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DEPOSITIONAL ENVIRONMENT OF THE WREFORD MEGACYCLOTHEM (LOWER PERMIAN) OF KANSAS

By

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ABSTRACT

The Speiser shale, Wreford limestone, and Wymore shale member of the Matfield formation were studied in east-central Kansas. More than 200 exposures were examined, of which 138 were measured and described. The results of this stratigraphic work have been incorporated into a correlation chart. Several completely exposed sections were sampled, representative specimens from each distinctive lithologic unit being collected for laboratory analysis.

Samples of rock from six key sections were examined in detail to collate information derived from observation of outcrops, polished surfaces of chert, polished and etched limestone surfaces, insoluble residues of limestones, washed shales, sand/shale ratio studies, and pipette analyses. In addition, thin sections were made of sandstcnes, limestones, and cherts; large blocks of limestone were etched in an acid bath; and three subsurface sections were examined.

A complete stratigraphic description of the outcropping rocks of the Wreford limestone and adjacent shales is presented. The sequence exhibits repetition of lithologies and faunas that is attributed to cyclic sedimentation. Two nearly complete cycles of deposition are recognized, the rocks of each constituting a cyclothem. The two cyclothems, which include strata extending from the middle of the Speiser shale to the middle of the Wymore shale, comprise the Wreford megacyclothem. Each of the major types of sedimentary rock is characterized by a distinctive fossilized biota (or lack of one) and is the product of a particular environment.

Sandstones and red shales are continental deposits. The sandstones are unfossiliferous, representing accumulation in ancient river channels; red shale, bearing sparse charophyte oogonia, accumulated in interfluve areas of a broad low plain that bordered the early Permian sea.

Green shales, grayish-yellow mudstones, and molluscan limestones were deposited in the area between the shoreline and the outer limit of marine waters of less-than-normal salinity. Ostracodes and fragmentary remains of other kinds of invertebrates are characteristic of the first two lithologies; *Aviculopecten* and *Septimyalina* characterize the third.

Calcareous shales represent deposition moderately far from shore in marine waters of normal salinity. These rocks contain the most abundant and taxonomically varied fauna of the megacyclothem. *Derbyia, Dictyoclostus, Composita,* and *Chonetes* are the dominant megafossils.

Cherty limestones were deposited during the stage of maximum transgression of the sea. Lack of inorganic clastic constituents suggests deposition in clear water far from shore. The fauna includes bryozoans and brachiopods as the dominant types.

Chalky limestones bearing little chert are a special development of the cherty-limestone phase of deposition. They locally form relatively thick reefs, which are dominantly composed of bryozoans and algal remains. The environment of deposition shoreward from the reefs is believed to have been governed partly by their presence.

Algal limestones are present in the regressive hemicycles of sedimentation and correspond in relative position to the transgressive molluscan phases. Some algal limestones are believed to be the product of a hypersaline environment. Algal limestones that contain large burrowing clams and are situated shoreward from the ancient reefs are interpreted as having accumulated in a somewhat brackish environment, because the associated invertebrate fossils are similar to those seen in transgressive molluscan limestones.

In the limetones that were deposited during maximum transgression there are two types of chert. Compact noncalcareous cherts are believed to be primary chemical precipitates; layered or laminated calcareous cherts formed from silica deposited more slowly than the noncalcareous cherts and owe their present appearance to changes that occurred during diagenesis.

The typical transgressive hemicycle in the Wreford megacyclothem begins with red shale (locally with a sandstone) followed, in upward order, by green shale, mudstone, molluscan limestone, calcareous shale, and cherty limestone (including local chalky-limestone reef development). The typical regressive hemicycle includes the same rock types in reverse stratigraphic order except that the molluscan limestone equivalent is commonly algal. Neither of the Wreford cyclothems is complete.

Subsurface sections in which the end members of the hemicycles can be detected indicate widespread distribution of the environments controlling the different phases of sedimentation.

Similar repetitions of lithologic types, each with its particular faunal assemblage, are seen in the stratigraphic sequence above the Wreford limestone up to and including the Winfield limestone.

INTRODUCTION

Purpose of Investigation

The sedimentary deposits of Wolfcampian (Early Permian) age in Kansas exhibit features of cyclical deposition as has been observed, but specific information relating to the individual formations at many places along the outcrop is wanting. The Wreford limestone (subdivided in upward order into the Threemile limestone, Havensville shale, and Schroyer limestone members) was chosen for detailed study because it is well exposed, its stratigraphy can be treated conveniently, and it is the oldest of the Kansas Permian formations to contain abundant chert.

The origin of bedded and nodular chert, of the sort seen in the Wreford limestone, has been long disputed. Study of stratigraphic and lithologic relationships of the chert was undertaken in order that light might be shed upon its origin.

The Wreford limestone was observed at as many exposures as possible as a preliminary part of the study, in order that stratigraphic and geographic variations could be analyzed. Because of cyclic relationships, the Speiser shale, below the Wreford limestone, and the Wymore shale, above it, were included in the investigation. Specimens of the several rock types were studied in the laboratory to facilitate interpretation of the deposits from which the specimens were obtained. An understanding of persistence or lateral change in lithology and of stratigraphic relationships is one of the main objects of the investigation.

An interpretation of the broad faunal relationships and the specific nature of local associations of lithology and fossils is also an objective of the study. Paleoecological interpretation of the various rock types may thus be facilitated.

The major purpose of the investigation, however, is an interpretation of the setting of Permian sedimentation on the ancient shallow sea bottom. Knowledge of the depositional environment of the Wreford limestone may serve as a basis of comparison for similar deposits, older and younger, in Kansas and adjacent states and may provide information on the occurrence of economically important mineral deposits.

Previous Work

Meek and Hayden (1860) published the earliest description of the Wreford limestone. A section measured by them at Fort Riley is 40 feet thick. The rock consists of light-gray and whitish magnesian limestone, contains "*Spiriger, Orthisina, Productus, Acanthocladia,* and *Cyathocrinus*", and bears many concretions of flint in the lower part. This description is number 18 (from the top) of their generalized Permian section (1860, p. 17).

Descriptions of Permian sections are included in Swallow's report (1866, p. 11-16). The Wreford limestone comprises beds 58 to 62 of the Permian section that he measured near Fort Riley. Bed 62, the "Fifth Cherty Limestone", is the Threemile limestone member of current usage, and bed 58, the "Fourth Cherty Limestone", is the Schroyer member. The intervening beds (59-61) constitute the Havensville shale. At this locality the Wreford limestone is about 50 feet thick and contains "*Productus, Chonetes, Orthisena, Athyris, Acephala, Arca,* and crinoids", according to this report.

The Wreford limestone was named by Hay (1893, p. 104) from exposures near Wreford in Geary County. His brief description is inaccurate and inadequate compared to modern standards.

Several lengthy papers by Prosser (1894, 1895, 1902, etc.) on the upper Paleozoic rocks (Permo-Carboniferous and Permian) include discussions of previous investigations, revisions of nomenclature, correlations, and lists of fossils from the Wreford limestone. Prosser (1895) proposed the name Strong flint for strata previously called Wreford limestone.

The work of Beede and Sellards (1905) contains an excellent summary of Lower Permian stratigraphy in Kansas. Many measured sections are described. The scarp-forming nature of the Wreford limestone is noted and a map of its outcrop figured. Discussion of the Carboniferous-Permian boundary problem and of the Wreford limestone as the base of the Permian is presented.

Plant fossils in the Wreford limestone were mentioned by Sellards (1908) and their climatic significance was interpreted by Elias (1936).

A paper concerning the origin of the chert in the Foraker and Wreford limestones at the Kansas-Oklahoma border was published by Twenhofel (1919). He examined 500 exposures of the Wreford limestone and described several of them in detail. The chert in the Wreford limestone was judged to be penecontemporaneous (early diagenetic) in origin.

Condra and Upp (1931) named all the members of the Wreford limestone, redefined the Speiser shale, and named the Wymore shale in a very comprehensive paper pertaining to the correlation of Lower Permian rocks in Nebraska. Numerous measured sections of the Wreford limestone and adjacent shales are presented.

The first published mention of cyclic sedimentation in the Permian of Kansas is that by Jewett (1933). The sequence recognized by him as cyclical comprised the upper Speiser shale and lower Threemile limestone and constitutes but a fraction of the entire cyclothem as it is now known.

The most important paper dealing especially with the environments of deposition of the Lower Permian rocks of Kansas is that of Elias (1937). He compares Permian forms of life with presumably equivalent modern types and postulates the depth of deposition of sedimentary phases associated with each faunal assemblage of the "Big Blue Series". On the basis of his investigation, Elias set forth the ideal "Big Blue" cycle of deposition for north-central Kansas. His paper is a basic reference for ecological studies of Lower Permian strata in Kansas.

Bulletins of the Kansas Geological Survey that describe the geology of various counties containing exposures of Permian rocks, notably those by Bass (1929) and Jewett (1941), give information concerning localities where these beds may be seen. Measured sections of the Wreford limestone appear in several of these bulletins.

Although numerous published papers briefly outline the stratigraphy of the Wreford limestone and the adjacent shales, only two papers contribute importantly to interpretation of the genesis of the rocks. Twenhofel (1919), who later (1950, p. 414) cast doubt on his theory of penecontemporaneous origin of chert in the Wreford limestone, and Elias (1937) are the authors of those two papers.

Location and Description of Area

Geography.—The Wreford limestone crops out in a nearly north-south belt from northern Marshall County to southern Cowley County (Fig. 1). Major re-entrants along the strike are formed by the eastward-flowing Kansas and Cottonwood Rivers, southeastward-flowing Neosho River, and southward-flowing Big Blue River. Wreford outliers in Nemaha, Pottawatomie, and Jackson Counties were isolated from the main area of Wreford by erosion across the intervening Table Rock anticline. In western Pottawatomie County and southern Marshall County, Big Blue River has isolated a large area of Wreford limestone. Other outliers of considerable areal extent are situated in Wabaunsee and Cowley Counties.

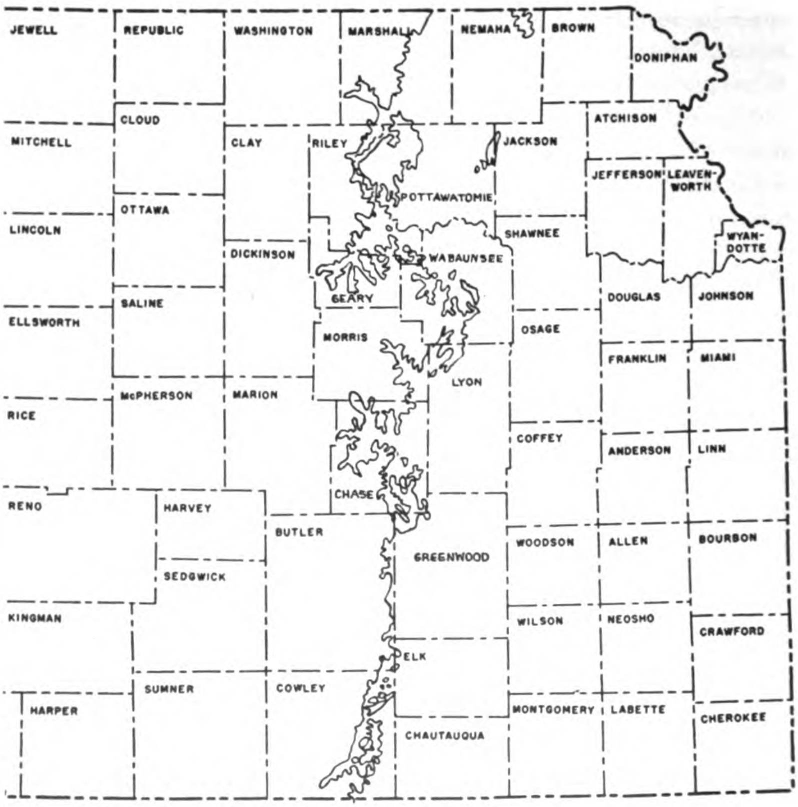

FIG. 1. Location of Wreford limestone outcrop (adapted from Geol. Map of Kansas, 1937).

Width of the Wreford limestone outcrop is generally less than one-tenth of a mile. Where the dip decreases or where erosion has stripped back overlying formations, as in the outliers, the Wreford limestone crops out in a belt many miles wide.

Topography.—Physiographically, according to a diagram by Schoewe (1949, p. 276), the Wreford limestone crops out in the Flint Hills section of the Osage Plains from Riley and Pottawatomie Counties southward, and in the attenuated Drift Border and Kansas Drift Plains of the Dissected Till Plains in Marshall, Nemaha, Jackson, and Pottawatomie Counties, in the north. Glacial deposits mask much of the latter area, so exposures are poor and hard to find. The land surface is gently rolling and generally heavily vegetated. The Flint Hills section, named for the dark chert so prevalent in the limestones there, consists of a series of roughly parallel cuestas. Escarpments formed on the cherty limestones, which are separated by somewhat thicker shales, dominate the topography. The Wreford limestone, oldest of the Permian formations in which chert is consistently abundant, forms a major escarpment. Where the Wreford outcrop is narrow, the bench formed on its dip slope is subordinate to the upland surface formed on the Barneston limestone above (Pl. 4A,B). On the other hand, widespread upland surfaces develop on the Wreford dip slope in areas of broader outcrop (Pl. 4C). In the easternmost portions of its outcrop, the Wreford thus characteristically produces an upland surface or a bench below the surface developed on the Barneston limestone.

Each of the three members of the Wreford generally is expressed in the topography. Thickest and most resistant of the members is the lowest, the Threemile limestone. A ledge or low, narrow, round-edged bench is its usual expression. In areas of broad outcrop, the Threemile is commonly the only member exposed. The upper, less-cherty part of the Threemile, which weathers so as to appear porous or cavernous, is more resistant than the lower, cherty portions. A ledge or rimrock of upper Threemile limestone may be viewed continuously for miles in many parts of the Flint Hills (Pl. 5A). The more easily weathered lower Threemile limestone produces a chert-covered slope below the rimrock. Thinner and less resistant is the highest member, the Schroyer limestone, which is commonly the member on which the main part of the Wreford bench or upland surface is developed. In this situation, it crops out only as weathered cherty rubble at the edge of the bench or upland surface (Pl. 5B). Most of the few natural exposures of the Schroyer are found along streams. The most resistant unit in the Schroyer is an algal limestone at the top of the member (Pl. 5C). When weathered, the cherty basal portion, as in the Threemile member, forms a debris-covered slope. At most exposures where the Threemile and Schroyer limestones crop out close together, the Havensville member is expressed topographically as a steep slope, partly or wholly covered. Where the Wreford outcrop is broad, the Havensville shale is exposed only in the sides of gullies. In northern Kansas this member includes no resistant units except locally, but

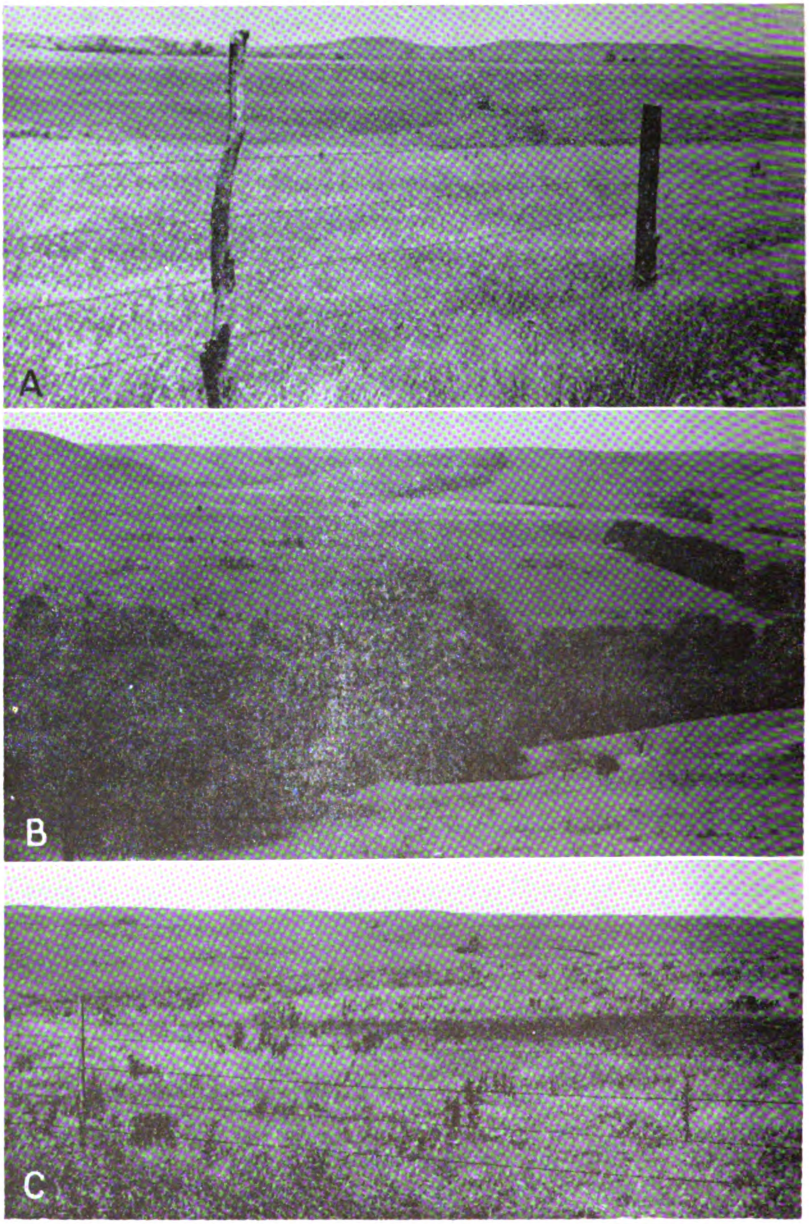

PLATE 4. Topography of the Wreford limestone. **A**, Surface developed on the Wreford limestone. Hills in background capped by Barneston formation. SW¼ sec. 29, T. 8 S., R. 8 E., Pottawatomie County. **B**, Middleground bench developed on Wreford limestone. Upland to left and in distance developed on Barneston limestone. SE¼ sec. 18, T. 11 S., R. 7 E., Geary County. **C**, Upland surface on Wreford limestone outlier. SW¼ sec. 29, T. 12 S., R. 11 E., Wabaunsee County.

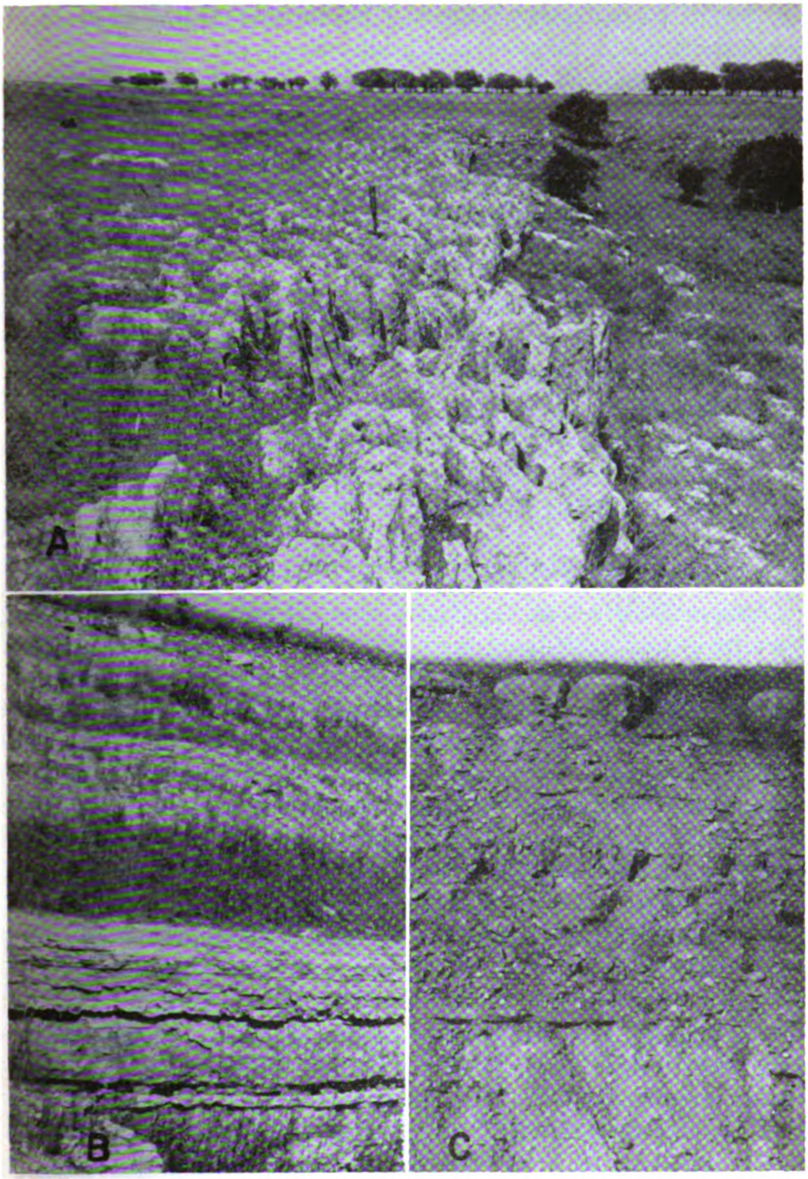

Plate 5. Topographic expression of the Wreford limestone. **A**, Bench formed by resistant algal part of the upper Threemile member. Surface in distance developed on upper Wreford limestone. Cylindrical openings are clam borings enlarged by solution. Center S line sec. 24, T. 32 S., R. 6 E., Cowley County (Loc. 116). **B,** Upland surface developed on Schroyer limestone (top of cut). Havensville and Threemile members exposed below. NE¼ sec. 21, T. 4 S., R. 7 E., Marshall County (Loc. 7). **C**, Surface developed on resistant algal limestone at top of Schroyer member. NE¼SE¼ sec. 30, T. 11 S., R. 8 E., Geary County (Loc. 35).

southward, as in Cowley County, a thick resistant limestone comprises most of the member and locally forms the surface.

The Wymore shale, which overlies the Wreford, and the Speiser shale, which underlies it, are characteristically slope-formers. Rare, indeed, are natural entire exposures of these units. Every complete section measured in the present investigation was studied in a highway or railroad cut. Most exposures of the upper Speiser shale are those in which the lower Threemile limestone is also exposed.

In summation, the shale units are slope-formers and rarely are completely exposed naturally. The Threemile limestone generally forms conspicuous, though narrow, benches traceable over great distances, and the Schroyer limestone is most commonly expressed as a chert-covered surface or slope. The Wreford limestone forms a conspicuous escarpment in the Flint Hills and lies directly below broad expanses of upland surface locally.

Methods of Investigation

Approximately 200 exposures were examined, and sections were measured with hand level and tape at 137 locations. Field description of sections was based on subdivision of each member into units having distinctive lithologic or paleontologic characteristics or both. Limestone units were measured and notation made of the color of fresh and weathered surfaces, hardness, and special features, such as chert, geodes, and solution cavities. For shale units thickness, siltiness, calcareousness, and color were recorded. Trenching of the shales in a direction normal to the bedding was standard procedure in exposing fresh rock. Graphic columns accompanying each description were prepared in order to show the nature of weathering, kinds of fossils, and distribution of various types of chert.

Samples for laboratory study were collected at six key localities, each chosen on the basis of completeness of the exposed section, geographic position, stratigraphic variations, or combinations of these factors. At these places at least one representative sample was selected from every lithologic unit. Each colored shale in sequences of alternating red and green shales was sampled separately. Shales were collected by means of continuous sampling in a trench cut to fresh rock. Limestones were sampled so as to include fresh rock in each specimen. Fossils were collected from the key sections and from all studied localities where well-preserved organic remains are to be seen.

In the laboratory, a series of operations was designed to gain detailed information from each sample. Limestones were cut, polished, and etched in commercial hydrochloric acid (diluted to 5 percent by volume) for a period of about 45 seconds. This brought into distinct relief the various textural and structural features of the rock. The etched surfaces were examined microscopically, and acetate peels were prepared from the etched surfaces. The acetate peels are made by immersing the etched limestone surface in acetone, then "rolling" the rock onto a piece of clear, medium-weight acetate of suitable dimensions. Orientation and identification is then recorded in india ink. After drying, the acetate is peeled off. Such peels make excellent photographic negatives and are easily stored for ready reference. Their greatest limitation lies in the lack of color contrast and compositional distinction.

Insoluble residues were made by using a modification of the method described by Ireland (1951, p. 141-142). Commercial hydrochloric acid, diluted to 30 percent by volume, was poured over a sample of limestone that had first been broken up in a small jaw crusher. The amount of limestone used was determined volumetrically in a graduated vial, the average weight being about 15 g. When effervescence ceased, the mixture was allowed to rest for approximately a minute and then decanted. The sample was then treated with more acid to insure complete digestion of all soluble materials, washed and decanted three times, and dried. The percentage of residue was determined volumetrically in a small calibrated vial. The residue was then examined by means of a binocular microscope. Volumetric analysis was used in preference to weighing samples because it is faster and because much of the residue is lost in decanting the clay and silt. The fines were not kept or studied, because they add little information to the description of the residue and tend to obscure the coarser, more diagnostic particles. Terminology used for insoluble residues is that published by Ireland and others (1947).

Chert from the key sections was cut and polished and then examined with a binocular microscope. Acid applied to the surface of the chert revealed the distribution and relative amount of calcareous material contained therein. Glycerine spread over the polished surface of the chert cut down adverse reflection and facilitated a careful examination of the matrix as well as of the enclosed structures.

Shales from the six key sections were broken down for paleontological examination by thorough drying followed by a several-hour period of soaking in kerosene. The kerosene was then decanted, water was added, and the sample was allowed to sit for a half hour or more. Washing, accompanied by decanting of the clay and silt, left a residue consisting primarily of fossils and aggregates of silt and fine sand, which was further cleaned by boiling the sample for a few minutes and washing it again. The residue was examined with a binocular microscope. The sample was sieved through 20- and 40-mesh screens to facilitate study. The percentage of calcareous material and the sand/shale ratio were determined by treating 15 g of shale with 30 percent hydrochloric acid. The residue was then sieved through a 230-mesh screen, which retained all sand-size particles. Both fractions were placed in beakers, dried, and weighed. The sand/sale ratio is determined for the undissolved residue only. Addition of residue fractions, division by 15 (the original weight in grams), and multiplication by 100 gives the percentage of residue. For two of the key sections, pipette analyses were run on several of the shale units in order to determine the amount of silt and clay-size particles in the various types of shale.

Condensed descriptions of the six key sections are contained in the appendix.

In addition to the above-described analyses of key sections, studies were undertaken to provide for more general description of rock types. Thin sections of the various rock types, including several kinds of limestone, chert, sandstone, and conglomerate, were made and studied petrographically. Numerous large blocks of limestone were etched in commercial hydrochloric acid (diluted to approximately 30 percent by volume) in order to determine the abundance and kind of silicified fossils. In general, however, the results were unrewarding, because only a few rocks were found to contain abundant, well-preserved, silicified organic remains.

Of 137 sections measured, 120 have been used in the preparation of correlation charts of the Wreford limestone and adjacent shales (Pl. 1-3). The area between northern Nemaha County and southern Cowley County is included. Lithologies, faunas, and interrelationships of the sections are shown in these diagrams. Details of stratigraphic configuration, such as bedding thickness and chert shapes, are accurately portrayed. (Refer to Plates 1, 2, and 3 whenever locality citations are encountered in the text.)

Acknowledgments

The field expenses of the Wreford limestone project were underwritten by the Shell Oil Company and I wish to express my sincere thanks to the officers of the company who made this support available. Especial thanks go to James Parks and Prof. Paul Tasch, who met me in the field and made many valuable suggestions concerning the satisfactory completion of the work. Thanks are also due Melville Mudge of the U.S. Geological Survey, who gave helpful information concerning location of Wreford limestone exposures. Mr. Mudge also aided in interpretation of some of the reef limestones found. Lastly, my greatest thanks go to my wife, whose assistance in the field and laboratory and whose preparation of the manuscript has been of utmost value in the completion of this investigation.

STRATIGRAPHY

General Discussion

Main divisions of Wolfcampian (Lower Permian) rocks in Kansas, which have been long recognized by the Kansas Geological Survey (Moore and others, 1951), are as follows, in ascending order: Admire group, Council Grove group, and Chase group (Fig. 2). The Chase group (called Chase formation by Prosser, 1895), which was named from exposures in Chase County, Kansas, comprises approximately 300 feet of conspicuous ledge-forming limestones separated by shale units. The limestones are commonly interbedded with chert or flint, a characteristic feature of the Chase group; most shales between limestone formations are green or red, or both.

The lowest formation in the Chase group is the Wreford limestone, which was named by Hay (1893, p. 104) from exposures of flint-bearing limestone near Wreford, Geary County, Kansas. Hay's description is as follows: "The Wreford limestone. Flints

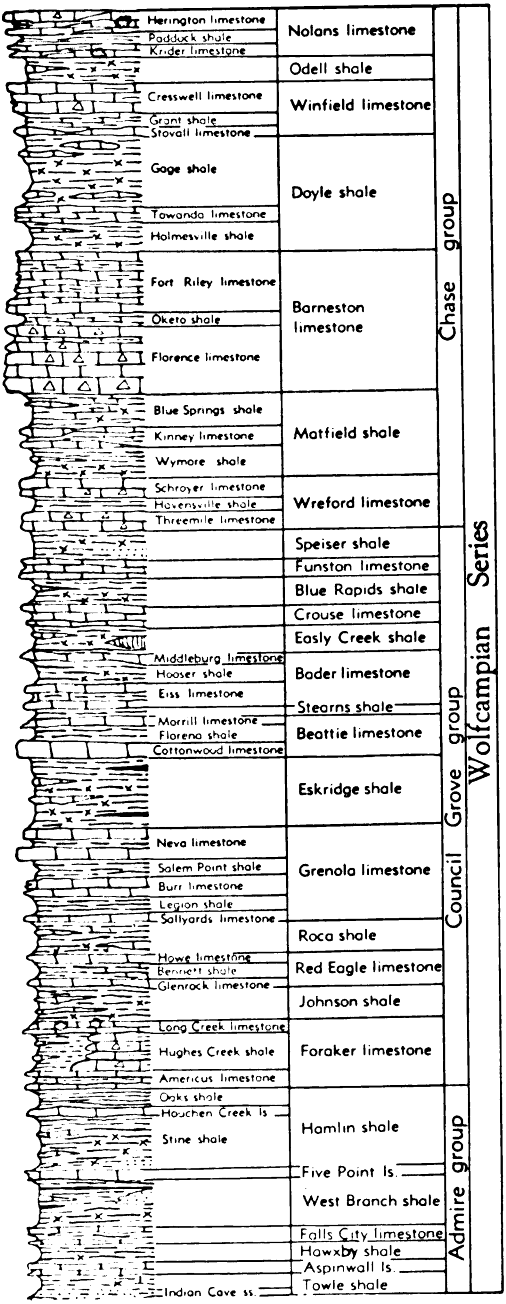

FIG. 2. Stratigraphic classification of Wolfcampian Series in Kansas (after Moore and others, 1952).

as in No. 9. Parts of the beds are silicified in localities as if by infiltration. Crinoids, syntrilasma, athyris, retzia, pinna, meekella, producti, cup corals. Twenty-five feet." The "No. 9" flints referred to are in the Florence limestone. The same description was published earlier by Hay (1891, p. 94) but Wreford was misspelled Walford. Prosser (1895, p. 772) applied the name Strong flint to the limestone and flint cropping out on top of Crusher Hill, just west of Strong City, Kansas. Earlier, in discussing the "Wreford Limestone" of Hay, Prosser (1894, p. 48) suggested that the name Ogden flint should be used if Wreford proved an undesirable name, for Hay had mentioned exposures of this limestone near Ogden, in Riley County, at the top of the bluffs east of Three Mile Creek.

The name Wreford was adopted because it has priority and is not for any obvious reason unsuitable. Three members are now recognized (Condra and Upp, 1931). In ascending order they are (1) Threemile limestone, (2) Havensville shale, and (3) Schroyer limestone. Both limestone members are chert-bearing.

Poor exposures in the old quarry at Wreford reveal about 15 feet of somewhat chalky, fossiliferous limestone, which contains bedded chert only in its basal part. On the hill slope a hundred feet west of the quarry, 9 feet of a stratigraphically higher, thick- to massive-bedded granular limestone is exposed. Large calcareous chert nodules have weathered out from the base, and abundant minute crinoid stems are contained in the rocks near the top. Just south of the Smoky Hill River bridge on U.S. Highway 77, a mile northwest of Wreford, the same type of granular limestone may be seen, here containing very abundant organic debris and large, ellipsoidal, bluish-gray masses of calcareous chert. These and the strata cropping out at Wreford are assigned to the Threemile member, which reaches a total thickness of more than 25 feet in the type area of the formation. The Schroyer at this place (U.S. Highway 77) is much like that seen at localities 30 and 133, a few miles east and northeast, respectively, except that the basal unit and upper (algal) limestone are thicker. The total thickness of the member is about 12 feet. The Havensville shale is recognized here as a thin shaly unit, about 2 feet thick, which lies between the thick- to massive-bedded granular limestone at the top of the Threemile member and the chert-bearing limestone at the base of the Schroyer member. Thus, in the vicinity of the type locality, the Wreford formation is at least 39 feet thick.

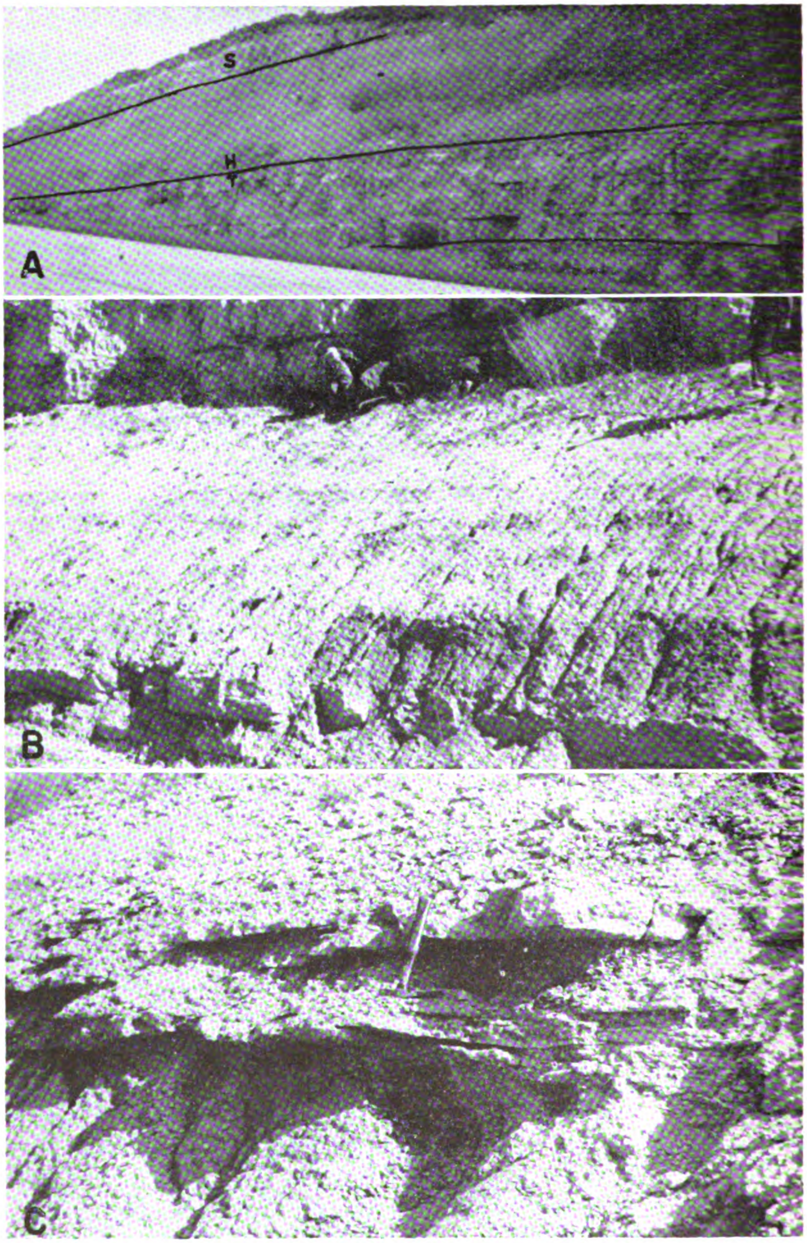

PLATE 6. Exposures of the Wreford limestone and Speiser shale. **A,** Wreford formation on U.S. Highway 40 east of Junction City. At present this is its finest Kansas exposure. NE¼ sec. 34, T. 11 S., R. 6 E., Geary County (Loc. 30). **B,** Typical exposure of Speiser shale. Wreford limestone above and Funston limestone below. NE¼ sec. 34, T. 11 S., R. 6 E., Geary County (Loc. 30). **C,** Channel conglomerate in lower part of Speiser shale. NE¼ sec. 15, T. 16 S., R. 10 E., Lyon County (Loc. 57).

The Threemile member is abnormally thick in the section described above and is believed to be reeflike in nature. The thickening of the upper Threemile limestone coincides with thinning of the Havensville shale. This and other reeflike bodies are discussed below.

Complete sections of the Wreford limestone are scarce because the commonly thick Havensville shale member forms slopes in most places and the comparatively thin Schroyer limestone is only moderately resistant to erosion (Pl. 6A). This is especially true in northern Kansas. Southward, the shale member becomes very calcareous and much thinner, and complete sections are more numerous. The variation in thickness of the Wreford limestone across Kansas is graphically shown in Figure 3A. One can observe from this diagram that the Wreford limestone reaches its maximum thickness near the center of the state and thins appreciably southward therefrom.

An analysis showing ratio of shale to limestone in the Wreford formation indicates that the ratio decreases markedly southward along the outcrop across Kansas (Fig. 4). Thinning of the Wreford limestone southward is correlated with decrease in shale deposition, but the basal member is thicker southward, especially in Cowley County.

Cyclic Sedimentation

The Wreford limestone and associated shales exhibit certain repetitive features of sedimentation that may be attributed to cyclical deposition. Jewett (1933, p. 137) seemingly was the first to describe the similar sequences of lithologic types to be found in many of the formations of the "Big Blue series" (Wolfcampian) of Kansas. He recognized ten such repetitions, or cyclothems, in the stratigraphic sequence that extends from the Elmdale formation up to the Herington limestone, the following lithologic types being represented, in upward order: (1) variegated shale (red, green, brown); (2) thin limestone or calcareous-shale unit; (3) very fossiliferous gray or yellow shale; (4) thick, massive, light-colored limestone. Although Jewett discussed neither the upper parts of some of the formations, many of which contain fairly complete cycles, nor the complete cycle as it is now understood, his conclusions were reached independently. No attempt to relate organic remains to lithologic types was made by Jewett.

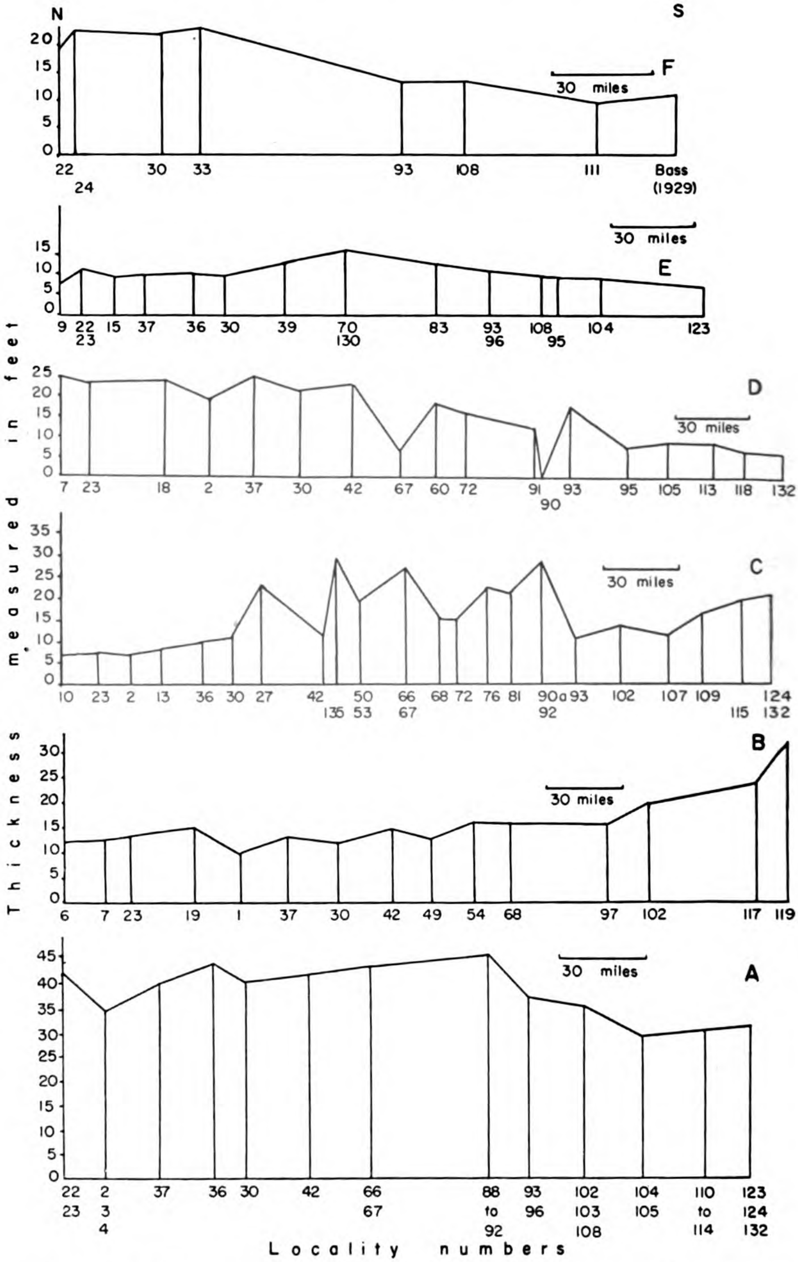

FIG. 3. Thickness changes in formations and members: **A.** Wreford limestone. **B.** Speiser shale. **C.** Threemile limestone. **D.** Havensville shale. **E.** Schroyer limestone. **F.** Wymore shale.

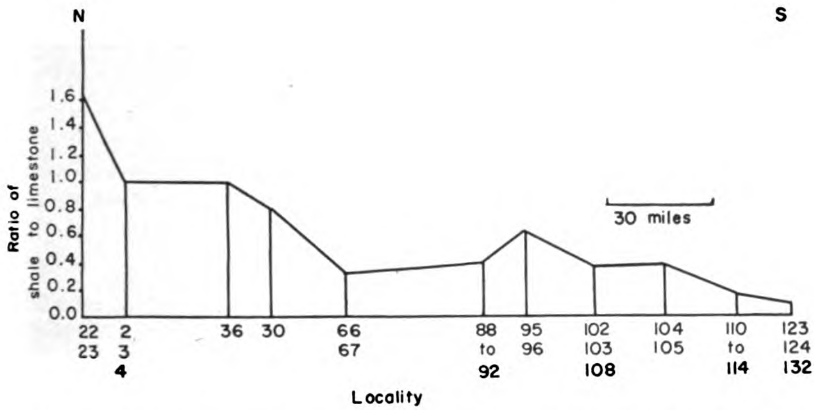

FIG. 4. Graphic representation of the ratio of shale to limestone in Wreford formation.

Elias and Moore (1934, p. 100) called attention to the distinct cyclical succession in the "Big Blue series" of Kansas, and Elias (1934, p. 366) presented the symmetrical succession of the progressive and regressive hemicycles of the "Big Blue" series. These publications are merely abstracts; no lengthy description is included therein.

Later, Elias (1937, p. 403) published a detailed discussion of the depth of deposition of the "Big Blue" sediments in Kansas. Permian cycles are defined on the basis of lithologies and faunas, and a depth zonation chart is figured. He diagrammatically illustrated his interpretation of "Big Blue" deposition, showing that the Wreford limestone, with subjacent and superjacent shales, comprises two complete cycles of sedimentation and parts of two more (Elias, 1937, p. 406). Elias' ideal Permian cyclothem (1937, p. 411) is shown in Table 1.

Elias states that in many cycles thalloid-like algae are found in phases 2 and 4, that massive encrusting algae may be found in phases 4 and 5, and that in the underlying Pennsylvanian strata the latter type of algae are to be found in phase 6 and rarely in 7. Also, he says that no single cycle in the Big Blue series shows all phases of the ideal cycle, that neighboring cycles above and below a given cycle commonly exhibit its missed phases, and that the Barneston and Beattie limestones are cyclically the best developed.

TABLE 1. *Elias' ideal Permian cyclothem.*

	No.	Phases established chiefly on paleontologic evidence	Corresponding typical lithology
	1 .	Red shale	clayey to fine sandy shale
Regressive hemicycle	2r.	Green shale	rarely consolidated
	3r.	Lingula phase	sandy, often varved?, rarely clayey shale
	4r.	Molluscan phase	clayey shale, mudstone to bedded limestone
	5r.	Mixed phase	massive mudstone, shaly limestone
	6r.	Brachiopod phase	
	7 .	Fusulinid phase	limestone, flint, calcareous shale
	6p.	Brachiopod phase	
Progressive hemicycle	5p.	Mixed phase	massive mudstone, shaly limestone
	4p.	Molluscan phase	clayey shale, mudstone to bedded limestone
	3p.	Lingula phase	sandy, often varved?, rarely clayey shale
	2p.	Green shale	clayey to fine sandy shale
	1 .	Red shale	rarely consolidated.

