Paleoecology and Biostratigraphy of the Red Eagle Cyclothem (Lower Permian) in Kansas

By Alistair W. McCrone

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ABSTRACT

The Red Eagle cyclothem, a Lower Permian (Wolfcampian) marine sedimentary rock succession, includes, in ascending order, rocks of the Johnson Shale, Red Eagle Limestone, and Roca Shale. Despite facies changes, these and their component stratigraphic units can be traced along their outcrop belt southward from Lincoln, Nebraska, across Kansas to Burbank, Oklahoma.

Detailed stratigraphy, sedimentary petrography, and paleontology of the Red Eagle cyclothem provide the bases for interpretations of its depositional environments and its plant and animal megafossils and microfossils. Postulates concerning the approximate physical and chemical characteristics of the Red Eagle cyclothem marine environments are advanced. The assembled evidence suggests that the depositional environments of the various faunal-lithologic phases of this and other Lower Permian cyclothems were most directly controlled by marine water depths which ranged from 0 to scarcely more than 60 feet. Other combined factors sometimes were more important than or modified the depth effects.

The Red Eagle cyclothem sediments accumulated in a broad, shallow epicontinental sea, the floor of which was flattest during accumulation of the oldest part of the Red Eagle Limestone. Slight changes of water depth caused widespread changes in depositional conditions.

The accumulation of red mud in very shallow water began the Red Eagle cyclothemic succession in the middle part of Johnson time and concluded it near the middle of Roca time. Muddy depositional conditions which produced the Johnson Shale were similar to those which later produced the Roca Shale. Limestones of the Red Eagle Formation, and their shaly equivalents, accumulated in slightly deeper waters.

Faint upwarps of the earth's crust in the Nemaha Arch and contiguous areas of east-central Kansas seem to have influenced water circulation and thereby exercised minor control over the accumulation of sediments in the Red Eagle Limestone.

Fossil spores found in the Red Eagle cyclothem seem similar to somewhat younger Permian floral assemblages from other parts of the world.

Ten fundamental faunal-lithologic facies types are recognized in the Red Eagle cyclothem. Most of these facies are also represented in other Kansas cyclothems.

Résumé: Le Red Eagle cyclothème, une succession de marines roches sédimentaires du Lower Permian (Wolfcampian), comprend, dans un ordre ascendant, des roches de Johnson Shale, de Red Eagle Limestone, et de Roca Shale. Malgré les changements de faciès, on peut découvrir ceux-ci et leurs constituantes unités stratigraphiques le long de leur bande d'affleurement au Sud de Lincoln, Nebraska, à travers le Kansas à Burbank, Oklahoma.

La stratigraphie détaillée, la pétrographie sédimentaire, et la paléontologie du Red Eagle cyclothème fournissent des bases pour des interprétations de ses environnements de dépôt et ses mega- et micro-fossiles des plantes et desanimaux. Des postulats à l'égard des caractéristiques physiques et chimiques approximatives des environnements marins du Red Eagle cyclothème sont proposés. L'évidence assemblée suggère que les environnements de dépôt des phases faunal-lithologiques du Red Eagles cyclothème et d'autres cyclothèmes du Lower Permian étaient contrôlées le plus directement par les profondeurs d'eau marine qui variaient de 0 à presque pas plus que 20 mètres. D'autres facteurs combinés de temps en temps étaient plus importants ou modifiaient les effets de la profondeur.

Les sédiments du Red Eagle cyclothème se sont accumulés dans un mer epicontinental large et de petit profondeur, dont le fond était le plus plat pendant l'accumulation de la partie la plus vieille du Red Eagle Limestone. De légères variations de la profondeur d'eau ont causé des changements générals dans les conditions de dépôt.

L'accumulation de boue rouge dans l'eau très peu profond a commencé la succession cyclothèmique du Red Eagle dans la moyenne partie de l'époque Johnson et l'a terminée près du milieu de l'époque Roca. De boueuses conditions de dépôt qui ont produit le Johnson Shale ressemblaient à celles qui ont produit plus tard le Roca Shale. Les calcaires de la Red Eagle Formation et leurs équivalents schisteux ont accumulé dans les eaux un peu plus profondes.

De faibles mouvements en haut de l'écorce terrestre dans la Nemaha Arch et dans les aires adjacentes de Kansas est-central semblent avoir influencé la circulation d'eau et par ces moyens ont exercé un contrôle mineur sur l'accumulation des sédiments dans la Red Eagle Limestone.

Les spores fossilisées que l'on a trouvé dans le Red Eagle cyclothème paraissent semblables aux assemblages de flore du Permian un peu plus jeunes d'autres parties du monde.

Dix genres fonda mentaux de faciès faunal-lithologiques se trouvent dans le Red Eagle cyclothème. La plupart de ces faciès se sont représentés aussi dans d'autres cyclothèmes de Kansas.

Resumen: El ciclotema Red Eagle, una sucesión de rocas sedimentarias y marinas de edad de el Lower Permian (Wolfcampian), incluye en orden ascendiente rocas de las formaciones Johnson Shale, Red Eagle Limestone, y Roca Shale. A pesar de cambios de facies, estas formaciones y sus unidades estratigráficas pueden ser delineadas a lo largo de la faja de afloramientos hacia el sur desde Lincoln, Nebraska, a través de Kansas hasta Burbank, Oklahoma.

La estratigrafía en detalle, la petrografía sedimentaria, y la paleontología de el ciclotema Red Eagle proveen las bases para interpretaciones de los ambientes de deposición de el ciclotema y de sus megafósiles y microfósiles de plantas y animales. Algunos postulados concernientes a las características físicas y químicas aproximadas de los ambientes marinos de el ciclotema Red Eagle son propuestos más adelante en este informe. La evidencia congregada sugiere que los ambientes de deposición de las varias fases faunaleslitológicas de este ciclotema y otros ciclotemas de el Lower Permian fueron dominadas directamente por la profundidad de el agua del mar que recorrían desde 0 hasta un poco más de 20 metros. Otros factores combinados fueron más importante o modificaron los efectos de la profundidad.

Los sedimientos de el ciclotema Red Eagle se acumularon en un mar epicontinental extenso y poco profundo. El piso de esta cuenca era más plano durante el tiempo en que la parte más vieja de la Red Eagle Limestone fué acumulada. Los pequeños cambios en la profundidad del agua causaron cambios extensivos en las condiciones de deposición.

La acumulación de lodo rojo en aguas de muy poca profundidad inició le sucesión ciclotémica de las rocas de el Red Eagle durante la parte media de el Johnson y a la vez concluyó la sucesión aproximadamente durante la parte media de la Roca. Las condiciones sedimentarias de enlodamiento que producieron el Johnson Shale fueron similares a las condiciones que producieron el Roca Shale. Calizas de la Red Eagle Formation, y los equivalentes lutitosos de estas calizas, fueron acumulados en aguas un poco más profundas.

Indistintos alabeos de la corteza terrestre en el Nemaha Arch y en áreas contiguas en la parte oriental-central de Kansas parecen haber influenciado la circulación de el agua y de este modo ejercieron control secundario sobre la acumulación de los sedimentos de la Red Eagle Limestone.

Las esporas fosilizadas que fueron encontradas en el ciclotema Red Eagle parecen similares a los conjuntos florales de otras partes de el mundo pero de el Permian más reciente.

Diez tipos fundamentales de facies faunales-litológicas son reconocidos en el ciclotema Red Eagle. La mayoría de estas facies son representadas también en otros ciclotemas de Kansas.

Aufzug: Das Red Eagle Zyclothem, eine marine Sedimentgestein-Folge des Lower Permian (Wolfcampian), umfasst—in aufsteigender Reihenfolge—Gesteine der Johnson Shale, Red Eagle Limestone und Roca Shale. Trotz Faciesveränderungen können sie und ihre zugehörigen stratigraphischen Einheiten an ihrem Zutagezliegen entlang von Lincoln, Nebraska, aus südwärts durch Kansas nach Burbank, Oklahoma, verfolgt werden.

Ausführliche Stratigraphie, Sedimentpetrographie und Paläontologie des Red Eagle Zyclothems ergeben die Grundlagen für eine Interpretation seiner Ablagerungsumgebungen und seiner pflanzlichen und tierischen Mega- und Microfossilien. Postulate hinsichtlich der ungefähren physikalischen und chemischen Charakteristika der marinen Umgebungen des Red Eagle Zyclothems sind fortgeschritten. An Hand des angesammelten Beweismaterials kann angenommen werden, dass die Ablagerungsumgebungen der verschiedenen faunal-lithologischen Phasen dieses und anderer Zyclotheme des Lower Permian am entscheidendsten durch marine Wassertiefen reguliert wurden, die von O bis zu kaum mehr als 18 Meter reichten. Andere kombinierte Faktoren waren gelegentlich bedeutsamer oder wandelten die Auswirkungen der Wassertiefe ab.

Sedimente des Red Eagle Zyclothems lagerten sich in einer breiten flachen Schelfmeer ab, dessen Boden während der Anhäufung der ältesten Teile der Red Eagle Limestone am flächsten waren. Leichte Veränderungen in der Wassertiefe verursachten weit verbreitete Veränderungen der Ablagerungsbedingungen.

Die Anhäufung rotes Schlammes in sehr seichtem Wasser markiert den Beginn der Red Eagle zyclothemischen Folge in der Mitte der Johnson-Zeit und beendete sie um die Mitte der Roca-Zeit. Schlammige Ablagerungsbedingungen, unter denen sich der Johnson Shale bildete, waren denen ähnlich, die später den Roca Shale hervorbrachten. Kalkgesteine der Red Eagle Formation und ihre schieferartigen Äquivalente sammelten sich in etwas tieferem Wasser an.

Schwache Erhebungen der Erdkruste im Nemaha Arch und angrenzenden Gebieten des östlichen Zentral-Kansas haben anscheinend die Wasserzirkulation beeinflusst und dadurch eine untergeordnete Kontrolle über die Ansammlung von Sedimenten im Red Eagle Limestone ausgeübt.

Fossile Sporen, die im Red Eagle Zyclothem gefunden wurden, scheinen etwas jüngeren floralen Ansammlungen aus dem Permian anderer Teilen der Welt ähnlich zu sein.

Zehn faunal-lithologische Facies-Grundtypen wurden im Red Eagle Zyclothem erkannt. Die meisten dieser Facies finden sich auch in anderen Zyclothemen in Kansas.

INTRODUCTION

Purpose and Scope of Investigation

Cyclothems, especially in Pennsylvanian rocks, have provoked much study and discussion. They present problems of correlation which can be resolved only by detailed studies that lead to paleoecological interpretations. Once their stratigraphy and paleoecology are understood, the problems concerning their origin remain. Understanding of the broader aspects of the origin of cyclothems and, specifically, of Permian cyclothemic history cannot be expected until most or all of the Lower Permian cyclothems of Kansas have been examined carefully.

The objective of this study was to interpret the sedimentary and ecological setting that yielded lithofacies and biofacies recognizable as the Red Eagle cyclothem in Kansas. This approach entailed explanation of certain facies patterns that have hindered attempts by earlier stratigraphers to trace the cyclothem across Kansas. Moreover, this investigation supplied information supplementary to the work of others toward an understanding of Permian cyclothems and geologic history in the classic Midcontinent region of Kansas and Nebraska.

This investigation of the Red Eagle cyclothem was the outgrowth of the author's interest in the Red Eagle Limestone itself. Preliminary work showed that this formation could not be understood properly unless the underlying Johnson Shale and overlying Roca Shale were studied also.

The Red Eagle cyclothem, named for its principal limestone formation, includes the Johnson Shale, Red Eagle Limestone, and Roca Shale formations (Table 1). These rocks occur in the Council Grove Group of the Lower Permian (Wolfcampian) about 150 feet stratigraphically above the base of the system. Red shale within the Roca and Johnson Formations marks the upper and lower limits, respectively, of the Red Eagle cyclothem (Elias, 1937).

Table 1.—Stratigraphic placement of Red Eagle cyclothem units (marked by asterisks) in Lower Permian rock succession of Kansas.

Wolfcampian Stage
Chase Group
Council Grove Group
Speiser Shale
Funston Limestone
Blue Rapids Shale
Crouse Limestone
Easly Creek Shale
Bader Limestone
Stearns Shale
Beattie Limestone
Morrill Limestone
Florena Shale
Cottonwood Limestone
Eskridge Shale
Grenola Limestone
Neva Limestone
Salem Point Shale
Burr Limestone
Legion Shale
Sallyards Limestone
*Roca Shale
*Red Eagle Limestone
*Howe Limestone
*Bennett Shale
*Glenrock Limestone
*Johnson Shale
Foraker Limestone
Long Creek Limestone
Hughes Creek Shale
Americus Limestone
Admire Group
Virgilian Stage (Pennsylvanian System)

Previous Work

Some of the earliest scientific explorers of America noted the distinctive Permian and Pennsylvanian rocks of the Midcontinent, sampled their profuse fossil remains, and measured and described sections. Swallow and Hawn (1858) published the earliest reference to Permian rocks in Kansas. Meek and Hayden (1860) provided additional information, as did Swallow (1866) when he placed the lower boundary of the Permian at a horizon included in the Grenola Limestone of present classification. This position is stratigraphically above the Red Eagle cyclothem.

In the 65 years following Swallow's (1866) publication, a series of renamings and reclassifications of Upper Pennsylvanian and Lower Permian rocks appeared in geologic literature. The newer, more positive correlations led to revision of the older classifications. Rocks of the Red Eagle cyclothem were included by Prosser (1902) in the "Elmdale Formation," which embraced rocks ranging upward from the top of the Americus Limestone Member of the Foraker Limestone, to the base of the Neva Limestone Member of the Grenola Limestone. Bass (1929) did not alter this classification essentially when he added the Neva Limestone to Prosser's Elmdale Formation. By moving the Pennsylvanian-Permian boundary upward to the base of the Cottonwood Limestone Member of the Beattie Limestone, he left the Red Eagle rocks in the Upper Pennsylvanian. Moore and Moss (1934) defined the Pennsylvanian-Permian boundary at the base of the Indian Cave Sandstone, which is the lowest unit of the Admire Group. Thus, the Johnson, Red Eagle, and Roca Formations were transferred to the Lower Permian.

The Johnson Shale and Roca Shale, named by Condra (1927), have presented no serious correlation problems because they lie between widely persistent, readily recognizable units. The Red Eagle Limestone was named by Heald (1916) from exposures in Osage County, Oklahoma. It was thought to be part of the Elmdale Formation of Prosser (1902). Condra (1927) named the Glenrock, Bennett, and Howe units from exposures in southeastern Nebraska. Subsequently, Condra traced them southward into Kansas, where he was able to recognize them near Manhattan and elsewhere.

O'Connor and Jewett (1952, p. 333) summarized the work of Bass (1936) in establishing the correlation of the Glenrock, Bennett, and Howe of Nebraska with the Red Eagle Limestone of Oklahoma as follows:

> Bass (1929, pp. 54-55) identified the Red Eagle limestone in Cowley County, Kansas, and expressed the belief that it is continuous into central Kansas in the Cottonwood River Valley. Later, Bass (1936, pp. 41-42) stated that he recognized as members of the Red Eagle limestone beds in Cottonwood River Valley bluffs east of Elmdale that Moore and Condra had identified as equivalents of the Glenrock limestone, Bennett shale, and Howe limestone of northern Kansas and southern Nebraska. Thus, correlation of the Red Eagle limestone, Bennett shale, and Howe limestone in southern Nebraska was indicated.

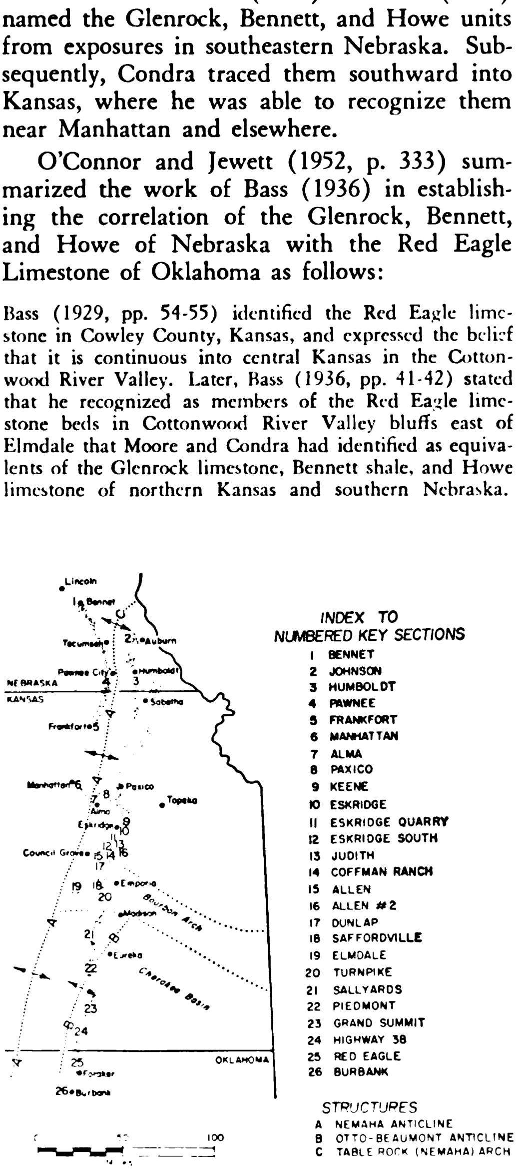

FIGURE 1.—Map of Red Eagle cyclothem outcrop belt showing locations of key sections and major structures.

The work of O'Connor and Jewett (1952) verified the correlations indicated by Bass (1936), and added some detailed stratigraphic descriptions useful in tracing the Red Eagle Formation across Kansas.

Jewett (1933) recognized the cyclic nature of certain Permian rocks of Kansas. This view was greatly amplified by Elias (1937) when he described the faunas associated with the sequences of lithologic units making up the many cycles of the Lower Permian ("Big Blue Series") of Kansas. Elias' principal postulate was that the repeated lithologies and especially the faunas of the cycles were controlled primarily by water depth during deposition. Moore (1959) lucidly summarized the present understanding of cyclic sedimentation as manifested in Pennsylvanian and Permian rocks of Kansas. His conclusions emphasized the need for more study of cyclothems.

Area of Investigation

The Red Eagle cyclothem crops out in a narrow belt extending roughly north-south from Lincoln, Nebraska, through Manhattan, Kansas, to Burbank, Oklahoma (Fig. 1).

Well-exposed sections are rare. Most of the limestone members form minor topographic benches, but the shales commonly lie beneath grassy slopes and are exposed in relatively few places. Fortunately, road cuts and quarries provide sections in areas where nature did not.

From Chase County, Kansas, northward to Lincoln, Nebraska, the more resistant (limestone) members of the Red Eagle assemblage are thin and, where exposed, form only minor benches on valley slopes below the major upland benches of the Neva and Cottonwood Limestones. In southern Kansas and northern Oklahoma, where the Red Eagle becomes a thick limestone, it forms benches more conspicuous than the Neva and Cottonwood.

In northern Kansas, between the Nebraska border and Manhattan, beds belonging to the Red Eagle cyclothem are mostly hidden by glacial drift. This lack of exposure caused no correlation problem, because the sequences at Manhattan and Frankfort, Kansas, and Pawnee, Nebraska, are remarkably similar to one another. In southern Kansas, however, facies changes occur where there are few outcrops, so that correlations are less obvious. The best Red Eagle exposures are in southeastern Nebraska and between Manhattan and Emporia in Kansas.

The topography of the outcrop belt is dominated by gently rolling hills, locally supported by flatter limestone benches. The relief rarely exceeds 200 feet. Major valleys—such as those of the Nemaha, Kansas, Big Blue, Neosho, and Cottonwood Rivers—are wide and have alluvial floors. The many lesser tributaries derive most of their water from normal runoff, but a number are spring-fed. Vegetation ranges from grass on the uplands to woods in the valleys.

Methods of Investigation

During preliminary field reconnaissance for this project in the fall of 1956, study of the Red Eagle Limestone formation was extended to include the Johnson and Roca Formations. For purposes of comparison, other cyclothemic rocks of the Council Grove Group were also studied. Detailed sampling and study of sections for this report was begun in the fall of 1958. Approximately 50 exposures were examined. Of these, 27 were measured, sampled, and described in detail.

Continuous shale samples were obtained by channeling through the section, extreme care being taken to avoid contamination. Samples of from 1 to 5 (rarely 10) pounds were usually taken. Thick beds with uniform lithologies were sampled at intervals of not more than 0.5 foot to avoid overlooking details of microfacies not observed in the field. Thus, at least one sample was taken from every lithologic unit thicker than approximately half an inch. Intervals as thin as 0.05 foot were sampled where field relations dictated.

Limestone was sampled by removing, where possible, a fresh, vertically oriented slab or elongate fragment from fractured portions of the outcrop. This was best accomplished in road cuts where blasting had provided freshly fractured limestone in place. Each sample was marked to indicate the top of the bed.

Every sample was examined under the binocular microscope to check and augment the field description.

Representative limestone samples were broken to pea size by means of mortar and pestle. A weighed quantity of each broken sample was then digested in dilute (10 percent) hydrochloric acid. Insoluble residues from each digested sample were weighed and later studied under the binocular microscope. The percentage (by weight) of insoluble material in each sample was computed and is expressed in bar graphs beside the graphic rock columns in the Appendix. A few selected limestone samples were digested in acetic acid to check against the results obtained from the same material in hydrochloric acid. Differences between the two were found to be insignificant. Microfossils were picked from the insoluble residues and identified as to genus.

Shale samples were boiled in a dispersant solution in order to liberate megafossils and microfossils. Dispersed silt and clay were usually decanted. Some dispersed clay was allowed to settle on microscope slides for use in x-ray studies. The dried shale samples also yielded microfossils and megafossils which were subsequently identified generically.

Limestone specimens were cut perpendicular to the bedding planes and polished. The polished surfaces were etched for 5 or 10 seconds in dilute (1 percent) hydrochloric acid. When the imperceptibly etched surfaces were dry, they were fixed in a level face-up position and wetted with acetone. The acetate film was pressed against them to obtain on the film an impression of the rock texture. These films were used to make magnified photographic prints (peel prints) of the textural details. The polished limestone surfaces were compared with and studied alongside the magnified peel photographs (see McCrone, 1963).

The laboratory procedures described above were supplemented by x-ray diffraction studies and differential thermal analyses of clay from selected samples. Fossil spore content of selected samples was also determined.

Acknowledgments

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STRATIGRAPHY

Structural Setting

Jewett (1951) provided a concise summary of the major structural features of Kansas. Reed (1954) indicated the Nebraska names for extensions of the structures identified by Jewett. As examples, Table Rock Arch is the Nebraska name for the famous Nemaha Anticline of Kansas, and Central Nebraska Basin is the Nebraska name for the northern extension of the Salina Basin of Kansas. It should be interesting to observe the relations of the Red Eagle cyclothem to these structures, because if they existed in Red Eagle time they might have influenced the cyclothemic sedimentary facies.

In southern Kansas (Cowley and Elk Counties) the Red Eagle Limestone crops out in a belt close to and paralleling the axis of the Otto-Beaumont Anticline (Fig. 1). In southwestern Greenwood County the trend of the Otto-Beaumont Anticline swings northeastward toward Eureka. The Red Eagle outcrop belt continues northward, in a position between the Nemaha Anticline to the west and the Otto-Beaumont Arch on the east. Farther north, the band of outcrop lies athwart the Nemaha Anticline-Bourbon Arch area of Chase County and the Nemaha Anticline-Alma area of Riley and Wabaunsee Counties. Northward from Manhattan the band of outcrop divides, running parallel to the Nemaha Anticline on either flank in Marshall and Nemaha Counties, Kansas, and in Nebraska.

The close association of the outcropping rocks with these structurally positive areas raises a question as to whether the structures were tectonically active during deposition of the Red Eagle cyclothem, and if so, whether they controlled the sedimentary facies. Evidence to support this possibility may be sought in facies changes in Red Eagle rocks as the belt of outcrop wanders away from, or toward, the aforementioned structural trends.

Moreover, the facies patterns may give evidence not only of activity along major structural trends (e.g., Nemaha Anticline) during Red Eagle time, but they also may indicate short intervals of tectonic activity in isolated areas where the structural record has not been amplified by accumulated "pre- and post-Red Eagle" movements.

Whereas rocks of the Red Eagle cyclothem crop out along a belt trending roughly north-south from Lincoln, Nebraska, through Manhattan, Kansas, to Burbank, Oklahoma, their gentle regional dip is toward the west. They can be detected in wells drilled as far west as Barber and Rice Counties, Kansas (Lee, 1949).

Figure 1 shows the outcrop belt and locations of key sections that were measured and sampled for this report. Detailed descriptions and illustrations of these sections appear in the Appendix. Figure 2, a simplified north-south cross section through localities shown on Figure 1, shows the fundamental correlations of rock units within the Red Eagle cyclothem.

Stratigraphic Relations

The gray shale and mudstone of the Johnson Shale are easily recognizable below the lowest fusulinid-bearing limestone (Glenrock) of the Red Eagle Limestone, and above the upper (Long Creek) limestone member of the Foraker Limestone.

Near Manhattan, Kansas, the Red Eagle Limestone is a kind of "sandwich"—the gray Bennett Shale Member lies between the Glenrock Limestone Member, below, and the pelletoid Howe Limestone Member, above.

The Glenrock Member is commonly a single, massive, light-brown limestone unit about 1 foot thick, containing abundant fusulinid remains. Its uniformity of thickness and lithology through 150 miles of outcrop from Lincoln, Nebraska, to Allen, Kansas, is truly remarkable. South of this area the fusulinid-bearing Glenrock is thinner or absent.

The Bennett Member can be readily recognized by its basal black *Orbiculoidea*-bearing shale that rests on the distinctive Glenrock Limestone. The gray shale and light-cream-gray limestone may also be identified by virtue of their relation to the overlying, equally distinctive Howe Limestone.

The Howe Member is a massive limestone unit commonly 2 or 3 feet thick. North of Manhattan much of the unweathered rock is aphanitic. In a number of localities south of Manhattan it is distinctively pelletoid (pseudo-oolitic). The pellets are coatings of calcium carbonate around tiny nuclei such as foraminifers or ostracodes.

The Roca Shale is easily identifiable by its position above the Howe Limestone. The top of the Roca is equally clear at the base of the overlying Sallyards Limestone (lowest member of the Grenola Limestone). The Sallyards Limestone is a thin, light-gray-brown unit crowded with well-preserved pelecypods (e.g., *Pseudomonotis, Aviculopecten*). Red shale is common in the midst of the principal gray and greenish-gray shale of the Roca Shale.

The three members of the Red Eagle "sandwich" of northern Kansas merge to form the single Red Eagle Limestone of southern Kansas and northern Oklahoma. This merging occurs because the Bennett Member is shaly in northern Kansas and changes to limestone in the south. Throughout the area studied the Johnson and Roca Shales are readily recognizable by their relations to the Red Eagle Limestone and to distinctive marker horizons above and below. Near Burbank, Oklahoma, the lower half of the Roca Shale is mostly red.

Rocks of the Red Eagle cyclothem can be detected and traced in wells as far west as central Kansas, where their general stratigraphic relations seem similar to those in the outcrop belt. The thin Bennett Shale, however, is not clearly recognized in the subsurface. Subsurface sections seem similar to outcropping sections. Lee (1949) has shown that the thicknesses and major lithic types of the Johnson, Red Eagle, and Roca in southern and central Kansas are generally similar to those in the outcrop belt 100 miles to the east. Lee's data, taken with observations made in this study, lead to the conclusion that in the southeastern quadrant of Kansas, major facies patterns of the Red Eagle cyclothem developed in roughly east-west belts. Well data also reveal the presence of gray and red shale in the Roca and gray shale in the Johnson parts of the column. Traces of selenite seem to be present near the redbeds in the subsurface Roca.

The locations of sections mentioned in the following pages are shown in Figure 1 and listed in Table 2.

Table 2.—Observed outcrops of the Red Eagle cyclothem.

