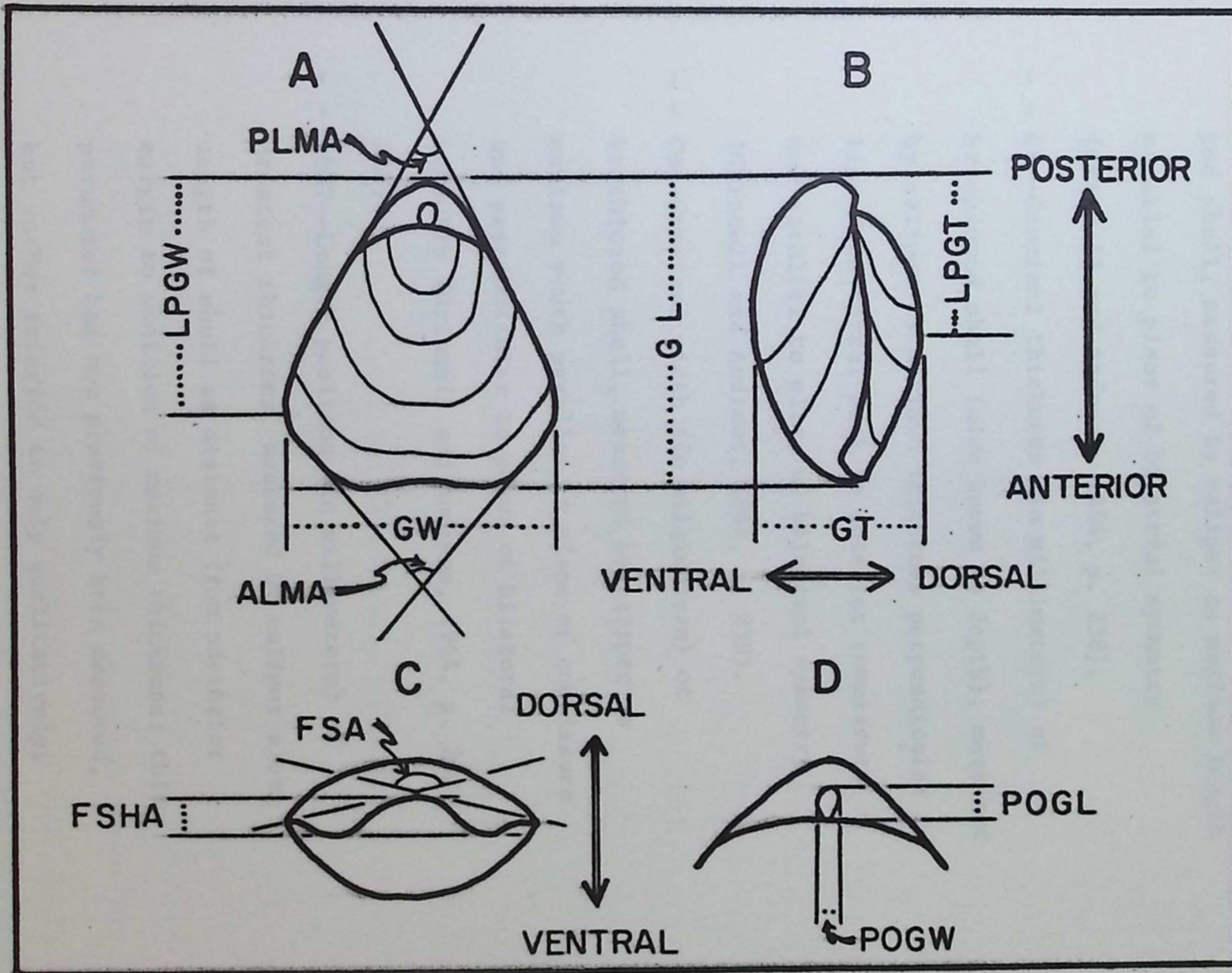
For this study, several measurements were made on each uncrushed specimen of Composita. Previous workers have included

in their descriptions only overall length, width, and thickness (or depth) as measures of shell morphology, supplementing other qualitative observations. I have also quantified other information that Composita shells show as well, in the belief that such measurements are important in showing whether or not there is an intergradation among the morphological variants within the Wreford Composita population-sized sample.

The following section defines the quantities measured, and Figure 7 illustrates them. Not all quantities were measured on every specimen, owing to breakage or distortion obscuring them.

- - ALMA--Angle (in degrees) formed by anterolateral margins of shell, measured with contact goniometer; not measured on shells with no fold and sulcus, because no clearly distinct anterolateral margins are then visible.
- - FSA--Fold and sulcus angle (in degrees), measured with contact goniometer in plane parallel to plane formed by greatest width and greatest thickness of shell; points determining this angle are shown in Figure 7.
- - FSHA--Height (in millimeters) of fold and sulcus, measured by caliper parallel to plane of bilateral symmetry and parallel to maximum thickness of shell. This morphologic character was important to earlier brachiopod students in differentiating species and varieties of Composita, but previously was determined only qualitatively, that is, a fold and sulcus was

Figure 7. Four views of Composita subtilita, showing morphological characters measured on Wreford specimens. A) Dorsal view. B) Lateral view. C) Anterior view. D) Enlargement of dorsal view showing pedicle opening.



described as smaller or larger than another but not precisely measured.

- - GL--Greatest length (in millimeters) of brachiopod shell, measured by caliper as maximum length parallel to plane of bilateral symmetry (Grinnell and Andrews, 1964, p. 238).
- - GT--Greatest thickness (in millimeters) of brachiopod shell (also known as depth), measured by caliper as maximum thickness perpendicular to line from dorsal beak to anterior commissure and parallel to plane of bilateral symmetry (Grinnell and Andrews, 1964, p. 239).
- - GW--Greatest width (in millimeters) of brachiopod shell, measured by caliper as maximum width parallel to plane of commissure and perpendicular to plane of bilateral symmetry (Grinnell and Andrews, 1964, p. 238-239).
- - LPGT--Length position (in millimeters) of greatest thickness, measured by caliper along length of shell as distance from posterior margin to position of maximum thickness; this parameter has not previously been measured, but rather referred to only qualitatively, as in the phrase "greatest thickness posterior to mid-length" (Sturgeon and Hoare, 1968, p. 57).

- - LPGW--Length position (in millimeters) of greatest width, measured by caliper along length of brachiopod as distance from posterior margin to position of maximum width; LPGW has only been referred to qualitatively in previous work.
- - PLMA--Angle (in degrees) formed by postero-lateral margins of shell, measured by contact goniometer; this is another quantity previously described only qualitatively, that is, as either an acute or an obtuse angle (Sturgeon and Hoare, 1968, p. 57-59).
- - POGL--Greatest length (in millimeters) of pedicle opening, measured by caliper as maximum length parallel to plane of bilateral symmetry.
- POGW--Greatest width (in millimeters) of pedicle opening, measured by caliper as maximum width perpendicular to plane of bilateral symmetry and perpendicular to POGL.

DATA ANALYSIS

The IBM 360-series and 370-series computers of the Computation Center at The Pennsylvania State University performed statistical calculations on the measurements of specimens of Composita subtilita. J. C. Griffiths' sedimentary-petrologic program NORMSTAT provided standard sample statistics (mean, variance, standard deviation,

skewness, and kurtosis), as well as chi-square tests for normality of data. Additional sample statistics (coefficient of variation and standard error) were obtained via the statistical routine STSUM within the Computation Center's library program STPAC. The routine SCRDT1, also part of STPAC, printed scatter diagrams for designated pairs of variables, and also lines of best fit and correlation coefficients.

Hand plots of frequency diagrams and triangular graphs, the t-test for comparing the means of two samples (Simpson, Roe, and Lewontin, 1960, p. 176-183), and various ratios computed from the measurements all proved helpful in analyzing numerical data. However, more elaborate computerized techniques such as cluster analysis or factor analysis could add nothing significant, because their potential contributions were pre-empted by discovery of numerous morphologic intermediates between recognizably distinct end-members within the Wreford population of Composita subtilita.

Statistical treatment of measurement data can help the paleontologist to more precisely characterize suites of fossil specimens. However, when applying statistics to data derived from a group of fossils, it is important to remember the cautionary words of Imbrie (1959, p. 353):

"Although biometrical methods can be a useful adjunct to taxonomic work, it must be kept in mind that statistics characterize a sample, they do not describe it; they emphasize group characteristics, but they do not judge the biologic or stratigraphic significance of the features so emphasized; and although they permit an investigator to place the essential features of a large group of samples on a single sheet of paper,

they do not in themselves constitute a synthesis. Like the hand lens, the microscope, the geology hammer, and the camera, statistics are neither more nor less than instruments of an enquiring mind."

Additional comments by Mayr (1969, p. 165) include this statement:

"The taxonomist must also keep in mind that what may be 'significant' for the statistician may not be at all significant biologically or at least taxonomically." Thus, the primary concern of statistical applications in this paper is not with demonstrating statistically sophisticated methods, but rather with increasing understanding of biologically significant variations among Wreford Composita subtilita specimens.

DISTRIBUTION AND ABUNDANCE OF THE BRACHIOPOD

ASSOCIATES OF WREFORD COMPOSITA SUBTILITA

TYPES AND PRESERVATION OF BRACHIOPODS

Several different groups of brachiopods occur in the rocks of the Wreford Megacyclothem. Only Composita subtilita (the subject of this paper) has thus far been studied in detail; however, I am currently studying the other Wreford brachiopod groups intensively. In order to provide background for the present and future Wreford brachiopod studies, I report here the distribution and abundance of each major group, as Cuffey (1967, p. 19-27) did in laying the foundation for subsequent Wreford bryozoan papers (Newton, 1971; Warner and Cuffey, in press).

Most of the Wreford brachiopod genera were listed first by Hattin (1957) but were not discussed in any detail. I have tentatively identified the genera in my Wreford collections as follows (arranged in approximate order of importance):

Composita (Composita subtilita var. subtilita and ovata).

Derbyia.

Chonetids (possibly Lissochonetes, possibly Neochonetes).

Productids (possibly Juresania, Dictyoclostus, Marginifera,
Reticulatia).

Enteletes.

Wellerella.

Orbiculoidea.

Petrocrania.

Lingula.

Cleiothyridina.

Many Wreford brachiopods are well preserved and whole, but others are distorted or fragmented. Many brachiopods in some calcareous shales are crushed because of compaction, especially Composita, Enteletes, Wellerella, and Derbyia. In southern Kansas and northern Oklahoma, some calcareous shales contain large numbers of Derbyia and other fossils that are entire and undistorted.

Brachiopod materials picked from kerosened shale residues are mostly only fragmentary, probably due to the size of the shale sample and its treatment. Most of the brachiopods in the limestones are unbroken and undistorted.

Some Wreford brachiopod shells are encrusted by bryozoans, others contain holes made by boring organisms, and still others serve as a hard substrate for the attachment of the inarticulate Orbiculoidea, and also of very small-sized productids attached by their spines.

ABUNDANCE ESTIMATES

Because studies currently in progress will eventually yield precise statements concerning the abundances of each Wreford brachiopod group, I here report only the relative abundance of each group in semi-quantitative terms. I estimated the abundance of a particular brachiopod type in a particular rock unit at a given locality by counting the number of specimens collected there, and recording the semi-quantitative category according to the following boundaries, defined so as to reflect the collector's impressions of relative abundance (in the same manner as de Laubenfels did for reefal sponges in 1954, and Cuffey did for modern reef-dwelling bryozoans, in press):

<u>Number of specimens</u>	<u>Category</u>
0	absent
1	very rare
2-5	rare
6-25	common
26-100	abundant
>100	very abundant

Obtaining such semi-quantitative abundance estimates for samples composed largely of whole specimens was relatively easy. Samples consisting mostly of broken brachiopod fragments, however, posed problems, but abundance could still be determined satisfactorily (as indicated by consistency of results upon repetition tests). The procedure involved counting the number of fragments containing cardinal areas and using this as an estimate of the

number of individuals represented by the fragments; this procedure was necessary especially for the productids and for Derbyia.

Moreover, another problem involves correlating abundances derived from float samples with abundances estimated from picked and bulk-fresh samples; the problem exists because float samples contain consistently many more fossils than do the others. Therefore, I estimated the brachiopod abundances for each float sample as described above, and then reduced the abundance by one category (for example, "abundant" became "common").

After estimating the abundances of each brachiopod type in each Wreford sample, I tabulated the abundance information for each brachiopod group in each stratigraphic horizon and particular rock type, and obtained approximate averages which indicate the general trends of abundances as discussed below.

Previous studies (Cuffey, 1967; Newton, 1971; Lutz-Garihan and Cuffey, in preparation) included informal subdivision of the Wreford Megacyclothem into 22 successive stratigraphic horizons, each dominated by one or a few particular rock types or lithofacies (abbreviations for which are presented in Table 6) in a particular geographic region. Table 7 indicates these horizons, which furnish the basic framework for consideration of Wreford brachiopod distributions and abundances; in order to facilitate reference, the horizon abbreviations defined in Table 7 are utilized in presenting stratigraphic distributions. (For more detailed and precise representation of Wreford stratigraphy and Composita distribution, see Figure 8, in pocket.) Also, details of Wreford lithofacies and brachiopod distribution could be presented by maps like those for Tabulipora

Table 6. Abbreviations for rock types comprising dominant lithofacies at various Wreford horizons, and utilized in Figures 9-18 to report Wreford brachiopod distribution and abundance.

<u>ABBREVIATION</u>	<u>ROCK TYPE</u>
alg ls	algal limestone
alg-moll ls	algal-molluscan limestone
argill ls	argillaceous limestone
black sh	black shale
brach-moll ls	brachiopod-molluscan limestone
calc sh	calcareous shale
chlky ls	chalky limestone
chnl cgl	channel conglomerate
chty ls	cherty limestone
coal	coal
grn sh	green shale
gr-yl mud	gray-yellow mudstone
int brecc	intraformational breccia
moll ls	molluscan limestone
red sh	red shale
red ss	red channel sandstone
resid cl	red residual clay
tan ss	tan quartzose sandstone

Table 7. Abbreviations for stratigraphic horizons recognized within Wrefore Megacyclothem and utilized (in Figures 9-18) to record Wreford brachiopod distribution and abundance.

<u>ABBREVIATION</u>	<u>STRATIGRAPHIC HORIZON</u>		
mMw-----	middle part		of
lMw-----	lower part	of Wymore Shale Member	Matfield Shale
uWs-----	upper part		
umWs-----	upper beds	of middle part	of Schroyer Limestone
lmWs-----	lower beds		Member
lWs-----	lower part		of
uuWh-----	upper beds	of upper part	Wreford
luWh-----	lower beds		of Havensville Shale
mWh-----	middle part		Member
ulWh-----	upper beds	of lower part	
ullWh--	upper portion	of lower beds	
lllWh--	lower portion		

Table 7 (Continued)

<u>ABBREVIATION</u>	<u>STRATIGRAPHIC HORIZON</u>
uuWt-----upper beds	
muWt-----middle beds	of upper part
luWt-----lower beds	of Threemile Limestone of
mWt-----middle part	Member Wreford
lWt-----lower part	Limestone
uuSp-----upper beds	
muSp-----middle beds	of upper part
uluSp--upper portion of lower beds	of Speiser
lluSp--lower portion	Shale
mSp-----middle part	

carbonaria (Cuffey, 1967, p. 73-78); however, the number of figures required would clearly be excessive.

DISTRIBUTION OF WREFORD BRACHIOPOD GROUPS

Figures 9-18 present, for each Wreford brachiopod group, its distribution and abundance in the dominant lithofacies at each stratigraphic horizon in the different geographic areas within the Wreford outcrop belt. In addition, because of the potential relevance of varying abundances in different rock types for paleo-ecological studies of the brachiopods, I briefly summarize such data in the following paragraphs, and also include appropriate observations which do not lend themselves to the graphic presentations.

A general consideration of the distribution of Composita furnishes a good basis for comparison with the other brachiopod groups; more detailed consideration of Wreford Composita subtilita distribution and its implications follows the systematic section of this paper. Composita occurs only in some Wreford rock types, namely, in brachiopod-molluscan limestones, algal-molluscan limestones, algal limestones, cherty limestones; chalky limestones, and calcareous shales (Figure 9).

Derbyia, another abundant and wide-ranging brachiopod group in the Wreford, is found in calcareous shales, brachiopod-molluscan limestones, algal-molluscan limestones, and cherty limestones (Figure 10).

The chonetids are not as abundant or widely distributed as Composita and Derbyia (Figure 11). The only lithology that contains

Figure 9. Distribution and abundance of Wreford Composita subtilita; no symbol indicates species is absent from that rock type at that horizon in that region; symbol shape indicates abundance (small circles: rare, triangles: common, large squares: abundant); open symbols imply species is found at only a few or some localities, while solid symbols imply it occurs at many or most localities examined there; rock-type abbreviations from Table 6, stratigraphic-horizon abbreviations from Table 7.

<u>Composita</u>	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls ▲	alg ls ▲	alg ls ▲	alg-moll ls ○	
umWs	chty ls ○ ; calc sh □	brach-moll ls ○	chty ls ○ ; calc sh ▲	calc sh ○	gr-yl mud
lmWs	calc sh ●	calc sh ▲	calc sh ▲	calc sh ○	gr-yl mud
lWs	chty ls ●	chty ls ●	chty ls ○	chty ls ○	alg-moll ls ○ ; tan ss
uuWh	calc sh ▲	calc sh ●	calc sh ▲	calc sh ○	
luWh	moll ls ○	brach-moll ls ●	alg ls ○	alg-moll ls ○	
mWh	gr-yl mud	gr-yl mud ○ ; calc sh ▲	gr-yl mud	brach-moll ls ○	
ulWh	moll ls ○	brach-moll ls ○	alg ls ○	alg-moll ls ○	alg-moll ls ○ ; moll ls
ullWh	calc sh ▲	calc sh ▲	alg ls ▲	alg-moll ls ○	alg-moll ls ○
lllWh	calc sh ▲	calc sh ▲	alg ls ▲	alg-moll ls ●	alg-moll ls ○ ; tan ss
uuWt	chty ls ○	chty ls ○	chty ls ○	chty ls ○	brach-moll ls
muWt	chiky ls ○	chiky ls ▲	chty ls ●	chty ls ○	brach-moll ls
luWt	chty ls ○	chty ls ○	chty ls ○	chty ls	brach-moll ls ○
mWt	calc sh ○	calc sh ○	calc sh ○	calc sh ●	brach-moll ls ○
lWt	chty ls ○	chty ls ○	chty ls ▲	brach-moll ls ▲	alg-moll ls ○ ; tan ss ; moll ls
uuSp	calc sh ▲	calc sh ■	calc sh ▲ ; brach-moll ls ○	calc sh ○ ; brach-moll ls ▲	
muSp	moll ls	moll ls ▲	calc sh ○ ; brach-moll ls ○	gr-yl mud	
uluSp	gr-yl mud	gr-yl mud	gr-yl mud	(ruled pattern indicates interbedded red shale and red sandstone)	
lluSp	grn sh	grn sh	gr-yl mud		
mSp	red sh	red sh	red sh		

Figure 10. Distribution and abundance of Wreford Derbyia; see Figure 9 for explanation.

<u>Derbyia</u>	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls	alg ls ○	alg ls ○	alg-moll ls ○	
umWs	chty ls ○; calc sh ●	brach-moll ls ○	chty ls ○; calc sh ○	calc sh	gr-yl mud ○
lmWs	calc sh ●	calc sh ○	calc sh	calc sh	gr-yl mud ○
lWs	chty ls ●	chty ls ○	chty ls	chty ls	alg-moll ls ○; tan ss
uuWh	calc sh ○	calc sh ●	calc sh ○	calc sh	
luWh	moll ls ○	brach-moll ls ○	alg ls	alg-moll ls	
mWh	gr-yl mud ○	gr-yl mud ○; calc sh ●	gr-yl mud	brach-moll ls	
ulWh	moll ls ●	brach-moll ls ●	alg ls	alg-moll ls ○	alg-moll ls ▲; moll ls
ullWh	calc sh ●	calc sh ●	alg ls	alg-moll ls ○	alg-moll ls ▲
lllWh	calc sh ●	calc sh ●	alg ls ○	alg-moll ls ○	alg-moll ls; tan ss
uuWt	chty ls ○	chty ls ○	chty ls ○	chty ls ○	brach-moll ls
muWt	chlky ls	chlky ls ○	chty ls ○	chty ls ○	brach-moll ls
luWt	chty ls ○	chty ls ○	chty ls ○	chty ls ○	brach-moll ls ○
mWt	calc sh ●	calc sh ●	calc sh ○	calc sh ○	brach-moll ls ○
lWt	chty ls ○	chty ls ○	chty ls ○	brach-moll ls ○	alg-moll ls; tan ss; moll ls
uuSp	calc sh ●	calc sh ▲	calc sh ●; brach-moll ls ●	calc sh ●; brach-moll ls ●	
muSp	moll ls ○	moll ls ○	calc sh ●; brach-moll ls ▲	gr-yl mud ○	
uluSp	gr-yl mud	gr-yl mud ○	gr-yl mud ○	(ruled pattern indicates interbedded red shale and red sandstone)	
lluSp	grn sh	grn sh ○	gr-yl mud		
mSp	red sh	red sh	red sh		

Figure 11. Distribution and abundance of Wreford chonetids; see Figure 9 for explanation.