Red shales may have been deposited subaerially, probably near the shore of the Permian sea. Green silts are thought to represent deposition in the area slightly awash, the molluscan fauna occupied a shallow near-shore environment, and so on. The fusulinid-limestone phase was evidently deposited farthest from shore and at greater depth than the other phases. Regression of the shallow sea resulted in deposition of similar sediments bearing like organic remains, but in reverse order.

The present investigation shows general conformity of the Wreford formation to the plan of Elias' ideal cyclothem. A further discussion will follow descriptions of rock types and environments of deposition.

SPEISER SHALE

The name Speiser shale was proposed by Condra (1927, p. 232) to include the shales and limestones in the upper part of the so-called Garrison shale, between the "Sabetha limestone" (Crouse limestone, by priority), below, and Wreford limestone, above (Fig. 2). The various named subdivisions of the Garrison shale of Prosser (1902, p. 712), comprising shales and limestones between the Cottonwood limestone, below, and Wreford limestone, above, have been elevated to formational rank by Moore (1936a, p. 50) and the name Garrison discarded. The Speiser shale was redefined by Condra and Upp (1931, p. 23) to include the rocks between the Funston and Wreford limestones (Pl. 6B). The type locality of this formation is in Speiser Township, Richardson County, Nebraska, where the exposure consists of about 19 feet of shale including a thin limestone bed near the top.

The Speiser shale is the uppermost stratigraphic unit of the Council Grove group, the latter including, in the present classification of the Kansas Geological Survey (Moore and others, 1951), the limestones and shales from the base of the Foraker limestone to the base of the Wreford limestone (Fig. 2). The Council Grove group, and thus also the Speiser shale, was classed as Pennsylvanian by Frech (1899, p. 378); however, the Pennsylvanian-Permian boundary is now placed at the base of the Admire group (Moore and Moss, 1934, p. 100).

The Speiser shale is cyclically inseparable from the Wreford limestone. From the base of the Speiser in some localities, but from the middle in most exposures, the ascending sequence of lithologic types forms a well-defined stratigraphic pattern with regard to depositional environment. This sequence is related to the older, or first, of the Wreford cycles of sedimentation.

Three main stratigraphic subdivisions of the Speiser shale can be traced, with only minor change in facies, across the entire state of Kansas. The basal portion comprises an alternating red and green shale sequence, commonly olive gray or grayish yellow at the top. This shale ranges in thickness from about 10 feet in the northern part of the state to a maximum of 34 feet in Cowley County. In the vicinity of the type locality it is 15 to 16 feet thick. In most localities red shale lies at the base of this part of the formation and is followed in ascending order by transitional beds of red and green shale upon which lies green shale and finally grayish-yellow to olive-gray shale. At several localities green shale is found below the red, and at locality 117 grayish shale forms the base of the formation. The transitional beds present either an alternation of green and red shale or an intimate mixture of the two colors, the latter being a truly variegated shale. In northwestern Lyon County, along U.S. Highway 50N, at locality 57, a well-defined series of channel sandstones and fine-grained conglomerates is exposed in the lower part of the Speiser shale (Pl. 6C). The conglomerate is obviously local, because nearby exposures do not show this feature. In Cowley County light-colored fine-grained lenticular sandstone is a feature of the lower Speiser (Pl. 7A,B). As many as four sandstone bodies can be observed at a single exposure (Loc. 120), and at one place (Loc. 121) more than 20 feet

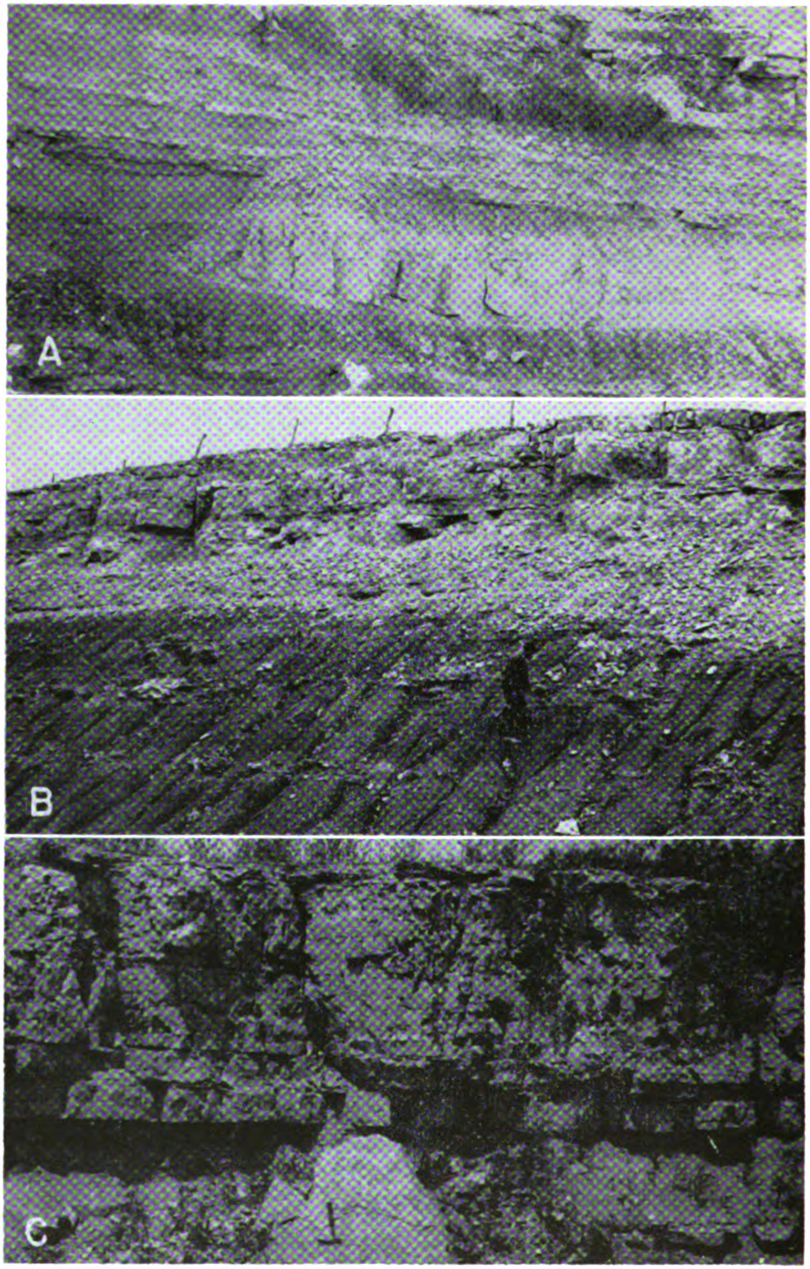

Plate 7. Speiser shale exposures. **A,** Channel sandstone in upper Speiser shale. NE¼ sec. 12, T. 34 S., R. 6 E., Cowley County (Loc. 120). **B,** Channel sandstones in Speiser shale. Individual units reach 3 feet in thickness. All exhibit cross bedding. SW¼ sec. 31, T. 33 S., R. 7 E., Cowley County (Loc. 119). **C,** *Aviculopecten*-bearing limestone in upper Speiser shale. Bed is at level of hammer head; calcareous-shale phase exposed above. SW¼ sec. 3, T. 7 S., R. 9 E., Pottawatomie County (Loc. 2).

of massive cross-bedded sandstone is exposed. At locality 117 a thin nonpersistent coal parting lies near the top of the shale. Ostracodes, especially *Bairdia* and *Cavellina,* are the dominant element of the fauna in the green and yellowish portions, and charophyte oogonia are the only fossils that were found in the red shale, these at locality 117. The basal gray shale at locality 117 contains an abundant and well-preserved mixed fauna of foraminifers, bryozoans, brachiopods, echinoderms, and ostracodes. In composition this assemblage resembles closely that of the uppermost Speiser shale, which is described below.

Near the top of the Speiser shale, generally within 3 feet of the contact with the Threemile limestone, lies a limestone phase of deposition, which is traceable, with distinct change in facies, across the entire state. To the north, the limestone is a single thick bed or two or more thinner beds and is characterized by the presence of *Aviculopecten* (Pl. 7C), but to the south the unit gradually thins and is shaly bedded or consists of several thin beds that alternate with gray shale. From southern Chase County to Cowley County it is commonly indistinguishable from limestones lying in the shale above, and even loses its identity locally. *Septimyalina,* some large orbiculoid, *Juresania,* and *Derbyia,* as well as *Aviculopecten,* are conspicuous elements of the fauna of this phase to the south, and *Derbyia*-bearing thin-bedded limestone without *Aviculopecten* is the first bed above the red and green shale sequence at many localities in southern Kansas. The maximum thickness of this unit in northern Kansas is 2 feet; it exceeds 4 feet in the southern part of the state where, however, the bed seems to be locally absent. The usual stratigraphic span is 0.5 to 1 foot.

The uppermost phase of the Speiser shale comprises ordinarily about 3 feet or less of very calcareous, dusky-yellow to medium-dark-gray, fossiliferous shale (Pl. 7C). In the north it contains some limestone, and toward the south thin-bedded fossiliferous limestone beds are common (Pl. 8A). This unit attains its maximum thickness of 10 feet in Butler County. The fauna is dominated by *Derbyia* in association with *Chonetes, Composita, Dictyoclostus, Petrocrania* (in northern Kansas), many genera of bryozoans (notably *Thamniscus* and *Fenestrellina*), echinoderms, ostracodes, trilobites, and foraminifers.

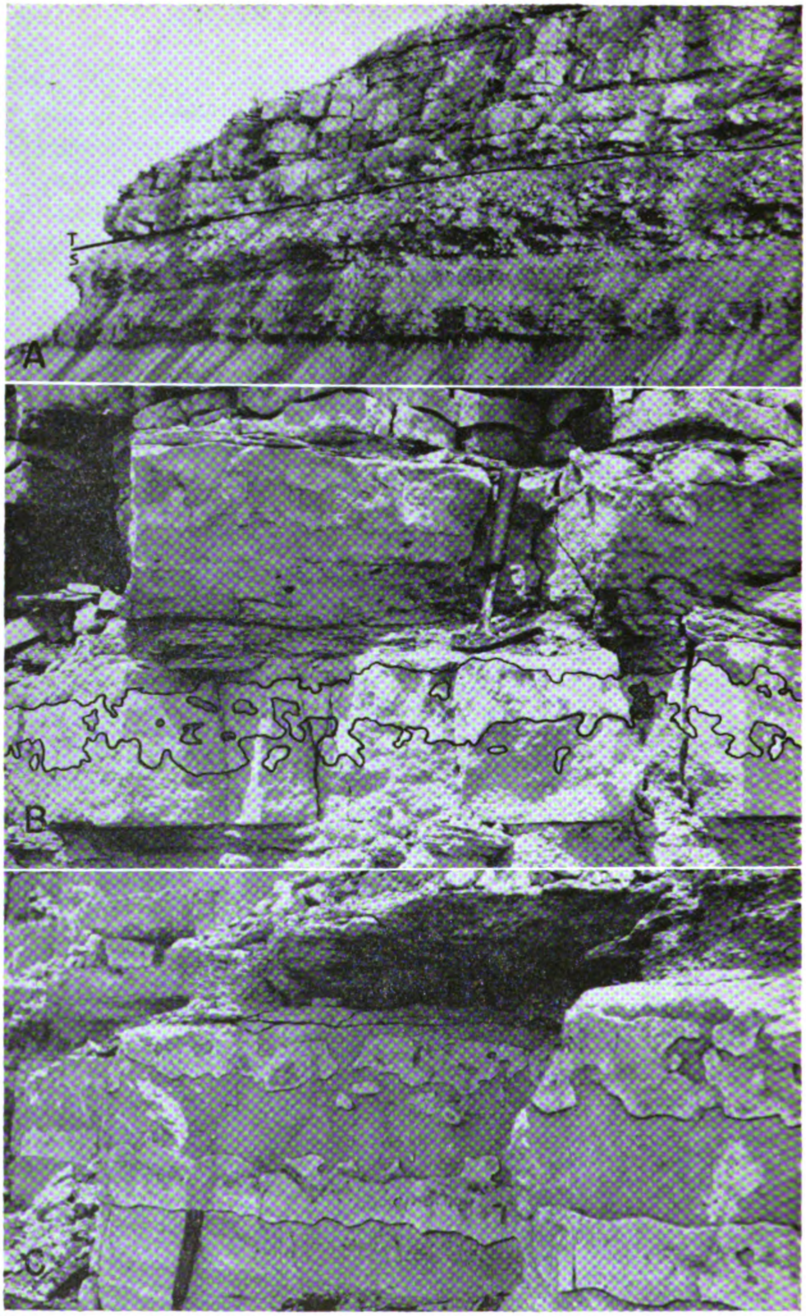

PLATE 8. Exposures of Speiser shale and Threemile limestone. **A,** Speiser shale and Threemile limestone. Note interbedded limestone and shale in upper Speiser formation. SW¼ sec. 19, T. 32 S., R. 8 E., Cowley County (Loc. 117). **B,** Basal unit of Threemile limestone showing chert bed. Note shaly phase above (at hammer head). SW¼ sec. 3, T. 7 S., R. 9 E., Pottawatomie County (Loc. 2). **C,** Chert beds in basal Threemile limestone. Note calcareous shale above. SE¼ sec. 25, T. 11 S., R. 7 E., Geary County (Loc. 32).

The Speiser shale shows a steady increase in thickness, with local variations, as one proceeds southward across the state. A minimum development of 10.1 feet is observed at locality 134 and a maximum of 39 feet at locality 119 in Cowley County. The change in thickness is presented graphically in Figure 3B.

WREFORD LIMESTONE

Threemile limestone member.—The lower member of the Wreford limestone was named the Fourmile limestone by Condra and Upp (1931, p. 31) from Fourmile Creek in southwestern Richardson County, Nebraska. The thickness at this exposure is 7.5 feet. Moore (1936, p. 12) replaced the name Fourmile with Threemile, from Threemile Creek in Riley County, Kansas, because the older name is preoccupied. The exact type locality of the Threemile limestone is not stated; however, a suitable type exposure may be definied as that in the quarry in the NW¼ SW¼ sec. 11, T. 11 S., R. 6 E., on the Fort Riley Military Reservation, close to Threemile Creek. The thickness of the member at this locality (Loc. 133) is about 12 feet. The basal portion is covered but the rest of the member looks very similar to the rocks exposed at locality 30, about 3 miles farther south.

One of the most easily traceable subdivisions of the Threemile limestone is the basal thick-bedded cherty limestone unit, which is separated from the main body of limestone by a persistent body of calcareous shale or shaly to thin-bedded argillaceous limestone. The basal bed is lithologically typical of the cherty limestones to be described below. In northern Kansas the unit has the minimum thickness of 0.75 feet but in southern Kansas it reaches 4.4 feet. The average thickness of the unit at 30 localities across the state is 2.1 feet. Throughout most of northern Kansas this part of the Threemile limestone contains a single bed of chert (Pl. 8B), although as many as four distinct chert beds may be present (Pl. 8C, 9A). At many localities in central Kansas there is again only a single bed, the chert being nearly a foot thick at these places (Pl. 9B). Still farther south, in Cowley County, at some localities the chert is completely nodular and locally almost wholly absent, whereas at other exposures it exists as a single thin bed; however, as if to make up for the lack of bedded chert, silicified fossils are abundant at the latter localities. There is a marked decrease in

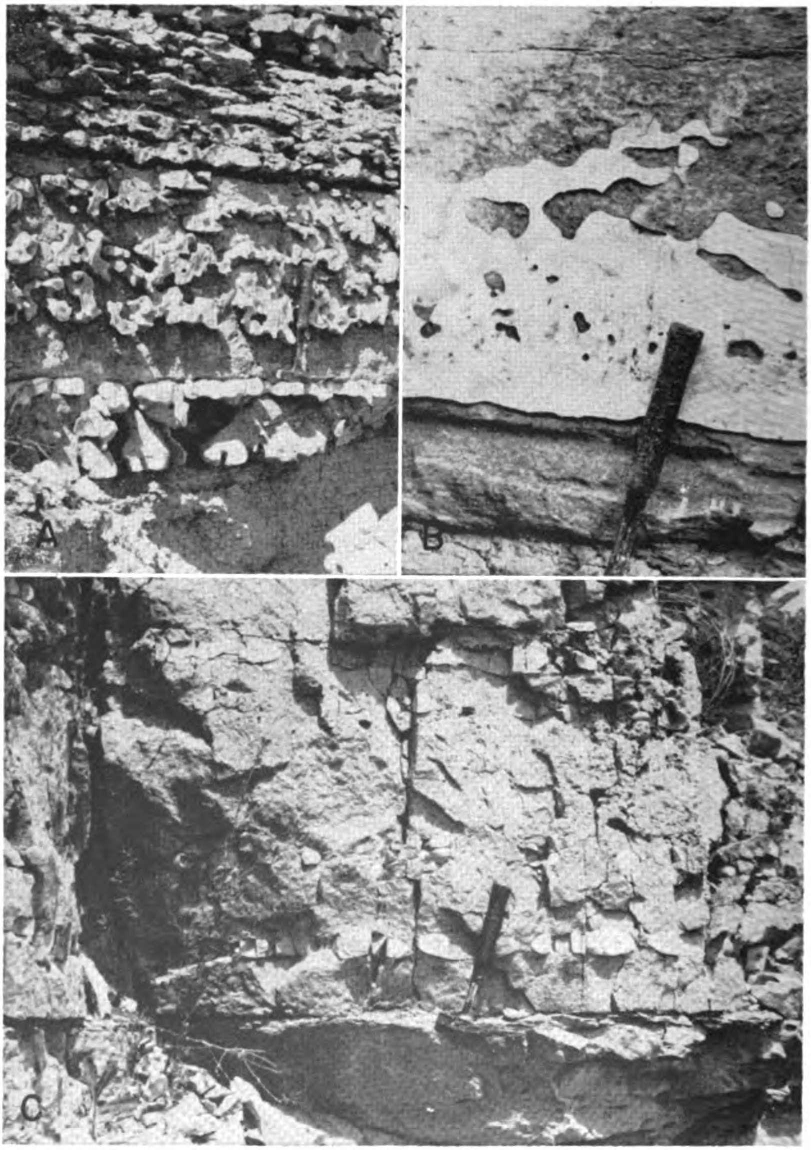

PLATE 9. Chert in the Threemile limestone. **A,** Lower Threemile member showing several nodular beds of light-colored chert. Shaly limestone above contains abundant chert nodules. NE¼ sec. 13, T. 22 S., R. 8 E., Chase County. **B,** Thick chert bed in lower Threemile limestone. SW¼ sec. 30, T. 15 S., R. 8 E., Morris County (Loc. 66). **C,** Nodular-bedded chert in middle of Threemile member. SW¼ sec. 3, T. 7 S., R. 9 E., Pottawatomie County (Loc. 2).

the amount of chert in this bed from central to southern Kansas. In the Butler County area, a thick, and in some places discontinuous, bed of dark-gray calcareous chert, which exhibits roughly concentric lamination, is seen in the basal limestone.

The fauna of the lowermost unit of the Threemile limestone is dominated by the brachiopods *Composita*, *Derbyia*, *Dictyoclostus*, and *Enteletes*. At several localities these fossils are fragmentary or absent, and there echinoderms and bryozoans of fenestrate and ramose types are dominant. *Aviculopinna* is found at many localities also. A zone of *Wellerella* in the lower part of the basal limestone unit is traceable from locality 36 in Riley County to locality 105 in Butler County. Nowhere are the specimens very abundant and they do not range through a large stratigraphic thickness, but their persistence is significant, suggesting contemporaneous deposition of the containing beds. Robust specimens of *Schwagerina* are found in the lowest 0.1 to 0.2 foot of the member at four closely spaced sites in central Chase County.

The second phase of the Threemile limestone is a shaly unit, which ranges in thickness from 0.1 foot in northern Kansas to as much as 2 feet in southernmost Kansas. Lithologically, the unit is variable. In northern Kansas it consists of shaly limestone (Pl. 8B), which grades into the overlying limestone. Over much of central Kansas it locally becomes a calcareous shale (Pl. 8C), a shaly limestone, or a coarse granular, tough, cavernous-weathering, resistant limestone bed. Southward from central Kansas the percentage of limestone steadily increases, and the unit is a shaly to thin-bedded limestone from southern Chase County to southern Cowley County, where it generally contains numerous irregular scattered gray chert nodules (Pl. 9A). *Enteletes*. *Dictyoclostus*, *Composita*, *Derbyia*, and *Chonetes* are the dominant elements in the fauna of this phase, one or more of these genera being observed at nearly every exposure. The composition of the fauna is the same, in general, as that of the upper Speiser shale.

Above the shaly limestone unit is the main thick-bedded cherty limestone of the Threemile member. The lower part of this unit lithologically resembles the basal limestone bed of the member and contains numerous beds of light- to dark-gray chert (Pl. 7C; 8B,C; 9C). Across most of Kansas these chert beds are less than 0.5 foot thick and nearly continuous, although commonly consisting of isolated nodules (Pl. 9C). In Cowley County the lower por-

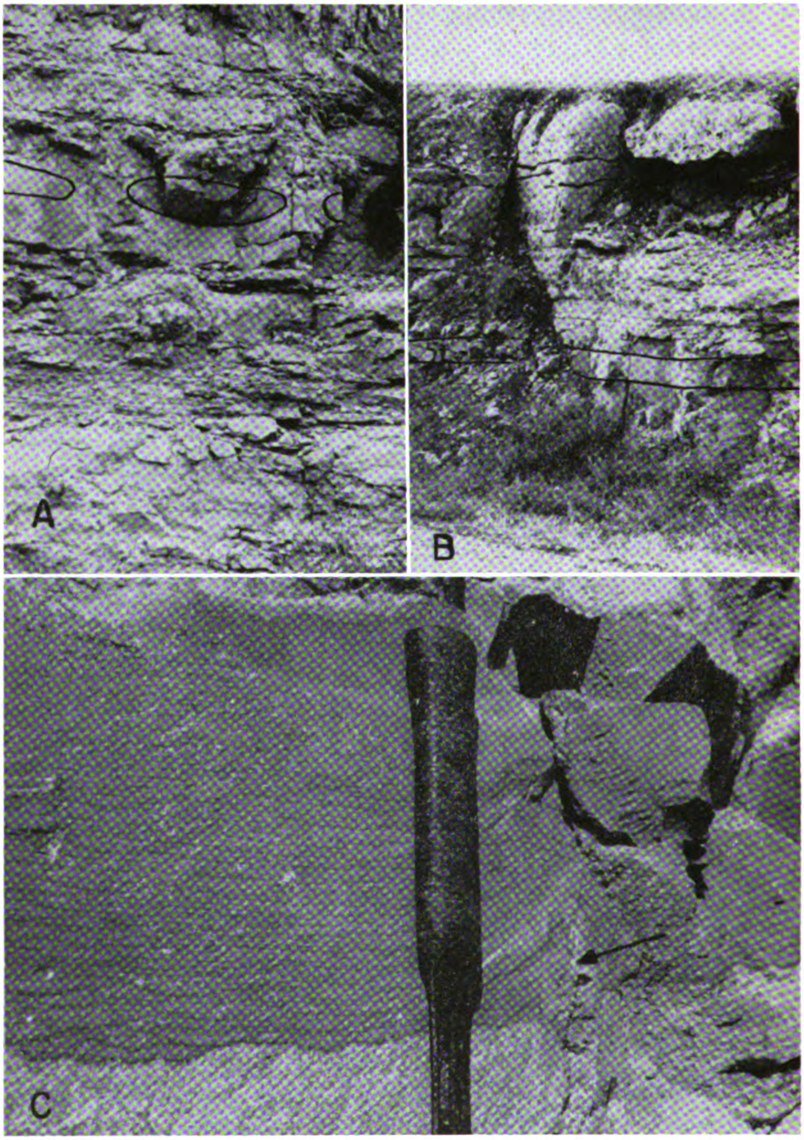

PLATE 10. Calcareous chert in the Threemile limestone. **A,** Nodules of thick-bedded, bluish-gray, calcareous chert in middle of Threemile limestone. SW¼ sec. 19, T. 32 S., R. 8 E., Cowley County (Loc. 117). **B,** Thick-bedded, bluish-gray, calcareous chert bed. Same bed as "A," above. Algal unit at top. SW¼ sec. 19, T. 32 S., R. 7 E., Cowley County (Loc. 115). **C,** Detail of bluish-gray, concentrically layered, calcareous chert. Same bed as "A" and "B," above. Note nodule of noncalcareous chert in lower right (arrow). SW¼ sec. 19, T. 32 S., R. 7 E., Cowley County (Loc. 115).

tion of the upper Threemile is characterized by the presence of abundant irregular chert nodules in place of bedded chert.

Some of the chert beds locally in northern Kansas contain nuclei or marginal portions of dark-gray concentrically layered calcareous chert. South of southern Chase County, this type of chert becomes more and more prominent. In Cowley County one massive, nearly continuous bed reaches a thickness of 1 foot at some exposures (Pl. 10A,B,C). One or two other almost continuous beds of this same type are contained in the upper Threemile limestone in the Cowley County area (Pl. 11A).

The next higher part of the Threemile limestone exhibits one of the more interesting phases of Wreford sedimentation. In northern Kansas it is thick- to massive-bedded, light-colored, pitted, somewhat chalky limestone that contains little chert (Pl. 11B). Where present, chert forms thin continuous beds or isolated flattened nodules. Layered calcareous chert is associated with the noncalcareous variety at many exposures. Huge spheres and subspherical masses of calcareous chert lie near the top of the chalky limestone at locality 90 (Pl. 11C, 12A). The thickness of the chalky limestone ranges from about 2 to 5 feet in the area between Marshall County and western Wabaunsee County. Between southern Wabaunsee County and southern Chase County the chalky limestone is abnormally thick at many places (Pl. 12B). Thicknesses of 10 to 25 feet have been observed for this unit. Such abrupt thickening of the unit in very short distances indicate a reeflike nature. Across northern and central Kansas the chalky limestone typically weathers with a pitted to cavernous surface and is a resistant ledge former.

This part of the Threemile limestone loses its characteristic appearance south of the Matfield Green area of Chase County; although it retains a somewhat chalky lithology as far south as southern Butler County, several persistent chert beds appear. In Cowley County the entire upper part of the member is granular, mostly chert bearing, light yellowish brown, and massive to thin bedded, and may be divided into an upper and a lower subdivision. Because the lower of these two subdivisions lies in the same stratigraphic position as the chalky limestone and because of certain faunal characteristics (as discussed below) it is thought to be a facies equivalent of the chalky limestone.

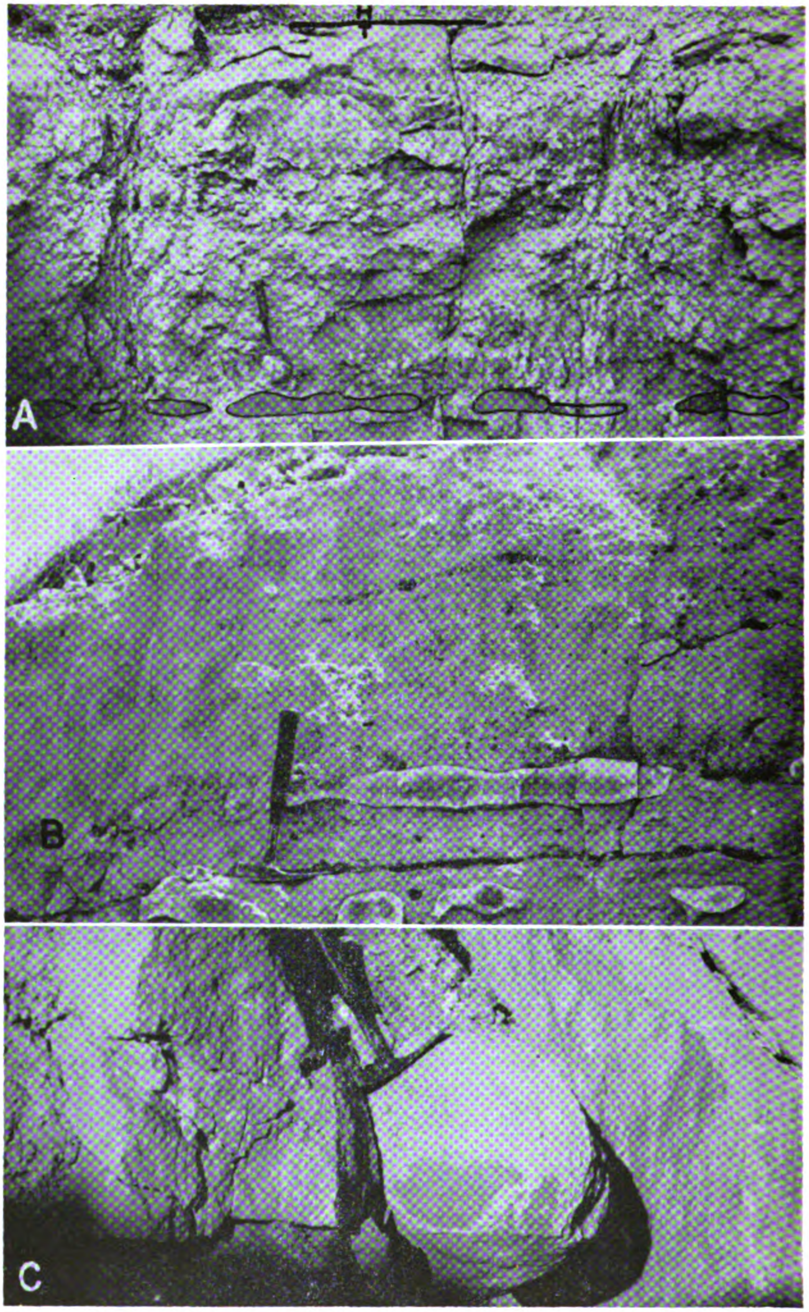

PLATE 11. Chert in the upper Threemile member. **A,** Calcareous chert bed near base of algal unit in upper Threemile. NW¼ sec. 30, T. 33 S., R. 7 E., Cowley County (Loc. 118). **B,** Chert in upper chalky portion of Threemile member. Note pitted surface of limestone, and thick chert bed above. SE¼ sec. 25, T. 11 S., R. 7 E., Geary County (Loc. 32). **C,** Spheroidal nodule of calcareous chert in upper Threemile limestone. SE¼NW¼ sec. 19, T. 22 S., R. 8 E., Chase County (Loc. 90).

PLATE 12. Features of the upper Threemile member. **A,** Calcareous chert in upper Threemile limestone. Note irregular shape of nodule and thinness of Havensville shale at this locality. SE¼NW¼ sec. 19, T. 22 S., R. 8 E., Chase County (Loc. 90). **B,** Reef in upper Threemile limestone. Member reaches its maximum thickness here. S½SE¼ sec. 26, T. 13 S., R. 9 E., Wabaunsee County (Loc. 135). **C,** Clam borings in upper Threemile member. Center S line sec. 24, T. 32 S., R. 7 E., Cowley County (Loc. 116).

Megafossils found in the chalky limestone consist mainly of fenestrate and ramose bryozoans associated with brachiopods and with spines and plates of echinoids. *Fenestrellina* and *Composita* are nearly ubiquitous forms in these rocks. Among the brachiopods, *Dictyoclostus, Derbyia,* and *Chonetes* are found at some exposures. At many localities, especially those where the chalky limestone reaches reeflike proportions, fenestrate bryozoans are by far the most abundant group of organisms. The cup corals *Stereostylus* and *Dibunophyllum* are to be found at most localities. Echinoid spines and crinoid stems are present in all reef sections. At the change in facies noted in Butler and Cowley Counties the lower portion of the upper Threemile limestone is characterized by dominant brachiopods (*Derbyia, Dictyoclostus, Composita*) and it contains echinoderm remains associated with profuse productid spines. In short, there is little difference from the fauna of the chalky limestone except in relative abundance. It may be stated generally that the chalky limestone and its southern equivalent are sparsely fossiliferous, only locally containing an abundance of megascopic organic remains.

In northern and central Kansas the uppermost part of the Threemile member is lithologically similar to the limestone that lies directly above the shaly break near the base of the member. As compared with the underlying chalky limestone, the amount of chert is notably increased (Pl. 11B), likewise the abundance and variety of fossils. In most places this part of the Threemile member is 2 to 3 feet thick. In northern Kansas, especially, the uppermost portion is commonly a shaly-bedded limestone, which in some places contains small chert nodules and bears a sparse fauna of brachiopods, crinoids, and bryozoans. The faunal assemblage is intermediate in composition between that of the calcareous shale of the upper Speiser shale and that of the cherty limestone. In central Kansas, over the thick reef limestone, the uppermost part of the member is a hard, thick-bedded, slightly cherty limestone, which is in sharp contact with the overlying shale, there being no transitional phase of shaly limestone. At most exposures where reeflike thickenings are observed, corals of the genus *Dibunophyllum* are abundant at the top of the member.

An algal bed lies at the top of the Threemile limestone in the area between northeastern Butler County (Loc. 103) and southern Cowley County. At its northernmost exposure in Butler County it is 3 feet thick; it reaches a maximum of 6.75 feet in thickness south of Dexter, Cowley County (Pl. 11A). The minimum observed thickness of this bed is 1.25 feet in southern Butler County, locality 107. Characteristically, the algal bed is very resistant to weathering and forms a prominent bench wherever it crops out (Pl. 5A). The exposed surface is pitted to cavernous. Paleontologically, the bed assumes great importance because of its position in the cycle of deposition, as will be discussed under environments of deposition. The fossils include many *Osagia*-like algae at most exposures. These are somewhat sparser at the base of the bed, although the distribution is almost uniform. Mollusks such as *Aviculopinna, Allorisma, Schizodus, Astartella, Bellerophon?*, and, more rarely, *Aviculopecten* and *Septimyalina* constitute the group of invertebrates. Also present is an assortment of brachiopod, bryozoan, echinoid, and crinoid remains. At all exposures from localities 115 and 117 southward to the Silverdale area of Cowley County, vertical tubular openings can be observed in the algal bed; they start near the base and extend more than halfway through the bed. The openings are numerous at many places, locality 116 being an excellent example, and they range from less than 1 inch to 3 inches or more in diameter (Pl. 12C, 13A,B). Boring clams such as *Aviculopinna* and *Allorisma* are found at each locality where the burrows are exposed, stratigraphically at or near the bottom of the tubular openings. They are oriented almost invariably in a vertical position and commonly occupy the bottoms of holes. Twenhofel (1919, p 410) believed the openings to be worm burrows, but in light of the presence of large burrowing clams in some of the holes it is almost certain that they were made by these mollusks (Pl. 13C).

Chert is rare in the algal bed, but close to the base of the unit a fairly persistent but thin, discontinuous bed of concentrically layered bluish-gray calcareous chert is found at most of the exposures in Cowley County (Pl. 11A). Sparse small nodules of gray *Osagia*-bearing chert lie in the upper part of the algal bed locally.

Throughout its outcrop area the algal bed forms a distinctive ledge, especially in Cowley County, north and east of Dexter in the area traversed by Kansas Highway 38. The borings in the bed become very large upon weathering and form a conspicuous "pipe rock" that has a rough, fluted surface (Pl. 5A).

The observed thickness of the Threemile limestone ranges from 6.25 feet in Marshall County (Loc. 7) to slightly less than

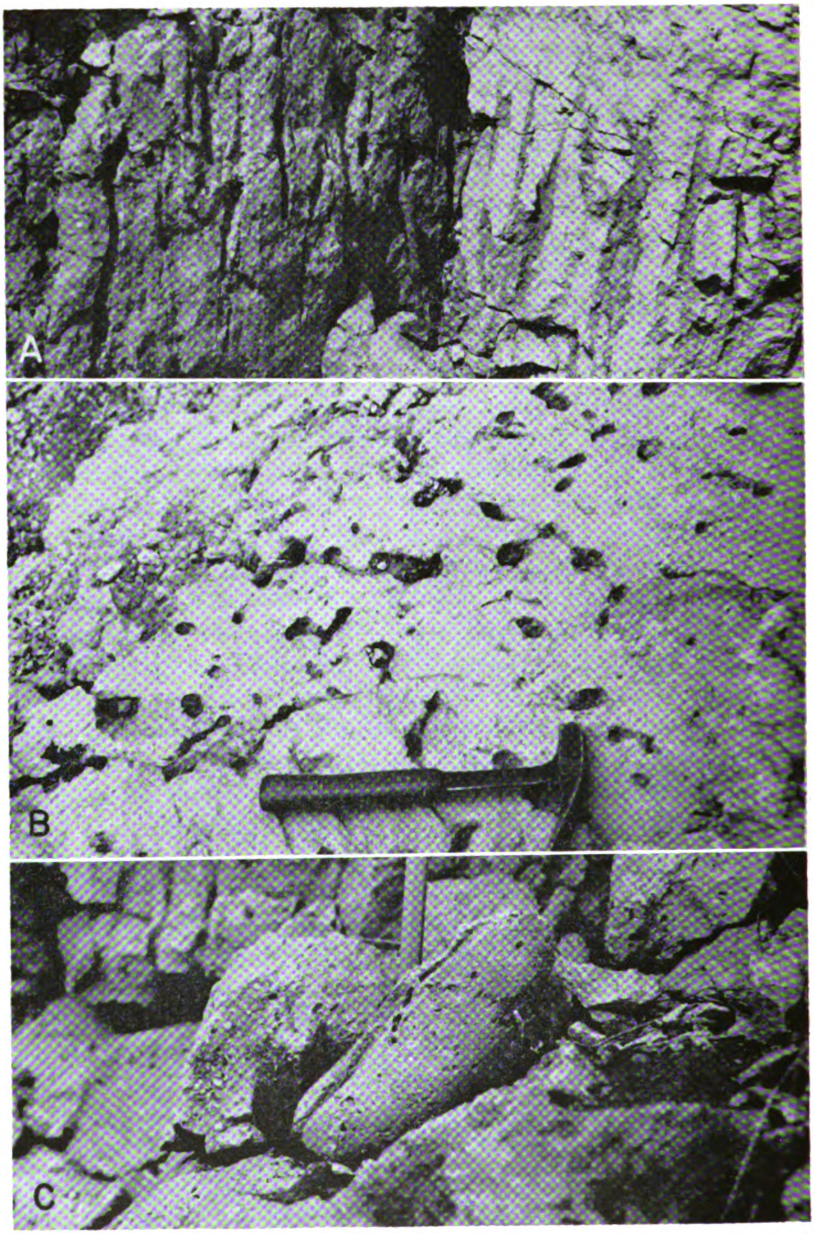

PLATE 13. Clam borings in the upper Threemile limestone. **A,** Detail of clam borings. Center S line sec. 24, T. 32 S., R. 7 E., Cowley County (Loc. 116). **B,** Plan view of clam borings. Center S line sec. 24, T. 32 S., R. 7 E., Cowley County (Loc. 116). **C,** Clam at base of boring. SW¼ sec. 19, T. 32 S., R. 8 E., Cowley County (Loc. 117).

33 feet in Wabaunsee County (Loc. 136), where a reeflike expansion in the upper part augments the normal development. The thickness is about 30 feet at localities 66 and 67 in Morris County and at locality 90a in Chase County. The great thickness at these places also is due to reef development. Throughout Cowley County the member commonly is about 20 feet thick. Changes in thickness of the member are illustrated in Figure 3C.

Havensville shale member.—The middle member of the Wreford limestone was named by Condra and Upp (1931, p 32) from exposures in cuts on Kansas Highway 63 about 2 miles south of Havensville in Pottawatomie County, Kansas (Pl. 14A). They state that the thickness of the Havensville shale at the type locality is 18 to 19 feet, but 5 feet of shale and limestone at the base is not definitely assigned to either the Threemile limestone or the Havensville shale. On the basis of close examination of the lithology and paleontology of the lower Havensville at numerous localities in northern Kansas the writer would certainly place these questioned beds in the Havensville member. At the same place a limestone bed and overlying shale unit, both included as the lower 3 feet of the Schroyer limestone by Condra and Upp (1931, p. 34), are also lithologically and paleontologically a part of the Havensville shale. Thus the thickness of this member at the type locality is 27 feet. From north to south across Kansas a great variation in the thickness of this middle member of the Wreford limestone is observed. The maximum development is 27 feet at the type locality in Pottawatomie County. Throughout northern Kansas as far south as locality 42 in Wabaunsee County the thickness is approximately 23 feet except at locality 2, where it is only 18.8 feet (Pl. 14B). The minimum thickness of the member is only 1.5 feet at locality 90 (Pl. 14C). At all exposures where the upper Threemile member contains reef limestone the Havensville shale is abnormally thin. In southern Kansas the Havensville member is thin and exhibits remarkable development of thick-bedded limestone. It is only by careful observation that the member can be traced with certainty into Cowley County from Butler County. South of locality 90 the member thins steadily from 16.2 feet at locality 93 in Chase County to 5.5 feet at Silverdale in southern Cowley County.

Although dominantly a shale unit, at nearly all localities the Havensville member contains one or more limestone beds of fair-

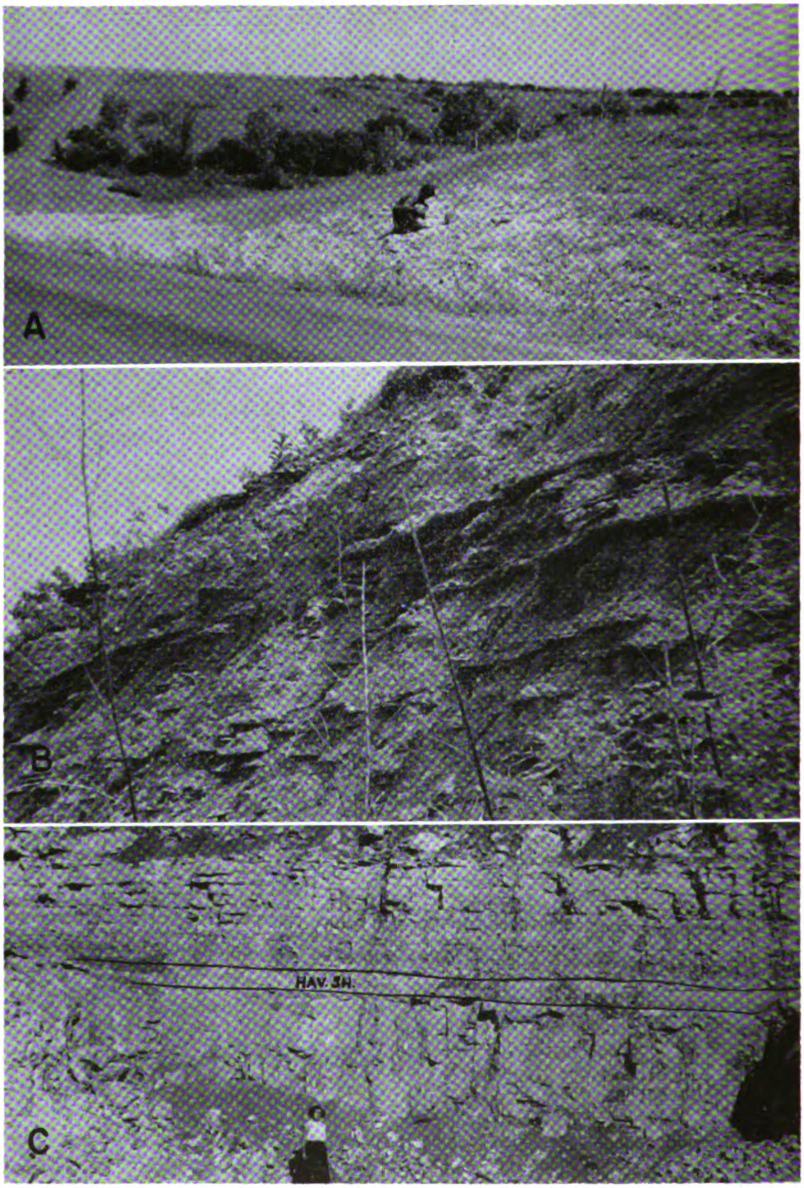

PLATE 14. Exposures of the Havensville shale. **A,** Havensville member at the type locality. SW¼ sec. 34, T. 6 S., R. 12 E., Pottawatomie County (Loc. 18). **B,** Thin development (19 feet) is unusually small for this part of Kansas. SW¼ sec. 3, T. 7 S., R. 9 E., Pottawatomie County (Loc. 2). **C,** Minimum thickness of the Havensville shale. At this exposure it is only 1.5 feet thick, owing to great thickening of the upper Threemile limestone. SE¼NW¼ sec. 19, T. 22 S., R. 8 E., Chase County (Loc. 90).

ly distinctive lithological and paleontological character. Over much of Kansas the basal part of the member is a shale, which ranges in thickness from 0.5 to 10.5 feet and is generally characterized by a mixed fauna consisting mainly of brachiopods, bryozoans, ostracodes, foraminifers, crinoids, echinoids, and trilobites. The fauna is much like that found in the upper Speiser shale. At most places the fossils are fragmentary and sparse, but at some exposures they are well preserved and abundant.