Locality	Section	Township	Range	County
NEBRASKA				
Bennet	NE 11	8 N	8 E	Lancaster
Glen Rock	NW SW 30	6 N	14 E	Nemaha
Johnson	NW NE 6	5 N	13 E	Nemaha
Tecumseh	NE 33	5 N	10 E	Johnson
Howe	NE 15	4 N	14 E	Nemaha
Pawnee North	NW 26	2 N	10 E	Pawnee
Pawnee	C NW NW 11	1 N	10 E	Pawnee
Pawnee South	SW 23	1 N	10 E	Pawnee
Richardson East	NW 19	1 N	14 E	Richardson
Richardson West	SW 27	1 N	13 E	Richardson
Humboldt	SE SE 16	1 N	13 E	Richardson
KANSAS				
Frankfort	NE NW 21	4 S	9 E	Marshall
Manhattan	NE 7	10 S	8 E	Riley
Manhattan East	CNL 20	10 S	8 E	Riley
Manhattan West	NW NE 24	10 S	7 E	Riley
Paxico	SW 30	11 S	12 E	Wabaunsee
Alma	SW NE 11	12 S	10 E	Wabaunsee
Keene	SE 24	13 S	12 E	Wabaunsee
Eskridge	SE NE 17	14 S	12 E	Wabaunsee
Eskridge Quarry	NW 32	14 S	12 E	Wabaunsee
Eskridge South	NE 6	15 S	12 E	Wabaunsee
Judith	NW NW 7	15 S	12 E	Wabaunsee
Coffman Ranch	S/2 NW 23	15 S	11 E	Lyon
Allen	NW SW 36	15 S	11 E	Lyon
Allen No. 2	SW NW 35	15 S	11 E	Lyon
Dunlap	SE SE 23	17 S	9 E	Morris
Saffordville	NW SW 30	19 S	9 E	Chase
Elmdale	C 26	19 S	7 E	Chase
Turnpike (mile 118.1)	17	20 S	10 E	Lyon
Sallyards	SW NW 11	26 S	8 E	Greenwood
Piedmont	NE SW 30	27 S	8 E	Greenwood
Grand Summit	SE 3	31 S	8 E	Elk
Highway 38	S line 21	32 S	8 E	Cowley
OKLAHOMA				
Red Eagle	SW SE 25	28 N	6 E	Osage
Burbank	C 25	26 N	5 E	Osage

Johnson Shale

The Johnson Shale was named by Condra (1927, p. 86), "From exposures 1½ miles north of Johnson, Johnson County, Nebraska; formed of bluish argillaceous shale modified by thin, grayish, sandy layers, calcareous plates, and some gypsiferous material, and geodes; thickness 16 to 18 feet. There are very few fossils."

The Johnson Shale formation is still well exposed in a creek bank north of Johnson, Nebraska, approximately where Condra indicated. However, Johnson is in Nemaha (not Johnson) County, Nebraska. This location is east of the axis of the Table Rock (Nemaha) Arch (Fig. 1).

At the type locality (Johnson section; see Appendix) the base of the Johnson Shale is difficult to ascertain. The Long Creek Limestone below is badly disintegrated and weathered to a rusty to greenish, limonitic, chalky, soft residuum. In parts of Kansas the Long Creek Limestone is more resistant and clearly defined.

The Johnson Shale is approximately 17 feet thick at the type locality, where it is composed mainly of medium- to light-gray mudstone. The upper 1.5 feet comprises medium-gray, moderately laminated, very calcareous (50 percent), slightly silty shale that weathers to light buff. Some of this shale seems to be vaguely ripple marked. Laboratory examination revealed that it contains fish teeth, ostracodes, and small gastropods.

A thin, light-brownish-gray, argillaceous limestone underlies the upper, fossil-bearing shale. In the field this limestone appears aphanitic, but actually it is a laminated argillaceous calcisiltite having a few angular calcareous mudstone fragments. It exhibits vague, small-scale diastems and graded bedding. Fragments of carbonized woody plant detritus are present in the light-greenish-gray mudstone that immediately underlies this limestone.

At the type locality the remainder of the Johnson Shale, down to its base, is mainly greenish-gray calcareous mudstone. In the lower half of the formation the mudstone is slightly less calcareous than in the upper half. A thin plate of light-brownish-gray, dense, argillaceous limestone occurs just below the middle of the formation, but below it the only "limestone" present is sparse calcium carbonate nodules within the greenish-gray calcareous mudstone.

The northernmost exposure, near Bennet, Nebraska, is about 25 miles northwest of the axis of the Table Rock (Nemaha) Arch. The Johnson Shale is nearly 16 feet thick at the Bennet section (Appendix). The upper 2 feet of medium-gray, well-laminated shale is apparently equivalent to the upper 1.5 feet of moderately laminated shale at the type section. This shale is barren of fossils and much less calcareous (15 percent) than its equivalent at the type section. The rest of the formation consists almost entirely of moderately laminated, calcareous light-gray shale, the lower half of which is somewhat more calcareous than the upper—the reverse of the conditions at the type section.

A thin (0.5-foot) red shale, which seems to have no red equivalent elsewhere, appears in the middle of the Johnson Shale at the Bennet section. This is taken as the lower boundary of the Red Eagle cyclothem (Elias, 1937). Shale with limestone lenses near the base of the Bennet section seems equivalent to the mudstone with limestone nodules near the base of the type Johnson section. Traces of foraminifers, gastropods, and fish teeth occur about 5 feet from the base of the Bennet section.

To the south, in Pawnee County, Nebraska, 6 miles west of the Table Rock (Nemaha) Arch axis (Pawnee section; see Appendix), the Johnson Shale is composed mainly of mudstone very similar to that at the type locality. A few fragments of carbonaceous plant remains occur in thin, shaly, medium-gray mudstone in the top foot of the unit. This fine-silty mudstone also contains traces of ostracodes, a few clay-filled tubes suggesting worm burrows, and local mudstone-pebble breccia (some pebbles are oriented roughly parallel to bedding planes). The rest of the formation is virtually unfossiliferous.

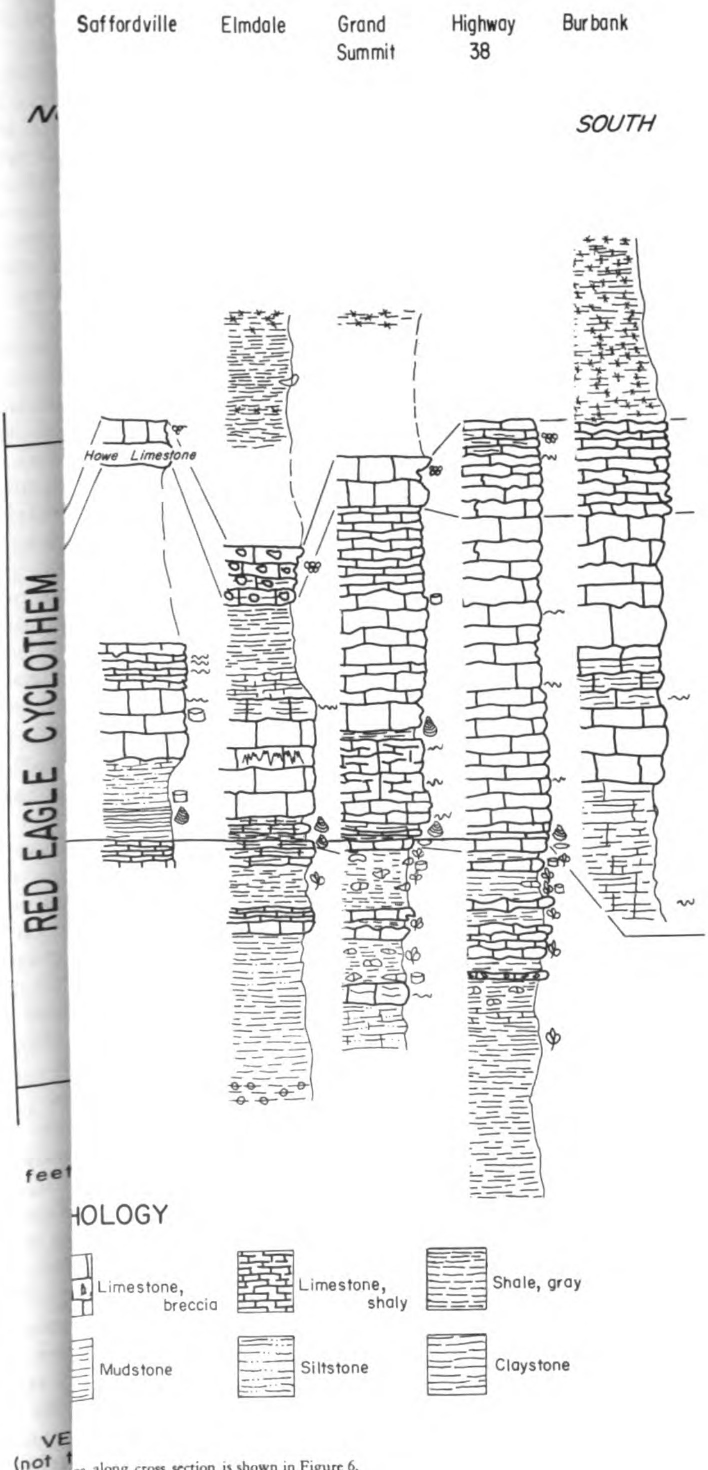
A compact, laminated siltstone or mudstone unit (microbrecciated in places) appears near the top of the Johnson Shale at Pawnee. Textures vary microscopically from one lamina to another. This unit yields platy debris and, for convenience in the following descriptions, is called platestone. Commonly this unit is calcareous.

The remainder of the formation at the Pawnee section consists mainly of gray and greenish-gray mudstone and calcareous muddy siltstone. This sequence is interrupted only by a massive, 1-foot argillaceous limestone, vaguely nodular in some places, which occurs about 2 feet below the platestone. Megascopically this limestone appears uniformly aphanitic. However, magnified peel prints reveal that it contains minute wavy laminations associated with microscopic graded textures, suggesting slight diastems.

About 20 miles east of the Pawnee section, 0.5 mile east of the Humboldt Fault, the upper part of the Johnson Shale is exposed in a small road cut (Humboldt section; see Appendix). The upper Johnson argillaceous sediments resemble those at the Pawnee section in general appearance. In carbonate content they resemble the upper Johnson at the type section. The thin uppermost shale unit of the Johnson Shale at the Humboldt section correlates with shale in analogous position at the other Nebraska sections. At Humboldt, however, this upper shale is deeply weathered from its original gray color to a light yellowish gray-brown.

The Frankfort section (Appendix) lies just west of the axis of the Nemaha Anticline, about 30 miles south of the Pawnee section. Only the upper part of the Johnson Shale is exposed at Frankfort—sufficient to show the same clay shale at the top and a thinner, more compact platestone unit than is developed farther north. Ostracodes occur in shale between these units. Here the platestone is a limestone, thinly laminated, yielding platy debris much more brittle than the more argillaceous equivalents to the north. The bulk of the Johnson Shale at Frankfort consists of calcareous, light-gray and greenish-gray shale and mudstone typical of the Johnson Shale elsewhere.

At the Manhattan section (Appendix) the Johnson Shale consists largely of light-gray shale, with some light-greenish-gray shale in the lower half. The section is slightly thicker (17.8 feet) here than in Nebraska, where other complete sections (15-16 feet) of Johnson Shale are exposed. The distinctive platestone horizon occurs about 4 feet below the top of the formation, although nearby it is only 2 feet below the top.



es along cross section is shown in Figure 6.

Above it is the usual ostracode-bearing light-gray shale, topped by a foot of well-laminated shale containing traces of crinoid, echinoid, bryozoan, brachiopod, and ostracode remains. This uppermost shale correlates with beds similar in position and lithology farther south. Beneath the platestone unit, the medial few feet of the formation contains light-buff to gray argillaceous limestone and very calcareous light-gray shale. Greenish-gray and gray slightly calcareous shale makes up the lower one-third of the formation. The base rests on resistant Long Creek Limestone. The Manhattan section lies just west of the crest of the Nemaha Anticline.

The Alma section (Appendix) is 20 miles southeast of Manhattan and east of the Nemaha Anticline. At this locality only a few feet of the Johnson Shale are sufficiently exposed to permit reliable sampling. The familiar platestone occurs here, overlain by the equally familiar ostracode-bearing gray shale of the uppermost Johnson. Slumping confuses supradjacent beds, but the fossils indicate that the sampled shale is nearly equivalent to the topmost Johnson Shale. However, the local absence of the Glenrock Limestone precludes definitive measurement to the top of the Johnson.

The upper part of the Johnson Shale is well exposed at the Paxico section (Appendix). Three feet of typical gray, well-laminated, ostracode-bearing shale tops the formation and rests on 4 feet of calcareous mudstone and shale, which in turn rests on the platestone. Thus, at the Paxico section there is about twice the usual thickness of Johnson sediments above the platestone horizon. Moreover, the platestone is comparatively even textured and much less argillaceous than at other sections. Light-greenish-gray mudstone lies beneath the platestone.

At the Keene section (Appendix), 10 miles southeast of Paxico, only the platestone part of the Johnson Shale is well exposed. Here the platestone is well laminated and has the typical microscopically graded textures. The low content of insoluble mud in platestone at Keene is similar to that of the platestone at Paxico. About 5 feet of upper Johnson shale? above the platestone is not exposed.

The Eskridge section (Appendix) provides the southernmost exposure of the platestone facies of the Johnson Shale in Wabaunsee County. The platestone is faintly ripple marked and shows channeling as deep as 2 mm. About 3 feet of ostracode-bearing shale lies above the platestone. Light-gray and greenish-gray calcareous mudstone and shale typical of the Johnson Shale lie below. Beds below the platestone are similar to their equivalents in Nebraska and northern Kansas, except that rare traces of ostracodes and carbonaceous remains occur in the upper 2 or 3 feet. Charophytes are present near the base of the exposure.

At the Eskridge South section (Appendix), 4 miles south of the Eskridge locality, the upper half of the Johnson Shale is partly exposed in a farmyard. Dark-gray, calcareous, ostracode-bearing shale, some with plant remains, forms the upper 5 feet of the exposure. This rests on muddy limestone, possibly equivalent to the platestone horizon. The lower part of the exposure contains greenish-gray shale below a thin, local, argillaceous limestone that contains traces of ostracodes.

The few feet of upper Johnson sediments exposed at the Coffman Ranch section (Appendix) are similar to those at Eskridge South. Ostracodes and carbonaceous plant remains are rare to common in the upper 4 feet of calcareous shale. Traces of carbonaceous remains are visible in the underlying laminated muddy limestone.

At the Allen section (Appendix) carbonaceous remains and ostracodes are rare to common in the upper shale of the Johnson Shale. These beds rest on vaguely laminated muddy limestone and limy mudstone which are very similar to the stratigraphic equivalents at the nearby Coffman Ranch locality.

About 40 miles southwest of Allen, at the Elmdale section (Appendix), the upper two-thirds of the Johnson Shale is well exposed. Here, too, plants and ostracodes are present in the uppermost shale. Approximately 2.5 feet from the top, a laminated platy argillaceous limestone unit, faintly ripple marked, is the apparent equivalent of the platestone farther north in Kansas. Some of the laminations are extremely smooth and even. Greenish-gray mudstone, increasingly calcareous towards the base, makes up the remainder of the Johnson Formation.

At the Saffordville section (Appendix), 12 miles east of Elmdale, only platy limestone, bearing ostracodes, is exposed below the Red Eagle Formation. This appears to be the southernmost observable development of Johnson platestone facies.

In southern Kansas, at the Grand Summit section (Appendix), the upper half of the Johnson Shale is well exposed. The uppermost 5 feet is light-brownish-gray and medium-gray, calcareous, well-laminated shale containing light-gray aphanitic limestone nodules and lenticles. The shale contains gastropods, ostracodes, brachiopods, and carbonized fragmental plant material. Among the brachiopods, ***Linoproductus***, ***Chonetes***, and ***Productella?*** are common. Gastropod and brachiopod fragments occur in the limestone. Calcareous mudstone and shale constitute most of the remainder of the Johnson Shale at Grand Summit.

At the Highway 38 section (Appendix) in Cowley County, the upper half of the Johnson Shale is similar to that at the Grand Summit locality. Here, in the upper 5 feet, similar shale with nodular limestone contains the same assemblage of ostracodes, plant remains, and common productid brachiopods observable at Grand Summit. A thin maroon mudstone occurs about 16 feet below the top of the Johnson Shale. This is taken as the base of the Red Eagle cyclothem. No good exposures of Johnson Shale are known south of Highway 38.

SUMMARY.—The Johnson Shale is composed mainly of light-gray shale and mudstone immediately below the distinctive Red Eagle Limestone. In Nebraska it is at least 15 feet thick, and it thickens to 25 feet southward in Kansas. Workable exposures are rare. In most places, especially in southern Kansas and northern Oklahoma, it forms gentle grass-covered slopes between thin limestone benches. Maroon mudstone has been observed in the lower half of the formation only at the Oklahoma-Kansas border, in southern Kansas, and at Bennet, Nebraska. In southern Kansas the upper 5 feet of the Johnson Shale consists of fossiliferous shale containing aphanitic limestone nodules and lenticles. From central Kansas to the Nebraska border, the upper few feet of the Johnson Shale consists of laminated gray shale with ostracodes and carbonized plant remains. (The plant remains are rare in Nebraska.) In the same area the laminated shale is underlain by a horizon characterized by laminated muddy limestone yielding platy debris. In some places the purer, platy, brittle limestone may be conveniently called platestone. The platy horizon is identifiable from a few miles north of the Nebraska-Kansas border southward to Saffordville, Kansas. Shale in the lower half of the formation is almost invariably unfossiliferous.

Red Eagle Limestone

The Red Eagle Limestone was named by Heald (1916, p. 24-25) from "excellent" exposures near Red Eagle School, about 3 miles west of Foraker, Osage County, Oklahoma. Heald referred to these exposures as ". . . a number of distinct beds of limestone, between which are beds of shale in some localities." The Red Eagle School mentioned by Heald was destroyed many years ago, and the limestone exposures in that neighborhood (Red Eagle section; see Appendix) represent only a part of the total thickness.

The best exposures of the Red Eagle Limestone in the type area are in the large quarry immediately north of U.S. Highway 60, just east of Burbank, Osage County, Oklahoma (Burbank section; see Appendix). This is the southernmost locality sampled for this investigation.

The Burbank section exposes approximately 21 feet of limestone beds. The Red Eagle base is buried. In the lower 6 feet of the exposed interval, brownish-gray, aphanitic to microcrystalline, medium- to thin-bedded limestone grades laterally into similar but shaly laminated limestone. Somewhat wavy, laminated, calcareous shaly interbeds are characteristic of this part of the sequence. These limestone beds contain rare to common productid brachiopod fragments, crinoid columnals, and ostracodes, all oriented roughly parallel to bedding planes. Three feet of hard, dense, massive, medium- to thick-bedded, light-brownish-gray limestone rests on the aforementioned shaly limestone. Rare to common crinoid columnals and rare brachiopod and ramose bryozoan remains are present in the dense microcrystalline matrix. Stringers of shaly calcareous material and calcareous shale intergrade laterally with this limestone. Shaly interbeds up to 0.5 inch thick emphasize the thick, resistant limestone beds. Eight feet of light- to medium-greenish-gray, argillaceous, medium-bedded limestone overlies the massive, brownish-gray, microcrystalline limestone. The greenish-gray color accompanies a greater (10 to 15 percent more) clay content than that in the lower brownish limestone. Crinoid discs and brachiopod fragments are rare to common in the aphanitic argillaceous matrix. Some beds are vaguely laminated and argillaceous enough to appear shaly when deeply weathered.

The strata just described from the Burbank section total about 17 feet in thickness. Their lithologies, bedding, and faunal content indicate that they represent a facies of the Bennett Member of the Red Eagle Limestone. The more massive, resistant parts of this Bennett Member form subdued topographic benches in northern Oklahoma and southern Kansas.

At the Burbank section 4 feet of irregularly bedded limestone, resting on the limestone of the Bennett Member, is distinctive—thickly to thinly bedded, pitted, rusty weathering, and penetrated by brick-red clay and clayey limestone stringers and tubes. Traces of crinoids, brachiopod fragments, and arenaceous foraminifers are present. Nothing quite like these beds is known in Kansas. They are tentatively correlated as equivalents of the Howe Member of the Red Eagle Limestone, mostly because of their position below Roca red shale and above probable Bennett limestone. No equivalents of the Glenrock Member of the Red Eagle Limestone have been recognized in Oklahoma.

South of the Burbank area the Red Eagle Limestone is poorly and only partly exposed. The resistant portions of the Bennett Member thin southward in Osage County, Oklahoma, and can be traced to the Arkansas River west of Fairfax, where Fisher (1956, p. 83) noted a thickness of 1.9 feet of Red Eagle Limestone within a 125-foot covered interval.

In the Foraker area, at the Red Eagle section (Appendix), about 1.5 miles east-southeast of Heald's type locality, the massive limestone of the middle of the Bennett Member forms a minor hillside bench. This can be traced northward into Kansas and southward beyond Burbank, Oklahoma. Depending upon the proportion of the less resistant argillaceous limestone, the ledge-forming limestone of the Bennett Member ranges in thickness from 3 to 6 or more feet. The Red Eagle section reveals 5 feet of massive, thick-bedded, light-brownish-gray, somewhat vuggy, pure limestone. The assemblage of bryozoans, arenaceous foraminifers, crinoids, and brachiopod fragments suggests that these beds are equivalent to the medial, nearly pure, resistant limestone unit of the Bennett Member at the Burbank section. In the Foraker (Red Eagle section) area of northern Oklahoma, the Howe Member equivalent does not seem to resist weathering any better than the softest of the Bennett limestone beds. The Howe is detectable in the Foraker area only from rare slabs of limestone float (similar to Burbank "Howe") in covered intervals just above the resistant Bennett limestone.

In southern Kansas, at the Highway 38 section (Appendix), the members of the Red Eagle Limestone are all definitely recognizable. The Glenrock Member disappears somewhere south of Highway 38, probably near the state line. Northward from Highway 38, the Glenrock, Bennett, and Howe Members of the Red Eagle Limestone are traceable through facies changes to and beyond their type localities in southeastern Nebraska. The Elmdale, Saffordville, and Alma localities (Appendix), where the Glenrock Member is not recognized, are somewhat anomalous. Facies changes within the members of the Red Eagle Limestone formation are discussed below.

Glenrock Limestone Member

The Glenrock Limestone Member of the Red Eagle Limestone was named by Condra (1927, p. 86) ". . . from exposures high in the valleyside just northwest of Glenrock, Nemaha County, Nebraska; dark gray, dense, weathering light gray or slightly buff; thickness 1 to 2 feet. This forms rectangular blocks. The leading fossils are Fusulina, bryozoa, brachiopods, and Pinna sp."

At its type locality near Glen Rock,* Nebraska, the Glenrock Member forms an inconspicuous ledge cropping out on long, gentle, grassy slopes which hide the shale above and below. Upper and lower contacts are not visible. The unit may be sampled best from rare blocks displaced by road building, or in ditch cuts. The type Glenrock Member is a light-brownish-gray fusulinid-bearing limestone, 1 foot thick. It weathers to light gray. Common fusulinids (*Triticites* sp.), brachiopods, and ostracode fragments repose in a microcrystalline to aphanitic calcareous matrix containing only 10 percent insoluble clays. The rock is hard and even textured, and it presents an oatmealy appearance on fresh surfaces. Fusulinids here are slightly smaller than in other exposures of the Glenrock Member.

O'Connor and Jewett (1952, p. 343) asserted that "the Glenrock limestone can be divided into two faunal and lithologic parts: (1) fusulinid-bearing rock above, and (2) a nonfusulinid part at the base" and that "in a few places one or the other is not present or is poorly developed." This is an accurate appraisal of what field reconnaissance reveals. Detailed studies show that the lower portion of the Glenrock Member is not everywhere "nonfusulinid," although its fusulinid content is commonly sparse. Where this twofold character of the Glenrock Limestone is manifest, the fusulinid-bearing rock grades into "nonfusulinid" rock with no perceptible break.

At the Bennet section (Appendix) the Glenrock Limestone is a massive, ledge-forming unit

* The spelling "Glenrock" for the rock unit is retained for reasons discussed by Moore (1952).

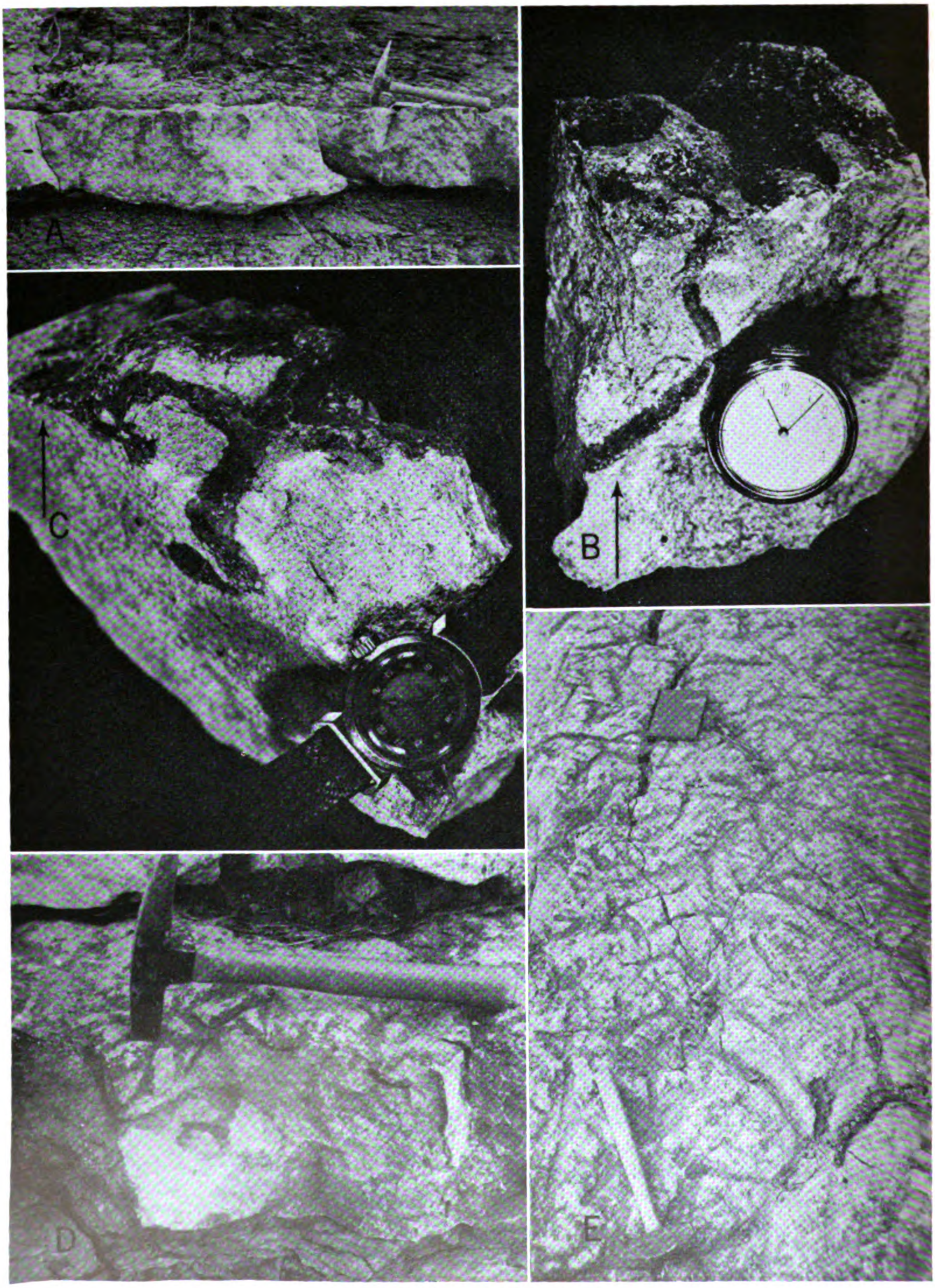


PLATE 1.—Glenrock Limestone at Pawnee section. **A**, Undulatory base; **B** and **C**, uppermost limestone showing black tubes interpreted as worm burrows; **D**, closeup showing worm burrows on outcrop (below face of hammer); **E**, channels and trails in top of Glenrock. Arrows point to top of bed.