Chonetids	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls ○	alg ls	alg ls	alg-moll ls	
umWs	chty ls ;calc sh ▲	brach-moll ls	chty ls ;calc sh	calc sh	gr-yl mud
lmWs	calc sh ●	calc sh ○	calc sh	calc sh	gr-yl mud
lWs	chty ls	chty ls ○	chty ls ○	chty ls	alg-moll ls ;tan ss
uuWh	calc sh ○	calc sh ○	calc sh	calc sh ○	
luWh	moll ls	brach-moll ls	alg ls	alg-moll ls ○	
mWh	gr-yl mud	gr-yl mud ○ ;calc sh ○	gr-yl mud	brach-moll ls	
ulWh	moll ls ○	brach-moll ls ○	alg ls	alg-moll ls	alg-moll ls ;moll ls
ullWh	calc sh ○	calc sh ○	alg ls	alg-moll ls	alg-moll ls
lllWh	calc sh ■	calc sh ●	alg ls	alg-moll ls	alg-moll ls ;tan ss
uuWt	chty ls ○	chty ls ○	chty ls ○	chty ls	brach-moll ls
muWt	chlky ls	chlky ls	chty ls	chty ls	brach-moll ls
luWt	chty ls ○	chty ls	chty ls	chty ls	brach-moll ls
mWt	calc sh ●	calc sh ●	calc sh ●	calc sh ●	brach-moll ls
lWt	chty ls ○	chty ls ○	chty ls ○	brach-moll ls ○	alg-moll ls ;tan ss ;moll ls
uuSp	calc sh ▲	calc sh ■	calc sh ○ ;brach-moll ls ○	calc sh ;brach-moll ls	
muSp	moll ls ○	moll ls ○	calc sh ○ ;brach-moll ls ○	gr-yl mud	
uluSp	gr-yl mud	gr-yl mud	gr-yl mud	(ruled pattern indicates interbedded red shale and red sandstone)	
lluSp	grn sh ○	grn sh	gr-yl mud		
mSp	red sh	red sh	red sh		

Figure 12. Distribution and abundance of Wreford productids; see Figure 9 for explanation.

Productids	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls	alg ls ○	alg ls	alg-moll ls ○	
umWs	chty ls ○ ; calc sh ○	brach-moll ls ●	chty ls ○ ; calc sh ○	calc sh	gr-yl mud
lmWs	calc sh ●	calc sh ○	calc sh ○	calc sh	gr-yl mud
lWs	chty ls ●	chty ls ●	chty ls ●	chty ls ○	alg-moll ls ○ ; tan ss
uuWh	calc sh ○	calc sh ●	calc sh ○	calc sh ○	
luWh	moll ls ○	brach-moll ls ○	alg ls ●	alg-moll ls	
mWh	gr-yl mud ○	gr-yl mud ; calc sh ●	gr-yl mud	brach-moll ls ○	
ulWh	moll ls ○	brach-moll ls ○	alg ls	alg-moll ls ○	alg-moll ls ○ ; moll ls
ullWh	calc sh ○	calc sh ●	alg ls	alg-moll ls ○	alg-moll ls ○
lllWh	calc sh ▲	calc sh ○	alg ls	alg-moll ls ○	alg-moll ls ○ ; tan ss
uuWt	chty ls ○	chty ls ○	chty ls ●	chty ls ○	brach-moll ls
muWt	chlky ls	chlky ls ○	chty ls ○	chty ls ○	brach-moll ls
luWt	chty ls ○	chty ls ○	chty ls ○	chty ls ○	brach-moll ls
mWt	calc sh ○	calc sh ●	calc sh ●	calc sh ●	brach-moll ls
lWt	chty ls ●	chty ls ○	chty ls ●	brach-moll ls ●	alg-moll ls ○ ; tan ss ; moll ls
uuSp	calc sh ▲	calc sh ▲	calc sh ○ ; brach-moll ls ○	calc sh ○ ; brach-moll ls ○	
muSp	moll ls ●	moll ls ○	calc sh ● ; brach-moll ls ○	gr-yl mud ○	
uluSp	gr-yl mud	gr-yl mud ○	gr-yl mud ○	(ruled pattern indicates interbedded red shale and red sandstone)	
lluSp	grn sh spines ○	grn sh	gr-yl mud		
mSp	red sh	red sh	red sh		

Figure 13. Distribution and abundance of Wreford Enteleles; see Figure 9 for explanation.

<u>Enteletes</u>	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls	alg ls	alg ls	alg-moll ls	
umWs	chty ls ;calc sh	brach-moll ls	chty ls ;calc sh	calc sh	gr-yl mud
lmWs	calc sh ○	calc sh	calc sh	calc sh	gr-yl mud
lWs	chty ls	chty ls	chty ls	chty ls	alg-moll ls ;tan ss
uuWh	calc sh	calc sh	calc sh	calc sh	
luWh	moll ls	brach-moll ls	alg ls	alg-moll ls	
mWh	gr-yl mud	gr-yl mud ;calc sh	gr-yl mud	brach-moll ls	
ulWh	moll ls ○	brach-moll ls ○	alg ls	alg-moll ls	alg-moll ls ;moll ls
ullWh	calc sh ○	calc sh	alg ls	alg-moll ls	alg-moll ls
lllWh	calc sh △	calc sh	alg ls	alg-moll ls	alg-moll ls ;tan ss
uuWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
muWt	chlky ls	chlky ls ○	chty ls	chty ls	brach-moll ls
luWt	chty ls ○	chty ls ○	chty ls	chty ls	brach-moll ls
mWt	calc sh ▲	calc sh △	calc sh ○	calc sh ○	brach-moll ls
lWt	chty ls ●	chty ls ○	chty ls ○	brach-moll ls	alg-moll ls ;tan ss ;moll ls
uuSp	calc sh ●	calc sh ●	calc sh ○;brach-moll ls	calc sh ;brach-moll ls	
muSp	moll ls	moll ls ○	calc sh ;brach-moll ls	gr-yl mud	
uluSp	gr-yl mud	gr-yl mud	gr-yl mud		(ruled pattern indicates interbedded red shale and red sandstone)
lluSp	grn sh	grn sh	gr-yl mud		
mSp	red sh	red sh	red sh		

Figure 14. Distribution and abundance of Wreford Wellerella; see Figure 9 for explanation.

<u>Wellerella</u>	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls	alg ls	alg ls	alg-moll ls	
umWs	chty ls ; calc sh	brach-moll ls	chty ls ; calc sh	calc sh	gr-yl mud
lMws	calc sh	calc sh	calc sh	calc sh	gr-yl mud
lWs	chty ls	chty ls	chty ls	chty ls	alg-moll ls ; tan ss
uuWh	calc sh	calc sh	calc sh	calc sh	
luWh	moll ls	brach-moll ls	alg ls	alg-moll ls	
mWh	gr-yl mud	gr-yl mud ; calc sh	gr-yl mud	brach-moll ls	
ulWh	moll ls	brach-moll ls	alg ls	alg-moll ls	alg-moll ls ; moll ls
ulIWh	calc sh	calc sh	alg ls	alg-moll ls	alg-moll ls
lIIWh	calc sh	calc sh	alg ls	alg-moll ls	alg-moll ls ; tan ss
uuWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
muWt	chlky ls	chlky ls	chty ls	chty ls	brach-moll ls
luWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
mWt	calc sh	calc sh ○	calc sh	calc sh	brach-moll ls
lWt	chty ls ▲	chty ls ▲	chty ls	brach-moll ls	alg-moll ls ; tan ss ; moll ls
uuSp	calc sh ●	calc sh ○	calc sh ○ ; brach-moll ls ○	calc sh ; brach-moll ls	
muSp	moll ls	moll ls	calc sh ○ ; brach-moll ls	gr-yl mud	
uluSp	gr-yl mud	gr-yl mud	gr-yl mud		(ruled pattern indicates interbedded red shale and red sandstone)
lluSp	grn sh	grn sh	gr-yl mud		
mSp	red sh	red sh	red sh		

Figure 15. Distribution and abundance of Wreford Orbiculoidea; see Figure 9 for explanation.

<u>Orbiculoidea</u>	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls	alg ls	alg ls	alg-moll ls	
umWs	chty ls ; calc sh	brach-moll ls	chty ls ; calc sh	calc sh	gr-yl mud
lmWs	calc sh ○	calc sh ○	calc sh	calc sh	gr-yl mud
lWs	chty ls	chty ls	chty ls ○	chty ls	alg-moll ls ; tan ss
uuWh	calc sh	calc sh ○	calc sh	calc sh	
luWh	moll ls	brach-moll ls	alg ls	alg-moll ls	
mWh	gr-yl mud	gr-yl mud ; calc sh ○	gr-yl mud	brach-moll ls	
ulWh	moll ls	brach-moll ls	alg ls	alg-moll ls	alg-moll ls ; moll ls
ulWh	calc sh	calc sh ○	alg ls	alg-moll ls	alg-moll ls
lllWh	calc sh ○	calc sh	alg ls	alg-moll ls	alg-moll ls ; tan ss
uuWt	chty ls	chty ls ○	chty ls	chty ls	brach-moll ls
muWt	chlky ls	chlky ls	chty ls	chty ls	brach-moll ls
luWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
mWt	calc sh ○	calc sh	calc sh	calc sh	brach-moll ls
lWt	chty ls	chty ls	chty ls	brach-moll ls	alg-moll ls ; tan ss ; moll ls
uuSp	calc sh ●	calc sh ●	calc sh ○ ; brach-moll ls ○	calc sh ; brach-moll ls	
muSp	moll ls	moll ls	calc sh ○ ; brach-moll ls ○	gr-yl mud	
uluSp	gr-yl mud	gr-yl mud	gr-yl mud ○	(ruled pattern indicates interbedded red shale and red sandstone)	
lluSp	grn sh	grn sh	gr-yl mud		
mSp	red sh	red sh	red sh		

Figure 16. Distribution and abundance of Wreford Petrocrania; see Figure 9 for explanation.

<u>Petrocrania</u>	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls	alg ls	alg ls	alg-moll ls	
umWs	chty ls ;calc sh	brach-moll ls	chty ls ;calc sh	calc sh	gr-yl mud
lmWs	calc sh	calc sh	calc sh	calc sh	gr-yl mud
lWs	chty ls	chty ls	chty ls	chty ls	alg-moll ls ;tan ss
uuWh	calc sh	calc sh	calc sh	calc sh	
luWh	moll ls	brach-moll ls	alg ls	alg-moll ls	
mWh	gr-yl mud	gr-yl mud ;calc sh	gr-yl mud	brach-moll ls	
ulWh	moll ls	brach-moll ls	alg ls	alg-moll ls	alg-moll ls ;moll ls
ullWh	calc sh	calc sh	alg ls	alg-moll ls	alg-moll ls
lllWh	calc sh ○	calc sh	alg ls	alg-moll ls	alg-moll ls ;tan ss
uuWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
muWt	chlky ls	chlky ls	chty ls	chty ls	brach-moll ls
luWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
mWt	calc sh	calc sh	calc sh	calc sh	brach-moll ls
lWt	chty ls	chty ls	chty ls	brach-moll ls	alg-moll ls ;tan ss ;moll ls
uuSp	calc sh ○	calc sh ○	calc sh ;brach-moll ls	calc sh ;brach-moll ls	
muSp	moll ls	moll ls	calc sh ;brach-moll ls	gr-yl mud	
uluSp	gr-yl mud	gr-yl mud	gr-yl mud		(ruled pattern indicates interbedded red shale and red sandstone)
lluSp	grn sh	grn sh	gr-yl mud		
mSp	red sh	red sh	red sh		

Figure 16. Distribution and abundance of Wreford Petrocrania; see Figure 9 for explanation.

<u>Petrocrania</u>	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls	alg ls	alg ls	alg-moll ls	
umWs	chty ls ;calc sh	brach-moll ls	chty ls ;calc sh	calc sh	gr-yl mud
lmWs	calc sh	calc sh	calc sh	calc sh	gr-yl mud
lWs	chty ls	chty ls	chty ls	chty ls	alg-moll ls ;tan ss
uuWh	calc sh	calc sh	calc sh	calc sh	
luWh	moll ls	brach-moll ls	alg ls	alg-moll ls	
mWh	gr-yl mud	gr-yl mud ;calc sh	gr-yl mud	brach-moll ls	
ulWh	moll ls	brach-moll ls	alg ls	alg-moll ls	alg-moll ls ;moll ls
ulWh	calc sh	calc sh	alg ls	alg-moll ls	alg-moll ls
lllWh	calc sh ○	calc sh	alg ls	alg-moll ls	alg-moll ls ;tan ss
uuWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
muWt	chlky ls	chlky ls	chty ls	chty ls	brach-moll ls
luWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
mWt	calc sh	calc sh	calc sh	calc sh	brach-moll ls
lWt	chty ls	chty ls	chty ls	brach-moll ls	alg-moll ls ;tan ss ;moll ls
uuSp	calc sh ○	calc sh ○	calc sh ;brach-moll ls	calc sh ;brach-moll ls	
muSp	moll ls	moll ls	calc sh ;brach-moll ls	gr-yl mud	
uluSp	gr-yl mud	gr-yl mud	gr-yl mud	(ruled pattern indicates interbedded red shale and red sandstone)	
lluSp	grn sh	grn sh	gr-yl mud		
mSp	red sh	red sh	red sh		

Figure 17. Distribution and abundance of Wreford Lingula; see Figure 9 for explanation.

Lingula	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls	alg ls	alg ls	alg-moll ls	
umWs	chty ls ; calc sh	brach-moll ls	chty ls ; calc sh	calc sh	gr-yl mud
lmWs	calc sh	calc sh	calc sh	calc sh	gr-yl mud
lWs	chty ls	chty ls	chty ls	chty ls	alg-moll ls ; tan ss
uuWh	calc sh	calc sh	calc sh	calc sh	
luWh	moll ls	brach-moll ls	alg ls	alg-moll ls	
mWh	gr-yl mud	gr-yl mud ; calc sh	gr-yl mud	brach-moll ls	
ulWh	moll ls	brach-moll ls	alg ls	alg-moll ls	alg-moll ls ; moll ls
ulWh	calc sh	calc sh	alg ls	alg-moll ls	alg-moll ls
lllWh	calc sh	calc sh	alg ls	alg-moll ls	alg-moll ls ; tan ss
uuWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
muWt	chlky ls	chlky ls	chty ls	chty ls	brach-moll ls
luWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
mWt	calc sh	calc sh	calc sh	calc sh	brach-moll ls
lWt	chty ls	chty ls	chty ls	brach-moll ls	alg-moll ls ; tan ss ; moll ls
uuSp	calc sh	calc sh ○	calc sh ○ ; brach-moll ls	calc sh ; brach-moll ls	
muSp	moll ls	moll ls	calc sh ○ ; brach-moll ls	gr-yl mud	
uluSp	gr-yl mud	gr-yl mud	gr-yl mud		(ruled pattern indicates interbedded red shale and red sandstone)
lluSp	grn sh	grn sh	gr-yl mud		
mSp	red sh	red sh	red sh		

Figure 18. Distribution and abundance of Wreford Cleiothyridina; see Figure 9 for explanation.

<u>Cleiothyridina</u>	northern Kansas and southernmost Nebraska	central Kansas	southern Kansas	southernmost Kansas and northernmost Oklahoma	northern Oklahoma
mMw	red sh	red sh	red sh	red sh	
lMw	grn sh	grn sh	grn sh	red sh	
uWs	alg ls	alg ls	alg ls	alg-moll ls	
umWs	chty ls ; calc sh □	brach-moll ls ○	chty ls ○ ; calc sh	calc sh	gr-yl mud
lMws	calc sh	calc sh	calc sh	calc sh	gr-yl mud
lWs	chty ls	chty ls	chty ls	chty ls	alg-moll ls ; tan ss
uuWh	calc sh	calc sh	calc sh	calc sh	
luWh	moll ls	brach-moll ls	alg ls	alg-moll ls	
mWh	gr-yl mud	gr-yl mud ; calc sh	gr-yl mud	brach-moll ls	
ulWh	moll ls	brach-moll ls	alg ls	alg-moll ls	alg-moll ls ; moll ls
ullWh	calc sh	calc sh	alg ls	alg-moll ls	alg-moll ls
lllWh	calc sh	calc sh	alg ls	alg-moll ls	alg-moll ls ; tan ss
uuWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
muWt	chky ls	chky ls ○	chty ls	chty ls	brach-moll ls
luWt	chty ls	chty ls	chty ls	chty ls	brach-moll ls
mWt	calc sh	calc sh	calc sh	calc sh	brach-moll ls
lWt	chty ls	chty ls	chty ls ○	brach-moll ls	alg-moll ls ; tan ss ; moll ls
uuSp	calc sh	calc sh	calc sh ; brach-moll ls	calc sh ; brach-moll ls	
muSp	moll ls	moll ls	calc sh ; brach-moll ls	gr-yl mud	
uluSp	gr-yl mud	gr-yl mud	gr-yl mud	(ruled pattern indicates interbedded red shale and red sandstone)	
lluSp	grn sh	grn sh	gr-yl mud		
mSp	red sh	red sh	red sh		

chonetids at almost all localities is calcareous shale. Also, chonetids do not range as far south in the Wreford as do the other two groups.

The productids are a third widely distributed group of brachiopods in the Wreford Megacyclothem (Figure 12). They occur in calcareous shales, cherty limestones, and algal limestones, and are found more frequently in cherty limestones than any other brachiopod type. Occasionally, productid spines are found in rock units that have few, if any, other fossils. This implies that the small light spines were washed in from other areas, rather than that the productids themselves lived there. For example, the green shale of the lowermost part of the upper Speiser Shale contains only productid spines. It is likely that the productids lived elsewhere, in a more suitable environment, and their spines were carried into the area by water currents.

The remaining groups of brachiopods are minor parts of the fauna in the Wreford Megacyclothem and are not as widely or as abundantly distributed as the above groups.

Enteleles is most common in calcareous shales, and also occurs in cherty limestone, chalky limestone, and molluscan limestone (Figure 13). Stratigraphically, it occurs primarily in the Threemile Limestone Member. The lithologic limitations also restrict Enteleles geographically to northern and central Kansas.

Wellerella is even more restricted than Enteleles (Figure 14). Wellerella occurs only in cherty limestones, calcareous shales, and brachiopod-molluscan limestone. The only occurrence of Wellerella

in cherty limestone is in the lower beds of the Threemile Limestone Member, in the central part of Kansas. This Wellerella zone was also noted by Hattin (1957, p. 31), who thought the occurrence was valuable to stratigraphy by indicating contemporaneous deposition for this unit. Equally probable, Wellerella indicates similar ecologic factors rather than the same time of burial. Wellerella seems more restricted lithologically and stratigraphically than geographically.

Orbiculoidea is the most widely distributed and abundant of the Wreford inarticulate brachiopods. It occurs throughout the stratigraphic section, mostly in northern and central Kansas (Figure 15). The lithologies that contain Orbiculoidea are mostly calcareous shales and cherty limestones, and rarely brachiopod-molluscan limestones and grayish-yellow mudstones.

Petrocrania is an inarticulate brachiopod that lived by cementing the pedicle valve to some hard object, such as another brachiopod shell. It is found in the Wreford attached to Derbyia and productids. Its distribution thus depends on the distribution of the animals to which it attached. The Wreford Petrocrania occurs mostly in calcareous shales, and in a few brachiopod-molluscan limestones (Figure 16).