In northern Kansas, as far south as locality 72, the second unit is generally a hard calcareous shale, shaly limestone, or limestone unit, which contains the diagnostic genera *Aviculopecten* and *Septimyalina.* Because the Havensville shale shows great changes of thickness and because at some exposures either the limestone bed is absent or several limestone beds are present, it is difficult to judge which beds are equivalent to those of other localities. The lithology, as well as the thickness and position of the limestone beds, changes enough to make correlation uncertain. The unit just described is a good example. In some places it contains only mollusks and is very shaly; in some others it is absent altogether; in still others it is a hard limestone. Position in the stratigraphic succession and faunal composition are the the best keys to identification of such beds. Even paleontologically there are significant variations. Brachiopods, crinoids, echinoid remains, and bryozoans are common in the pecten bed.

At many exposures the pecten bed is overlain by a shale or, at some exposures, a mudstone, which contains few megafossils; it contains a well-preserved though restricted microfauna, dominantly of ostracodes, at locality 30. Where megafossils are present, *Aviculopecten* and *Septimyalina* are the typical forms. At many localities, especially in the area north of Geary County, a very argillaceous, sparsely fossiliferous, thin-bedded limestone lies within the shale. At localities 50 and 55, and just west of locality 54, the central portion of this shale unit is a very dusky yellow-green to grayish-green shale that strongly resembles the green strata in the Speiser shale. Fossils in the greenish shale include ostracodes, especially *Bairdia* and *Cavellina*, and fragmentary vertebrate remains. At locality 18, the type of the Havensville, a well-preserved *Neuropteris* flora is seen in yellowish-gray mudstone, which lies between overlying pale olive shale and underlying molluscan-limestone beds. The mudstone and pale olive shale occupy the same stratigraphic position as the shale containing greenish beds at locality 55. Sellards (1908, p. 387) and Elias (1936, p. 696) mention plant fossils from the Havensville shale of Butler County, but the forms there are *Walchia*, *Callipteris*, and *Cordaites*. A thin- to thick-bedded, somewhat argillaceous limestone lies next higher stratigraphically. The fauna of this unit is observed to be molluscan at some exposures, mixed brachiopod, bryozoan, trilobite, and echinoderm at others, and at a few places, molluscan at the base and mixed at the top. Where the fauna of the bed is wholly molluscan, algal structures are not uncommon. At locality 13 a resistant, bench-forming thick-bedded limestone containing an algal-molluscan fauna is observed in this stratigraphic position. In this area the top unit of the Havensville member is commonly a shale or mudstone. It contains either an abundant mixed fauna that lacks mollusks, or only a sparse assemblage of microfossils. *Lingula* and *Orbiculoidea* are abundant in mudstone at the top of the Havensville shale at locality 32.

Thus, in its northern exposures, the Havensville member shows a rough but observably symmetrical pattern of sedimentation. The lower half of the member includes sediments much like those of the upper Speiser shale, but in reverse stratigraphic order; the upper Havensville sequence resembles roughly that of the upper Speiser. At only four observed exposures north of locality 72, however, does the sequence that represents regressive sedimentation include the green-shale phase of Elias' ideal cyclothem. Absence of the green shale indicates that subaerial deposition definitely did not occur during accumulation of the Havensville, at least not in the area of these outcrops.

A variety of patterns of sedimentation is seen in exposures of the Havensville shale south of locality 72. In northern Chase County only one limestone unit is observed, this occupying an essentially central stratigraphic position in the member, although it probably lies almost directly on the Threemile limestone at locality 77. A mixed fauna, including *Derbyia, Dictyoclostus, Composita*, echinoids, crinoids, and bryozoans of ramose and fenestrate types, is found in the lower shaly unit in association with sparse specimens of *Aviculopecten*. The limestone unit is characterized by an abundant mixed fauna at the base, including a few gastropods, and a dominantly molluscan fauna in the upper part. In this area the upper Havensville shale was observed to contain megafossils at only one locality (Loc. 77); the fossils constitute a mixed fauna like that of the upper Speiser shale.

Very calcareous shale predominates throughout much of the Havensville member at localities 83 and 93, except for 2 or 3 feet of less calcareous shale at the top. A mixed fauna is characteristic; *Aviculopecten* is found only sparingly.

The Havensville sequence is of much different aspect at localities 67 and 90, where reeflike thickening of upper Threemile limestone hindered deposition of Havensville shale. At locality 67 there is 5 feet of shale, the lower portion very calcareous and bearing a mixed fauna; at locality 90 only 1.5 feet (Pl. 14C) of blocky shale containing an *Ammodiscus* and fish fauna is found.

Two limestones at localities 95 and 108 both contain elements of a mixed fauna; southward from these exposures, in Butler and Cowley Counties, a single prominent limestone unit is included in the Havensville shale member (Pl. 15A,B). This limestone contains both molluscan and mixed faunas. *Aviculopinna* and, less commonly, *Allorisma*, can be observed in the limestone in Cowley County; clam borings like those of the upper Threemile are fairly numerous. The bed is progressively more algal to the south. Cross-bedding of the lower part of the unit is conspicuous at locality 124 (Pl. 15C). At several exposures small sparse chert nodules are contained in the limestone. Mixed faunas are characteristic of the shale units in Butler County. In Cowley County a sparse *Aviculopecten* and fish-tooth assemblage is observed in the shale below the limestone, and an algal-molluscan or mixed assemblage is seen in the calcareous shale above it.

Thickness variations of the Havensville member are plotted in Figure 3D.

Schroyer limestone member.—The upper member of the Wreford limestone was named by Condra and Upp (1931, p. 33) from exposures 1¼ miles south of Schroyer, Marshall County, Kansas. A thickness of 22 feet 2 inches is cited, but no exposure examined during the present study includes more than 13 feet of what can be called Schroyer limestone. The member is about 13 feet thick ¾ mile south of the type locality, according to Walters (1954, p. 107). Across all of Kansas the basal part of the Schroyer member, a cherty limestone containing a brachiopod-bryozoan fauna, lies on shale or, in a few places, noncherty argillaceous limestone (Pl.

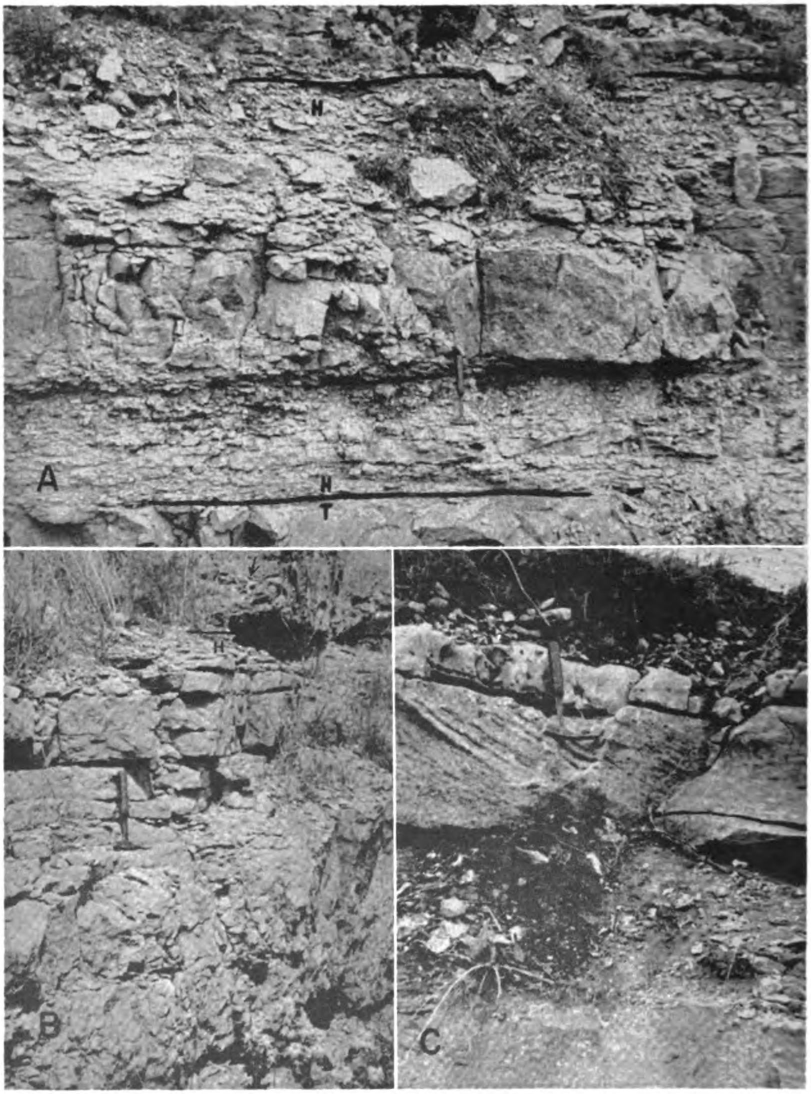

PLATE 15. Limestone in the Havensville member. **A,** Thick-bedded limestone in the Havensville shale of southern Kansas. NW¼ sec. 30, T. 33 S., R. 7 E., Cowley County (Loc. 118). **B,** Limestone phase of Havensville shale. SW¼ sec. 19, T. 32 S., R. 7 E., Cowley County (Loc. 115). **C,** Cross-bedded limestone in middle of Havensville shale. Below lies basal Havensville in contact with thick-bedded upper Threemile limestone. NW¼ sec. 10, T. 34 S., R. 6 E., Cowley County (Loc. 124).

16A,B). If a member may be defined as containing rocks of characteristic and persistent lithology, then much of what has been called Schroyer at the type locality should be included in the Havensville shale. Limestones lying below cherty limestone near the town of Schroyer are very argillaceous, bear no chert, and in addition, are faunally distinct from those containing chert. At several places in Marshall and Pottawatomie Counties the upper Havensville shale includes a molluscan-limestone phase, which contains *Aviculopecten* and other pelecypods. Locally, as at Schroyer, the limestone thickens and is contiguous with overlying cherty limestone. At first appearance the molluscan limestone seems to belong in the Schroyer member. Placement of this unit in the Havensville member, however, is harmonious with respect both to cycles of sedimentation and to observed thicknesses of more shaly exposures of the Havensville at nearby outcrops. Therefore only 5 feet of cherty limestone at the type section should be classified as Schroyer, and at present only 1.6 feet of the Schroyer is actually exposed. Other sections measured by Condra and Upp (1931, p. 33-35) likewise include beds that are typically Havensville in lithology (very argillaceous) and stratigraphic position. The boundary between the Schroyer limestone and Havensville shale is here placed at the contact of chert-bearing limestone on shale or noncherty argillaceous limestone, the strata above and below the contact thus being lithologically and stratigraphically compatible units. This is done with the object of providing a firmly established datum, which can be traced over great distances.

Three units are invariably present in the Schroyer member. In upward order these are: (1) a basal cherty limestone, which locally contains some shale in northern Kansas (Pl. 16C), (2) a shaly unit, which commonly contains a cherty limestone bed, and (3) an algal limestone (Pl. 17A,B). The first of these units is remarkably persistent laterally and consists of brachiopod-bearing limestone interbedded with light- to dark-gray chert, some of which is the layered calcareous type. Three to six beds of chert may be observed at the various exposures. In Cowley County the chert beds are less persistent, being generally represented by large nodules that show definite parallelism to bedding (Pl. 17C). Thin-bedded cherty limestone at localities 35 and 70, and medium-bedded chert-bearing limestone below a thin shale unit at

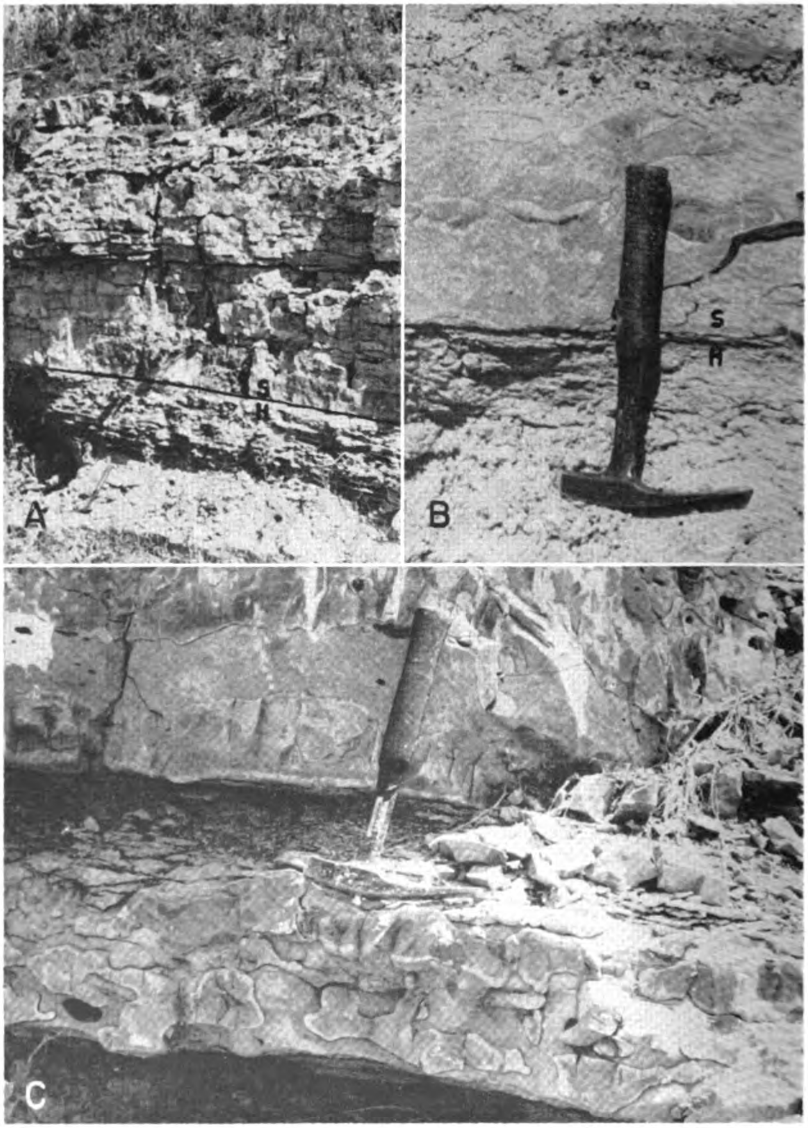

PLATE 16. Lower Schroyer limestone. **A,** Schroyer-Havensville contact (1.5 feet above hammer handle). Upper Havensville is very calcareous. Type locality of the Havensville. SW¼ sec. 34, T. 6 S., R. 12 E., Pottawatomie County (Loc. 18). **B,** Sharp contact of Schroyer limestone on Havensville shale. NE¼SW¼ sec. 11, T. 11 S., R. 6 E., Riley County (Loc. 133). **C,** Basal cherty limestone of Schroyer member. Note shaly phase above hammer head. SW¼ sec. 3, T. 7 S., R. 9 E., Pottawatomie County (Loc. 3).

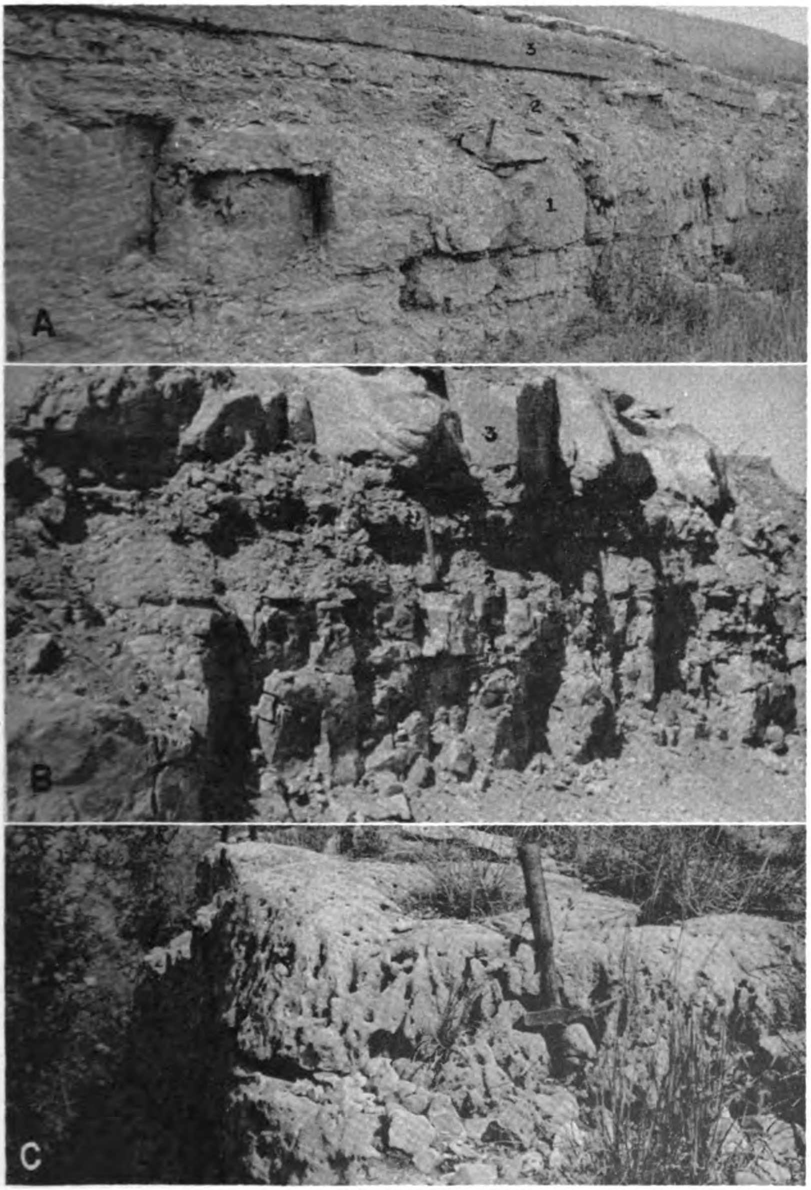

Plate 17. Schroyer limestone. **A,** Exposure of Schroyer member showing (1) basal chert-bearing phase (hammer), (2) middle shaly phase (contains a chert-bearing limestone near the top), and (3) thick-bedded algal bed, in upward order. NE¼ sec. 34, T. 11 S., R. 6 E., Geary County (Loc. 30). **B.** Threefold division of the Schroyer limestone showing in upward order (1) basal chert-bearing limestone, (2) middle shaly phase (with chert-bearing limestone at end of hammer handle), and (3) thick-bedded algal unit. NE¼ sec. 34, T. 12 S., R. 5 E., Geary County (Loc. 137). **C,** Lower Schroyer member. Note nodular chert layer below hammer head. NW¼ sec. 30, T. 32 S., R. 7 E., Cowley County (Loc. 115).

locality 67 provide the only observed exceptions to the generalization that thick-bedded cherty limestone forms the basal unit of the Schroyer member.

Derbyia, Composita, and *Dictyoclostus* are the dominant fossils at many exposures. Fenestrate and ramose bryozoans, crinoids and echinoids, and more rarely, *Aviculopinna,* trilobites, and corals constitute other important faunal elements.

A minimum thickness of 3.1 feet is observed for the basal cherty limestones at localities 91 and 122 in Chase and Cowley Counties. The maximum development is 5.9 feet at locality 35 in Geary County. In all places where thickness exceeds 5 feet the additional thickness is due to the presence of thin-bedded cherty limestone that underlies the thicker beds.

Above the basal cherty portion of the Schroyer member is a shaly unit, which at most places, especially in northern Kansas, contains a thin- to thick-bedded cherty limestone (Pl. 17A,B). The chert is light to dark gray and is locally absent. The limestone is either isolated within the shale or in contact with the overlying algal limestone. At some exposures, localities 70, 108, and 123 being examples, noncherty limestone almost wholly takes the place of the shale. The fauna of the shale is typically mixed and includes the brachiopods *Derbyia, Dictyoclostus, Composita,* and *Chonetes.* Fenestrate, ramose, and massive bryozoans, echinoderm remains, corals, trilobites, abundant ostracodes, and rare specimens of *Septimyalina* are also present. Minute juvenile fusulinids are found in the basal part at localities 67, 93, and 108. Brachiopods, bryozoans, and fragmentary echinoderms are dominant in the cherty limestone. The minimum thickness of the shaly unit is 0.8 foot (Loc. 123). The maximum thickness of 9.5 feet is observed at locality 83.

At all localities where the contact with the overlying Wymore shale is exposed (Pl. 17A,B), the uppermost unit of Schroyer limestone is a thick-bedded algal limestone. At most other localities an algal bed is present in the same stratigraphic position, but absence of higher beds in the Schroyer cannot be proved because Wymore shale is not exposed above. Enough widely distributed sections are known to indicate that the algal bed is almost certainly the uppermost unit of the Schroyer member across all of Kansas. The bed, which is hard and resistant, forms a bench along its outcrop and characteristically is pitted or even somewhat cavernous on weathered surfaces.

Osagia-like algae are ubiquitous in this persistent unit, and in most exposures they are accompanied by minute gastropods, ostracodes, crinoid fragments, brachiopod fragments, and bryozoan debris. Locally, pleurotomariids, *Aviculopecten,* and other mollusks are present. Some difference in shape of the algal colonies is observed, not all being *Osagia*. Minimum thicknesses of 0.95 foot (Loc. 108) and 1 foot (Loc. 9, 83) have been observed for this unit. A maximum thickness of 4.25 feet of algal limestone can be seen at locality 96. The average thickness of this unit is 2.1 feet for 17 localities across Kansas.

The Schroyer limestone maintains a fairly uniform lithology throughout the state and shows the least lateral variation of any member of the Wreford formation. The most marked change observed in the member is a thinning southward and northward from central Kansas. This is graphically shown in Figure 3E.

Matfield Shale

General statement.—The 60 feet or so of shale and limestone lying between the Wreford limestone and the Florence flint was named the Matfield formation from exposures in Matfield Township, Chase County, Kansas, by Prosser (1902, p. 714). Three subdivisions have been recognized. In ascending order they are the Wymore shale, Kinney limestone, and Blue Springs shale members (Condra and Upp, 1931, p. 37-38).

Wymore shale member.—This member was named from exposures 2½ miles east of the south side of Wymore, Nebraska, by Condra and Upp (1931, p. 37). A thickness of 22 feet is known at the type locality.

Only a few complete sections of Wymore shale could be located, because the thickness of the member and the relatively unresistant character of the overlying Kinney limestone commonly result in slopes that are covered completely or only poorly exposed. Generally only the upper part of the Wymore member can be seen at sites where the Kinney crops out. At some places the basal Wymore shale is exposed in gullies for a short distance above the upper Schroyer limestone. Although few localities revealed all of the Wymore shale, several sections that are almost completely exposed were noted. Most of the exposures recorded in older reports are now almost completely covered.

The Wymore shale generally exhibits a fourfold depositional sequence. In upward order lie: (1) silty green shale, (2) silty red shale and red mudstone, (3) silty green shale, and (4) very silty shale, very calcareous mudstone, or hard, very silty limestone. Locally, there is thin interbedding of green and red portions near the contact; at some other exposures, alternating red and green hues are seen throughout the lower part of the member. A thin, sparsely fossiliferous limestone lies between the first reddish zone and the second greenish zone at locality 4. A purplish-red, very calcareous shale lies above the base of the member at locality 30, and a nodular limestone is seen in the basal green portion at locality 108. Condra and Upp (1931, p. 40) describe a nodular limestone near the base of the Wymore shale at locality 111, but such a limestone is not mentioned by Bass (1929, p. 75) or Beede and Sellards (1905, p. 104) and was not seen during the present investigation. Moore and others (1951, p. 45) state that beds of limestone and fossiliferous shale are included in the lower part of the Wymore shale in southern Kansas, but no published section that includes such limestones could be located, and on exposures examined in southern Kansas contain limestone.

The green shales of the Wymore contain a fossilized biota that is dominantly composed of ostracodes, especially *Bairdia* and *Cavellina,* but charophytes and vertebrates are also represented. Charophyte oogonia are rare except at locality 4. Some high-spired gastropods can be collected in the basal 0.5 foot of the lower green shale at locality 30. In places the green shales are nearly unfossiliferous, and the red shales are everywhere unfossiliferous. Mottled red and green shale commonly contains ostracodes. It has been observed that the silty green shales are less fossiliferous than the clayey green strata. Fossils in the silty shale or calcareous mudstone in the upper Wymore member are known only from localities 24, 30, and 93.

The greatest observed thickness of the Wymore beds is 26 feet (Loc. 37), and the minimum thickness is 9 feet (Loc. 111). Bass (1929, p. 75) reports about 10 feet of Wymore shale a mile north of the Oklahoma line south of Silverdale, Kansas. Progressive southward thinning of this member is indicated in Figure 3F.

NATURE AND SIGNIFICANCE OF SEDIMENTARY ROCK TYPES

General Statement

The Wreford limestone and adjacent shales include beds that are traceable laterally for great distances and that consist of lithologic types that are repeated two, three, or more times within the stratigraphic span of the formations studied. Moreover, these recurrent types have a definite stratigraphic relation to one another. The adherence of the Wreford limestone to the general pattern of sedimentary cycles in the "Big Blue" series of Kansas has been noted above. The individual rock types represent phases of rhythmic sedimentation during successive advances and retreats of the early Permian sea. The sediments deposited during a single sedimentary cycle of the type that occurred during Pennsylvanian time have been called cyclothems by Wanless and Weller (1932, p. 1003). Hemicycle is a name that can be applied to either the transgressive or regressive portion of a cyclothem. Megacyclothem is the name applied to a cycle of cyclothems (Moore, 1936a, p. 29).

Some rock types are encountered at only one or very few places. These include a coal seam 1.0 mm thick in the Speiser shale at one exposure and a fine-grained channel conglomerate at another. Certain limestones observed locally in various stratigraphic positions contain no diagnostic fossils and are very argillaceous. They have no easily interpretable relationship to other parts of the cyclothem. Based on the past observations by the writer, they are judged to be deviant rock types still within the limits of variation of adjacent types.

Rocks that have characteristic lithology, fauna, and cyclic position and that are common in the Speiser shale, Wreford limestone, and Wymore shale are each described in detail below. Reference is made first to the physical characteristics, then to the environment of deposition, including consideration of position in the sedimentary cycles.

Physical Characters

Sandstone.—At four localities in southern Kansas lenticular bodies of unfossiliferous sandstone exist in the midst of the red shale sequence. At two places the standstone is massive to thick bedded, friable to well cemented, cross-bedded, and light-grayish yellow-orange. The grain size of the sandstones is coarsest at locality 121, where the maximum thickness of 20 feet was observed. The edge of a channel is well exposed at locality 125. Three and four bodies of sandstone are present at localities 119 and 120, respectively (Pl. 7A). At both these exposures the several sands are thin to medium bedded, well cemented, very fine grained, locally cross-bedded, and yellowish gray but exhibiting some reddish staining. An exception is a thick-bedded, light-yellowish-gray, lenticular sandstone bed, the uppermost of four at locality 120 (Pl. 7A), which resembles more closely the sands at localities 121 and 125. Wherever observable, the sandstone bodies are level on the upper surface and convex downward on the lower.

Grain sizes of sandstone in the Speiser shale at locality 120, Cowley County.

1/2 to 1/4 mm	1.12 percent
1/4 to 1/8 mm	80.05 "
1/8 to 1/16 mm	12.10 "
<1/16 mm	6.72 "
	99.99 percent

The sand grains of this sample are predominantly quartz and are angular owing to crystal growth by secondary addition of silica. Most of the grains of all sizes show some well-developed crystal surfaces, and many euhedral crystals can be observed. Granular reddish-brown limonite is sparsely present in the fine-sand fraction. Limonite cubes pseudomorphous after pyrite, as well as flakes of muscovite, are common in the very fine sand. Other minerals are virtually absent. Other sands examined are composed of quartz grains except for a very small amount (less than 1 percent) of muscovite and minor amounts of limonite. In a few specimens calcite cement is observed, but most samples are only slightly calcareous.

Petrographic examination of some of the more compact sands, which could not be disaggregated readily, showed uniform grains dominantly of fine and very fine sand size. Most of the grains show angularity, perhaps due to secondary addition like that described above. The reddish color observed is probably a limonitic stain. Quartz grains are dominant; minor amounts of limonite and muscovite are present.

Red shale.—Red shales are characteristic features of the middle parts of the Speiser and Wymore shales. The color ranges from pale red to very dusky red and includes grayish and purplish hues. Shaly bedding and a tendency to weather blocky are characteristic of the red shales. In most places red shale is in abrupt contact above and below with shale of greenish hue, or thinly interstratified with several beds of greenish shale, or grades through transitional beds mottled with greenish shale.

Almost all of the red shales are silty, locally enough so as to be classed as mudstones. Fine sand is present in the red mudstones, although in most it is only a small percentage of the whole. Sand/shale ratios for most red shales are less than 1/10, though ratios of 1/2 have been observed. As much as 84 percent of calcareous material has been noted in one of the red-shale units, and all the red shales are calcareous to some degree; 30 percent soluble material is not unusual for this type of rock. Mineral grains found in washed residues include quartz sand and silt grains and granular reddish-brown limonite.

Fossils are exceedingly rare in the red shales. A few charophyte oogonia were found at a single locality.

Green shale.—Green shale is commonly observed in the lower part of the Speiser shale and is almost invariably present in the middle Speiser and lower and middle parts of the Wymore shale. It is uncommon in the Havensville shale. The green strata cyclically precede and follow red shales where the latter are present. The color ranges from grayish-yellow green to grayish green and includes some shades of olive green. Bedding and weathering characteristics are much the same as in red shale.

Most of the green shales are silty and are as sandy as the red, and many are true mudstones. Sand, where present, is very fine grained. Sand/shale ratios ranging from 1/2 to 1/25 are observed. As much as 50 percent soluble material has been detected in green shale, but 30 percent is more usual. The washed residues contain grains of clear detrital quartz, aggregates of granular limonite, sparse crystalline pyrite, crystalline calcite pellets, and sparse hematitic material.

These fossils, with exception of *Paraparchites, Bairdia, Cavellina,* and fragmentary vertebrate remains, were noted in samples

Fossils Observed in Green Shales of the Speiser, Havensville, and Wymore Shales.

Ostracodes	?*Silenites* sp.
Bairdia sp.	Mollusks
Bythocypris sp.	Gastropods, high-spired
Cavellina sp.	Vertebrates
Knoxina sp.	Fragmentary remains
Macrocypris sp.	Plants
Paraparchites sp.	*Neuropteris* sp.
?*Hollinella* sp.	Charophyte oogonia
?*Microcheilinella* sp.	Seaweed impressions

from only one or two localities. The fauna as a whole is very sparse, and some seemingly unfossiliferous green shales were encountered.

The contact of green shale with red has been discussed above. At many exposures a grayish-yellow, dusky-yellow, or light olive-gray shale overlies the upper green shale of the Wymore and Speiser shales. The contact between the two is transitional, and the fauna in the yellowish shale shows a change to marine conditions.

Grayish-yellow mudstone.—Between the green-shale phase and the molluscan-limestone phase of the Wreford megacycle lies dusky-yellow, yellowish-brown, grayish-yellow, or olive-gray silty shale, mudstone, or argillaceous limestone. This seemingly heterogeneous assemblage of rocks has a constant position in relation to cycles of sedimentation. The phase is so named because grayish-yellow mudstone is more common in this part of the cycles than any of the other variants. At some exposures green shale is in direct contact with molluscan limestone, the yellowish phase being absent altogether. In most exposures contact of mudstone with overlying molluscan limestone is sharp, but that with underlying green shale is gradational, the transition beds being mottled. Usually, units of this lithology are sparsely fossiliferous. Faunas, where present, are intermediate in composition between those of the green shale and the molluscan limestone. As much as 84 percent of calcareous material has been observed in samples from these beds. The sand/shale ratio ranges from about 1/2 to 1/100. In most places a large percentage of silt and sand is observed. Shaly or laminated bedding is characteristic of strata having this lithology. This phase is represented in the upper Wymore shale at some localities (24, 30, 93) by a medium-hard, very calcareous mudstone or very silty limestone that is thin bedded or laminated.

Minerals in the grayish-yellow mudstones include subangular to well-rounded clear or amethystine quartz grains of granule, sand, and silt size; jaspery silica; milky-white replacement silica; hematite; limonite as granular pellets, tiny botryoidal masses, and as an alteration product of hematite and pyrite; finely divided muscovite; and calcite in granular pellets, small crystals, and crystalline masses.

. This phase of sedimentation contains a much more diversified fauna than the green shale. The following fossils have been observed, sparse forms being idicated by (s) and common forms by (c).

Fossils of the Grayish-Yellow Mudstones of the Speiser, Havensville, and Wymore Shales.

Plants
- Charophyte oogonia (s)

Foraminifers
- *Ammovertella* sp. (s)
- *Cornuspira* sp. (s)
- *Globivalvulina* sp. (c)
- *Orthovertella* sp. (s)

Annelids?
- Worm tubes (s)

Bryozoans
- *Septopora* sp. (s)

Brachiopods
- Productid spines (c)

Mollusks
- *Aviculopecten* sp. (s)

Ostracodes
- *Bairdia* sp. (c)
- *Bythocypris* sp. (s)
- *Cavellina* sp. (c)
- *Hollinella* sp. (s)
- *Kirkbya* sp. (s)
- *Knoxina* sp. (s)
- *Macrocypris* sp. (s)
- *Paraparchites* sp. (s)

Echinoderms
- Crinoid stems (s)
- Echinoid spines (s)
- Holothurian hooks (s)

Vertebrates
- Fragmentary remains (s)

Molluscan limestone.—Beds of argillaceous to very shaly limestone typically lie between the grayish-yellow mudstone (or green shale) phase and the calcareous-shale phase in the Speiser shale and Wreford limestone. Most deposits representing this phase of sedimentation are 0.1 to nearly 1 foot thick. Individually, the units consist of a single thick bed, several thin beds, or shaly strata. The limestones range from yellowish gray to dark gray. At all exposures where the limestones are well developed, *Aviculopecten* (Pl. 18A) and, commonly, *Septimyalina* are the diagnostic megafossils. It is for this reason that the name "molluscan limestone" has been applied.

A remarkable development of molluscan limestone is found in the Havensville shale at many exposures in northern Kansas, especially in Marshall and Pottawatomie Counties. At localities 8, 10, 12, and 21 the middle of the member includes a fairly thick

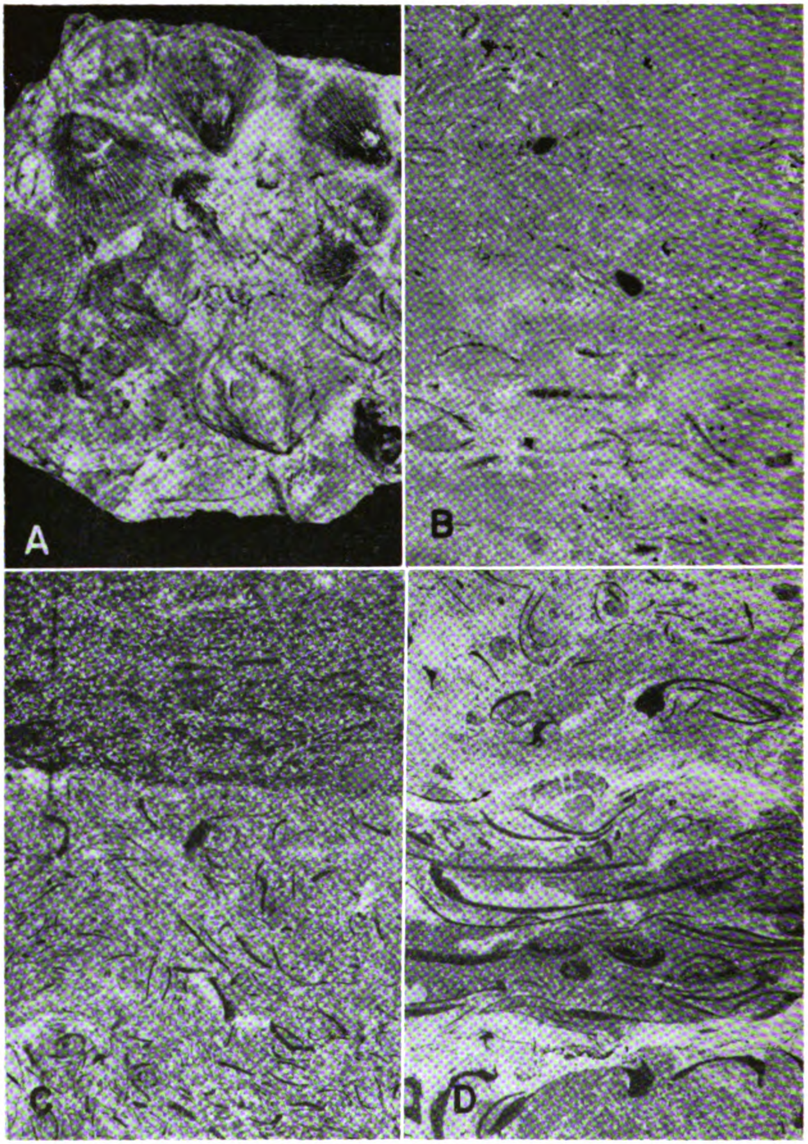

PLATE 18. Molluscan limestone. **A,** Slab containing abundant *Aviculopecten* from limestone bed in lower Havensville shale, ×1. NW¼ sec. 21, T. 11 S., R. 8 E., Riley County (Loc. 36). **B,** Peel photograph, ×4, of molluscan limestone from Speiser shale. Note rough alignment of structures. NW¼ sec. 10, T. 7 S., R. 9 E., Pottawatomie County (Loc. 1). **C,** Peel photograph, ×4, of molluscan limestone from Havensville shale. Note abundant *Ammodiscus* (white rod-shaped structures) SW¼ sec. 3, T. 7. S., R. 9 E., Pottawatomie County (Loc. 2). **D,** Peel photograph, ×4, of limestone from the upper Speiser shale. Note abundant organic structures. SW¼ sec. 19, T. 32 S., R. 8 E., Cowley County (Loc. 117).

sequence of thin-bedded, very argillaceous limestone, which contains a sparse molluscan assemblage. Above this lies a thick molluscan-limestone bed, which bears abundant algal remains as well as *Aviculopecten* and various other small pelecypods. The thick bed is profusely fossiliferous at locality 13, but the mollusks are small. Adjacent sections likewise include a greater-than-usual thickness of molluscan limestone, although not so much as in the named exposures. The mudstone phase of sedimentation, which is ordinarily found between two molluscan limestone beds in the Havensville in northern Kansas, is absent in these sections.

At several localities in northern Kansas rounded granules and pebbles of clay and limestone are found in the molluscan-limestone phase of the upper Speiser shale. Bedded and nodular chert is not observed to be present.

A finely granular texture is prevalent among the molluscan limestones (Pl. 18B). Much of the matrix consists of silt and clay, especially in the more shaly varieties. Etched surfaces exhibit numerous fossil fragments and entire shells, the latter aligned parallel to the bedding. Aligned fossil fragments are found in one sample. Many of the fossils are silicified. Algal structures resembling *Osagia* are present in several of the specimens studied, but they are not abundant.

Insoluble residues contain much the same sort of material seen in other limestones of the Speiser shale and Wreford limestone. All molluscan-limestone residues contain moderate to profuse numbers of foraminifers of the genus *Ammovertella*, which is found commonly with *Ammodiscus*. The latter is present in great abundance in a few places (Pl. 18C). The types of insoluble materials present in selected rock specimens are listed below in order of their relative abundance in the samples. An average residue of about 4 percent is observed, although one specimen yielded 20 percent.

Insoluble Residues of Molluscan Limestones of the Speiser Shale and Wreford Limestone.

Arenaceous fossils
Granular and chalcedonic chert, mostly as fossil-replacing minerals
Quartz silt and sand grains and losely aggregated silt (in part? foraminiferal debris)
Limonite, reddish-brown to yellowish-orange, granular
Pyrite
Asphaltic residue

Petrographic examination of a thin section of the more thick-bedded variety of molluscan limestone (Loc. 1) shows a rock of uniform texture composed of minute grains of calcite. Small fossil fragments aligned parallel to the bedding are common, many of them being affected by recrystallization. Crystalline calcite fills the interior of some of the fossils. Scattered oölites exhibit concentric lamination of thin calcite layers. A faint cross formed in the planes of polarization and radial appearance in the laminae suggest orientation of calcite crystals perpendicular to the surface of the oölites. _Nubecularia_, a calcareous foraminifer, is abundant in the thin section and it is commonly contained within oölites. A selected sample of the more argillaceous shaly bedded type of molluscan limestone also shows, in thin section, a fine-grained calcite matrix but appears "dirty" because of an abundance of clay. Numerous fossils, mostly fragmentary, are oriented quite diversely, and nearly all consist of recrystallized calcite.

Crystalline calcite is found as internal fillings and drusy calcite as internal incrustations of fossils. Numerous specimens of _Ammodiscus_ are conspicuous, these likewise showing random orientation.

Although only one or two fossils seem to be ubiquitous in the molluscan limestones, many are believed by the writer to maintain a fairly constant association. In the following tabulation of fossils an asterisk denotes the diagnostic forms.

Fossils Observed in the Molluscan Limestones of the Speiser and Havensville Shales.

Plants
- _Osagia_ sp.

Foraminifers
- _Nubecularia_ sp.
- *_Ammovertella_ sp.
- *_Ammodiscus_ sp.
- _Globivalvulina_ sp.

Bryozoans
- Fenestrate types
- Ramose types

Brachiopods
- Productid spines
- _Dictyoclostus_ sp.
- _Juresania_ sp.
- _Lingula_ sp.
- _Orbiculoidea_ sp.

Mollusks
- _Pseudomonotis_ sp.
- _Aviculopinna_ sp.
- *_Aviculopecten_ sp.
- *_Septimyalina_ sp.
- *_Pelecypods_, molds
- *Gastropods, tiny internal molds
- _Bellerophon_ sp.

Ostracodes
- ?_Cavellina_ sp.
- Ostracodes sp.

Echinoderms
- Crinoid remains

Ordinarily, the molluscan fauna is found in a limestone phase of sedimentation that contains few, if any, forms typical of other units. Probably no ideally complete cycle of sedimentation exists, however, and in the sequence of the Wreford megacyclothem there are definite exceptions to every generalization. The most symmetrically disposed molluscan beds, with relation to the Wreford limestone, are found in northern Kansas. Fairly persistent and faunally distinctive molluscan beds lie below and above the Threemile limestone in the first cycle of deposition and below the Schroyer limestone in the second cycle. In the upper Schroyer member, there are beds equivalent to the molluscan limestone, although the organic content of these, to be described below, differs markedly. Locally, as in Pottawatomie County, the molluscan beds of the Havensville shale are decidedly more algal than elsewhere.

Maximum divergence from ideal cyclic conditions is observed in Cowley County. The molluscan beds of the upper Speiser shale contain admixtures of the fauna typical of the calcareous-shale unit above. Locally, *Aviculopecten* and other diagnostic fossils seemingly are lacking in the limestone near the top of the Speiser shale. Instead, elements of the calcareous shale fauna are found in the first limestone above the red-shale—green-shale—mudstone sequence. Furthermore, mollusks are very commonly found stratigraphically above *Derbyia*-bearing limestone, which also contains other fossils characteristic of calcareous-shale units. In southern Butler County and in Cowley County the entire upper portion of the Speiser shale consists of interbedded thin limestones and shales. *Derbyia*, *Juresania*, *Aviculopecten*, and *Aviculopinna* are the dominant fossils in these rocks. The two phases of sedimentation, which are so distinct to the north, are here intermingled lithologically and paleontologically.

Local variations in the position of the molluscan phase are known. At a few exposures the *Aviculopecten* assemblage of the upper Havensville shale lies in the upper part of limestone that contains a calcareous-shale fauna. This is unusual because the phenomenon is observed in the transgressive stage of sedimentation and the normal succession of faunas is reversed. At these localities, however, mollusks are found also in the shale below the limestone.

Thin sections of limestone containing fossils characteristic of both the molluscan-limestone phase and the calcareous-shale phase were made and studied petrographically. These sections are described as follows:

1. Upper Speiser shale (Loc. 117). The very fine granular matrix is composed of calcite grains. The rock is medium gray. Numerous large fossil fragments are aligned parallel to the bedding and are composed of coarsely crystalline secondary calcite. The internal filling of most of the larger fossils clearly shows a finer grain than the surrounding rock. Innumerable foraminifers, which resemble *Ammodiscus*, and small fossil fragments are present in the rock (Pl. 18D).

2. Upper Speiser shale (Loc. 117). The finely granular, medium-gray matrix contains numerous crystallized fossils and abundant *Ammodiscus*. A few structures show thinly laminated concentric layers of calcite. Under crossed nicols, a black cross appears, which is centered over the structure. This indicates a radial arrangement of calcite crystals perpendicular to the laminae. Undoubted oölites show this petrographic feature, and it may be that the structures are true oölites.

3. Upper Havensville shale (Loc. 72). The matrix is composed of irregular fine grains of calcite and extremely abundant fossil fragments. Fossils are aligned parallel to the bedding. The shell fragments have not been recrystallized to any marked degree; original structure is preserved in many. Incrustations of thin laminae of calcite around many fossil fragments seem to be oölites. A black cross under crossed nicols indicates radially arranged crystals in the laminae. The rock is mottled yellowish brown and medium gray.