1.5 feet thick. The upper 0.5 foot of this rock contains numerous fusulinids, but the lower 1 foot contains none. Brachiopods, other foraminifers, and ostracodes are common where fusulinids are absent. Faint traces of linear algae occur in this lower portion. The calcareous microcrystalline matrix for fusulinids and other fossil detritus contains less than 10 percent insoluble clay. The upper foot of the unit has a few random patches of muddy limestone somewhat similar to the overlying shale of the Bennett Member. Fusulinids in this part of the Glenrock Member show some tendency toward orientation parallel to the bedding. Vague, wavy, clay-limestone seams, much fainter than the subtlest diastem, share the vague preferential orientation. The lower 0.5 foot of the member is practically structureless and even textured. The Glenrock Limestone weathers light gray. The lower contact of the Glenrock is gently undulatory, and the Glenrock rests on the shale of the uppermost Johnson Shale with only slight evidence of erosion. The upper contact is also slightly undulatory beneath dark-gray *Orbiculoidea*-bearing Bennett Shale. These contacts are unusually clear and sharp.

At the Johnson section (Appendix) the Glenrock Limestone is 1 foot thick and resembles its equivalent at the type section. The upper 0.9 foot contains abundant fusulinids and rare to common brachiopod detritus. The basal 0.1 foot of the unit consists of hard, dense, aphanitic to microgranular limestone which lacks fusulinids. The upper and lower contacts are weakly undulatory and typically sharp.

The Pawnee section (Appendix) exposes a distinctive development of Glenrock Limestone. The thickness ranges from 0.7 to 1.0 foot. Fusulinids abound in the upper half of the unit, along with common frail brachiopod fragments and rare gastropods. The lower half lacks fusulinids and gastropods but contains common brachiopod fragments. Acetate peel prints reveal that many of these brachiopod fragments are coated with secondary calcite, similar to the alga *Osagia*. The partly bioclastic calcareous matrix for the detrital material is aphanitic to microgranular and somewhat argillaceous.

The base of the unit is gently undulatory (Pl. 1A) and locally rests on small lenses, an inch or two thick, of buff aphanitic limestone containing brachiopod fragments. The upper limit is even more distinctive than the gently undulatory base. It is undulatory, or lumpy and channeled, but on a small scale (1-inch relief). The pattern of lumps and channels suggests that the top of the limestone is traversed at random by depressions representing the trails of benthonic animals (Pl. 1E). The shale of the overlying Bennett Member is impressed into these trails and, surprisingly, contains fusulinids. The top few inches of the limestone is randomly penetrated by tubes (worm burrows?) filled with black muddy material (Pl. 1B, 1C, 1D) continuous with the black shale of the basal Bennett Member. Some of these black tubes also contain fusulinids and *Osagia*-coated shell detritus.

In southwestern Richardson County, Nebraska, atop the Nemaha Anticline, the Glenrock Limestone is well exposed at the Humboldt section (Appendix). Here, also, the base of the unit is undulatory, with relief of about 0.1 foot. The upper contact is almost flat. As usual, fusulinids abound, along with many brachiopod fragments, in a microcrystalline to very finely granular (aphanitic) calcareous matrix. Most of these fossils are oriented crudely parallel to the bedding. Some of the brachiopods are coated by calcareous deposits which suggest *Osagia* or other algae. There is also some evidence of linear algae. Articulate brachiopod shells are present but scarce. They are filled with calcarenaceous bioclastic detritus in a microcrystalline, clear calcitic matrix. Locally the rock is medium grayish brown on fresh surfaces, but it weathers to medium rusty brown rather than the light gray typical of most weathered Glenrock Limestone. It forms an indistinct ledge, 1 foot thick, in the grassy hillsides of the area.

The Glenrock Member is thicker (1.8 feet) than average at the Frankfort section. Fusulinids are extremely rare in the lower 0.5 foot of the unit but gradually increase in number upward. Where fusulinids are scarce, brachiopods are quite common. The upper 0.5 foot of the Glenrock Limestone contains abundant fusulinids and scarce brachiopods, which include *Composita* sp. and productids. Not all shell detritus is broken. Traces of articulated brachiopod shells are visible in polished rock sections. A few ostracodes and uncrushed gastropods accompany the brachiopod detritus. A few of the frail brachiopod fragments are coated by calcareous algal deposits similar to *Osagia*. The organic detritus in the fusulinid-rich limestone is not visibly sorted. In the lower portion of the unit a patchy sorting is common where some textural patterns vaguely extend parallel to bedding, and some brachiopod shell detritus is similarly aligned.

At the Manhattan section (Appendix) the Glenrock Member (1.3 feet thick) is superficially normal, but close examination reveals a distinctive local lithology. The Glenrock Member comprises fine conglomeratic, calcirudaceous, medium- to light-brownish-gray limestone. Randomly oriented granules and small pebbles of aphanitic, greenish-gray to buff, argillaceous limestone are bound by a calcarenaceous to calcaphanitic limy matrix containing many brachiopod shells. Most of these shells are coated by calcareous deposits similar to *Osagia*, and some show crude preferential orientation parallel to bedding. Ostracodes and gastropods are also present in the matrix. The rock lacks fusulinids. Upper and lower contacts are relatively even and clearly defined.

At the Paxico section (Appendix) the lithology of the Glenrock Limestone is intermediate between the nonfusulinid material found locally at the Manhattan section and the widespread, fusulinid-rich rock found elsewhere. Aphanitic buff limestone granules occur in the calcisiltaceous to calcaphanitic light-creamy-gray matrix of the lower part of the unit. Fusulinids are rare and the limestone granules are scarce in the similar but medium-brownish-gray matrix of the upper limestone. A few brachiopod fragments and spines, ostracodes, bryozoans, and small gastropods occur randomly throughout the unit. The upper and lower contacts are even and distinct.

The Glenrock Limestone Member is apparently absent from the Alma section (Appendix) area. This observation was first made by O'Connor and Jewett (1952, p. 350). Shale of the Bennett Member of the Red Eagle Limestone probably rests paraconformably on upper shale of the Johnson Shale. Moreover, poor exposures make it impossible to determine whether the Glenrock is the only missing part of the Red Eagle Limestone formation. Such absence might be the result of nondeposition. O'Connor and Jewett (1952, p. 343) placed the base of the Red Eagle Limestone "at the contact between the black or dark-gray shale beds and the gray-green or gray limy beds of the Johnson." Actually, this dark-gray shale contains ostracodes and carbonaceous remains characteristic of uppermost Johnson elsewhere. Hence the contact must be slightly higher in the Alma section than the lithologic level noted by O'Connor and Jewett. Precisely how much higher could not be ascertained because of unsatisfactory exposures.

About 13 miles southeast of Alma and Paxico, at the Keene section, the Glenrock Member is a normal-appearing, 1-foot, light-brownish-gray, calcarenaceous, fusulinid-bearing limestone. Traces of *Osagia*-coated shell fragments occur with the fusulinids. The base of the unit is even. The upper contact, partly obscured by weathering, is somewhat lumpy and resembles the one at the Pawnee section. In some parts of the outcrop, the top inch of Glenrock Limestone is argillaceous, lacks fusulinids, and is medium gray, as though heralding a complete change to Bennett black shale at the top contact. Traces of *Orbiculoidea* fragments are present in a few places within the top half inch.

At the Eskridge section (Appendix) the Glenrock is the usual fusulinid-bearing light-brownish-gray limestone about 1 foot thick. Traces of argillaceous material bearing *Orbiculoidea* fragments are present in the uppermost 1 inch. Upper and lower contacts are mostly distinct, but weathering has obscured details of the upper contact in some places. The top fusulinid-rich inch, which contains *Orbiculoidea* fragments, shows evidence of burrowing and resettling from the Bennett Member above. Traces of milky, secondary opaline silica are present in the top inch of the unit.

The Glenrock Member at the Judith section (Appendix) is very similar to that at the Eskridge section, but the upper contact has not been weathered. Fusulinids abound, along with many brachiopods and a few ostracodes and smaller foraminifers, in the calcarenaceous to calcaphanitic matrix. The top is gradational to the Bennett Member above through half an inch of shaly argillaceous limestone. This thin limestone contains numerous *Orbiculoidea*, traces of *Lingula*, and traces of fish teeth. The lower contact is buried.

At Eskridge South (Appendix) the Glenrock Limestone lithology is almost the same as at the Judith section, except that the upper half inch contains patches of dark-gray argillaceous material. The top is lumpy and gently undulatory (0.05-foot relief) and displays random patches of fusulinid coquina with traces of *Orbiculoidea* and fragments of bryozoans.

The section at Coffman Ranch (Appendix) shows the Glenrock Member as a medium-brownish gray limestone, considerably thinner than at sections to the north. It resembles Glenrock lithofacies in southern Kansas and yet shows other features characteristic of Nebraska

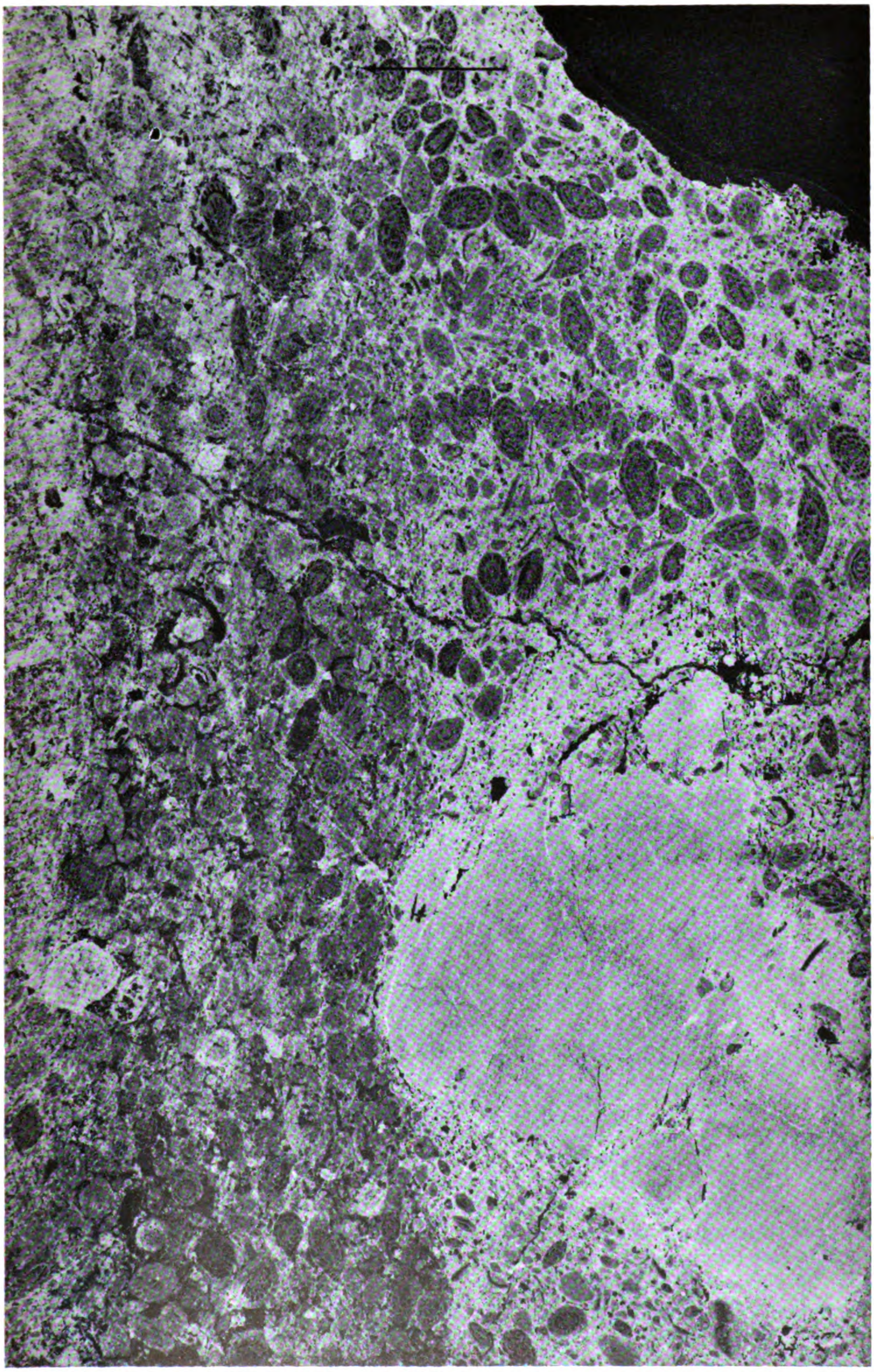


PLATE 2.—Peel print (X3.0) of Glenrock Limestone from Coffman Ranch section. Note large aphanitic limestone pebble and slight preferential orientation of fusulinids parallel to bedding planes. Arrow points to top of bed.

and northern Kansas facies. Its thickness ranges from about 0.2 to 0.4 foot within the 500-yard exposure. The base is gently undulatory through about 0.1 foot of section. Fusulinids, extremely abundant in the calcarenitic to calcaphanitic matrix, are accompanied by many or few brachiopods and small foraminifers. Many of the brachiopod fragments have coatings of algal calcium carbonate *(Osagia?)* but other fossils do not. Some parts of the rock are faintly conglomeratic, containing granules and pebbles of aphanitic argillaceous limestone or calcareous mudstone similar to but much less numerous than those at the Manhattan and Paxico sections. The pebbles are best represented in the otherwise normal fusulinid-bearing rock (Pl. 2) at and near the base of the Glenrock. The fragments at the base have lithology (and contain carbonaceous remains) similar to upper Johnson sediments. One such fragment is covered by *Osagia*-like algal material. Locally, the upper part of the unit is penetrated by tubes of *Orbiculoidea*-bearing, medium- to dark-gray argillaceous material continuous with the Bennett Shale above. These are much like the tubes at the Elmdale and Pawnee sections (Pl. 1, 3). At the top, the Glenrock Limestone grades upward through 0.1 inch of rock, from a fusulinid subcoquina to an *Orbiculoidea* subcoquina continuous with the overlying black *Orbiculoidea*-bearing shale of the Bennett Member. That is, the top contact is typically sharp.

At the Allen section (Appendix) the Glenrock Member is a light-brownish-gray ledge-forming limestone 1.3 feet thick. The upper half of the unit is crowded with fusulinids. Downward their number decreases, so that the lower one-third of the limestone is almost barren of fusulinids. Common aphanitic limestone granules and small pebbles similar to those at Manhattan are present in the medial part of the unit, where fusulinids are numerous (Pl. 4). Some of these algal? pebbles show shrinkage cracking. The pebbles are rarer and smaller in the lower part of the unit. A variety of fragmental fossil remains, most of which are brachiopods, along with a few tiny gastropods and ostracodes, occur amid the fusulinids and limestone granules. These fragments are more common where fusulinids are lacking. Many of the brachiopods are coated with deposits of calcium carbonate similar to *Osagia*. The matrix for the detritus is aphanitic to arenaceous, slightly argillaceous, calcium carbonate. The top contact of the Glenrock Member is gently undulatory, but the lower contact is even (Pl. 3).

The Glenrock Limestone at Allen No. 2 section (Appendix) is similar to its equivalent at the Allen section. Fusulinids are abundant, and occur with many brachiopods and a few gastropods in the usual calcaphanitic to calcarenitic matrix. Granules of aphanitic limestone and algal-coated brachiopods are uncommon. Irregular tubes of gray argillaceous material containing *Orbiculoidea* (similar to those at the Pawnee and Coffman Ranch localities) penetrate the upper 2 inches of limestone. The base of the unit is quite distinct and even but the top is gently undulatory and sharply defined. A subcoquina (similar to the one at the Coffman Ranch section), 0.15 inch thick, of *Orbiculoidea* and *Lingula* fragments in a black argillaceous matrix continuous with the overlying Bennett Shale, is plastered upon the top of the Glenrock Limestone.

The Glenrock is not present at the Saffordville section (Appendix), where lower shale of the Bennett rests paraconformably on upper (not uppermost) Johnson Shale.

A peculiar lithofacies which could be mistaken for Glenrock is visible at the Elmdale section (Appendix) below Bennett black shale. It is about 1 foot of argillaceous, light-gray to brownish-gray, vaguely laminated and faintly cross-laminated limestone. Tubes of dark clayey material containing *Orbiculoidea* and fish teeth, and short burrows containing Glenrock-like fusulinid-bearing limestone, penetrate the upper 0.1 foot of the unit from the thin Bennett black shale above (Pl. 3B). A patchy coquina of *Orbiculoidea* lies at the base of the overlying shale. Because these lithologies and structures are similar to those in the uppermost Glenrock Limestone at the Pawnee, Coffman Ranch, and Allen sections, this unit might be mistaken for an argillaceous facies of the Glenrock Member. However, the top of the unit is clearly defined and somewhat undulatory, and the less distinct base grades to shale which contains plant remains and ostracodes typical of the upper part of the Johnson Shale. Moreover, the color of the unit, its softness, its microstructures, its insoluble clay content, and its fossils suggest that it is part of the Johnson Shale. Thus, the combined evidence seems to demonstrate that the Glenrock member is absent at the Elmdale section, probably because of erosion.

The Glenrock Limestone is about 1.5 feet thick at the Piedmont section (Appendix). It consists of thin beds of limestone bearing abundant fusulinids in a microcrystalline matrix. Upper and lower contacts cannot be described in

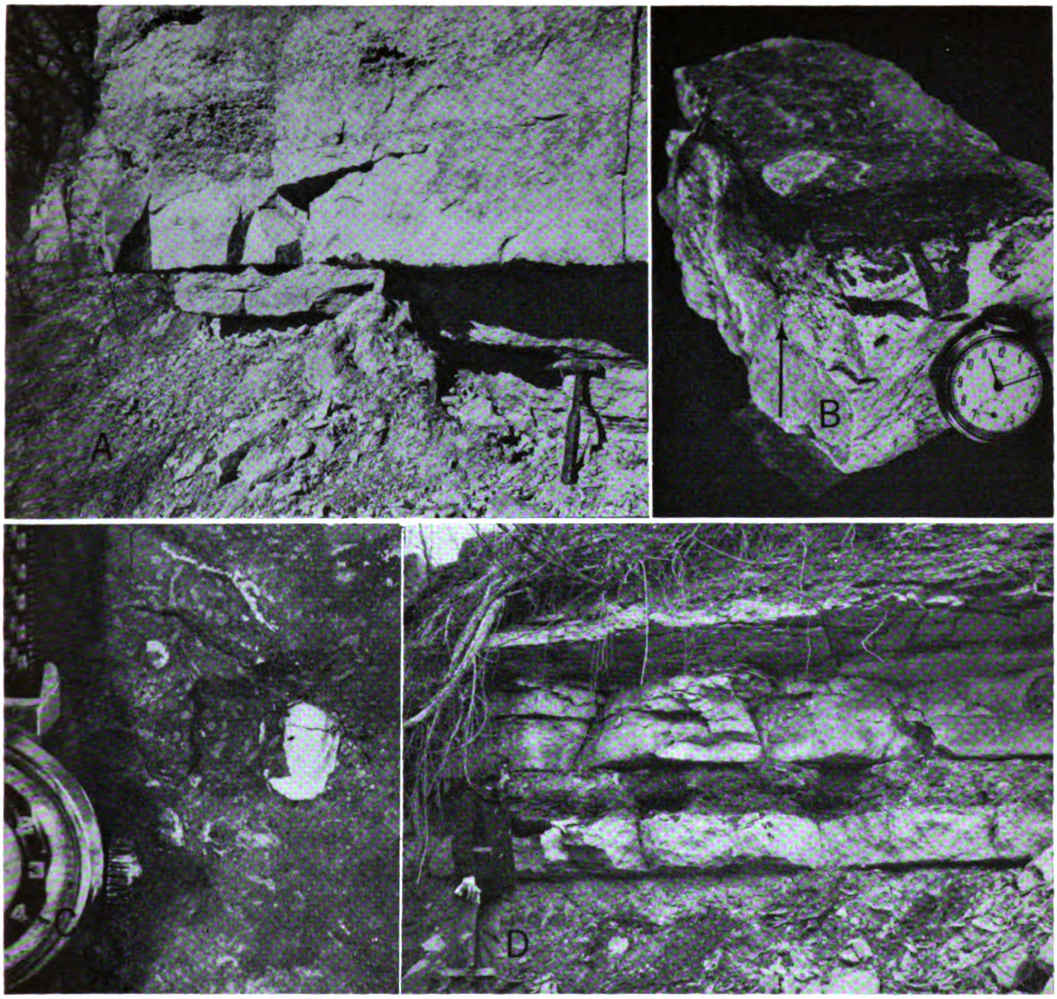


PLATE 3.—**A,** Contact of Johnson Shale and Bennett Member of Red Eagle Limestone at the Elmdale section. Hammer head is at contact. **B,** Sample of uppermost Johnson Shale from Elmdale section. Arrow points to top of bed. Note dark *Orbiculoidea*-bearing tubes near top. **C,** *Lingula* sp. in black basal Bennett Shale from Bennet section. **D,** Glenrock and Bennett Members of Red Eagle Limestone at Allen section. Observer's hand touching top of Glenrock; eye level at contact between lower shale and medial limestone facies of Bennett Member.

detail because they are poorly exposed. Nodules and blebs of milky and medium-gray chert are randomly present in the limestone.

At the Grand Summit section (Appendix) the Glenrock Limestone is thin (0.25 foot) but readily recognizable. Fusulinids are abundant and brachiopods are rare in the usual aphanitic matrix. Traces of gastropods and crinoid discs are also evident. The contacts are gently undulatory. Some fresh surfaces show a few small, round, dark-gray argillaceous spots (containing rare tiny *Orbiculoidea* fragments) suggesting cross sections of worm burrows. The overlying shale of the Bennett contains abundant *Orbiculoidea.*

The Highway 38 section (Appendix) is the southernmost studied exposure of the fusulinid-bearing Glenrock Limestone. As at the Piedmont section, the Glenrock Member is thin (0.5 foot) and is identified as much by its relation to the overlying *Orbiculoidea*-bearing Bennett Shale as by its own distinctive fossils and lithology. At the Highway 38 locality, the Glenrock Limestone is softer and more argillaceous than its

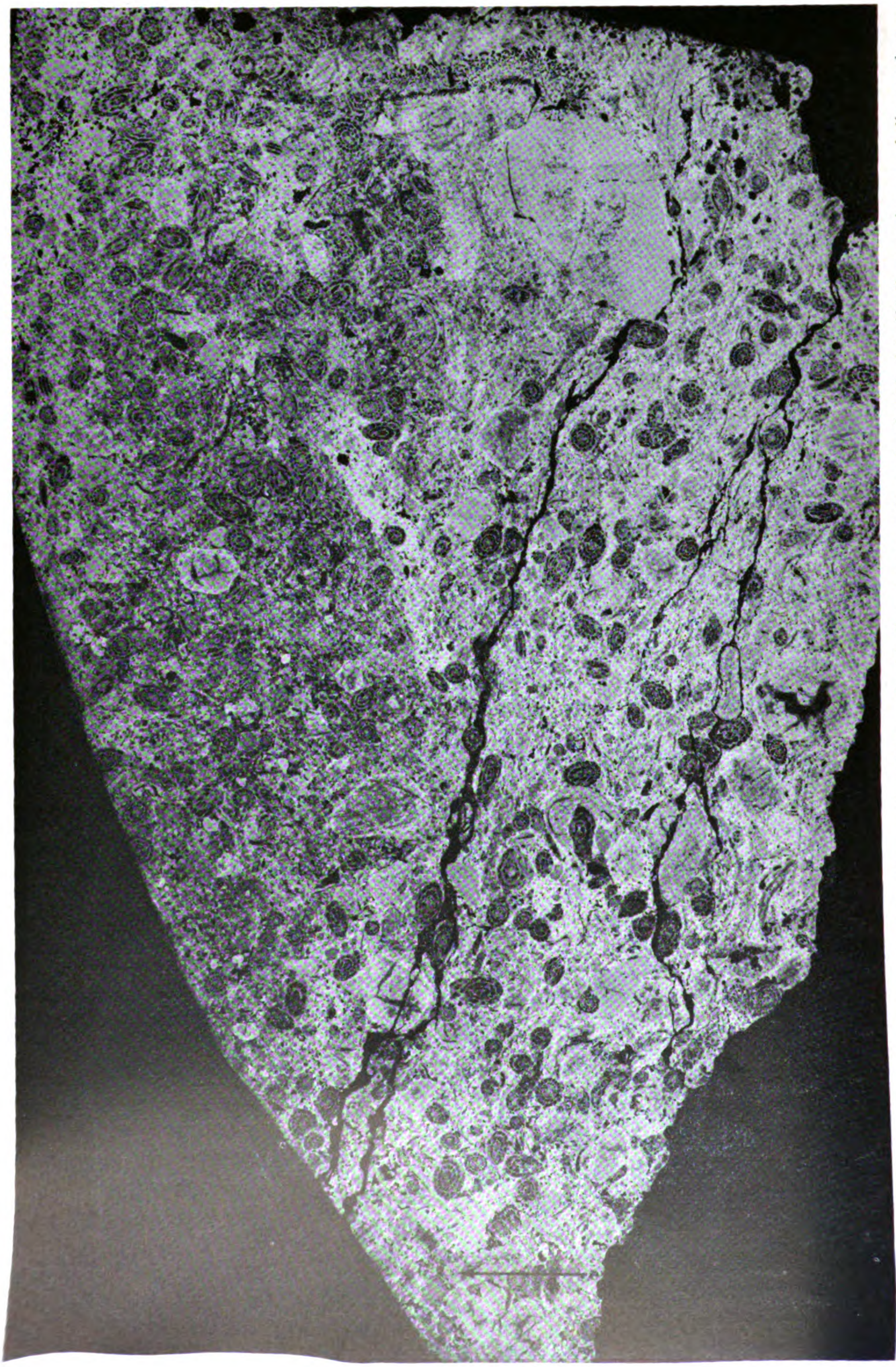


PLATE 4.—Peel print (X2.5) of Glenrock Limestone from Allen section. Note aphanitic limestone granules and aphanitic (algal?) lime coatings on shells near bottom left of picture. Note shrinkage cracks in granules at bottom, left, and top center of picture. The long axes of many fusulinids are crudely oriented parallel to the bedding planes. Arrow points to top of bed.

equivalents to the north, but it contains the same fusulinids. Some brachiopods and crinoid discs accompany the fusulinids. Rare wormy tubes of black clay penetrate the top 1 to 2 inches of the limestone. Upper and lower contacts are gently undulatory.

SUMMARY.—The Glenrock Limestone Member of the Red Eagle Limestone is commonly a fusulinid-bearing, medium- to light-brownish-gray limestone. Over much of its outcrop belt (north of Allen, Kansas) it is a single unit about 1 foot thick and locally resistant enough to support minor topographic benches. It is readily identifiable in the field by its lithologic characteristics and by its position beneath black *Orbiculoidea*-bearing shale of the lower Bennett Member. In localities where the Bennett limestone facies is thick, the Glenrock Member is normally less than 0.5 foot thick. Where the Glenrock Member is absent, the position of the corresponding paraconformity can be closely approximated at the base of the Bennett *Orbiculoidea*-bearing black or gray shale where it lies directly on ostracode- and plant-bearing gray shale or platestone of the upper part of the Johnson Formation. The Glenrock Limestone commonly contains brachiopod fragments and spines, traces of gastropods and ostracodes, and profuse fusulinids set in a calcareous matrix. Much of the matrix is bioclastic calcium carbonate grading from calcarenaceous to calcilutaceous to microcrystalline.

Wormlike tubes and ribbons of *Orbiculoidea*-bearing gray clay that are continuous with the basal shale of the Bennett penetrate the top of the Glenrock at some localities. *Osagia*-like calcium carbonate coatings on brachiopod fragments are rare to common in the Glenrock Limestone, especially in Nebraska and northern Kansas.

The outstanding characteristic of the Glenrock Limestone is its uniformity of thickness and lithology between Bennet, Nebraska, and Allen, Kansas. Between Allen and Highway 38 the Glenrock Limestone is commonly less than 0.5 feet thick. No stratigraphic equivalent of the Glenrock Member is known in Oklahoma and southern Kansas south of Highway 38. It is probable that the Glenrock pinches or phases out in this area.

The fusulinid-bearing Glenrock Limestone, with black *Orbiculoidea*-bearing Bennett Shale resting directly upon it, is a reliable stratigraphic marker, recognizable and useful from Bennet, Nebraska, to southern Kansas.