Few Lingula were collected from the Wreford Megacyclothem; those found are from the calcareous shales of the Speiser Shale (Figure 17).

The articulate brachiopod genus Cleiothyridina, although found in other Permian units, has not been reported previously as occurring in the Wreford Megacyclothem. However, I found very small specimens

of this genus at five areas in the Wreford in Kansas. Cleiothyridina is abundant in a minor calcareous shale within the cherty limestone of the upper middle Schroyer Limestone Member at locality GE01; Cleiothyridina is rare, however, in the other four areas indicated in Figure 18.

PAST PRACTICES IN IDENTIFICATION OF SPECIES OF COMPOSITA

Literature search reveals several different schools of thought regarding the separation of various morphological forms of the genus Composita into species. As Grinnell and Andrews (1964, p. 233) report, Composita existed as a series of intergrading forms from the time of its first appearance in the Upper Devonian (?) to its disappearance at the end of the Guadalupian. It is especially the fact that these apparently different forms morphologically intergrade at any given stratigraphic horizon which has caused extensive problems in nomenclature; at least, ample precedent exists for dealing nomenclaturally with stratigraphically successive, gradually changing populations (like Composita) which are interpretable as evolving lineages.

Hall and Clark (1894, p. 95) noted that, although fossil Composita populations included variously shaped individuals, "very abundant material shows the difficulty of separating them." They imply that intergrading forms should therefore be included in the same single species.

Girty (1909, p. 388), in describing a new Guadalupian species of Composita, justified his distinction of a new species by saying that "Composita shows so few lines of specific evolution that differences, if at all well marked or constant, may be given unusual weight in the discrimination of species." Yet Girty (1915, p. 264) later noted that the Composita problem had not been solved: "A typical species for an investigation of this sort would be Composita subtilita, under which are united quite a variety of kindred and connected forms, which no one has as yet had the hardihood to distinguish and to name."

Weller (1914, p. 485-486) discussed the problem of the difficulty of drawing conceptually sharp specific boundaries within Composita, and commented that isolated specimens could be placed in separate species but that all the forms were seen to be intergradational when part of a large collection. One is thus confronted with two alternatives; either include all the forms in one variable species, or else recognize several groups as species or varieties. Weller also comments (1914, p. 485-486) that

"The last of these methods appeals most strongly to the writer, and preference is given to the recognition of the groups as of specific rank, there being little utility in giving a particular shell three names, when two will serve as well. . . It matters not that a few of the individuals agree essentially in all their characters with a few individuals from another specific group from another locality and horizon. The important fact is the central, average type of shell, and as many such types as can be clearly recognized are worthy of specific recognition."

Weller thought that gradation of types was only important as an indication of the close relationship of the forms and of the evolutionary youth of the genus.

Sayre (1930a,b) noted the abundance of Composita in the Pennsylvanian Drum Limestone in Kansas, and placed them all in the species Composita subtilita because of their intergradation.

Dunbar and Condra (1932, p. 362-373) described several separate species of Composita because, to them, it was more conservative to distinguish species than to include all the forms in one protean species and designate several varieties of that species.

In the Carboniferous beds of Alberta are several forms of Composita, although Composita subtilita is not included in the descriptions by Brown (1952, p. 65). However, the forms there also intergrade in outline, convexity, size of beaks, and development of the sinus, yet Brown distinguished several species and varieties.

Similarly, Chronic (1953, p. 71-72) noted several species of Composita from the upper Paleozoic of Peru, and also described a new species, yet he noted the presence of intermediate forms between species.

Burk (1954) discussed his Oklahoma Pennsylvanian collections of Composita and mentioned that three general shapes could be recognized, although there was a gradation of specimens between these groups. He considered the three forms as varieties of one species, Composita subtilita.

Mudge and Yochelson (1962) studied the fauna of uppermost Pennsylvanian and lowermost Permian rocks in Kansas. They acknowledged the fact that, based on external shell characteristics, it is difficult to recognize separate species of Composita.

Consequently, rather than identifying their specimens to species, they identified them only to genus, and noted that improved means of identifying species of Composita are necessary before they can be identified with confidence.

Grinnell and Andrews (1964) presented a valuable and comprehensive survey of all described species of Composita and included them all in a hypothetical phlogeny which shows much intrapopulation variation. They also studied several collections of Composita to determine whether each collection could be split into distinct groups (species) and concluded (1964, p. 239, 242) that

"The collections are actually segments of local fossil populations in which certain morphologic variants exist. . . They are not neontological species but rather intergrading typological species. . . A case could be made for suppression of all specific names except Composita subtilita and possibly one or two others. In view of the association of these forms and their intergradation in shape, many of the specific names may not be valid neontologically. However, the writers deem it wise not to change the present terminology of the Late Pennsylvanian and Early Permian compositas. The names are valuable for reference even though they may not be technically correct."

They go on to say (1964, p. 243) that

"There seem to be enough differences between the samples to make taxonomic revision, say on the subspecific level, a possibility. Such revision, however, would only serve to clutter the literature with some useless subspecific names and is therefore thought to be unnecessary."

Composita specimens from the Pennsylvanian of New Mexico were termed Composita "subtilita" by Sutherland and Harlow (1967) because they interpreted the continuous gradation visible in shell shapes as possibly representing intrapopulation variation.

Sturgeon and Hoare (1968) followed the practice of naming and differentiating Composita groups with different morphologic features as separate species, even though they admitted that there was some intergradation of forms.

Stehli and Grant (1970) also described a new species of Composita, while admitting at the same time (1970, p. 34) that "Species of Composita are variable, and few have distinguishing characteristics that can be differentiated other than by intensive study of very large samples."

In summary, there have historically been three ways of dealing with specific identifications within the brachiopod genus Composita. In addition, in spite of the development of three approaches to this problem, it was recognized early and universally that, at any one geographic locality and stratigraphic horizon, the Composita population consisted of forms that morphologically intergraded. Yet the first and most popular method of identifying the forms of Composita has been to designate each different recognizable form as a separate species. A second method is to place all the intergrading forms into one species (for Pennsylvanian and Permian forms, that species is Composita subtilita, which seems to be the basic morphologic form). Or third, the different forms can be designated as varieties of a species (as Burk (1964) has done with Composita subtilita), as I do in this paper with the Wreford specimens.

MORPHOLOGIC VARIABILITY AND ITS IMPLICATIONS FOR
IDENTIFICATION OF WREFORD COMPOSITA SUBTILITA

The Wreford Composita specimens constitute an intergrading series of individuals (Plate 1, Figures 1-8; Plate 2, Figures 1-16) which cannot be separated into clearly distinct groups interpretable as different species. Some specimens could be referred to Composita subtilita because they have a high fold and sulcus and are longer than they are wide; other specimens might well be placed in Composita ovata because they have a low fold and sulcus and a rounded outline. Still other specimens might be placed in either species because they have some characteristics of each, or are intermediate in characteristics between the two concepts. Appropriate plotting of measurements of well-preserved specimens (from samples described later; see page 127) indicates sizeable overlap between these two nominal species (Figure 19), as well as the normal frequency distributions (Figure 20, combined data) expected of a single biological species population. One fossil, had it been found alone, could have been termed Composita elongata because of its elongate form. All other collections of Composita reported in the literature, as discussed above, also apparently constitute intergrading populations.

Neontological species concepts should be kept in mind by practicing paleontologists, and applied wherever possible. (These concepts were defined and discussed by Mayr in 1963, p. 12-31 and in 1969, p. 23-36; an example of their application to paleontology is the 1967 paper by Cuffey.) Much previous reasoning about Composita, as for example by Weller (1914), seems not to appreciate

Figure 19. Triangular graph showing overlap of the two Wreford varieties of Composita subtilita. A, area occupied by well-preserved subsample of Composita subtilita var. subtilita; B, area occupied by well-preserved subsample of Composita subtilita var. ovata. The numbers plotted here for each specimen (say the i^{th} specimen with length L_i , width W_i , and thickness T_i) are "percentage dimensions" defined as follows:

$$\text{length plotted} = \frac{100L_i}{L_i + W_i + T_i},$$

$$\text{width plotted} = \frac{100W_i}{L_i + W_i + T_i}, \text{ thickness}$$

$$\text{plotted} = \frac{100T_i}{L_i + W_i + T_i}; \text{ such transformations}$$

are necessary in order to utilize triangular diagram representation of the data (Burma, 1948, p. 752; Tasch, 1955, p. 172). Only the pertinent part of the triangle is represented in the figure.

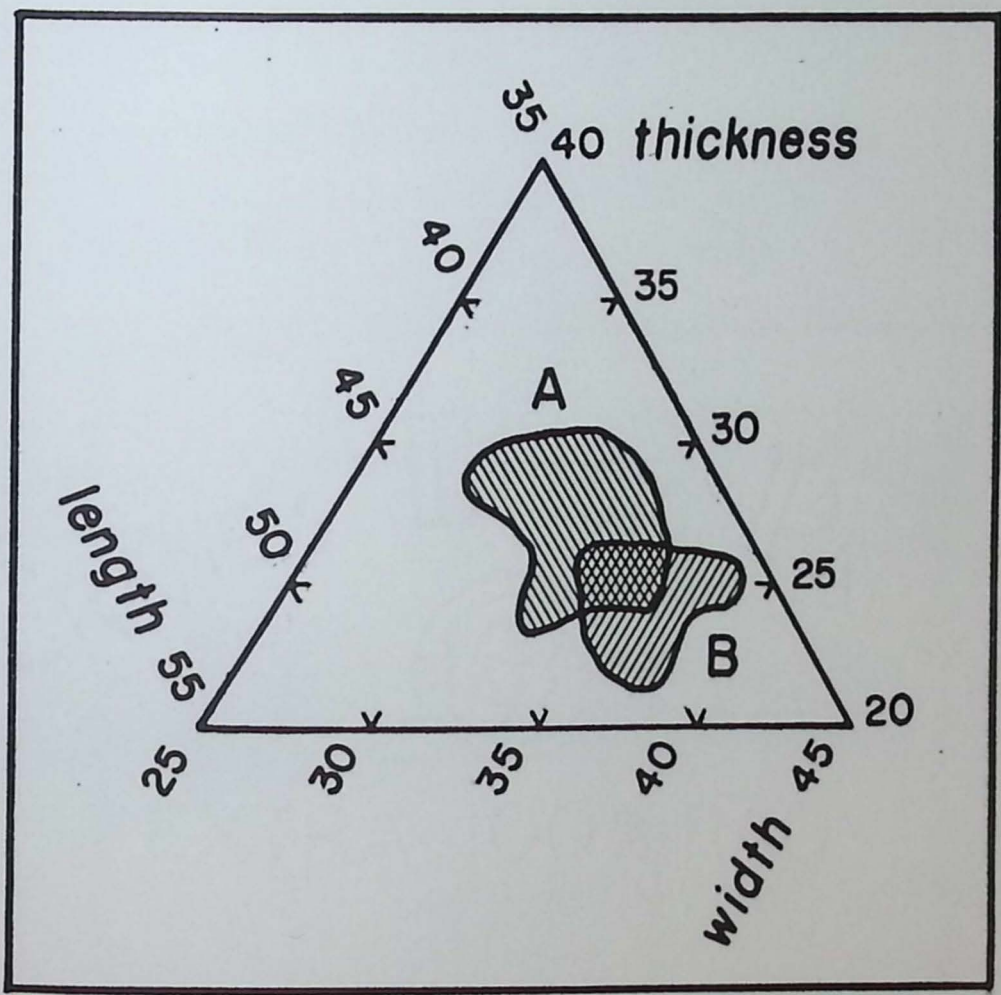
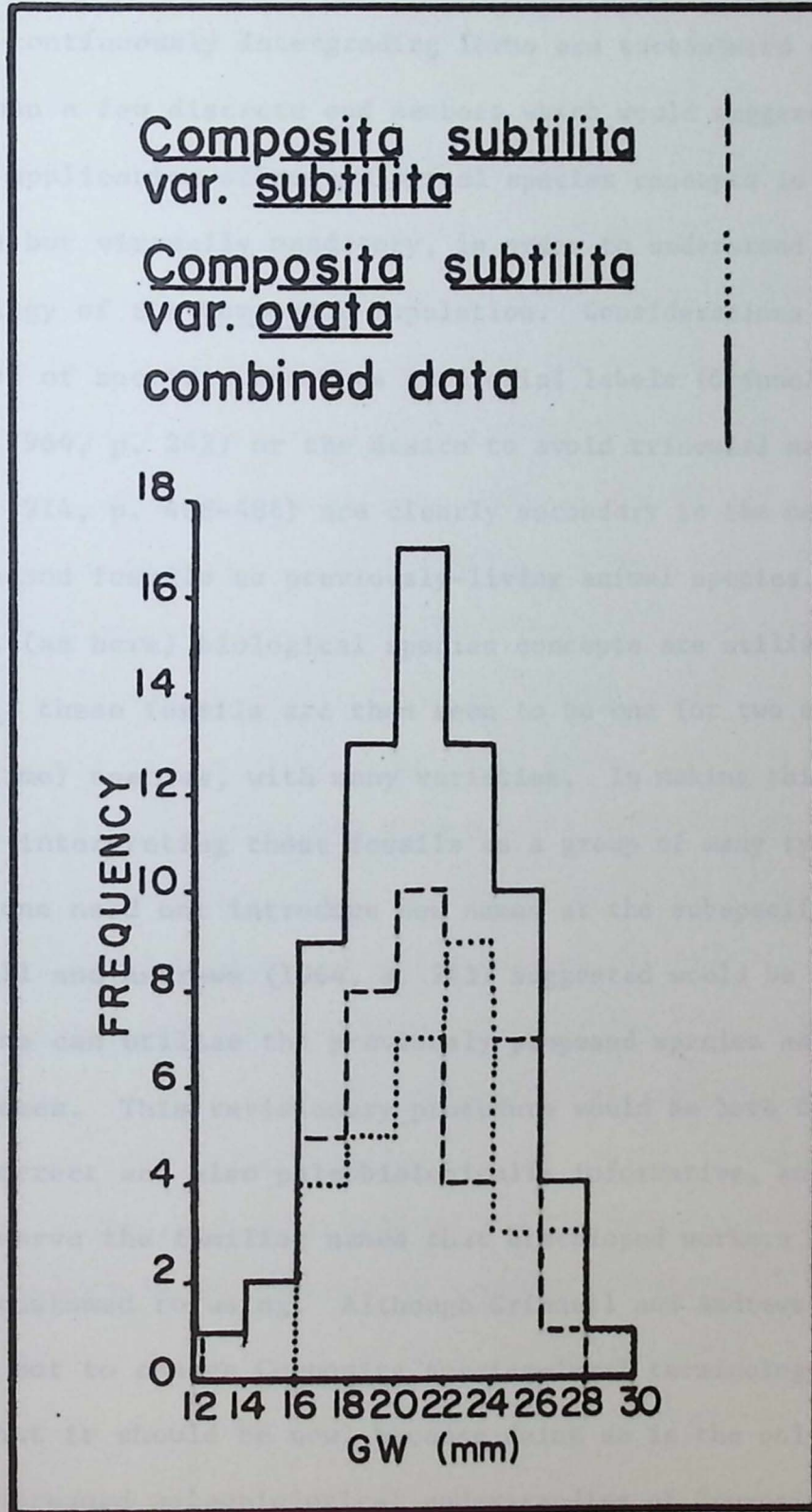


Figure 20. Frequency distributions of GW for sub-samples of well-preserved and full-sized Wreford specimens of Composita subtilita var. subtilita and Composita subtilita var. ovata, and for the combined data of the two varieties.



the potential relevance of the biological concepts of species or of the use of specific names to identify populations of previously living animals. Especially for a group as well known as Composita, in which continuously intergrading forms are encountered everywhere, rather than a few discrete end members which would suggest separate species, application of neontological species concepts is not only desirable but virtually mandatory, in order to understand fully the paleobiology of the Composita population. Considerations like usefulness of specific names as curatorial labels (Grinnell and Andrews, 1964, p. 242) or the desire to avoid trinomial names (Weller, 1914, p. 485-486) are clearly secondary to the necessity to understand fossils as previously-living animal species.

When (as here) biological species concepts are utilized for Composita, these fossils are then seen to be one (or two or three, through time) species, with many varieties. In making this change away from interpreting these fossils as a group of many typological species, one need not introduce new names at the subspecific level, as Grinnell and Andrews (1964, p. 243) suggested would be necessary; rather, one can utilize the previously proposed species names for variety names. This revisionary procedure would be both taxonomically correct and also paleobiologically informative, and moreover would preserve the familiar names that brachiopod workers have become accustomed to using. Although Grinnell and Andrews (1964) preferred not to change Composita species-level terminology, I believe that it should be now, because doing so is the only way for our increased paleobiological understanding of Composita populations to be reflected taxonomically.

A formal revision of all species within the genus Composita through time is far beyond the scope of this paper. A complete revision would require thorough investigation of the types of all named Composita species, of which there are at least 42 (Grinnell and Andrews, 1964, p. 229). From examination of the relevant literature, however, the genus at any one geological moment does appear to me to represent a single but highly variable species population that also changes morphologically through Late Paleozoic time enough that segments of the evolving lineage could well be regarded as chronologically successive species. In particular, the phylogeny suggested by Grinnell and Andrews (1964, p. 233) shows no significant morphologic breaks in the characteristics of the population through time.

In spite of the impracticability of a complete revision of Composita now, I can nonetheless apply neontological species concepts and their taxonomic consequences to Wreford Composita. Therefore, I refer all these fossils to the species Composita subtilita, and I designate the two extreme end-members of the continuous morphological spectrum shown by the Wreford population as varieties of this species, namely Composita subtilita variety subtilita and Composita subtilita variety ovata. (Combining "species" which show morphological intergradation should be mandatory; a recent example is a paper by Walker, 1973.) A third variety, which would be named Composita subtilita variety elongata, may also have existed during the Wolfcampian; however,

because only one Wreford specimen could be tentatively assigned to it, I do not believe that this is sufficient material for me to adequately describe this variety.

Grinnell and Andrews (1964, p. 233) indicated that the "species" of Composita that existed during the Wolfcampian were Composita subtilita, Composita ovata, and Composita elongata. The present designation of the Wreford specimens of Composita subtilita as C. subtilita var. subtilita, C. subtilita var. ovata, and one specimen that might be C. subtilita var. elongata is consistent with their information.

These two varieties are morphotypes of the single species Composita subtilita. They cannot be regarded as subspecies because, as Mayr (1969, p. 41) indicated, subspecies are geographically separate groups, and these two varieties occur in single samples of Composita subtilita collected from individual localities. Nor are they sexual dimorphs because there is too much continuous intergradation morphologically. Since the use of the term "variety" has common precedents, I retain the term here, rather than use the term "morphotype" as Cuffey (1967, p. 61-63) did for the Wreford Tabulipora carbonaria. In the present instance, as discussed above, it is better to retain the Latin names that were previously applied to groups of Composita that were thought of as species, rather than introduce new, unfamiliar names that are not Latin.

SYSTEMATIC DESCRIPTION OF WREFORD COMPOSITA SUBTILITA

Phylum BRACHIOPODA Duméril, 1806

Class ARTICULATA Huxley, 1869

Order SPIRIFERIDA Waagen, 1883

Suborder ATHYRIDIDINA Boucot, Johnson, and Staten, 1964

Superfamily ATHYRIDACEA M'Coy, 1844

Family ATHYRIDIDAE M'Coy, 1844

Subfamily ATHYRIDINAE M'Coy, 1844

Genus COMPOSITA Brown, 1849

COMPOSITA SUBTILITA (Hall, 1852)

(Plates 1, 2)

SYNONYMY

In order not to duplicate bibliographic material readily available, this listing refers to previous synonymic indexes and bibliographies (Schuchert, 1897; Weller, 1898; Girty, 1915; Branson, 1948; Carter and Carter, 1968) wherever possible.

Terebratula argentea Shepard, 1838, Am. Jour. Sci., v. 34,
p. 152, fig. 8.

Terebratula subtilita Hall, 1852, Stansbury Exped. Gt. Salt Lake,
p. 409, pl. 2, fig. 1a, b, 2a, b, c.