The limestones that contain fossils characteristic of both the molluscan phase and the calcareous-shale phase of sedimentation are yellowish gray to medium-dark gray, including yellowish-brown and olive-gray hues. Finely granular texture and alignment of fossils parallel to the bedding are typical. Residues contain the same insoluble materials as those from the molluscan limestone, arenaceous foraminifers being conspicuous. The following list of organic remains shows the mingling of molluscan-limestone fauna and calcareous-shale fauna in these beds.

Fossils Observed in Certain Unusual Molluscan Limestones of the Speiser Shale and Wreford Limestone.

Plants
- *Osagia* sp.

Foraminifers
- *Globivalvulina* sp.
- *Ammodiscus* sp.
- *Ammovertella* sp.

Bryozoans
- Fenestrate and ramose types
- *Fenestrellina* sp.
- *Septopora* sp.

Brachiopods
- *Composita* sp.
- *Derbyia* sp.
- *Dictyoclostus* sp.
- *Juresania* sp.
- *Orbiculoidea* sp.
- Productid spines

Mollusks
- *Allorisma* sp.
- *Aviculopecten* sp.
- *Aviculopinna* sp.
- *Septimyalina* sp.
- *Schizodus* sp.
- Pelecypods, molds
- Gastropods, molds
- *Bellerophon* sp.
- *Euomphalus* sp.
- *Euphemites* sp.
- ?*Cymatospira* sp.

Ostracodes
- *Bairdia* sp.
- *Cavellina* sp.
- *Knoxina* sp.
- *Hollinella* sp.
- *Paraparchites* sp.
- *Monoceratina* sp.
- *Kellettina* sp.

Echinoderms
- Crinoid remains
- Echinoid plates
- Echinoid spines

The preceding discussion of variations in the phases of sedimentation indicates that (1) the calcareous-shale type of mixed fauna is not wholly restricted to rocks of that lithology; (2) the molluscan-limestone type of fauna may be found in shale, although not typically so; and (3) the two assemblages may be found intermingled in both limestone and shale units. None of these variations is in serious disharmony with the cyclic pattern of sedimentation. The paleoecological implications are discussed below.

Calcareous shale.—Very fossiliferous calcareous shales lie stratigraphically between chert-bearing limestone and argillaceous limestone bearing near-shore mollusks or are situated between two chert-bearing limestones. Calcareous shale typically ranges from grayish yellow and yellowish gray to medium and dark gray. The colors are commonly mottled. Thin limestone nodules or lenses are common in northern and central Kansas, and toward the south this type of lithologic unit becomes progressively more calcareous. In the latter region shaly limestones or thin-bedded, gray, argillaceous limestones are a conspicuous feature of the calcareous-shale units. Bedding in the calcareous shales is typically shaly even where the shale locally grades into an argillaceous limestone. The contact with underlying or overlying limestones is somewhat gradational.

Shale of this type may contain as much as 75 percent soluble material, although about 60 percent is average. The sand/shale ratio ranges from 1/2 to 1/25, but the larger ratios are due to the presence of silicified fossil fragments retained in the sand fraction. Except for fossils, the sand grains are very fine and consist chiefly of quartz. Of the other minerals found in these shales, most common are small aggregates of reddish-brown granular limonite, but common also are botryoidal limonite, hematite, drusy pyrite, plates and small granular pellets of secondary crystalline calcite, chert as fossil-replacing material, quartz sand and silt grains, small clusters of euhedral quartz crystals, and asphaltic residue. Not all of these are present in any one sample, but some are found in each sample examined.

The fauna of the calcareous-shale units is the most abundant and most varied taxonomically of any in the Wreford megacyclothem. Certain forms are nearly everywhere found in the assemblage. The fossils are tabulated below by phyla. Asterisks precede the forms that are diagnostic, and forms that are sparse, or known only locally, are indicated by (s). All other fossils listed have a moderate distribution in the calcareous-shale units.

Fossils Observed in Calcareous-Shale units of the Spesier Shale and Wreford Limestone.

Plants
- *Osagia* sp. (s)

Foraminifers
- *Ammovertella* sp.
- *Climacammina* sp. (s)
- Fusulinids, juveniles (s)
- **Globivalvulina* sp.
- *Geinitzina* sp. (s)
- *Hyperammina* sp.
- *Tetrataxis* sp.
- ?*Orthovertella* sp. (s)

Corals
- *Aulopora* sp. (s)
- *Stereostylus* sp. (s)

Bryozoans
- Cyclostome, encrusting (s)
- **Fenestrellina* sp.
- *Penniretepora* sp.
- *Polypora* sp.
- *Rhabdomeson* sp.
- **Rhombopora* sp.
- *Septopora* sp.
- *Streblotrypa* sp. (s)
- Trepostome, encrusting (s)
- **Thamniscus* sp.
- ?*Batostomella* sp. (s)
- ?*Leioclema* sp.

Brachiopods
- **Chonetes* sp.
- **Composita* sp.
- **Derbyia* sp.
- **Dictyoclostus* sp.
- **Enteletes* sp.
- *Juresania* sp.
- *Lingula* sp.
- *Orbiculoidea* sp.
- *Petrocrania* sp.
- *Productid spines

Mollusks
- *Aviculopecten* sp. (s)
- *Aviculopinna* sp.
- *Euomphalus* sp.
- *Pseudomonotis* sp. (s)
- *Septimyalina* sp. (s)
- Gastropods, molds

Ostracodes
- *Amphissites* sp.
- **Bairdia* sp.
- *Bythocypris* sp.
- **Cavellina* sp.
- *Cornigella* sp. (s)
- *Ellipsella* sp. (s)
- *Healdia* sp. (s)
- *Hollinella* sp.
- *Kellettina* sp.
- *Kirkbya* sp.
- *Knightina* sp.
- **Knoxina* sp.
- *Macrocypris* sp.
- *Monoceratina* sp.
- *Paraparchites* sp.
- *Roundyella* sp.
- *Silenites* sp.
- ?*Haworthina* sp. (s)

Trilobites
- *Ditomopyge* sp.

Echinoderms
- **Delocrinus* sp.
- *Crinoid plates and stems
- *Echinoid plates
- *Echinoid spines
- Holothurian spicules, wheels (s) and hooks

Vertebrates
- Conodonts (s)
- *Fragmentary remains, plates, teeth, bones

Although typically characterized by brachiopods, bryozoans, and echinoderms, these beds do contain mollusks. The assemblage has been called the mixed phase by Elias (1937, p. 411) and is number 5 of his ideal "Big Blue" cycle.

Chert-bearing limestone.—Chert-bearing limestone is the most persistent and prominent type of rock in the Threemile and Schroyer members of the Wreford formation. Such beds invariably lie at the base of each of these members, in the upper Threemile limestone at most exposures, and commonly within the shale sequence below the algal limestone of the Schroyer member (Pl. 5B, 9A, 16C, 17C, etc.).

Chert, which is the most diagnostic feature of the Wreford limestone, comprises both discontinuous-nodular and continuous pinching-and-swelling beds. Two general types are common: (1) hard, gray, noncalcareous, compact to slightly porous chert, which commonly exhibits a lighter-colored weathered shell; and (2) hard, bluish-gray, porous, calcareous chert, which exhibits concentric layering throughout.

Limestones in which chert is a persistent feature exist in distinguishable units 0.5 to more than 6 feet thick. Strata of this type are dominantly medium to thick bedded and generally hard. The color most commonly observed is yellowish gray or grayish yellow, dusky-yellow, light-gray and light-olive-gray hues being seen more rarely. Weathered, the rocks take on a grayish-yellow hue. These beds are topographically expressed as chert-covered slopes. The completely fractured nature of the chert beds causes rapid collapse during stream undercutting, and there is little resistance to slumping and creep on hill slopes. The most characteristic fossils to be found in this phase of sedimentation are fragments of fenestrate and ramose bryozoans, crinoid stems, echinoid plates and spines, productid spines, and shells of *Dictyoclostus*, *Composita*, and *Wellerella*.

Texturally, finely-granular and subgranular matrixes are the most common (Pl. 19A,B,C,D). Subcrystalline textures are observed in only a few samples. Structures in the limestone consist mainly of shell fragments, many of which are replaced by chert. Fossil debris is at best fragmentary and only moderately abundant in most places; however, locally there are great quantities of whole fossils and broken fragments. Alignment parallel to bedding

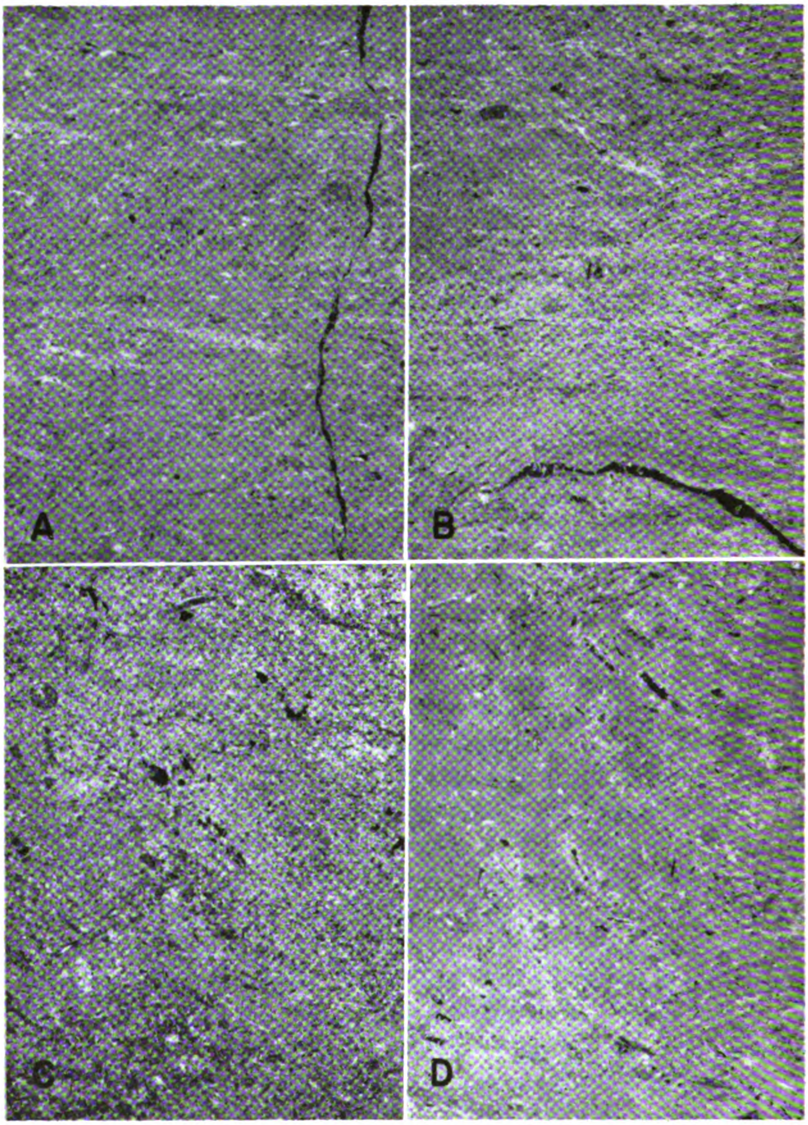

PLATE 19. Chert-bearing limestone. **A,** Peel photograph, ×2, of cherty limestone from lower Threemile member. SW¼ sec. 3, T. 7 S., R. 9 E., Pottawatomie County (Loc. 2). **B,** Peel photograph, ×4, of cherty limestone from upper Threemile member. Center sec. 35, T. 22 S., R. 9 E., Chase County (Loc. 93). **C,** Peel photograph, ×2, of cherty limestone from lower Schroyer member. SE¼ sec. 16, T. 15 S., R. 7 E., Morris County (Loc. 67). **D,** Peel photograph, ×4, of cherty limestone from upper Schroyer member. NE¼ sec. 34, T. 11 S., R. 6 E., Geary County (Loc. 30).

planes is the usual arrangement of these constituents (Pl. 20A,B,C).

Insoluble residues of the cherty limestones are diagnostic. Quartz-silt aggregates are abundant in most of the samples studied. Limonite is common, but it is seen in residues of all phases of deposition. Granular and chalcedonic chert, existing as fossil-replacing materials, are found in all the residues, but they are likewise observed in nearly every type of limestone studied. The insoluble substances found in residues of chert-bearing limestone are listed below. An asterisk indicates the most abundant types and an (s) follows those that are uncommon.

Insoluble Residues of Cherty Limestones of the Wreford Formation.

*Fossils replaced by granular and chalcedonic chert
*Quartz silt, loose and aggregated
*Quartz sand, very fine grains
*Limonite
*Beekite
Asphaltic residue
Arenaceous foraminifers
Pyrite
Chalky tripolitic chert
Chalky chert (s)
Limonite pseudomorphs of pyrite (s)
Glauconite (s)
Granulated chert (s)
Gilsonite (s)
Drusy chert (s)
Drusy quartz (s)
Hematite (s)
Muscovite (s)
Lacy granular chert (s)

The arenaceous foraminifers are of the same types as occur in molluscan limestone and in algal beds. Aggregates of quartz silt grains are probably in part the fragments of these protozoans or may belong to some problematic foraminiferal species. Most of the limestones produced 1 percent or less of residue, although as much as 70 percent was observed. All large percentages of insoluble materials are due to abundant tripolitic chert, which, though large in volume, comprises a relatively small proportion of the total sample weight.

Thin sections of chert-bearing limestone from several localities were studied petrographically. Brief descriptions of these follow.

1. Lower Threemile limestone (Loc. 102). Matrix of very fine granular calcite. Few fossils, small, and aligned parallel to the bedding. Some areas filled by crystalline calcite.

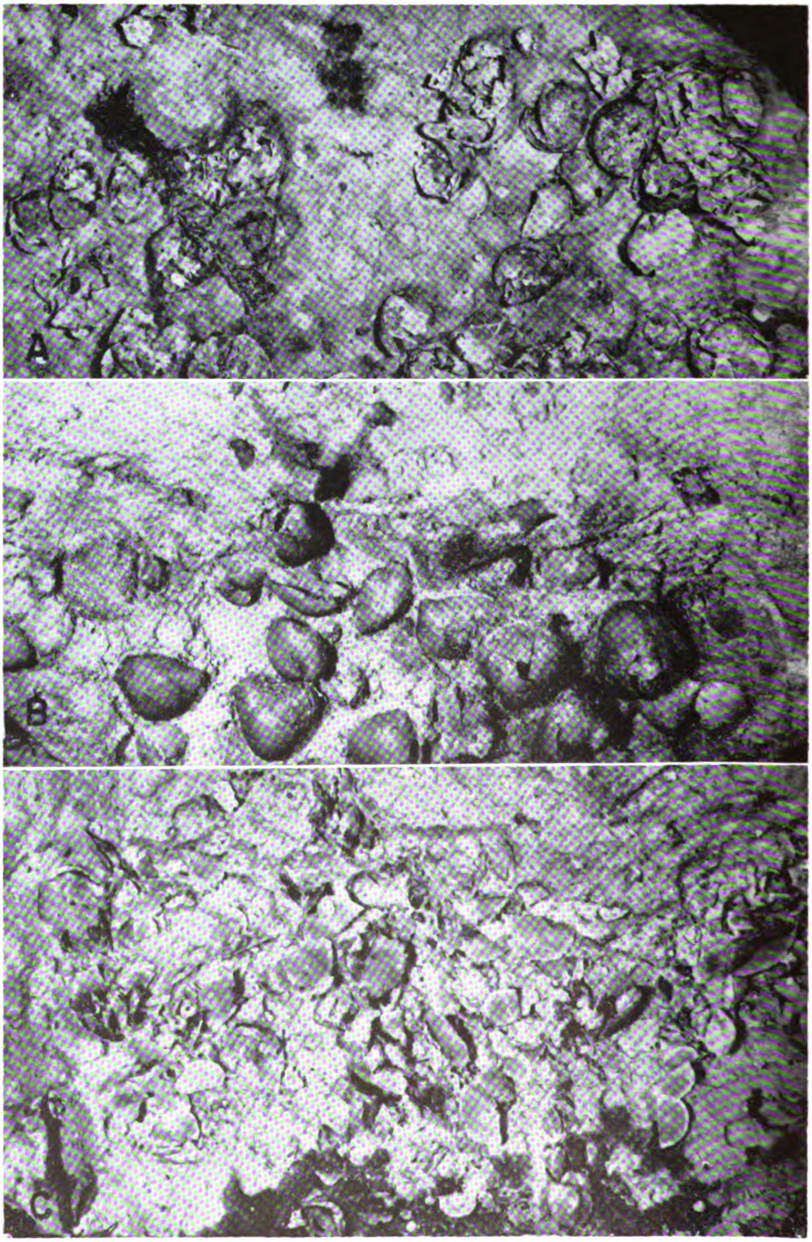

Plate 20. Silicified fossils in cherty limestone. **A,** *Enteletes* from lower Threemile limestone, ×½. Center sec. 35, T. 22 S., R. 9 E., Chase County (Loc. 93). **B,** *Composita* from lower Threemile limestone, ×½. SW¼ sec. 36, T. 32 S., R. 8 E., Cowley County. **C,** *Chonetes* from upper Threemile limestone, ×1. SW¼ sec. 22, T. 16 S., R. 10 E., Lyon County (Loc. 69).

2. Lower Threemile limestone (Loc. 115). Matrix of very fine granular calcite. Fossils very abundant, rudely oriented parallel to the bedding, commonly recrystallized, some filled internally or replaced by chert. Bryozoan and brachiopod debris especially abundant. A few structures show concentric lamination around crystalline nuclei and exhibit a black cross under crossed nicols. These are possibly algal in origin but may be oölites.

3. Lower Threemile limestone (Loc. 115). Matrix of fine granular calcite. Fossils abundant, fragmentary, commonly replaced by crystalline calcite or chert, but many show original structure. Bryozoan and brachiopod fragments are recognizable. Small chert nodules are irregular in shape and are in gradational contact with the limestone. Rosettes of fibrous chalcedony and other cryptocrystalline features are abundant in the chert.

4. Lower Schroyer limestone (Loc. 30). Matrix of extremely fine granular calcite. No structures other than sparse tiny ?fossil fragments. A single grain of crystalline quartz noted. This is a very dense limestone.

5. Lower Schroyer limestone (Loc. 67). Matrix of fine granular and crystalline calcite. Fossil fragments very abundant; most show original structure, commonly filled internally with crystalline calcite, and very roughly oriented parallel to the bedding. Crinoid, bryozoan, and brachiopod fragments abundant. Concentrically laminated calcite structures resemble those of (2) above.

6. Middle Schroyer limestone (Loc. 3). Matrix of very fine granular calcite. Fossil fragments very abundant, aligned parallel to the bedding, many recrystallized, but most exhibit original structure. Large areas of coarsely crystalline calcite. Some replacement of fossils by crystalline quartz. Most recognizable organic fragments are bryozoan and brachiopod remains.

It is clear, upon reviewing these descriptions, that the dominant type of matrix is finely granular. Crystalline calcite is common. Abundant, very small fossil fragments are in evidence and are either unmodified, recrystallized, or replaced by chert. All three types generally exist in each chert-bearing limestone.

The fossils of the cherty limestone are similar to those found in the calcareous shale but are generally less abundant and far less diversified. Of course, many fossils in the shale are microscopic and are easily detected in washed samples, whereas in limestone only insoluble microfossils can be identified easily. In the following list of fossils seen in the cherty limestone an asterisk precedes the most common forms and an (s) follows those that are uncommon.

Fossils Observed *in the Cherty Limestones of the Wreford Formation.*

Plants
- ***Osagia*** sp. (s)

Foraminifers
- ***Ammodiscus*** sp. (s)
- ***Ammovertella*** sp.
- ***Schwagerina*** sp. (s)

Sponges
- Sponge spicules

Corals
- *Stereostylus* sp.
- *Aulopora* sp. (s)

Bryozoans
- **Fenestrellina* sp.
- *Penniretepora* sp.
- *Rhombopora* sp.
- *Septopora* sp.
- *Tabulipora* sp.
- *Thamniscus* sp.
- *Fenestrate and ramose types

Brachiopods
- *Chonetes* sp.
- **Composita* sp.
- **Derbyia* sp.
- **Dictyoclostus* sp.
- *Enteletes* sp.
- *Orbiculoidea* sp. (s)
- *Productid spines
- *Wellerella* sp.

Mollusks
- *Aviculopecten* sp. (s)
- *Aviculopinna* sp. (s)
- Gastropods, small molds (s)
- *Septimyalina* sp. (s)

Trilobites
- *Ditomopyge* sp.

Ostracodes
- *Bairdia* sp.
- Ostracodes, indeterminable

Echinoderms
- *Delocrinus* sp.
- *Crinoid stems
- *Echinoid spines
- *Echinoid plates

Vertebrates
- Fragmentary remains

Chalky limestone.—In northern and central Kansas the upper Threemile limestone contains persistent beds of light-colored, thick-bedded to massive, porous, sparsely fossiliferous chalky limestone that bears little chert. In most exposures the chalky limestones are light yellowish gray to light grayish yellow. The weathered rock is grayish yellow and commonly is cavernous. The surface of freshly broken rock is powdery. Chert-bearing limestone generally lies above, as well as below, these beds. Limestones of this lithology are traceable from Marshall County to Chase County. There the rock aspect changes; chert is more abundant, and the color of the rock darkens. In Marshall, Pottawatomie, Riley, and Geary Counties this part of the Threemile limestone, with a single observed exception, is 2 to 5 feet thick. The small amount of chert contained within these beds comprises one to five layers of small spheroidal nodules, or at a few exposures, continuous beds of chert. The sparse fossils in these beds consist mainly of echinoderm, bryozoan, and brachiopod remains.

Beds representing this phase of sedimentation exhibit remarkable thickening within very short distances in Wabaunsee, Morris, Lyon, and Chase Counties, and at two exposures (including Loc. 27) in Geary County. The chalky limestone is about 25 feet thick at locality 135, and at locality 90 it is about 22 feet thick. The thick chalky limestones contain a few discontinuous "beds" of small, spheroidal nodules of compact chert, most of which lie at the base or in the uppermost portion. Huge spheres and irregular nodules of layered calcareous chert as much as 3 feet in diameter are seen at localities 27 and 90 (Pl. 11C, 12A). The main body of limestone at these places is thickbedded to massive, virtually structureless, and only sparsely fossiliferous.

Fossils, where abundant in these unusual limestones, consist mainly of fenestrate bryozoans. These are present in quantity sufficient to contribute significantly to the large thickness encountered. At many places, notably localities 67 and 90, corals are moderately abundant in the top foot of the massive limestone. *Stereostylus* and *Dibunophyllum* are represented, the latter commonly crowded together to form an almost colonial mass (Pl. 21A). Specimens of the brachiopod genus *Composita,* although nowhere abundant in the chalky limestone, are found at most exposures.

Where the Threemile limestone is abnormally thick, the Havensville shale is very thin. There is only 1.5 feet of shale between the Threemile and Schroyer members at locality 90 (Pl. 12A). Similarly, at locality 67, only 5 feet of shale is present. Although most of the upper part of the section is covered at locality 135, there seems to be only 3 or 4 feet of Havensville shale. Because there is an almost unbroken geographical succession of localities where the thickening is observed, it is concluded that the chalky limestones constitute a virtually continuous body of fairly homogeneous character. Because of uniformity in lithology, fossils, geographic pattern, and lateral stratigraphic relationships, the sections that exhibit an abnormal thickness of chalky limestone are judged to be exposed parts of a large reef. When plotted on a map, the localities form a broadly arcuate belt convex toward the northwest (Fig. 5). Local, coarse, conglomeratic to coquinoidal limestones in the upper Threemile limestone and lower Havensville shale are known in exposures adjacent to reef sections. These deposits, none of which is very thick, may be talus that accumulated along the reef flank before burial by younger sediments.

Texturally, finely granular matrix is dominant in the chalky beds. The individual grains of loosely cemented calcite are dull and lusterless. The chalky limestones are nearly all very porous. Irregularly rounded or elongate solution pits abound in the rock. Some beds containing abundant randomly oriented, subequal, elongate openings are traceable for many miles. Some crystalline calcite is present in openings in the rock, and the surfaces exposed

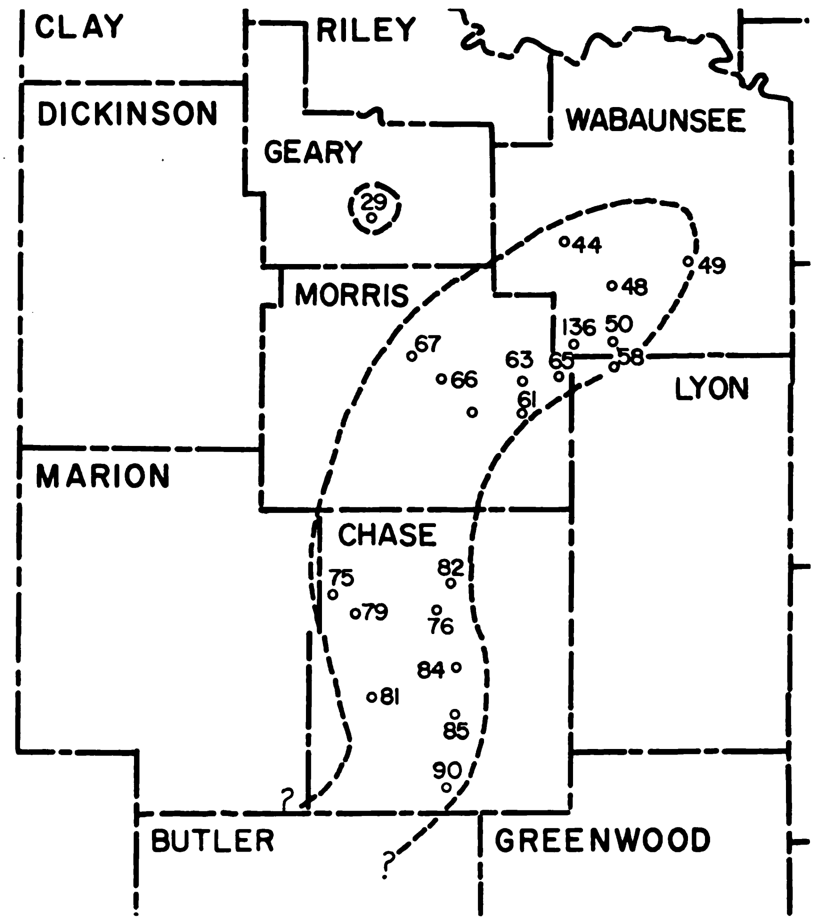

FIG. 5. Location of sections exposing reeflike thickening of Threemile limestone.

to weathering commonly are recrystallized to a depth of as much as 0.5 inch.

Structures in the rock consist of fossils, which are generally fragmentary and aligned roughly parallel to the bedding. There is little replacement of organic structures by silica.

Insoluble residues of the chalky limestones amount to less than 1 percent. Although many types of residue material are common, none is diagnostic. The list of residues below is arranged in order of relative abundance.

Insoluble Residues Observed in Chalky Limestone of the Threemile Member.

Fossils replaced by granular and chalcedonic chert
Limonite
Beekite
Quartz silt aggregates
Quartz sand, very fine
Drusy quartz
Asphaltic residue
Arenaceous foraminifers
Pyrite
Drusy granular chert
Limonite pseudomorphous after pyrite

Several thin sections of chalky limestone were studied. Brief petrographic descriptions of these follow.

1. Upper Threemile limestone (Loc. 49). Matrix of very fine granular calcite and a minor quantity of finely crystalline calcite. Structures include extremely abundant small fossil fragments, oriented quite randomly. Bryozoans are most numerous. Little recrystallization of organic fragments. Some replacement by cryptocrystalline silica.
2. Upper Threemile limestone (Loc. 58). Matrix of very fine granular calcite. Abundant minute fossil fragments aligned roughly parallel to the bedding, mostly bryozoan. Numerous tubular and threadlike structures, probably *Girvanella*. Many fossils are recrystallized; few are replaced by cryptocrystalline silica.
3. Upper Threemile limestone (Loc. 67). Matrix of very fine granular calcite. Fairly abundant fossils, randomly oriented, consist mostly of small bryozoan fragments. Some fossils are recrystallized or internally filled with crystalline calcite, or both. Cryptocrystalline silica is common as replacement material in fossils.
4. Upper Threemile limestone (Loc. 90). Matrix of very fine granular calcite. Abundant, small, randomly oriented fossil fragments, mostly bryozoan. Sparse tubular, threadlike structures may be *Girvanella*. One large bryozoan fragment is encrusted by laminated calcite, which contains discontinuous radiating tubules. This structure is probably algal. Some fossils recrystallized.
5. Upper Threemile limestone (Loc. 135). Matrix of very fine granular calcite. Sparse crystalline calcite partly as internal fillings of fossils. Structures include numerous small fragmentary fossils, dominantly bryozoan. Many fossils encrusted by dense laminated calcite of ?algal origin. Very abundant tubular threadlike structures, probably *Girvanella*.

All the slides examined have a very fine granular matrix and a minor amount of crystalline calcite. Cryptocrystalline silica is sparse. Bryozoan and algal remains constitute the dominant structures.

The fossils seen in the chalky limestones, with the exception of *Dibunophyllum* and *Streblotrypa,* are all abundant in the calcareous-shale phase and the cherty-limestone phase. Although not abundant, *Dibunophyllum* seems to be diagnostic, because it was observed in other kinds of rocks in only one or two places. The relative abundance of other organisms is more significant than mere presence of any one genus or a particular assemblage of genera. Fenestrate bryozoans, echinoderm remains, and corals are proportionately much more common than in other phases of sedimentation. Shells of *Composita,* although nowhere numerous, are seen at almost every exposure of chalky limestone. Listed below, by phyla, are the fossils that are observed. An asterisk precedes the more abundant forms, and rare kinds are followed by and (s).

Fossils Observed in Chalky Limestone of the Threemile Member.

Plants
- *Girvanella* sp.

Foraminifers
- *Ammovertella* sp.
- *Globivalvulina* sp.
- *Tetrataxis* sp. (s)

Sponges
- Sponge spicules (s)

Corals
- **Dibunophyllum* sp.
- **Stereostylus* sp.

Bryozoans
- **Fenestrellina* sp.
- **Penniretepora* sp.
- *Polypora* sp.
- **Rhombopora* sp.
- **Septopora* sp.
- **Streblotrypa* sp.
- **Thamniscus* sp.
- Bryozoans, encrusting types

Brachiopods
- *Chonetes* sp.
- **Composita* sp.
- *Derbyia* sp.
- *Dictyoclostus* sp.
- *Enteletes* sp.
- Productid spines

Mollusks
- Gastropods, tiny molds (s)

Echinoderms
- *Echinoid plates and spines
- *Crinoid remains

Trilobites
- *Ditomopyge* sp.

Algal limestone.—Across the entire state a very prominent algal limestone lies at the top of the Schroyer member. Algal beds are also seen at the top of the Threemile limestone southward from northern Butler County and in the Havensville shale in Chase, Cowley, and Pottawatomie Counties. The thickness of these beds is variable, ranging from 0.8 foot to more than 6 feet. In general, the thickest algal limestones are seen in southern Kansas. Grayish yellow, yellowish brown, and yellowish gray are dominant colors. The algal beds are massive to thick-bedded and very hard. There is a common tendency toward (1) cavernous weathering and (2) the formation of well-rounded exposed surfaces. Topographically, the algal beds form benches that may be traced for many miles, the limestone cropping out as a resistant rimrock.

Algae constitute a large proportion of the rock, hence the name. In many samples, as much as 95 percent of the limestone is made up of calcareous structures probably formed by lime-secreting algae. The most common, indeed almost ubiquitous, form is that called *Osagia*. An individual colony consists of a small, somewhat disc-shaped calcareous mass, which, when sectioned, exhibits roughly concentric calcite laminae around a curved shell fragment in the central portion. Thickening of the laminae on top and around ends of the shell fragment causes a concavity on the lower side of the colony. The resulting colony appears bean-shaped in vertical section. Some forms that are referred to *Osagia* have a straight central bar and in section appear elliptical. In no other way do they differ from the typical *Osagia*. The calcareous foraminifer *Nubecularia* is commonly intergrown with *Osagia*, although it can also be free in the limestone matrix. Associated with *Osagia*, and at one or two places almost wholly making up beds that elsewhere contain abundant *Osagia*, are small (1 to 3 mm) concentrically laminated calcareous structures that exhibit radial crystal arrangement. These closely resemble radial-type oölites in every detail. Elongate or irregular shapes are most commonly observed. It is possible that these structures are algal in origin. Mollusks and arenaceous foraminifers are almost invariably associated with the algae, and a small proportion of the fauna consists of brachiopods, bryozoans, and echinoderms.

The algal limestones are not uniform in texture. Subgranular to subcrystalline matrixes are characteristic, and the matrix is ordinarily subordinate to the more abundant algal portion of the rock.

Structures in the algal beds seemingly are due mainly to the activity of lime-secreting algae. So abundant are the individual colonies (and oölites in some beds) that they are commonly packed tightly one against the other, generally with completely random orientation (Pl. 21B,C). Fragments of mollusks, brachiopods, and other invertebrate fossils can be seen in most of these beds. Complete or partial replacement of shell fragments by milky-white chalcedonic silica is a common feature.

Of unusual interest are vertical cylindrical openings an inch or two in diameter and as much as 3 feet in length, which are abundant in the algal limestones of the Threemile limestone and Havensville shale in Cowley County. Large boring clams of the genera *Aviculopinna* and *Allorisma* are found associated with these holes, and for this reason the openings are regarded as the

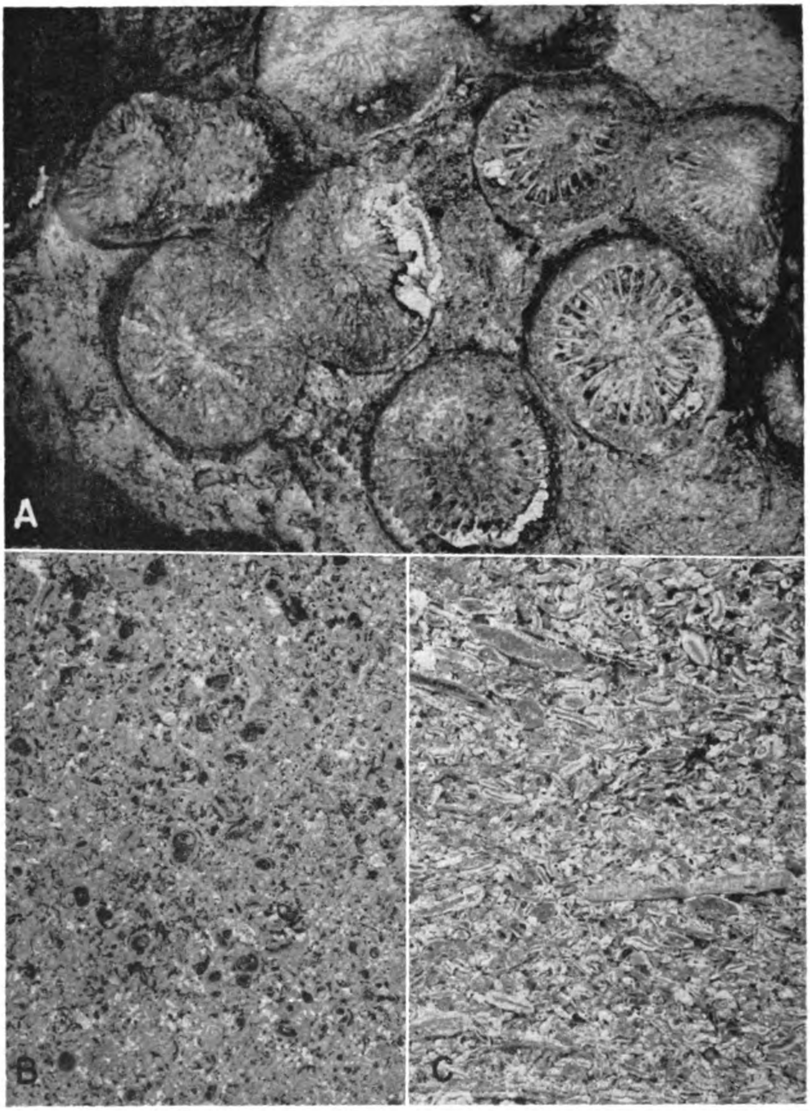

PLATE 21. Features of chalky and algal limestones. **A,** Chalky limestone containing abundant corals (*Dibunophyllum*), ×½. SE¼ sec. 16, T. 15 S., R. 7 E., Morris County (Loc. 67). **B,** Peel photograph, ×4, of algal limestone from the upper Schroyer member. SW¼ sec. 16, T. 11 S., R. 8 E., Riley County (Loc. 36). **C,** Peel photograph, ×2.5, of algal limestone from the upper part of the Threemile member. NE¼ sec. 19, T. 25 S., R. 8 E., Butler County (Loc. 103).

borings of these oragnisms. The abundance of mollusks in these beds and a smaller number of algae than are observed in the Schroyer algal beds have led the writer to refer to these boring-filled strata as algal-molluscan limestones. The walls of most borings are studded with *Osagia.* In many places along the outcrop of the limestone the borings have been enlarged by solution. Within the borings are fragmentary fossils, mostly bryozoan, brachiopod, and echinoderm remains. In Cowley County, borings of the type described were observed in each of the three members of the Wreford limestone.

The algal-molluscan beds in the middle Havensville shale and upper Threemile limestone of Cowley County contain sparse small, light-gray nodules of compact chert at a few localities. A bed of bluish-gray layered calcareous chert lies near the base of the upper Threemile algal-molluscan bed. The petrography of these rocks is discussed in the part of the paper devoted to chert.

The insoluble residues of the algal limestones are listed below in order of decreasing importance.

Insoluble Residues of Algal Limestones from the Wreford Formation.

Arenaceous foraminifers
Limonite
Quartz silt aggregates
Fossils replaced by granular and chalcedonic chert
Beekite
Granular chert
Glauconite
Asphaltic residue
Quartz sand grains
Muscovite
Drusy chert
Pyrite
Drusy quartz

The most characteristic portion of the residue consists of arenaceous foraminifers; an abundance of quartz silt aggregates and limonite is observed in nearly every limestone residue, and the other materials are not found everywhere in the algal beds. Abundant quartz sand grains are present in the uppermost Threemile limestone bed in Cowley County.

Several thin sections of algal limestone from each of the three members of the Wreford formation were examined petrographically. Brief descriptions of these follow.

1. Top of Threemile limestone (Loc. 103). Matrix of coarsely crystalline calcite. Structures include randomly oriented fossil fragments (crinoid remains, bryozoans, gastropods, and ostracodes are recognizable) all coated

with a thin layer of finely crystalline or laminated calcite, seemingly algal. Many of the algal incrustations are truly *Osagia*. The central nucleus of each algal colony is a recrystallized shell fragment.

2. Top of Threemile limestone (Loc. 115). Matrix of finely crystalline and finely granular calcite is dominant over enclosed structures. Numerous fossil fragments, most of which are encrusted by a thin calcareous layer probably of algal origin. Relatively few structures resemble *Osagia*. *Nubecularia* sparsely represented.

3. Upper Havensville shale (Loc. 13). Matrix of coarsely crystalline calcite. Structures include abundant, mostly recrystallized fossil fragments encrusted with thinly laminated calcite. All incrustations are probably algal in origin. Many *Osagia*-like algae are present, some clearly showing the slender tubular structure of *Girvanella*. Supposed oölitic structures are possibly algal incrustations around nontabular nuclei.

4. Middle of Havensville shale (Loc. 115). Matrix finely granular; sparse crystalline calcite. Fossils moderately abundant; crinoid remains, *Nubecularia*, ostracodes, and numerous small *Osagia*. *Osagia* have nuclei of recrystallized fossil fragments; *Nubecularia* inclusions in the encrusting laminae. Threadlike structure of *Girvanella* visible in some *Osagia* colonies.

5. Top of Schroyer limestone (Loc. 36). Matrix of coarsely crystalline calcite. Oölitic structures very abundant, exhibiting concentric laminae of calcite in which individual calcite crystals are radially arranged. *Nubecularia*, also very abundant, commonly encrusted by algae. *Osagia* present but not abundant. Nuclei of all algal structures are recrystallized shell fragments, molds of gastropods, or foraminifers.

6. Top of Schroyer limestone (Loc. 104). Matrix finely subcrystalline. Structures are mainly oölitic incrustations around recrystallized fossil fragments. Ostracodes, *Nubecularia*, and crinoid fragments are recognizable. Oölites exhibit laminated calcite with radially arranged crystals in each layer. *Osagia* present but not abundant.

7. Top of Schroyer limestone (Loc. 108). Matrix subgranular. Structures consist of fossils and fossil fragments encrusted by laminated calcite, individual crystals of laminae radially arranged. *Nubecularia* very common, some not encrusted. Crinoid remains are recognizable. *Osagia* present but not abundant; central nuclei consist of calcite, which is probably recrystallized fossil fragments.

The fossils that have been found in algal beds are listed below. The diagnostic forms are preceded by an asterisk. Sparse non-typical forms are followed by (s).

Fossils Observed in Algal Limestones of the Wreford Limestone.

Plants
- **Osagia* sp.
- *Epimastopora* sp. (s)
- *Algal oölites

Foraminifers
- **Ammovertella* sp.
- **Nubecularia* sp.
- *Ammodiscus* sp.
- *Tetrataxis* sp. (s)

Bryozoans
- Fenestrate and ramose types

Brachiopods
- *Chonetes* sp. (s)
- *Composita* sp. (s)
- *Derbyia* sp. (s)
- *Dictyoclostus* sp. (s)
- Productid spines

Mollusks
Aviculopecten sp.
Allorisma sp.
**Aviculopinna* sp.
**Bellerophon* sp.
*Gastropods, tiny molds
Schizodus sp.
Septimyalina sp. (s)
?*Astartella* sp. (s)
Ostracodes
Echinoderms
Fragmentary remains
Vertebrates
Fragmentary remains (s)

Chert.—Two types of chert are known in the Threemile and Schroyer members of the Wreford limestone. The most common is compact to slightly porous, noncalcareous, nodular to bedded, and fossiliferous, and is abundant at every Kansas exposure. The color ranges from very light grayish yellow to almost black, and mottling is observed in many specimens. The name flint has been applied to the dark-gray and black varieties; however, in order to avoid confusion, the writer will use the term chert for all colors, with the understanding that darker varieties commonly are referred to as flint. Weathering of the chert produces a light-colored shell ("patina" of some geologists), which is of variable depth. Small nodules are commonly weathered all the way to the center. Continuous beds of the chert are 0.1 foot to 1 foot thick. All the chert beds exhibit conchoidal fracture and are vertically jointed at close intervals.

The configuration of the chert beds presents one of the most interesting and characteristic features of the two limestone members (Pl. 8B,C; 9A,C; 11B; 16B,C, etc.). The average thickness of continuous beds of chert is about 0.2 to 0.3 foot. The upper and lower surfaces are nodular, at many exposures exhibiting elongate vertical projections (Pl. 22A). At several places a higher bed or flattened ellipsoidal nodule may be connected to a lower bed by vertical projections, which thus join the two. Vertical openings or "holes" through the chert layers are observable in most of the beds, and vertical sections through the openings give the appearance of discontinuity in otherwise continuous beds. Circular to elliptical bodies of limestone are commonly seen within the chert in vertical exposures of the latter. These are not isolated nodules but normally deposited limestone lying between two layers of chert that have more than the ordinary number of vertical protuberances, or limestone within very nodular chert beds (Pl. 9B). Some beds are composed of very irregular nodules with knobby surfaces, but nevertheless are persistent laterally (Pl. 22B).