Bennett Shale Member

The Bennett Shale Member of the Red Eagle Limestone was named by Condra (1927, p. 86) ". . . from exposures along the Little Nemaha and its branches south of Bennett, Lancaster County, Nebraska; formed of bluish gray and nearly black argillaceous shale, with one carbonaceous streak resembling coal and a thin yellowish to brownish limestone; combined thickness 5 to 11 feet.

Fauna: Orbiculoidea missouriensis, Lingula sp., Composita subtilita, Spirifer cameratus, and a few other species."

At the type section (Bennet* section; see Appendix) the Bennett Member is approximately 8 feet thick. The lowermost 4 feet is slightly calcareous gray shale and mudstone containing *Orbiculoidea* and an abundant microfauna. The basal shale is dark gray to black and contains abundant *Orbiculoidea*. Much of the black shale emits a fetid odor when treated with hydrochloric acid. A few frail specimens of *Lingula* (Pl. 3C) are associated with common *Orbiculoidea* just above the contact with the distinctive Glenrock Limestone. Equivalents of this basal *Orbiculoidea*-bearing black shale are an excellent stratigraphic marker traceable to southern Kansas. About 4 feet from its base, the Bennett Member includes a hard, light-brownish-gray, slightly argillaceous, microgranular limestone 1 foot thick. Above this limestone is another 3 feet of buff-colored calcareous shale and mudstone. These beds lack conodonts and orbiculoids, but some contain fish teeth and ostracodes. Three feet of massive, hard, aphanitic, light-gray Howe Limestone rests on the tooth-bearing beds. The type locality is satisfactory for observation of the lower Bennett shale beds and their relations to the Glenrock Member, but for purposes of long-distance correlation the relations of upper Bennett to the overlying Howe Limestone are much more understandable if observed in central Kansas.

Only 5 feet of light- and medium-gray shale and mudstone containing *Orbiculoidea* and other brachiopod fragments is exposed at the Tecumseh section. These beds contain a characteristic Bennett microfauna of conodonts and fish teeth in the darker, less calcareous shale. Ostracodes and foraminifers are present in the calcareous shale and mudstone.

About 2 feet of basal Bennett dark-gray or

* Note that Condra misspelled the town name Bennet. The spelling "Bennett" is retained in stratigraphic nomenclature for reasons discussed by Moore (1952).

black, well-laminated, *Orbiculoidea*-bearing shale having abundant microfossils is exposed at the Johnson section (Appendix). The contact with the Glenrock Limestone is sharp and gently undulatory.

Excellent exposures of the Bennett Member are available at the Pawnee section (Appendix). The lower contact of the basal black shale is impressed into peculiar channels (Pl. 1B, 1C, 1E) and fills the tubes in the uppermost Glenrock Limestone. Some of the black shale within the channels and against the top of the Glenrock contains small, lumpy accumulations of crushed shells and carbonate rich in fusulinids. Individual free fusulinids are common on the upper surface of the Glenrock Limestone, where they are surrounded and covered by black Bennett clay. *Lingula* accompanies *Orbiculoidea* in the lowermost 0.25 inch of shale resting on the Glenrock Limestone.

The basal 4.5 feet of the Bennett Member at Pawnee consists of gray to very dark gray, almost black, slightly calcareous shale which contains a varied microfauna and few, but conspicuous, articulated brachiopod shells and spines oriented roughly parallel to bedding and fissility. *Orbiculoidea* is typical of the entire assemblage. The dark shale sequence grades upward through 1 foot of calcareous, buff siltstone and mudstone into the soft, pitted Howe Limestone.

The Bennett Member at the nearby Pawnee South section is quite similar to its equivalent at Pawnee, but its fauna is less abundant.

Only the basal 3 feet of the Bennett Member is exposed at the Humboldt section (Appendix), and this is the same as the dark-gray, well-laminated, *Orbiculoidea*-bearing shale at the type section. The unit is estimated to be about 5 feet thick in this area. A 0.25-inch horizon of *Orbiculoidea* coquina occurs near the base of the black shale. At the very base, where many of the shells are only slightly flattened, rare *Lingula* accompany the orbiculoids.

Only the basal 2 feet of the Bennett Shale is exposed at the Frankfort section. The beds are almost identical with the slightly calcareous black shale exposed at the Humboldt section, with the exception that a few ostracodes occur with the abundant *Orbiculoidea* at the base.

At the Manhattan section (Appendix) the Bennett Member is about 4 feet thick and well exposed. At the other exposures within the Manhattan metropolitan area, and at the Tuttle Creek dam a few miles north of Manhattan, the Bennett Shale is also about 4 feet thick. In these exposures, and at the sampled section, the Bennett Member is entirely shale. *Orbiculoidea* is rare in these beds but bryozoans and brachiopods are common. The shale is well laminated, calcareous, and waferlike.

The Bennett facies of the Paxico section (Appendix) differs from those of Nebraska and northern Kansas. More than 2 feet of the characteristic black fissile shale lies at the base, but the remaining 6 feet consist of brownish-gray, vaguely laminated, argillaceous limestone. Despite the different lithofacies, traces of *Orbiculoidea* and fish teeth are present from base to top of the member. *Orbiculoidea* coquina similar to the one at Humboldt is present along some laminae in the basal 0.5 foot of the black shale.

Exposures are so poor at the Alma section that they yield little information about the local characteristics of the Bennett Member. The estimated thickness is about 19 feet. The uppermost Bennett beds, beneath the Howe Limestone, are argillaceous calcisiltites somewhat similar to beds in similar stratigraphic position at Paxico.

At the Eskridge section (Appendix) only the Glenrock Member is well exposed, but the Bennett is estimated to be about 6.5 feet thick and composed of shale. This local feature of the Bennett Member might be regarded as unimportant were it not for a thick limestone development in the Bennett close by. That is, within a distance of 3 miles, the Bennett changes from about 6.5 feet of topographically weak shale at the Eskridge section to about 3 feet of shale overlain by about 15 feet of medium-bedded resistant limestone and 3 feet of rubbly-bedded limestone at the Eskridge Quarry section (Appendix). Thus, the most abrupt lithofacies change in the Bennett Member is indicated (see Figure 3).

When quarrying is active, a complete section of the Bennett Member can be seen at the Eskridge Quarry. During suspension of quarry operations the excavations accumulate enough water to submerge the lower 7 feet of the Bennett Member. At such times these lower beds may be sampled at the nearby Judith section, where the Bennett facies is nearly the same as at the Quarry.

At the Eskridge Quarry and Judith sections the basal 3 feet of the Bennett Member consists of typical black *Orbiculoidea*-bearing shale. The lowermost bed also contains traces of *Lingula* and conodonts. Medium-bedded, and very light brownish-gray limestone more than 15 feet thick rests upon the shale. *Orbiculoidea* and fusulinids are present in the lower 1 to 2 feet of this Bennett limestone. Brachiopods, echinoid and brachiopod spines, crinoid discs, and foraminifers are rare to common in the aphanitic calcareous matrix which constitutes most of the rock. Laboratory analyses revealed that little of this limestone contains more than 1 percent of insoluble clay residue. The sudden thickening and the purity of this limestone suggest that it might be a part of a Bennett reef facies.

The thickened limestone accumulation extends from the Eskridge Quarry through the Judith and Coffman Ranch areas, where it forms a conspicuous bench on the local grassy hillsides. Shallow sinkholes in the Bennett limestone are common topographic features of this Eskridge-Coffman Ranch area.

O'Connor and Jewett (1952) noted this Bennett lithofacies (Fig. 3) and called it a bioherm. The original definition of bioherm by Cumings (1932, p. 333) applies the term to "reeflike, moundlike, lenslike or otherwise circumscribed structures of strictly *organic origin*, embedded in rocks of different lithology." In broad outline the Bennett limestone of the Eskridge-Coffman Ranch area faintly resembles part of a bioherm or reef. However, internal characteristics of this limestone (e.g., bedding) certainly are not reeflike, nor can its "strictly" organic origin be verified, although much of the mass is obviously organic shell detritus and much may be of algal origin. Moreover, the Bennett limestone lithofacies of southern Kansas and Oklahoma is remarkably similar to that of the Eskridge-Coffman Ranch area, except that the southern lithofacies is too broadly distributed and uniform in thickness to permit the slightest suggestion that it is biohermal or reeflike in form.

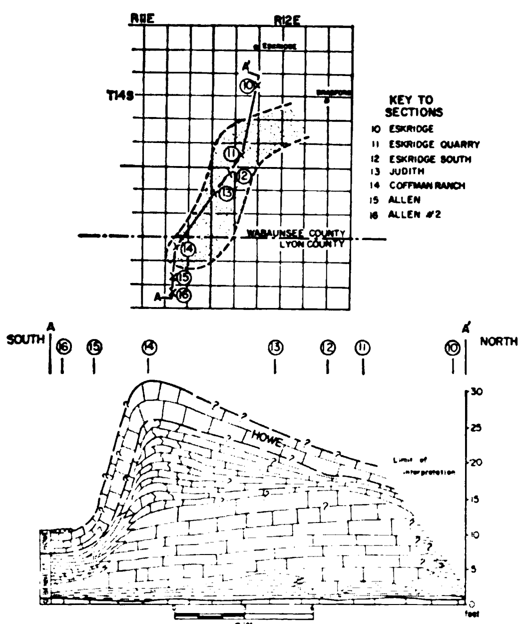


FIGURE 3.—Diagrammatic cross section showing interpretation of thick Bennett limestone facies in Eskridge-Coffman Ranch area. Area of thick Bennett limestone facies is shown on location map (modified from Mudge and Burton, 1959, pl. 9).

It must also be noted (Fig. 3) that whereas the western and northern margins of the Eskridge-Coffman Ranch area of Bennett limestone are bounded by shale ("rocks of different lithology"; Cumings, 1932) the southern edge of the thickened beds passes gradually into thinner beds of like composition, visible within the Bennett Member at the Allen, Elmdale, and Saffordville sections.

The words of Moore (1957, p. 1790) seem to describe perfectly these stratigraphic conditions found in the Bennett.

> It seems objectionable to class as reefs (bioherms) the locally thickened masses of bedded limestone that occur in some formations . . . even though these masses are predominantly (or exclusively) made by organisms and originally formed prominences on the sea floor. The thickened beds pass very gradually, not abruptly, into thinner beds of like composition.

Paleoecological evidence presented below indicates that this thick Bennett limestone probably was deposited in quite shallow water. Its maximum thickness is not much more than 30 feet and it is surrounded by contemporaneous shale at least 5 feet thick. Its minimum horizontal dimension is about 2 miles. Clearly, the Bennett limestone in the Eskridge-Coffman Ranch area could not have formed much more than a slight, flat prominence on the sea floor. Such a low feature on the sea floor can not be regarded as a reef or bioherm.

Mudge and Burton (1959, p. 60, pl. 9) also noted this feature of Bennett stratigraphy but called it a biostrome (Cumings, 1932, p. 334). This writer believes that the term biostrome is not applicable to the local stratigraphic relations of the Bennett described herein. Moreover, Moore (1957, p. 1789, 1790) and Weller (1958, p. 612) have shown good reasons why biostrome should be dismissed altogether from stratigraphic vocabulary.

The terms bioherm and biostrome being inappropriate, there is no concise substitute term which, by definition, would describe the stratigraphic relationships manifested by the locally thick limestone and associated shale of the Bennett Member in the Eskridge-Coffman Ranch area . Consequently, nomenclatural difficulties are avoided in this report by simply referring to thick or thin limestone or shale facies which are best developed at certain localities (e.g., the Eskridge-Coffman Ranch limestone facies of the Bennett Shale Member). The assumption is that shades of meaning will be quite clear from context. Moore (1957, p. 1782) and Weller (1958, p. 632) endorsed the general practicality and clarity of this sort of facies nomenclature.

The thick limestone accumulation of the Bennett Member at the Eskridge Quarry continues through the Judith and Coffman Ranch sections and southward, where it gives way to the thinner limestone and shaly facies visible at the Allen sections and beyond (Fig. 3).

A richly crinoidal lithology is present in the upper part of the Bennett limestone at Eskridge Quarry and Coffman Ranch. Bryozoans, ostracodes, brachiopods, holothurian sclerites, foraminifers, and algae are common, and crinoid columnals are abundant in this unevenly thin-bedded rubbly limestone. Laboratory analyses showed that these rocks contain about 5 percent less calcium carbonate than the underlying massive Bennett limestone.

The Bennett Member is about 8 feet thick at the Allen section (Appendix). Here, as elsewhere, the lowermost beds (1 foot thick) are dark-gray, *Orbiculoidea*-bearing shale. Only 2 feet of hard, massive, light-gray limestone similar to the Coffman Ranch limestone rests on this basal shale. The limestone contains silicified brachiopods, a few fusulinids, and light-gray chert nodules in an aphanitic calcitic matrix. The upper half has medium-gray chert nodules (Pl. 3D). It grades upward into shaly light-gray limestone that contains a typical Bennett mixed fauna of brachiopods, horn corals, crinoids, and *Orbiculoidea*.

At the Allen No. 2 section the lowest Bennett shale is only 0.6 foot thick. Nearly 1 foot of *Orbiculoidea*-bearing massive limestone rests on the shale. The upper few inches of this limestone contain milky chert and silicified fossils. It grades upward through approximately 2 feet of shaly limestone into 2.5 feet of gray and greenish-gray calcareous shale bearing *Orbiculoidea* and the Bennett mixed fauna. The uppermost 1 foot of the unit is a light-gray muddy limestone that contains a sparse Bennett fauna and lacks *Orbiculoidea*.

The Bennett limestone facies is approximately 5 feet thick at the Saffordville section (Appendix), where it rests on nearly 2 feet of *Orbiculoidea*-bearing, dark-gray, calcareous shale, typical of the lower Bennett. Algal deposits of calcium carbonate occur at random throughout the limestone. Some algae *(Anchicodium)*, called linear algae, appear in vertical sections as thin wavy lines oriented roughly parallel to bedding. In three dimensions they are really ribbonlike or sheetlike crusts, but the term linear is retained because it is commonly used in field descriptions and reflects the gross appearance of the structures in vertical sections. Other calcareous algal particles form much of the apparently structureless aphanitic matrix of the Bennett limestone.

The top of the limestone section consists of 0.4 foot of unique moundlike limestone structures which seem to contain both of the above types of algal calcium carbonate, as well as fossil detritus. Rusty iron staining seems to favor the sheetlike algal structures. Rubbly, wavy-bedded limestone makes up most of the upper 2 feet of Bennett limestone at the Saffordville section. The lower 3.5 feet is mainly massive, light-gray, resistant, pure limestone containing scattered linear algae, some of which are broken, and a few fusulinids at the base. In general aspect this limestone resembles equivalent limestone at the Allen section. About 7 feet of upper Bennett sediments, probably shale, is covered at the Saffordville section.

At the Elmdale section (Appendix) the lower *Orbiculoidea*-bearing black shale of the Bennett Member is reduced in thickness to about 0.1 foot. The shale lies below 5 to 6 feet of predominantly pure, massive, and resistant limestone (Pl. 3A) which contains a few fusulinids at the base. This limestone is similar in thickness, position, and fauna to the Bennett limestone exposed at Saffordville. Within the upper foot of this limestone sequence at the Elmdale section is linear algal limestone (Pl. 5A). About 4 feet of medium-gray calcareous shale rests on the thick Bennett limestone. A typical Bennett fauna of common brachiopods *(Neospirifer, Linoproductus, Crurithyris, Ambocoelia, Wellerella)*, bryozoans *(Fenestella, Rhombopora)*, foraminifers, ostracodes, and fish teeth is abundantly represented in this shale.

Two feet of massive limestone enclosed by

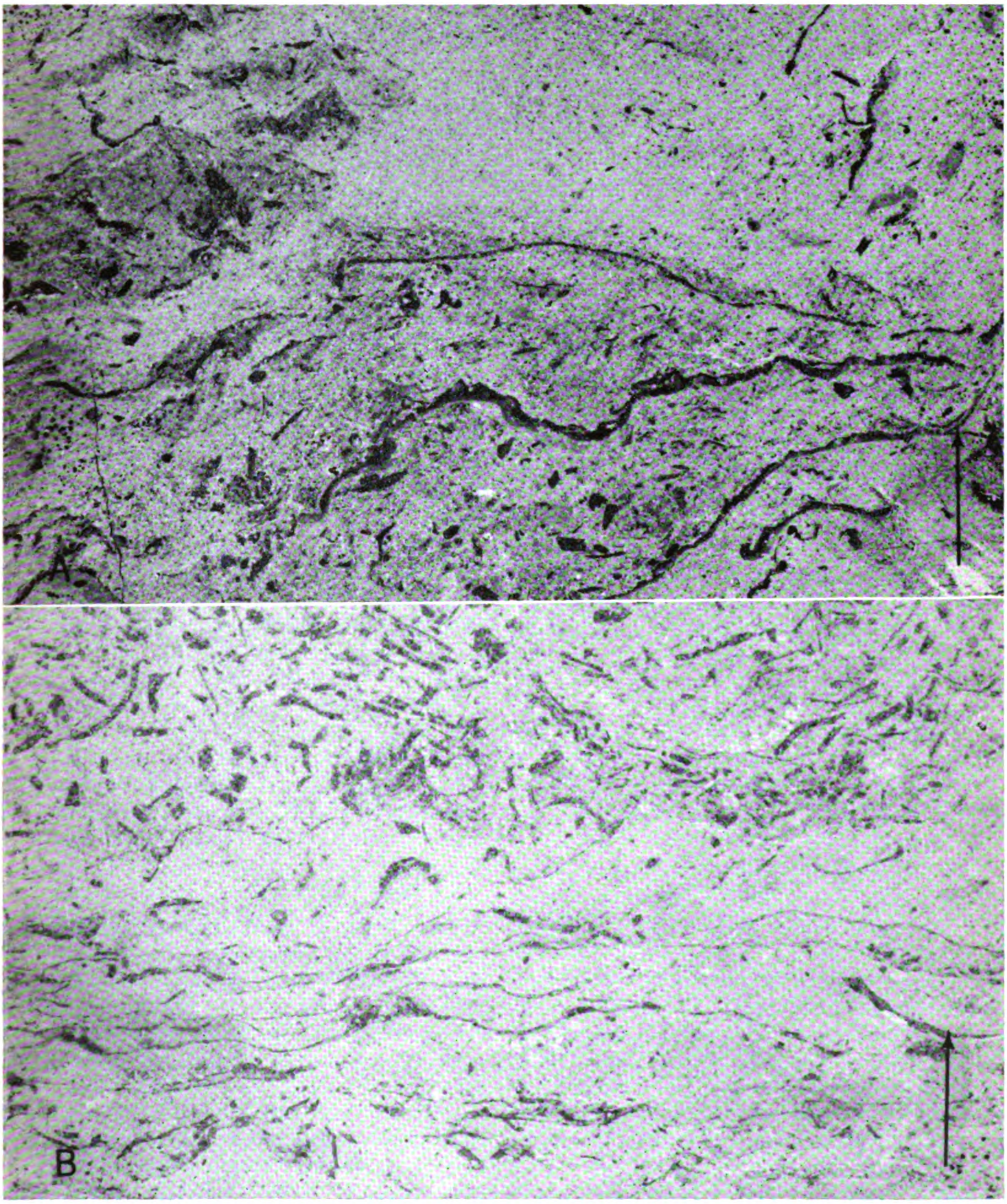


Plate 5.—**A,** Peel print (X3.0) of upper Bennett limestone from Elmdale section. Wavy dark lines are sheetlike algal crusts *(Anchicodium?)*. Note crust fragments in lower and upper left of picture. **B,** Peel print (X3.5) of Bennett limestone from Highway 38 section. Note wavy sheetlike algal crusts in lower half of picture and broken algal crusts with brachiopod fragments in upper half. Arrows point to top of bed.

shale at the Turnpike section superficially resembles Glenrock Limestone. However, this designation is refuted by the presence in the limestone of *Orbiculoidea*, *Fenestrellina*, and linear algae typical of the Bennett Member and by the absence of fusulinids. This evidence indicates that the limestone may be a thin, tongue-like southward extension of the Bennett limestone facies. The Bennett limestone bed rests (paraconformably?) on shale of the upper Johnson Shale. Calcareous shale immediately above the limestone contains a profuse Bennett-like fauna. Equivalents of the lower Bennett *Orbiculoidea*-bearing black shale are absent from the Turnpike section.

Fossils in the 2 feet of limestone and shale observed at the Sallyards section indicate that these beds are also correlative with Bennett sediments farther north.

At the Piedmont section (Appendix) shaly light-gray limestone containing common fusulinids makes up the lower 1.5 feet of the Bennett exposure. The overlying 12 feet of massive, resistant, light-gray, medium- to thick-bedded limestone forms the remainder of the Bennett Member at Piedmont. *Orbiculoidea* is present in the lowermost bed of this limestone. Fusulinids are rare to common throughout the section, together with a typical Bennett fauna with brachiopods, ostracodes, and crinoid discs. Some of the limestone is vuggy; other parts contain secondary chert nodules surrounding silicified fossils. South of the Piedmont section the light-gray limestone of the Bennett Member makes up most of the Red Eagle Limestone.

The basal shale is only 0.1 foot thick at the Grand Summit section (Appendix). This thickness is reminiscent of conditions at Elmdale. *Orbiculoidea* abounds in this shale, together with many fusulinids, ostracodes, conodonts, and brachiopod fragments. The rest of the Bennett is hard, light-gray, aphanitic limestone. The lower 4 feet of limestone weathers out as thin wavy beds in which linear algae are common. Five feet of massive thick- to medium-bedded limestone forms the medial part of the member. Thinner beds make up the upper 4 feet. Brachiopods, crinoid columnals, ostracodes, and small gastropods are rare to common in an aphanitic matrix.

At the Highway 38 section (Appendix) the massive, light-gray, medium-bedded limestone which constitutes the entire Bennett Member is similar in thickness, purity, and lithology to its equivalent at the Grand Summit section. Of the sections studied, Highway 38 is the southernmost one in which correlations of the Red Eagle Limestone of Oklahoma with its members to the north can be recognized. Farther south the Glenrock Limestone probably disappears, whereas the Bennett limestone section thickens and becomes more argillaceous toward the Burbank area, where it makes up the bulk of the limestone defined as the Red Eagle Limestone formation.

Limestone of the Bennett Member at the Highway 38 section embodies characteristics typical of all limestone lithofacies of the Bennett Member. Fragments of brachiopods, bryozoans, and ostracodes are rare to common in an aphanitic calcareous matrix. *Orbiculoidea* and fusulinids are rare to common at the base of the unit and rare throughout the remainder. Linear algae *(Anchicodium?)* (Pl. 5B) are present in limestone near the base of the Bennett Member.

SUMMARY.—At the type area near Bennet, Nebraska, and southward to Manhattan, Kansas, the Bennett Shale Member is mainly calcareous, medium-gray, moderately to well-laminated shale. Brachiopod shells and spines are rare to common, whereas bryozoans, conodonts, foraminifers, ostracodes, and crinoid discs are rare. The lowest shale is fissile, dark gray or black, and characteristically contains numerous *Orbiculoidea*, but only a few conodonts and fish teeth and even fewer fusulinids. The shale is easily identified in the field because it rests on the distinctive Glenrock Limestone. Sparse *Orbiculoidea* fragments may occur throughout the Bennett Member, regardless of lithology.

The Bennett Member is about 8 feet thick at Bennet, Nebraska, and gradually thins southward to 4 feet at Manhattan, Kansas. Between Manhattan and Paxico the Bennett "shale" becomes thicker (19 feet) and more calcareous until, at the Paxico section, only the basal black fissile shale maintains the typical northern character (approximately 30 percent $CaCO_3$). In the same area the upper two-thirds of the Bennett Member appears in the field to consist of light-gray, very calcareous mudstone and shale. Laboratory analyses revealed that this is laminated muddy *limestone* containing approximately 70 percent calcium carbonate.

This argillaceous-calcareous facies of the Bennett Member continues southward to an area about 3 miles south of Eskridge, where the facies changes abruptly to include the medium-bedded, very pure (95 to 99 percent $CaCO_3$) limestone, 15 feet thick, at the Eskridge Quarry.

The thickest part of this limestone facies of the Bennett Member trends in a band about 2 miles wide (Fig. 3) southwest from Bradford, through the Eskridge Quarry to the Coffman Ranch section, where it supports a conspicuous bench on local hillsides and creek banks. Sinkholes are present in this limestone. Brachiopods, crinoid columnals, horn corals, bryozoans, and fusulinids are rare to common throughout the limestone. Between the Coffman Ranch section and the Allen section the entire Bennett Member thins to about 8 feet. The pure limestone facies thins to about 2 feet, whereas the rest of the upper Bennett changes to muddy limestone facies like that at Paxico. In the short distance from the Allen section to Allen No. 2 section, the Bennett Member thins to less than 8 feet, the pure limestone becomes slightly argillaceous, and the muddy limestone becomes shaly.

The black and dark-gray lower shale of the Bennett maintains a thickness of about 1 foot in the area of the aforementioned facies changes of the medial and upper Bennett.

Southwestward from Allen No. 2 to Elmdale, the Bennett Member thickens slightly to more than 9 feet. The massive, pure limestone facies of the Bennett Member thickens to about 5 feet, whereas the basal black shale thins to less than 0.1 foot at the Elmdale section. Some of the massive limestone contains linear algae. Upper Bennett shale contains the same kind of mixed fauna as is visible in Nebraska.

Between Saffordville and Piedmont there are few sections of the Bennett Member suitable for sampling. Where it was studied, the member lacks black shale and is made up of fossiliferous gray shale overlying massive (1 to 2 feet), pure limestone beds similar to those at the Allen section.

In southern Kansas, between the Sallyards and Piedmont sections, the Bennett Member thickens and changes to a thick limestone facies very similar to the lithofacies at the Eskridge Quarry. This relatively thick (10 to 15 feet) limestone assemblage is continuous southward into Oklahoma, where it constitutes most of the Red Eagle Limestone. The basal Bennett black shale is scarcely an inch thick in southern Kansas but it is, nonetheless, readily recognizable at the base of the massive Bennett limestone.

Orbiculoidea fragments, so abundant in the Bennett black shale all the way from Nebraska into southern Kansas, are rare in the lower and middle portions of the Bennett limestone. Their presence (with a few fusulinids) in the lower Bennett limestone facilitates correlation, especially where the Glenrock Limestone and lower Bennett black shale are absent or not exposed.

Bennett limestone is all nearly pure $CaCO_3$ (95 to 99 percent) in southern Kansas. In northern Oklahoma it is more argillaceous (commonly 60 to 80 percent $CaCO_3$). The limestone weathers to shades of light gray with tints of rusty yellow and brown.

Wherever the Bennett Member is composed of shale it underlies grassy slopes between the minor hillside benches supported by Howe and Glenrock Limestones. Bennett limestone facies of central and southern Kansas commonly form hillside benches which are more conspicuous than those supported by the thinner Glenrock and Howe Limestones to the north.

Howe Limestone Member

This upper member of the Red Eagle Limestone formation was named by Condra (1927, p. 86) ". . . from exposures south of Howe, Nebraska; stone in its unweathered condition, dark gray, massive, and dense, with considerable free calcite; weathers buff to yellowish, granular, vesicular or cavernous, and very irregular; thickness about 4 feet. This carries geodes at places. It has few fossils."

Only one small, incomplete exposure of this limestone is observable about half a mile south of Howe, Nemaha County, Nebraska. Condra's description seems to apply fairly well to this limestone, except that it understates the amount of solution pitting and decay.

The decayed limestone that Condra described is not satisfactory as a type section for reference in correlating Howe rocks of other localities. The limestone at the exposure designated by Condra is so badly pitted, decayed, and recrystallized as to preclude confident estimation of its original lithology. Moreover, there are no nearby exposures of Roca or fossil-bearing Bennett beds, which could aid in identification of the limestone as Howe on the basis of stratigraphic position.