Seminula argentea, Schuchert, 1897, U.S. Geol. Surv., Bull. 87,
p. 377; -----, Weller, 1898, U.S. Geol. Surv., Bull. 153,
p. 560-562.

Composita subtilita, Girty, 1908, U.S. Geol. Surv., Prof. Paper
58, p. 383-388; -----, Girty, 1915, U.S. Geol. Surv.,

Bull. 544, p. 96-99; -----, Sayre, 1930, Kan. Geol. Surv., Bull. 17, p. 102, pl. 6, fig. 4-8c (1931); -----, Branson, 1948, Geol. Soc. Amer., Mem. 26, p. 323; -----, Carter and Carter, 1968, Geol. Soc. Amer., Mem. 128, p. 372-374.

Composita ovata Mather, 1915, Bull. Sci. Lab. Denison Univ., v. 18, p. 202-203, pl. 14, fig. 6-6c; -----, Carter and Carter, 1968, Geol. Soc. Amer., Mem. 128, p. 97-98.

SHELL MORPHOLOGY

Composita subtilita has a smooth, globular, or lens-shaped shell, the only external shell features being concentric growth lines. The pedicle valve is pierced by an oval foramen, or pedicle opening, and the anterior margin is characterized by a dorsal fold and ventral sulcus in mature specimens, although this feature may be absent in immature forms.

Shell small- to medium-sized, moderately biconvex, dimensions highly variable, but GL, GW, and GT averaging about 17, 15, and 10 mm, respectively. (Table 8 gives values for these and other numerical characteristics.) Shell, when viewed perpendicularly to plane of commissure oval to round or subquadrate in outline; width-length ratio (GW/GL) averaging about 0.9. (Table 9 summarizes ratio data.) Valves biconvex, mean convexity (GT/GW) approximately 0.7. Greatest width of shell in many specimens anterior to midpoint of shell but in others at midpoint or posterior to midpoint; LPGW averaging about 10 mm;

Table 8. Tabulation of measured characters for all (782) measured specimens of Composita subtilita from the Wreford Megacyclothem. (N = number of specimens; \bar{X} = mean; CL = confidence limit; SD = standard deviation; CV = coefficient of variability.)

	<u>N</u>	\bar{X} <u>95% CL</u>	\bar{X}	SD <u>95% CL</u>	<u>SD</u>	<u>Range</u>	<u>CV%</u>
GL	482	16.35-17.99	17.17	8.99-9.85	9.23	2.2-40.1	53.74
GW	430	13.99-15.55	14.77	7.94-8.76	8.20	1.9-36.2	55.51
GT	233	9.45-10.93	10.19	5.37-6.46	5.86	1.2-23.4	57.51
LPGW	361	8.94-10.12	9.53	5.26-6.08	5.62	1.1-26.4	58.99
LPGT	217	7.00-8.14	7.57	3.95-4.78	4.33	0.9-16.4	57.12
POGL	395	1.69-1.81	1.75	0.60-0.69	0.64	0.3-3.9	36.72
POGW	389	1.25-1.33	1.29	0.42-0.48	0.45	0.2-2.9	35.03
FSA	148	145.82-154.96	150.39	25.49-32.09	28.35	95.0-180.0	18.85
PLMA	157	87.50-90.56	89.03	8.78-11.01	9.78	52.0-158.0	10.98
ALMA	58	82.47-88.19	85.33	9.20-13.38	10.86	58.0-107.0	12.72
FSHA	163	2.11-3.01	2.563	2.59-3.23	2.876	0.0-9.8	112.2

Table 9. Summary of ratios calculated from measurements of Wreford Composita subtilita specimens. (Symbolization as for Table 8.)

<u>Ratio</u>	<u>\bar{X}</u>	<u>SD</u>	<u>Range</u>	<u>N</u>
GW/GL	0.91	0.08	0.69 - 1.10	321
GT/GW	0.66	0.10	0.42 - 0.96	176
LPGW/GL	0.60	0.06	0.37 - 0.92	308
LPGT/GL	0.45	0.05	0.32 - 0.61	188
FSHA/GT	0.33	0.10	0.08 - 0.57	55

ratio of length position of greatest width to shell length (LPGW/GL) averaging about 0.6. Greatest thickness at midpoint or posterior to midpoint of shell length, but in some anterior to midpoint; LPGT averaging about 8 mm; ratio of length position of greatest thickness to shell length (LPGT/GL) averaging about 0.5. Hinge line short. Beak of pedicle valve curving around beak of brachial valve. Anterior margin of shell marked by dorsal fold and ventral sulcus, of height (FSHA) varying from 0 to 9.8 mm but averaging about 2.6 mm; relative fold and sulcus height (ratio of height in mm to greatest shell thickness, FSHA/GT) ranging from 0.08 to 0.57 but averaging near 0.3; in shells with folds and sulcus developed, fold and sulcus angle (FSA) averaging about 150° ; fold and sulcus begin at varying distances from the posterior end. Posterolateral margins of shell forming angle (PLMA) varying from 52° to about 160° but averaging approximately 90° . Anterolateral margin angle (ALMA) mean approximately 85° .

Pedicle valve most convex at apex, gradually sloping off to the shell margins. Pedicle opening an oval foramen at beak of valve; opening averaging about 1.3 mm wide (POGW) by 1.8 mm long (POGL); delthyrium (triangular open space below foramen) covered by brachial valve. A few pedicle valves bearing shallow median groove beginning at or slightly anterior to apex and continuing to anterior commissure.

Brachial valve most convex posterior to mid-length and curving more gradually from there to shell margins.

Pedicle valve interior bearing two hinge teeth supported by dental lamellae extending to floor (interior surface) of valve. Muscle scars

elongate, causing thinning of shell. Deep channel in middle of shell near posterior end for pedicle muscles (Dunbar & Condra, 1932, p. 364). Pallial sinuses of one specimen showing a simple bifurcating pattern (described below).

Brachial valve interior with two sockets on either side of a quadrate hinge plate. Adductor scars long and narrow. Previous workers (Boucot et al, 1965) have described brachidia: jugal saddle present; jugal bifurcations terminating between first and second volutions of spiralia. Spiralia laterally directed.

Exterior surface of valves smooth except for irregularly spaced growth lines, which become more prominent toward anterior.

Dimensions of 5 individuals are presented in Table 10.

PALLIAL SINUSES

Pallial sinuses are visible on one Wreford specimen of Composita subtilita, in which the shell material has been partly broken away to leave an internal cast showing the pallial sinuses as ridges. The pattern formed by these pallial sinuses is shown in Figure 21A and Plate 1 and closely resembles that described by Weller (1931, p. 355-357); his figure 3 (p. 357) is modified here as Figure 21B (the specimen of Figure 21B is an internal cast and is a particularly round morphotype and thus appears different from the Wreford specimen). Other specimens of Composita subtilita with pallial sinuses have also been figured. One figure by Whitfield (1895, Plate XII, Figures 7-9) was similar to that of Weller (1931), except that the main trunks are all directed anteriorly. Specimens figured by Hall and Clarke (1894, Plate XLVII, Figures 27, 28) do not show bifurcation of the

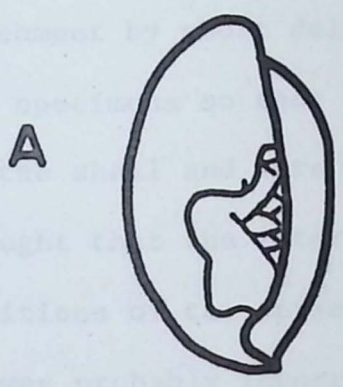
Table 10. Dimensions of some specimens of Wreford Composita subtilita.

<u>Specimen Number</u>	<u>GL</u> (mm)	<u>GW</u> (mm)	<u>GT</u> (mm)	<u>LPGW</u> (mm)	<u>LPGT</u> (mm)	<u>POGL</u> (mm)	<u>POGW</u> (mm)	<u>FSA</u> (degrees)	<u>PLMA</u> (degrees)	<u>ALMA</u> (degrees)	<u>FSHA</u> (mm)
CH16E-p-01	30.4	25.6	18.9	17.8	14.3	2.6	1.7	116.0	82.0	77.0	7.9
BU04I-p-03	19.3	17.7	10.4	10.9	8.3	1.7	1.1	149.0	90.0	95.0	1.8
CY49A-p-13	24.2	22.6	16.0	14.4	11.9	1.8	1.5	123.0	99.0	86.0	5.1
KA01J-f1-08	23.0	19.6	13.4	13.6	8.8	2.0	1.7	135.0	93.0	91.0	4.2
KA08A-f1-10	25.8	22.5	17.4	16.9	13.3	2.7	2.0	127.0	81.0	58.0	4.4

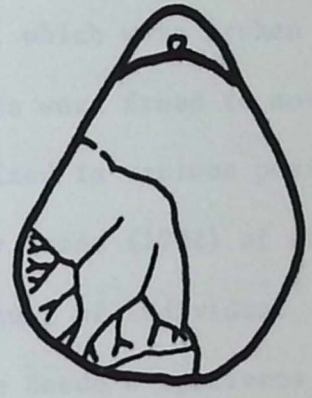
Figure 21. Pallial sinuses of Composita subtilita. A) Diagrammatic sketch of a specimen from the Wreford Megacyclothem with portions of the shell broken away to show an internal cast of the pallial sinuses; drawing of lateral view does not show pallial sinuses present on the brachial valve. B) Dorsal view of an internal cast of a specimen from Ohio; the specimen is a particularly round morphotype. (modified from Weller, 1931, p. 357).

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illustrated by other authors.

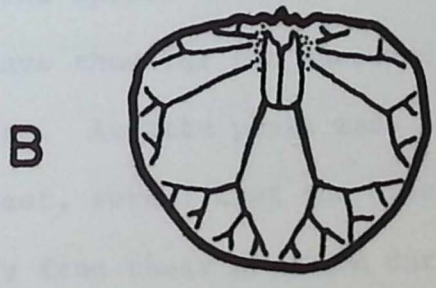
BRACHIDIA



lateral view



dorsal view



dorsal view

main trunks, and also include several more trunks than fossils illustrated by other authors.

BRACHIDIA

Weller (1931) also discussed the position of the lophophore-bearing spires within shells of Composita subtilita. He noted their attachment by short delicate crura, which were broken in almost all specimens so that the brachidia were freed to move around in the shell and were thus fossilized in various positions. Weller thought that the interpretation by Beede (1902) of the varied positions of the spiralia as a result of individual variation was probably incorrect, because Beede's specimens did not include crura and therefore more likely displayed spiralia that had merely been detached from the crura.

Although many of the Wreford Composita subtilita still contain brachidia, even in crushed specimens, these brachidia are not attached in most cases. Some of them appear to be still in life position with the spires directed laterally (Plate 2, Figure 17), but I have thus far not observed brachidia directly attached to the crura. Acetate peels made from several other specimens, in contrast, reveal that the brachidia within have been moved variously from their position during life (Plate 2, Figure 18).

MORPHOTYPES

As discussed previously, I recognize two distinct morphotypes within the Wreford population of Composita subtilita:

Composita subtilita var. subtilita (Hall)

(Plate 1, Figures 1-4)

Variety similar to species description, differs by being relatively elongate, with a low width/length ratio (that is, length noticeably greater than width, GW/GL averaging about 0.8). The anterior line of commissure varies from uniplicate to parasulcate. The fold and sulcus are high, both absolutely (FSHA averaging about 6 mm) and relatively (FSHA/GT averaging near 0.4). Summary statistics for the ratios of this variety are given in Table 11.

Composita subtilita var. ovata (Mather)

(Plate 1, Figures 5-8)

Variety similar to description of species, differs by having a rounded outline, with a comparatively high width/length ratio (GW/GL averaging about 0.9), and length and width about the same. The anterior line of commissure is uniplicate. The fold and sulcus are low, both absolutely (FSHA averaging about 4 mm) and relatively (FSHA/GT averaging near 0.3). Summary statistics for ratios of this variety are indicated in Table 12.

STRATIGRAPHIC DISTRIBUTION

According to Grinnell and Andrews (1964, p. 235), the oldest specimens of Composita subtilita are from Pennsylvanian (Atokan) rocks, and the youngest are found in the Leonardian Series of the Permian. All of these specimens are similar in external morphology.

Table 11. Summary of ratios calculated from measurements of
 Wreford Composita subtilita var. subtilita.
 (Symbolization as for Table 8.)

<u>Ratio</u>	<u>\bar{X}</u>	<u>SD</u>	<u>Range</u>	<u>N</u>
GW/GL	0.83	0.05	0.70-0.95	32
FSHA/GT	0.37	0.08	0.19-0.57	32

Table 12. Summary of ratios calculated from measurements of
 Wreford Composita subtilita var. ovata.
 (Symbolization as for Table 8.)

<u>Ratio</u>	<u>\bar{X}</u>	<u>SD</u>	<u>Range</u>	<u>N</u>
GW/GL	0.92	.07	0.85-1.11	27
FSHA/GT	0.26	0.10	0.08-0.50	23

Within the Wreford population at least, Composita subtilita does not show any microevolutionary variability.

CAUSES OF MORPHOLOGIC VARIABILITY WITHIN THE
WREFORD POPULATION OF COMPOSITA SUBTILITA

As indicated in the foregoing sections, Wreford specimens of Composita subtilita fall into two varieties which, though recognizably distinct as end-members, are connected by a continuous spectrum of morphologically intergrading intermediates (as shown in Plate 2, Figures 1-16); the end-members consequently must be viewed as varieties within a single species rather than as separate paleobiological species. In order to determine the reasons for these different varieties being present, aspects of their morphology and distribution were scrutinized carefully.

First, since the varieties appear much alike to the casual observer, it was hoped that the numerical characteristics of a sample consisting of exceptionally well-preserved Wreford specimens would indicate critical differences between varieties which might have escaped the notice of previous investigators, critical differences which would indicate possible causes of the variability. Moreover, it was suspected that the varieties might tend not to occur together in the same collecting sites, and thus that differences in distribution and abundance of the varieties might also be informative. However, such did not develop. The two varieties were found to be discouragingly similar (and thus their descriptions previously given could be quite brief). They also occurred in approximately equal numbers in the different Wreford rock types, stratigraphic

horizons, and geographic regions. The two varieties within Composita subtilita thus cannot be explained as being two ecotypes produced by different sedimentary environments, nor chronologically successive evolutionary populations, nor geographically separate subspecies; they can be regarded only as morphotypes similar to those noted in other species (Cuffey, 1967, p. 61-64).

To obtain better numerical characterization of the two varieties of the Wreford Composita subtilita, I obtained a subsample composed of 74 specimens which were essentially very well-preserved and of full size, so that all or most of the characters could be measured on each specimen. This subsample included 40 specimens referable to Composita subtilita var. subtilita, and 34 specimens to Composita subtilita var. ovata. Some of these specimens were easily placed in one group or the other, but many were intermediate in their external characteristics and could only be placed more or less arbitrarily in whichever variety to which they seemed more similar.

Summary statistics for these data were calculated (Tables 13 and 14); for each morphologic characteristic, I tested (with a t-test) the two means for significant differences between the two varieties. Table 15 reports statistically significant differences between the varieties in some characters but not others. Even where the means of numerical characters differ significantly between the two varieties, the close similarity in their absolute values leads the observer to despair of ever learning what (if any) biologically significant differences they indicate.

Table 13. Tabulation of measured characters for well-preserved full-sized Wreford Composita subtilita var. subtilita specimens. (Symbolization as for Table 8.)

	<u>N</u>	\bar{X} <u>95% CL</u>	\bar{X}	<u>SD</u> <u>95% CL</u>	<u>SD</u>	<u>Range</u>	<u>CV%</u>
GL	40	23.96-26.16	25.06	2.84-4.48	3.45	18.0-31.7	13.79
GW	37	19.58-21.74	20.66	2.68-4.29	3.27	12.2-26.7	15.83
GT	36	15.90-17.66	16.78	2.13-3.45	2.61	10.4-21.2	15.60
LPGW	35	14.50-16.04	15.27	1.84-2.99	2.26	10.0-19.6	14.81
LPGT	35	11.39-12.73	12.06	1.61-2.62	1.98	8.3-16.4	16.47
POGL	16	2.12-2.44	2.28	0.22-0.46	0.30	1.7-2.7	13.18
POGW	15	1.45-1.79	1.62	0.23-0.49	0.31	1.1-2.0	18.60
FSA	31	110.61-117.85	114.23	7.86-13.15	9.84	95.0-140.0	8.59
PLMA	32	80.35-86.09	83.22	6.37-16.00	7.95	60-94	9.53
ALMA	31	78.28-86.10	82.19	8.51-14.24	10.65	58-97	12.98
FSHA	37	5.31-6.53	5.92	1.49-2.39	1.82	1.5-8.6	30.60

Table 14. Tabulation of measured characters for well-preserved full-sized Wreford Composita
subtilita var. ovata specimens. (Symbolization as for Table 8.)

	<u>N</u>	\bar{X} <u>95% CL</u>	\bar{X}	<u>SD</u> <u>95% CL</u>	<u>SD</u>	<u>Range</u>	<u>CV%</u>
GL	31	22.37-24.81	23.59	2.69-4.50	3.37	17.2-31.4	14.25
GW	32	20.75-23.09	21.92	2.62-4.35	3.26	17.0-29.5	14.92
GT	27	13.43-15.73	14.58	2.22-3.86	2.81	9.9-21.0	19.39
LPGW	31	13.53-15.13	14.33	1.73-2.89	2.17	10.6-18.9	15.17
LPGT	26	10.11-11.75	10.93	1.59-2.80	2.02	7.5-15.7	18.37
POGL	20	1.90-2.30	2.10	0.33-0.63	0.43	1.5-2.9	20.49
POGW	21	1.42-1.68	1.55	0.13-0.40	0.28	1.0-2.0	18.05
FSA	25	127.71-139.89	133.8	11.54-20.59	14.78	97-161	11.03
PLMA	29	90.53-93.89	92.21	3.51-5.98	4.42	82-102	4.79
ALMA	18	85.76-91.80	88.78	4.58-9.14	6.10	77-98	6.88
FSHA	25	3.32-5.10	4.21	1.77-3.16	2.27	1.0-9.4	53.90

Table 15. Results of t-tests on character means of Composita subtilita var. subtilita vs. Composita subtilita var. ovata (ns = not significantly different at 5%; sig = significantly different at 5%).

<u>Character</u>	<u>Result of t-test</u>
GL	ns
GW	ns
GT	sig
LPGW	ns
LPGT	sig
POGL	ns
POGW	ns
FSA	sig
PLMA	sig
ALMA	sig

Parenthetically note that statistics were also calculated for each character from all measurable Wreford specimens of Composita subtilita (Table 8). This summary therefore includes measurements taken on many smaller specimens (on the order of 5 mm in length) as well as the full-sized ones. Consequently, many character means for the Wreford population as a whole (Table 8) are somewhat lower than the mean values for the varieties as calculated from the well-preserved full-sized subsample (Tables 13 and 14). Moreover, ratios were not employed in treating this subsample, in order to avoid the possibility that formation of a ratio from the character values might obscure or disguise variations in those values.

When comparing scatter diagrams of various pairs of variables for each of the two varieties by testing for parallelism of regression, all of the regression lines were statistically parallel at the 5% level of significance (although two were not, at the 1% level) (Table 16).

Several characters, such as pedicle opening length and width, do not differ significantly between the two varieties. Although such characters may not be important morphological features for comparing the two varieties in the Wreford population, they conceivably could be productively examined in future studies comparing specimens of Composita from various horizons in the Late Paleozoic stratigraphic section.

The shape of specimens of Composita subtilita from the Wreford is rounded or elongate, the convexity is high or low, and the line of commissure along the anterior portion of the valves is parasulcate,

Table 16. Summary of data from scatter plots of various pairs of characters measured for the two Wreford varieties of Composita subtilita, including results of tests for parallelism of regression. (ns = not significantly correlated at 5%; sig = significantly correlated at 5%; yes = significantly parallel at 5% and 1%; * = significantly parallel at 5% but not at 1%.)