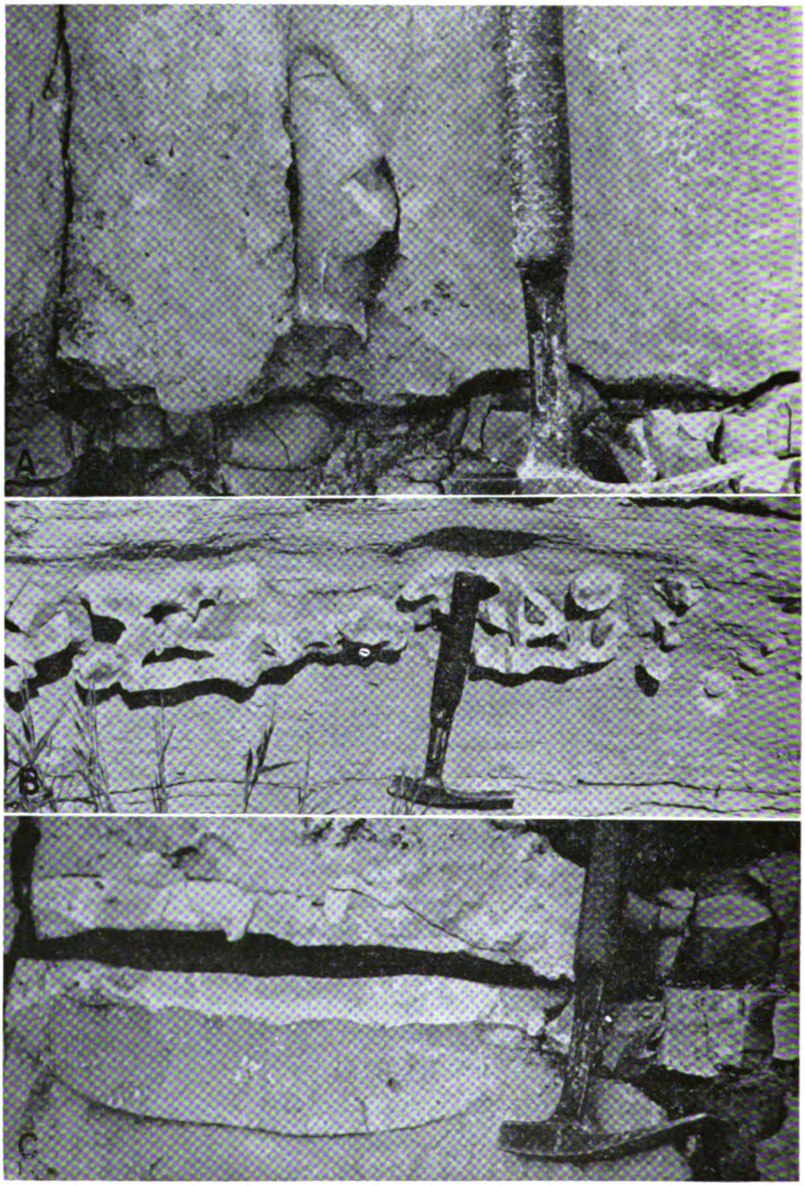

PLATE 22. Unusual features of chert beds. **A,** Upward projection of chert bed in Threemile limestone. Center sec. 13, T. 16 S., R. 10 E., Lyon County (Loc. 54). **B,** Very nodular bed of chert in upper Threemile limestone. NE¼ sec. 21, T. 4 S., R. 7 E., Marshall County (Loc. 7). **C,** Calcareous chert lens below chert bed in Threemile limestone. SE¼ sec. 3, T. 17 S., R. 8 E., Morris County (Loc. 68).

The contact of chert beds with the surrounding limestone is sharp in almost all places. The outer edges of chert beds and the surfaces surrounding limestone inclusions are smoothly rounded, broken only by the slight projection of some of the numerous fossils concentrated at the outer edges of the beds.

Laterally, the chert in many beds is observed to be interrupted by limestone, the bed in such places appearing as a layer of large flattened nodules. Where the horizontal extent of limestone masses equals or exceeds the length of the stratigraphically equivalent chert masses, a truly nodular bed of chert exists. Many of the so-called "beds" of chert consist of isolated nodules, which are elliptical (rarely almost circular) in vertical section. Nodular layers of chert generally lie not along bedding planes but completely surrounded by unbroken beds of limestone. At many localities elliptical nodules spaced many feet apart lie at the same stratigraphic level. Almost without exception the nodules are aligned parallel to the bedding. At a very few exposures in Cowley County, cylindrical bodies of chert are found oriented oblique to the bedding. The origin of these nodules is explained below.

Shaly bedded agrillaceous limestones of the chert-bearing type ordinarily contain no bedded chert but do bear numerous small spheroidal to irregular nodules throughout. These are generally completely weathered, and invariably they are oriented parallel to the bedding.

Polished surfaces of chert samples show two main types of matrix, (1) a yellowish-brown fairly clear portion and (2) a translucent to nearly opaque whitish portion. Either type may be dominant. Where the first is dominant, the second exists as cloudy inclusions of whitish silica grains. Where the second type dominates, the first exists as minute clear globules enmeshed in what seems to be a lacy or skeletal meshwork of whitish silica. The skeletal meshwork may be smoothly continuous or composed of innumerable minute grains.

Fossils within the chert are almost invariably silicified, although unreplaced crinoidal fragments can be seen here and there. Secondary calcite is observed sparingly as an internal filling in fossil fragments. Large fossils are generally concentrated at the borders and minute ones scattered within the chert. Bryozoan, echinoderm, and brachiopod remains are the most abundant. Numerous rodlike structures, which resemble small productid or echinoid spines, are found in many samples and may be sponge spicules, but this is questionable because few undoubted sponge remains were observed during the investigation.

The fossils are oriented randomly. Only rarely are bedding planes noted in the chert. Almost all the chert exhibits a homogeneous interior without evidence of stratification or uniform orientation of constituent structures. Shrinkage cracks are almost entirely absent in the chert.

Several thin sections were examined with a petrographic microscope. Brief descriptions of these are presented below:

1. Upper Threemile limestone (Loc. 2). Matrix of minutely crystalline chalcedony. Fossils sparse, some filled with finely crystalline quartz, some replaced by fibrous chalcedony, which shows a brushlike structure. Small circular areas filled with fibrous chalcedony that has radial structure.

2. Upper Threemile limestone (Loc. 68). Matrix of minutely crystalline chalcedony. Fossils common, replaced by chalcedony. Some fossils filled internally by fine crystalline quartz, others by fibrous chalcedony. Numerous circular areas of fibrous chalcedony that shows radial structure.

3. Upper Threemile limestone (Loc. 69). Matrix of minutely crystalline chalcedony. Structures include numerous fossil fragments, all replaced by chalcedony, some of which is fibrous. Circular areas of fibrous chalcedony that has radial structure. Some crystalline quartz grains. Dark concentric layering visible on fresh rock parallel to border of nodule. The color pattern has no relationship to texture and was probably caused by weathering.

4. Middle Threemile limestone (Loc. 115). Matrix of minutely crystalline and fibrous chalcedony. Fossils replaced by fibrous chalcedony. Crystalline quartz grains and circular areas of radially arranged fibrous chalcedony. Nodules gradational with limestone.

Most fossils in the chert are excellently preserved. Forms are the same as those contained in the surrounding limestone. Bryozoans, brachiopods, echinoderm remains, and trilobite fragments are most common. A few foraminifers were generically identified by examination of polished surfaces. It is unnecessary to tabulate the fauna because of its similarity to that of the limestone. Presumably, all forms to be found in the limestone should be in the chert also.

The second type of chert contains disseminated calcite and is calcareous, brownish gray to dark bluish gray or dark gray, concentrically layered, and sparsely fossiliferous (Pl. 10A,B,C; 11A). Although this kind of chert can be seen in both limestone members of the Wreford formation across the entire state, in the Schroyer limestone member it is most abundant in northern Kansas, whereas in the Threemile limestone member there is a much greater quantity in southern Kansas. In northern Kansas, calcareous chert forms incomplete rims around or nuclei within the more abundant ordinary chert. Hemispherical masses of calcareous chert lie below and above the smaller, elliptical, ordinary chert nodules at localities 68 and 82 (Pl. 22C). Southward from central Chase County the calcareous chert occupies a more and more prominent place in some beds of chert. In northern Butler County both the Threemile and Schroyer limestone include beds that contain nearly equal amounts of both types of chert. In southern Butler County, a 1-foot bed of the calcareous chert lies in the lower Threemile limestone. Two such beds are found over most of Cowley County, a 1-foot bed in the middle Threemile, and a 0.3-foot bed at the base of the algal-molluscan phase in the uppermost part of the member. Locally, irregular nodules of noncalcareous chert are enclosed within the calcareous cherts (Pl. 10C). At some exposures both of these beds are nodular rather than continuously bedded (Pl. 10A, 11A). Calcareous cherts are not generally in as sharp contact with the limestones as are the noncalcareous cherts.

Samples of calcareous chert were sectioned and studied with a petrographic microscope. Typial descriptions are given below.

1. Lower Schroyer limestone (Loc. 30). Matrix of mottled finely granular calcite and minutely crystalline chalcedony, some areas of nearly equal admixture of calcite grains and chalcedony. Fossils in calcareous part mostly unreplaced, some of those in chert replaced by fibrous chalcedony. Some radially fibrous chalcedony in the chert.

2. Lower Schroyer limestone (Loc. 108). Limestone, calcareous chert, and ordinary chert. Chert matrix of minutely crystalline chalcedony, fossils replaced by crystalline quartz and fibrous chalcedony. Calcareous chert dominantly finely granular calcite and unreplaced fossil fragments, subordinate cryptocrystalline chalcedony and crystalline quartz. Chert–limestone contact sharp, chert–calcareous-chert contact fairly sharp, calcareous-chert–limestone contact gradational.

3. Middle Threemile limestone (Loc. 115). Matrix banded, light-colored broad bands dominantly finely granular calcite and some cryptocrystalline chalcedony, dark narrow bands of cryptocrystalline chalcedony and finely granular calcite. Light-colored bands contain abundant fossil fragments, some unreplaced, others replaced by fibrous chalcedony or internally filled by crystalline quartz. Circular areas of fibrous chalcedony in both types of bands. Light-colored bands grade outward to darker ones, which contrast sharply with the next light-colored band. A limonite film is concentrated at the sharp contact, and limonite grains are disseminated in the dark bands.

Fossils in the calcareous chert are the same kinds as those of the adjacent limestone. Crinoid stems and productid spines dominate the sparse assemblage.

Environment of Deposition

Sandstone.—The lenticular profile, local distribution, and abrupt lateral variation in thickness of the sandstone bodies found in the Speiser formation in southern Kansas suggest that the sands are channel deposits. Seemingly the thickest sandstone was deposited in the channel of a stream flowing across a broad alluvial plain on which red clay and silt were accumulating. Periodic channel enlargement or flooding resulted in deposition of numerous thinner layers of finer sand found at adjacent exposures. A channel bank sharply intersecting red silty shale is clearly exposed at locality 125. The upper part of the sandstone extends laterally beyond the lower, so overlies portions of the red shale at this place, thus demonstrating the channel-fill origin of the sand body. Interpretation of the red shale as marine sediment might seem to require interpretation of the sands as offshore bars, but it would still seem more logical to interpret them as fill in extended submerged channels. The sandstone lenses at three exposures show flat upper surfaces and downwardly convex lower surfaces, whereas most buried bars have nearly flat lower surfaces and convex upper surfaces.

The fine grain size of the sandstone indicates deposition by slow-moving water. In an exposure (Loc. 121) that is believed to represent a deeper portion of the ancient channel, grains of fine-sand size are dominant; laterally, very fine sand is seen to predominate. No sand larger than 0.25 mm is evident.

It is concluded that because the sandstones are localized geographically, they represent deposits of a single broad shallow stream that flowed across a low-lying plain bordering the sea. Occasional flooding resulted in deposition of thin sandstones in areas adjacent to the main channel. Dapples (1947, p. 95) classifies rocks of this environment and lithology as "platform sandstone" of the quartz-muscovite type. He states that such rocks in the Pennsylvanian Interior Coal Basin are the product of deposition by large rivers emptying into regions of extensive tidal flats.

The source of the sand was probably an area to the south that was tectonically active throughout much of Pennsylvanian and

Permian time. Wreford plant fossils (seed ferns) of northern Kansas suggest low-lying land areas to the north, whereas fossil conifers from southern Kansas indicate possibly higher land areas adjacent thereto during Wreford deposition. At both localities the plants are in marine sediments, but it is unlikely that they were transported very far. At locality 18 the plant remains are well preserved, showing little evidence of having been carried any great distance. From the combined evidence of fossil plants, sandstone deposits, and known tectonic activity, it may be inferred that the nearest high ground lay to the south or southeast. Two exposures in Cowley County at which massive-bedded sandstone is seen (Loc. 121 and 125) suggest a channel trending slightly north of west. Subsurface data show that marine conditions similar to those indicated by rocks at the surface existed west of the present Wreford outcrop during Early Permian time. This somewhat strengthens the hypothesis that the river in which the sand was deposited flowed westward from a source lying to the southeast.

Channel sandstone is not included in the ideal Permian cyclothem of Elias (1937, p. 411), perhaps because these deposits are so rare. Because channel sandstone does exist locally, however, and because this is its logical position in the stratigraphic sequence, the writer believes it should appear as a phase of the ideal cycle. In order to maintain the numerical system of Elias, the sandstone is here designated as phase 0.

Red shale.—The redbeds of the Speiser and Wymore shales seem best interpreted as the product of a nonmarine, chiefly subaerial environment. Red shale nearly everywhere occupies the same relative position with regard to the sequence of lithologic types, that is, between overlying and underlying fossiliferous green shale. Only at a few localities does red shale rest directly on the Funston limestone and nowhere was red shale observed to lie directly on the Schroyer member of the Wreford formation. Fossils are virtually absent in the redbeds, and the few recorded are freshwater forms. Strata lying adjacent to the red shales contain fossils of marine origin. Above the redbeds, ascending from green shale to cherty limestone, there is noted (1) a progressive increase in the abundance of fossils and (2) a trend from nearshore brackish-water faunas to normal marine assemblages. Ascending from cherty limestone, through green shale, to red shale the two trends are reversed. Thus, the redbeds seem to represent a nonmarine environment, having been deposited after regression of the sea.

Further evidence in support of a nonmarine environment includes sandstones, which are prevalent in the red shale of the Speiser formation at many exposures in Cowley County. These sands are thick at some locations, suggesting deposition in a river channel (as mentioned above) and at other places form a series of thinly cross-bedded lenticular bodies representing deposition on a plain bordering the river. The existence of channel sandstones in the red-shale sequence implies that one is dealing with the sediments of a low-lying, nearshore plain upon which sands, silt, and clay were being deposited by slowly shifting sluggish streams.

Oxidation of sediments subaerially, derivation of red sediments from a source area of red soils, or a combination of the two has probably caused the red coloration. Iron in the red sediments was not reduced during submergence, presumably because most of the organic matter was already oxidized. The interstratification of thin green and red shale beds between the main green and red shale portions of the stratigraphic section indicates deposition in a zone of fluctuation between marine and nomarine conditions. Mottling of transitional beds between red and green shales was caused seemingly (1) by incomplete destruction of organic matter during subaerial oxidation of the red shale and subsequent submarine reduction of the iron in these patches, (2) by an occasional "bathing" of the subaerially accumulating sediments by very minor, probably local, transgression of the sea, or (3) during regression, by partial subaerial oxidation of green sediments before their burial. The possibility exists, of course, that the redbeds represent nearshore, shallow-water marine deposits that were exposed and oxidized during regression, little if any nonmarine sediment being present. A complete absence of redbeds fossils might, in such a case, be explained by leaching during exposure; however, calcareous nonmarine plant remains in the red shale, though rare, seem to minimize the likelihood that all the marine fossils, had they ever existed, would have been destroyed.

The evidence favors a nonmarine environment for the accumulation of the red shales. Subaerial accumulation within a given area may not have begun until after some exposed green sediments were oxidized. Beds of red shale correspond to phase 1 of Elias' ideal Permian cyclothem (1937, p. 411).

Green shale.—The faunas indicate a marine environment of deposition for the green shales. More specifically, the preponderance of ostracodes suggests brackish water, which in turn implies deposition not far from shore. Terrestrial plant fossils, which are noted at two localities, consist of well-preserved *Neuropteris* pinnules in one section, a condition which suggests that these remains were possibly not transported a very great distance before burial. If, as indicated in the preceding paragraphs, red shales were deposited in a subaerial environment, it follows that the underlying and overlying green shales were deposited in very shallow coastal waters during regressive and transgressive stages of sedimentation, respectively.

The green coloration of these strata is the result of deposition under reducing conditions. Grim (1951, p. 231) states that red or green sediment indicates the absence of appreciable organic material and says that green coloration is due to the color of the clay minerals present. The evidence discovered in the present investigation confirms this, because at three localities where abundant organic matter is seen in the green-shale phase, the rock color is grayish to brownish rather than plain green.

Krumbein (1947, p. 105) has classified such widespread green shales as "platform type" and states that they are deposited on a widespread stable platform with no strong positive areas nearby. The inferred environmental conditions, according to his paper, are broad seas or wide alluvial plains. The latter, of course, are ruled out by the presence of marine fossils in the green shales under consideration. The green shales represent phases 2p and 2r of Elias' ideal Permian cyclothem (1937, p. 411).

Grayish-yellow mudstone.—The position of the grayish-yellow mudstones, and equivalent strata, between sparsely fossiliferous green marine shale and molluscan limestone containing an abundant marine fauna confirms the opinion that this type of rock has a specific place in the general cycle of Wreford sedimentation. The fauna is clearly intermediate between those of green shale and molluscan limestone. The former is characterized by ostracodes, the latter by near-shore mollusks. In the mudstones and related rocks there are productid spines, an assortment of foraminifers and echinoderm remains, rare bryozoans, and pelecypods of the genus *Aviculopecten,* as well as numerous ostracodes. Abundant organic matter in this phase has resulted in the grayish-yellow to olive-gray color.

Because the green shale seems to indicate deposition in an area only slightly awash, it follows that the mudstone accumulated farther seaward in an area of transition between the green-shale and molluscan-limestone sites of deposition. The marine fauna and smaller amount of sand-size clastics substantiate this conclusion. Although green shale is seen in the middle of the Havensville member at some exposures, mudstone is the middle unit in most of central and northern Kansas. This demonstrates that the sea did not recede far enough for green shale to be deposited at most places where the Havensville is now exposed.

Elias (1937, p. 411) includes rocks of this lithology as phases 3p and 3r in his ideal cycle. He states (1937, p. 408) that *Lingula,* supposed to be characteristically associated with this lithology, has been observed only in the regressive hemicycle in the Kansas Permian. The author has found *Lingula* to be abundant in yellowish-gray mudstone of the transgressive stage of sedimentation at one exposure (Loc. 32) and also has collected *Orbiculoidea* and *Lingula* in the calcareous-shale phase of the transgressive hemicycle. *Lingula* is not ordinarily found in the mudstone phase; hence it should not be regarded as the diagnostic fossil for this part of the Wreford megacyclothem.

Molluscan limestone.—Relationships of the molluscan limestones to adjacent strata are nearly everywhere identical and indicate that such beds are assignable to a specific place in the cycle of sedimentation in the Wreford limestone. The symmetrical disposition above and below the Threemile limestone in northern Kansas and also with regard to beds in the upper Havensville shale that have the same fauna and lithology leaves little doubt as to the cyclical nature of molluscan-limestone deposition. As described above, the red-shale phase, and the green-shale and mudstone phases of sedimentation were deposited in continental and brackish near-shore environments, respectively. Next above these rocks in the transgressive stage of sedimentation, or below them in the regressive stage, lies the molluscan limestone, which is characterized by *Aviculopecten, Septimyalina, Ammovertella, Ammodiscus,* and *Osagia. Aviculopecten* is most common in argillaceous limestones but, according to Newell (1937, p. 13), is found also in oölitic limestone and sandy or shaly beds. No specimens were found in sandy beds and very few in oölitic limestone during the present investigation, but some were found in argillaceous limestones and a few in shales. Newell (1942, p. 19) stated that mytilids prefer a very shallow water near-shore environment and are not found in relatively pure limestones of the Pennsylvanian and Permian because such rocks, commonly fusulinid-bearing, represent deposition in waters too deep for the mytilids. He (Newell, 1942, p. 16-17) also indicated the tolerance of mytilids to wide ranges of temperature, salinity, and bottom conditions. These pelecypods, which are locally profuse although other megafossils are absent, indicate a depositional environment intermediate between that of the more shoreward sediments and the typical marine calcareous shale.

It is significant that many benthonic marine organisms (corals, crinoids, bryozoans, various brachiopods, and echinoids) that prefer a shelly or hard bottom are present only in small numbers in the molluscan limestones. The abundance of shells and the calcareous composition of the bottom in this environment surely should have been sufficient to induce growth of these forms of life had conditions of temperature, depth, salinity, and other factors been suitable. It is concluded, therefore, that the environment represented by molluscan limestones was perhaps too shallow, too warm, or too brackish to support the above-mentioned benthonic forms. The tendency of *Lingula*, *Mya*, and *Mytilus* assemblages to frequent brackish environments has been noted by Krumbein (1947, p. 102). Adaptation of articulate brachiopods to shallow-water environment is suggested by Moore (1929, p. 469), who states also (1948, p. 126) that phosphatic brachiopods such as *Lingula* and *Orbiculoidea* seem to be adjusted to brackish water. Schuchert (1911, p. 262) observed that modern lingulid brachiopods commonly prefer a brackish habitat. Thus it seems fairly well established that an assemblage containing the mytilid *Septimyalina* and the phosphatic brachiopods *Lingula* and *Orbiculoidea* represents a shallow brackish-water environment of deposition. The repeated association of these genera with *Aviculopecten*, *Ammovertella,* and *Ammodiscus* indicates the partiality of the latter three forms also to a shallow and brackish-water habitat.

The seeming lack of some forms of life, such as certain genera of ostracodes, may merely attest to shortcomings in laboratory technique. Possibly the shells of these animals were not silicified, hence were not observable in insoluble residues, or difficulty of identifying them on polished surfaces may account for the paucity of ostracodes in the fossil list. On the other hand, abundance of silt, sand, and local conglomerates indicates the existence of currents, which may have inhibited the propagation of such organisms.

It is very likely due to the abundance of fine sand- and silt-size detritus and to special conditions of salinity and temperature that the arenaceous foraminifers *Ammovertella* and *Ammodiscus* are so abundant in the molluscan phase of sedimentation. The presence of numerous specimens of both forms in the near-shore, and presumably more brackish, mudstone phase and the presence of only a few *Ammovertella* in the calcareous-shale phase suggests that a moderately brackish, shallow-water environment was preferred by these two genera.

In the Havensville shale in the area of outcrop the greatest degree of regression is indicated by sediments of the green-shale phase, which is found only in a few localities. In most places in this member, the mudstone or a shale equivalent of it indicates a lesser degree of regression. The thick, argillaceous, molluscan limestones in the middle Havensville member in Pottawatomie and Marshall Counties clearly indicate that the environment favorable to molluscan-limestone deposition persisted in this area during regression in neighboring territory. A slight depression of the sea bottom could maintain the conditions favorable to molluscan-limestone deposition in this restricted area while other conditions prevailed not far away. The algae in the thick-bedded molluscan limestone at the top of this sequence of sediments present a unique problem. Moore (1948, p. 126) suggests that a hypersaline environment is indicated by the algal-molluscan limestones. The depauperate mollusks present in algal limestones supposedly resulted from these abnormal conditions. Drainage of connate salt water out of recently formed deposits uncovered by the retreating shallow sea, poor circulation of water in the postulated depressed or possibly somewhat baylike area, or evaporation may have caused the excess salinity. A more extended discussion of this environment will be taken up in the discussion of algal limestones.

Mingling of fossils characteristic respectively of the molluscan-limestone phase and the calcareous-shale phase of sedimentation naturally should be expected in areas between those in which each of the two types of sediment was being deposited. Numerous exposures are known that exhibit this relationship. In certain other exposures, however, a molluscan fauna succeeds a calcareous-shale fauna in the transgressive stage. This reversal of the normal cyclical sequence is probably to be accounted for by slight oscillations of sea level, resulting in minor regression that temporarily brought back to the area the environment favorable to the existence of a molluscan fauna. In nearly all places where this reversal is observed, a sparse assemblage of mollusks can be seen in the shales directly below, as well as above, beds containing the calcareous-shale assemblage.

Alternations of calcareous shale and argillaceous limestone in the upper Speiser shale in southern Butler County and Cowley County indicate that the sea level was oscillating; hence the sediments bear fossils ordinarily found in two separate phases of sedimentation. The predominant color of the upper Speiser shale sequence in this area is medium to medium-dark gray and is most likely due to organic matter.

The source of the calcium carbonate in the molluscan limestone is believed to be twofold. First, because the molluscan phase is of near-shore shallow-water origin, it seems reasonable to assume that wave action was operative in the area where these sediments were being deposited. Agitation of the sea water with resultant loss of CO_2 could cause chemical precipitation of calcium carbonate in this phase. Second, fossils are abundant in the molluscan limestone and constitute a large proportion of the rock. Calcium carbonate in modern near-shore muds off Cape Hatteras is sufficient to form impure limestones upon consolidation, according to Stetson (1939, p. 234), and the source of this carbonate, which constitutes as much as 80 percent of the mud, is shell detritus and oölites. In similar fashion, shell fragments comminuted by wave abrasion probably contributed greatly to the molluscan limestone of the Wreford megacyclothem.

The molluscan beds constitute phase 4 of Elias' "Big Blue" cyclothem. He estimates the depth of deposition of these sediments at 60 to 90 feet (1937, p. 410).

Calcareous shale.—The abundance of sedentary organisms, such as bryozoans and crinoids, and presence of corals in the calcareous-shale units imply deposition in fairly quiet marine waters, because sessile forms of life, unless encrusting, prefer this environment. Paleozoic Bryozoa flourished best in relatively quiet waters and at depths probably slightly below the zone of strong wave action, according to Ulrich (1911, p. 252). Most deep-water brachiopods are thin shelled and delicate (Schuchert, 1911, p. 266), but the brachiopods of the calcareous shale, with minor exceptions, are moderately heavy shelled, strongly ribbed, or both, as *Composita, Dictyoclostus*, and *Derbyia*. A shallow-water environment and some current or wave activity may be inferred from the presence of such organisms. The large percentage of calcareous matter and the small amount of sand-size inorganic clastic particles suggest sedimentation far from shore, generally beyond the range of coarse-clastic deposition. Symmetrically disposed below and above the calcareous shales, which lie below and above the chert-bearing limestone member, are the limestones containing a near-shore molluscan fossil assemblage. The fauna of the calcareous-shale units typifies marine deposition farther from shore, and perhaps also in deeper water than the molluscan limestones, but nearer shore and in shallower water than the thick-bedded chert-bearing limestones, which, because of the sparseness of coarse detrital material and greater relative abundance of corals and delicate bryozoans, seem to have formed in very quiet water far from shore.

At three localities the calcareous shale lying above the basal cherty limestone of the Schroyer member contains fairly numerous juvenile fusulinids. No adults were observed. Seemingly these foraminifers were washed into the area by current action and were unable to survive because of unsuitable environment.

The mingling of a few mollusks with the fossils of the calcareous shale proves overlapping of the two environments. In the calcareous shales, fossils are most abundant at the top of units in the transgressive hemicycle, but at the base of units in the regressive hemicycle; most mollusks in this phase are found in the strata lying nearest the molluscan limestone. Calcareous shale appears as unit 5 in Elias' cycle (1937, p. 411); however, he states that the typical lithology of this phase in the "Big Blue" cycles is massive mudstone and shaly limestone.

Chert-bearing limestone.—The stratigraphic position of chert-bearing limestone with respect to other phases of sedimentation, the minor quantity of land-derived materials, such as clay, silt, and sand, and the nature of organic remains to be found in them, indicate that these rocks represent deposition in quiet marine waters far from shore. From the red-shale phase to the cherty limestones, in transgressive order, the amount of coarse clastic material diminishes because these sediments were deposited successively farther from shore. The converse is also true.

The most common fossils in the chert-bearing beds include crinoids, delicate bryozoans, and brachiopods. Although all three groups are seen in the calcareous shales, they are relatively more abundant in the cherty limestones. Paleozoic bryozoans are believed to have flourished in an environment that was fairly quiet and slightly deeper than the zone of violent wave action, and in water where slightly argillaceous limestone was being deposited (Ulrich, 1911, p. 252). Crinoids could hardly have survived the rigorous conditions of a near-shore shallow-water environment, and the corals present probably required clear water and a relatively hard substratum. Typical near-shore invertebrates, such as mollusks, are rare in the cherty limestones; lime-secreting algae are also sparsely represented. Most of the fossils in these limestones, however, are common in the calcareous shales as well. The most abundantly fossiliferous parts of these shales are the more calcareous portions, which lie directly adjacent to the cherty limestones. The seemingly greater diversity of organisms in the calcareous shales undoubtedly is due partly to ease in examination of shales, both in field and laboratory.

In a very small area in central Chase County abundant adult fusulinids of the genus *Schwagerina* in the lowermost Threemile limestone present a problem. These organisms should appear in phase 7 of the cycle, which seems to be nowhere typically developed in the Wreford limestone as far east as the outcrop.

The source of the calcium carbonate in the chert-bearing limestones is probably threefold. First, insoluble residues and petrographic studies show that a large proportion of the chert-bearing limestone contains abundant organic debris. Second, algae, although sparse in these limestones, undoubtedly contributed to formation of the rock. Third, some of the calcium carbonate may be the result of inorganic chemical processes. Reactions produced by (1) mingling of solutions, (2) evaporation, and (3) escape of carbon dioxide by various means are the three ways by which calcium carbonate is chemically precipitated, according to Twenhofel (1950, p. 373). He states that little is known about the first of these with the exception of water charged with calcium carbonate entering saline waters. That the second means of precipitation was not effective in deposition of the cherty limestone is indicated by the normal marine fauna. Action of the third process seemingly precipitated some of the calcium carbonate in the cherty limestones. Twenhofel says that precipitation may be due to an increase in temperature, agitation of the water, or decline in pressure. Bacteria also are known to cause precipitation of calcium carbonate indirectly, but Twenhofel (1950, p. 372) states that it has not been demonstrated that they are responsible for large-scale formation of limestones. According to Pettijohn (1949, p. 308), it is probable that most limestone is organically formed and that direct precipitation is not important.

The writer believes that the chert-bearing limestone is produced mainly by accumulation of organic remains and by algal growth, inorganically precipitated calcium carbonate being dominant only where evidence of organic constituents is virtually absent. Limestones of this nature are classified by Sloss (1947, p. 110) as normal marine (precipitation inorganically or by algae) or fragmental (dominantly of shell fragments) of the "platform" type. The chert-bearing limestones appear as phase 6 in the ideal "Big Blue" cycle of Elias (1937, p. 411).

Chalky limestone.—The abnormally thick chalky limestone deposits are concluded to be those of a large reef or of several parallel, discontinuous reefs, because of abrupt lateral thickening at the expense of the Havensville shale, geographic distribution of exposures, and uniformity of lithology. The lack of land-derived clastic material (clay, silt, sand) in these pure limestones indicates deposition in water far from shore. Corals, which are seen at almost every exposure, give further testimony of clear water. Certain points of the ecology of modern reef corals are summarized by Vaughan and Wells (1943, p. 68-69) as follows: (1) reef corals can survive a minimum temperature of 18.5°C., but the optimum temperature is between 25 and 29°C.; (2) reef corals live at depths to 300 feet but most live in less than 150 feet of water; (3) few corals can survive where sedimentation is heavy; (4) corals thrive best in waters of about the salinity of normal sea waters. If the reef corals of the Lower Permian may be interpreted as having thrived within these environmental limitations, it seems that the sea during the deposition of the chalky limestone sediments (maximum transgression) was clear, warm, and perhaps less than 150 feet deep. Strength is lent to the last of these conditions by Elias' statement (1937, p. 425), based on comparisons with modern foraminifers and the presence of algae, brachiopods, and mollusks, that the fusulinid phase of the "Big Blue" cycle was deposited at a maximum depth of 180 feet. Elsewhere he indicates 160 feet as the normal minimum depth for these organisms. Absence of fusulinids in the reef limestones suggests that perhaps the water was not of sufficient depth to favor their presence and thus was less than 160 feet deep. Other factors, of course, may have caused the absence of fusulinids in the chalky limestones. Lime-secreting threadlike algae (*Girvanella*) seen in the reef limestones by the writer indicate that the depth of deposition was less than 200 feet, because these organisms ordinarily thrive best at depths less than 200 feet (Twenhofel, 1932, p. 307). Admixture with the corals and algae of a great abundance of bryozoans and of brachiopod and crinoid remains implies deposition in waters shallower than the 160-foot depth mentioned above. Fragmentation of crinoid and delicate bryozoan fossils suggests that the environment was subjected to moderate wave action.

The chalky limestones exist in the upper Threemile member all across northern and central Kansas, and cyclically they represent the phase deposited during maximum transgression. The beds in northern Kansas are thin and are overlain by cherty limestone formed during regression of the sea. The chalky limestones thicken in Wabaunsee County where they pass abruptly into reeflike bodies. Two exposures in western Geary County show similar abrupt thickening. Coquinoidal and conglomeratic limestones are seen locally in the uppermost Threemile limestone and in the lowermost Havensville shale. It is concluded that these deposits represent reef talus and that the reef had significant relief during the time of deposition of the upper part of the Threemile member. It is possible that reef growth continued into Havensville time, resulting in a facies relationship between chalky reef limestone and Havensville shale. In northern Kansas, however, the Havensville shale shows a normal regressional pattern in its lower part, which proves that the sea remained at maximum transgression here only during the time of deposition of the chalky beds in this area. This evidence, combined with that of conglomeratic limestones mentioned above, suggests that reef growth was rapid, and essentially complete before regression began. Not at every reef exposure, but at many, thin chert beds of the type found in phase 6 lie in the uppermost part of the reef; these seem to have been developed normally during regression. A pre-Havensville completion of reef growth is therefore indicated by several lines of evidence.

The origin of the chalky limestone is doubtless varied. Petrographic examination of the rock shows a profusion of tiny fossil fragments, mostly bryozoan. These organisms definitely contributed greatly to the accumulation of chalky limestone sediments. Most thin sections show tubular threadlike structures resembling *Girvanella*, and one rock sample contains great numbers of these threads. According to Mudge[1] the same structures have been seen in the rocks and identified as algal in origin by J. Harlan Johnson. It is concluded that a large proportion of the reef limestone is attributable to the accumulation of calcium carbonate secreted by algae. Most modern reefs are known to be formed dominantly by the activity of lime-secreting algae, and Johnson (1943, p. 7-8) states that many limestones of Paleozoic age are best interpreted as algal in origin. To what extent the chalky limestone may be of inorganic origin cannot be stated positively; however, it seems that between the algal contributions, accumulation of abundant microscopic fossil fragments, and larger fossils, a large percentage of the limestone can be accounted for easily. Inorganically formed limestone probably is likewise a constituent of the Threemile reefs, however. Relative warmness and postulated wave agitation of water covering the reefs could cause chemical precipitation of calcium carbonate.

The map of localities at which reef sections are exposed shows a broadly arcuate belt convex northwestward (Fig. 5). The easternmost end of this belt has been destroyed by erosion. To the southwest, the Wreford limestone dips beneath younger strata, thus obscuring the westward extension of the reefs. If, as sug-

[1] Melville R. Mudge, U.S. Geological Survey, personal communication.

gested above, the shoreline lay to the southeast, the reef belt lies northwest of and roughly parallel to the shoreline, as offshore-barrier reefs. Reef limestones in a platform environment tend to form in isolated and discontinuous masses, according to Sloss (1947, p. 110). Whether or not the Threemile reefs are actually several small patches, elongate parallel reefs, or a single mass pinching and swelling gently in all directions, is uncertain. It is known that they present a well-defined geographic pattern and that continuous exposures of thick chalky limestone are traceable for many miles. The writer is inclined to think that the reef body is essentially a homogeneous connected body that is broken only locally into (1) isolated masses or (2) smaller parallel reefs. Originally the reef may have extended much farther to the east, and it may also extend farther westward in the subsurface.

North and west of the reef the nature of the sediments indicates deposition in a normal marine environment during the time of reef growth. In the Wreford limestone, sedimentation approaches the ideal cycle most closely in this region. South and east of the reef there is a distinct change in facies in the upper Threemile limestone. Cherty limestone of different lithologic and faunal character grades laterally into the reef facies. In Cowley County the algal-molluscan beds that overlie the cherty limestones in the upper Threemile limestone and middle Havensville shale seem to be the product of an environment that may have been restricted by the presence of the reefs and that probably was subjected to freshening by streams entering the sea from the southeast.

Chalky limestone is not included in Elias' ideal Permian cyclothem. Reefs of this type are unknown elsewhere in the Kansas Permian, except in the Red Eagle formation. The position with regard to other parts of the cycle, the sparseness of chert, and the lack of fusulinids are sufficient to show that the chalky limestones are a unique development in phase 6 of the ideal "Big Blue" cyclothem.

Algal limestone.—The most prominent algal limestone in the Wreford formation lies at the top of the Schroyer member. Cyclically, algal limestone beds occupy the same position in the regressive stage as the molluscan limestone does in the transgressive. Ordinarily, the regressive calcareous-shale phase is developed directly below and the green-shale phase directly above the algal unit of the Schroyer member. The regressive molluscan phase of the lower Havensville shale locally exhibits an abundance of algae.

Almost all transgressive molluscan limestones have a sparse algal component, but rarely are algae as numerous as in the regressive stages. Exceptions to this generalization can be seen in western Pottawatomie County where, at several exposures, rock that seems to be a transgressive molluscan phase is abundantly algal. The paleoecological aspect of these beds has been discussed in the paragraphs on molluscan limestone.

Other prominent algal beds representing a regressive phase of sedimentation are observed at the top of the Threemile limestone in Butler and Cowley Counties. The deposits here rest directly upon sparsely fossiliferous chert-bearing limestone and are overlain by grayish-yellow shale. The thick algal beds of the Havensville member in Cowley County are in many respects very similar to these Threemile beds. They are separated from the Threemile beds by only 2 feet or so of shale. All of these deposits contain, generally, far fewer algae than the beds at the top of the Schroyer member, differ lithologically from the latter, and are characterized by the presence not only of algae but also of robust clams. As mentioned previously these strata are called algal-molluscan limestones.

The association of mollusks with all the algal deposits clearly indicates that the phase of sedimentation represented by the latter is similar to that of the transgressive molluscan limestone. This is especially true of the algal beds in the Schroyer member. Some environmental factor (s) of the regressive sea, not existent during transgression, may be sought to account for the abundance of lime-secreting algae in the last limestone deposit of the regressive hemicycle. During transgression, a continuous supply of seawater of nearly normal salinity would be available at or near the margin of the advancing sea. Under suitable conditions of temperature, depth, etc., mollusks and associated organisms, including some algae, would thrive in near-shore areas of the sea bottom. During regression, the effects of circulation by landward-moving waters would be at a minimum, or even nonexistent except during minor readvances during the general retreat. Evaporation of the shallow near-shore water, without replenishment by normal marine waters as during transgression, could increase the salinity slightly. This change might result in an environment favorable to the propagation of abundant lime-secreting algae of the sort found in the Schroyer algal beds.

Local irregularities of the sea bottom inducing lagoonal areas, which were wholly or partly cut off from open circulation, could have resulted in evaporation of water along the shore and the development of a hypersaline environment. As already stated, this may have been one of the conditions that led to the deposition of algal beds in the upper Havensville shale of Marshall and Pottawatomie Counties.

Moore (1948, p. 126) states that salt water left as connate water in recently formed marine sediments could have drained into the marginal areas and thus have caused hypersaline conditions during regression of the sea. Proof of hypersaline conditions in the regressive part of one early Permian cycle is the gypsum deposit of the Easly Creek shale (red, green, gray) of the upper Council Grove group.

The dwarfed faunas commonly associated with the algae were also mentioned by Moore (1948, p. 126). It is of interest to note that at most of the localities where mollusks are found in algal limestone, they are small or even minute. This is especially true of all algal deposits in the Schroyer limestone and of those in the Havensville shale of northern Kansas.

The environment of deposition of the clam-bearing algal beds of Cowley County seems to have been somewhat different from that of the algal limestones at the top of the Schroyer member. All indications tend to support the hypothesis that during Wreford deposition the shoreline in this area lay to the southeast, perhaps not very far away. Abundant silt and sand is present in nearly all the shales and argillaceous limestones of the transgressive part of the Speiser shale in southernmost Kansas. Residues obtained from samples representing the upper Threemile limestone and Havensville shale algal beds with clam borings contain abundant quartz sand, more than is found in any other limestone beds analyzed. It seems evident that streams reaching the border of the sea not far to the southeast had sufficient velocity to carry sand-size grains to the site of deposition of the thick-bedded algal-molluscan sediments in which *Aviculopinna* and *Allorisma* abound.

Burrowing clams such as *Barnea, Ensis, Solen,* and *Mya,* which resemble in form the burrowers of the Late Paleozoic, are abundant in the bottom muds of the near-shore brackish-water environments of present-day seas. Although not necessarily related genetically, these modern forms may perhaps be regarded as homeomorphs of late Paleozoic burrowing clams.

Aviculopinna and *Allorisma* are found in considerable numbers in the transgressive limestones of the uppermost Speiser shale in Butler and Cowley Counties. The abundance of these fossils in the uppermost Threemile and Havensville algal-molluscan limestones indicates a depositional environment that must have resembled that of the *Aviculopinna-Allorisma* beds of the Speiser shale. It has been noted above that the fauna of the algal-molluscan beds, which contain clam borings, differs from that of more typical algal beds in containing abundant robust clams; also, algae are not nearly as abundant in the former.

It is concluded, primarily on the faunal evidence, that in Cowley County the algal-molluscan limestones of the upper Threemile limestone and middle Havensville shale were deposited in shallow brackish waters, near shore. Such an environment could have resulted from freshening of the sea water between the reefs of central Kansas and the shore, which seems to have lain only a short distance to the south or southeast; that is, the offshore barrier reef very possibly aided in producing the restricted environment in which the algal-molluscan beds were deposited. Currents must have existed in the area, however, because (1) brachiopods, crinoids, and bryozoans in the beds, presumably transported from a deeper-water environment farther offshore, are completely broken up and are commonly seen as material seemingly washed into clam burrows, and (2) local cross-bedding is observed in the algal-molluscan limestone of the Havensville shale.

It has been noted that although algae are thought to have thrived in both hypersaline and brackish environments, they are very sparse or wholly absent in the intermediate environment characterized by normal salinity. Observed relationships seem to indicate that bottom conditions, temperature, depth of water, and other environmental factors also control the activity of *Osagia*-like lime-secreting algae. The greater abundance of algae in the upper Schroyer member may indicate that, in combination with other factors, the hypersaline environment generally was somewhat more favorable to abundant algal growth than the brackish environment. On the other hand, the species of algae in the Schroyer may not be the same as those in the algal-molluscan beds in the Threemile limestone and Havensville shale.

Chert in the Cowley County algal-molluscan beds suggests that the environment of deposition, although probably brackish, provided conditions conducive to the precipitation of silica. The origin of cherts is discussed below.

Most of the calcium carbonate in the algal beds seems to have resulted from the activity of lime-secreting algae. Shell fragments and other organic debris also added much, locally, to these limestones. Oölites may form by direct chemical precipitation in waters of higher than normal salinity and temperature, according to Pettijohn (1949, p. 308). He states that inorganic precipitation of calcium carbonate is further favored by an environment in which plants have reduced the carbon dioxide content of the water. Both these conditions may have prevailed during deposition of the Schroyer algal beds, which contain abundant oölite-like structures, and the latter condition would apply to the algal-molluscan limestones. Local cross-bedding in the Havensville algal-molluscan beds indicates water agitation, which could have resulted in precipitation of calcium carbonate. Relative warmness of the shallow near-shore waters would also favor precipitation of calcium carbonate during algal-limestone deposition. Thus, inorganically precipitated limestone probably constitutes part of all the algae-bearing beds.

Calcareous encrusting algae are noted in phases 4 and 5 of the ideal Permian cyclothem, according to Elias (1937, p. 411). The thick-bedded algal limestone of the upper Schroyer member is clearly phase 4r of the second (younger) Wreford cyclothem. The cyclic position of the Threemile algal beds in Butler and Cowley Counties and the Havensville algal beds in Cowley County is less evident. The Threemile beds seem to represent phase 4r and the Havensville beds 4p in Elias' ideal cycle.

Chert.—The depositional environment of the chert is the same as that of the adjacent limestones, provided that the chert is a primary sedimentary deposit. For years the origin of chert and flint has been a major issue of controversy in sedimentology. The various theories for syngenetic, penecontemporaneous, and epigenetic origin of these rocks have been discussed and extensive bibliographies presented by Twenhofel (1950, p. 398-415) and Pettijohn (1949, p. 320-333). The work of Tarr (1917, 1926) is notable because of his firm insistence that chert bed and nodules, especially of the kind typical of the Burlington limestone, are primary chemical precipitates. Large bodies and some small bodies of chert represent original inorganic precipitation, according to Twenhofel (1950, p. 414). He believes that chert and flint form in all three of the above-mentioned ways. The weight of evidence for the origin of chert and flint favors metasomatic replacement following burial, according to Pettijohn (1949, p. 332). Krumbein and Sloss (1951, p. 141-142) state that the nature of some cherts and flints strongly suggests primary deposition by chemical processes, but that most common cherts, such as nodules and concretionary layers in limestone, are secondary. These statements illustrate the range in existing opinion. Van Tuyl (1918, p. 449-456) lists evidence of replacement or at least favoring the replacement hypothesis. Most of his factors do not apply to the Wreford cherts, and those that do can be as easily explained by the syngenetic hypothesis as by the epigenetic. After studying the Wreford limestone in southern Kansas and northern Oklahoma, Twenhofel (1919, p. 407-429) favored a penecontemporaneous origin for the siliceous deposits there. Tarr (1926, p. 33) refutes the conclusions, however, and Twenhofel himself (1950, p. 412) states that it has not been explained why silica, once deposited in disseminated form, should go back into solution and later be reprecipitated in the form of massive chert replacing some of the limestone in which it lies.