In southeastern Nebraska the Howe Limestone is normally a light-gray aphanitic limestone that weathers to shades of rusty and yellowish light brown as a result of secondary iron oxide deposition within interstices of the rock. It is about 3 to 5 feet thick. The commonly pitted and irregularly cellular (vuggy) limestone has been partially dissolved by ground water in many places. Near the Pawnee section, springs

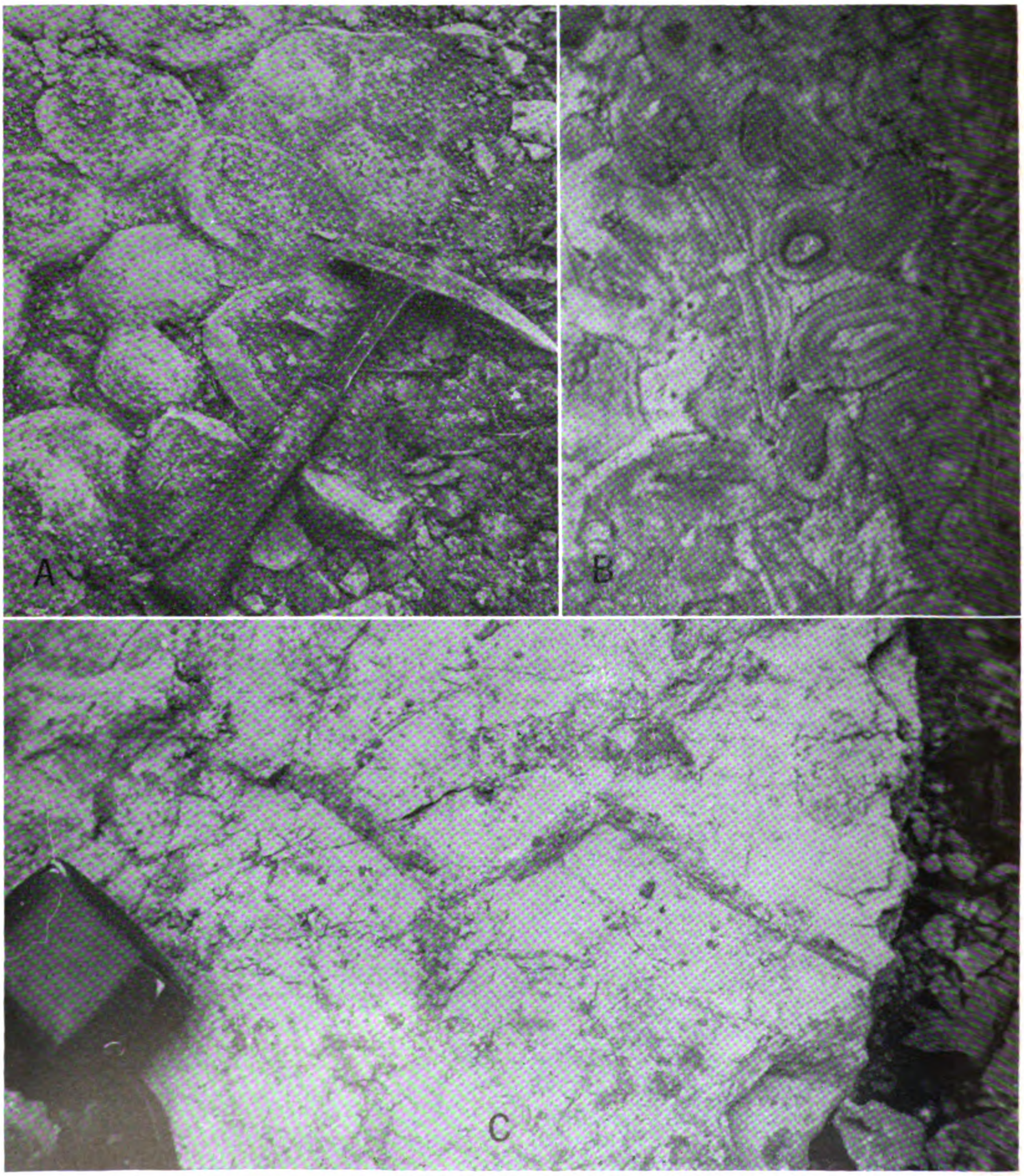


PLATE 6.—**A,** Algal buns at top of Howe Limestone at Allen No. 2 section. **B,** Pelletoid Howe Limestone (osagite) from Alma section, magnified X30 from thin section. Pellets or pseudo-oolites are tiny fossil fragments (ostracodes, foraminifers, brachiopods) covered by layers of algal *(Osagia)* calcium carbonate. **C,** Base of limestone bed in Roca Shale at Pawnee section. Raised, angular, wall-like structures fill cracks in top of underlying lower Roca Shale.

of potable water emerge from the Howe Limestone. Iron oxides and travertine are being deposited in larger solution cavities (vugs) at the springs. The underlying fossiliferous shale in the Bennett serves as an effective aquifuge or aquiclude, preventing appreciable seepage of water downward from the Howe.

The Howe Limestone is well exposed at the Bennet and Pawnee sections. The latter would be a good standard section for the Howe Limestone in Nebraska. The lower contact is commonly gradational through a few inches of section into the shale of the topmost Bennett. This northern facies of the Howe Limestone contains few fossils, so that usually the Howe can be identified in the field only by lithology and stratigraphic position. Nebraska characteristics of the Howe Limestone may be followed southward to the Manhattan area of Kansas. Throughout this distance the Howe forms indistinct, light-brownish-gray or rusty-gray limestone benches cropping out on grassy hill slopes. Where it caps hilltops it is usually badly pitted, decayed, and iron stained. The thinner, fusulinid-bearing Glenrock bench is readily recognizable a few feet below the Howe.

A change of Howe facies occurs between the Manhattan and Paxico areas of Kansas. The northern aphanitic texture gives way to the pseudo-oolitic or pelletoid texture (osagite) that is visible in the vicinity of Paxico and Alma (Pl. 6B). This distinctive texture characterizes the Howe Limestone of central and south-central Kansas between Paxico and Grand Summit.

The pseudo-oolites or pellets are calcareous nuclei, such as small foraminifers, ostracodes, or shell detritus, surrounded by coatings of algal calcium carbonate (*Osagia* sp.). Aggregates of these, with microcrystalline interstitial cement, produce the pelletoid texture (osagite) characteristic of the Howe Limestone in central Kansas. The rock weathers to light gray, commonly stained by limonitic, rusty-yellow or brown iron oxides.

A very remarkable development of larger calcareous algal structures is present at the top of the Howe Limestone at the Allen No. 2 section. A thick pseudo-oolitic limestone bed makes up the bulk of the unit, but the upper 2 or 3 inches are bun-shaped or roughly hemispherical masses of concentrically layered algal calcium carbonate (Pl. 6A). O'Connor and Jewett (1952, p. 352) called these structures "*Cryptozoon*-like". One of these masses was underlain by a nautiloid cephalopod coated by half an inch of aphanitic, laminated, hard calcium carbonate (Pl. 7). The nautiloid was in the top of the pelletoid limestone. Its suborthochoanitic siphuncle contains numerous osagitic pellets. Greenish shale of the overlying Roca Shale is impressed into and around the tops of the algal buns.

The distinctive pelletoid Howe facies (osagite) persists, with minor modification, southward to the vicinity of the Kansas-Oklahoma border. At the Highway 38 section near Cloverdale, Kansas, the pellets are smaller and less distinct than in central Kansas. Also, the proportion of elongate or discoid pellets of calcium carbonate is greater, and algal coatings of the individual pellets are thinner.

In Oklahoma, because the pelletoid facies is absent, it is difficult to identify the Howe Limestone or its equivalents. Largely because of its stratigraphic position atop limestone of the Bennett and beneath red shale of the Roca, the irregularly and thinly bedded, pitted, rusty, sparsely fossiliferous limestone at the top of the Burbank section is correlated with the Howe Member of the Red Eagle Limestone.

SUMMARY.—The Howe Limestone Member of the Red Eagle Limestone is a massive limestone recognizable in exposures along nearly 250 miles of an outcrop belt between Bennet, Nebraska, and Cloverdale, Kansas. Throughout this distance the rock generally is 2 to 5 feet thick and it exhibits only one major facies change. In Nebraska and northern Kansas the Howe Member is an aphanitic light-gray limestone locally pitted and decayed by weathering. In central and southern Kansas the Howe Limestone is a brown to gray-brown pelletoid limestone (osagite). The pellets are composed of fragments of organic shell detritus coated by algal (*Osagia*) calcium carbonate. Fossils are common to absent; a few ostracodes, brachiopods, and arenaceous foraminifers can be seen in some fresh exposures and in polished sections.

Roca Shale

The Roca Shale was named by Condra (1927, p. 86) ". . . from Roca, Lancaster County, Nebraska; composed of bluish gray, olive green, and reddish argillaceous shale. There are thin fossiliferous limestone seams in the upper portion: thickness of division 18 to 20 feet in Nebraska and somewhat greater in Kansas. The limestone seams carry many pelecypods, as Pleurophorus sp., Pseudomonotis sp., and Aviculopecten occidentalis."

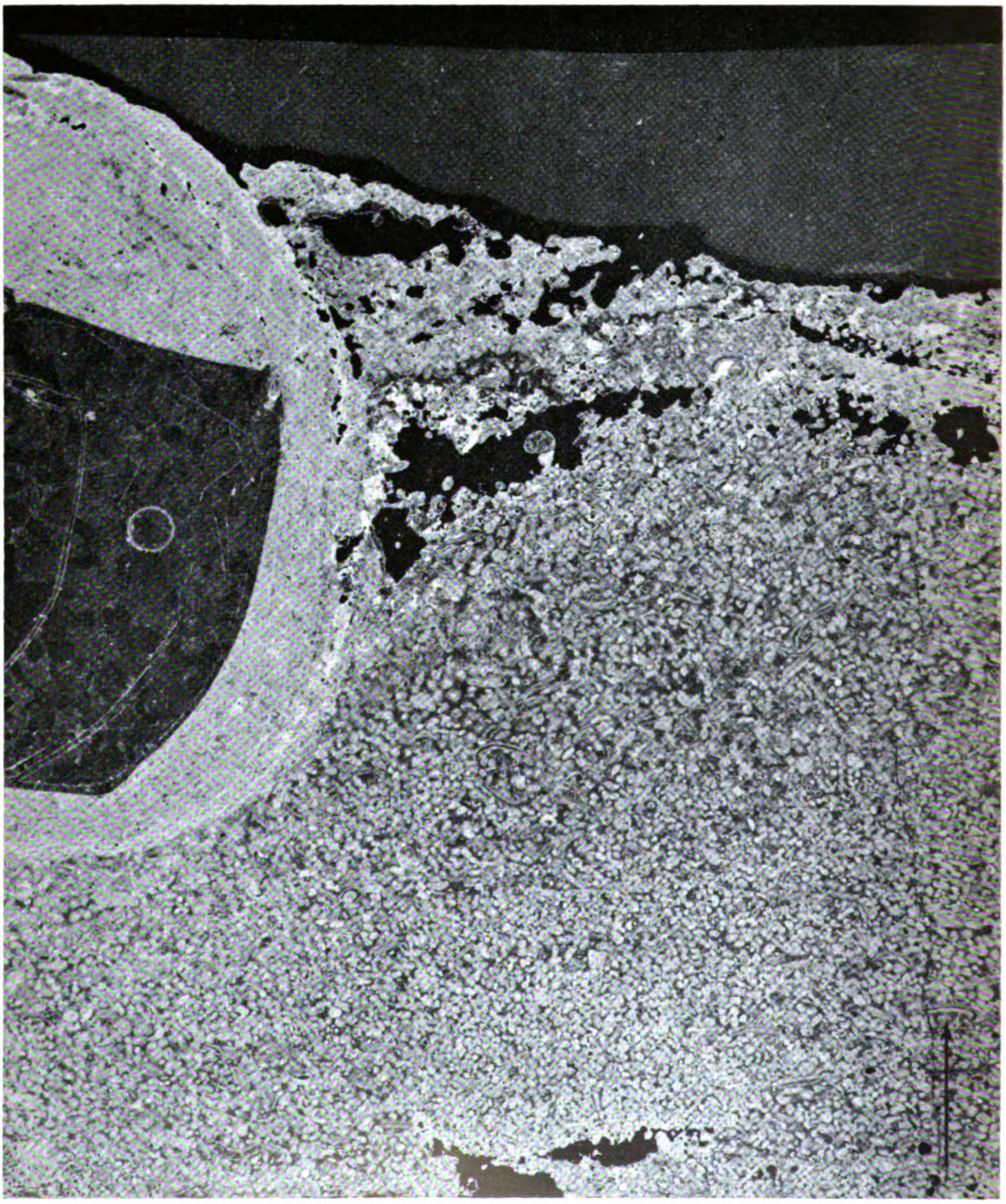


PLATE 7.—Peel print (X3.0) of pelletoid Howe Limestone (pseudo-oolite or osagite) from Allen No. 2 section. Large fossil at left of picture is a coiled nautiloid cephalopod filled with clear sparry calcite and coated by *Osagia* type of algal calcium carbonate. Note that pellets are fossil fragments (ostracodes, foraminifers, brachiopods) coated by *Osagia*. (See also Plate 6B.) Arrow points to top of bed.

The pelecypod-bearing limestone ascribed by Condra to the upper portion of the Roca Shale is now known to be part of the Sallyards Limestone, the lowest unit of the Grenola Limestone (Condra and Busby, 1933, p. 7-10).

As implied by Condra and Busby (1933, p. 7) and recognized by later workers (e.g., Lane, 1958, p. 127), the upper boundary of the Roca Shale is at the base of the Sallyards Limestone. That is, the Sallyards is the first limestone above the red shale of the Roca Shale.

Thus, the Roca Shale formation is readily recognizable not only by its own red shale content, but by its position between the Howe Limestone below and the *Pseudomonotis*-bearing Sallyards Limestone above. It is characteristic of this portion of the Kansas rock column that correlation and identification of rock units is achievable only by recognition of unusual lithologies in their peculiar sequence. In this way the Roca Shale formation, in turn, may be used to affirm the stratigraphic position and boundaries of the Red Eagle Limestone below and the Grenola Limestone above.

The Roca Shale is not now exposed at Roca, Nebraska. A few slopes in the town are reddish, after the fashion of weathered red shale of the Roca visible elsewhere, but they owe their color to red Pleistocene silt and loess.

At the nearby Bennet section (Appendix), the lower 9.6 feet of the Roca Shale is well exposed. The lowermost approximately 3 feet consists of gray and greenish-gray, slightly calcareous shale with traces of ostracodes and gastropods. About 1 foot of hard, light-brownish-gray, aphanitic limestone separates the lower shale from overlying gray shale, which includes approximately 1 foot of vivid red mudstone. Gray shale below the redbeds contains a few ostracodes and rare traces of fish teeth. Shale above the redbeds is unfossiliferous. A thin, aphanitic, light-gray limestone caps the incomplete Roca exposure at the Bennet section. The complete Roca Shale thickness is estimated to be 15 feet.

Exposures of Roca Shale satisfactory for detailed sampling without risk of contamination are extremely rare in southeastern Nebraska and in Kansas. Shaly beds of the Roca commonly underlie broad, gentle, grassy slopes between limestone of the overlying Grenola Limestone formation and the underlying Red Eagle Limestone formation.

A partial exposure (lower 18 feet) of the Roca Shale occurs at the Pawnee section (Appendix). Above a 3.1-foot covered interval at the base is about 6 feet of light-greenish-gray calcareous mudstone and shale barren of fossils. This is overlain by 2 feet of massive, light-brownish-gray, hard, sublithographic limestone. The base of the limestone shows evidence of having covered and filled large cracks in the uppermost greenish-gray shale and mudstone. This feature can be seen on the weathered base of overturned slump blocks of the limestone (Pl. 6C). The limestone grades upward through 0.2 foot of laminated, flaky, argillaceous limestone and 0.2 foot of calcareous shale having traces of tiny gastropods, brachiopod fragments, and arenaceous foraminifers. The red mudstone next above is barren of fossils. Five feet of unfossiliferous light-greenish-gray argillaceous limestone and shale make up the uppermost exposed beds. If unit thicknesses are disregarded, the sequence of green and red shale and limestone of the Pawnee section correlates satisfactorily with similar beds at the Bennet section despite the absence of fossils. Such correlation of subdivisions of the Roca Shale is not presently possible in Kansas because of numerous local inconspicuous changes in facies, lack of fossils, and distance between exposures.

The Roca Shale is entirely exposed and accessible at the Manhattan section (Appendix). The thickness of the unit here is 18.5 feet. Light-greenish-gray calcareous mudstone and shale are the principal rock types, but three units of maroon and red shale constitute nearly one-third of the sequence. Distinct calcareous nodules occur in some of the calcareous red shale. Some of the maroon beds grade to light-green color. A nodular microgranular limestone is present just below the middle of the unit. Rare traces of brachiopods *(Crurithyris?)* are present in greenish-gray shale near the middle of the unit.

At the Alma section (Appendix) the Roca Shale is 10 feet thick and composed chiefly of medium- to light-gray and light-greenish-gray, slightly calcareous, unfossiliferous shale. There is a thin red shale (noncalcareous) near the top of the sequence and about 2 feet of limestone near the base.

The Roca is about 21 feet thick and contains several thin limestone beds at the Dunlap section (Appendix). One limestone, just below the middle of the unit, contains rare traces of ostracodes. As elsewhere, most of the Roca beds are light-greenish-gray, slightly calcareous, and unfossiliferous. Only 2 feet of the greenish shale is not calcareous. One bed of noncalcareous red shale occurs in the middle of the section.

The Roca Shale at the Elmdale section (Appendix) is predominantly light-greenish-gray or gray and only mildly calcareous. A maroon mudstone near the top of the unit is noncalcareous to slightly calcareous.

The same general characteristics of the Roca Shale observable at Elmdale persist through southern Kansas into Oklahoma. Traces of carbonaceous remains, ostracodes, and gastropods are present close to the top of the unit. In the area of the Kansas-Oklahoma border, the Roca Shale consists of an upper 6-foot division of buff-weathering gray shale and a lower one of red and maroon shale 11 feet thick (Taylor, 1953, p. 57).

At the Burbank section the lower 7 feet of the Roca Shale is red shale. Pinkish-gray shale 4 feet thick lies between the lower red shale and 6 feet of buff-weathering gray shale at the top of the unit. Traces of carbonaceous remains, ostracodes, and gastropods are present in the upper 2 feet of Roca beds at the Burbank section.

SUMMARY.—Good exposures are rarer for the Roca Shale than for other units of the Red Eagle cyclothem. Between Bennet, Nebraska, and Grand Summit, Kansas—a distance of 250 miles—the Roca Shale consists of light-gray, slightly calcareous shale commonly about 14 to 18 feet thick. Red shale and mudstone 1 or 2 feet thick is invariably present and conspicuous within the characteristic gray shale sequence. Except at the top, where traces of ostracodes and gastropods are sometimes found, the Roca Shale is almost entirely unfossiliferous.

In northern Oklahoma the lower one-third of the Roca Shale consists of red shale, succeeded upward by a sequence of gray shale which weathers light yellowish gray or buff.

MINERALOGY

Studies of insoluble residues obtained by acid treatment of rocks belonging to the Red Eagle cyclothem showed that clays are the most abundant minerals. Clay is the bulk of the shale in the Johnson and Roca, regardless of color, and is an important constituent of the Red Eagle Limestone. Differential thermal analyses and x-ray diffraction patterns from selected samples taken at the Bennet, Manhattan, and Pawnee sections showed that illite is the most common and abundant clay mineral in the northern part of the outcrop belt. Chlorite is commonly present in small amounts. These green minerals account for the greenish tint in most of the gray Johnson and Roca Shales. Traces of calcium montmorillonite and some unknown mixed-layer minerals are randomly rare in the Johnson and Roca Shales.

It is significant that, as in the shale, the major constituent of the small amounts of clay in limestone of the Red Eagle is illite; there are traces of chlorite.

The mineral calcite is next in abundance in the Red Eagle cyclothem. Finely divided calcite is present in almost all shale and in all limestone matrices. Shell remains, some originally aragonite but now changed to calcite, make up a large part of the calcium carbonate in the Red Eagle Limestone. Algal calcium carbonate is also significant. Traces of dolomite are present in some shale beds of the Red Eagle cyclothem.

Insoluble residues also showed that traces of clear subangular to subrounded quartz silt are widespread in all units of the Red Eagle cyclothem. The minor amounts of quartz silt in the Red Eagle Limestone seem mostly to have been built into the shells of arenaceous foraminifers. In the Johnson and Roca Shales the quartz silt is sparsely dispersed. Traces of muscovite rarely accompany the quartz in some residues.

Glauconite is extremely rare in the Bennett Shale. At the Grand Summit section glauconite fills tiny gastropod shells in the lower part of the Bennett.

Variable small amounts of limonite occur in limestone of the Red Eagle cyclothem in some places. The osagite facies of the Howe Limestone is characteristically limonitic where weathered. Limonitized fossils are rarely evident in limestone of the Bennett Member. Hematitic pyritohedral pseudomorphs are present in the limestone near the type locality of the Red Eagle Limestone in Oklahoma.

Siliceous materials such as beekite are rare in the Red Eagle Limestone of southern Kansas.

Rare manganese dioxide dendrites are present along shaly laminae in some of the weathered calcareous shale in the Red Eagle cyclothem.

PALEONTOLOGY

PALEOBOTANY

Fragmentary carbonized plant remains and impressions are commonly present in the uppermost gray shale of the Johnson Formation. Much of this material is vitreous and is coalified to the extent that details of original organic structure are rarely visible. Only one fragment could be identified definitely as remains of a gymnosperm. Traces of fragmentary carbonized materials are present but rare in some gray shale in the lower part of the Bennett Member and in the uppermost shale of the Roca Formation.

Evidence of the activities of algae is present in the Red Eagle Formation. The secondary laminar calcium carbonate deposits which coat small shell detritus, especially in the Howe Limestone and to a much lesser degree in the Glenrock Member, are attributed to precipitation caused by algae and have been given the "form" generic name *Osagia* (Johnson 1946, p. 1104). The Howe Member so abounds with these pellets of *Osagia* that it and similar rocks in other parts of the column have been called osagite. Limestone of the Bennett Member contains traces of so-called linear algae at some localities (Pl. 5). These are really ribbon-like and thin, crustose, often sparry, calcium carbonate structures, some of which are related to *Anchicodium*. Harbaugh (1959) noted similar algal materials in Pennsylvanian rocks. Also, the masses of apparently structureless calcium carbonate which constitute much of the matrix of Bennett limestone are believed to be largely algal in origin (consolidated algal "dust" particles).

Oogonia of charophytes ascribed to the genus *Trochiliscus** have been found in upper (and lower) parts of the Johnson Shale at two localities. Lane (1958, p. 129) was the first to note "charophytes" in uppermost shale of the Roca in southern Kansas.

Several genera of spores are present in the lower black shale of the Bennett Member. These include *Pityosporites* sp., *Lueckisporites* sp., *Florinites* sp., *Punctatisporites* sp., *Nuskoisporites* sp., *Entylissa* sp., and *Cycadopites?* sp. This list records results from analyses of the few samples chosen to give a general indication of the spore content in the Red Eagle cyclothem. Doubtless the list is incomplete. It is interesting to note that the genera seem to be similar to younger Permian assemblages from other parts of the world. Could this indicate that in Wolfcampian time middle North America was the cradle of development of a floral assemblage which did not flourish on other continents until later in the Permian?

Few works on fossil spores and pollen from the Pennsylvanian and Permian rocks of Kansas have been published. It may be expected that much will be added to understanding of cyclothems and paleoclimatology when more spore and pollen data are assembled. The new information should be used to affirm or revise the presently recognized (Moore and Moss, 1934) position of the Pennsylvanian-Permian boundary in Kansas and adjoining states.

Paleozoology

The Johnson and Roca Shales are mostly either barren of fossils or only very sparsely fossiliferous. On the other hand, the Red Eagle Limestone is abundantly fossiliferous. Gastropods and ostracodes are the only major groups of invertebrates that occur in all stratigraphic units of the Red Eagle cyclothem. The invertebrates represented are mostly confined to the Red Eagle Limestone formation. Table 3 lists all animal fossils found in the Red Eagle cyclothem.

Stratigraphic Paleontology

Figure 4 shows the stratigraphic position of all fossils recognized in the Red Eagle cyclothem as a result of this study. To some extent recognition of these fossils and estimations of relative abundance depend on the efficiency and refinement of extraction methods. Most genera named were collected from shale of the Bennett Shale Member of the Red Eagle Limestone. A. G. Fischer recognized ostracodes, gastropods, bryozoans, spicules, and echinoid fragments in the algal colonies at the top of the Howe Member at the Allen No. 2 locality (H. G. O'Connor, personal communication).

The fusulinid *Triticites* is the most abundant fossil in the entire Red Eagle cyclothem (Fig. 4). It is mainly confined to the Glenrock Limestone, wherein at many places its large numbers constitute a major part of the rock. A few *Triticites* are present in the lowermost shale and the limestone facies of the Bennett Member, and in the uppermost beds of the Johnson Shale only at the Highway 38 section. O'Connor and Jewett (1952, p. 335) observed a fusulinid in the Howe Limestone near the Allen No. 2 section.

With only five exceptions, identified foraminifer genera are confined to the Red Eagle Limestone. *Ammodiscus*, *Ammovertella*, and *Tolypammina* are arenaceous foraminifers found in both the Johnson and Red Eagle Formations. There are no publications on Permian arenaceous foraminifers, but Ireland (1956) has found

* Some of the charophytes might be assignable to the new genus *Catillochara*, described by R. E. Peck and J. A. Eyer (1963).

TABLE 3.—Animal remains recognizable in the Red Eagle cyclothem.

Foraminifers

Larger forms (fusulinids)

Schwagerina
Triticites

Smaller forms (mostly arenaceous)

Ammobaculites	*Glomospira*
Ammodiscella	*Glyphostomella*
Ammodiscina	*Hyperammina*
Ammodiscus	*Nodosinella*
Ammovertella	*Nummulostegina*
Bigenerina	*Tetrataxis*
Cornuspira	*Tolypammina*
Globivalvulina	*Trochammina*

Coelenterates

Unidentified horn corals (lophophyllids)

Bryozoans

Cryptostomes

Acanthocladia	*Polypora*
Bactropora	*Rhabdomeson*
Chainodictyon	*Rhombopora*
Fenestella	*Saffordotaxis*
Fenestrellina	*Septopora*
Megacanthopora	*Syringoclemis*
Minilya	*Thamniscus*
Penniretepora	

Trepostomes

Leioclema?

Brachiopods

Inarticulates

Lingula
Orbiculoidea

Articulates

Ambocoelia	*Linoproductus*
Chonetes	*Marginifera*
Composita	*Neospirifer*
Crurithyris	*Rhipidomella*
Derbyia	*Schuchertella?*
Dictyoclostus	*Wellerella*
Echinoconchus	Unidentified fragments and spines
Hustedia	
Juresania	

Mollusks

Pelecypods

Allorisma
Aviculopinna

Gastropods

Anematina?
Bellerophontids
Small unornamented forms

Cephalopods

Unidentified coiled and straight nautiloids

Echinoderms

Crinoids

Columnal discs

Echinoids

Spines
Interambulacral plates

Arthropods

Trilobites

Unidentified pygidial or thoracic remains

Ostracodes

Amphissites	*Jonesina*
Aparchites	*Kirkbya*
Bairdia	*Kirkbyella*
Bythocypris	*Knightina*
Cavellina	*Macrocypris*
Cypridina	*Paraparchites*
Cytherella	*Roundyella*
Discoidella	*Ulrichia*
Geffenina	*Youngiella*
Hollinella	

Holothuroids

Achistrum
Netlike sclerites *(Eocaudina?)*
Small, wheel-shaped sclerites *(Paleochiridota?)*

Conodonts

Cavusgnathus	*Polygnathodella*
Hindeodella	*Prioniodina*
Lonchodus	*Streptognathodus*
Moreyella	*Synprioniodina*
Ozarkodina	

Tooth fragments

Cooleyella	*Multidentodus*
Cooperella	*Palaeoniscus*
Distacodus	*Scolopodus*
Idiacanthus	

Worm burrows

them in beds younger than Red Eagle and has stated that they are indistinguishable from Late Pennsylvanian forms he has described. *Tetrataxis* ranges from uppermost beds of the Johnson Shale, through the Red Eagle Limestone, to the lowermost Roca Shale. *Cornuspira* is very rare in the upper part of the Johnson Shale.