<u>Pairs of Characters</u>	<u>Composita subtilita</u> var. <u>subtilita</u>	<u>Composita subtilita</u> var. <u>ovata</u>	<u>Parallelism</u>
GL-GW	sig	sig	yes
GW-GT	sig	sig	yes
FSA-FSHA	sig	sig	yes
GL-FSHA	sig	sig	*
POGL-POGW	sig	sig	yes
GL-POGW	ns	ns	yes
GW-POGW	sig	sig	yes
GL-PLMA	ns	ns	yes
GL-ALMA	ns	sig	*
GL-LPGW	sig	sig	yes
GL-LPGT	sig	sig	yes

uniplicate and low, or uniplicate and high. These character states can be combined in 12 possible ways. The Wreford population of Composita subtilita includes individuals matching each of these combinations, underscoring the failure of any single character to adequately differentiate the varieties, and strengthening the conclusion that the varieties seen merely represent morphotypes.

Because consideration of the morphology and occurrence patterns of the two varieties of the Wreford Composita subtilita did not lead to hoped-for results, attention turned instead to considering the characteristics of the entire Wreford species population in order to better understand intraspecific morphologic variability and its possible causes. As discussed previously, the Wreford population of Composita subtilita comprises a continuously intergradational series between the two named varieties as end-members. Consequently, all specimens regardless of varietal type which were collected from particular rock types, stratigraphic horizons, or geographic areas were grouped together, and the morphologic characteristics of each such group were summarized statistically and graphically.

In order to discover whether any differences exist among specimens of Composita subtilita from the various Wreford rock types, plots of character means calculated for all specimens from each rock type were drawn. Figure 22 summarizes the means for GT for Composita subtilita from different rock types. This and similar plots (Appendix E contains values from which the plots were made) show no trends or large differences in the means. Thus, Composita subtilita did not vary morphologically between any of the various rock types in which it was found.

Figure 22. Variation in the character GT, greatest thickness of shell, (dot indicates mean, bar extends one standard deviation on each side) for Wreford Composita subtilita specimens from different rock types (arranged approximately according to cyclic order). Rock-type abbreviations are from Table 6.

For the groups of specimens obtained from the various stratigraphic horizons indicated by calcareous nodules, smaller plots were made. These plots are also ambiguous in that they show no trends in the data for any of the above characters (Figure 2) summarize this information for GT and Appendix 2 includes the data). Plots were also made for specimens of *Goniatites aquilina* from cherty limestone horizons and from cherty limestone horizons and smaller results were obtained (Appendices 3 and 4 contain these data). Coffey (1967, p. 27-31), by using similar methods, was able to show progressive change in several characters of *Trochidontes* geographically in a stratigraphically vertical direction.

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- chty ls
- calc sh
- brach-moll ls
- moll ls
- alg-moll ls
- alg ls
- gr-yl mud

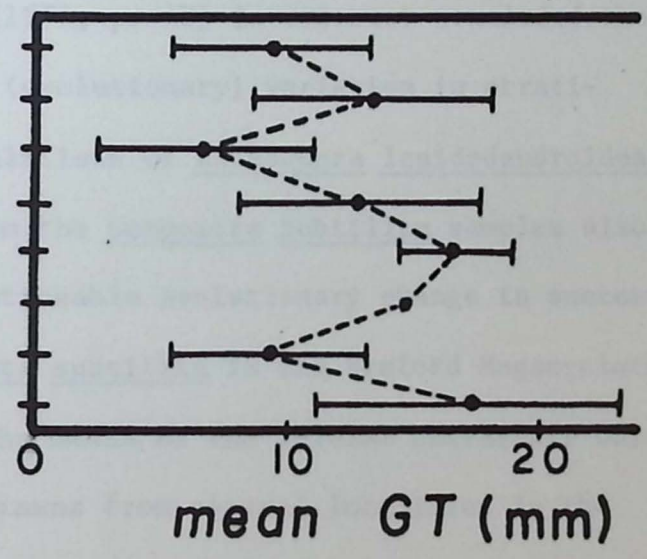


Figure 2 compares for groups of specimens from the various stratigraphic horizons indicated by calcareous nodules. (Figure 2 summarizes this information for GT and Appendix 1 contains the data.) Coffey (1967, p. 27-31) was able to show initial variation in *Trochidontes* geographically in a north-south direction in the Western Hemisphere. The plots for *Goniatites aquilina*, however, do not indicate any geographic variation geographically. Bowers (1971, p. 33) reported that *Goniatites* was geographically uniform.

For the groups of specimens obtained from the various stratigraphic horizons dominated by calcareous shales, similar plots were made. These plots are also ambiguous in that they show no trends in the data for any of the eleven characters (Figure 23 summarizes this information for GL and Appendix F includes the data). Plots were also made for specimens of Composita subtilita from cherty limestone horizons and from brachiopod-molluscan limestone horizons and similar results were obtained (Appendices G and H contain these data). Cuffey (1967, p. 85-86), by using similar methods, was able to show progressive change in several characters of Tabulipora carbonaria in a stratigraphically vertical direction, whereas Newton (1971, p. 43) in contrast concluded that there was no stratigraphic (evolutionary) variation in stratigraphically successive populations of Rhombopora lepidodendroides. The information derived from the Composita subtilita samples also indicates, therefore, no noticeable evolutionary change in successive populations of Composita subtilita in the Wreford Megacyclothem.

In a similar manner, the means of the several characters were compared for groups of specimens from several localities in the upper Speiser calcareous shale. (Figure 24 presents this information for GW and Appendix I contains the data.) Cuffey (1967, p. 70-71) was able to show clinal variation in Tabulipora carbonaria in a north-south direction in the Wreford Megacyclothem. The plots for Composita subtilita, however, do not indicate any systematic variation geographically. Newton (1971, p. 43) obtained similar results for Rhombopora lepidodendroides.

Figure 23. Evolutionary (stratigraphic) variation in the character GL, greatest length of shell, (dot indicates mean, bar extends one standard deviation on each side) for Wreford Composita subtilita specimens from various calcareous shale horizons. Horizon abbreviations are from Table 7.

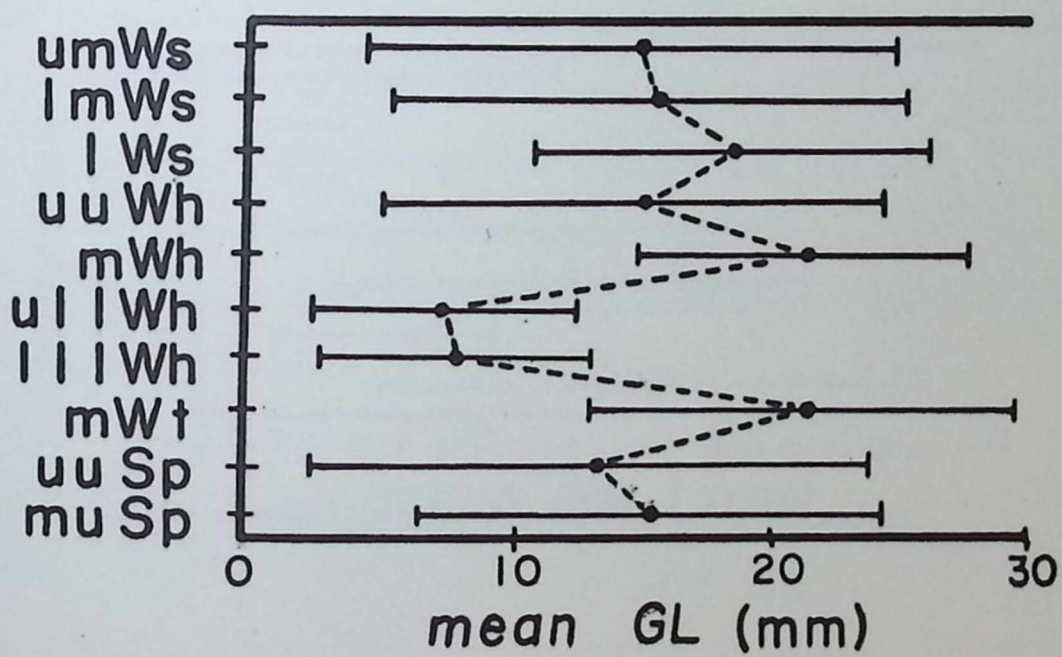
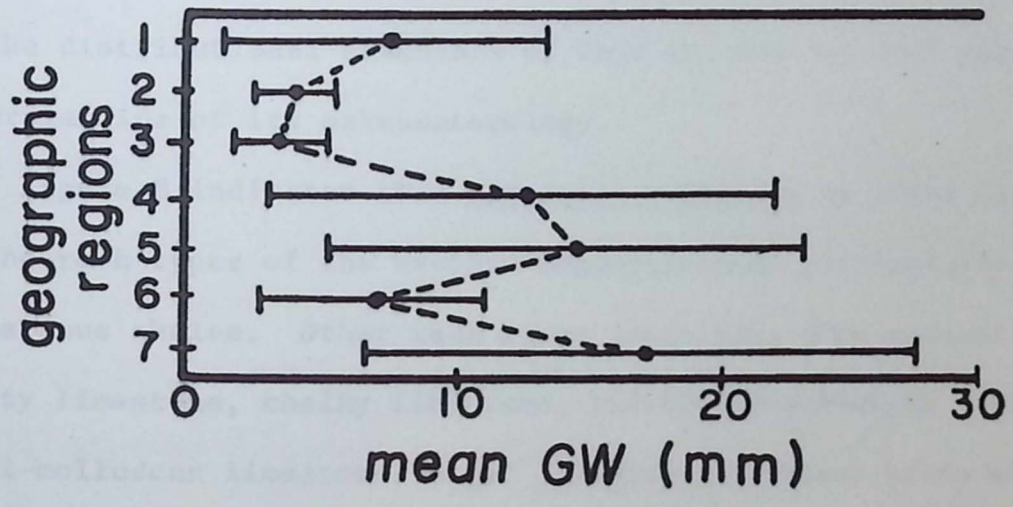


Figure 24. Clinal (geographic) variation in the character GW, greatest width of shell, (dot indicates mean, bar extends one standard deviation on each side) for Wreford Composita subtilita specimens from the upper part of the Upper Speiser calcareous shale; regions utilized are: 1) Gage Co., Neb.; Marshall and northern Pottawattomie Cos., Kan.; 2) southern Pottawattomie, Riley, and Geary Cos., Kan.; 3) Wabaunsee, Morris, and Lyon Cos., Kan.; 4) northern Chase Co., Kan.; 5) southern Chase and Greenwood Cos., Kan.; 6) Butler Co., Kan.; 7) Cowley Co., Kan.; Kay, Osage, Pawnee, and Noble Cos., Okla.

Thus, in overall terms of the morphological characters, the
 most varied species, which is, however, not necessarily the
 most varied in terms of the number of characters, does
 show any systematic variation with the geographical region,
 evolutionarily, or otherwise.

DISTRIBUTION, ABUNDANCE, AND EVOLUTIONARY
 OF VARIOUS SPECIES

The fact that American species are found in
 numbers from some of the well known species in
 various parts of the world...



...and range of geographical distribution...
 distribution (presence or absence of...)
 ...producing these rock types...
 in the normal marine calcareous...
 ...corals in other rock types...

Thus, in overall summary of the morphologic variability seen among Wreford Composita subtilita, neither consideration of morphotype varieties nor examination of the entire species population shows any systematic variations which can be interpreted ecologically, evolutionarily, or clinally.

DISTRIBUTION, ABUNDANCE, AND PALEOECOLOGY

OF WREFORD COMPOSITA SUBTILITA

The fact that Composita subtilita can be collected in large numbers from some of the well-understood lithologic facies and horizons within the Wreford Megacyclothem implies that variations in the distributional abundance of this species may well yield understanding of its paleoautecology.

Figure 8 indicates that Composita subtilita is found in many of the rock types of the Wreford Megacyclothem, particularly the calcareous shales. Other rock types containing this species are cherty limestone, chalky limestone, brachiopod-molluscan limestone, algal-molluscan limestone, algal limestone, southern parts of molluscan limestone, and (rarely) grayish-yellow mudstone. Because Composita subtilita existed throughout the time of deposition of the Wreford, and ranged geographically throughout the mid-continent, its distribution (presence or absence) in particular rock types must reflect dependence on the conditions of the environments of deposition producing those rock types. Thus, Composita subtilita occurs abundantly in the normal marine calcareous shales and cherty limestone, and is common in other rock types formed in shallow water which was slightly brackish or normal marine or even slightly hypersaline, and which

mostly lacked large influxes of terrigenously derived clays. Its occurrence only at the southern ends of some molluscan limestone beds would imply that the water varied somewhat even within the depositional area of a single rock type (in this case, molluscan limestone) by becoming too shallow or too brackish or too sediment-laden farther north for survival of Composita subtilita. Perhaps salinity is a more severely limiting environmental factor than depth, because Composita subtilita generally does not occur in the grayish-yellow mudstones, which formed in very shallow, brackish water which probably was somewhat less saline than, but possibly as deep as, water in which molluscan limestone formed. It thus seems that Composita subtilita could not tolerate differences much above or below normal marine salinity, or localities with a high sediment supply that would smother them.

The presence of a pedicle opening and epifaunal bryozoans and productids on Composita subtilita suggest that this animal lived attached to the substrate by its pedicle (rather than being cemented or burrowing). Moreover, its presence in the Wreford rocks, which probably accumulated as relatively soft sediments, either terrigenous or carbonate muds, suggests that it probably had to attach to other shells, the only available hard material. There was no evidence within the Wreford collection of the specific kind of substrate to which these specimens were attached. At one locality (CY07) there were brachiopod "nests" composed of Composita subtilita and Derbyia sp. in an algal limestone; such "nests" may represent a cluster that was attached to one particularly large piece of hard substratal material, as noted by Rudwick (1970, p. 77).

Rudwick (1970, p. 160) also noted that few living brachiopods, attached by a pedicle can live in areas of strong currents or waves (due to the limited pedicle strength). Also, Composita subtilita had no obvious method for filtering out large sedimentary particles, because its commissure is improperly shaped (Rudwick, 1970, p. 110); it would have lived in areas with no strong currents capable of bringing in detailed sand particles.

Referring again to Figure 8, specimens of Composita subtilita from the uppermost Speiser horizon become more abundant to the south; this trend is particularly noticeable in field collecting around the Kansas-Oklahoma border. Because this trend is not seen in other horizons to such a great extent, it seems likely that the southern part of the Wreford belt at that time was an area with large shell beds covering the floor of the Wreford sea. Derbyia sp. also is abundant here along with Composita subtilita.

Two calcareous shale horizons yielded large numbers of very small specimens of Composita subtilita; this "dwarfed" fauna might indicate that conditions had become unfavorable for survival of this species to fully adult maturity. However, a few large specimens are found there as well. There was no accompanying evidence of mass mortality of all forms at these horizons, so it seems unlikely that this occurrence results from drastic changes in the environment (such as water-quality changes or a large influx of sediment). Perhaps the large number of small specimens of this species simply indicate insufficient food resources to support such a large number of immature individuals until maturity.

SUMMARY AND CONCLUSIONS

1) Collections of brachiopods from the Lower Permian Wreford Megacyclothem in Nebraska, Kansas, and Oklahoma include large numbers of well preserved specimens of Composita.

2) Other widespread and abundant Wreford brachiopod groups include Derbyia and productids, with chonetids being somewhat less abundant and widely distributed. Minor Wreford brachiopod groups are Enteleles, Wellerella, Cleiothyridina (not previously reported from the Wreford, Orbiculoidea, Petrocrania, and Lingula. Semi-quantitative abundance estimates made for each of these Wreford brachiopod associates of Composita show variations which may well yield detailed understanding of the paleoecology and variability of each group.

3) Various standard techniques were employed to investigate the Wreford specimens of Composita. In addition, eleven numerical characters were defined and measured on each well-preserved specimen, thus generating quantitative data for analysis to better understand the paleobiology of this species.

4) The brachiopod genus Composita at any one Wreford stratigraphic horizon consists of various morphologically distinct forms, which have been treated by some previous workers as separate species, or as varieties within one species by others. The Wreford Composita population comprises an intergradational series of individuals not clearly separable into distinct groups which can be interpreted as separate species. Thus, I regard the two morphological end members of this continuously intergradational series as varieties of a single species, namely Composita subtilita var. subtilita, and Composita

subtilita var. ovata; thus the two "species" Composita subtilita and Composita ovata are synonymized for the Wreford population. This treatment is consistent with a more truly paleobiological understanding of the Composita population as a highly variable single species.

5) Systematic descriptions of Wreford Composita subtilita and its varieties, including summaries of numerical data, are given in this paper.

6) Analysis of the numerical characteristics of sub-samples consisting of well-preserved specimens of both varieties shows statistically significant differences between the varieties in some characters but not in others. The close similarity in absolute values of these characters, however, prevents biologically meaningful explanations for these statistical differences. Moreover, the two varieties do not differ as to their distribution and abundance in different Wreford rock types, stratigraphic horizons, or geographic regions. Thus, the varieties cannot be explained as ecotypes, evolutionary populations, or subspecies, and can only be regarded as intraspecific morphotypes.

7) Morphologic (especially numerical) characteristics of the entire Wreford Composita subtilita population as a whole were considered in order to determine whether differences due to paleoecological (lithologic), evolutionary (stratigraphic), or clinal (geographic) causes exist; however, none appear to be present.

8) The distribution and abundance of Composita subtilita in the Wreford Megacyclothem in particular rock types presumably reflects dependence on the environmental conditions of deposition

producing those rock types. The occurrences of this species in various rock types suggests that salinity or sediment influx was its principal limiting environmental factor.

9) Attachment of Composita subtilita by a pedicle, coupled with a lack of readily apparent methods of filtering out sand-size particles, suggest that areas where this species was abundant were not sites of strong currents capable of bringing in detrital sand particles.

10) A trend towards increasing abundance of Composita subtilita to the south in the uppermost Speiser implies that large shell beds covered the floor of the Wreford sea in the southern part of its geographic extent.