The writer is inclined to believe that at least the noncalcareous chert of the Wreford limestone is primary in origin, having been precipitated inorganically from sea water during the accumulation of the limestone members in which it is seen. This conclusion is based chiefly upon detailed observations in the field. The widespread geographic distribution of the cherts, both in surface and subsurface sections, and the constancy of lithologic association are not satisfactorily explained by theories of secondary chert formation. A list of features observed in the noncalcareous Wreford cherts, with explanations that lend support to the hypothesis of primary origin, follows:

1. Rounded surfaces. Nearly all the nodular and bedded cherts have smoothly rounded surfaces and are in sharp contact with the surrounding rock. Secondary chert should have borders gradational with the limestone, or very irregular surfaces, stringers leading off in all directions along favorable replacement channels, rather than sharp contacts. The smooth surfaces are unexplainable by the replacement theory. Rarely, in very argillaceous limestones, the chert has gradational contacts. The more rapid sedimentation in beds of this sort, in contrast with the less-argillaceous cherty limestones, may account for the indefinite edges.

2. Persistence. Many of the chert beds can be traced great distances in the outcrop with little change of thickness or position in the section. Lee (1949, 1953) and Edson (1945) have observed chert in the subsurface Wreford far west of the outcrop. Examination of well cuttings during the present study indicates that the chert maintains a constant stratigraphic relationship to other parts of the Wreford megacyclothem.

3. Lack of associaion with bedding planes. Many replacement theories call for deposition of the chert along bedding planes. The chert in the Wreford limestone lies not mainly along the bedding planes but between them, within the thick-bedded limestones. Beds of unconnected nodules generally show no evidence of having been deposited along bedding planes (Pl. 8A, 9A, 11B, etc.).

4. Chert beds parallel to bedding. Secondary chert would hardly be so consistently arranged parallel to bedding planes. Nodules, nodular-bedded cherts, and beds of smooth-surfaced chert are nearly all deposited parallel to the bedding. Uncommon exceptions to this generalization are seen in Cowley County, where cylindrical bodies of chert are oblique or even perpendicular to the bedding. Features of this sort are stratigraphically restricted to one position in the section and seem best explained as chert fillings of burrows of some bottom-dwelling organism. Vertical connections between two closely spaced chert beds seem to be the result of (1) interconnection of coincidentally opposed projections of adjacent unsolidified beds of silica or (2) the continuous accumulation of silica at isolated points during a period of decreased silica precipitation. Increased precipitation after such a decrease would result in formation of a new bed of chert connected to the older or lower one by the upward-directed protuberances of the older bed.

5. Isolated nodules aligned parallel to bedding. In numerous sections nodules that are elliptical or (rarely) circular in vertical section and that lie along definite horizons are separated horizontally from one another by distances measured in feet. It seems clear that these nodules are deposited synchronously during accumulation of the limestone. Most such nodules do not lie along bedding planes. Origin by replacement could hardly account for the stratification of the remotely isolated nodules. Even solitary nodules of irregular shape are observed to rest at the same stratigraphic level.

6. Elliptical shape. Isolated nodules, though not invariably elliptical in vertical section, are dominantly so shaped. This suggests origin as balls of soft silica, which, because of lack of rigidity, assumed the form of oblate spheroids on and parallel to the sea bottom. Secondary replacement could not so consistently produce nodules of this shape and orientation.

7. Lithologic association. No chert is seen in the purely molluscan or purely algal limestones (although the algal-molluscan limestones of southern Kansas contain some chert), or in limestones ordinarily observed in the calcareous-shale phase of deposition (typical cherty limestone in calcareous shale of the upper Schroyer member in northern Kansas is a simply explained exception, minor transgression having interrupted the general regression). If the chert were all secondary, it seems strange indeed that none is found in limestones other than those representing particular depositional environments. The presence of chert mainly in the offshore phases of deposition is not unique to the Wreford limestone among the Permian formations of Kansas.

8. Distribution of fossils. The chert beds and nodules show a definite concentration of coarser fossil fragments in the outer portion; no such concentration is noted in the adjacent limestone or within the chert. It is reasonable to conclude that shell fragments lying on the sea bottom were picked up by the somewhat mobile unsolidified chert gel. Many of the fragments failed to break the surface tension and thus remained at the border after solidification.

These observations and many items of evidence indicate that the compact noncalcareous cherts are probably primary in origin. Similar conclusions were reached by Tarr (1917, 1926) for chert of the type seen in the Burlington limestone. The features of source, transportation, precipitation, accumulation, and solidification of the Wreford chert were probably much the same as those outlined by Tarr (1926, p. 24) for the Burlington chert. That many cherts precipitated rapidly is shown by their general lack of included calcium carbonate; that precipitation commenced suddenly and ended abruptly is shown by the sharp contacts with adjacent limestone.

Experiments by Moore and Maynard (1929, p. 272-303) indicate that silica is not precipitated from sea water in the manner postulated by Tarr. Tarr's experiments may have lacked proper control, but though Moore and Maynard used natural sea water, it is doubtful that they duplicated the exact conditions of Permian (and other) primary chert precipitation, or whether these conditions can ever be duplicated in the laboratory.

The concentrically layered calcareous cherts of the Wreford limestone probably represent calcareous silica that has been diagenetically altered. These cherts are most abundant in Butler and Cowley Counties, which suggests that the environment of deposition that caused formation of this type of chert rather than noncalcareous chert was affected by nearness to shore and perhaps also by the existence of the chalky limestone reefs. Insoluble residues of limestones lying adjacent to the calcareous chert beds of Cowley County show that tripolitic chert comprises as much as 70 percent of the rock volume. The tripolitic chert seemingly represents primarily precipitated silica that, because of somewhat brackish conditions, settled to the sea bottom too slowly to form solid chert. From time to time the salinity increased slightly and caused more rapid deposition of silica but still not fast enough to form chert that did not contain calcium carbonate. Such calcareous silica is believed to have later become the layered calcareous chert. That these cherts represent original sedimentary deposits, now diagenetically altered as described below, is demonstrated by the following: (1) lateral persistence of most such beds, (2) lack of bedding-plane association (Pl. 10A, 11A, 12A, etc.), (3) chert beds parallel to bedding, (4) isolated nodules aligned parallel to bedding, (5) lithologic association, all the calcareous cherts lying within beds that also contain some primary noncalcareous chert, the implication of environmental control being evident.

The layering of the calcareous cherts seems to be of diagenetic origin and may be a liesegang phenomenon resulting from diffusion of silica ions through the deposit during compaction of the sediments. Limonite concentrated in the darker layers may represent iron that was in solution during diagenesis and that was possibly involved in the reaction that precipitated the silica. Localized reorganization of the calcareous silica during compaction could result in nodular calcareous cherts such as those at localities 90, 117, and 124 (Pl. 10A, 11A).

Small patches of layered calcareous chert associated with noncalcareous chert, seams of layered calcareous chert between seams on noncalcareous chert, as at locality 106, and beds of calcareous chert enclosing noncalcareous chert, as at localities 107 and 109, are explained as being due to changes in rate of silica accumulation in bottom sediments. Small nodules of noncalcareous chert such as that figured in Plate 10C are the result of sharp increases in salinity and accumulation of almost pure silica balls on the sea bottom in areas where calcareous silica was being deposited penecontemporaneously. The curvature of the calcareous chert layering over the noncalcareous chert nodule figured in Plate 10C certainly suggests diagenetic origin for the layering.

The nature of diagenetic action on calcareous silica accounts for the general lack of contact sharpness between this type of chert and adjacent limestones.

Thus, two main types of chert in the Wreford limestone seem to have had different origins. Compact noncalcareous cherts seem explainable by the syngenetic precipitation hypothesis, whereas layered calcareous chert owes its present appearance to diagenetic alteration of silica deposited more slowly than that now represented by the noncalcareous chert.

Cycles of Sedimentation in Wreford Limestone

A definite repetitive sequence of sedimentary rock types has been observed in the Wreford limestone and adjacent shales. The physical and faunal characteristics clearly show that the sediment forming the rocks was deposited during stages of transgression and regression of the shallow Early Permian sea. The sequence of deposits that accumulated at a given locality during advance of the sea (transgressive hemicycle) was repeated in reverse order during retreat (regressive hemicycle). All sediments of whatever kind deposited during a complete cycle of deposition are known as a cyclothem. Within the Speiser shale, Wreford limestone, and Wymore shale two nearly complete cyclothems are recognized, and it is for this assemblage of rocks that the name Wreford megacyclothem is proposed. The term megacyclothem, as explained previously, refers to a cycle of cyclothems. The Threemile and Schroyer members of the Wreford limestone are close together stratigraphically and are lithologically and faunally very much the same. For these reasons the two cyclothems of the Wreford limestone are classed together and are given the names Threemile cyclothem and Schroyer cyclothem because these two limestone members comprise the middle part of the lower and upper cycles, respectively. The degree of development of the cyclothem differs between one exposure and the next, and between some localities the changes in facies in some of the sedimentary phases obscure the cyclic nature of part of the section. In northern Kansas the megacyclothem is most nearly complete. Reefs in the Threemile limestone caused deviation from normal cyclic sedimentation in central Kansas and seemingly had a pronounced effect on sedimentation in the upper Threemile limestone and Havensville shale of southern Kansas.

A composite tabulation of phases observed in the Wreford megacyclothem is presented in Table 2. All but phase 0 are seen in northern and central Kansas. In the Threemile cyclothem in Cowley County, phase 6 chalky limestone is missing, although a lateral equivalent of it can be seen, and phase 5 is absent in the regressive hemicycle. Phases 2r to 2t of the Threemile and Schroyer cyclothems are absent in Cowley County. Phase 3r has nowhere been observed by the author in the Schroyer cyclothem. A diagrammatic sketch showing inferred relationship of the sediments in northern Kansas to those in the south is presented in Figure 6.

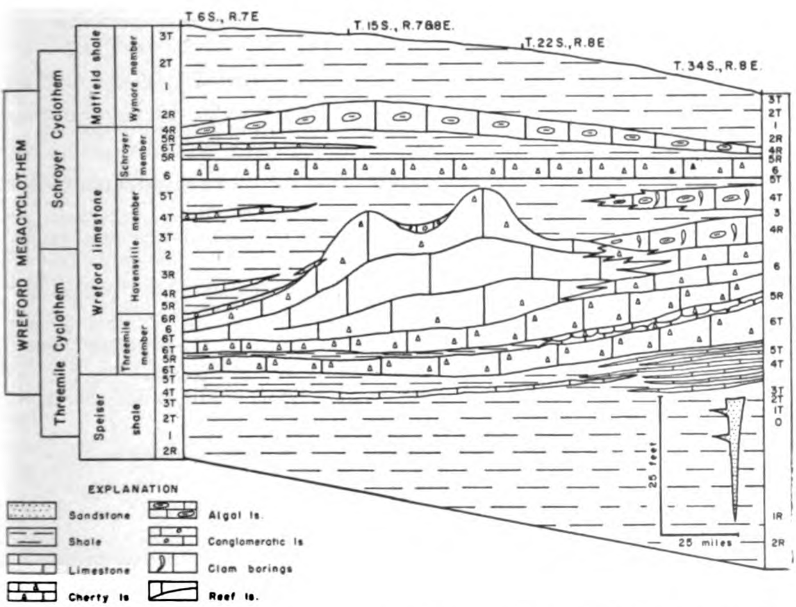

Fig. 6. Relationship of sedimentary deposits in the Wreford megacyclothem. Numbers refer to phases of deposition (Table 2). Unlettered numbers are terminal phases of hemicycles.

Table 2. *Observed sedimentary phases of the Wreford megacyclothem.*

	Fm.	Mbr.	Phase	Description
SCHROYER CYCLOTHEM	MATFIELD SHALE	Wymore shale	1 .	Red shale
			2r.	Green shale, ostracodes
	WREFORD LIMESTONE	Schroyer limestone	4r.	Algal limestone
			5r.	Calcareous shale, mixed fauna, *Derbyia* dominant
			6 .	Chert-bearing limestone, brachiopod-bryozoan fauna
		Havensville shale	5t.	Calcareous shale, mixed fauna, *Derbyia* dominant
			4t.	Molluscan limestone, *Aviculopecten, Septimyalina*
			3t.	Grayish-yellow mudstone, ostracodes
			2 .	Green shale, ostracodes and sparse plant remains
THREEMILE CYCLOTHEM			3r.	Grayish-yellow mudstone, ostracodes
			4r.	Molluscan limestone, *Aviculopecten, Septimyalina*
			5r.	Calcareous shale, mixed fauna, *Derbyia* dominant
		Threemile limestone	6r.	Chert-bearing limestone, brachiopod-bryozoan fauna
			6 .	Chalky limestone, *Fenestrellina,* corals
			6t.	Chert-bearing limestone, brachiopod-bryozoan fauna
	SPEISER SHALE		5t.	Calcareous shale, mixed fauna, *Derbyia* dominant
			4t.	Molluscan limestone, *Aviculopecten, Septimyalina*
			3t.	Grayish-yellow mudstone, ostracodes
			2t.	Green shale, ostracodes and sparse plant remains
			1t.	Red shale, charophytes
			0 .	Sandstone, unfossiliferous

Numbering corresponds to that of Elias (1937, p. 411) where applicable. t=transgressive phase, r=regressive phase. End members of hemicycles are not lettered. (Minor regressions and transgressions not shown).

Comparison with Subsurface Sections

Three subsurface sections represented by well cuttings from the following localities: (1) sec. 15, T. 8 S., R. 14 W.; (2) sec. 17, T. 29 S., R. 23 W.; and (3) sec. 26, T. 21 S., R. 2 W., were studied. The heterogeneous nature of the cuttings, impossibility of accurately reconstructing sections in detail, and lack of well-preserved fossils obviated examination of a greater number of well samples, because little precise information pertaining to depositional environment would be obtained.

The significant facts that could be determined are as follows: the shales between limestone formations are in part green or red; chert is present in the Wreford limestone in all three sections, although it is sparse in section 2; and shale is a prominent part of the Wreford limestone in the subsurface, although it can be correlated only roughly with the Havensville member.

The Wreford limestone thins and the shales above and below it thicken southwestward from eastern Saline County to southeastern Barber County, Kansas, according to Lee (1949, p. 3-4). From southeastern Smith County to southwestern Meade County the Wreford limestone is gray, granular, siliceous, and cherty in the northeast, but darker and more argillaceous toward the southwest, according to Lee (1953, p. 8). In this cross section, the Wreford formation is 12 to 40 feet thick and locally bears no chert. In a series of sections from Ford County to Wallace County, Edson (1945) shows chert in the Wreford in all wells except two in westernmost Kansas.

It may be concluded from the above statements that (1) the variation in thickness of the Wreford limestone is greater in the subsurface than at the surface; (2) cherty limestone, red shale, and green shale are prominent in the subsurface far west of the outcrop of the rocks in the Wreford megacyclothem and lie in the same relative stratigraphic positions as at the surface; (3) the depositional environment of the cherty limestone, red shale, and green shale were the same as for lithologically similar rocks at the surface and thus had great geographic range. Naturally, a given environment did not prevail simultaneously over the entire area under consideration.

COMPARISON WITH HIGHER PERMIAN STRATA

Good sections of the Matfield shale, Barneston limestone, and Winfield limestone at several places were measured and described and notes made on the fossils seen in each type of rock encountered.

Above the Wymore shale lies the Kinney limestone member of the Matfield formation. It contains no chert, and the fossils are dominantly mollusks. Within the limestone, calcareous shale containing *Derbyia* is present at exposures examined in Chase and Geary Counties. The upper member of the Matfield formation is the Blue Springs shale. This exhibits an alternating sequence of grayish-green to dusky-red silty shales, the red beds predominating in the middle. Sandstone lenses exist in both sections examined (Geary County), mainly in the red shale. The upper Blue Springs member contains molluscan limestone at both exposures.

The overlying Barneston formation comprises, in upward order, the Florence limestone, Oketo shale, and Fort Riley limestone. The lower member, which was studied along U.S. Highway 40 in Geary County, greatly resembles lithologically the chert-bearing limestones of the Wreford formation and is characterized by the presence of abundant, persistent nodular beds of dark-gray chert. The fauna includes brachiopods, bryozoans, echinoderms, and fusulinids. The top of the Florence limestone includes alternating chert beds and calcareous shale units, both containing abundant fossils like those found in lithologically similar rocks of the Wreford limestone. The Oketo member consists of calcareous shale and bears the mixed fauna characteristic of this lithology. The Fort Riley limestone, which was examined in Riley and Geary Counties, generally bears no chert and is dominantly characterized by a molluscan fauna. Thick-bedded limestone in the lower portion contains *Aviculopinna* and vertical borings similar to those in the Wreford limestone of Cowley County. Several calcareous-shale units, containing the characteristic fossils, are interbedded with the limestones in the lower part of the member. Above the fossiliferous-shale phases, argillaceous, thin- to thick-bedded limestones make up most of the upper part of the Fort Riley member. The fauna contained in these limestones is dominantly molluscan.

The Doyle shale was not examined; however, it comprises three members, which correspond closely in sequence and lithology to those of the Matfield shale. In a single known exposure chert is observed in the middle member, and *Derbyia* is abundant near the top of the upper member (Jewett, 1941, p. 81-82.)

Overlying the Doyle shale is the Winfield limestone, which contains three members. In ascending order these are the Stovall limestone, Grant shale, and Cresswell limestone. The Stovall consistently contains chert, and the Grant shale bears a mixed fauna typical of the calcareous-shale phase. The Cresswell limestone fauna is more or less typical of cherty limestone, but chert is common only in central and southern Kansas.

The brief studies of these formations seem to show that cyclical sedimentation very similar to that represented in the Wreford megacyclothem resulted in deposition of similar sediment in some of the younger Permian formations in Kansas.

The Matfield shale contains two red-shale phases, one in each member, which were deposited during maximum regression of the sea. The *Derbyia*-bearing calcareous-shale phase of the middle Kinney limestone represents the phase of maximum transgressive deposition in the formation. Sandstones in the red shale of the Blue Springs member may be compared to those of the Speiser shale in Cowley County. The upper Blue Springs is cleary transgressive, as indicated by the ascending sequence of red shale, green shale, and molluscan limestone in its higher portion.

The Florence limestone, with its fusulinids, was laid down during maximum transgression of the Barneston cycle. Fluctuation between regression and minor readvance of the Early Permian sea is indicated by interstratified calcareous shale and cherty limestone in the upper part of the member. The Oketo member, a calcareous-shale phase, clearly is part of the regressive hemicycle. The molluscan and somewhat algal fauna of the thick-bedded limestone near the base of the Fort Riley limestone suggests a phase of sedimentation much like that observed in the upper Threemile limestone in Cowley County. In both members (Fort Riley and Threemile) these beds are found in the regressive hemicycle. The upper part of the Fort Riley member contains some rocks of the calcareous-shale type, but the dominantly molluscan limestone indicates deposition mainly during a very slow regression of the sea.

The lower member of the Doyle shale, from the base upward, shows regressive sedimentation to the red-shale phase, then transgressive units. The middle limestone member, locally containing chert, represents the maximum stage of transgression attained during the deposition of the formation. The upper member represents regression to the red-shale phase, then renewed transgression.

The chert-bearing Stovall limestone in the basal part of the Winfield formation is the maximum transgressive deposit of the cycle that begins with red shale in the upper Doyle formation. A calcareous-shale fauna is observed in the Grant shale member of the Winfield limestone, indicating that regressive sedimentation followed the deposition of the Stovall limestone member. The Cresswell member represents deposition during a readvance of the sea, as shown by the fact that it contains chert.

Thus, the sedimentary deposits above the Wreford limestone demonstrate that sedimentation was cyclic in this part of the section also. The Barneston limestone and adjacent strata comprise the best developed single cyclothem but, where studied, do not match the Wreford formation in perfection of cyclical symmetry.

SUMMARY

The Wolfcampian Wreford megacyclothem comprises the Wreford limestone, part of the underlying Speiser shale, and part of the overlying Wymore shale member of the Matfield formation. The Speiser shale consists of three widely recognizable units including, in upward order, (1) basal red shale and green ostracode-bearing shale, (2) a molluscan-limestone unit containing *Aviculopecten* and *Septimyalina*, and (3) a calcareous shale best characterized by *Derbyia, Dictyoclostus, Composita,* and *Chonetes*. Sandstone is locally intercalated in the red shale; grayish-yellow mudstone commonly lies below the molluscan limestone.

The Threemile member of the Wreford limestone comprises, in ascending order, (1) a persistent chert-bearing member containing a brachiopod-bryozoan fauna, (2) a likewise persistent shaly phase containing a mixed fauna, (3) chert-bearing limestone, (4) chalky, less cherty limestone characterized by bryozoans and some corals (unit absent in southernmost Kansas), and (5) cherty limestone (northern and central Kansas) or algal-molluscan limestone (southern Kansas).

The middle member of the Wreford limestone, the Havensville shale, generally includes, in northern Kansas, the following beds in upward order: (1) calcareous shale, (2) molluscan limestone, (3) mudstone, (4) molluscan limestone, and (5) calcareous shale; one or more of these units is commonly poorly developed. Each unit contains a fauna resembling that in equivalent phases of the Speiser shale. Green shale is seen locally in the middle Havensville. In southern Kansas an algal-molluscan limestone that lies in the middle of the member is underlain by mudstone and shale, and overlain by calcareous shale.

The Schroyer limestone, uppermost member of the formation, comprises a basal cherty limestone, a middle calcareous shale, and an upper algal limestone. The calcareous shale contains a thin cherty limestone in northern Kansas. The faunas in these units are similar to those in lithologically equivalent units lower in the section.

The Wymore shale includes, in upward order, green shale, red shale, green shale, and calcareous mudstone or very silty limestone.

Recurrence of lithologic types, each with characteristic fossils (or lack of them), suggests cyclic sedimentation. Two nearly complete cycles and parts of two others are represented in the sections studied. The complete cycles, each divided into transgressive and regressive hemicycles, are the Threemile cyclothem and the Shroyer cyclothem; these combined constitute the Wreford megacyclothem.

Strata in the transgressive hemicycle of the Threemile cyclothem include sandstone and red shale of continental origin successively overlain by marine green shale, mudstone, molluscan limestone, calcareous shale, and chert-bearing limestone. The organic and inorganic constituents of the various phases indicate marine deposition progressively farther from shore as one proceeds from green shale to cherty limestone. Chalky limestone reefs, special developments in the chert-bearing limestones, were formed during maximum transgression in central Kansas. Intermingling of molluscan and calcareous-shale phases is common in southernmost Kansas.

The Threemile regressive hemicycle includes cherty limestone, calcareous shale, molluscan limestone, mudstone, and, rarely, green shale. South of the reef limestone exposures, the upper Threemile limestone contains an algal-molluscan limestone unit the depositional environment of which undoubtedly was tempered by the presence of the reefs; the regressive hemicycle in this area terminates in mudstone of the basal Havensville shale. The ascending order of phases indicates progressively shoreward deposition.

In northern Kansas the Schroyer transgressive hemicycle includes green shale, mudstone, molluscan (locally algal) limestone, calcareous shale, and cherty limestone, in upward order. In southern Kansas the transgressive hemicycle includes mudstone, algal-molluscan limestone, calcareous shale, and cherty limestone.

The Schroyer regressive hemicycle is uniformly developed over much of Kansas. Included are cherty limestone, calcareous shale, algal limestone, green shale, and red shale. In northern Kansas, minor reversal during regression caused deposition of a widespread cherty limestone bed in the calcareous shale.

Subsurface sections far west of the outcrop contain red shale, green shale, and cherty limestone in the same relative stratigraphic positions as at the surface. The environments favoring deposition of these phases thus had wide geographic distribution in both north-south and east-west directions, although presumably a single environment did not prevail throughout the area at any given time.

The stratigraphic section above the Wreford limestone as high as the Winfield limestone shows repetition of lithologies and faunas that can be demonstrated to represent parts of five cyclothems. Of these the Barneston cyclothem is most nearly complete.

CONCLUSIONS

1. The various phases of the Wreford megacyclothem are assignable to depositional environments and can be shown to lie in an orderly and logical stratigraphic sequence comprising two nearly complete cyclothems.

2. Fine-grained channel sandstones in the Speiser shale of Cowley County were deposited along a stream that flowed across a broad, low alluvial plain.

3. Red shales seem to be subaerial deposits laid down on a broad, low alluvial plain bordering the Early Permian sea. The

red color is caused either by oxidation of the soil from which the sediment was derived, by subaerial oxidation after deposition, or both.

4. Green shales are the product of sedimentation in the zone of marine deposition nearest shore. Reduction of iron and organic material permits dominance of green color, which is due to the presence of green clay minerals. The restricted fauna indicates a brackish-water environment.

5. Grayish-yellow mudstone was commonly deposited next offshore from the area of green-shale accumulation. More abundant organic matter accounts for the difference in color. Dominance of ostracodes suggests a brackish-water environment.

6. Molluscan limestone represents marine deposition in water of more nearly normal salinity in an offshore zone where some turbulence resulted from wave activity. The calcium carbonate is believed to be chiefly a product of shell disintegration and wave agitation.

7. Calcareous shale represents deposition in a normal marine offshore area where wave agitation was not strong. Conditions favorable to many forms of life resulted in prolific faunal development.

8. Chert-bearing limestone was deposited in relatively deeper, clear, offshore water of normal salinity. The calcium carbonate is primarily an accumulation of shell fragments, but it also contains algal and inorganic components.

9. The chalky limestone is believed to comprise a system of reefs, which have an arcuate, seawardly convex pattern. The reefs seem to be more or less connected and are probably of the offshore-barrier type. Most of the calcium carbonate is organic in origin, algae and bryozoans having contributed heavily to its accumulation. Wave agitation of warm water probably caused chemical precipitation of some calcium carbonate, also.

10. The reef in the Threemile limestone of central Kansas possibly had an important effect on sedimentation. The fore-reef sediments display the best cycles of sedimentary rocks; the back-reef facies includes algal-molluscan limestone in the upper Threemile member, which overlies southern equivalents of the chalky limestone, and similar beds in the Havensville shale in Cowley County.

11. On the basis of geographic, stratigraphic, and lithologic relationships, the compact noncalcareous chert is thought to be a primary inorganic precipitate. The concentrically layered calcareous chert represents slowly deposited inorganic silica in which calcium carbonate was incorporated; the present aspect is due to diagenetic alteration of the original sediment. The chert is observed mainly in limestones containing brachiopod-bryozoan-echinoderm-coral faunas; hence optimum conditions for silica deposition occurred during the maximum stage of transgression and earliest stage of regression.

12. Noncalcareous chert is progressively less abundant to the south in Kansas; calcareous chert is more abundant southward. Most chert of the latter type is attributed to deposition nearer shore where the environment was intermediate between that suited for rapid precipitation of silica and that in which silica was precipitated very slowly.

13. Algal limestone was deposited in a special sort of environment and is a regressional equivalent of molluscan limestone. There is a constant association of algae and mollusks in these beds. The profusely algal limestones may have resulted from a hypersaline environment, and algal beds that contain large boring clams suggest a brackish environment of deposition.

14. The upland area affecting Wreford sedimentation probably lay not far to the south or southeast. Plant fossils provide inconclusive evidence for high ground in the south and low-lying land areas adjacent to the sea in northern Kansas.

15. Broad-leaved-conifer and seed-fern fossils indicate that a warm climate prevailed during Wreford deposition.

16. The cycles of the Wreford megacyclothem contain the following lithologic types, arranged in stratigraphic order:

Threemile cyclothem

2 . Green shale*
3r. Mudstone
4r. Molluscan limestone
5r. Calcareous shale*
6r. Cherty limestone
6 . Chalky limestone*
6t. Cherty limestone
5t. Calcareous shale
4t. Molluscan limestone
3t. Mudstone
2t. Green shale
1t. Red shale
0 . Sandstone†

Schroyer cyclothem

1 . Red shale
2r. Green shale
4r. Algal limestone
5r. Calcareous shale
6 . Cherty limestone
5t. Calcareous shale
4t. Molluscan limestone
3t. Mudstone
2 . Green shale*

*absent in southern Kansas
†absent in northern Kansas

17. Individual phases, as well as complete cyclothems, are commonly traceable for as much as 200 miles in Kansas even though they may be very thin. This phenomenon suggests that some depositional environments extended almost unmodified over broad areas during the time in which the Wreford megacyclothem was deposited.

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APPENDIX—*Description of sections*

General.—Six key sections along the outcrop of the Wreford limestone are described in condensed form. The sections are presented in descending stratigraphic order, individual units being numbered from the base upward. Locations precede the description of beds in each different exposure; four of the sections are composite.

Explanation of terms.—The following is a glossary of definitions and explanations of terms that, owing to various usages, might be misinterpreted. All terms used are those that are most generally accepted or seem most adequately to describe the features observed.

(a)—Abundant. Refers to fossils that are numerous enough to be readily seen either on an etched surface or in a washed sample.

Blocky—Characteristic weathering of many green and red shales, which produces subcubical rock fragments.

(c)—Common. Refers to fossils that are numerous but not abundant enough to be immediately conspicuous in the sample.

Chalky—Applies to limestones that are somewhat powdery on broken surfaces and are composed of dull, lusterless fine grains of calcite.

Chert—Cryptocrystalline silica of any color. The constant interchange of the terms chert and flint in a description is confusing, and because colors are gradational no sharp distinction can be made. Dark-gray and black chert may be interpreted to be flint; lighter-colored varieties may be called chert.

Color—Descriptive colors used are those found in the *Rock-Color Chart* prepared by the Rock-Color Chart Committee of the National Research Council (Goddard and others, 1948.)

Granular—Applies to limestones having relatively uniform-size grains that exhibit no well-defined crystal surfaces and have a dull to glimmering luster. Finely granular limestones are those in which individual grains can not be distinguished by the naked eye.

Laminated—Applies to strata having bedding planes 1 mm apart or less.

Massive-bedded—Strata having bedding planes more than 6 ft. apart.

Medium-bedded—Strata having bedding planes 50 to 150 mm (2 to 6 in.) apart.

(p)—Profuse. Applies to fossils that are a major constituent of the rock.

(s)—Sparse. Applies to fossils very poorly represented in the rock.

Shaly bedded—Strata having bedding planes 1 to 10 mm apart. Applies to both shale and limestone.

Subcrystalline—Applies to dominantly crystalline limestones that have a partly granular matrix.

Subgranular—Applies to dominantly granular limestones that have a partly crystalline matrix.

Thick-bedded—Strata having bedding planes 6 in. to 6 ft. apart.

Thin-bedded—Strata having bedding planes 10 to 50 mm (⅓ to 2 in.) apart.

Key section 1. Road cuts on State Highway 99 about 5 miles north of Westmoreland, Pottawatomie County. Includes Speiser shale, Wreford limestone, and part of Wymore shale member of Matfield formation.

Loc. 4, NW¼ sec. 3, T. 7 S., R. 9 E.

MATFIELD SHALE

Wymore shale member, 12.9 feet exposed

	Thickness, feet
22. Shale, olive gray to greenish gray, very calcareous, very sandy, upper part shaly bedded, lower part thin bedded and much harder, unfossiliferous	3.0
21. Mudstone, lower 3 feet dark greenish gray becoming dark reddish purple then greenish gray, top 2 feet olive gray and more calcareous, very silty, shaly bedded, weathers blocky; Fossils, green shale, charaphyte oögonia, *Bairdia*, *Cavellina*, and fragmentary vertebrate remains; red shale, unfossiliferous	5.0
20. Limestone, light gray, weathers light grayish yellow, very hard, thin bedded, very fine granular matrix; Fossils, *Cavellina*, *Bairdia*, and *Euomphalus*	0.4

	Thickness, feet
19. Mudstone, reddish purple to grayish green, calcareous, very sandy, shaly bedded, weathers blocky; FOSSILS, *Cavellina* and ?*Bairdia* comprise the very sparse fauna	4.5
WREFORD LIMESTONE	
Schroyer limestone member, 8.8 feet	
18. Limestone, grayish yellow, weathers grayish yellow, hard, cellular owing to solution, thick bedded, uneven texture, subgranular matrix, profusely algal; FOSSILS, *Osagia* (p), *Ammovertella* (c), bryozoan fragments (s), tiny gastropods (s), and crinoid stems (s)	3.0
17. Covered interval, shale, some cherty limestone	?2.5
16. Limestone, light gray, weathers light yellowish gray, hard, thick bedded, chert-bearing, contains siliceous geodes, uneven texture, fine- to medium-granular matrix; CHERT, three beds numbered 1 to 3 in upward order, (1) mottled light gray, (2) very light gray mottled with grayish white, scattered calcareous patches common, (3) medium to light gray; FOSSILS, *Ammovertella* (s), *Rhombopora* (s), fenestrate bryozoans, *Dictyoclostus* (c), *Derbyia* (s), *Composita* (c), *Chonetes* (s), productid spines (a), *Septimyalina* (s), crinoid stems; chert contains fenestrate bryozoans, productid spines, brachiopod shells	2.0
15. Shale, yellowish gray, very calcareous, slightly silty, shaly bedded; FOSSILS, *Fenestrellina, Composita, Derbyia*, productid spines, *Pseudomonotis*, tiny fragment of gastropod internal mold, echinoid plates and spines (s), crinoid stems, *Cavellina, Knoxina, Bairdia, Hollinella*, tiny fish teeth and vertebrate remains; fauna varied but sparse and poorly preserved	0.4
14. Limestone, light gray, weathers yellowish gray, hard, thick bedded, chert-bearing, contains some geodal fossils, uniform texture, fine-granular matrix; CHERT, light gray to grayish white, contains scattered patches of dark-gray calcareous chert; FOSSILS, *Ammovertella* (c), sponge spicules (s), fenestrate and ramose bryozoan fragments, *Fenestrellina, Dictyoclostus, Composita* (c), productid spines (a), crinoid stems, echinoid spines and plates; chert contains bryozoan fragments, productid spines, ?*Composita* fragments; fauna known chiefly from silicified remains etched from limestone	0.9
Loc. 2, SW¼ sec. 3, T. 7 S., R. 9 E.	
Havensville shale member, 18.8 feet	
13. Shale, olive gray, silty, very calcareous, deeply weathered; FOSSILS, worm tubes, internal molds of several kinds of low- and high-spired gastropods (a), brachiopod spines, and small, fragmentary vertebrate remains; fauna poorly preserved	3.0

Thickness, feet

12. Limestone, light yellowish gray, weathers yellowish gray, soft, medium bedded, uniform texture, fine-granular matrix, basal 0.1 foot is a hard undulatory bed of finely crystalline and coarsely granular calcite; FOSSILS, basal 0.1 foot, *Ammovertella* (s) 3.0
11. Mudstone, olive gray to medium gray, very calcareous at base, less so at top, very sandy, thin bedded to laminated, several irregular to nodular limestone beds, thicker more persistent bed of very argillaceous earthy limestone 0.3 foot thick lies 2.5 feet above base; unfossiliferous 8.5
10. Limestone, mottled reddish purple, yellowish gray, and brownish gray, weathers dark gray at base and yellowish brown at top, lower part very argillaceous and medium hard, upper part hard, lower argillaceous part has uniform texture and fine-granular matrix, upper hard bed has uneven texture, and subgranular matrix; FOSSILS, lower bed, small *Aviculopecten,* other pelecypods, productid spines (s); upper bed, *Ammodiscus* (p), tiny bryozoan fragments, small gastropods (s), fragmentary fossil shells; top bedding plane, *Ammodiscus* (p), *Aviculopecten* (a), *Septimyalina* (c), small pelecypods, tiny gastropods, and *?Cavellina* (s) 0.5
9. Shale, olive gray, dark gray near center, calcareous, silty, weathers blocky, calcareous nodules in lower part, worm ? trails in upper part; FOSSILS, lower 0.75 foot, *Globivalvulina,* ramose and fenestrate bryozoan fragments, *Rhombopora, Fenestrellina, Septopora,* productid brachiopod fragments and spines, hook type holothurian spicules, crinoid stems, echinoid plates, trilobite fragments *(?Ditomopyge)* (c), *Kellettina, Cavellina, Bairdia, Knightina, Macrocypris;* upper 3 feet, *Cavellina* (s), *Aviculopecten* and small pelecypods; abundant fauna in lower part, upper part sparsely fossiliferous 3.8

Threemile limestone member, 7.1 feet

8. Limestone, light yellowish gray, weathers yellowish gray, medium hard, shaly to thin bedded, argillaceous, sparse siliceous geodes and very sparse small chert nodules, uneven texture, fine-granular matrix, aggregates of granular limonite; FOSSILS, *Ammovertella* (c), *Penniretepora,* fenestrate and ramose bryozoan fragments, brachiopod fragments, productid spines (c), mytilid ?, crinoid stems and spines, trilobite pygidium; fauna moderately abundant but mostly fragmentary 0.5
7. Limestone, light gray, weathers yellowish gray, hard, thick bedded, chert-bearing, uniform texture, fine-granular matrix; CHERT, two beds numbered 1 and 2 in upward order,

	Thickness, feet
(1) medium gray, (2) mottled, very light gray and light grayish yellow; FOSSILS, *Ammovertella* (c), *Stereostylus*, ramose and fenestrate bryozoan fragments, *Rhombopora*, brachiopod fragments, *Chonetes* (s), *Derbyia* (s), *Composita* (c), *Enteletes* (c), productid spines, crinoid stems, echinoid spines, vertebrate remains; chert contains fenestrate and ramose bryozoan fragments, productid spines	1.0
6. Limestone, light whitish gray, weathers yellowish gray, chert-bearing, hard, thick bedded, chalky, basal 0.1 foot shaly and very fossiliferous, unit is characterized by numerous irregular pores (to 4 mm across) and pitted weathered surface, uniform texture, fine-granular matrix; CHERT, five nodular beds numbered 1 to 5 in upward order, (1) light gray to white, (2) medium to light gray, (3) mottled medium dark, light, and very light gray, (4) light grayish white, (5) medium gray to light grayish yellow; FOSSILS, *Ammodiscus*, *Fenestrellina*, *Rhombopora*, *Composita* (s), *Enteletes* (a), *Derbyia* (s), productid spines, crinoid stems and plates, echinoid spines and plates; chert contains fenestrate and ramose bryozoan fragments, brachiopod fragments, productid spines	3.8
5. Limestone, light gray, weathers yellowish brown, chert-bearing, thick bedded, in basal 0.1 foot, shaly bedded, uniform texture, fine-granular matrix; CHERT, small nodules, yellowish gray; FOSSILS, *Rhombopora*, fenestrate bryozoans, *Dictyoclostus*, *Derbyia* (c), *Enteletes* (a), productid spines, crinoid stems, echinoid spines; chert contains ramose bryozoan fragments, productid spines, and crinoid stems	1.0
4. Limestone, light gray, weathers grayish yellow, chert-bearing, hard, thick bedded, uniform texture, fine-granular matrix; CHERT, gray to grayish white; FOSSILS, *Ammovertella*, bryozoan fragments, *Enteletes* (s), *Chonetes* (s), productid spines, *Aviculopinna*, and crinoid stems; chert contains *Tetrataxis*, *Fenestrellina*, brachiopod fragments, productid spines, echinoid spines, and ostracodes	0.8

Loc. 1, NW¼ sec. 10, T. 7 S., R. 9 E.

SPEISER SHALE

3. Shale, olive gray, very calcareous, silty, shaly bedded, sparse black flint pebbles at top; FOSSILS, *Osagia* (c), *Globivalvulina* (c), *Tetrataxis* (c), *Ammodiscus* (c), *Ammovertella* (c), *Fenestrellina* (a), *Rhombopora* (a), *Polypora* (s), *Penniretepora* (a), *Lingula* (s), *Derbyia* (c), *Dictyoclostus* (c), *Composita* (s), *Chonetes* (c), productid spines, small high- and low-spired gastropod internal molds, *Delocrinus* plates (s), crinoid stems, echinoid spines

	Thickness, feet
and plates, *Knightina* (a), *Knoxina* (c), *Cavellina* (c), *Amphissites* (a), *Paraparchites* (c), *Hollinella*, *?Kirkbya*, *Kellettina* (s), *Bairdia;* megafossils mostly fragmentary	2.1
2. Limestone, light yellowish gray, weathers light yellowish gray, hard, single bed, uniform texture, fine-granular matrix; FOSSILS, *Osagia*-type algae, *Nubecularia* commonly associated with *Osagia* (s), *Ammovertella* (p), ramose bryozoan fragments, *Juresania* (s), productid spines (c), minute gastropods, *Aviculopecten* (s), *Septimyalina* (s), Aviculopinna (s), ostracodes; fossils not abundant, poorly preserved as fragments and molds	0.4
1. Shale, lower 6 feet reddish brown, upper 4 feet greenish gray, calcareous, silty, weathers blocky; FOSSILS, lower 6 feet, unfossiliferous; upper 4 feet, small ramose and fenestrate bryozoan fragments, productid fragments and spines, small high- and low-spired gastropod internal molds, echinoid spines and plates, *Cavellina*, *?Hollinella*, *Bairdia;* fossils sparse except *Cavellina*	10.0
Total	60.1

Key section 2. Road cuts on U.S. Highway 40 about 4 miles east of Junction City, Geary County. Includes Speiser shale, Wreford limestone, and Wymore shale member of Matfield formation.

Loc. 30, NE¼ sec. 34, T. 11 S., R. 6 E.