Bryozoans (mostly cryptostomes) are mostly confined to the Bennett and Glenrock Members of the Red Eagle Formation. *Penniretepora*, characteristic of the Bennett Member, is also found at the top of the Johnson Shale and rarely in the upper part of the Roca Shale. All bryozoan genera named were washed from shale. The fenestellate bryozoans in the Glenrock Limestone are not readily identifiable because they are difficult to extract. A few more genera are present in the upper Bennett than in the lower part of the Bennett.

Brachiopod fragments generally occur profusely in the Glenrock and Bennett Members and sparingly in the Howe Member of the Red Eagle Formation.

The inarticulate brachiopod *Orbiculoidea* is rare to common in the black shale of the lower Bennett, and rare in gray shale and buff limestone higher in the Bennett Member. Here and there *Lingula* accompanies *Orbiculoidea* at the base of the Bennett. *Orbiculoidea* is the stratigraphic indicator of the Bennett Member.

Productid brachiopod fragments and spines are numerous in the Glenrock and Bennett Members. In southern Kansas the upper parts of the Johnson Shale contain *Linoproductus* and *Juresania*.

Crurithyris and *Chonetes* are very rare in uppermost Johnson shale and more numerous in Bennett shale. *Crurithyris*, the only brachiopod found in all three formations, is very rare in the Roca Shale.

Although ostracodes are present in all units of the Red Eagle cyclothem, they are most numerous in the Red Eagle Limestone. Only the uppermost shale of the Johnson Formation contains many ostracodes, together with the carbonized plant remains. An association of *Bairdia*, *Cavellina*, and *Bythocypris* characterizes the upper part of the Johnson. These genera also appear sporadically in the Red Eagle and Roca Formations. A few *Geffenina* and *Paraparchites* are found in the uppermost part of the Johnson Shale but are unknown in the rest of the section. *Cypridina*, *Discoidella*, *Kirkbya*, *Kirkbyella*, and *Knightina* have been observed only in the Bennett Member. Ostracodes are rare in the Howe Limestone. Scarce *Bairdia*, *Bythocypris*, *Cavellina*, *Cytherella*, and *Macrocypris* are the only ostracodes in the generally unfossiliferous Roca Shale.

All conodonts are confined to the Bennett Member. They prevail in the black shale of the lower part of the Bennett. *Streptognathodus* is the most common genus. Minute fish teeth? *(Idiacanthus, Distacodus)* that usually accompany the Bennett conodonts are very scarce in the upper part of the Johnson Shale and in the Roca Shale. The Howe Limestone lacks conodonts and tooth remains.

Tiny gastropods, resembling *Anematina*, are present in all units of the Red Eagle cyclothem.

Allorisma and *Aviculopinna* are the only pelecypods found in the Red Eagle cyclothem. *Aviculopinna* was observed in only two (Nebraska) localities. It occurs, with *Allorisma*, at the top of the Glenrock Limestone, in Howe Limestone at one locality, and in the Bennett Shale and Howe Limestone at another. One coiled and several straight nautiloid cephalopods were found at the top of the Howe Limestone (Pl. 7 and page 93).

Crinoid columnals are fairly numerous in the Bennett Shale Member of the Red Eagle Limestone, and a few may also be found in the upper part of the Johnson and in the Glenrock and Howe units. Some columnals in shale are flattened by pressure perpendicular to the bedding, presumably from overburden of younger sediments. Echinoid spines are rare to common throughout the Red Eagle Limestone, and they are very rare in the upper beds of the Johnson Shale. Cidaroid interambulacral plates are scarce in the Bennett Member. A single plate was found in the upper part of the Johnson calcareous shale.

Extremely rare pygidial and thoracic remains of trilobites (cf. *Ditomopyge*) are present only in the Bennett and Glenrock Members of the Red Eagle Limestone.

Holothuroid sclerites may be found only in the upper part of the Johnson Shale and in the Bennett and Howe Members of the Red Eagle Limestone. *Achistrum*, a hooked form, and *Eocaudina?*, a netlike sclerite, occur exclusively in the upper part of the Johnson Shale. Wheel-shaped sclerites *(Paleochiridota?)* are present in the Bennett Shale, the Howe Limestone, and the upper part of the Johnson Shale.

Worm burrows are visible in limestone lenticles of the upper part of the Johnson Shale and in the top of the Glenrock Member of the Red Eagle Limestone.

PALEOECOLOGY

Rocks of the Red Eagle cyclothem are believed to have been deposited in warm, shallow marine water, sometimes clear, sometimes turbid, sometimes teeming with organisms, and sometimes almost lifeless. All animal fossils in the Red Eagle cyclothem are marine forms.

Following the principle of uniformitarianism, one may interpret ancient environments on the assumption that animals similar to living forms experienced analogous influences, preferences, and tolerances. Thus, certain fossils have come to be considered as reliable indicators of environment (environmental index fossils). They are admitted as evidence for reconstructing the environments in which the sediments were deposited. Conversely, the sediments may serve to indicate something of the conditions in which the fossils lived.

Commonly, the paleoecology of individual types of fossils is interpreted from their associations in a faunal assemblage. Certain members of the assemblage may be environmental indicators from which the living conditions of the

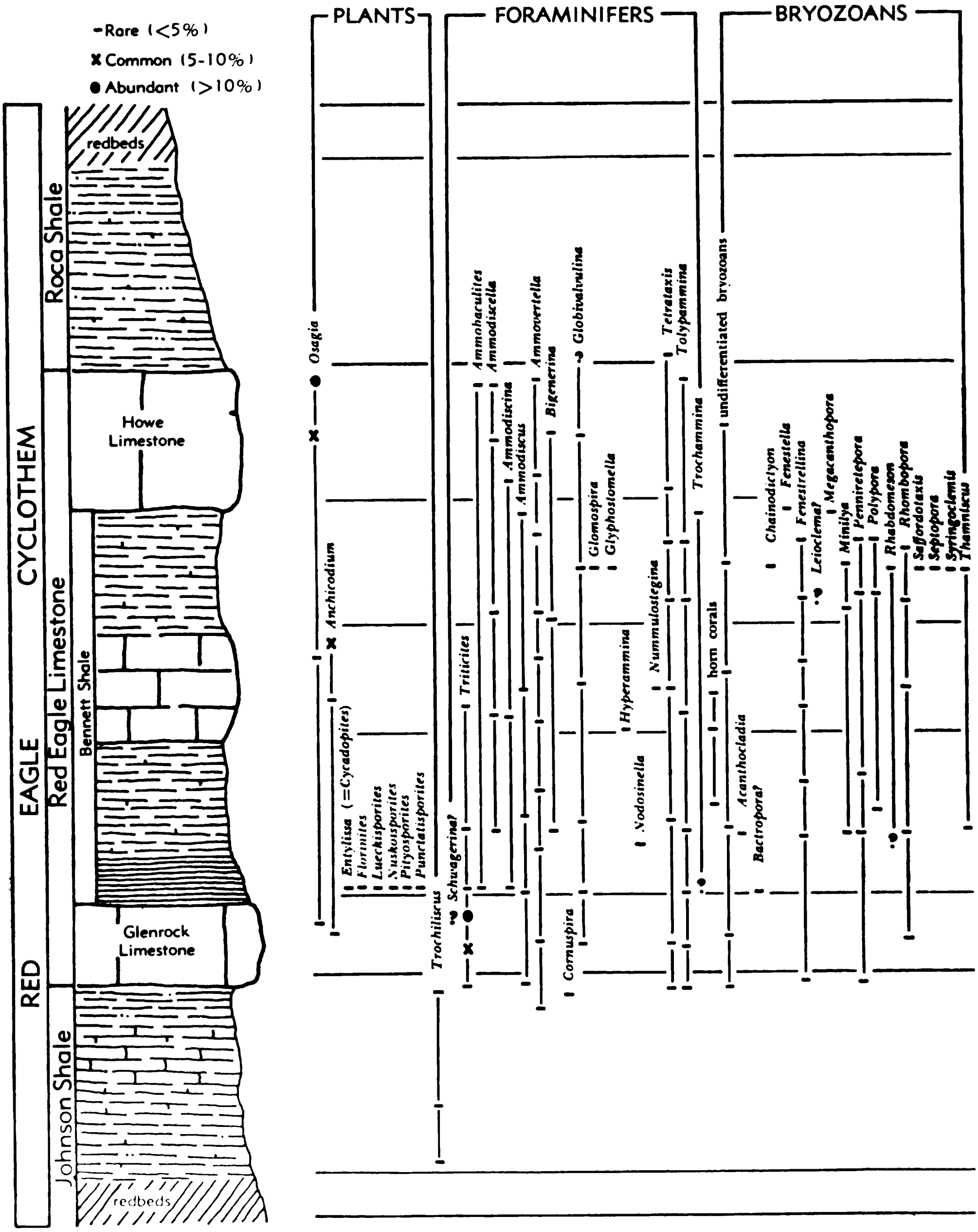
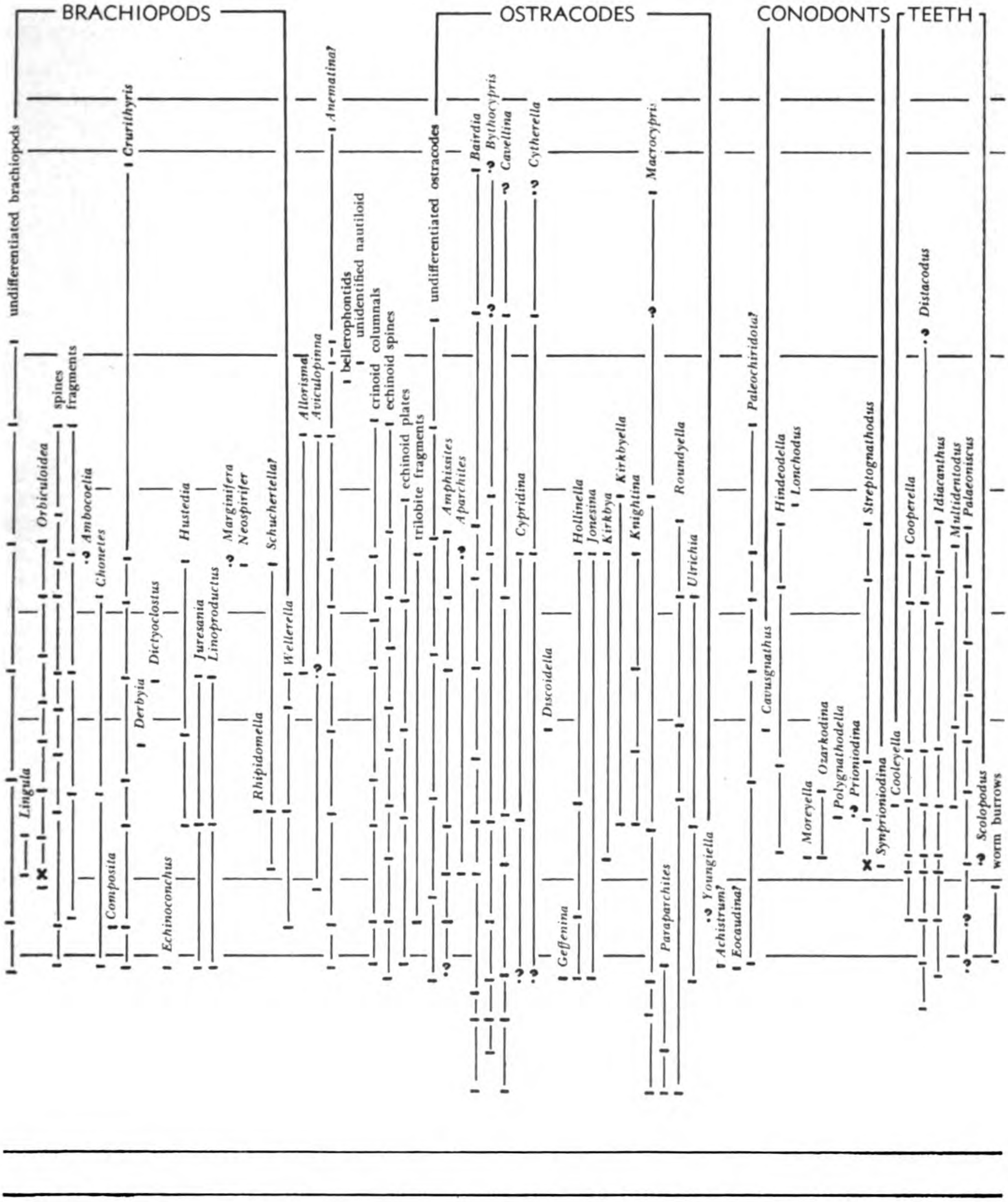


FIGURE 4.—Chart of stratigraphic position of Red Eagle cyclothem fossils. Abundance is estimate of



percentage of rock bulk.

entire group may be inferred. The assemblage, thus having acquired paleoecological significance, can then be used in paleosedimentary interpretations, even in the absence of some of the environmental index fossils which originally defined it.

Because the enclosing sediments may show that fossils were moved from their original positions and came to rest in a different environment, one should not depend on fossils alone for paleoecological interpretation. However, when fossils are absent, the paleoecology can be interpreted only from the physical characters of the rocks. Interpretations may be hindered by the fact that diagenesis can obscure or destroy the paleoecological record.

In the following discussion two aspects of paleoecology are treated separately. This first section summarizes the paleoecology of important groups and genera of invertebrates as generally interpreted and as supported or amended by this study. This section also deals with environmental index fossils and their significance. The second section presents the paleosedimentation (depositional environments) of the major lithologic units in the Red Eagle cyclothem, interpreted by using information from the first section and other relevant data.

Detailed discussions of ecologic factors that control and limit the activities of organisms appear in both volumes of the *Treatise on Marine Ecology and Paleoecology* (Hedgpeth, ed., 1957; Ladd, ed., 1957). Weller (1957, 1960) gave concise appraisals of ecologic factors as they apply in paleoecology. The interpretations which follow are based on such current knowledge of ecologic factors.

Marine Plants

Calcareous Algae

All three members of the Red Eagle Formation contain calcium carbonate of algal origin. It is recognizable as the *Osagia* (Johnson, 1946) coating on shell fragments in the Glenrock and especially Howe Limestones. Another type appears as long, roughly horizontal, ribbonlike or sheetlike crustose layers (Pl. 5), commonly called linear algae (*Anchicodium?*), that occur mainly in limestone of the Bennett Member. Intact specimens are presumably *in situ*. Some of the ribbonlike material is broken and randomly oriented (Pl. 5B). It may have come from encrusted upright-growing algal forms (see Harbaugh, 1959, p. 303-306).

It is axiomatic that algae thrive only at depths where light penetration is sufficient to support photosynthesis. Turbidity and turbulence control light penetration in sea water. The purity of the Bennett Limestone containing obvious algal deposits suggests that there was little muddy material in the water.

If it is assumed that the earth crust of the Midcontinent region has not "drifted" appreciably since Permian time, present-day observations support an additional assumption: in clear water, the base of the photic zone and the compensation depths—in Kansas latitudes at noon on a cloudless, calm June 21st during Wolfcampian time—could have been at least 200 feet below the surface. Elias (1937) postulated that limestone such as the Glenrock was deposited at depths less than 180 feet. The presence in the Glenrock Limestone of small amounts of algal material *in situ* indicates that Elias probably did not underestimate the depth of deposition of Glenrock-type limestone in the Kansas Lower Permian. Probably he overestimated it, because, as Ellison (1951) noted, about "95 percent of light available for photosynthesis has been absorbed in waters 50 meters in depth." In fact, more than 50 percent of the total incident light is transformed into heat and is extinguished in the *top meter* of pure water (Reid, 1961, p. 97). Certainly algal growth involves more than mere presence of light. Intensity and wave length of light are also significant if algae are to flourish.

Elias (1937, p. 410) stated that calcareous algae favor depths between 75 and 110 feet. Illing (1954) pointed out that in the Bahama Banks calcareous algae abound near the edge of the banks (depths of about 50 to 60 feet), where they contribute the major portion (40 percent) of calcium carbonate to accumulating sediments. Johnson (1954, p. 36) stated that the modern coralline algae grow best at depths less than 70 feet. Deeper than this (Johnson, 1954; Teichert, 1958) they diminish in size and abundance. Cloud and Barnes (1948) wrote that depths less than 15 fathoms (90 feet) are favorable to good development of algae. Williams and Barghoorn (1959) were convinced that control of calcium carbonate precipitation by plants is best at depths shallower than 60 feet. Algal biscuits in Florida Bay are found in waters 2 to 5 feet deep (Ginsburg and Lowenstam, 1958). *Cryptozoon*-type algal stromatolites (algal buns) are presently forming in intertidal depths at Shark Bay, Western Australia (Logan, 1961). Accordingly, it seems wholly justifiable, and rather conservative, to assume that the profuse oolitic *(Osagia)* carbonates in the Howe Limestone were probably deposited in water much less than 60 feet deep, because analogous pelletoid materials are presently accumulating in water less than 5 feet deep on the Bahama Banks (Imbrie, 1962, personal communication; Freeman, 1962).

The few algal-coated shell fragments within the Glenrock Limestone show no signs of abrasion or other suggestions of damage due to transportation. This indicates that although the fragments must have been turned over by gentle currents from time to time on the Glenrock lime oozes (in order for the algae to grow all around the nuclei), these materials are found essentially in place and demonstrate that light penetration was sufficient to support sparse benthonic algal life at the same depths wherein fusulinids lived. Hence, the question arises as to whether such light penetration was because of shallow depth of water in Glenrock time or merely because slightly deeper water was exceptionally clear (free of suspended detritus). The amount of insoluble clay residue in northern Howe limestone is greater than in the northern Glenrock, so there is the possibility that Howe waters were slightly more turbid than Glenrock waters.

Large parts of the calcareous matrices of the Red Eagle Limestone are aphanitic-microcrystalline. Johnson (1946) suggested that such very fine grained calcite is an accumulation of dust-like algal particles. In these matrices traces of algal threads of the sort described by Johnson (1946, p. 1107) are rarely observable, possibly because of effacement by recrystallization. Thus, it seems reasonable to believe that much of the structureless, aphanitic calcium carbonate in the Red Eagle Formation limestone (especially Bennett limestone facies) is of algal origin. Also, bacteria may have precipitated some of the particulate calcium carbonate by removing carbon dioxide from sea water (Field, 1932). Where consolidated aphanitic algal accumulations are associated with crustose fragments of linear algae (Pl. 5), it can be suggested that if the algal ribbons grew in the upright position they may have served as filter traps for the fine algal detritus. Moreover, as Harbaugh (1959, p. 306) suggested, mats of fallen algal ribbons may have been "sufficiently rigid to maintain open spaces" which also could have served as filter traps for fine sediment. This may have led to accumulation of shallow calcareous banks similar to those described from Florida Bay by Ginsburg and Lowenstam (1958).

Marine and Brackish-Water Plants

Charophytes

Oogonia of charophytes are present only in the Johnson Formation of the Red Eagle cyclothem. Johnson (1946) has pointed out that although many living forms of charophytes live in fresh and brackish water, Paleozoic forms seem to have lived in shallow marine water. They appear to have thrived in clear, lime-rich water.

The oogonia of charophytes in calcareous mudstone of the Johnson Formation support the conclusion that these beds were deposited in shallow marine, limy water of less than normal salinity. Perhaps this is why fossils are so rare in the Johnson Formation. A tentative explanation of such abnormal conditions is given on page 48.

Spores

Spores are present in a number of shale units of the Red Eagle cyclothem, especially the Bennett black shale. They are of little use in marine environmental interpretations because they must have been blown or washed into the Red Eagle cyclothem sediments from terrestrial sources. However, the assemblage seems to indicate a cool climate (H. L. Cousminer, personal communication) on land surrounding the sea of earliest Bennett time.

Waxy plant residue is also present in the Bennett black shale. Presumably much of this unidentifiable material is, like the spores, of terrestrial origin. Its presence merely demonstrates that the Bennett black-mud environment preserved plant material.

Carbonized Terrestrial Plant Material

The only significant black carbonaceous plant remains occur in the uppermost shale of the Johnson Formation. Plant material is randomly distributed through the mudstone and shale. It must have been buried quickly under accumulating Johnson clastics to have avoided destruction by physical or organic agencies. Some is gymnospermous, but other fragments, which might be seaweed, appear grassy. The material is too badly altered for certain identification.

Marine Animals

Foraminifers

Larger foraminifers, of which the fusulinid *Triticites* is representative in the Red Eagle cyclothem, are thought to have lived in warm, shallow seas. Elias (1937, p. 418) suggested that fusulinids were benthonic organisms that lived in tropical waters shallower than 180 feet. *Triticites* is abundant in the Glenrock Limestone Member of the Red Eagle Formation and rare in the Bennett Member.

In the Glenrock Limestone, fusulinids are so abundant that they commonly constitute a major part of the rock. They are associated with numerous brachiopod fragments and traces of ostracodes, bryozoans, and smaller foraminifers in a nearly pure calcareous matrix. Unlike the broken associated organisms, the fusulinids are only slightly damaged. This is typical of fusulinids (Dunbar, 1957). Their shape, size, and cellular internal structure all tend to resist breakage, but their undamaged surfaces here are nonetheless remarkable, and suggest that they are found nearly in place. At some localities the long axes of the fusulinids show slight preference for orientation in the bedding plane direction, but otherwise they are oriented randomly. Orientation in the bedding plane is to be expected, because spindle-shaped objects would be unstable in any other position than on their "sides". Their random orientation in the Glenrock Limestone might be explained by a seafloor covering of viscous calcareous ooze, which would tend to hold fallen fusulinids in random position somewhat in the way that gelatin can support fragments of fruit.

Another noteworthy characteristic of the fusulinids in limestone of the Glenrock and Bennett Members is that they do not have algal calcium carbonate coatings (e.g., *Osagia*), even in the company of brachiopod and other fragments which do have such coverings. This suggests that the fusulinids were moving about on a substratum where algae were depositing calcium carbonate on and around broken shell detritus of several kinds. Perhaps the fusulinids were either too active to permit algae to accumulate on them, in the way (literally) that "rolling stones gather no moss," or their physiologic habits repelled algae. Perhaps, even after death, the chemical makeup of their shells was distasteful to algae.

There is no doubt that Red Eagle fusulinids preferred clear water. They are numerous only in limestone containing less than 15 percent of insoluble clay and silt detritus. Moreover, the pure calcium carbonate tests of fusulinids can be as much as 60 percent (by volume) of the rock. Thus, if a limestone containing 50 percent (by volume) of fusulinid tests yields, for example, 5 percent (by weight) of insoluble residue, the matrix would actually contain about 10 percent of insoluble residue. It is, of course, the matrix that reflects the degree of turbidity of the depositional waters. Glenrock matrices where fusulinids are abundant contain slightly more calcium carbonate than where fusulinids are sparse.

The association of fusulinids with algal carbonates also indicates warm clear water shallow enough to permit light penetration sufficient for algal photosynthesis. This evidence suggests that Elias (1937) was correct to the extent that he postulated fusulinids in Lower Permian rocks of Kansas (including the Red Eagle Formation) lived in water *less than* 180 feet deep. However, they might have lived at depths less than 30 feet (Imbrie and others, 1959, p. 78).

Normally, temperature is a major control of the distribution of foraminifers in open seas (Glaessner, 1955; Myers and Cole, 1957), but it does not dominantly influence zonation in shallow water (Myers and Cole, 1957, p. 1076). Hence, temperature being less important at such shallow depths, light (function of depth) should have been one of the principal controls of Red Eagle foraminiferal distribution, probably because of its control over the microscopic plants necessary in the foraminifers' diet.

During Glenrock time clear, marine, fusulinid-rich water of uniform depth and faunal content must have covered much of northeastern Kansas and southeastern Nebraska. That is, deposition of the Glenrock Limestone was uniform over broad areas of the Midcontinent region, far from shore or sources of detrital silicates.

In brief, the sedimentary relations of fusulinids in the Glenrock Limestone indicate that, as Dunbar (1957, p. 753) phrased it, "they lived and accumulated on a quiet sea floor free from active agitation by waves and free from bottom currents capable of transporting and size grading the empty shells." Dunbar made it clear that the normal habitat of the benthonic fusulinids is believed to have been in shallow epeiric seas.

Fusulinids in black tubes near the top of the Glenrock Limestone seem to have fallen into worm tubes or holes made by some other animals. The tube-makers must have burrowed downward from basal Bennett black mud into loosely consolidated Glenrock lime mud. The few loose fusulinids that lie atop the Glenrock Limestone (slightly impressed into it) and that are largely engulfed by black Bennett mud could have been killed by the first incursion of toxic Bennett muddy conditions.

If the sparse fusulinids which are present in some Bennett limestone beds are approximately *in situ*, they must have lived under conditions close to the tolerance limits of fusulinids. The implication of their smaller numbers, their faunal association, and their association with large volumes of algally deposited limestone would be that these fusulinids lived in very shallow water (?<50 feet: Laporte, 1962; Imbrie and others, 1959). A corollary to this would be that the algae possibly used large quantities of nutrients necessary to support fusulinid life. Moreover, the particulate algal calcium carbonate that was probably precipitating rapidly might have interfered with the food-intake mechanisms of the fusulinids, perhaps killing many before they could reproduce.

On the other hand, it is remotely possible that the fusulinids could have washed into the area of study from unknown sources, or that they might have been reworked from now-absent Glenrock deposits in central Kansas. However, these possibilities seem unlikely because the Bennett fusulinids show no damage or abrasion to suggest erosion or long transportation.

The very rare fusulinids in the top part of the Johnson Shale at the Highway 38 section are broken and abraded, suggesting damage during long transportation from an unknown source area. The single fusulinid shown by O'Connor and Jewett (1952, p. 335, pl. 10) is insufficient to permit explanations of its significance in the Howe environment.

Almost all smaller foraminifers of the Red Eagle cyclothem are arenaceous forms. They are common in the Red Eagle Limestone, rare in the Johnson Shale, and extremely rare in the Roca Shale. They are not as restricted in their lithologic associations as *Triticites*. Such foraminifers, because of their small size and fragility, are difficult to extract from sedimentary rocks. Hence, their record and sedimentary associations in these and other sediments are incompletely known, and any paleoecological interpretation based on them is tentative.

The tolerance of the smaller foraminifers for a variety of marine conditions is suggested by their occurrence in lithologies ranging from nearly pure limestone to moderately calcareous shale and mudstone. Although *Tetrataxis* and *Ammodiscus* are present in various Red Eagle cyclothem lithologies, they occur most commonly in the rocks containing less than 40 percent of calcium carbonate. *Glyphostomella* is found in lithologies containing about 75 percent of insoluble clastic residue. On the other hand, *Ammovertella* and *Tolypammina* seem to favor the calcareous environments represented by lithologies containing less than 10 percent of insoluble residue. Thus, their preference for clear water is suggested. Also, calcareous places of attachment were preferred by these genera. *Ammovertella* were found encrusted on fragments of *Rhabdomeson?* and *Fenestrellina?*. *Tolypammina* are rarely seen encrusted on ostracodes.

Lane (1958) and Hattin (1957) noted that certain specimens of *Osagia* contained traces of the arenaceous foraminifer *Ammovertella*, together with *Nubecularia*, which, as Johnson (1946, p. 1103) discovered, is the intimate associate of calcareous algal filaments in all *Osagia*. In this study, too, traces of *Ammovertella* were found in *Osagia* of the Howe Limestone, and on some linear algae *(Anchicodium?)* in the Bennett Member as well. However, the *Ammovertella* are so few that these coincidences of occurrence can not be said to indicate definite organic associations (e.g., commensal, symbiotic). That is, considering the variety of calcareous materials on which it encrusts, *Ammovertella* in the Red Eagle cyclothem simply seem to have preferred calcareous surroundings or places of fixation. If they had encrusted on a calcareous algal coating of *Osagia*, they would naturally have been covered by the next-deposited *Osagia* layer, giving the false impression that *Ammovertella* were functional interrelatives of algae and active contributors to *Osagia*.

Insoluble residues from limestone in all parts of the Red Eagle cyclothem commonly contain traces of "stuck together" quartz silt, most of which probably came directly from arenaceous foraminiferal tests similar to (or actually belonging to) *Ammovertella* and *Tolypammina*.