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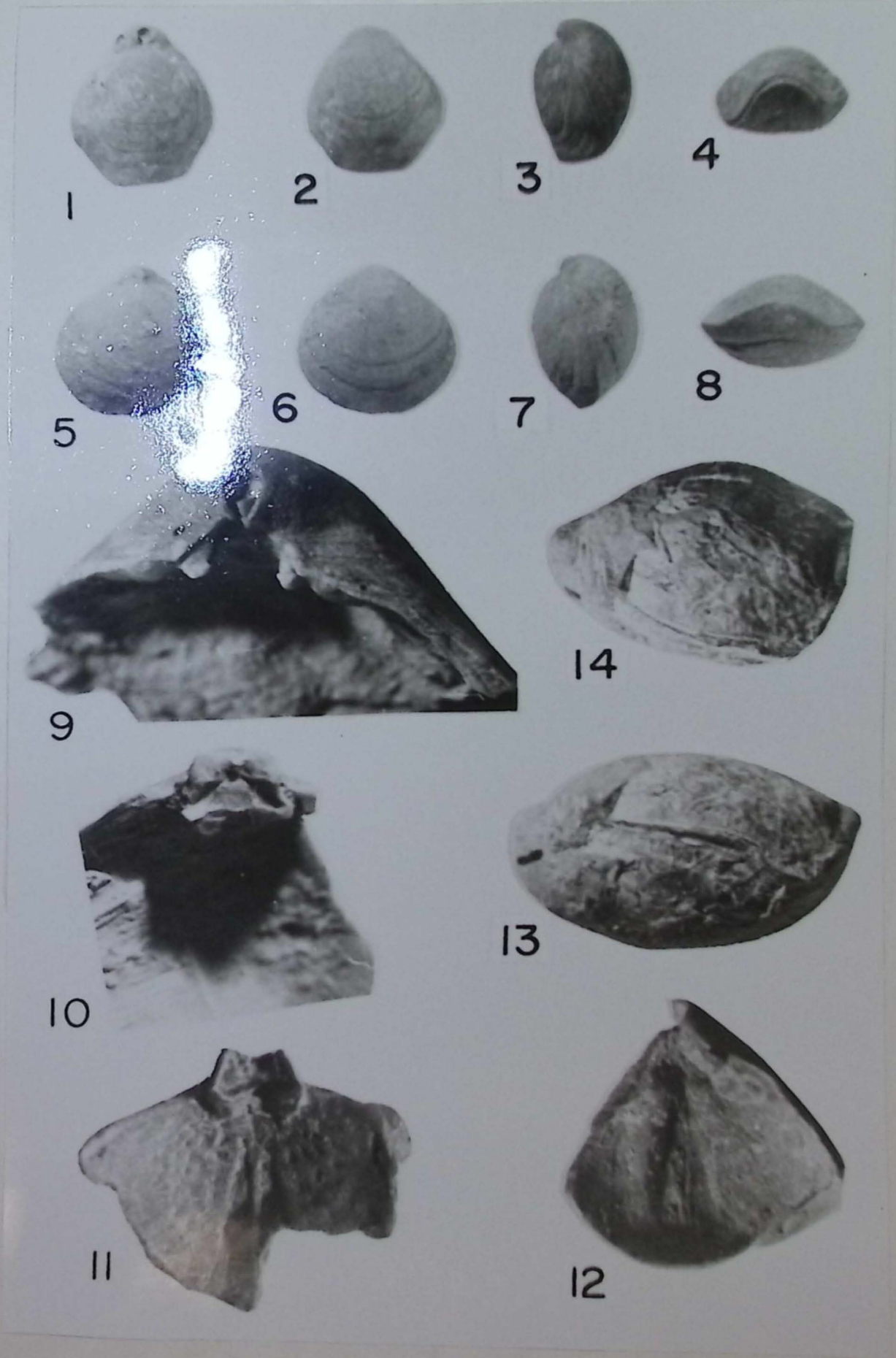
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EXPLANATION OF PLATE 1

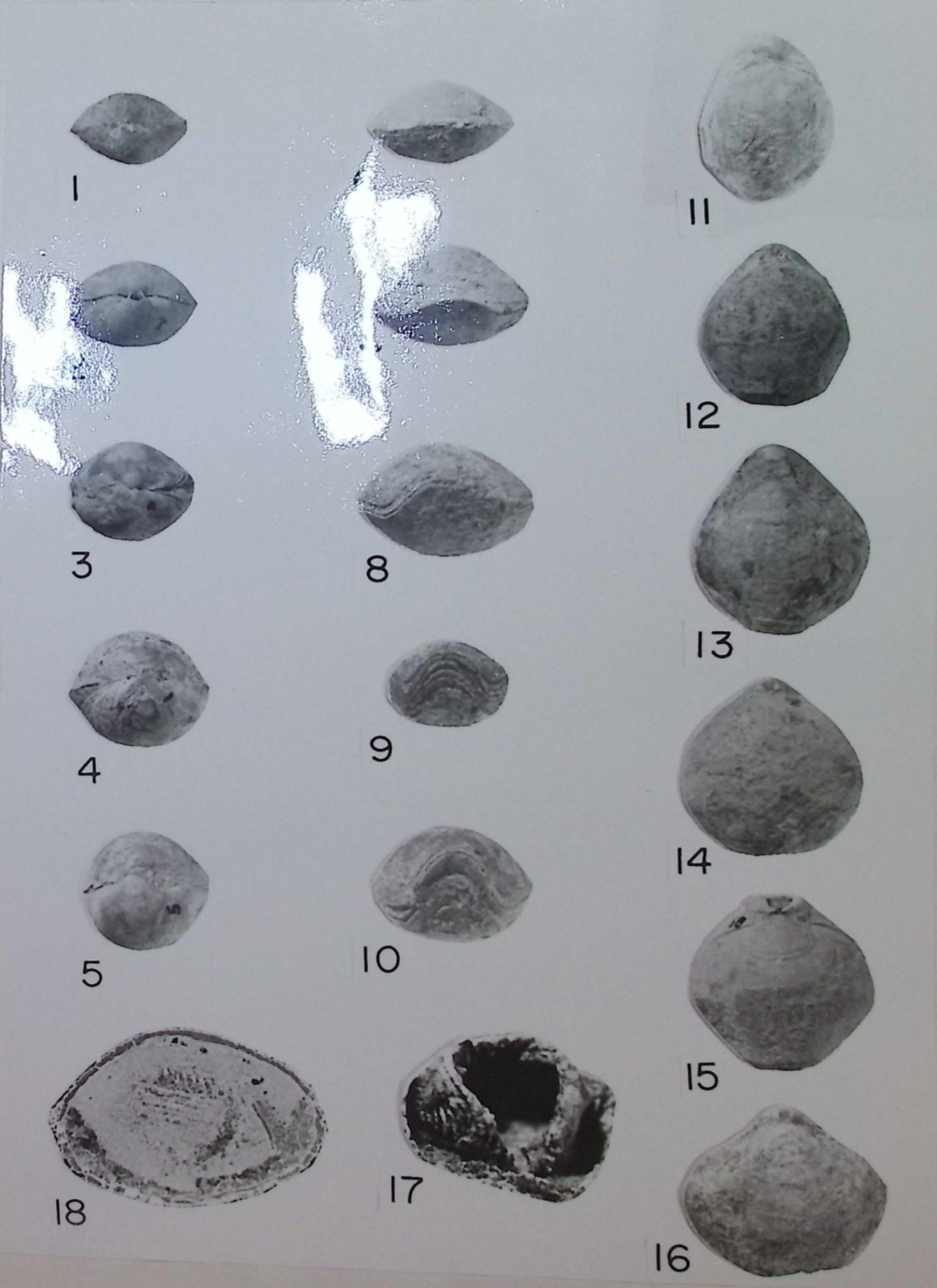
Composita subtilita from the Wreford Megacyclothem. 1-4, Composita subtilita var. subtilita: 1, dorsal view; 2, ventral view; 3, lateral view; 4, anterior view; specimen slightly asymmetrical from uneven growth; specimen KA08A-fl-04, (all X1); 5-8, Composita subtilita var. ovata: 5, dorsal view; 6, ventral view; 7, lateral view; 8, anterior view; specimen CH33D-fl-31, (all X1); 9, interior of pedicle valve showing oval pedicle opening (foramen), triangular delthyrium below pedicle opening, and hinge teeth, specimen CH33D-fl-03, (X3); 10, interior of brachial valve, showing subquadrate hinge plate, specimen CH33D-fl-07, (X3.5); 11, interior view of brachial valve of another specimen, showing hinge plate and elongate adductor muscle scars, specimen ML01D-fl-05, (X3.5); 12, interior of pedicle valve showing elongate adductor muscle scars and deep channel for pedicle muscles near pedicle opening, specimen CH33D-fl-06, (X2); 13-14, specimen showing internal mold of pallial sinuses: 13, lateral view, (X2.3); 14, oblique view of brachial valve, (X2); specimen CH22H-p-01. (Figured and cited specimens are housed in the Paleobryozoological Research Collection, Department of Geosciences, The Pennsylvania State University.)



EXPLANATION OF PLATE 2

(X1 unless otherwise indicated)

Composita subtilita from the Wreford Megacyclothem. 1-5, series of specimens showing a gradual increase in convexity of both valves from lens-shaped (1) to globular (5); specimens: 1, BU04P-p-03; 2, CY20Ha-p-02; 3, KA01J-fl-03; 4, CY46C-p-01; 5, KA01J-fl-05; 6-10, series of specimens showing a gradual increase in fold and sulcus height from very low (6) to very high (10); specimens: 6, CH18L-fl-01; 7, KA01J-fl-01; 8, KA08A-fl-01; 9, GRO1P-p-02; 10, KA01J-fl-09; 11-16, series of specimens showing a gradual change in shape from elongate (length greater than width) (11) to round (15) and elongate (width greater than length) (16); specimens: 11, KA01J-fl-05; 12, CY37Jb-p-02; 13, KA01J-fl-19; 14, CH16E-p-02; 15, KA01J-fl-18; 16, CY49B&A-fl-21; 17, specimen with outer part of shell eroded away, revealing laterally directed spiralia, probably in place, specimen CY04Cm3-p-01, (X2); 18, peel photograph, showing broken spiralia; left spiral is within right spiral, (X2).



APPENDIX A

DESCRIPTIONS OF MEASURED STRATIGRAPHIC SECTIONS OF
WREFORD ROCKS IN NORTHERN OKLAHOMA

Nine key sections of the Wreford Megacyclothem in Oklahoma are described here. The sections are presented in descending stratigraphic order, and individual units are numbered from the base upwards. Locations are given in Table 1 and shown on Figure 1 in the text; their correlation is indicated on Figure 5. This figure is a continuation into Oklahoma of the correlation of the Wreford Megacyclothem in Kansas by Hattin (1957, Plates 1, 2, 3). Insoluble residue percentages are indicated in parentheses at the end of the description of each unit.

Locality KA01

Unit

WREFORD LIMESTONE

Schroyer Limestone Member, 1.5 feet

thickness,
feet

10. Limestone, very poorly exposed, light grayish orange, speckled with rusty spots, weathers light to medium gray, thin- to medium-bedded, dense, hard, bored; FOSSILS, Derbyia, crinoid stems, (13%) 1.0

9. Covered 0.5

Havensville Shale Member, 3.6 feet

8. Covered 0.5

7. Limestone, light grayish-orange, weathers medium gray, bored, medium-bedded (>6"), rounded weathering, large borings (3"-4") enhanced by weathering; FOSSILS, algae, crinoid stems, echinoid spines, Composita, Derbyia, bryozoans, clams, (4%) 2.0

6. Limestone, shaly, nodular, light gray, weathers grayish orange to light brownish gray, thin-bedded, burrowed, medium hard; FOSSILS, Derbyia, productids, crinoid stems, pelecypods, gastropods, bryozoans, echinoid spines, (9%) 1.1

Threemile Limestone Member, 9.0 feet

5. Limestone, algal, light grayish orange with rust colored stains, weathers light to medium gray, dense, weathers rounded, bored, medium-bedded; FOSSILS, algae, Derbyia, crinoid stems, gastropods, bryozoans, echinoid spines, (1%) 1.5

	thickness, feet
4. Limestone, cherty, light gray, weathers grayish orange, thick-bedded, hard; CHERT, light to medium gray; upper third: FOSSILS, crinoid stems, productid spines, <u>Derbyia</u> (11%); middle third: FOSSILS, bryozoans, crinoid stems, <u>Derbyia</u> (13%); lower third: FOSSILS, <u>Derbyia</u> , <u>Composita</u> , bryozoans, productid brachiopods, echinoid spines, (42%)	4.0
3. Limestone, shaly, light yellowish-gray to medium yellowish-gray, weathers dark yellowish-gray, medium hard, (43%)	0.5
2. Shale, light grayish-yellow, weathers yellowish-brown, shaly-bedded, calcareous, medium hard, (45%)	1.0
1. Limestone, medium brown, weathers yellowish-brown, thick-bedded; FOSSILS, very common <u>Composita</u> , <u>Derbyia</u> , <u>Enteletes</u> , productid brachiopods, crinoid stems, bryozoans, pelecypods, (29%)	<u>3.5</u>
Total	14.1

Locality KA02

Unit

WREFORD LIMESTONE

Schroyer Limestone Member, 3.5 feet

20. Limestone, very poorly exposed, light yellowish-gray, weathers medium gray, thick-bedded, fitted weathering, burrowed, very fossiliferous; FOSSILS, algae, Derbyia, Composita, echinoid spines, crinoid stems, echinoid plates, bryozoans, (13%)
- 1.5

	thickness, feet
19. Shale? Covered	1.0
18. Limestone, very poorly exposed, light yellowish-gray, weathers medium gray, thick-bedded, pitted weathering, burrowed; FOSSILS, algae, (8%)	1.0
Havensville Shale Member, 7.4 feet	
17. Shale? Covered	1.0
16. Limestone, medium yellowish-brown, weathers grayish-brown, thin-bedded, pitted weathering, nodular, hard, (12%)	1.0
15. Limestone, light yellowish-white to light yellowish-gray, weathers medium gray, medium- to thick-bedded, hard, burrowed, rounded weathering, pitted where burrowed; FOSSILS, algae (<u>Osagia?</u>), <u>Derbyia</u> , echinoid spines, <u>Composita</u> , echinoid plates, crinoid stems, (18%)	2.0
14. Interbedded limestone and shale; limestone, light gray, weathers medium gray to grayish orange, nodular beds, medium-bedded, hard; shale, light gray, weathers medium gray, shaly-bedded; FOSSILS, limestone, vertical <u>Aviculopinna?</u> , crinoid stems, (13%)	1.6
13. Limestone, light gray, weathers grayish orange, hard, medium-bedded, slightly burrowed, abundant fossils; FOSSILS, Productids, <u>Composita</u> , <u>Derbyia</u> , echinoid spines, crinoid stems, bryozoans, vertical <u>Aviculopinna?</u> , (17%)	1.8

	thickness, feet
Threemile Limestone Member, 11.0 feet	
12. Shale, medium gray, weathers olive gray, medium hard, shaly-bedded, calcareous; FOSSILS, <u>Composita</u> , (47%)	0.2
11. Limestone, cherty, contains one chert bed at the bottom, and scattered chert nodules, light yellowish-gray, weathers grayish-orange, thick-bedded, hard, pitted weathering where exposed to weathering longest; CHERT, light to medium gray; FOSSILS, crinoid stems, bryozoans, <u>Composita</u> , fossil hash, (11%)	1.5
10. Limestone, cherty, with chert as scattered nodules, light gray to light yellowish-gray, weathers grayish-orange, thick-bedded, hard; CHERT, light to medium gray; FOSSILS, <u>Derbyia</u> , crinoid stems, bryozoans, fossil hash, (10%)	1.8
9. Limestone, with chert, light gray, weathers grayish-orange to yellowish-gray, thick-bedded, hard; CHERT, three nodular beds, non-calcareous, medium to light gray, other scattered chert nodules medium to light gray; FOSSILS, <u>Derbyia</u> , crinoid stems, bryozoans (fenestrate, branching), (31%)	2.0
8. Shale, olive-gray, weathers medium yellowish-gray to olive gray, shaly-bedded, grades down into shaly limestone below, medium hard; FOSSILS, rare, <u>Derbyia</u> , pelecypods, crinoid stems	0.1

thickness,
feet

7. Shaly limestone, light yellowish-gray to medium yellowish-gray mottled yellow to yellow white, weathers dark yellowish-gray, medium hard; FOSSILS, Composita, Derbyia, pelecypods, (56%) 0.3
6. Shale, light grayish-yellow, weathers yellowish-brown, shaly-bedding, calcareous, medium hard, silty (?), calcareous nodules present; FOSSILS, Chonetes, Derbyia, Composita, productids (uncommon), bryozoans, crinoid stems (lower half, 51%; upper half, 36%) 1.3
5. Limestone, light gray, weathers yellowish-gray or yellowish-brown, thick-bedded, upper 6" thin-bedded, about 8" from bottom, has a horizon with very abundant Composita, top half of unit more Derbyia-rich, pinna clams only in bottom 1.3'; FOSSILS, very abundant Composita, Derbyia, productids, vertical pinna clams, crinoid stems, gastropods, bryozoans (Rhombopora), (39%) 3.8
- SPEISER SHALE, 4.8 feet
4. Shale, contains lenticular limestone; shale, yellowish-brown, weathers dark yellowish-orange to rusty manganese stained, calcareous, shaly-bedded, very friable and weathers easily, sparsely fossiliferous; limestone, fossiliferous; FOSSILS, shale; Derbyia; limestone, Derbyia, (29%) 0.3

	thickness, feet
3. Limestone, light gray, weathers yellowish-brown, thick-bedded, upper part cross-bedded(?), weathers pitted, styolites present; FOSSILS, <u>Derbyia</u> , molluscs, (9%)	2.5
2. Shale, medium gray, calcareous, soft, shaly-bedded, unfossiliferous, (83%)	1.5
1. Shale, basal part covered, exposed portion is dusky red, mottled medium gray, calcareous, soft, shaly-bedded, unfossiliferous, (87%)	<u>0.5</u>
Total	26.7

Locality KA04

Unit

MATFIELD SHALE

Wymore Shale Member

WREFORD LIMESTONE

Schroyer Limestone Member

Havensville Shale Member, middle and upper

14. Limestone, undescribed 5.0

13. Sandstone, light red, quartzose, fine-grained, friable, thin bedded, unfossiliferous, (99%) 5.5

12. Covered, largely red shale (and sandstone??) 25.0

Havensville Shale Member, lower, 1.8 feet

11. Limestone, bored, light gray with many 1 mm. diameter dark rust spots, weathers medium gray to medium brown, rounded weathering, medium-bedded, hard, forms pavement

	thickness, feet
in field; FOSSILS, echinoid spines, algae, crinoid stems, <u>Derbyia</u> , <u>Composita</u> (some, small), (10%)	1.8
Threemile Limestone Member, 7.0 feet	
10. Limestone, contains chert, light yellowish-brown with many 1 mm diameter dark brown pellets (limonitized <u>Osagia</u>), weathers medium brown to yellowish-brown, chert is a 6" bed 1" up from base of unit, thin- to medium-bedded; CHERT, non-calcareous, nodular bedded, light yellowish-brown, weathers medium yellowish-brown, contains productid spines(?), small red spots (limonite??); FOSSILS, algae, (lower half, 53%; upper half (10%)	3.4
9. Shale, light grayish-brown, weathers to light gray, shaly-bedded, soft, friable, calcareous, powdery weathering, unfossiliferous, (lower half, 53%; upper half, 58%)	1.3
8. Limestone, light grayish-green, weathers light yellowish-gray, thick-bedded, hard; FOSSILS, very abundant <u>Composita</u> , <u>Derbyia</u> , productids, crinoid stems, bryozoans, rare vertical pinna clams, (22%)	2.3
SPEISER SHALE, 23.3 feet	
7. Shale, medium gray, weathers light yellowish-gray, shaly-bedded, calcareous; FOSSILS, <u>Derbyia</u> , bryozoans, pelecypods(?), (37%)	0.1
6. Shale, light grayish-yellow, mottled with light grayish-blue, calcareous, unfossiliferous, (74%)	0.1

	thickness, feet
5. Shale, medium reddish-brown, mottled with light grayish-green, weathers reddish-gray, shaly-bedded, calcareous, not resistant, unfossiliferous, (90%)	3.5
4. Covered	3.8
3. Sandstone, light reddish-purple, mottled with white in places, weathers light reddish-brown, cross-bedded, medium- to thick-bedded, fine-grained, quartzose, friable, unfossiliferous, (100%)	7.5
2. Covered	2.8
1. Sandstone, pale reddish-brown, weathers reddish-brown, thin-bedded, fine-grained, quartzose, friable, covered at bottom, unfossiliferous, (95%)	<u>5.5</u> <u>exposed</u>
	Total exposed 67.6

Locality KA05

Unit

WREFORD LIMESTONE

Schroyer Limestone Member, lower, 2.0 feet

- | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 11. Limestone float on butte top, algae, medium grayish-brown with dark brown spots closely spaced throughout, weathers medium brownish-gray, smooth weathering, bored, thin-bedded; FOSSILS, algae, vertical pinna clams, (10%) | 2.0 |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|

	thickness, feet
Havensville Shale Member, middle and upper, 5.0 feet	
10. Covered	5.0
Havensville Shale Member, lower, 2.2 feet	
9. Limestone, algal, light olive gray with some 1 mm. dark brown stains (not as many as in unit 11 above), weathers medium gray, vertically bored, rounded weathering, hard, dense; FOSSILS, algae, vertical pinna clams, <u>Composita</u> (?), (9%)	2.2
Threemile Limestone Member, 4.0 feet	
8. Limestone, algal (?), light gray with dark yellowish-brown limonitic (?) stains as small dots, weathers medium gray, hard, dense. FOSSILS, algae(?), molluscs(?), brachiopods(?), crinoid stems, (6%)	0.3-0.5
7. Limestone, shaly, light yellowish-gray, weathers grayish-orange, some yellowish-brown stains, medium hard, medium-bedded, not very resistant; FOSSILS, algae(?), crinoid stems, <u>Composita</u> (?), (17%)	0.6
6. Limestone, light grayish-brown, weathers light to medium grayish-brown (tending towards osagite?), hard, dense; FOSSILS, algae(?), <u>Derbyia</u> , <u>Composita</u> , crinoid stems, (9%)	0.2
5. Limestone, medium gray, weathers same with brown lichen, has dark brown 1 mm. to 1 cm. spots (<u>Osagia</u> ?), medium-bedded, bored, hard, dense; FOSSILS, algae, <u>Composita</u> , crinoid stems, molluscs, (9%)	0.5

	thickness, feet
4. Limestone, light brown, weathers light grayish-brown, occasional dark brown 1 mm. spots, lenticular thin- to medium-bedded, dense, top 1/2" is shaly parting; FOSSILS, algae(?), (7%)	2.3
SPEISER SHALE, 46.5 feet	
3. Covered, red soil	41.0
2. Sandstone, medium red laminated with dark red layers, weathers dark red, very finely laminated, slabby weathering, forms rubble covered slope, quartzose, poorly exposed, unfossiliferous, (99%)	5.5
FUNSTON LIMESTONE, 0.8 feet exposed	
1. Limestone, light gray, weathers dark gray, medium-bedded, hard, poorly exposed, lichen-covered	<u>0.8</u>
Total	60.5