MATFIELD SHALE

Wymore shale member, 22.4 feet

22. Mudstone and silty limestone, light yellowish brown to grayish yellow, very silty, thin bedded to laminated, medium hard; FOSSILS, *Cornuspira*, *Hollinella*, *Paraparchites*, *Cavellina*, *Knoxina*, *Bairdia*, echinoid spines, crinoid stems. Fauna sparse	6.4
21. Shale, dusky green (basal 4 to 5 feet), dusky purple and dusky red (middle 8 feet), and dusky green (upper 4 feet), calcareous, silty, shaly bedded, weathers blocky, soft shaly bedded pale-purplish-red limestone (0.2 to 0.5 foot thick) 1.5 feet above base; FOSSILS, foraminifera?, small low-spired gastropod, large high-spired gastropods (c), *?Cavellina*, *Paraparchites*, *?Microcheilinella*, *Macrocypris*, *Charophyte* oögonia (c); fauna sparse, most abundant in lower 1 foot of green shale. No fossils seen in middle red and upper green portions	16.0

WREFORD LIMESTONE

Schroyer limestone member, 8.9 feet

20. Limestone, yellow to grayish yellow, weathers yellowish brown, very hard, thick bedded, moderately algal, very re-

	Thickness, feet
sistant to weathering, somewhat cellular in lower part, uniform texture, fine-granular matrix; FOSSILS, *Osagia*-type algae (m), *Ammovertella* (c), bryozoan fragments (s), productid spines (s), tiny gastropods (c), and ostracodes (a)	1.75
19. Shale, light yellowish gray, very calcareous, silty, shaly bedded; FOSSILS, biscuit-like calcareous structures intermediate in size and shape between *Osagia* and *Ottonosia*-type algae (thin section shows tubular thread-like *Girvanella,* which indicates that whole structure is probably a colonial mass of *Girvanella), Globivalvulina* (s), *Derbyia* (s), echinoid spines (s), holothurian spicules (hooks), tiny gastropod internal mold, *Paraparchites* (a), *?Knoxina, ?Cavellina, Hollinella* (s), *Bairdia* (s), *Bythocypris* (s), tiny fish teeth, a single blade-type conodont. Fauna dominantly composed of *Paraparchites* of very large size	0.25
18. Limestone, light yellowish gray, weathers brownish yellow, hard, medium bedded, chert-bearing, uniform texture, fine-granular matrix, which is limonite stained; CHERT, mottled medium gray to very light gray; FOSSILS, *Ammovertella* (s), sponge spicules, ramose and fenestrate bryozoans (s), productid brachiopod shell fragments and spines, crinoid stems, echinoid spines, ostracodes; chert contains ramose and fenestrate bryozoans, shell fragments, crinoid stems; fauna fragmentary, small, and not abundant	0.5
17. Shale, light yellowish gray, very calcareous, silty, shaly bedded, many small biscuit-like calcareous structures and thin lenses of argillaceous limestone; FOSSILS, *Globivalvulina, Girvanella* colonies, *Fenestrellina* (c), *Penniretepora* (s), *Polypora* (s), *Septopora* (s), *Rhombopora*, ramose bryozoan *(?Leioclema), Composita, Chonetes, Derbyia, Dictyoclostus* (c), productid spines, *Septimyalina*, crinoid stems, tiny gastropods, echinoid plates and spines, *Bairdia, Cavellina, Knightina, Kirkbya, Kellettina, Knoxina, Paraparchites, Monoceratina, Hollinella,* trilobite pygidium, fish tooth, and fragmentary vertebrate remains. Abundant microfauna; megafauna mostly fragmentary	1.2
16. Limestone, medium gray, shaly at base, grayish yellow in middle portion, and yellowish gray at top, weathers grayish orange, hard, thick bedded, granular, chert-bearing, porous below second chert bed, nonuniform texture, subgranular matrix; CHERT, three beds numbered 1 to 3 in upward order, (1) very light gray, calcareous, (2) mottled dark gray and medium gray, calcareous, containing	

Thickness, feet

scattered patches of dense, dark gray, very calcareous, concentrically layered chert, (3) very light gray to medium light gray; FOSSILS, sponge spicules (s), fenestrate and ramose bryozoan fragments, *Dictyoclostus,* brachiopod fragments and productid spines, crinoid stems, ostracodes; chert contains *Tetrataxis,* sponge ? fragments, productid spines, brachiopod fragments, *Aviculopinna,* and echinoid spines 2.7

15. Limestone, base yellowish gray and thin bedded, main part very light gray, weathers grayish yellow, hard, thick bedded, very porous, some pits 2 mm or more in diameter, base uneven, chert-bearing, remarkably uniform texture, very fine granular matrix, nearly devoid of structures; CHERT, main bed light gray, somewhat mottled, scattered small chert nodules near top of unit; FOSSILS, *Ammovertella* (s), brachiopod fragments, productid spines, ostracodes; chert contains bryozoan fragments, productid spines 2.5

Havensville shale member, 21.2 feet

14. Shale, olive gray, grading upward to dark gray and thence to olive gray, grayish yellow in uppermost part, calcareous, thin lenses of silt throughout, shaly bedded near base, earthy and massive in upper 0.6 to 0.7 foot, upper part bears large calcareous geodes; FOSSILS, tiny high-spired gastropod internal mold, *Paraparchites,* echinoid plate, minute vertebrate remains including tooth fragments; fossils very sparse 3.7

13. Limestone, mottled medium and yellowish gray, weathers grayish yellow, medium hard, thick bedded, uniform texture, fine-granular matrix, somewhat mottled by faint iron staining; FOSSILS, *Osagia*-type algal incrustations around shell fragments (s), *Ammovertella* (a), fenestrate bryozoans (c), brachiopod shell fragments and productid spines, crinoid remains, ostracodes (s) 2.1

12. Shale, medium gray (top 0.5 foot is yellowish brown), very calcareous, silty, shaly bedded and fissile; FOSSILS, *Globivalvulina, Ammovertella,* ramose (c) and fenestrate (s) bryozoan fragments, productid spines, pelecypod fragments, small high-spired gastropod internal molds, crinoid plates and stems, echinoid spines, *Cavellina, Hollinella, Bairdia, Kirkbya, Macrocypris, Knoxina, Paraparchites,* small fragmentary vertebrate remains 2.5

11. Limestone, dark yellowish brown, weathers same, medium hard, very argillaceous, thin to medium bedded, intercalated thin shaly beds, uniform texture, very fine granular matrix, medium to large granules of calcite scattered throughout; FOSSILS, fragments, ostracodes (s) 2.4

	Thickness, feet
10. Shale, medium dark gray, yellowish brown in upper 2 feet, calcareous, very silty, shaly bedded; FOSSILS, *Cornuspira*, brachiopod fragments, small high-spired gastropod internal molds, crinoid stems, *Knoxina, Cavellina, Hollinella, Kirkbya;* abundant and well preserved microfauna, larger fossils very sparse	8.0
9. Limestone, mottled olive and dark gray, weathers to dark-gray shale, soft, very argillaceous, shaly bedded, uniform texture, fine-granular matrix; FOSSILS, *Ammodiscus* (a), shell fragments (a), productid spines, *Aviculopecten* (c), tiny pelecypod internal mold, tiny gastropods (c), ostracodes (s), crinoid remains (s)	0.4
8. Shale, dark gray, weathers yellowish gray at base and yellowish brown at top, calcareous, silty; shaly bedded, thin limestone lenses present, sparse siliceous nodules and pale rose-quartz geodes, fossils mostly at base of unit; FOSSILS, *Tetrataxis, Globivalvulina, Rhombopora, Fenestrellina,* bryozoan fragments, *Enteletes, Derbyia* (c), productid spines (c), *Euomphalus* (s), tiny gastropod internal molds (c), *Cavellina, Amphissites, Kirkbya, Bairdia, Cornigella, Knightina, Macrocypris,* crinoid stems and plates, echinoid spines, hook-type holothurian spicules; fauna varied but not abundant	2.1
Threemile limestone member, 11.6 feet	
7. Limestone, light grayish yellow to light yellowish gray, weathers same, hard, thick bedded, chert-bearing; lower 4 feet is chalky, very porous, has scattered deep solution pits to 3 mm across and a concentration of pits 0.7 foot above the base, uniform texture, fine-subgranular matrix, sparse grains of crystalline calcite; CHERT, three beds numbered 1 to 3 in upward order, (1) medium dark to very light gray, (2) mottled light gray to grayish black, darkest areas are very calcareous, (3) light gray, porous; FOSSILS, lower 4 feet, brachiopod fragments; upper 1 foot, sponge spicules ?, *Ammodiscus* (s), fenestrate and ramose bryozoan debris, brachiopod fragments and productid spines, crinoid stems; chert contains fenestrate bryozoans, brachiopod fragments, productid spines, ostracodes (s), crinoid stems, and echinoid spines; fossils generally sparse and fragmentary, mostly from upper portion of unit	5.2
6. Limestone, very light grayish yellow, weathers pale brownish yellow, medium hard, thick bedded, somewhat chalky, very porous, small deep pits scattered throughout, uneven texture, fine-subgranular matrix, scattered grains of crystalline calcite; CHERT, two beds, dark to very light gray; FOSSILS, sponge spicule, ramose bryozoan frag-	

	Thickness, feet
ments, ostracodes, productid spines; chert contains ramose and fenestrate bryozoans, productid spines	2.7
5. Shale and limestone, basal portion shale, light gray, very calcareous, silty, shaly bedded, grades upward into very argillaceous limestone, mottled dark gray and yellowish gray, weathers light olive gray, medium hard and thin bedded; FOSSILS, in shale, *Rhombopora, Thamniscus, Fenestrellina, ?Polypora, Derbyia* (c), *Enteletes* (s), productid spines, crinoid stems, echinoid spines, small high-spired gastropod internal molds, *Amphissites, Bairdia, Kellettina,* fish tooth and fragmentary vertebrate remains; in limestone, ramose and fenestrate bryozoan fragments, *Dictyoclostus* (c), *Composita* (s), productid spines, crinoid remains	0.9
4. Limestone, pale yellowish gray at base, slightly more yellowish gray toward top, weathers moderate yellowish brown, hard, thick bedded, chert-bearing, uneven texture, dominantly fine-granular matrix, pores and fissures filled with crystalline calcite locally give rock a blotchy appearance; CHERT, main bed dark gray to very light gray, containing calcareous patches; upper nodular layer of chert very light gray; FOSSILS, *Ammovertella* (s), fenestrate bryozoan fragments, crinoid remains (s), ostracodes; fossils very sparse and mostly fragmentary throughout unit	2.8
SPEISER SHALE, 15 feet	
3. Shale, medium gray at base becoming very calcareous laterally; medium gray, very calcareous middle portion laterally becomes hard; upper part yellowish gray; all silty, shaly bedded; FOSSILS, *Globivalvulina, Ammovertella, Tetrataxis, Thamniscus, Penniretepora, Rhombopora, ?Polypora, Fenestrellina, Septopora, ?Leioclema, Derbyia, Composita, Chonetes, Dictyoclostus,* productid spines, echinoid plates and spines (s), crinoid stems (a), *Knoxina, Bythocypris, Kirkbya, Cavellina, Knightina, ?Haworthina, Bairdia, Silenites, Amphissites, Hollinella,* fish teeth and fragmentary vertebrate remains; fauna very abundant, especially the microfossils and bryozoans	2.4
2. Limestone, yellowish gray to light brown, weathers yellowish gray, medium hard, thin to shaly bedded, fine-granular matrix has uniform texture, conglomeratic, pebbles as much as 0.9 mm in greatest dimension very abundant near base of unit, smaller and fewer upward; FOSSILS, algal colonies (s), *Nubecularia, Ammovertella,* fenestrate bryozoan fragments, productid shell fragments and spines, *Aviculopecten*, small high-spired gastropods, ostracodes; fauna only locally abundant	0.6

Thickness, feet

1. Shale and mudstone, dark greenish gray, dusky red, dusky green, dusky purple, grayish green, and olive gray in ascending order, colors gradational and even intermixed locally, calcareous, very silty, shaly bedded, weathers blocky; FOSSILS, productid spines (s), *Bairdia, ?Silenites, Bythocypris, ?Macrocypris,* and fragmentary vertebrate remains are all from green shale 12.0
   Total 79.1

Key section 3. Measured along stream bank 2 miles southwest of Kelso and in road ditches 1½ miles south of Parkerville, Morris County. Includes Speiser shale (upper ⅔) and Wreford limestone.

Loc. 67, SW¼ sec. 15, SE¼ Sec. 16, T. 15 S., R. 7 E.

WREFORD LIMESTONE

Schroyer limestone member, 14.2 feet exposed

15. Limestone, yellowish gray, weathers grayish yellow, very hard, single bed, nonuniform texture, subgranular matrix, fine-granular calcite dominant, much secondary crystalline calcite filling small solution channels and openings; FOSSILS, *Ammovertella* (c), *Aulopora* (s), fenestrate bryozoan fragments, crinoid stems, fossil debris 0.4
14. Shale, light gray, very calcareous, silty, shaly bedded; FOSSILS, *Globivalvulina, Aulopora, Fenestrellina, Thamniscus, Septopora, Streblotrypa, Rhombopora,* cyclostome, *?Dictyoclostus Composita,* productid spines, *Roundyella, Kirkbya, Cavellina, Bairdia,* echinoid plate and spines, crinoid stems 1.3
13. Limestone, dusky yellow, weathers same, medium hard, thin wavy bedded, chert-bearing, uniform texture, fine-granular matrix; CHERT, dusky yellow; FOSSILS, *Ammovertella* (c), sponge spicules (s), *Stereostylus, Aulopora* (a), *Fenestrellina* (c), *Penniretepora* (s), ramose bryozoan fragments, *Composita* (a), crinoid stems, plates, and arms (a), echinoid spines and plates (a), ostracodes (s); chert contains ramose and fenestrate bryozoan fragments, crinoid remains, and shell fragments (a), all replaced by milky-white silica 1.5
12. Shale, yellowish brown, very calcareous, silty, shaly bedded, contains small limestone nodules, basal portion covered; FOSSILS, *Aulopora* (c), *Thamniscus* (a), *Polypora* (c), *Fenestrellina* (a), *Septopora* (c), *Penniretepora* (a), *Rhombopora* (c), *Streblotrypa* (a), cyclostome, *Composita* (c), *Dictyoclostus* (s), *Derbyia* (s), echinoid plates and spines (a), crinoid stems and plates (a), *Knoxina,*

Thickness, feet

Ellipsella, Bairdia, Roundyella, Kirkbya, Amphissites, Cavellina, Hollinella, and fragmentary vertebrate remains; fossils very abundant, though mostly small and fragmentary; bryozoans are profuse on some bedding planes 2.4

11. Limestone, grayish yellow, weathers grayish yellow to moderate yellowish brown, very hard, thin bedded in upper and lower portions, thick bedded in middle, chert-bearing, nonuniform texture, fine-subgranular matrix, much crystalline calcite, mottled owing to secondary deposition of calcite; CHERT, pale yellowish brown to light gray; FOSSILS, *Ammovertella,* bryozoan fragments (s), *Composita* (c), echinoid spines and plates (a); chert contains fenestrate and ramose bryozoan fragments and shell debris 2.2

10. Shale, yellowish brown, calcareous, silty, shaly bedded; FOSSILS, *Globivalvulina* (a), *Tetrataxis* (a), *Geinitzina, ?Orthovertella, Climacammina* (a), juvenile fusulinids, *Polypora* (s), *Fenestrellina* (s), *Penniretepora* (c), *Thamniscus* (s), cyclostome (s), productid spines (s), *Composita* (c), *Chonetes* (s), crinoid stems (c), echinoid spines and plates (c), holothurian spicules (wheel and hook types), *Knoxina, Bairdia, Knightina, Amphissites, Paraparchites, Healdia, Monoceratina, ?Cavellina, Hollinella;* fossils of the shale very abundant though mostly small; thin argillaceous limestone bed near top, moderate yellowish brown, nonuniform texture, subgranular matrix; FOSSILS, *Ammovertella,* bryozoan fragments, productid spines, ostracodes, crinoid stems 1.6

9. Limestone, yellowish gray, weathers dusky yellow, hard, thick bedded, chert-bearing, nonuniform texture, subgranular matrix; CHERT, four beds numbered 1 to 4 in upward order, (1) light gray to very light gray, dark-gray calcareous chert at top of bed, (2) like (1) but contains calcareous patches within the chert, (3) light to dark gray, mottled, (4) very light gray to medium dark gray, mottled; FOSSILS, fenestrate bryozoan fragments, productid spines, *Composita,* crinoid stems, echinoid spines, ostracodes, fragmentary vertebrate tooth ?; chert contains *Tetrataxis, Geinitzina,* ramose and fenestrate bryozoan fragments, productid spines, echinoid spines and plates, crinoid remains; fauna sparse, consisting mostly of small fragmentary debris 3.0

8. Shale, grayish yellow, very calcareous, silty, shaly bedded; FOSSILS, *Rhombopora* (s), *Fenestrellina* (c), *Thamniscus,*

	Thickness, feet
productid spines, *Chonetes* (s), *Composita* (s), *Dictyoclostus* (s), echinoid plates and spines (c), crinoid stems, *Knoxina* (c), *Bairdia* (c), *Kirkbya* (c), *Amphissites* (c), *Roundyella* (s), *Macrocypris* (s), *Hollinella* (c), fragmentary vertebrate plates; megafauna sparse, microfauna abundant; limestone bed 0.1 foot thick and 0.5 foot below top is grayish yellow and somewhat chalky, uniform texture, very fine granular matrix; FOSSILS, fenestrate bryozoans (s), productid spines (c), fossil debris	1.2
7. Limestone, light yellowish gray, wethers same, hard, thin to medium bedded, chert-bearing, uniform texture, very fine granular matrix; CHERT, 2 beds, medium gray to yellowish gray; FOSSILS, *Ammovertella* (s), *Composita*, productid spines, brachiopod fragments, crinoid stems, echinoid plates, *Bairdia;* chert contains bryozoan fragments, *Dictyoclostus*, ostracodes; fauna sparse and fragmentary	1.6
Havensville shale member, 5.5 feet	
6. Shale, dusky yellow, very calcareous, silty, shaly bedded, calcareous nodules near top, dark-gray limy lenses near center (0.1 foot thick), yellowish-brown shaly limestone at base is irregularly bedded, as much as 2.2 feet in thickness; FOSSILS, *Globivalvulina, Tetrataxis, Thamniscus, Rhombopora, Fenestrellina, Composita, Dictyoclostus, Derbyia*, productid spines, echinoid spines and crinoid stems, minute gastropods, *Cavellina, Knightina, Knoxina, Bythocypris, Hollinella*, trilobite, abundant fossil debris; megafossils sparse, microfossils varied and moderately abundant	5.5
Threemile limestone member, 21 feet exposed	
5. Limestone, light grayish yellow, weathers grayish yellow, hard, very thick bedded to massive, very porous, solution pits 2 cm or more across extend deeply into the rock, chert-bearing, uppermost foot is dusky yellow and nonporous; four specimens taken at 5-foot intervals show the following: (1) nonuniform texture, fine-subgranular matrix, (2) crystalline at border (owing to weathering), locally crystalline within, mostly fine-granular matrix, (3) uniform texture, fine-granular matrix, (4) uniform texture, finely crystalline matrix; CHERT, five main nodular layers numbered 1 to 5 in upward order, (1) yellowish gray to very light gray, (2) yellowish gray, (3) light yellowish gray to very light gray, containing scattered dark patches, (4) grayish yellow to very light gray, (5) light gray to very light gray; FOSSILS, *Tetrataxis* (c), *Ammovertella* (s), *Dibunophyllum* (s), *Stereostylus* (c),	

Thickness, feet

Fenestrellina (a), ramose bryozoan fragments, encrusting bryozoans (c), *Composita* (c), productid spines, echinoid spines and plates, crinoid stems; chert contains fusulinids?, *Tetrataxis* (c), ramose and fenestrate bryozoan fragments, productid spines, fossil debris 21.0

Loc. 66, SW¼ sec. 30, T. 15 S., R. 8 E.

4. Limestone, basal 0.5 foot light yellowish gray to dark gray mottled, medium hard to soft, shaly to thin bedded, grades laterally into hard limestone; limestone above is yellowish gray, hard, massive; both chert-bearing, nonuniform texture, fine-subgranular matrix; CHERT, two beds numbered 1 and 2 in upward order, (1) medium dark gray, mottled, (2) medium gray, concentrically marked; FOSSILS, bryozoan fragments, *Derbyia, Dictyoclostus, Composita, Chonetes,* productid spines, crinoid stems (a); chert contains bryozoan fragments, crinoid stems, ostracodes, fossil debris 3.7

3. Limestone, pale yellowish brown to mottled light gray and medium dark gray, weathers yellowish brown, hard, thick bedded, chert-bearing, nonuniform texture, fine-subgranular matrix; CHERT, medium gray to grayish yellow; FOSSILS, fenestrate bryozoan fragments, *Derbyia,* crinoid stems and echinoid spines; chert contains ?*Rhabdomeson,* fragmentary fenestrate bryozoans, crinoid stems, and fossil debris; fossils sparse, mostly fragmentary 1.75

SPEISER SHALE, 8.2 feet exposed

2. Shale, medium gray mottled dark gray, very calcareous, medium hard, shaly bedded, grades vertically and laterally to very argillaceous shaly bedded limestone, base more persistently a limestone; FOSSILS, *Tetrataxis* (c), *Rhabdomeson, ?Leioclema, Septopora, Fenestrellina* (a), *Rhombopora, Thamniscus, Chonetes* (c), *Dictyoclostus* (s), *Derbyia* (s), *Composita* (s), productid spines (a), echinoid spines, crinoid stems, holothurian spicules, trilobite fragment, *Knoxina, Amphissites* (c), *Hollinella, Knightina* (c), *Bairdia, Monoceratina, Paraparchites,* fragmentary vertebrate remains; basal limestone has uniform texture, fine-granular matrix; FOSSILS, *Ammovertella* (a), *Ammodiscus* (c), ramose and fenestrate bryozoan fragments, *Globivalvulina,* productid spines and brachiopod fragments, *Dictyoclostus* (s), *Aviculopinna* (s), *Aviculopecten* (s), small high- and low-spired gastropods (c), ostracodes (c), crinoid remains 3.0

1. Shale, basal 0.5 foot dusky red, next 1.5 feet grayish green, next 1 foot dusky yellowish green, upper 2.2 feet light olive

Thickness, feet

gray, two lower units noncalcareous, upper two very calcareous, all silty, lower 2 feet weathers blocky, next 1 foot thick bedded, top 2.2 feet shaly bedded; base of shale section is covered; FOSSILS, lower 3 feet unfossiliferous; upper 2.2 feet, *Cornuspira* (s), *Globivalvulina* (s), *Orthovertella* (s), *Ammovertella* (c), *Septopora* (s), productid spines (s), tiny gastropod internal molds (c), tiny clam internal mold, *Cavellina, Bythocypris, Hollinella, Paraparchites, Knoxina;* fauna varied but not very abundant 5.2

Total 55.4

Key section 4. Road cut and gullies on west side of Teeterville oil pool, southeastern Chase County. Includes Speiser shale (upper half), Wreford limestone, and Wymore member of the Matfield shale.

Loc. 93, center sec. 35, T. 22 S., R. 9 E.

MATFIELD SHALE

Wymore shale member, 13 feet

16. Mudstone, dusky yellow and very silty at base, yellowish brown and very calcareous in upper part, medium hard, thin bedded, weathers blocky; FOSSILS, *Globivalvulina* (c), *Orthovertella* (s), *Cornuspira* (s), productid spines (c), *Bairdia* (c), *Cavellina* (s), *Knoxina* (s), *Hollinella* (s), crinoid stems, holothurian hooks, and fragmentary vertebrate remains 5.0

15. Shale, basal part covered, exposed portion, in ascending order, is grayish red, very dusky red, very dusky grayish greenish red (variegated), dusky green, and moderate yellow; calcareous, very silty, weathers blocky, uppermost part shaly bedded; unfossiliferous 8.0

Loc. 96, SE¼ sec. 36, T. 22 S., R. 9 E.

WREFORD LIMESTONE

Schroyer limestone member, 10.3 feet

14. Limestone, light olive gray, weathers same or slightly darker, very hard, thick bedded, abundantly algal, resistant to weathering, nonuniform texture, fine-subgranular matrix constitutes only a small portion of total volume, abundant algal structures, numerous irregular-spaced, deep solution pits; FOSSILS, *Osagia*-type algae (p), *Ammovertella* (s), other foraminifera (s), small gastropods (c), ostracodes (c) 4.5

13. Limestone, moderate yellowish brown to light olive gray, weathers moderate yellowish brown, hard, thick bedded, argillaceous, resistant to weathering, moderately algal locally, nonuniform texture, fine-subgranular matrix, cal-

Thickness, feet

cite is recrystallized locally; FOSSILS, *Osagia*-type algae (c), *Ammovertella* (c), productid spines (s), *Aviculopecten* (a), minute high-spired gastropods (a), crinoid stems (c), and fish tooth 0.8

Loc. 93, center sec. 35, T. 22 S., R. 9 E.

12. Limestone, light grayish yellow, weathers dark yellowish orange, hard, thin bedded, chert-bearing, nonuniform texture, fine-subcrystalline matrix, much recrystallized calcite; CHERT, mottled grayish yellow and light olive gray; FOSSILS, *Osagia*-type algae (c), *Ammovertella* (s), sponge spicule, ramose and fenestrate bryozoan fragments, *Derbyia* (s), *Dictyoclostus* (s), productid spines, *Aviculopecten* (s), echinoid plates and spines, crinoid stems; chert contains bryozoan fragments, productid spines, brachiopods, fossil debris; fauna abundant but mostly fragmentary 0.7
11. Shale, light olive gray, very calcareous, silty, shaly bedded, thin limestone lens near base; FOSSILS, *Globivalvulina* (c), *Tetrataxis* (c), *Climacammina* (s), *Geinitzina* (s), juvenile fusulinids (a), *Rhombopora* (s), ?*Leioclema* (s), *Septopora* (s), *Fenestrellina* (c), *Dictyoclostus* (s), productid spines, crinoid stems (a), echinoid plates and spines (c), *Amphissites* (s), *Hollinella* (s), *Bairdia* (c), *Knightina* (s); fauna abundant, larger forms fragmentary 1.2
10. Limestone, light olive gray, weathers darker olive gray, very hard, thick-bedded, resistant to weathering, characterized by presence of limonite-lined solution pits, chert-bearing, nonuniform texture, subcrystalline matrix; CHERT, four beds, medium to dark gray, top bed mottled in center; FOSSILS, fenestrate bryozoan fragments, *Dictyoclostus,* crinoid stems, echinoid plates and spines; chert contains fenestrate and ramose bryozoan fragments, productid spines, crinoid stems; fauna abundant but fragmentary 3.1

Havensville shale member, 16.2 feet

9. Shale, basal 1.3 feet covered, base of exposed part dark gray, upper part light olive gray, very calcareous especially in top 1 foot, silty, shaly bedded in lower and upper portions, middle weathers blocky, limestone lens 0.1 foot thick lies 0.1 foot below top; FOSSILS, *Tetrataxis* (s), *Ammovertella* (s), *Fenestrellina* (a), *Rhombopora* (c), *Thamniscus* (c), ?*Leioclema, Dictyoclostus* (s), *Composita* (c), productid spines (a), *Euomphalus* (s), *Aviculopecten* (s), crinoid stems (c), holothurian hooks (c), *Knoxina* (a), *Bairdia* (a), *Cavellina* (c), *Hollinella* (c), *Knightina* (c), *Monoceratina* (s); fossils varied, mostly small 3.7

Thickness, feet

8. Shale, olive gray, very calcareous, silty, shaly bedded, three limestone portions are numbered 1 to 3 in upward order; FOSSILS, *Climacammina* (s), productid spines (a), *Knoxina* (c), *Cavellina* (c), *Bairdia* (c), *Hollinella* (c), fragmentary vertebrate remains; limestone, (1) like (3), (2) yellowish gray to olive gray, shaly to thin bedded, medium hard to hard, uniform texture, very fine granular matrix, (3) light olive gray, medium hard, shaly bedded, very argillaceous, nonuniform texture, fine-subgranular matrix; FOSSILS, (1) *Globivalvulina*, ramose and fenestrate bryozoan fragments, *Derbyia*, tiny high-spired gastropods, crinoid spines, echinoid plates, *Cavellina, Knoxina, Hollinella;* (2) *Globivalvulina* (c), *Ammodiscus* (s), *Fenestrellina* (s), *Derbyia* (s), productid spines (s), tiny high-spired gastropod, *Aviculopecten* (c), crinoid stems, *Kellettina, Monoceratina, Paraparchites, Bairdia, Hollinella;* (3) *Globivalvulina* (c), *Ammovertella* (a), *Fenestrellina* (s), *Septopora,* ramose bryozoan fragments, *Composita, Derbyia,* productid spines (s), *Aviculopecten*, tiny high-spired gastropod, crinoid stems, *Cavellina, Knoxina* (c), *Hollinella, Bairdia* (c) 12.5

Threemile limestone member, 11.2 feet

7. Limestone, light yellowish gray in lower part, becoming dusky yellow above, weathers grayish yellow, hard, thick bedded (except uppermost 1 foot, which is shaly to thin bedded,) middle 4.5 feet somewhat chalky, most of unit characterized by deep, irregular solution pits as much as 1 cm across, chert-bearing, uniform texture, fine-granular matrix; CHERT, eight beds numbered 1 to 8 in upward order; FOSSILS, sponge spicules? (c), ramose bryozoans, productid spines, *Dictyoclostus, Enteletes,* crinoid stems; chert contains ramose and fenestrate bryozoans, crinoid stems, ostracodes (s), fossil debris, fossils very sparse and fragmentary throughout 6.3

6. Limestone, moderate yellowish brown, weathers same, medium hard, thin wavy bedded, argillaceous, chert-bearing, nonuniform texture, fine-subgranular matrix; CHERT, olive gray to grayish yellow; FOSSILS, productid spines, crinoid stems, fossil fragments; chert contains *Fenestrellina,* bryozoan fragments, productid spines (a), and opaque white minute spicule- or spine-like structures (a) 1.5

5. Limestone, yellowish gray, weathers moderate yellowish brown, hard, massive, chert-bearing, uniform texture, fine-granular matrix; CHERT, several poorly defined beds, lowermost chert grayish yellow to yellowish gray; chert in rest of unit is mottled medium to olive gray; FOSSILS,

Thickness, feet

ramose and fenestrate bryozoan fragments, *Enteletes* (a), *Derbyia* (s), *Composita* (s), *Chonetes* (s), productid spines, *Wellerella* (s), crinoid stems, and echinoid spines; chert contains *Osagia*, productid spines, *Derbyia*, and crinoid stems, in basal 0.2 foot; middle chert contains *Fenestrellina* (s), ramose bryozoan fragments, and small white spine-like structures (a) 3.4

SPEISER SHALE, 7.5 feet exposed

4. Shale, olive gray, calcareous, silty, shaly bedded; FOSSILS, *Rhombopora, Rhabdomeson, Fenestrellina, Thamniscus,* encrusting trepostome, *Tetrataxis* (c), *Globivalvulina* (s), *Derbyia, Composita, Chonetes,* productid spines, crinoid stems, echinoid plates and spines, holothurian hook-type spicules, *Knightina* (c), *Amphissites* (c), *Healdia* (s), *Bairdia* (c), *Knoxina* (s), *Roundyella* (s), *Hollinella* (c), *Ditomopyge,* cone-type conodont?, fragmentary vertebrate remains, including bones and teeth; fossils moderately abundant, megafossils mostly fragmentary 1.7

3. Shale dark gray, light olive gray less common; very calcareous especially in middle and upper portions, hard, shaly to thin bedded; FOSSILS, *Tetrataxis* (c), *Globivalvulina* (s), *Cornuspira* (a), cryptostomatous and ramose bryozoans (s), *Thamniscus* (s), *Dictyoclostus* (s), *Derbyia* (s), *Chonetes* (s), *Composita* (s), small high-spired gastropod, *Aviculopecten* (s), productid spines (c), crinoid remains (c), holothurian hook-type spicules, *Knoxina* (c), *Cavellina* (s), *Amphissites* (s), *Knightina* (c), *Hollinella* (s), *Bairdia* (c), *Paraparchites* (s) 2.5

2. Limestone, dusky yellow, weathers same, medium hard, thin bedded, uniform texture, fine-granular matrix, stained with iron oxide; FOSSILS, *Derbyia* (p), *Dictyoclostus* (s), productid spines; fossils very abundant, mostly crushed 0.3

1. Shale, pale brown in lower part, mottled with pale olive in middle, more yellowish in the upper portion, calcareous, silty, weathers blocky, small irregular nodules of limestone in uppermost part; FOSSILS, lower brownish portion, charophyte oögonium; upper yellowish portion contains *Knoxina* (s), *Tetrataxis* (s); fossils very sparse 3.0

Total 58.2

Key section 5. Road cuts and ravines about 4 miles northeast of Rosalia, Butler County. Includes Speiser shale, Wreford limestone, and Wymore member of Matfield shale.

Thickness, feet

Loc. 108, SE¼ sec. 19, T. 25 S., R. 8 E.

MATFIELD SHALE

Wymore shale member, 12.5 feet exposed

25. Shale, from base upward the unit is dusky yellowish green mottled with reddish purple, grayish red purple mottled with dusky yellowish green, dusky yellowish gray, grayish red, and dusky yellowish green, all calcareous except second red zone, all silty, calcareous nodules common especially in lower two color phases; FOSSILS, red shale, unfossiliferous; green shale, charophyte oögonia (s), *Hollinella* (s), *Knoxina* (s), *Bairdia* (s), fragmentary vertebrate remains; fossils exceedingly sparse 12.5

WREFORD LIMESTONE

Schroyer limestone member, 9.4 feet

24. Limestone, moderate yellowish brown, weathers same, very hard, one bed, uneven texture, subgranular matrix, profusely algal in structure; FOSSILS, *Osagia*-type algae (p), *Nubecularia* (a), *Ammovertella* (c), minute high-spired gastropods (s), fragmentary crinoid remains, ostracodes, fragmentary vertebrate remains 0.3

23. Limestone, grayish yellow, weathers dusky yellow, very hard, one thick bed, uneven texture, subcrystalline matrix, profuse randomly oriented algal structures; FOSSILS, *Osagia*-type algae (p), *Nubecularia* (a), *Ammovertella* (s), tiny high-spired gastropods, ostracodes, crinoid remains 0.7

22. Limestone, grayish yellow, weathers yellowish gray, hard (weathers soft,) thin bedded, somewhat algal, nonuniform texture, subgranular matrix, limonite and manganese stains common; FOSSILS, *Osagia*-type algae (c), *Ammovertella* (s), ramose bryozoan fragments, *Fenestrellina*, productid spines, tiny high-spired gastropod internal molds (s), *Aviculopinna* (s), *Aviculopecten* (s), crinoid debris (a), ostracodes (c); fossils abundant but mostly fragmentary 1.2

21. Limestone, moderate yellowish brown, weathers yellowish brown, hard, thin bedded in lower portion, grading upward to a single thick bed, somewhat algal especially near the top, uniform texture, finely crystalline matrix, some areas of more coarsely crystalline calcite, much limonite and manganese staining; FOSSILS, *Osagia*-type (sparse near base, common near top), *Ammovertella* (s), fenestrate and ramose bryozoan fragments (s), productid shell

Thickness, feet

debris and spines, crinoid debris; fossils very abundant, mostly fragmentary 1.6

20. Shale, dark gray, calcareous, hard, silty, shaly to thin bedded; FOSSILS, fusulinids (sparse juveniles,) *Derbyia* (s), small high-spired gastropods (s), crinoid stems (c), echinoid spines (s), *Paraparchites, Knoxina, Bairdia,* trilobite pygidium, fragmentary vertebrate remains; fossils very sparse 0.3

19. Limestone, light olive gray, weathers same, medium hard, very argillaceous, shaly to thin bedded, uniform-grained texture, fine-granular matrix; FOSSILS, bryozoan and crinoid fragments, productid spines, fossil debris; fossils very sparse and fragmentary 1.0

18. Limestone, yellowish gray, weathers light olive gray, hard, thick bedded, chert-bearing, small deep solution pits abundant, nonuniform texture, mostly fine granular, irregularly distributed clear crystalline calcite areas; CHERT, four beds, lowest three beds medium gray containing scattered patches of medium-dark-gray, more or less concentrically layered calcareous chert; FOSSILS, *Fenestrellina* (s), ramose bryozoan fragments (s), *Composita* (c), crinoid stems (c), echinoid spines and plates; chert contains whitish spicule-like spines (c), fenestrate bryozoan fragments, productid spines; fossils very fragmentary and sparse except in top 0.75 foot 4.3

Havensville shale member, 11.5 feet

17. Shale, olive gray, calcareous, slightly silty, shaly bedded, almost covered and deeply weathered; FOSSILS, *Globivalvulina* (c), *Rhombopora* (c), *Thamniscus* (c), *Fenestrellina* (c), ?*Leioclema* (s), ?*Batostomella* (c), *Rhabdomeson* (s), *Septopora* (s), *Dictyoclostus* (s), *Derbyia* (s), *Composita* (c), productid spines, tiny low-spired and pleurotomarid high-spired gastropod internal molds, crinoid stems (a), echinoid spines and plates (c), trilobite fragments (c), *Bairdia* (c), *Hollinella* (c), *Knightina* (c), *Knoxina* (c), *Amphissites* (s); fossils very abundant, megafossils mostly fragmentary 2.6

16. Limestone, medium gray, weathers dusky yellow, hard, very argillaceous, shaly to thin bedded, nonuniform texture, mostly fine-granular matrix, some finely crystalline calcite; FOSSILS, *Ammovertella* (c), *Ammodiscus* (s), ramose and fenestrate bryozoan fragments, *Composita* (s), *Derbyia* (s), productid spines (c), crinoid stems 1.9

15. Shale, light olive gray, slightly darker near top, very calcareous near base, silty, shaly bedded, mostly covered;

Thickness, feet

FOSSILS, *Globivalvulina* (c), *Rhombopora* (c), *Thamniscus* (s), encrusting bryozoans (c), ?*Leioclema, Fenestrellina, Dictyoclostus* (s), brachiopod fragments and spines (c), crinoid stems and holothurian hooks, *Macrocypris* (s), *Monoceratina* (s), ?*Cavellina* (s), *Bythocypris* (c), *Silenites* (s), *Knoxina* (c), *Bairdia* (c), fragmentary vertebrate remains; fossils abundant but mostly small or fragmentary 4.0

14. Limestone, grayish yellow to yellowish gray, weathers grayish yellow, hard, thick bedded, fairly uniform texture, mostly fine-granular matrix containing minor amount of crystalline calcite; FOSSILS, *Ammovertella* (c), ramose bryozoan fragments, *Derbyia* (s), productid spines, crinoid debris, tiny high-spired gastropod internal molds, *Bairdia*, other ostracodes 1.0

13. Shale, olive gray, very calcareous, especially at top, where it is essentially an argillaceous limestone, slightly silty, shaly bedded, mostly covered; FOSSILS, *Globivalvulina* (c), *Rhombopora* (s), crinoid stems (c), echinoid spines (s), ?*Roundyella* (s), *Cavellina* (s), *Knoxina* (c), *Bairdia* (c); fossils sparse, mostly microfossils 2.0

Loc. 103, NE¼ sec. 19, T. 25 S., R. 8 E.

Threemile limestone member, 14.5 feet

12. Limestone, moderate yellowish brown, weathers yellowish gray, pitted, some cellular development, hard, thick bedded, profusely algal, resistant ledge-former, very irregular texture, dominantly fine- to medium-crystalline matrix containing minor amount of granular calcite, stained with iron oxides; FOSSILS, *Osagia*-type algae (p), *Ammovertella* (p), *Ammodiscus* (c), productid spines (s), bryozoan fragments (s), *Composita* (s), *Derbyia* (s), tiny gastropods, *Aviculopinna*, echinoid plates and spines, crinoid stems; fauna typically algal molluscan, other fossils mostly fragmentary and sparse 3.0

Loc. 108, SE¼ sec. 19, T. 25 S., R. 8 E.

11. Limestone, lower part grayish yellow, weathers same, hard, medium to thick bedded, chert-bearing, fairly uniform texture, fine-subgranular matrix; upper part yellowish gray, weathers same, hard, shaly to thin bedded, chert-bearing, nonuniform texture, dominantly finely to medium crystalline; CHERT, uppermost bed medium dark gray to yellowish gray; FOSSILS, *Ammovertella* (s), *Fenestrellina* (s), *Thamniscus* (s), ramose bryozoans (c), *Derbyia* (s), *Dictyoclostus* (s), *Composita* (s), productid spines (c), crinoid stems (c), tiny gastropods (s), *Ditomopyge*, fragmentary vertebrate remains; chert contains ramose bryo-

Thickness, feet

zoan fragments, productid spines, crinoid stems, minute echinoid? spines 3.0

Loc. 103, NE¼ sec. 19, T. 25 S., R. 8 E.

10. Limestone, yellowish gray, weathers yellowish gray to grayish orange, hard, thick bedded, chert-bearing, nearly uniform texture, finely subgranular matrix; CHERT, two beds, lower thick bed medium gray, commonly more than 50 percent is dark-gray, concentrically layered, calcareous chert, which is in sharp contact with and which occupies hollows in the upper and lower surfaces of the rest of the chert; thin upper bed medium gray; FOSSILS, fenestrate bryozoan fragments, brachiopod fragments and productid spines (p), crinoid stems, echinoid spines; chert contains bryozoan fragments, productid spines, crinoid and echinoid debris; fossils abundant but small and fragmentary .. 3.0

Loc. 102, SW¼ sec. 17, T. 25 S., R. 8 E.

9. Limestone, yellowish gray, weathers grayish yellow, hard, thin irregular bedding, chert-bearing, uniform texture, finely granular matrix, some limonite staining; CHERT, two beds near base are medium gray, disseminated nodules in the upper half are light olive gray to nearly white; FOSSILS, fenestrate bryozoan fragments, brachiopod fragments, productid spines (p), echinoid spines and plates, crinoid stems; chert contains ramose and fenestrate bryozoan fragments, productid spines, echinoid spines, tiny bellerophontid gastropod, sponge? fragments; fossils, except for productid spines, are not abundant 3.0

8. Limestone, yellowish gray, weathers grayish orange, very hard, thick bedded, chert-bearing, nearly uniform texture, very fine subgranular; CHERT, single thin bed of light to medium gray; darker gray, concentrically layered calcareous chert occurs as isolated nodules along top of chert bed; FOSSILS, fenestrate bryozoan fragments, ***Composita*** (s), productid spines, *Wellerella* (s), echinoid spines and plates (s); chert contains fenestrate bryozoans (s), productid spines (s); fossils not abundant 2.5

SPEISER SHALE, 25 feet

7. Shale, grayish yellow, calcareous below to very calcareous above, somewhat silty, shaly bedded, upper part contains numerous very calcareous lenses; FOSSILS, ***Tetrataxis*** (c), *Globivalvulina* (s), *Rhombopora* (c), ***Thamniscus*** (c), *Streblotrypa* (s), *Fenestrellina* (c), productid spines (c), *Composita* (c), *Derbyia* (s), *Chonetes* (s), ***Orbiculoidea*** (s), crinoid stems (c) and plates (s), echinoid spines and plates (c), *Amphissites* (c), *Bairdia* (c), *Knoxina* (s), *Hollinella* (c), *?Silenites* (s), *Knightina* (s), *?Paraparchites*

	Thickness, feet
(s), *Cavellina* (s), *Roundyella* (s), fragmentary vertebrate remains; fossils abundant, megafossils mostly fragmentary	1.5
6. Limestone, grayish yellow mottled with yellowish gray, weathers grayish yellow, medium hard, shaly bedded, not very resistant, uniform texture, fine-granular argillaceous matrix; FOSSILS, fenestrate bryozoan fragments, *Derbyia* (c), *Composita* (c), *Dictyoclostus* (s), productid spines (c), tiny gastropods, crinoid stems, echinoid spines, fragmentary vertebrate remains; fossils mostly fragmentary	0.8
5. Shale, yellowish gray, very calcareous, silty, shaly bedded, small calcareous nodules common, top laterally grades to shaly limestone, not very resistant; FOSSILS, *Globivalvulina* (s), *Tetrataxis* (s), *Thamniscus* (c), *Fenestrellina* (c), *Rhombocladia* (s), *Septopora* (s), *Derbyia* (s), *Dictyoclostus* (s), productid spines (a), *Aviculopecten* (s), echinoid spines and plates, *Knoxina* (a), *Monoceratina* (c), *Healdia* (s), *Knightina* (s), *Bairdia* (c), fragmentary vertebrate remains; fauna mostly abundant microfossils, megafossils mostly fragmentary	3.6
4. Limestone, yellowish brown to yellowish gray, weathers grayish yellow, hard, shaly to thin bedded, not very resistent, very irregular texture, dominantly subcrystaline matrix is mostly of clear calcite, crowded with *Ammodiscus,* with horizontal partings of very argillaceous to fine-granular limestone, which is sparsely fossiliferous, whole somewhat limonite stained; FOSSILS, *Ammodiscus* (s), *Ammovertella* (s), ramose bryozoans, *Derbyia* (a), *Dictyoclostus* (c), tiny gastropods	0.8
3. Mudstone, yellowish gray, very calcareous, very silty, shaly bedded, weathers blocky; FOSSILS, *Cornuspira* (c), ramose bryozoan fragments (s), productid spines, *Derbyia* fragments (s), *Aviculopecten* fragments (s), tiny high-spired gastropod internal molds (two kinds,) *Cavellina* (a), *Bairdia* (c), *Knoxina* (s), *Macrocypris* (s), ostracode sp., crinoid stems (s), holothurian hooks (s), fragmentary vertebrate remains; fossils very sparse	1.8
2. Limestone, medium light gray to yellowish gray, hard, thin bedded, argillaceous, locally coquinoid (*Derbyia*), thin shaly beds interstratified, uniform texture, mostly very fine granular matrix, some limonite staining; FOSSILS, *Ammodiscus* (c), *Ammovertella* (s), *Rhombopora*, ramose bryozoan sp., productid spines (c), *Derbyia* (a), *Dictyoclostus* (c), tiny high-spired gastropods (replaced), ostracodes; fossils very abundant and well preserved	0.6

Thickness, feet

1. Shale, in ascending order, 12 feet pale red, 0.75 foot grayish yellow green, 2.5 feet grayish red, uppermost part grayish yellow green, all calcareous and slightly silty, weathers blocky; FOSSILS, red, unfossiliferous; green, one or two productid spines; entire unit essentially unfossiliferous 16.0

   Total 72.9

Key section 6. Measured in cuts along the Atchison, Topeka & Santa Fe Railroad; State Highway 38; and U.S. Highway 116 in Cowley County. Includes Speiser shale, Wreford limestone, and part of Wymore shale.

Loc. 111, NE¼ sec. 36, T. 31 S., R. 6 E.

MATFIELD SHALE

Wymore shale member, 9 feet

18. Mudstone and shale, lowermost 3 feet covered, mottled grayish red and grayish green in basal part of exposure grading up to pale olive, upper 4 feet dusky yellow, all calcareous and silty, top part very silty; FOSSILS, lower red, unfossiliferous; middle green, sparse ostracodes and one charophyte oögonium; upper yellow, unfossiliferous 9.0

Loc. 123, center sec. 23, T. 34 S., R. 5 E.

WREFORD LIMESTONE

Schroyer limestone member, 6.1 feet

17. Limestone, grayish orange, weathers grayish yellow, very hard, thick bedded, algal, weathered surface pitted and cellular, resistant, irregular texture, dominantly crystalline matrix, some finely granular portions; FOSSILS, *Osagia*-type algae (c), fenestrate bryozoan fragments, large pleurotomarid mold, tiny bellerophontids (s), crinoid stems and echinoid spines; fossils abundant, mostly small and fragmentary 1.4

16. Limestone, grayish yellow, weathers same, hard, shaly to thin bedded, uneven texture, dominantly fine-granular matrix with minor amount of crystalline calcite; CHERT, one thin layer, light olive gray to yellowish gray; FOSSILS, fenestrate bryozoan fragments, *Dictyoclostus*, productid spines, crinoid stems and echinoid spines, fossil debris; chert contains ramose and fenestrate bryozoan fragments, ?*Penniretepora*, productid spines, shell fragments, *Composita;* fossils abundant but small and fragmentary 0.8

Loc. 115, SW¼ sec. 19, T. 32 S., R. 7 E.