Few definite opinions about the paleoecology of the smaller foraminifers are forthcoming from the available evidence. Presence of these animals in a variety of lithologies suggests that they could tolerate a moderately wide range of environmental conditions and thus are of little use as environmental indicators in paleoecological interpretations. Information about their environmental preferences must be deduced from considerations of their role as part of the entire faunal assemblage and of the paleosedimentation of the Red Eagle and other cyclothems.

Johnson waters (see Table 7) seem to have been generally inhospitable to foraminifers. Only *Ammovertella* and *Tolypammina* were able to establish themselves during periods of clearer water in later Johnson time, represented by limestone layers in the upper part of the Johnson Shale. Large and small foraminifers thrived in the clear water of Glenrock time. Foraminifers did not live in the toxic water or on the black muddy sea bottom of early Bennett time. As deposition of the Bennett Member progressed and the environment became more favorable, smaller foraminifers and the other marine invertebrates abounded in the calcareous, sometimes turbid, waters represented by Bennett limestone and shale. The clear, shallow-water environment represented by the sparsely fossiliferous aphanitic Howe Limestone of southeastern Nebraska seems to have been favorable enough for a foraminifer population somewhat reduced in number of genera and individuals as compared with the Bennett fauna and the osagitic Howe fauna.

Bryozoans

A variety of lithologies throughout the Red Eagle Formation contain bryozoans. They are especially common in the Bennett Member. Only a few traces of bryozoans are present in the uppermost parts of the Johnson and Roca Shales. Their association with a profusion of crinoids, brachiopods, foraminifers, and a variety of other marine organisms in the Red Eagle Limestone indicates that they thrived in normal marine water in the shallower reaches of the neritic range of environment, where the water was warm and life was abundant. Bryozoans in the Red Eagle Limestone, although broken, are little abraded, suggesting that they were not moved very far from their environment of origin.

Bryozoans are virtually absent from the Johnson and Roca Shales; thus, there is the question whether they were erased from the record during diagenesis or not deposited. The former possibility is rejected because a few calcareous marine fossils (some delicate) are present in the Johnson Formation, and there is no apparent reason why bryozoans, had they been present, should have been removed while the others remained. Thus, it seems probable that bryozoans were absent from the Johnson and Roca environments because of some unfavorable ecologic factor(s). Living bryozoans are known to abound from low-tide levels to depths greater than 600 feet, so that depth does not seem to have been an unfavorable factor. Another possibility is that bryozoans were absent from the mud-bottomed Johnson environments because substantial objects for attachment of their larvae (Duncan, 1957) were lacking.

Subnormal salinities, suggested by the presence of charophytes in the Johnson beds devoid of bryozoans, also may have prevented the establishment of bryozoans, probably during their larval stage. Osburn (1957, p. 1110) noted that, in general, salinities of less than 20 parts per thousand (normal open sea water averages about 36‰) are unfavorable to bryozoans. Thus, the absence of bryozoans from shale of the Johnson and Roca Formations lends support to the possibility that abnormally low salinity (brackish) conditions prevailed during their deposition.

Elias (1937) advanced the idea that bryozoans in these beds, and in adjacent cyclothems, lived in water between 75 and 160 feet deep. Stach (1936) noted that many bryozoans live at depths between 60 and 120 feet, where they are subject to some current and wave action. In view of the habits of living bryozoans, Elias' range of depth should not be construed as the depth limits outside of which bryozoans could not have lived during Early Permian time. The assumption should be that if waters had been deeper than 160 feet, bryozoans could have survived there. It also may be safely assumed that bryozoans could have become established in water shallower than 60 feet in protected places where they would not be destroyed by turbulence. Although there is no evidence of bottom relief sufficient to afford such protection, upright algal growths might have helped to provide it. If Elias' and Stach's figures are correct, it might be suggested that in the smooth-bottomed shallow sea indicated by the Red Eagle cyclothem, most turbulence (i.e., lowering of effective wave base) was shallower than 60 feet. That is, bryozoans favored bottoms below a normal wave base not deeper than 60 feet and possibly much shallower. Broken bryozoans in the Bennett calcareous shale suggest that turbulence during unusually severe storms might have shattered the bryozoans living below normal wave base, or fish such as sharks may have chewed them.

One specimen of *Rhombopora?* (possibly *Rhabdomeson?*) was seen encrusting part of a productid brachiopod spine. Duncan (1957, p. 789) stated that there are "examples of bryozoans attached to fossil shells that are highly suggestive of commensal or amensal relationships." Whether the bryozoan encrustation occurred during the life of the brachiopod or merely on a piece of spine detritus is uncertain.

The bryozoans in the Red Eagle Formation seem to have favored the clear, calcareous environments represented by limestone. However, they are found at random throughout a variety of fossiliferous calcareous mudstones, suggesting that they could tolerate a good deal of mud in water of approximately normal marine salinity. Their faunal and sedimentary associations demonstrate that they thrived below normal wave base in shallow water probably much less than 60 feet deep. The scarcity of bryozoans in any part of the Red Eagle sequence may be due to excessively shallow water or other unfavorable and physically severe conditions (see Duncan, 1957, p. 786). The euxinic environment of the Bennett black mud must have been very unfavorable to bryozoans. Temperature does not seem to have been a limiting influence on bryozoan growth within the Red Eagle cyclothem environments.

Brachiopods

Like other calcareous invertebrate remains, brachiopods are most numerous in the Red Eagle Formation and rare in the Johnson and Roca Formations. There is no doubt that the articulate brachiopods flourished in the clear calcareous environments represented by Red Eagle limestone beds, but many genera also occur in a variety of muddy lithologies. Only the inarticulates *Orbiculoidea* and *Lingula* are present in the laminated Bennett black shale (conodonts and fish teeth are usually the only other fossils present). These delicate fossils are commonly found unabraded and almost unbroken or gently crushed by vertical pressure, so that their occurrence *in situ* in black shale is quite certain. It seems, therefore, that these animals could tolerate foul, euxinic, black muddy bottoms. *Orbiculoidea* is present also in calcareous muddy lithologies and even in limestone (especially the lower parts of Bennett limestone beds), indicating that it could tolerate environments ranging from the very toxic black mud milieu to clean, "healthful," limy bottoms.

The suggestion that *Lingula* was tolerant of the toxic Bennett black mud milieu is in keeping with known habits of living *Lingula*. As remarked by Shrock and Twenhofel (1953, p. 339), "*Lingula* does not seem to be affected by brackish water or by water so foul from decomposing organic matter that burrowing molluscs are unable to survive." Thus, *Lingula* seems to be, in present seas, much as it was during Red Eagle time. In 1902, Morse (see Cooper, 1957b) stated that *Lingula* has always dwelt in a shallow-water shore zone and therefore has not felt the effects of eustatic or epeirogenic changes. Consequently, it evolved little and has been essentially unchanged through geologic ages.

Present-day *Lingula* lives on the benthos in warm, temperate water and is rarely present at depths greater than 60 feet. In fact, *Lingula* is commonly found in the littoral zone (Cooper, 1957a).

The *Lingula-Orbiculoidea* association in the black shale at the base of the Bennett Member is therefore thought to indicate that these beds were deposited in warm marine water almost certainly less than 60 and probably less than 10 feet deep. Moreover, the nature of the sediments as a whole indicates that the early Bennett waters were low in oxygen content and thereby rather toxic, so that most benthonic invertebrates could not live there. This further suggests that *Lingula* and *Orbiculoidea* had broad tolerance ranges for oxygen supply and salinity, but avoided depths greater than about 20 feet. It can be safely assumed that light, temperature, and supply of nutrients are factors involved in such depth sensitivity.

Articulate brachiopods, mostly calcareous, are very rare in the lower Johnson sediments, rare in upper Johnson and Roca sediments, and numerous in all members of the Red Eagle Limestone (especially the Bennett Shale). The organic and physical sedimentary associations of these brachiopods, and the nature of the brachiopods themselves, indicate that they lived in shallow, approximately normal marine water in both turbid and clear conditions on calcareous muddy bottoms. Many shells are broken or without their spines. This could be the result either of turbulent water or of the masticatory activities of mud-ingesting animals and nektonic and benthonic predators. The shell fragments are not worn or rounded.

Theories that the shape, ornamentation, and thickness of bivalve shells reflect the turbulent rigor of their living conditions are well known. The variety of brachiopod shell shapes, thicknesses, and sizes observable (broken and unbroken) in the Red Eagle sediments may indicate that they lived in water sometimes turbulent, sometimes quiet. Moreover, burrowing, fixed, and motile benthonic forms all seem to have thrived together in the Glenrock and especially Bennett environments.

Some indication of the temperatures of Bennett waters may be inferred from the presence of *Neospirifer* and *Chonetes* in calcareous shale. Lowenstam (1959) showed, from geochemical data, that the shells of some Early Permian *Neospirifer* probably formed in marine water at about 74°F.

Crurithyris, in a variety of lithologies and in all three formations of the Red Eagle cyclothem, seems to have been a brachiopod most tolerant of environmental changes.

The calcareous brachiopods in the upper part of the Johnson Shale are confined to southern Kansas, where the upper shale units are calcareous and contain a fauna somewhat similar to the Bennett of central and northern Kansas.

Gastropods

Small, smooth, spired and planispiral evolute gastropods are present, although scarce, in all units of the Red Eagle cyclothem. They occur in all lithologies of the cyclothem except the Bennett black shale. This suggests that although they could have lived in most sedimentary environments in water considerably less than 100 feet deep, they were among the many animals unable to tolerate the toxic early Bennett conditions. A slight preference for the more calcareous environments is suggested by relatively greater numbers of gastropods in limestone.

Many gastropods in osagite of the Howe Limestone are not coated by algal calcium carbonate. This may signify that these gastropods were moving about while the algae were growing, or that the geochemistry of their shells was distasteful to algae. Coated shells may have acquired their coverings after death.

Cephalopods

The unique occurrence of a coiled nautiloid cephalopod at the top of the Howe Limestone near Allen, Kansas, is of little significance in paleoecological interpretation. Its stratigraphic association merely indicates the presence of coiled nautiloids in the very shallow Howe-type waters. That only one such nautiloid has been seen in the Red Eagle cyclothem suggests that it may be a freak occurrence, transported (alive or dead) far from its birthplace. Living nautiloids can float long distances before coming to final rest. Miller and Youngquist (1949, p. 4) seemed almost certain that most Permian nautiloids behaved similarly to presently living nautiloids. The unbroken condition of the Howe nautiloid suggests that it was not subjected to violent current action or other serious abuse after coming to rest on the Howe sea bottom. Its envelope of algal calcium carbonate indicates occasional gentle rolling so that algae were able to grow on all sides of the shell.

Modern *Nautilus* lives in depths from near low tide to almost 2,000 feet. Its ecology is poorly known.

The several straight nautiloids found only in the Howe Limestone at Coffman Ranch are not coated by algal carbonates, but they are embedded in an osagitic matrix. These nautiloids probably developed in a fairly open sea environment, but to attain their present position they must have been washed into the constricted Howe sea and stranded on the soft subtidal bottom.

Pelecypods

Molds of *Aviculopinna* are extremely rare in the Glenrock and Howe Limestones. It is thought to have been a burrowing form (Elias, 1937, p. 419), but its rarity precludes definite paleoecological interpretation. The original shells buried in limestone could have been preserved because the lime was not stirred violently by currents before consolidation. On the other hand, diastems and common broken shell detritus in the Bennett Shale indicate that those Bennett sediments were disturbed by turbulent waters. It is not known whether *Aviculopinna* lived in Bennett mud. Perhaps some of the broken Bennett shell material is (comparatively frail) *Aviculopinna. Allorisma* is more robust than *Aviculopinna* and is very rarely found in the Bennett shale and in the Howe Limestone.

Worms

One explanation of the peculiar flattened clay-filled tubes in the Glenrock Limestone (Pl. 1B, 1C) is that they are worm burrows. Apparently worms burrowed into the Glenrock sediments from the overlying black Bennett mud. The tubes suggest that in earliest Bennett time the Glenrock had not fully consolidated, so that worms could forcefully advance through the soft sediments. However, some worms can bore through consolidated limy material by secreting acids. Thus, it is not known whether the tubes were made in the Glenrock sediments before or during appreciable consolidation. However, individual fusulinids, *Orbiculoidea* fragments, and Bennett mud trapped in the tubes suggest that the sediment was firm enough for the tubes to remain open.* Flattened parts of the tubes indicate that consolidation and compaction were completed after the time of burrowing. The tubes had to be open to allow the fragments of *Orbiculoidea*, fusulinids, and mud particles to fall from the Bennett mud above to the bottom of the tubes.

Other smaller and somewhat different worm tubes are present in upper Johnson calcareous mudstone and upper Roca limestone. Some might be tubes of animals similar to phoronids.

The assumption that the tubes were made by worms does not preclude the possibility of their manufacture by some other type of tube-making organism. It is difficult to imagine what sort of organism this could be, because no pelecypod, crustacean, echinoderm, or any other shelled burrower has been found at the end of any tube. Consequently, worms seem to be the best possibility, because their soft bodies could decay and leave no trace.

Ostracodes

Ostracodes are common in the uppermost shale of the Johnson Formation and in the Red Eagle Formation, but they are rare in the Roca Formation. They occur in almost all calcareous rock types in the Red Eagle cyclothem but not in red or black shale.

Sediments enclosing the ostracodes and their numerous and varied faunal associates indicate that some kinds of ostracodes could survive in almost every calcareous marine environment within the Red Eagle cyclothem. As a group they seem to be independent of sedimentary facies. Apparently most of them thrived best in somewhat turbid carbonate-rich water of normal salinity. The toxic conditions indicated by the Bennett black shale and high salinities suggested by Roca red shale were probably inimical to most ostracode life.

The relatively greater number of smooth-shelled ostracodes (in both horizontal and vertical distribution), such as *Bairdia* and *Cavellina*, suggests that they were able to tolerate a broader variety of marine environments than the rarer ornamented forms, such as *Amphissites*.

It is remarkable that many ostracodes in the Red Eagle cyclothem are either intact or gently crushed flat by vertical pressure, especially where they accumulated along laminae of shale. In view of their molting habits, delicate shells, easy transport, and association with coarse detritus, it seems clear that these almost undamaged ostracodes were not transported far. Soft and muddy bottom sediments may account partly for their preservation. If some types of ostracodes died in their burrows, the bottom muds could have protected them from abrasion. Also, if eroded, the muddy bottom would cushion them against the adverse effects of tumbling by gentle currents. Many ostracodes present in the nonlaminated mudstone beds seem to have been quickly buried.

If ostracodes were ingested and subsequently evacuated by larger organisms it is likely that they were too small to suffer the same degree of damage or breakage by mastication as larger shells. This seems tenable because it is known that shells much larger than ostracodes can pass through the alimentary tracts of fish with little breakage and virtually no abrasion (Sogandares-Bernal, 1955, personal communication).

Within the Red Eagle Limestone formation, especially the limestone members, many ostracodes are randomly oriented. In Bennett shale units there is some preferential orientation of ostracodes parallel to bedding and along laminae, but orientations are random in mudstone. The shape and light weight of ostracode shells is such that they should tend to lie flat on the sea bottom. Even the gentlest of currents would aid such alignment. Perhaps the muddy bottom tended to support some ostracodes in random orientation exactly as they fell, without permitting realignment.

It is noteworthy that great numbers of exceedingly frail, smooth ostracode shells occur along laminae in uppermost Johnson gray shale and mudstone. In fact, these layers of ostracodes are planes of textural difference and, consequently, of weakness or parting, which are recognized as laminations. The frailty and lack of damage of the ostracodes indicate that they are probably *in situ*. Ostracodes are few and randomly oriented in the interlaminar mudstone. Perhaps these were burrowing forms.

Periodical mass mortality of ostracodes in late Johnson waters could have caused the rain

* Ginsburg (1957, p. 85), in discussing worm tubes in Recent sediments, pointed out that filled and "open unlined burrows are very abundant in shallow-water carbonates."

of ostracodes which accumulated along the lamination planes. It is suggested that such mass mortality may have resulted from a decrease of salinity caused by sudden influx of fresh water bearing plant detritus. This combination of events is admittedly hypothetical, but sporadic fluctuations of regional climate offer a tentative explanation for the phenomena recorded in the uppermost Johnson shale. If low salinity had been the prevailing condition during late Johnson deposition, and if the water cleared and became more normally saline and calcareous during periods of less rainfall on land, marine ostracodes may have become abundant. A return to low salinity would attend increased rainfall and dilution by fresh water carrying plant detritus and mud. This could explain both the mass mortality of ostracodes and the traces of carbonaceous woody plant remains in mudstone and shale between ostracode-bearing laminae.

Salinity changes may not have affected the ostracodes directly but could have controlled the microorganisms upon which the ostracodes fed. A few genera, such as *Bairdia*, *Bythocypris*, and *Cavellina*, apparently were able to endure a sizeable range of salinity conditions.

Crinoids

Except for the calcareous upper Johnson sediments at the Grand Summit section, columnal remains of crinoids within the Red Eagle cyclothem are present exclusively in the Red Eagle Limestone. Most crinoid columnals in the Red Eagle Limestone are disarticulated and dispersed but unabraded. This suggests a slight amount of transportation. The lack of abrasion may be due to their solid structure, as opposed to the soft Red Eagle bottoms on which they came to rest. Many columnals in shale are flattened, presumably during compaction of the sediment. No crinoid calices have been found in the Red Eagle cyclothem.

In the upper part of the Bennett at the Coffman Ranch section crinoid columnals are common, many still articulated. This suggests that they remained nearly *in situ*, where they accumulated to form a local crinoidal shell bank.

Laboratory analyses of the crinoidal limestone reveal a low percentage of insoluble clastics. This tends to confirm the judgment that crinoids lived in clear water. Preference of crinoids for clear calcareous environments is also shown by their rare to common occurrence in other Bennett limestone and their scarcity in the Bennett mudstone and shale. Such clear water also would have been ideal for the algae which are believed to have contributed much calcium carbonate to the limestone of the Red Eagle.

Echinoids

Echinoid spines are present in the Red Eagle Formation in the same sediments as crinoid stems, suggesting that echinoids favored nearly the same habitats as crinoids—warm, clear, calcareous, gently agitated waters on limy bottoms. Very few cidaroid interambulacral plates are present in the Bennett Member. Gentle currents could account for broken, disjointed, and dispersed but unabraded fragments of echinoids. Echinoid spines commonly accompany productid brachiopod spines.

Many Recent echinoids live in shallow clear water on either a sandy or limy bottom. Consequently, from the above interpretations it may be inferred that the habitats preferred by echinoids have not changed appreciably since Early Permian time.

Conodonts and Fish Remains

A somewhat arbitrary distinction is drawn between conodonts and fish teeth. In addition to color and structural differences, the mode of occurrence of conodonts is somewhat different from that of fish teeth. Conodonts (e.g., *Streptognathodus*, *Hindeodella*, *Ozarkodina*) are common in the black shale of the basal Bennett Member and rare in other Bennett shale. Fish teeth (e.g., *Idiacanthus*, *Palaeoniscus*, *Distacodus*) are rare in upper Johnson gray shale, common in all Bennett shale, and extremely rare in the Howe Limestone, Glenrock Limestone, and lower Roca Shale. Lower Johnson Shale and upper Roca Shale lack conodonts and fish teeth.

Conodonts are thought to be parts of the dental structures of vagrant nektonic animals similar in habit to, if not truly, fishes (Schmidt, 1950, cited *in* Ellison, 1957). Such habit explains the fact that they occur in black shale (barren of other fossils) indicative of toxic ecologic conditions, as well as in fossiliferous shale and limestone which record more favorable environments. If nektonic, these unknown animals could have lived in near-surface waters above bottom environments too poisonous to support aerobic organisms. When they perished, their remains could have fallen on any bottom, whatever its characteristics. An alternative possibility is that anaerobic environments provided the normal conditions for the animals from which conodonts are derived. Furthermore, the reducing conditions that account for black shale probably favored preservation of conodonts.

The absence of conodonts or fish teeth from most Johnson and Roca sediments is difficult to explain, because it is not unlikely that conodont-bearers and tooth-bearers could have lived in near-surface waters, if not close to the muddy Johnson and Roca bottoms. If conodont-bearers dwelt in or above the wide range of bottom environments recorded by Red Eagle sediments, it would seem odd that they should have been unable to tolerate the Johnson and Roca waters wherein a few ostracodes lived. Of course, they could have been removed from the sediments during diagenesis, but such diagenetic selectivity (removal of conodonts but not ostracodes) seems unlikely.

In the black shale, conodonts and fish remains are associated with *Orbiculoidea*, *Lingula*, macerated plant remains, and spores. This type of association was normal for conodonts even in the Devonian (Ellison, 1957, p. 993).

Cyclothemic Nature of the Faunal Assemblages

Elias (1937) asserted that depth of deposition seems to have been the main factor that controlled the sedimentation and fauna of the rock sequence of the Red Eagle and other cyclothems. He postulated that certain faunal assemblages lived in certain phases of the repetitious marine sedimentary environments which resulted from rhythmic changes of water depth early in Permian time. Consolidated faunal and sedimentary repetitions in orderly succession are recognized as cyclothems. Elias noted that each of these cycles has a progressive and a regressive half-cycle, which presumably reflect deepening and shallowing of the seas, respectively. In the regressive part of a theoretically complete cycle, the sequence is exactly opposite to that of accumulation during the progressive part. Elias (1937, p. 411) recognized seven faunal-lithological "phases" in each half of a complete, or ideal, cycle.

Table 4 is a modification of Elias' list of idealized cyclothemic phases, with his interpretation of their depths of deposition. Hattin (1957) suggested the addition of phase 0 at each end of the list to accommodate rare terrestrial channel sandstones not provided for by phases 1 through 7.

Elias (1937, p. 411) was careful to state that "no single cycle . . . shows all phases of the ideal cycle, but the missed phases of one cycle appear in proper position in neighboring cycles above and below." Several of these basic faunal assemblages (phases) are present in rocks of the Red Eagle cyclothem. Table 5 shows sedimentary units of the Red Eagle cyclothem recognized in this study and the phases they represent (following Elias). The progressive (transgressive) and regressive phases thus determined *within* the Bennett Member are noteworthy.

Table 4.—Idealized Lower Permian cycle of deposition in north-central Kansas (modified from Elias, 1937, and Hattin, 1957).

	No.	Phases, established chiefly on paleontologic evidence	Depth, feet
	0	Channel sandstone	+
	1r	Red shale	0
Regressive hemicycle	2r	Green shale	0-30
	3r	*Lingula* phase	30-60
	4r	Molluscan phase	60-90
	5r	Mixed phase	90-110
	6r	Brachiopod phase	110-160
	7	Fusulinid phase	160-180
	6p	Brachiopod phase	110-160
	5p	Mixed phase	90-110
Progressive hemicycle	4p	Molluscan phase	60-90
	3p	*Lingula* phase	30-60
	2p	Green shale	0-30
	1p	Red shale	0
	0	Channel sandstone	+

A fusulinid facies is characteristic of, and dominates, the upper part of the Glenrock Limestone. This corresponds to Elias' phase 7 (fusulinid phase), which he described as indicating depositional depths between 160 and 180 feet. A few brachiopods, bryozoans, foraminifers, calcareous algae, and crinoids accompany the fusulinids.

Lingula, with *Orbiculoidea* and conodonts, are the dominant fauna of the black and dark-gray shale of the lower Bennett Member. Elias' phase 3 is the lingula phase, which he estimated as indicating depths of deposition probably less than 60 feet. However, Elias noted sandy lithologies as typical bearers of *Lingula*. In the Red Eagle cyclothem *Lingula* occurs mainly in black shale.

A fauna rich in productaceans and spiriferids dominates the gray shale of the lower part of the Bennett Member immediately above the black-shale fauna. Bryozoans, with ostracodes, foraminifers, gastropods, crinoids, and holothurians, are lesser components of the fauna. This assemblage is recognized as the mixed phase (phase 5) of Elias, which he stated was deposited at depths between 90 and 110 feet. Bennett limestone exhibits a sparse brachiopod fauna (Elias' phase 6), including some horn corals.

TABLE 5.—Units of the Red Eagle cyclothem defined in terms of Elias (1937).

Unit of the Red Eagle cyclothem	Elias' depth of deposition, feet	Elias' phase	No.
Roca Shale			
medial red shale	0	Red shale	1
lower greenish shale	0-30	Green shale	2r
Red Eagle Limestone			
Howe Limestone Member	60-90	Molluscan phase	4r
Bennett Shale Member			
upper gray shale	90-110	Mixed phase	5r
medial limestone	110-160	Brachiopod phase	6
lower gray shale	90-110	Mixed phase	5p
basal black shale	30-60	*Lingula* phase	3p
Glenrock Limestone Member	160-180	Fusulinid phase	7
Johnson Shale			
upper greenish shale	0-30	Green shale	2p
medial red shale	0	Red shale	1

A mixed faunal assemblage (Elias' phase 5) of brachiopods, bryozoans, foraminifers, gastropods, crinoids, mollusks, and ostracodes is repeated in the upper part of the Bennett Member. It is succeeded by the very abundant, calcareous, algal osagite of the Howe Member. The Howe Limestone appears to be approximately equivalent to Elias' molluscan phase (phase 4), which he postulated as accumulating at depths between 60 and 90 feet.

Although it is agreed that regular or irregular changes of water depth must have been of prime importance in molding the Red Eagle cyclothem biofacies and lithofacies, this study recognizes that regional climate, tectonism, supply rate of muddy clastics, and movement and chemistry of the waters must all have been interrelated and must have modified and sometimes subordinated the depth effects on Red Eagle cyclothem sedimentation. Moreover, the effects of interference of eustatic and local tectonic influences on depth, facies-genesis concepts such as those of Imbrie and others (1959), and other factors (see Weller, 1957) must be considered when interpreting Red Eagle cyclothem paleoenvironments. In view of expanded knowledge of modern environments, some revisions of Elias' depths of deposition seem necessary. To explain the ecologic conditions suggested by the Red Eagle cyclothem, water depth no greater than 60 feet need be postulated.

PALEOSEDIMENTATION

The cyclic repetition of rock units similar in lithology, sequence, and thickness, one above the other, in the Lower Permian of Kansas has been well known since Elias' (1937) unique publication. These cyclothemic rocks are thought to have been deposited in shallow epicontinental seas covering a vast flat shelf area of the Nebraska-Kansas-Oklahoma region. Moore (1959) summarized current cyclothem interpretations involving matters such as the "significance of knife-sharp lithologic boundaries."

Without attempting to remark at length on the ultimate causes of cyclothemic sedimentation, several matters including the one quoted above from Moore should be introduced here in the light of what is observable in the Red Eagle cyclothem. This will set the stage for interpretation given in the following pages.

The sharp Glenrock-Bennett contact is, for all practical purposes, a time plane within the Red Eagle cyclothem. Although this contact is chosen for special mention, the Howe-Roca contact is almost as sharp. This does not imply that gradational lithologic boundaries are not common in the Red Eagle cyclothem. It is merely a reminder that boundaries ***between*** the members and formations are relatively sharp and that they reflect more sudden widespread changes in depositional conditions; whereas, *within* the formations and members sedimentary conditions must have changed more gradually, because most lithologic boundaries therein are gradational through an inch or two of column.

Another subject for comment is the proportion of noncalcareous clastic material to calcium carbonate in these rocks. Few clastic rocks in the Red Eagle cyclothem are free of calcareous matter, and so indicate a measure of continuous carbonate deposition. Clastic carbonates complicate the situation. Insoluble residues and stratigraphic data indicate that Red Eagle clastic silicates seem to have come from sources north, east, and south of the outcrop belt.

Paleoecological evidence indicates that the aforementioned sharp lithologic changes could result from abrupt changes of water depth. Current opinion acknowledges that the cause of the cyclothems generally embraces such depth changes over the entire Midcontinent shelf-basin. Whether the changing depths record epeirogenic or eustatic movements is a current problem. Changes in relative supply rates of clastic detritus are presumably allied to the depth changes, which affected other factors and helped to produce the different lithologies.

Because no cyclothem is complete or symmetrical, in the ideal sense of Elias (1937), it is obvious that depth changes were neither uniform in rate nor continuous. Within any cycle, and subservient to the overall deepening or shallowing of the seas and general subsidence of the shelf-basin, there were temporary reversals of direction (or local lags in the rate) of depth change.