Locality OS02

Unit

WREFORD LIMESTONE

Schroyer Limestone Member, lower, 2.8 feet

- | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 9. Limestone, very light gray with some yellowish gray staining, weathers light gray, fine-grained, brittle, dense, lower 0.5" thin-bedded, becomes very finely laminated 1.8' above base, upper foot medium-bedded, unfossiliferous, (lower part, 12%; upper part, 17%) | 2.8 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|

	thickness, feet
Havensville Shale Member, middle and upper, 4.0 feet	
8. Covered	4.0
Havensville Shale Member, lower, 2.5 feet	
7. Limestone, medium gray, weathers same, some orange staining, vertical borings, rounded weathering, small pits in weathered surface, thick-bedded but variable thickness (because bottom undulates); FOSSILS, algae, molluscs, vertical pinna clams, other pelecypods, <u>Derbyia</u> , <u>Composita</u> , crinoid stems, echinoid spines, (13%)	2.1-2.3
6. Limestone, algal, light gray, with yellowish-brown spots, weathers medium grayish-orange, shaly-bedded, variable thickness (undulating top and bottom surfaces); FOSSILS, algae, productids(?), (6%)	0.2-0.3
Threemile Limestone Member, 3.1 feet	
5. Limestone, moderately algal, medium gray, weathers medium dark gray, rarely geodal (siliceous), sugary texture, hard, fossils not obvious in field; FOSSILS, algae, (14%)	0.1
4. Limestone, algal, light yellowish-gray with some yellowish-brown spots (limonite?), weathers medium gray, rounded weathering, sometimes porous, hard, medium- to thick-bedded, pitted, bored; FOSSILS, algae, <u>Composita</u> , molluscs(?), (21%)	1.2

	thickness, feet
3. Limestone, algal, with a 1- to 2-inch shaly parting at top, light brownish-gray with common medium brown 1 cm. spots (limonite?), weathers yellowish-gray to medium gray, weathers rounded, thick-bedded, hard, includes abundant gastropods and pelecypods (coquinoid); FOSSILS, algae, gastropods, abundant pelecypods	1.8
SPEISER SHALE, 45.0 feet	
2. Covered, red soil, slabs of unit 3 above on surface	31.0
1. Interbedded shale and sandstone; shale, medium red, weathers same, shaly-bedded, medium hard, unfossiliferous; sandstone, finely laminated, white, fine-grained quartzose (from float), (100%)	<u>14.0</u>
Total	57.4

Locality OS03

Unit

WREFORD LIMESTONE

Schroyer Limestone Member

Havensville Shale Member, middle and upper

10. Covered, sandstone rubble to top of butte; sandstone, light tan, weathers dark gray to grayish-orange, orange lichen-covered, fine-grained, quartzose, bored, thin- to medium-bedded; FOSSILS, pelecypods, crinoid stems, (99%)	2.0
9. Covered	2.0

thickness,
feet

Havensville Shale Member, lower, 1.5 feet

8. Limestone, algal, with many fossil fragments, light grayish-orange to medium gray with some 1 mm. orange spots (limonitized Osagia?), weathers medium to dark gray, bored, medium- to thick-bedded, hard, ledge former, lower 0.3' shaly, upper 0.7' sandy and bored, middle 0.5' highly recrystallized, with some pockets of coquina 2-3" in diameter; FOSSILS, algae, pelecypods, crinoid stems, gastropods, echinoid spines, abundant shell cross sections and fragments throughout, (lower part, 14%; middle part, 21%; upper part, 28%) 1.5

Threemile Limestone Member, 2.2 feet

7. Limestone, algal, shaly, medium grayish-brown, some yellowish-brown limonitized Osagia, weathers medium gray, thin-bedded, somewhat more calcareous locally, somewhat less resistant to erosion than over- and under-lying units and so forms a re-entrant, locally slumped over and covered by more massive units above; FOSSILS, algae, (16%) 0.5
6. Limestone, slightly algal, medium grayish-brown, weathers medium gray, hard, slightly sandy, forma a ledge; FOSSILS, algae, pelecypods, (20%) 0.4
5. Limestone, rarely algal, medium grayish-brown with medium brown 1 mm. blotches (limonitized Osagia), weathers dark gray, slightly bored, hard, lower half medium-bedded,

	thickness, feet
upper half thin-bedded; FOSSILS, algae, pelecypods, brachiopods(?), (upper part, 37%)	1.3
SPEISER SHALE, 54.1 feet	
4. Covered	24.8
3. Shale, poorly exposed, medium red brown; soil medium red brown, clayey, probably not thick (shale near surface), (90%)	2.0
2. Covered	24.8
1. Sandstone, dark red brown, weathers same, fine- grained, quartzose, medium-bedded, slightly friable, unfossiliferous, (99%)	2.5 <u>exposed</u>
	Total exposed 61.8

Locality PW01

Unit

WREFORD LIMESTONE

Havensville Shale Member, lower, 1.5 feet

3. Limestone, sandy, light gray, with dark brown blotches more unevenly distributed than in lower units (2-3 mm. diam.), weathers medium gray with some red staining, sandy textured, recrystallized, hard, sandy partings in places, has some rare red shale chips, borings, lenses of pelecypod coquina, lower half more sandy than upper half and can be regarded as sandstone; FOSSILS, pelecypods, (lower part, 100%, upper part, 61%) 1.5

thickness,
feet

Threemile Limestone Member, 4.2 feet

- | | | |
|----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| 2. | Sandstone, calcareous; lower 1.5' medium red brown with some white mottling, weathers dark red, has many small (1 mm. dark brown blotches, medium-bedded, friable; upper 1.7' light grayish-orange to red with some white mottling, large dark brown blotches (2-3 mm.), weathers dark red brown, thin-bedded, friable; both sections very weathered, contain burrow fillings and borings; FOSSILS, pelecypods(?), (lower half, 100%; upper half, 100%) | 3.2 |
| 1. | Sandstone, calcareous, light gray with some dark brown blotches, weathers light grayish-orange, has some limestone nodules, medium-bedded, red-stained, medium hard, blocky outer surface, weathered surface (1/2") sandy from loss of carbonate; FOSSILS, pelecypods, (58%) | 1.0
<u>exposed</u> |
| | Total exposed | 5.7 |

Locality PW02

Unit

- | | | |
|-----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
| 12. | Sandstone, medium brown red with dark brown 1-2 mm. blotches, weathers same to dark red brown, well developed cross beds, thick-bedded, moderately friable, slightly calcareous, unfossiliferous, (94%) | 4.9-5.0 |
|-----|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|

thickness,
feet

11. Shale, red brown, purple and yellow mottled, weathers red brown, shaly-bedded, not resistant, unfossiliferous, has a small limestone layer 1' from sandstone, which thickens from 1" to 2" in 15' from north to south, (100%) 3.7

Havensville Shale Member, 0.8 feet

10. Sandstone, very calcareous, light gray mottled yellowish-gray, weathers grayish red, forms a resistant ledge, very hard, dense, 2" thick; 10' to the south unit becomes limestone, shaly, 4" thick, contains abundant molluscs, dark reddish-purple with limonite and hematite stains common, weathers medium reddish-brown; FOSSILS: sandstone, pelecypods(?); limestone, pelecypods, gastropods, crinoids, (48%) 0.2-0.3
9. Shale, reddish purple with some limonite staining, shaly-bedded, unresistant, non-calcareous, unfossiliferous, (96%) 0.3
8. Sandstone, light grayish-blue with limonite staining, weathers yellowish-brown, may be stained red from above units, fine-grained, quartzose, thin-bedded, calcareous, not very resistant, burrowed(?); FOSSILS, pelecypod molds(?), (98%) 0.3

Threemile Limestone Member, 3.1 feet

7. Shale, variegated reddish-purple, grayish-blue, moderate yellow, green, weathers reddish-brown and blue, shaly-bedded, not resistant, non-calcareous, unfossiliferous,

	thickness, feet
contains some lenticular light grayish-blue sandstone lenses (like unit 8) at base, (94%)	2.6
6. Limestone, similar to unit 10 above, looks conglomeratic, medium yellowish-gray, weathers grayish-blue to moderate yellow, heavily stained with limonite, outer 1/2" stained grayish-blue, medium-bedded, recrystallized; FOSSILS, gastropods, pelecypods, (38%)	0.5
SPEISER SHALE, 5.4 feet	
5. Shale, medium reddish-brown, weathers same, very slightly calcareous, shaly-bedded, not resistant, unfossiliferous, (97%)	1.7
4. Sandstone, light grayish-blue, weathers same, red stained, calcareous, fine-grained, quartzose, thin-bedded, unfossiliferous, (100%)	0.1
3. Shale, calcareous, medium reddish-brown, weathers same, shaly-bedded, unresistant, unfossiliferous	0.3
2. Sandstone, light grayish-blue, stains red from above units, calcareous, cross-bedded, fine-grained, quartzose, mud cracks, rain-drop imprints(?), unfossiliferous, (97%)	0.8
1. Shale, medium reddish-brown, some yellow stains, weathers same, shaly-bedded, hard, more resistant than other shales of section, blocky when breaks, calcareous, unfossiliferous, (100%)	<u>2.5</u>
Total exposed	18.0

thickness,
feetLocalities N001 and N002 combined

Unit

1. Sandstone, medium reddish-brown to light brown,
thin- to shaly-bedded, fine-grained, quartzose,
moderately friable, unfossiliferous, (100%) . 5 exposed

Locality 0137

Unit

WREFORE LIMESTONE

- 15. Limestone, light, with very well-developed nodules
- 14. Shale, calcareous, upper part sandy limestone, yellow brown
- 13. Limestone, cherty
- 12. Shale, calcareous

APPENDIX B

MEASURED SECTIONS OF ADDITIONALLY INFORMATIVE LOCALITIES IN SOUTHERNMOST KANSAS AND NORTHERN OKLAHOMA

- 9. Limestone, light, with nodules
- 8. Limestone, cherty
- 7. Limestone, thin-bedded, weathered gray
- 6. Limestone, cherty, chert only in some places

WREFORE SHALE

- 5. Shale, calcareous
- 4. Limestone, argillaceous
- 3. Shale, calcareous, with some thin limestone, grayish-blue
- 2. Shale, gray
- 1. Interbedded red shale and red limestone

Locality CY37

Unit

WREFORD LIMESTONE

	thickness, feet
15. Limestone, algal, with very well-developed burrows	2.0
14. Shale, calcareous, upper part shaly limestone, medium brown	1.5
13. Limestone, cherty	3.0
12. Shale, calcareous, gray, silty	1.5
11. Limestone, algal, with well-developed burrows	2.0
10. Limestone, nodular, shaly at base	1.5
9. Limestone, algal, with burrows	2.0
8. Limestone, cherty	13.0
7. Limestone, thin-bedded, weathers shaly	2.0
6. Limestone, cherty, chert only in minor amounts	3.0
SPEISER SHALE	
5. Shale, calcareous	0.1
4. Limestone, argillaceous	1.0
3. Shale, calcareous, with some shaly limestone, grayish-blue	4.0
2. Shale, gray	1.5
1. Interbedded red shale and red sandstone	20.0 <u>exposed</u>
Total	58.1

thickness,
feetLocality CY44

Unit

KINNEY LIMESTONE MEMBER

- | | |
|--------------------------------------|-----|
| 6. Limestone, molluscan, thin-bedded | 1.0 |
|--------------------------------------|-----|

WYMORE SHALE MEMBER

- | | |
|--------------------------------------|-----|
| 5. Shale to mudstone, grayish-yellow | 5.0 |
| 4. Covered | 6.0 |
| 3. Shale, red | 2.0 |
| 2. Covered, red shale float | 2.0 |

WREFORD LIMESTONE

- | | |
|-----------------------------------|------|
| 1. Limestone, algal, with burrows | 1.0 |
| Total exposed | 17.0 |

Locality CY45

Unit

WREFORD LIMESTONE

- | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 17. Chert float at top | |
| 16. Limestone, algal, medium gray with some orange staining, weathers light gray, thick-bedded, very hard, burrowed, rounded weathering, deeply weathered; FOSSILS, <u>Derbyia</u> , crinoid stems, echinoid spines, and plates, bryozoans | 1.0 |
| 15. Limestone, cherty, medium gray, weathers light grayish-orange, thin- to medium-bedded, hard, deeply weathered; CHERT, dark gray, weathers dark orange, deeply weathered, nodular in one bed; FOSSILS: limestone, echinoid spines, | |

thickness,
feet

- crinoid stems, bryozoans, Composita, productids,
pelecypods; chert, crinoid stems, productid spines,
Composita 1.8
14. Limestone, cherty, lower 8 inches contains calcareous
chert as nodular beds, one non-calcareous chert bed
6 inches from top, light gray, medium grayish-orange,
medium- to thick-bedded, hard; CHERT, lower, medium
gray, weathers light gray with orange staining; upper,
dark gray, weathers medium gray, with orange staining;
FOSSILS, limestone, crinoid stems, echinoid plates,
bryozoans, pelecypods, gastropods, Derbyia, productids,
Composita, chert, productid spines 1.3
13. Limestone, cherty, chert in very elongate nodules,
medium gray, weathers light grayish-orange, medium- to
thick-bedded, stylolitic layer 5 inches from top; CHERT,
dark gray, weathers medium gray, stains orange;
FOSSILS, limestone, crinoid stems, Derbyia; chert,
productid spines, bryozoans 1.8
12. Limestone, cherty, chert nodules in 5 crude beds, and
one continuous chert layer at top of unit, light brown,
weathers grayish-orange, thick-bedded, hard; CHERT,
light to medium gray, stains orange, productid spines
within and surrounding chert nodules; FOSSILS, crinoid
stems, echinoid spines, productid spines, productids,
bryozoans, gastropods 2.4

thickness,
feet

11. Shale, calcareous, upper 6 inches shaly limestone, light gray, weathers light grayish-orange, shaly-bedded, not very resistant, upper part more resistant and medium hard; FOSSILS, productids, chonetids, Derbyia, bryozoans 1.6
10. Limestone, medium gray, weathers yellowish-gray, medium-bedded, hard; FOSSILS, very abundant, Derbyia, Composita, productids, crinoid stems, pelecypods 1.5

SPEISER SHALE

9. Limestone, shaly, light gray, weathers yellowish-gray, shaly bedded, variable thickness, locally slightly more calcareous and very similar to beds above and below, gradational boundary to bed below; FOSSILS, Composita, Derbyia, rare productids, bryozoans 0.3-0.4
8. Limestone, yellowish-gray, weathers same, medium-bedded, hard, very fossiliferous; FOSSILS, Composita, Derbyia, crinoid stems, bryozoans
7. Interbedded shale and shaly limestone, mostly shale, some nodular limestone layers; shale, light to medium yellowish-gray, weathers same, shaly-bedded; limestone, medium gray, weathers yellowish-gray, thin- to medium-bedded, forms small resistant ledges; FOSSILS, Derbyia, productids, Composita, pelecypods, gastropods 2.3

	thickness, feet
6. Shale, medium grayish-yellow mottled with medium gray, weathers yellowish-gray, shaly-bedded, crumbly, not resistant, no fossils	0.3
5. Shale, medium grayish-green, weathers same, shaly-bedded, crumbly, non-resistant, no fossils	0.9
4. Sandstone, medium reddish-brown, weathers light reddish brown, thin-bedded, lenticular, not very resistant, friable, quartzose, fine-grained, no fossils	2.0
3. Shale, medium reddish-brown, weathers same, shaly-bedded, not resistant, no fossils	11.0
2. Sandstone, light reddish-brown, weathers medium reddish-brown, quartzose, fine-grained, cross-bedded, friable, slightly pitted (burrows?), channel?, no fossils	2.8
1. Shale, medium reddish-brown, shaly-bedded, not resistant, no fossils	<u>3.0</u>
Total	35.9

Locality CY46

Unit

WREFORD LIMESTONE

12. Covered	3.0
11. Limestone, dense, gray	0.5
10. Covered	2.0
9. Limestone, dense, gray, very poorly exposed	0.5

	thickness, feet
8. Covered (cherty?)	2.5
7. Limestone, cherty, poorly exposed, badly weathered, chert as nodules	3.5
6. Covered	1.0
5. Limestone, shaly, dark gray; FOSSILS, abundant <u>Composita</u>	1.0
4. Limestone, gray; FOSSILS, abundant <u>Composita</u> , productids, crinoid stems	1.5
SPEISER SHALE	
3. Interbedded shale and shaly limestone; FOSSILS: shale, rare <u>Derbyia</u> ; limestone, <u>Composita</u> , <u>Derbyia</u> , pelecypods	2.5
2. Covered (grayish-yellow mudstone?)	0.2
1. Interbedded red shale and sandstone; sandstone, red mottled with dark yellowish-orange, upper 4 feet	<u>6.0</u>
	Total exposed 24.2

Locality CY47

Unit

WREFORD LIMESTONE

8. Limestone, algal, rounded weathering, top not exposed	1.0
7. Limestone, cherty, medium-bedded, one chert layer; FOSSILS, <u>Composita</u> , echinoid spines, bryozoans, pro- ductid spines, <u>Derbyia</u>	1.3
6. Limestone, cherty, non-calcareous chert in top 4 inches, calcareous chert in lower 10 inches	1.2

	thickness, feet
5. Limestone, cherty, chert as scattered nodules	1.7
4. Limestone, cherty, one chert bed at top, and chert as scattered nodules	2.3
3. Shale, calcareous, very poorly exposed, upper 1 inch is shaly limestone; FOSSILS, bryozoans	1.0
2. Limestone, shaly; FOSSILS, <u>Derbyia</u> , pelecypods	0.5
1. Limestone, gray, bottom not exposed; FOSSILS, bryozoans, pelecypods, crinoid stems	<u>1.0</u>
	Total exposed 10.0

Locality CY48

Unit

WREFORD LIMESTONE

10. Covered	5.0
9. Limestone, algal, weathers very light gray, rounded- weathering, bored; FOSSILS, bryozoans, crinoid stems, echinoid spines, gastropods	1.4
8. Limestone, cherty, chert as scattered nodules, middle part less cherty than top and bottom; FOSSILS, productid spines (in chert), bryozoans, pelecypods, <u>Derbyia</u>	6.5
7. Shale, calcareous, yellow-brown, more calcareous in upper 1 inch; FOSSILS, productids, crinoid stems, bryozoans, <u>Derbyia</u>	0.5
6. Limestone, shaly, yellow-brown; FOSSILS, <u>Composita</u> , <u>Derbyia</u> , <u>Enteletes(?)</u> , productids, pelecypods,	0.5

	thickness, feet
5. Limestone, gray, medium-bedded; FOSSILS, <u>Composita</u> , <u>Derbyia</u> , crinoid stems, pelecypods	1.5
<u>SPEISER SHALE</u>	
4. Covered	1.5
3. Shale, grayish-yellow	0.5
2. Shale, grayish-green	0.4
1. Shale, red	<u>5.0</u>
Total	22.8

Locality CY49

Unit

WREFORD LIMESTONE

12. Covered. Chert float	3.0
11. Limestone, light gray, weathers medium grayish-orange, medium-bedded, medium hard	2.0
10. Covered	2.0
9. Limestone, light gray, weathers, medium gray, medium- bedded, hard	1.0
8. Covered	0.8
7. Limestone, cherty, light gray, deeply weathered to medium gray, medium- to thick-bedded, hard, rounded- weathering, appears algal but not algal, chert as uncommon nodules; CHERT, medium gray, weathers orange, has productid spines; FOSSILS, productids, crinoid stems	2.3

	thickness, feet
6. Limestone, cherty, no fresh color seen, deeply weathered to medium brown, medium-bedded, chert in 4 nodular layers, one at top of bed; CHERT, dark gray with white productid spines, weathers reddish-brown; FOSSILS, bryozoans, productid spines, echinoid spines, crinoid stems	2.3
5. Shale, calcareous, very poorly exposed, fresh color not seen, weathers light reddish-brown, shaly-bedded, not very resistant; FOSSILS, <u>Enteleles</u>	0.4
4. Limestone, light gray, weathers light grayish-orange, medium hard; FOSSILS, crinoid stems, bryozoans, <u>Derbyia</u>	0.3
3. Shale, calcareous, very poorly exposed, fresh color not seen, weathers light reddish-brown, shaly-bedded, not very resistant; FOSSILS, <u>Enteleles</u>	0.5
2. Covered	0.8
1. Limestone, medium gray, weathers light to medium gray, medium-bedded, hard; FOSSILS, very abundant <u>Composita</u> , crinoid stems, productids, rare <u>Enteleles</u> , <u>Derbyia</u> , bryozoans	<u>2.0</u>
Total	17.1

thickness,
feetLocality KA03

Unit

THREEMILE LIMESTONE

- | | |
|----------------------------------------------------------------------------------------------------------------------------------------|-----|
| 6. Limestone, gray, no chert; FOSSILS, <u>Derbyia</u> ,
<u>Composita</u> , pelecypods; in lower part only, productids,
bryozoans | 2.5 |
|----------------------------------------------------------------------------------------------------------------------------------------|-----|