15. Limestone, dusky to grayish yellow, weathers yellowish gray and cellular, hard, thick bedded, flecked with limo-

Thickness, feet

nite, tubular holes at top may be burrows, chert-bearing, uneven texture, about half fine-granular and half crystalline matrix, mottled yellowish owing to iron stain, many small grain-like areas of reddish-brown limonite; CHERT, very nodular layers, grayish yellow to yellowish gray; FOSSILS, fenestrate and ramose bryozoan fragments, *Dictyoclostus* (s), *Composita* (s), crinoid stems (locally p), echinoid spines and plates (c); chert contains *Rhombopora*, productid spines, abundant fossil debris; fossils abundant and fragmentary 3.9

Havensville shale member, 8.3 feet

14. Shale, yellowish gray to grayish yellow, medium hard, very silty, very calcareous, shaly bedded, somewhat nodular, laterally becomes a very shaly limestone; FOSSILS, *Fenestrellina* (s), ramose bryozoans (s), *Composita*, crinoid plates and stems, ?*Knoxina* (s), ?*Bairdia* (s); fauna sparse, fossils mostly recrystallized 0.8
13. Limestone, yellowish brown to yellowish gray, weathers yellowish brown, hard, thick bedded, sparsely chert-bearing, large tubular borings about 2 feet deep near base of unit, somewhat algal, nonuniform texture, mostly clear crystalline calcite matrix, some fine-granular areas; FOSSILS, *Osagia*-type algae (c), *Ammovertella* (c), productid spines (c), brachiopod? fragments, *Aviculopinna* (c), *Allorisma* (c), *Schizodus* (s), *Septimyalina* (s), gastropod molds and casts, echinoid spines and crinoid stems; productid spines abundant in upper part 5.3
12. Mudstone, basal 0.3 foot grayish yellow and very calcareous, upper part medium gray, all silty and shaly bedded; FOSSILS, gastropod fragments (s), *Aviculopecten* (s), ostracodes (s), fragmentary vertebrate remains, button-like teeth? of vertebrates 1.5
11. Shale, grayish yellow, earthy, very calcareous, very slightly silty, shaly bedded to massive in appearance; FOSSILS, worm tubes (s), gastropods (s), crinoid stems (s), shell fragments (s); secondary solution in this unit has eroded most of the fossils 0.8

Threemile limestone member, 19.9 feet

10. Limestone, yellowish gray to yellowish brown, weathers same, abundant small solution pits (fossil molds), hard, massive bedded, resistant, algal structures abundant, vertical clam borings in middle portion, chert-bearing, uneven texture, dominantly of finely to coarsely crystalline cloudy-white calcite matrix, small patches of fine-granular calcite; CHERT, scattered small nodules are light yellowish gray; continuous bed near base is medium light

	Thickness, feet
to medium gray, calcareous, concentrically marked by alternating light (thick) and dark (thin) layers without change of texture across the layers; FOSSILS, *Osagia* (a), *Ammovertella, Ammodiscus,* fenestrate bryozoan fragments (s), *Dictyoclostus* (s), ?*Bellerophon* (c), *Allorisma* (c), *Aviculopinna* (c), *Astartella* (s), *Schizodus* (c), crinoid stems (s), shark tooth?; chert contains productid spines, bryozoan and crinoid fragments; fossils very abundant, algae are robust	6.0
9. Limestone, yellowish gray, weathers same, somewhat darker at top, hard, thick bedded at base, somewhat thinner bedded at top, chert-bearing, nonuniform texture, dominantly fine-granular matrix, minor amount of clear crystalline calcite; CHERT, nodules of light-yellowish-gray ordinary chert lie within a calcareous chert bed near the base of the unit, and nodules of dark-gray chert lie in upper thin-bedded portion of the unit; chert near base is massive, calcareous, concentrically layered; FOSSILS, *Ammodiscus, Ammovertella,* fenestrate and ramose bryozoan fragments (c), *Dictyoclostus* (c), *Aviculopinna* (s), crinoid stems (c), echinoid spines and plates (c); chert contains bryozoan fragments, productid spines; fossils not abundant	6.2
8. Limestone, yellowish gray, weathers same, hard, thick bedded, chert-bearing, uniform texture, fine-granular matrix; CHERT, abundant irregular light- to medium-gray nodules; scattered nodules of calcareous, concentrically layered chert; FOSSILS, fenestrate and ramose bryozoan fragments (c), productid spines (c), *Aviculopinna* (s), crinoid stems and echinoid spines (c), ostracodes (s); chert contains productid spines, ramose bryozoans, and fossil debris	2.5
7. Limestone, light olive gray, weathers yellowish gray and shaly, medium hard, thin bedded, somewhat argillaceous, chert-bearing, uneven texture, fine- to medium-granular matrix, crystalline calcite locally abundant; CHERT, scattered nodules, light yellowish gray to milky white; FOSSILS, *Fenestrellina* (c), productid spines, ?*Composita* (s), brachiopod fragments, fish teeth; chert contains productid spines	0.8
6. Limestone, yellowish gray, weathers pale yellowish brown to yellowish gray, hard, thick bedded, subgranular, chert-bearing, uneven texture, subgranular matrix; CHERT, nodular, medium gray to yellowish gray; FOSSILS, ramose and fenestrate bryozoan fragments, *Derbyia* (c), *Dictyoclostus* (c), *Composita* (c), crinoid stems (c), *Avi-*	

Thickness, feet

culopecten (s), *Aviculopinna* (s), *Bairdia* (c), fossil debris; chert contains ramose bryozoans, *Derbyia*, white rodlike structures (probably productid spines), ostracodes (c); fauna abundant though mostly fragmentary 3.0

5. Limestone, medium light gray to yellowish gray, weathers grayish yellow to yellowish gray, hard, thick bedded, somewhat argillaceous, noncherty, beds are transitional from Speiser to Threemile lithology, uniform texture, dominantly fine-crystalline matrix, some fine-granular calcite also; FOSSILS, fenestrate bryozoan fragments (c), *Rhombopora* (c), productid spines (a), *Derbyia* (s), *Dictyoclostus* (c), *Composita* (c), *Aviculopinna* (s), crinoid remains (c); fossils very abundant but mostly fragmentary 1.4

Loc. 117, SW¼ sec. 19, T. 32 S., R. 8 E.

SPEISER SHALE, 30.3 feet

4. Limestone and shale; limestone medium gray, weathers same, medium hard, shaly to medium bedded, very argillaceous, uniform texture, fine-granular matrix, lowest 0.75-foot bed has dominantly fine to medium crystalline texture; FOSSILS, *Osagia* (c), *Ammodiscus* (s), *Ammovertella* (c), *Orbiculoidea* (c), ramose bryozoans, *Juresania* (a), *Derbyia* (a), *Septimyalina* (c), *Aviculopecten* (c), *Allorisma* (c), small high-spired snails, crinoid stems (s); fossils are a mixture of the mixed and algal-molluscan biota and are abundant. Shale, medium gray, fissile, very silty, very calcareous; FOSSILS, *Derbyia* (c), *Dictyoclostus* (s), productid spines (c), small gastropod internal molds (s), crinoid stems (s), holothurian hook-type spicules, *Bairdia* (c), *Knoxina* (s), *Cavellina* (s), *Knightina* (s), *Hollinella* (s), fragmentary vertebrate remains (c); fauna much like that of the interbedded limestones but less abundant and diversified 5.5

3. Shale and limestone; shale light olive gray, calcareous, silty, locally includes very thin silt lenses, shaly bedded; FOSSILS, *Ammovertella* (s), *Aviculopecten* (s), *Knoxina* (s), *Bairdia* (s), *Hollinella* (c), *Paraparchites* (c), *Cavellina* (c), tiny circular calcitic structures (organic?); fauna sparse. Lower of two limestone beds light to medium gray, hard, single 0.2-foot bed, argillaceous, irregular texture, dominantly finely crystalline matrix, some granular portions; upper limestone bed light gray, medium hard, thin bedded, nodular, very argillaceous, uniform texture, fine-granular matrix, flecked with limonite; FOSSILS, *Ammodiscus* (p), ?*Bairdia*, brachiopod fragments, tiny gastropods; fauna very sparse 3.5

	Thickness, feet
2. Shale, dark gray, calcareous, very calcareous at top, silty, thin lenses of silt, shaly bedded to platy; FOSSILS, ?*Leioclema* (s), productid spines (s), small low-spired gastropods (s), small circular calcitic structures (organic?), as in 3, *Macrocypris, Hollinella* (c), *Bairdia* (s), *Paraparchites* (s); fauna sparse	0.8
1. Shale, lower 5 feet yellowish gray, middle 10 feet grayish red, upper 5.5 feet light olive gray becoming medium dark gray in the top 1.5 feet, all silty and calcareous, shaly to blocky bedded, 1-mm coal parting near top locally; FOSSILS, upper gray shale, charophyte oögonia (s), middle red shale, charophyte oögonia; lower gray shale, *Globivalvulina* (s), *Hyperammina* (s), *Septopora* (c), *Thamniscus* (c), *Rhombopora* (c), ?*Leioclema* (s), *Fenestrellina* (c), productid spines (a), *Derbyia* (s), *Dictyoclostus* (s), *Knoxina* (c), *Cavellina* (c), *Bairdia* (c), echinoid spines (s)	20.5
Total	73.6

List of Localities

1. NW¼ sec. 10, T. 7 S., R. 9 E., Pottawatomie County. Road cut on State Highway 99. Funston limestone to basal Threemile limestone.
2. SW¼ sec. 3, T. 7 S., R. 9 E., Pottawatomie County. Road cut on State Highway 99. Speiser shale to basal Schroyer limestone.
3. Same as 2 but 0.2 mile north. Havensville shale and lower Schroyer limestone.
4. NW¼ sec. 3, T. 7 S., R. 9 E., Pottawatomie County. Road cut on State Highway 99. Upper Schroyer limestone and Wymore shale.
5. NE¼ SE¼ sec. 9, T. 6 S., R. 9 E., Pottawatomie County. Road cut on State Highway 99. Speiser shale and Wreford limestone.
6. NE¼ sec. 36, T. 2 S., R. 8 E., Marshall County. Road cut on U.S. Highway 36. Speiser shale and lower Threemile limestone.
7. NE¼ sec. 21, T. 4 S., R. 7 E., Marshall County. Road cuts on U.S. Highway 77. Crouse limestone to basal Schroyer limestone.
8. SW¼ sec. 13, T. 5 S., R. 7 E., Marshall County. Road cut 1 mile south of Irving. Upper Havensville and lower Schroyer limestone.
9. NW¼ sec. 26, T. 5 S., R. 8 E., Marshall County. Road cut 3.2 miles south of Bigelow. Upper Havensville shale and Schroyer limestone.
10. NE¼ sec. 31 and NW¼ sec. 32, T. 3 S., R. 7 E., Marshall County. Stream cuts 1.2 miles south of Schroyer. Wreford limestone.
11. SW¼ sec. 36, T. 6 S., R. 7 E., Pottawatomie County. Bluff 3.5 miles northeast of Olsburg. Schroyer limestone.
12. SW¼ sec. 4, T. 7 S., R. 7 E., Pottawatomie County. Road cut 3 miles northwest of Olsburg. Funston limestone through Havensville shale.
13. NW¼ sec. 27, T. 8 S., R. 8 E., Pottawatomie County. Road cut 7 miles southwest of Westmoreland. Speiser shale to lower Schroyer limestone.
14. SE¼ sec. 9, T. 8 S., R. 8 E., Pottawatomie County. Road and stream cut 6 miles southwest of Westmoreland. Funston limestone to lower Threemile limestone.
15. NW¼ sec. 23, T. 7 S., R. 8 E., Pottawatomie County. Stream cut 0.5 mile east of Fostoria. Havensville shale and Schroyer limestone.
16. SW¼ sec. 2, T. 6 S., R. 8 E., Pottawatomie County. Road cut 8 miles north of Fostoria. Blue Rapids shale to lower Schroyer limestone.
17. SE¼ sec. 21, T. 7 S., R. 12 E., Pottawatomie County. Road cut on Kansas Highway 63, 6 miles south of Havensville. Speiser shale and basal Threemile limestone.
18. SE¼ sec. 33 and SW¼ sec. 34, T. 6 S., R. 12 E., Pottawatomie County. Road cut on Kansas Highway 63, 2 miles south of Havensville. Threemile limestone through Schroyer limestone.
19. NE¼ sec. 4, T. 7 S., R. 12 E., Pottawatomie County. Road cut on Kansas Highway 16 just west of Kansas Highway 63. Speiser shale and lower Threemile limestone.
20. SW¼ sec. 3, T. 7 S., R. 12 E., Pottawatomie County. Small quarry on Kansas Highway 16 just east of Kansas Highway 63. Upper Threemile limestone.
21. SE¼ sec. 8, T. 7 S., R. 7 E., Pottawatomie County. Bluff along small valley 3 miles northwest of Olsburg. Upper Havensville shale and Schroyer limestone.
22. SW¼ sec. 10, T. 6 S., R. 7 E., Riley County. Road cut 0.5 mile north of Cleburne. Upper Schroyer limestone and Wymore shale.
23. SW¼ sec. 2, T. 6 S., R. 7 E., Riley County. Road cut 1.5 miles north of Cleburne. Funston limestone through Schroyer limestone.
24. NW¼ sec. 32, T. 6 S., R. 7 E., Riley County. Road cut 4 miles northeast of Randolph. Wymore shale.
25. SW¼ sec. 31, T. 6 S., R. 7 E., Riley County. Road cut on Kansas Highway 16. Speiser shale and lower Threemile limestone.
26. SW¼ NW¼ sec. 17, T. 10 S., R. 7 E., Riley County. Road cut on east side of Fort Riley Military Reservation. Speiser shale and Threemile limestone.

27. SE¼ sec. 35, T. 12 S., R. 5 E., Geary County. Quarry and hill slope at Wreford. Threemile limestone.
28. NE¼ sec. 7, T. 12 S., R. 6 E., Geary County. Road cut on U.S. Highway 40 just east of Smoky Hill River. Funston limestone through Threemile limestone.
29. SW¼ sec. 2, T. 13 S., R. 6 E., Geary County. Road cut just north of Davis Creek. Schroyer limestone.
30. NE¼ sec. 34, T. 11 S., R. 6 E., Geary County. Road cuts on U.S. Highway 40 about 4 miles east of Junction City. Funston limestone through Kinney limestone.
31. S½ sec. 30, T. 11 S., R. 7 E., Geary County. Road cuts on U.S. Highway 40 about 7.5 miles east of Junction City. Kinney limestone through Fort Riley limestone.
32. SE¼ sec. 25, T. 11 S., R. 7 E., Geary County. Road cut on U.S. Highway 40 about 3 miles west of junction of U.S. Highway 40 and Kansas Highway 13. Upper Speiser shale through Havensville shale.
33. SE¼ sec. 9 and NE¼ sec. 16, T. 12 S., R. 8 E., Geary County. Road cuts on Kansas Highway 13 about 3.5 miles south of junction of U.S. Highway 40 and Kansas Highway 13. Schroyer limestone and Wymore shale.
34. NW¼ sec. 21, T. 12 S., R. 7 E., Geary County. Road cut on Humboldt Creek about 6 miles southeast of U.S. Highway 40. Upper Speiser shale and Threemile limestone.
35. NE¼ SE¼ sec. 30, T. 11 S., R. 8 E., Geary County. Road cut on U.S. Highway 40 about 1.2 miles west of junction of U.S. Highway 40 and Kansas Highway 13. Schroyer limestone.
36. NW¼ sec. 21, T. 11 S., R. 8 E., Riley County. Road cuts on Kansas Highway 13 about 1 mile north of junction of U.S. Highway 40 and Kansas Highway 13. Speiser shale through Wymore shale.
37. Center sec. 29, T. 8 S., R. 7 E., Riley County. Road cut just west of Kansas Highway 13. Funston limestone to Kinney limestone.
38. NE¼ sec. 30, T. 12 S., R. 9 E., Wabaunsee County. Road ditch about 3 miles northwest of Volland. Schroyer limestone.
39. NE¼ sec. 15, T. 12 S., R. 9 E., Wabaunsee County. Road cut 6 miles west of Alma. Upper Havensville shale and Schroyer limestone.
40. NE¼ sec. 20, T. 12 S., R. 9 E., Wabaunsee County. Road cut 3.5 miles northwest of Volland. Lower Threemile limestone.
41. SE¼ sec. 21, T. 12 S., R. 9 E., Wabaunsee County. Road cut 3 miles north of Volland. Speiser shale.
42. SW¼ sec. 10, T. 13 S., R. 9 E., Wabaunsee County. Road cut 1 mile southeast of Volland. Speiser shale and Wreford limestone.
43. NE¼ sec. 15, T. 13 S., R. 9 E., Wabaunsee County. Stream bed 1.5 miles southeast of Volland. Upper Speiser shale.
44. NW¼ NE¼ sec. 25, T. 13 S., R. 9 E., Wabaunsee County. Road cut 4.2 miles southeast of Volland. Speiser shale and lower Threemile limestone.
45. SE¼ sec. 18, T. 12 S., R. 11 E., Wabaunsee County. Road cut 3 miles southeast of Alma. Upper Speiser shale and lower Threemile limestone.
46. Center N½ sec. 2, T. 13 S., R. 11 E., Wabaunsee County. Road cut 8 miles southeast of Alma. Funston limestone through Threemile limestone.
47. NE¼ sec. 31, T. 13 S., R. 12 E., Wabaunsee County. Road cut 1.5 miles north of Eskridge. Lower Threemile limestone.
48. SW¼ NW¼ sec. 10, T. 14 S., R. 10 E., Wabaunsee County. Road cut 11 miles south of Alma. Speiser shale and Threemile limestone.
49. SE¼ sec. 36, T. 13 S., R. 11 E., Wabaunsee County. Road cut 1 mile northwest of Eskridge on Kansas Highway 99. Speiser shale and Threemile limestone.
50. NW¼ sec. 10, T. 15 S., R. 10 E., Wabaunsee County. Road cut at Chalk school house. Threemile limestone and Havensville shale.
51. SE¼ sec. 9, T. 12 S., R. 9 E., Wabaunsee County. Road cut 6.5 miles west of Alma. Upper Speiser shale and Threemile limestone.

52. NE¼ sec. 15, T. 12 S., R. 9 E., Wabaunsee County. Stream bed 6 miles east of Alma (north of road). Threemile limestone.
53. SW¼ sec. 11, T. 15 S., R. 10 E., Wabaunsee County. Road cut 2 miles southeast of Chalk. Speiser shale and lower Threemile limestone.
54. Center sec. 13, T. 16 S., R. 10 E., Lyon County. Road cut on U.S. Highway 50 N, 1 mile north of Bushong. Speiser shale and Threemile limestone.
55. SW¼ sec. 23, T. 16 S., R. 10 E., Lyon County. Railroad cut 1 mile west of Bushong. Upper Threemile limestone to lower Schroyer limestone.
56. SE¼ NW¼ sec. 14, T. 16 S., R. 10 E., Lyon County. Road cut on U.S. Highway 50 N, 1.2 miles northwest of Bushong. Upper Threemile limestone.
57. NE¼ sec. 15, T. 16 S., R. 10 E., Lyon County. Road cut on U.S. Highway 50 N, 2 miles northwest of Bushong. Speiser shale.
58. NE¼ sec. 22, T. 15 S., R. 10 E., Lyon County. Stream cut and bluff 5 miles north of U.S. Highway 50 N. Upper Speiser shale and Threemile limestone.
59. NW¼ NE¼ sec. 34, T. 15 S., R. 10 E., Lyon County. Stream cut south of east-west road 3 miles north of U.S. Highway 50 N. Upper Speiser shale and Threemile limestone.
60. SW¼ sec. 9, T. 16 S., R. 9 E., Morris County. Road cut 3 miles east of Council Grove on U.S. Highway 50 N. Havensville shale.
61. NW¼ sec. 17, T. 16 S., R. 9 E., Morris County. Road cut 3 miles east of Council Grove on U.S. Highway 50 N. Threemile limestone.
62. SE¼ sec. 9, T. 16 S., R. 9 E., Morris County. Road cut 4 miles east of Council Grove on U.S. Highway 50 N. Upper Speiser shale and lower Threemile limestone.
63. NW¼ sec. 32, T. 15 S., R. 9 E., Morris County. Stream cut 4 miles northeast of Council Grove. Upper Threemile limestone.
64. NE¼ sec. 32, T. 15 S., R. 10 E., Lyon County. Stream cut about 3 miles north of U.S. Highway 50 N. Upper Speiser shale and lower Threemile limestone.
65. SW¼ sec. 26, T. 15 S., R. 9 E., Morris County. Stream cut about 3.2 miles north of U.S. Highway 50 N. Threemile limestone.
66. SW¼ sec. 30, T. 15 S., R. 8 E., Morris County. Stream cut 1.5 miles south of Kelso. Upper Speiser shale and Threemile limestone.
67. SW¼ sec. 15 and SE¼ sec. 16, T. 15 S., R. 7 E., Morris County. Road ditches about 1.5 miles south of Parkerville. Wreford limestone.
68. SE¼ sec. 3, T. 17 S., R. 8 E., Morris County. Road cut on Kansas Highway 13, just south of Four Mile Creek. Speiser shale and Threemile limestone.
69. SW¼ sec. 22, T. 16 S., R. 10 E., Lyon County. Railroad cut 2 miles west of Bushong. Speiser shale and Threemile limestone.
70. NW¼ sec. 35, T. 15 S., R. 8 E., Morris County. Road cut on Kansas Highway 13, 3 miles north of Council Grove. Upper Havensville shale and Schroyer limestone.
71. NW¼ sec. 10, T. 17 S., R. 9 E., Morris County. Road cut on Kansas Highway 13, 5 miles south of Council Grove. Upper Havensville shale and Schroyer limestone.
72. SE¼ sec. 1, T. 18 S., R. 8 E., Chase County. Stream and road cuts 0.5 mile south of county line. Speiser shale through lower Schroyer limestone.
73. NE¼ sec. 16, T. 19 S., R. 8 E., Chase County. Road cut and abandoned quarry 0.5 mile east of Strong City. Lower Threemile limestone.
74. SE¼ sec. 5, T. 19 S., R. 6 E., Chase County. Stream cut 8.5 miles northwest of Elmdale. Upper Speiser shale and lower Threemile limestone.
75. NW¼ sec. 17, T. 19 S., R. 6 E., Chase County. Stream cut 8.5 miles northwest of Elmdale. Upper Threemile limestone through lower Schroyer limestone.
76. NE¼ sec. 25, T. 19 S., R. 7 E., Chase County. Road ditches about 3 miles west of Cottonwood Falls. Threemile limestone.

77. SE¼ sec. 27 and NE¼ sec. 34, T. 19 S., R. 6 E., Chase County. Stream and road cuts on Kansas Highway 150, 5 miles west of junction of U.S. Highway 50 S and Kansas Highway 150. Threemile limestone and Havensville shale.
78. NW¼ sec. 34, T. 19 S., R. 6 E., Chase County. Road ditch about 0.5 mile west of locality 77. Lower Schroyer limestone.
79. SW¼ sec. 27, T. 19 S., R. 6 E., Chase County. Road cut 0.1 mile west of locality 78. Upper Threemile limestone.
80. Center sec. 34, T. 19 S., R. 6 E., Chase County. Stream bluff about 0.5 mile south of Kansas Highway 150. Upper Speiser shale and lower Threemile limestone.
81. NW¼ sec. 1, T. 21 S., R. 6 E., Chase County. Stream cut about 3 miles southeast of Clements. Threemile limestone.
82. SE¼ sec. 7, T. 19 S., R. 8 E., Chase County. Quarry on hill about 1 mile west of Strong City. Threemile limestone and Havensville shale.
83. SE¼ sec. 6, T. 21 S., R. 7 E., Chase County. Stream cut 4 miles southeast of Clements. Upper Havensville shale and Schroyer limestone.
84. NE¼ sec. 20, T. 20 S., R. 8 E., Chase County. Stream bed 2 miles northwest of Bazaar. Wreford limestone.
85. NW¼ sec. 17, T. 21 S., R. 8 E., Chase County. Bluff overlooking South Fork of Cottonwood River 4.5 miles north of Matfield Green. Threemile limestone.
86. NW¼ sec. 31, T. 21 S., R. 8 E., Chase County. Stream cut 2 miles northwest of Matfield Green. Upper Speiser shale and lower Threemile limestone.
87. SE¼ NE¼ sec. 7, T. 22 S., R. 8 E., Chase County. Railroad cut 0.25 mile south of Matfield Green. Speiser shale.
88. SW¼ sec. 18, T. 22 S., R. 8 E., Chase County. Railroad cut 2.2 miles southwest of Matfield Green. Schroyer limestone.
89. NW¼ sec. 19, T. 22 S., R. 8 E., Chase County. Railroad cut 3 miles southwest of Matfield Green. Wymore shale and Kinney limestone.
90. SE¼ NW¼ sec. 19, T. 22 S., R. 8 E., Chase County. Quarry 2.6 miles southwest of Matfield Green. Wreford limestone.

90a. SE¼ SW¼ sec. 18, T. 22 S., R. 8 E., Chase County. Bluff along dry creek bed 2.5 miles southwest of Matfield Green. Threemile limestone.

91. Center W½ sec. 18, T. 22 S., R. 8 E., Chase County. Railroad cut 2.1 miles southwest of Matfield Green. Havensville shale.
92. SE¼ sec. 7, T. 22 S., R. 8 E., Chase County. Railroad cut 1 mile southwest of Matfield Green. Threemile limestone.
93. Center sec. 35, T. 22 S., R. 9 E., Chase County. Gully on east side of Teeterville oil pool. Speiser shale through Kinney limestone.
94. Center sec. 4, T. 26 S., R. 8 E., Butler County. Railroad cut 4.5 miles east of Rosalia. Threemile limestone and Havensville shale.
95. NE¼ sec. 9, T. 26 S., R. 8 E., Butler County. Road cut 4.5 miles east of Rosalia. Threemile limestone through lower Schroyer limestone.

95a. SW¼ sec. 4, T. 26 S., R. 8 E., Butler County. Gully 4.5 miles east of Rosalia. Schroyer limestone.

96. SE¼ sec. 36, T. 22 S., R. 9 E., Chase County. Gully south of east-west road through Teeterville oil pool. Upper Schroyer limestone and Wymore shale.
97. SE¼ sec. 16, T. 23 S., R. 9 E., Greenwood County. Road cut 0.5 mile east of Teeterville. Speiser shale and Threemile limestone.
98. SW¼ sec. 25, T. 23 S., R. 8 E., Greenwood County. Gully 4 miles southwest of Teeterville. Schroyer limestone.
99. SW¼ sec. 18, T. 23 S., R. 9 E., Greenwood County. Road ditch 2.5 miles west of Teeterville. Upper Schroyer limestone.
100. SE¼ sec. 25, T. 23 S., R. 8 E., Greenwood County. Road cut 3.3 miles southwest of Teeterville. Speiser shale.
101. NW¼ sec. 19, T. 23 S., R. 9 E., Greenwood County. Stream bed 2.4 miles west of Teeterville. Middle Havensville shale.

102. SW¼ sec. 17, T. 25 S., R. 8 E., Butler County. Road cut 5 miles northeast of Rosalia. Speiser shale and lower Threemile limestone.
103. NE¼ sec. 19, T. 25 S., R. 8 E., Butler County. Ravine 5 miles northeast of Rosalia. Upper Threemile limestone.
104. NE¼ sec. 26, T. 28 S., R. 7 E., Butler County. Stream bed 3.5 miles north of Latham. Threemile limestone.
105. SE¼ sec. 24, T. 28 S., R. 7 E., Butler County. Road cut 4 miles northeast of Latham. Speiser shale and lower Threemile limestone.
106. NE¼ NW¼ sec. 31, T. 29 S., R. 8 E., Butler County. Stream cut 4 miles southeast of Latham. Upper Speiser shale and lower Threemile limestone.
107. SE¼ sec. 7, T. 28 S., R. 8 E., Butler County. Road and stream cut 2.5 miles southwest of Beaumont. Upper Speiser shale and Threemile limestone.
108. SE¼ sec. 19, T. 25 S., R. 8 E., Butler County. Ravine 4.5 miles northeast of Rosalia. Havensville shale through Wymore shale.
109. SW¼ sec. 14 and N½ sec. 22, T. 30 S., R. 7 E., Cowley County. Road and stream cuts 8 miles north of Cambridge. Upper Speiser shale and Wreford limestone.
110. Center sec. 31, T. 31 S., R. 7 E., Cowley County. Railroad cut 2.5 miles east of Burden. Upper Speiser shale and lower Threemile limestone.
111. NE¼ sec. 36, T. 31 S., R. 6 E., Cowley County. Railroad cut 1.75 miles east of Burden. Wymore shale and Kinney limestone.
112. NW¼ sec. 31, T. 31 S., R. 7 E., Cowley County. Railroad cut 2 miles east of Burden. Upper Threemile limestone.
113. SW¼ sec 29, T. 31 S., R. 7 E., Cowley County. Road cut on U.S. Highway 160, 3 miles east of Burden. Threemile limestone and Havensville shale.
114. SE¼ sec. 30, T. 31 S., R. 7 E., Cowley County. Road cut and ditch 2.75 miles east of Burden. Upper Havensville shale and Schroyer limestone.
115. SW¼ sec. 19 and NW¼ sec. 30, T. 32 S., R. 7 E., Cowley County. Road cut on Kansas Highway 38, 4.5 miles north of Dexter. Upper Speiser shale and Wreford limestone.
116. Center S line sec. 24, T. 32 S., R. 7 E., Cowley County. Road cut on Kansas Highway 38, 7 miles northeast of Dexter. Threemile limestone and Havensville shale.
117. SW¼ sec. 19, T. 32 S., R. 8 E., Cowley County. Road cut on Kansas Highway 38, 8 miles northeast of Dexter. Speiser shale through Havensville shale.
118. SW¼ sec. 19 and NW¼ sec. 30, T. 33 S., R. 7 E., Cowley County. Road cut on Kansas Highway 15, 2 miles south of Dexter. Speiser shale and Wreford limestone.
119. SW¼ sec. 31, T. 33 S., R. 7 E., Cowley County. Road cut on Kansas Highway 15, 3.3 miles south of Dexter. Speiser shale and lower Threemile limestone.
120. NE¼ sec. 12, T. 34 S., R. 6 E., Cowley County. Road cut on U.S. Highway 166, 4.7 miles south of Dexter. Speiser shale and Threemile limestone.
121. SW¼ sec. 18, T. 34 S., R. 7 E., Cowley County. Road cut 1.5 miles north of Otto. Upper Speiser shale and lower Threemile limestone.
122. NW¼ sec. 33, T. 34 S., R. 5 E., Cowley County. Stream cut 0.7 mile northeast of Silverdale. Upper Threemile limestone through lower Schroyer limestone.
123. Center sec. 23, T. 34 S., R. 5 E., Cowley County. Bluff along stream at bridge on U.S. Highway 166. Upper Threemile limestone through Schroyer limestone.
124. NW¼ sec. 10, T. 34 S., R. 6 E., Cowley County. Road cut on U.S. Highway 166, 6 miles northeast of Cameron. Threemile limestone and lower Havensville shale.
125. NW¼ sec. 11, T. 34 S., R. 6 E., Cowley County. Road cut on U.S. Highway 166, 2 miles west of junction of U.S. Highway 166 and Kansas Highway 15. Upper Speiser shale.

126. SW¼ sec. 10, T. 1 S., R. 14 E., Nemaha County. Road cut and ditch 5 miles northwest of Sabetha. Speiser shale and lower Threemile limestone.
127. SE¼ sec. 4, T. 1 S., R. 14 E., Nemaha County. Road ditch 5.5 miles northwest of Sabetha. Threemile limestone.
128. NE¼ sec. 32, T. 15 S., R. 9 E., Morris County. Stream bluff 4 miles northeast of Council Grove. Upper Threemile limestone.
129. NE¼ sec. 1, T. 8 S., R. 5 E., Riley County. Road cut 1.2 miles west of Walsburg. Winfield limestone.
130. SE¼ sec. 23, T. 15 S., R. 8 E., Morris County. Road cut on Kansas Highway 13, 4.5 miles north of Council Grove. Upper Schroyer limestone.
131. SE¼ sec. 20, T. 32 S., R. 7 E., Cowley County. Road cut on Kansas Highway 38, 5 miles northeast of Dexter. Upper Speiser shale and lower Threemile limestone.
132. NW¼ sec. 11, T. 34 S., R. 6 E., Cowley County. Road cut on U.S. Highway 166, 1.8 miles west of junction of Kansas Highway 15 and U.S. Highway 166. Lower Threemile limestone.
133. SW¼ sec. 11, T. 11 S., R. 6 E., Riley County. Quarry on bluff east of Threemile Creek on Fort Riley Military Reservation. Wreford limestone.
134. NW¼ sec. 9, T. 12 S., R. 8 E., Geary County. Stream cut just east of Kansas Highway 13, 2.5 miles south of junction of Kansas Highway 13 and U.S. Highway 40. Funston limestone through lower Threemile limestone.
135. SE¼ sec. 26, T. 13 S., R. 9 E., Wabaunsee County. Stream cut 4.5 miles southeast of Volland. Threemile limestone.
136. Center W line sec. 7, T. 15 S., R. 10 E., Wabaunsee County. Road cut and ditch 2 miles southwest of Chalk. Upper Havensville shale and Schroyer limestone.
137. NE¼ sec. 34, T. 12 S., R. 5 E., Geary County. Road cut on U.S. Highway 77 just south of Smoky Hill River. Upper Threemile limestone through Schroyer limestone.

State Geological Survey of Kansas

Bulletin 124

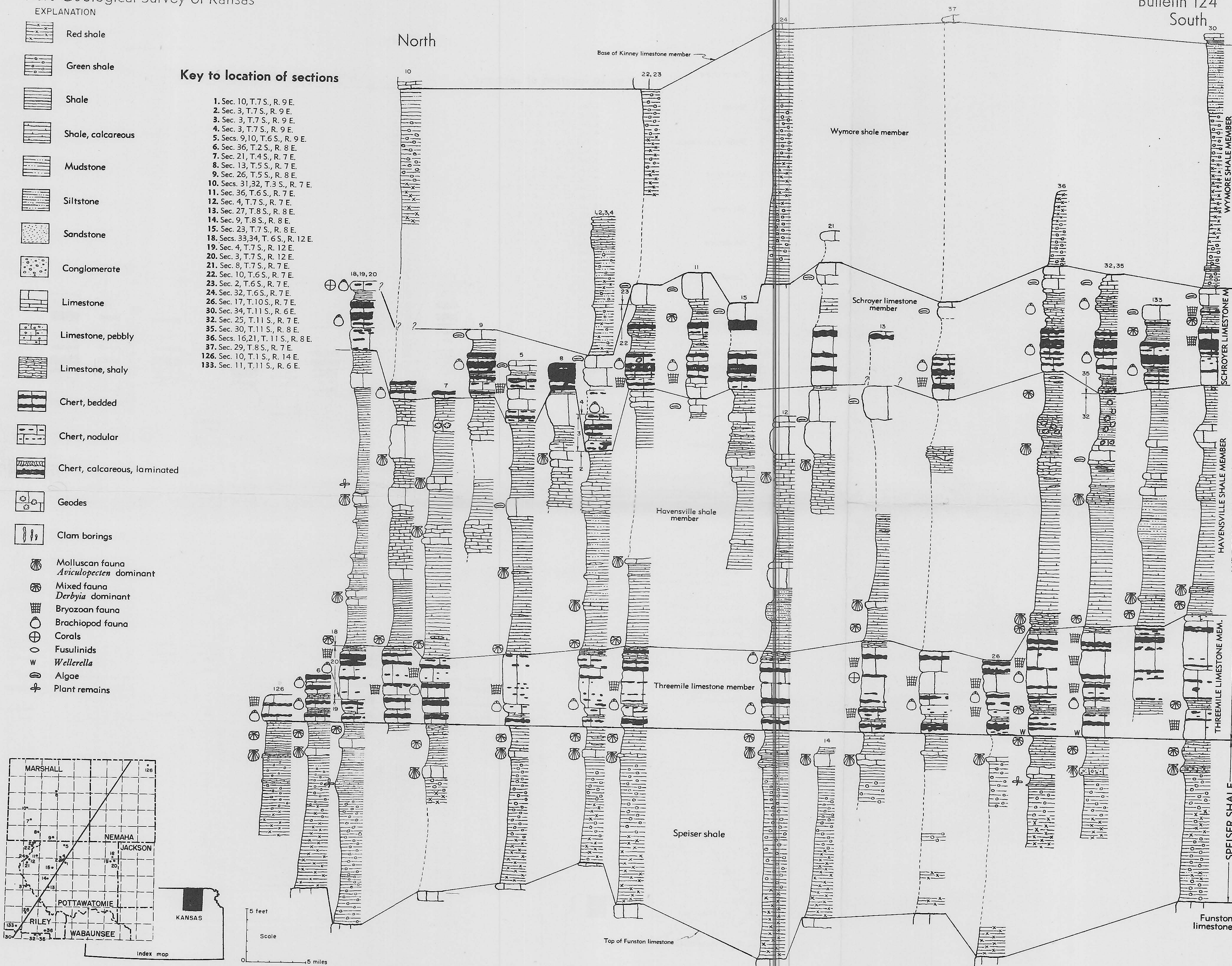


Plate 1. CORRELATION OF THE WREFORD MEGACYCLOTHEM

By Donald E. Hattin, 1954

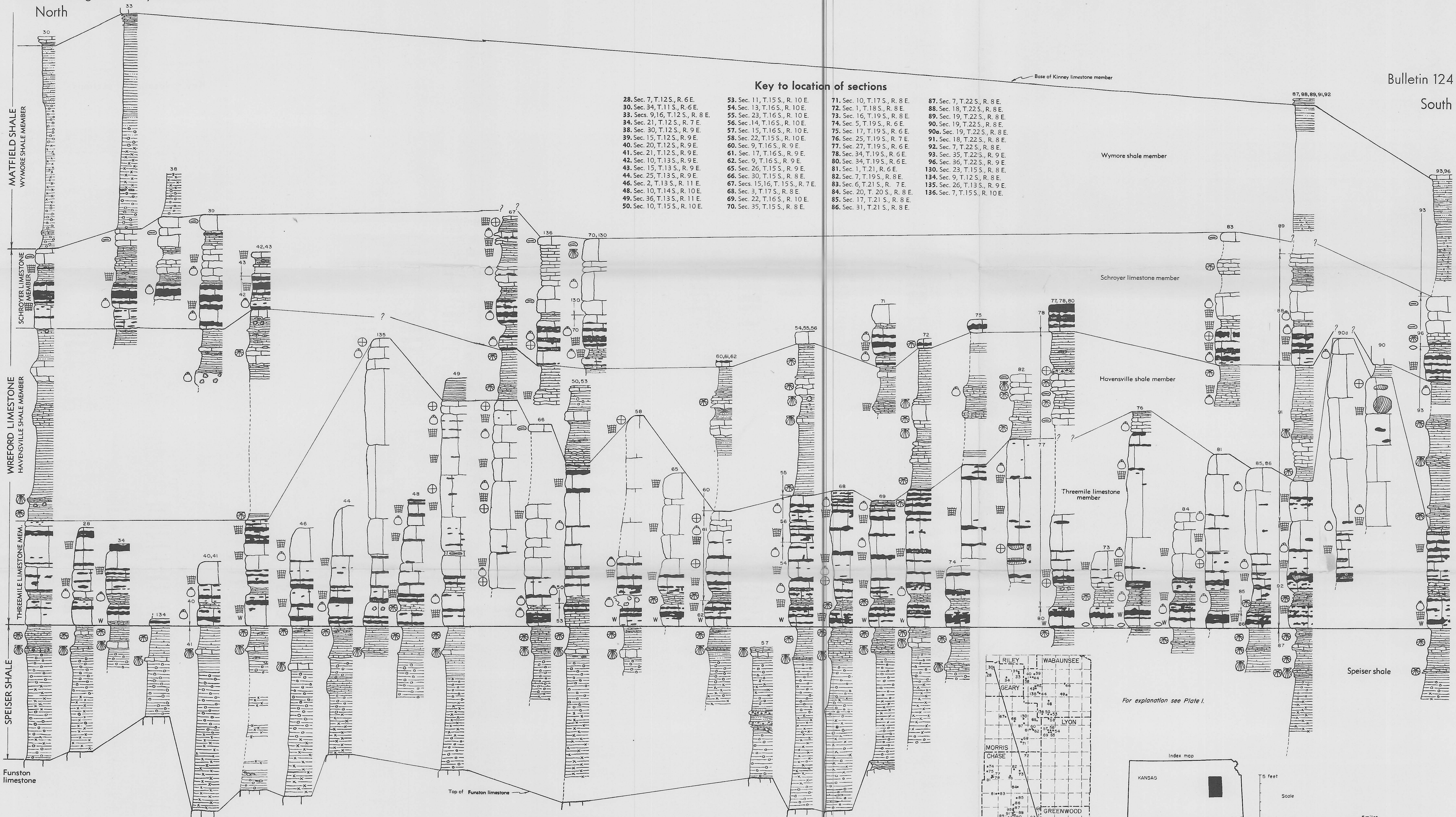
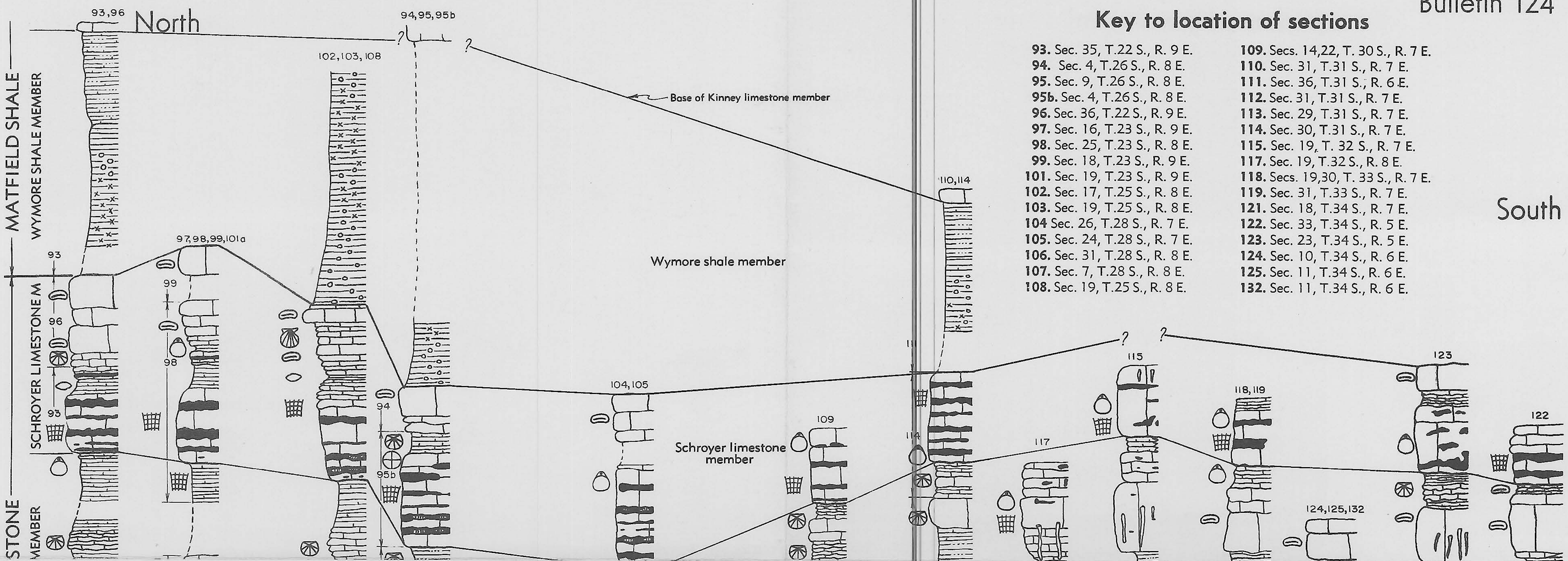


Plate 2. CORRELATION OF THE WREFORD MEGACYCLOTHEM
By Donald E. Hattin, 1954


North
South
MATFIELD SHALE
WYMORE SHALE MEMBER
SCHROYER LIMESTONE M
STONE
MEMBER
Base of Kinney limestone member
Wymore shale member
Schroyer limestone member
93,96
94,95,95b
102,103,108
97,98,99,101a
104,105
109
110,114
111
114
115
117
118,119
124,125,132
123
122
Key to location of sections
93. Sec. 35, T.22 S., R. 9 E.
94. Sec. 4, T.26 S., R. 8 E.
95. Sec. 9, T.26 S., R. 8 E.
95b. Sec. 4, T.26 S., R. 8 E.
96. Sec. 36, T.22 S., R. 9 E.
97. Sec. 16, T.23 S., R. 9 E.
98. Sec. 25, T.23 S., R. 8 E.
99. Sec. 18, T.23 S., R. 9 E.
101. Sec. 19, T.23 S., R. 9 E.
102. Sec. 17, T.25 S., R. 8 E.
103. Sec. 19, T.25 S., R. 8 E.
104 Sec. 26, T.28 S., R. 7 E.
105. Sec. 24, T.28 S., R. 7 E.
106. Sec. 31, T.28 S., R. 8 E.
107. Sec. 7, T.28 S., R. 8 E.
108. Sec. 19, T.25 S., R. 8 E.
109. Secs. 14,22, T. 30 S., R. 7 E.
110. Sec. 31, T.31 S., R. 7 E.
111. Sec. 36, T.31 S., R. 6 E.
112. Sec. 31, T.31 S., R. 7 E.
113. Sec. 29, T.31 S., R. 7 E.
114. Sec. 30, T.31 S., R. 7 E.
115. Sec. 19, T. 32 S., R. 7 E.
117. Sec. 19, T.32 S., R. 8 E.
118. Secs. 19,30, T. 33 S., R. 7 E.
119. Sec. 31, T.33 S., R. 7 E.
121. Sec. 18, T.34 S., R. 7 E.
122. Sec. 33, T.34 S., R. 5 E.
123. Sec. 23, T.34 S., R. 5 E.
124. Sec. 10, T.34 S., R. 6 E.
125. Sec. 11, T.34 S., R. 6 E.
132. Sec. 11, T.34 S., R. 6 E.