SPEISER SHALE

- | | |
|----------------------------------------------------------------------------|------|
| 5. Covered | 5.0 |
| 4. Covered, with red shale and red sandstone float | 10.0 |
| 3. Sandstone, some sandy shale, not well exposed,
some vertical burrows | 5.0 |
| 2. Covered | 15.0 |

FUNSTON LIMESTONE

- | | |
|-----------------------------------------------------------------|------------|
| 1. Limestone, reddish-gray; FOSSILS, gastropods,
brachiopods | <u>2.0</u> |
|-----------------------------------------------------------------|------------|

Total exposed	39.5
------------------	------

Locality KA06

Unit

- | | |
|------------------------------------------------------------------------------------------------|----------------|
| 1. Shale, dark reddish-brown, shaly-bedded, calcareous,
not very resistant, unfossiliferous | 2.0
exposed |
|------------------------------------------------------------------------------------------------|----------------|

Locality KA07

Unit

WREFORD LIMESTONE

Schroyer Limestone Member

- | | |
|-------------------------------------------------------------|--|
| 7. Limestone, light brown, weathers same, some light yellow | |
|-------------------------------------------------------------|--|

thickness,
feet

spots (calcareous chert?), thin-bedded, brittle,
very poorly exposed, some shell fragments seen

0.3
exposed

6. Limestone, cherty, very light gray, some light orange staining, weathers light to medium gray, rare 1 mm orange spots, thick-bedded, smooth rounded-weathering, slightly algal, bored, medium hard, some chert within upper 3-4 inches as small nodules; CHERT, slightly calcareous, light orange, weathers medium orange, 1-inch nodular bed, some fossils; FOSSILS, Derbyia, productids, algae, Composita, pelecypods, crinoid stems

2.3

Havensville Shale Member

5. Limestone, light to medium gray, with orange spots (1 mm), weathers medium gray, thick-bedded, hard, bored, algal, lower 2.9 feet has fewer fossils and more borings than upper 1.1 feet, the two parts separated by a very thin shaly parting, fossils not common; FOSSILS, echinoid spines and plates, algae, crinoid stems, productids, Composita, other shell fragments
4. Limestone, nodular, variable thickness, light gray, weathers medium gray, thin- to medium-bedded, interbedded with shale, hard, top and bottom bedding planes wavy, shale forms thin partings between limestone beds;

3.0

	thickness, feet
FOSSILS, crinoid stems, bryozoans, productids, pelecypods	0.5-1.0
3. Limestone, with a 1-inch shaly parting at base, medium gray, weathers light to medium gray, medium- to thick-bedded, hard, base of unit very shaly, wavy-bedded, contains abundant fossils and fossil debris, FOSSILS, crinoid stems, bryozoans, productids, <u>Composita</u>	1.0
Havensville Shale Member	
Threemile Limestone Member	
2. Limestone, cherty, light to medium gray, weathers medium gray, thick-bedded, hard; CHERT, upper bed 20 inches from base of unit, 3 inches thick; a lower bed 11 inches from base, 2 inches thick; above and below lower chert, a few scattered chert nodules; chert, medium to dark gray with dark and light areas (productid spines(?), crinoid stems), weathers medium gray, hard; FOSSILS, crinoid stems, bryozoans, <u>Derbyia</u> , <u>Composita</u> (?)	3.8
1. Limestone, slightly shaly, cherty, light gray, weathers medium gray, thick-bedded, fine-grained, hard, 1 chert bed and scattered nodules; CHERT, forms a 3 inch layer at top of unit, dark gray to light grayish-blue, with white fragments (productid spines); FOSSILS, crinoid stems	<u>2.3</u>
Total exposed	13.7

thickness,
feetLocality KA08

Unit

WREFORD LIMESTONE

8. Limestone, algal, bored, rounded-weathering; FOSSILS,
crinoid stems, echinoid spines, productids,

Composita

1.5

Threemile Limestone Member

7. Limestone, cherty, thin- to medium-bedded, occasional
chert nodules; FOSSILS, crinoid stems, echinoid
spines, Derbyia, Composita

4.5

6. Shale, calcareous; FOSSILS, bryozoans, Composita

0.7

5. Limestone, medium gray, bottom not exposed; FOSSILS,
bryozoans, crinoid stems, productids, Derbyia,

Composita1.2
exposed

4. Covered. Red sandstone float and float from unit 8
on surface

41.0

SPEISER SHALE

3. Interbedded red shale and sandstone

5.0

2. Limestone, undescribed

1.0

1. Shale, red

4.0Total
exposed 61.9

thickness,
feetLocality OS01

Unit

MATFIELD SHALE

6. Sandstone, white	2.0
5. Shale, variegated reddish-gray and yellowish-brown; FOSSILS, lower part, pelecypods, productids, crinoid stems, <u>Orbiculoidea</u>	12.0
4. Limestone	3.0
3. Shale, red	10.0

THREEMILE LIMESTONE

2. Limestone, lower part osagite	5.0
1. Red shale	<u>10.0</u>
Total	42.0

Locality OS04

Unit

WREFORD LIMESTONE

6. Chert float at top of section	
5. Limestone, algal, light gray with some reddish-brown blotches (2-3 mm), weathers light to medium gray, thick- bedded, hard, burrowed, rounded weathering; FOSSILS, algae, echinoid plates and spines, gastropods, <u>Composita</u> , pinna clams, productids, <u>Derbyia</u>	1.9

thickness,
feet

Threemile Limestone Member

- | | | |
|----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| 4. | Limestone, apparently non-cherty, very light gray, weathers medium to dark gray, medium-bedded, hard; FOSSILS, crinoid stems, echinoid fragments, bryozoans, <u>Composita</u> , productids | 2.5 |
| 3. | Limestone, cherty, very deeply weathered, grayish-orange-pink with dark gray 1 mm blotches, weathers grayish-orange to dark gray, medium- to thick-bedded, chert mostly in nodules; CHERT, light grayish orange with some dark gray 1 mm blotches, some orange staining, one nearly continuous bed 3" from top; FOSSILS, bryozoans, <u>Composita</u> , crinoid stems, pelecypods | 2.2 |
| 2. | Limestone, shaly, very light brown with dark gray blotches less than 1 mm (dendrites?), thin-bedded, irregular nodular beds, crumbly, hard, brittle, forms depressed zone of weathering, commonly grassed over; FOSSILS, bryozoans, pelecypods | 1.3 |
| 1. | Limestone, pinkish-gray, weathers medium to dark gray, medium- to thick-bedded, hard; FOSSILS, crinoid stems, <u>Composita</u> , <u>Derbyia</u> , productids | <u>3.0</u> |
| | Total | 10.9 |

thickness,
feetLocality OS05

Unit

WREFORD LIMESTONE

Threemile Limestone Member

- | | |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----|
| 3. Shale, red, undescribed. | |
| 2. Limestone, light gray with some dark gray dendrites(?), weathers dark grayish-orange to dark gray, some red staining from red shale above, medium-bedded, hard; upper part is a smooth weathering osagite; lower part is less algal, more micrite, more crumbly; FOSSILS, algae, echinoid spines, brachiopods, bryozoans, some forams | 1.5 |
| 1. Shale, red, undescribed | — |

Total exposed	1.5
---------------	-----

Locality PW03

Unit

Speiser Shale horizon

- | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|
| 1. Interbedded sandstone and shale; sandstone, medium reddish-brown mottled with grayish-green, has small (1 mm) dark brown spots (limonitized <u>Osagia?</u>), thin-bedded to cross-bedded, friable, fine-grained, quartzose, unfossiliferous; shale, variegated colors, medium reddish-brown, light to medium grayish-green, shaly-bedded unfossiliferous | 20.0 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------|

APPENDIX C

WREFORD ROCK TYPES - CHARACTERISTICS AND
INFERRED PALEOENVIRONMENTAL IMPLICATIONS

The rock types found in the Wreford Megacyclothem are best developed in Kansas, where they have been studied extensively and found to be typical of Early Permian marine cyclothem there. The rock types will be briefly described here; further details may be found in papers by Hattin (1957), Cuffey (1967), and Newton (1971). The order in which the rock types are presented is approximately the order in which they would occur in a transgressive hemicyclothem (i.e., the lower half of a cyclothem). Absolute depths of water for the depositional environments of some of these rock types are reported here, but are of course subject to later revision as the paleoenvironments are more thoroughly studied.

CHANNEL CONGLOMERATE

In the Speiser Shale are occasional thin lenses of greenish gray, calcareous, thin- to medium-bedded, limestone-, shale-, and chert-pebble conglomerate. At some localities (LY02, for example), the conglomerate contains abundant fragmentary vertebrate remains, probably similar to those mentioned by Rasmussen et al, 1971 (and mentioned in the text). This rock type was probably deposited in stream channels on a coastal plain or in marginal marine waters (Cuffey, 1967, p. 11; Newton, 1971, p. 7).

CHANNEL SANDSTONE

Channel sandstones are lenticular, yellowish-gray, friable to well cemented, very fine- to fine-grained, thin-bedded to massive, unfossiliferous sandstones. The sand grains are predominantly quartz, usually angular because of secondary crystal growth. They are probably also stream channel or marginal marine deposits (Hattin, 1957, p. 82-83; Cuffey, 1967, p. 11; Newton, 1971, p. 7). This rock type should probably be combined with the widely developed red sandstone of the northern Oklahoma Wreford (described in the text), because these channel sandstones are found only in southernmost Kansas as the northernmost edge of that red sandstone-red shale complex.

RED SHALE

Red shales are characteristic of the middle parts of the Speiser and Wymore shales. They are pale red to dusky red, calcareous, silty, shaly-bedded mudstones or shales which tend to weather blocky. They lack primary structures and are usually unfossiliferous. The red shales are thus probably subaerial coastal plain deposits (Hattin,

1957, p. 83-85; Lane, 1964, p. 16; Newton, 1971, p. 7), although they have also been interpreted as marine deposits formed as mud flats in the high intertidal zone (Lane, 1958, p. 150, 157; McCrone, 1963, p. 64, 65).

GREEN SHALE

The green shale ranges from grayish-yellow green to grayish-green, and is silty, moderately calcareous, blocky weathering, shaly-bedded mudstone or shale. It is sparsely fossiliferous, containing ostracods, charophyte oogonia, vascular plant remains, gastropods, and vertebrate fragments. This biota indicates a marine environment that probably was very shallow, nearshore, brackish water. Depth of water may have been up to 30 feet (as suggested by Hattin, 1957), or less than 2 or 3 feet in the intertidal zone (Newton, 1971, p. 8).

BLACK SHALE

Black shale is a rare Wreford rock type occurring as local thin beds in the Speiser Shale (Cuffey, 1967, p. 11). It is black, soft shale with carbonized plant remains; it may have been deposited in poorly oxygenated, very shallow water as mud rich in organic material.

COAL

Coal occurs infrequently as thin, local lenses in the Speiser Shale (Cuffey, 1971, p. 11). It probably formed as local accumulations of plant debris in shallow water.

ARGILLACEOUS LIMESTONE

Noncherty argillaceous limestones are found in various parts of the Wreford, usually in shale sequences, and have various lithologic

characteristics. They seem to be merely sections of the surrounding rock with a higher calcareous content than usual.

GRAYISH-YELLOW MUDSTONE

The grayish-yellow mudstone is grayish-yellow, yellowish-brown, dusky yellow, or olive-gray, silty, calcareous, shaly-bedded mudstone, shale, or argillaceous limestone. Usually this rock type is sparsely fossiliferous and contains arenaceous forams, ostracods, productid brachiopod spines, and occasionally bryozoans, pelecypods, echinoderm fragments, and vertebrate fragments. Hattin (1957, p. 85, 86) concluded that the environment of deposition for this rock type was slightly deeper and more saline than the green shale. Elias (1937) originally had suggested depths of 30 to 60 feet, which now seem too deep in view of later work.

INTRAFORMATIONAL BRECCIA

Intraformational breccia occurs at a few localities (CH18, CH19, CH20) in the upper part of the Havensville Shale Member. It is thin, light gray to light brown, unfossiliferous, and has flattened angular pebbles of very calcareous mudstone or very argillaceous limestone, in a matrix of a similar character. It may have originated when storm waves disturbed the shallow sea bottom.

MOLLUSCAN LIMESTONE

The molluscan limestone is a yellowish-gray to dark gray, silty, clayey, finely granular, shaly- to thick-bedded limestone. The diagnostic megafossils are the pelecypods Aviculopecten and Septimyalina, which give the rock its name. In thin section,

molluscan limestones are pelecypod-brachiopod sparse to packed biomicrites (Cuffey, 1967, p. 11); they may contain in addition intraclasts and oolites. Many fossils are found in these rocks, especially arenaceous forams, bryozoans, brachiopods, molluscs, ostracods, and crinoid fragments (Hattin, 1957, p. 58). These rocks were deposited in shallow, brackish marine waters about 10 to 60 feet deep (Elias, 1937, thought depth was 60 to 90 feet).

ALGAL LIMESTONE

In regressive hemicycles in the Wreford Megacyclothem the position of the molluscan limestone phase is represented instead by algal limestone. This is yellowish-gray, grayish-yellow, or yellowish-brown, thick-bedded to massive, very hard rock that tends to weather cavernous and with well-rounded surfaces (Hattin, 1957, p. 72). Algal structures make up much of the rock. The most common algal form is Osagia, which is actually intergrowths of algae and various forams (as discussed in the text). In thin section, the algal limestones are algally coated biomicrites and biosparites. They also may contain oolites and intraclasts. Fossil content includes forams, pelecypods, gastropods, and, in smaller quantities, brachiopods, bryozoans, echinoderm debris, and some vertebrate fragments. The presence of algae in large quantities has been interpreted as indicating that the environment of deposition was of somewhat greater than normal marine salinity (Hattin, 1957, p. 96-97; Cuffey, 1967, p. 12), and was nearshore, at least sometimes somewhat agitated, and shallow (0 to 10 feet deep according to Lane, 1958, p. 154).

ALGAL-MOLLUSCAN LIMESTONE

In some places, the algal limestone of the regressive hemicycle is instead algal-molluscan limestone. These are similar to algal limestones, but contain vertical cylindrical openings about 2 inches in diameter and as much as 3 feet long (Hattin, 1957, p. 73). Associated with these openings are large burrowing clams; the openings are probably burrows made by these clams. These rocks differ from typical algal limestones by containing fewer algae and more burrowing pelecypods, and are more silty and sandy. They also may contain small amounts of chert. They are petrographically biomicrites. As indicated by the presence of the large burrowing clams, the environment was probably brackish, nearshore, shallow marine water.

BRACHIOPOD-MOLLUSCAN LIMESTONE

The brachiopod-molluscan limestones are limestones with lithologic and faunal characteristics intermediate between those of the molluscan limestones and calcareous shales. They are thin-bedded, yellowish-gray to medium dark gray, argillaceous, and finely granular. In thin section, these rocks are brachiopod-bryozoan-pelecypod sparse biomicrites. They contain forams, bryozoans, brachiopods, pelecypods, and some algae, ostracods, and echinoderm debris. The environment of deposition for brachiopod-molluscan limestones was intermediate between environments for molluscan limestones and calcareous shales.

CALCAREOUS SHALE

Calcareous shales of the Wreford are grayish-yellow to yellowish-gray or medium and dark gray, very calcareous, very fossiliferous shales.

The fossils of the calcareous shales are the most abundant and varied of any of the rock types in the Wreford, and include forams, some corals, bryozoans, brachiopods, pelecypods, gastropods, ostracods, echinoderm debris, vertebrate remains, and sparse algae and trilobites. The calcareous shales were deposited in fairly quiet waters of normal marine salinity, at depths slightly below the zone of strong wave action (Hattin, 1957, p. 90) but still relatively shallow (10 to 30 feet, as Newton, 1971, p. 10, suggests; or 10 to 50 feet, suggested by Cuffey, 1967, p. 12; although Elias, 1937, p. 410, 411, thought depth was 90-110 feet).

CHERTY LIMESTONE

Cherty limestones are yellowish-gray to grayish-yellow, relatively pure, finely granular to sub-granular, medium- to thick-bedded, hard, chert-bearing limestones. The chert is of two types: 1) noncalcareous chert is light grayish-yellow to black, hard, with a light colored weathered shell; and 2) calcareous chert is bluish-gray to brownish-gray, hard, and concentrically layered. In thin-section; cherty limestone is a brachiopod-bryozoan sparse biomicrite (Cuffey, 1967, p. 12). Fossils are the same in both the chert and the limestone, and include bryozoans, brachiopods, echinoderm debris, and some algae, forams, corals, sponge spicules, pelecypods, gastropods, ostracods, trilobites, and fragmentary vertebrate remains. Cherty limestone was probably deposited in quiet, normal marine waters far from shore, and may have been deposited at the time of maximum depth of the sea. Depth may well have been 10 to 60 feet (Cuffey, 1967, p. 12) rather than the 110 to 180 feet originally postulated by Elias (1937, p. 410, 411).

CHALKY LIMESTONE

The chalky limestones are light yellowish-gray to light grayish-yellow, finely granular, very porous, thick-bedded to massive, powdery, and slightly cherty. Their weathered surfaces are pitted and cavernous. In thin section, the chalky limestones are sparse biomicrites (Cuffey, 1967, p. 12). Sparsely fossiliferous, they contain bryozoans and thread-like algal structures as dominant constituents, along with lesser numbers of corals, forams, sponge spicules, brachiopods, gastropods, echinoderm fragments, and trilobites. The chalky limestones thicken abruptly and irregularly within short distances, and seem to represent a group of submarine, carbonate mud banks, probably rising above the sea floor so that depth of water around them varied considerably within the general range of 10 to 60 feet (Cuffey, 1967, p. 12).

RED RESIDUAL CLAY

Rare, local thin beds of dusky red, silty, blocky clay that occur within the chalky limestone are termed red residual clay. They probably formed by solution of the chalky limestone, either during subaerial exposure of the carbonate mud banks, or by the action of ground water after diagenesis.

The stratigraphic units contained in the Wreford
are described here in a general manner. The details of the units
may be found in the 1931 paper by Smith. The units
shown on the generalized cross-section of the Wreford

Each of the stratigraphic units will be described in this
lower, middle, and upper parts. The lower part of the
Wreford, as divided by Smith (1931, p. 13) divided the Wreford into
of the Wreford Limestone, and the upper part of the
Wreford formation by considering it as the upper part of the
Wreford formation. The upper part of the Wreford is a
massive, vertically elongated, of the rock.

The middle part of the Wreford is the Wreford Limestone
formation, and is composed of gray to black limestone.

APPENDIX D

WREFORD STRATIGRAPHIC UNITS IN KANSAS

The lower part of the Wreford is the Wreford Limestone
formation, beginning with the first unit and ending with the
upper red shales, is composed of gray shale, which is
rich in fossils (although in places not so rich as the
upper part, is a massive limestone, which is
a well-developed limestone, which is a well-developed

The lower part of the Wreford Limestone is a massive
limestone, containing fossils, and is a well-developed
shale, bluish and becomes nodular in the upper part. The
middle part of the Wreford Limestone is a massive
shale, usually exposed as a resistant surface. The
upper part of the Wreford Limestone is a well-developed
limestone, which is a well-developed limestone, which is
a well-developed limestone, which is a well-developed
limestone, which is a well-developed limestone, which is