The assembled evidence indicates that all sediments of the Red Eagle cyclothem in Kansas were deposited in shallow, flat-bottomed, epicontinental seas far from land. Sedimentary conditions during deposition of the Roca Formation were somewhat similar to those that earlier produced the Johnson Formation. Sedimentary conditions that yielded the Red Eagle Formation were unique within the Red Eagle cyclothem.

Paleoecological interpretations developed in the preceding pages are used in the following attempts to reconstruct the paleosedimentation of the Red Eagle cyclothem.

Deposition of the Johnson Shale

The several aforementioned types of shale and mudstone which make up most of the Johnson Shale show no regularity of habit or stratigraphic position except in the upper few feet of the formation.

The few red shale beds in the middle part of the Johnson Formation at opposite ends of the Red Eagle outcrop belt are difficult to explain. They contain the same clay minerals and structures as the other clearly marine Johnson shale. It seems reasonable to believe that the redbeds are very shallow marine deposits probably derived from red soil. Their position at the northernmost and southernmost ends of the outcrop belt, hence probably closer to the Wolfcampian land, supports the possibility of terrestrial derivation. Conceivably the constituents of the green shale in areas between the redbeds might have lost an original red color by chemical reduction of iron during long transportation toward the central part of the basin. Had they been deposited in the red condition, they would probably still be red, because, as Grim (1951) pointed out, red sediments once deposited tend to stay red.

The origin of red terrestrial source materials requires comment. It is not likely that the red materials were derived from previously existing redbeds because few such beds are known to exist in older Paleozoic rocks to the north, east, and south of the Red Eagle belt of outcrop. The idea of red soil as the source material is favored. This implies the possibility of a warm, moist (Krynine, 1949) regional climate (periodically dry) at least for a short duration near the middle of Johnson time.

Many of the Johnson shale and mudstone units are greenish gray, and almost all are calcareous. The carbonate distribution is not systematic. Many beds contain 10 to 50 percent of calcium carbonate and a few contain less than 10 percent. These proportions vary abruptly from bed to bed. Most of the carbonate material is extremely fine grained. A small amount in the uppermost shale is attributable to calcareous ostracode shells.

Interpretation of the origin of these calcareous shale and mudstone beds requires an estimation of the method of precipitation of the calcium carbonate and of its relation to the preponderant muddy clastics that obscure it. Interpretations of the mechanics of precipitation of calcium carbonate have been reviewed at length by many authors (e.g., Cloud and Barnes, 1948; Emmons, 1928; Revelle and Fairbridge, 1957; Rodgers, 1957; Zeller and Wray, 1956). Two plausible explanations of the origin of the aphanitic calcium carbonate in the Johnson Shale are available: (1) inorganic precipitation resulting from liberation of CO_2 from sea water saturated with carbonate, by agitation or rise in temperature (Emmons, 1928; Zeller and Wray, 1956), and (2) organic precipitation as the familiar algal "dust" particles. In either circumstance, precipitation probably would have occurred mainly in the upper levels of the Johnson waters, and the precipitates would have mingled with the silicate clastic materials while descending to the depositional interface.

The preponderance of clay clastic material in the Johnson sediments suggests moderately turbid waters. The paucity of silt probably indicates deposition far from the source, although source rocks may have been sediments containing few coarse clastics. Sedimentary structures in a few of the laminated shale beds suggest accumulation in very shallow water. Some of the lamination and fissility may be ascribed to periodic thin accumulations of organic material (Ingram, 1948, 1953) or to laminar deposits of clay floccules (Keller, 1936). Difficulties of thin-sectioning such shale prevent certification of the textural nature of the laminae. However, in the laminated argillaceous limestone (platestone) of the upper part of the Johnson Shale, the laminae can be studied. Microscopic graded bedding above some platestone laminae (observable in magnified peel prints) seems to be diastemic, and, with traces of brecciation, may record turbulence which occasionally stirred up the accumulated sediments.

Faint scour effects and ripples are present in the platestone near the top of the Johnson Shale. A few indistinct low ripples are also evident in some of the laminated gray shale at the top of the formation. Such features could be caused by wave-induced turbulence.

The carbonized gymnosperm wood and spore assemblage in the upper few feet of Johnson Shale seems to indicate that the climate on land marginal to the sedimentary basin was temperate to cool (Cousminer, 1960, personal communication) as Johnson time drew to a close. Accordingly, it is suggested that the shallow waters of late Johnson time also might have been comparatively cool.

A few thin laminae in upper shale consist of accumulations of marly calcium carbonate. Presumably these reflect brief but rapid falls of algal or inorganically precipitated calcium carbonate particles. Variations of water temperature (an abnormally warm period) or clearing might have caused such vigorous carbonate production. It has been suggested above that the thin accumulations of ostracode shells along some calcareous laminae may be the result of mass mortalities caused by sudden changes of temperature or salinity. If salinity or temperature change was the cause of mortality, it might have been by way of control over inorganic and organic nutrients in the water rather than by direct effects on the perished ostracodes. If the laminae are of particulate algal calcium carbonate, the same sorts of indirect controls over nutrients might have stimulated algal activity temporarily. In any event, the chemistry of the water must have influenced the precipitation of calcium carbonate (organically or inorganically) and the settling of organic colloidal detritus in order to produce laminae in the Johnson mud.

Some of the smooth, delicate ostracodes in the upper Johnson may well be brackish-water forms. If so, they and the few charophytes that are also present would give support to the idea that waters of later Johnson time were less saline (brackish?) than those of the medial part of the Johnson when the redbeds were deposited.

In southern Kansas the uppermost Johnson Shale, which elsewhere has almost no fossils other than ostracodes and plant remains, is more calcareous than usual and has interbedded thin, nodular, aphanitic, argillaceous limestone. The shale beds contain common productid brachiopods and other fossils similar to the Bennett Shale fauna. Thus, in late Johnson time, while conditions hospitable to few animals other than ostracodes seemingly prevailed from central Kansas to Nebraska, southern Kansas seems to have undergone conditions favorable to establishment of a mixed fauna associated with periodic deposition of limy argillaceous, and calcareous, mud. Apparently limestone was deposited in temporarily clear water when the omnipresent calcium carbonate deposition outweighed the silicate clastics. That is, most of the clay clastics seem to have settled out before reaching Cowley County in southern Kansas. Perhaps this reflects temporarily dry climates in, and less erosion of, source areas. Stratigraphic data suggest that the source areas of upper Johnson clastics were located at some distance to the north, east, and south of Kansas.

Altogether, the Johnson facies pattern suggests that the Bourbon Arch area may have been weakly active in late Johnson time, so that it interfered with free passage of silicate clastics from the northeast into possibly deeper water (indicated by the mixed shelly fauna) of the Cowley County area. Silicate clastics from the south were not always sufficient to maintain an excess over carbonates. Thus, the Grand Summit area in Cowley County seems to have been an area in the Cherokee Basin which was sometimes beyond the reach of clastics from low source areas far to the north or northeast, but usually accessible to clastics from the south. This concept is not new. Jewett (1951, p. 127) suggested that during Late Pennsylvanian time sediments from areas to the north and south mingled in the Cherokee Basin. Such conditions seem to have persisted during the late Johnson part of the Early Permian. It may be assumed that much of the Johnson clastic material of Cowley County must have been transported from a landmass to the south and east of Kansas. The fact that the Highway 38 section (closer to the postulated southern source) has more Johnson clastics than the Grand Summit section lends support to this hypothesis.

Plant remains and ostracodes characteristic of the upper Johnson Shale in northern and central Kansas are mingled with the mixed fauna of the Cowley County area. Here the ostracodes are not confined mainly to laminae, as in the north. Perhaps this was the breeding area for the northern ostracodes. In order to attain their present distribution, the plant remains must have drifted all over the late Johnson sea. Landmasses generally to the north, east, and south of the present outcrop could have been the sources of such materials. Presumably their dispersal was assisted by winds.

In summary, Red Eagle cyclothem sedimentation is interpreted to have begun with the accumulation of redbeds in very shallow, turbid, warm, slightly hyperhaline water during the medial part of Johnson time. Deposition continued while the regional climate became cooler and more moist than when the redbeds were deposited. Clastics came from probably low landmasses to the north, east, and south. Tectonically active localities in the Ozark and Ouachita regions may have contributed clastics. The composition and fine texture of the clastic sediments both suggest distant source areas and reworking of earlier Paleozoic beds containing fine clastics. Calcium carbonate was deposited with the clastics. Late in Johnson time, faint upwarps in the area of the Bourbon Arch interfered with movement of clastics from northern and northeastern source areas to the Cherokee Basin. At the same time, waters were slightly deeper in the Cherokee Basin than farther north and a mixed fauna (see Table 5) developed. Land plant fragments, and possibly seaweed, drifted over the entire area during late Johnson time.

Deposition of the Red Eagle Limestone

Glenrock Limestone Member

The sharp basal contact of the Glenrock Limestone marks an abrupt change in depositional conditions. The muddy, sparsely populated Johnson waters cleared suddenly, and so provided the habitat for the prolific benthonic fauna of the Glenrock Limestone. This is inferred from insoluble residues, which showed a decrease of silicate clastics from nearly 90 to less than 10 percent across the Johnson-Glenrock contact.

It has been noted that in some places the lower part of the Glenrock Limestone is nearly void of fusulinids. Their numbers increase upward. In these few places fusulinids may have been late arrivals which slowly multiplied with the passage of time. The Glenrock sediments wherein fusulinids are sparse contain slightly larger amounts of insoluble residue in their matrices than where fusulinids abound. Moreover, the areas of such fusulinid scarcity are in Nebraska and northern Kansas. A suggested explanation is that in early Glenrock time sources of clastics were nearer to the sites of deposition than later in Glenrock time. That is, waters were deepest and shorelines most remote at the end of Glenrock time.

This explanation does not overlook the fact that percentages of insoluble residue may be controlled by relative rates of carbonate versus silicate-clastic deposition. However, upon consideration of the generally uniform character of the Glenrock, there is no evidence of marked change in rate of carbonate deposition during Glenrock time. That is, the slight variations in percentage of insoluble content are thought to be the result of changed rates of silicate clastic supply, and indicate a remote source of clastics.

The Glenrock Limestone is remarkably uniform in thickness (0.2 to 2 feet) and lithology through some 150 miles of outcrop between Bennet, Nebraska, and Allen, Kansas. Unique facies occur locally in the Manhattan and Paxico areas. Although its basal contact is gently undulatory (Pl. 1A), the top is remarkably flat and clearly defined. Thus, at the close of Glenrock deposition the floor of the sea must have been even flatter than at the beginning. During Glenrock time, sediments must have accumulated evenly over this shelf area or the unit would not be so uniform. Similarly, south of Allen, Kansas, where the average thickness of the Glenrock is less, accumulation must have been slower or of shorter duration. Uniform accumulation is easier to explain for lime materials than for silicate clastics. The silicate clastic materials in the Glenrock Limestone are mainly clays, which, because of their slow rate of settling, may well have drifted far from their source in only mildly agitated water. If it is granted that the bulk of the Glenrock Limestone was organically precipitated, and that it was probably derived locally, it seems evident that in order to deposit such a widespread uniform unit the same strikingly uniform depth and limy conditions must have prevailed over a great area of the Midcontinent shelf-basin.

It is clear that a sudden eustatic change of water depth would be effective almost simultaneously over all parts of such a flat area. This would be followed instantaneously by changes in animal growth and sedimentation across the shelf, which would explain the ubiquitous sharp (0.1-inch) contact between the Glenrock Limestone and the overlying Bennett black shale. These phenomena establish the Glenrock-Bennett contact as a distinct time plane. If not, the contact must be a plane which crosses time planes at an incalculably "small oblique angle" (Moore, 1959, p. 51).

The paleoecological evidence, derived principally from the fusulinids and traces of *Osagia*, suggests that the Glenrock Limestone was deposited in water less than 50 feet deep. Sedimentological evidence seems to support this estimate, because the Glenrock shows no internal traces of scour nor any breaks in depositional continuity. That is, the Glenrock was deposited below effective wave base, which is usually much shallower than 50 feet. In fact, Dietz and Menard (1951) have implied that the depth of vigorous abrasion of bottom sediments by wave turbulence is commonly less than 30 feet. This does not suggest that other currents did not influence the Glenrock bottom sediments, because it is likely that weak tidal currents were active.

In many places the shell components of the Glenrock Limestone are randomly oriented. However, the faint orientation of some fossil fragments roughly parallel to bedding is common enough to suggest that they were so aligned by gentle currents sweeping the Glenrock sea bottom. That some brachiopod shells were thus aligned, concave upward, seems a good indication that only gentle currents prevailed. Significantly, a number of delicate unbroken and articulated brachiopod shells are preserved, the fusulinids are essentially undamaged, and there is no internal evidence of scour. Slight textural variations of Glenrock matrix indicate that the currents, although always gentle, varied sporadically in their intensity.

Nevertheless, there is a considerable quantity of broken shell material in the Glenrock Limestone. In view of probabilities indicated by studies of present-day sediments, the breakage and comminution of these materials may be the result of their passage through the masticatory mechanisms or alimentary tracts of burrowing and mud-feeding organisms. Perhaps fish and other suprabenthonic organisms were similarly effective in breaking shells. Another possibility is that the shells were weakened by boring organisms to the point where the gentlest currents were sufficient to shatter them.

Upward of 60 percent of the Glenrock calcium carbonate is of clearly visible shell detritus (especially fusulinids and brachiopods). The remainder, the matrix, consists of aphanitic calcium carbonate. Some of the matrix is undoubtedly fine shell detritus, but much of it is suspected to be recrystallized algal particles and algal needles,* affected by intrastratal solutions during diagenesis. Whether such algal particles fell from near-surface waters or whether some of them formed in lesser amounts at greater depth is unknown. The latter possibility is mentioned because of the implied clarity of the water, which could have permitted photosynthesis, however slight, at the bottom of the Glenrock sea.

As stated above in the discussion of paleoecology, the traces of *Osagia* in parts of the Glenrock Limestone do not occur on the fusulinids. The same is true for tiny gastropods. From this it is inferred either that these organisms did not accumulate algal coatings because of their mobile habit, or that the chemistry of their shells or individual microenvironments was unfavorable to algae. The Glenrock fauna suggests nearly normal salinity and pH in clear water.

At the Manhattan and Paxico sections the Glenrock Limestone contains numerous *Osagia* and conglomeratic fragments of material similar to upper Johnson muddy limestone in the Alma area, where the Glenrock is absent (probably because of nondeposition). The numerous *Osagia* and the scarcity of fusulinids at Manhattan and Paxico indicate that Glenrock waters in these localities were slightly shallower than to the north or south. The combined lithologic and stratigraphic evidence is best explained by postulating a local rise of the Nemaha Anticline in the Alma area. Thus, the pebbly materials at

* Such aphanitic calcium carbonates have been attributed by some authors to purely physicochemical precipitation. Doubtless, some of it was thus derived, but as Lowenstam (1955) and others have pointed out, in Recent sediments algae are known to deposit aragonitic calcium carbonate needles which formerly would have been considered inorganic.

Manhattan and Paxico could have been eroded from upwarped Johnson deposits (shoals?) near Alma. This suggests that the Alma area was a shoal in Glenrock time, but it does not rule out the possibility that the area was actually elevated slightly *above* sea level. Neither is the possibility of partial deposition and removal of Glenrock at Alma entirely ruled out, despite the fact that Bennett sediments in adjacent areas contain no recognizable evidence of reworked Glenrock deposits.

The Glenrock Limestone is also absent at the Elmdale and Saffordville sections and in Greenwood County. This is also taken as evidence that gentle uplift (or lag in subsidence rate) of the Nemaha Anticline area at the western end of the Bourbon Arch and of the northern part of the Otto-Beaumont Anticline (Fig. 1) may have controlled the depositional pattern during Glenrock time.

Where the Glenrock Limestone reappears to the south of these structural features, just east of the Otto-Beaumont Anticline (Grand Summit and Highway 38 sections), it is comparatively thin, full of fusulinids, and somewhat similar to its local development at Coffman Ranch in central Kansas. These areas may have subsided slightly less rapidly during Glenrock time than did contiguous areas of Nebraska and northern Kansas; that is, the rate of accumulation of Glenrock sediments was slower in the south than in the north. Whereas the sedimentary pattern of Glenrock Limestone reflects positive tectonic activity in central Kansas, there is no corresponding evidence in Nebraska and northern Kansas, where the uniform physical properties and thickness of the Glenrock Limestone are independent of anticlinal structural trends.

Because the sea bottom was so nearly flat, it can be assumed that when Glenrock waters deepened, shorelines expanded far beyond their Johnson position, so that terrestrial silicate clastics could have settled long before they reached the area of study. This would account for the comparative purity of the Glenrock Limestone. The slightly greater than average amount of Glenrock clastics in southern Kansas (Highway 38 section) may indicate comparative closeness of source areas in Oklahoma or uplifts in the source areas, or both. It is believed that, southward in Oklahoma, the Glenrock Limestone must grade to a facies indistinguishable from Johnson Shale or undifferentiated Red Eagle Limestone.

Bennett Shale Member

The basal black shale of the Bennett Member is attributed to a strong reducing (euxinic) environment of deposition, where oxygen was used up by decaying organic matter more rapidly than it could be replaced by diffusion. *Lingula* and *Orbiculoidea* in the Bennett basal shale suggest deposition at nearly intertidal depths. Thus, it is evident that the change from Glenrock carbonates to Bennett dark mud attended a very rapid shallowing of the Red Eagle sea from depths of perhaps 40 to 10 feet or less.

The basal Bennett is black because it is charged with finely divided carbonaceous organic residues and traces of pyrite. Hydrofluoric acid residues from the black shale contain small amounts of dark-brown, waxy plant material together with spores. This brown substance also contributes to the dark color. Conditions at, or soon after, the deposition of the organically rich mud must have been such that the organic material (plant and animal) was only partially decomposed because of insufficient oxygen. Therefore it seems likely that this decomposition was effected principally by aerobic bacteria, but anaerobic bacteria, and enzymatic reactions (which can continue even after the death of enzyme-producing organisms), also might have been involved. Sulfides of hydrogen produced during this decay must have added to the toxicity of the environment and contributed, during diagenesis, to the traces of pyrite now present in the shale. Toxicity probably prevented scavenging and mud-eating organisms from dwelling in and working-over the bottom sediments. Thus, the original sedimentary lamination is preserved intact, and much carbonaceous organic material still remains. Some of the organic material is the waxy dark-brown substance mentioned above.

Conodonts and spores, with *Orbiculoidea* and a few *Lingula* at the base, are the principal fossils found in the black shale at the base of the Bennett Member. These mainly phosphatic remains were probably preserved because of, rather than in spite of, the toxic conditions, much in the same way that formaldehyde preserves flesh from decay by arresting bacterial activity. Arenaceous foraminifers and ostracodes are very scarce in the black shale.

The abundance of *Orbiculoidea* (with *Lingula*) at the base of the Bennett black shale and the relative paucity of these specimens above the base suggest that these animals were able to tolerate the initial Bennett toxicity but perished during a period of mass mortality, after which only a few hardy individuals and their descendants survived. These may have been the only animals actually able to live on the black muddy bottom of the earliest Bennett sea. The numerous conodonts and scarce foraminifers and ostracodes seem to have developed elsewhere than on the toxic bottom. Perhaps the conodont-bearing animals ventured too close to the toxic bottom water and perished. The scarce arenaceous foraminifers and ostracodes were possibly washed into the black mud area by very gentle currents. The organic material contributing to the black color was probably from soft-bodied pelagic, nektonic, or benthonic animals and some plant drifters which fell to the bottom.

It must be noted that even the blackest Bennett shale contains up to 30 percent of calcium carbonate. Certainly the calcareous material did not originate at the muddy bottom; because very little of it is shell material, it must have fallen from near-surface water where algae or agitation could have caused precipitation of calcareous particles.

The bulk of the black shale, and in fact all Bennett shale, is composed of illite and traces of calcium montmorillonite. Such mineralogy seems typical of black shale rich in organic matter (Weaver, 1958). The presence of montmorillonite with illite suggests that the pH of the water was somewhat greater than 7, because montmorillonite is unstable under acid conditions (Carroll, 1959). Perhaps the illite also is favored by such an alkaline environment (Grim, 1951).

A number of the black beds are claystone rather than shale. This might indicate essentially uniform conditions of deposition during comparatively lengthy periods in early Bennett time.

The laminations of the shale are ascribed to slight variations in particle size. Temporary diminution of near-surface turbulence may have allowed more coarse particles than normal to fall and to form laminae. On the other hand, slight variations in the amount of organic fall also seem to have contributed to the lamination, for some laminae appear darker. Ingram (1953) also noted that extremely thin organic films contribute to the lamination of shale. Some laminae seem to be concentrations of abnormally fine clay. Various factors might explain the sudden flocculation of fine clay in upper water levels; these include changes of ion concentration, concentration of colloids, and temperature.

The preservation of many of the primary black shale laminae indicates not only the absence of mud-working organisms but also the probable absence of turbulence capable of significant scouring, because no traces of scour or disrupted bedding are present. At first glance this might seem somewhat anomalous, because *Orbiculoidea* and *Lingula* indicate water shallow enough to be above normal wave base; that is, they lived within reach of wave-induced turbulence. However, it must be recognized that in shallow water much wave motion becomes translatory in direction and tends to smooth sediments, rather than scour them deeply. Moreover, the soft and sticky black mud may have been sufficient to protect the shells from breakage.*

Although the black shale reflects euxinic conditions of deposition, there is no ready explanation of the means by which the Bennett waters could have been restricted. Shallowing could have left shoals between the area of study and the open sea to the south and west. Coincidentally, the Glenrock Limestone is everywhere covered by black or dark gray Bennett Shale, and the two sedimentary units maintain an approximately proportional thickness. This could indicate that the same basin pattern persisted in the region during the accumulation of the two, despite their different lithologies, and that the changes of conditions across the Glenrock-Bennett contact were uniformly widespread.

The fusulinids at the top of the accumulated Glenrock deposits might have been suffocated by the Bennett black mud or poisoned by the increasingly toxic water. Death of the fusulinids was followed immediately by an influx of numerous *Orbiculoidea* and a few *Lingula*. It is scarcely possible that the fragmentation of the orbiculoids at the very base of the Bennett could be due to wave action. However, in the overlying black shale fewer orbiculoids are broken, so that wave action, if responsible for breakage, might not have been severe. *Lingula* in the basal Bennett black shale suggests that these beds probably were deposited at, or not far below, intertidal depths.

In view of the prevailing flatness of the underlying beds, the shallowed sea of earliest Bennett time must have exposed extensive mud flats at times of low tide, especially after pro-

* Numerous small, delicate pelecypods seen by the author in sticky black mud beneath only 25 feet of water in Long Island Sound, New York, are mostly unbroken.

longed periods of strong winds from one general direction. Exposure would have been most complete in nearshore areas of loosely consolidated deposits, which could have been eroded easily (e.g., by rainfall at low tide) and dispersed by waves. Much of the argillaceous material of the lower Bennett may have been thus derived. As the nearshore material was removed, erosion would become slower and less detritus would be available for transport. If the sea deepened again, the shoreline would move farther away and the supply of detritus to the area of study would diminish even more. Although these remarks emphasize the role of changing depth in governing the proportion of detrital material in the Bennett Shale, uplift or climatic change in distant source areas may have been the major control. However, the sedimentary record seems to indicate increasing depth with the passage of Bennett time, because Bennett black basal shale grades upward into gray* shale of the middle part of the Bennett, which contains a variety of shelly fossil remains but very few conodonts. This profuse medial Bennett fauna indicates that waters circulated more freely and had deepened slightly. Although freer circulation could have resulted from tectonic removal of a restrictive barrier, the breaching of a barrier by a eustatic rise of water is preferred because it better explains the deeper water fauna and sediment composition.

Some of the gray shale contains 10 to 20 percent more carbonate and is more coarsely laminated than the black shale. Some of the gray shale laminations seem to be tiny diastems. In central Kansas, the shale gives way to very pure medial Bennett limestone. Apparently the sea shallowed and the rate of clastic supply dwindled, so that the water cleared and carbonate deposition (largely by algae) overwhelmed the few clastics that did arrive.

Where the Glenrock Limestone is missing (e.g., Saffordville and Elmdale), Bennett gray calcareous shale rests on upper Johnson. This demonstrates a local paraconformity representing Glenrock and earliest Bennett time, and suggests uplift (shoals?) in the contiguous Nemaha Anticline and Bourbon Arch areas. Perhaps such elevations restricted the circulation of the early Bennett sea, and so led to the aforementioned euxinic bottom conditions.

Some Bennett gray shale contains traces of glauconite. Although much has been written about the origin of glauconite, few conclusions are definite. Glauconite in the Bennett suggests conditions such as those outlined by Lochman (1957), that is, slow sedimentation, much putrefying organic material, and a large and varied fauna. Lochman also noted that glauconite forms in marine water away from the freshening influence of large rivers, free of coarse detritus originating in crystalline source areas, and under somewhat anaerobic conditions. Cloud (1955) affirmed Lochman's basic requisites and also suggested that glauconite usually forms at depths less than 200 feet and at temperatures greater than 15° C (60° F). Faunal evidence places the deposition of Bennett Shale in water up to 50 feet deep and above 20° C (68° F).

The minor accumulation of medium-bedded limestone in the lower half of the Bennett Member in Nebraska has been described above with the stratigraphy of the Bennett. Limestone constitutes almost all of the Bennett Member, indeed, almost all of the Red Eagle Limestone formation, in southern Kansas and northern Oklahoma. Stratigraphic evidence shows that the carbonate deposition that predominated in the southern regions throughout Bennett time periodically advanced into the clay (shale) regions to the north—that is, the supply of clastics from the north diminished during these times so that tongues of pure limestone were deposited in central Kansas. At the same time, the relatively greater deposition of carbonates was sufficient to make mud in Nebraska extremely calcareous. Because much of the Bennett carbonate is believed to be algal, it might be expected that in clearer water during times of less suspended clay the absolute rate (unit thickness per unit time) of such carbonate deposition would have accelerated considerably. Conversely, comparatively less algal carbonate would accumulate from muddy water. Indeed, the thickness of limestone facies of the Bennett Member is greater than contemporaneous shale facies, perhaps giving a false impression that, on the average, rates of sedimentary accumulation of carbonates were markedly greater than for mud. However, when the differential diagenetic compaction of the two types of sediment is considered, it must be concluded that their rates and original amounts of sediment accumulation were not greatly different over broad areas. The absolute thickness and accumulation rate of all marine sediments are, of course, ultimately controlled by the rate and total amount of regional subsidence of the basin floor, as modified

* Gray color is the result of lesser amounts of carbonaceous organic material.

by local upwarpings or lags in rate of subsidence. Southern Kansas, where the Bennett section is slightly thickened and where calcareous facies predominate, appears to have experienced *slightly* greater total regional subsidence than Nebraska and northern Kansas. This coincides with the generally greater regional thickness of the Council Grove Group in Oklahoma than in Nebraska.

The major physical, chemical, and biological controls of carbonate deposition are well known. Cloud and Barnes (1948), Emmons (1928), and Revelle and Fairbridge (1957) have provided thorough summaries.

Most sea water is saturated with calcium carbonate (Twenhofel, 1932, p. 320). Rodgers (1957) suggested that large-scale carbonate deposition from sea water may require a small degree of oversaturation, and he noted that, with a few special exceptions, marine organisms acquire most of the available calcium carbonate *before* chemical precipitation can occur. This concept, with the field and laboratory evidence, lends weight to the interpretation that little of the Red Eagle Limestone was precipitated inorganically.

Trask (1937) noted that the percentage of calcium carbonate in shallow-water marine sediments increases with increase of surface-water temperature. He also observed a direct correlation between the calcium carbonate content of bottom sediments and the salinity of overlying surface water. Where salinity is below 34‰ (normal marine salinity is about 36‰), the sediments generally contain less than 10 percent of calcium carbonate. The sediments generally contain more than 50 percent of calcium carbonate where salinity slightly exceeds 36 ‰. Because nearly all Bennett sediments contain more than 10 percent of calcium carbonate, it seems likely that the salinity of normal marine Bennett water exceeded 35‰. Bennett limestone may have been deposited at slightly higher salinities than the shale, during climatic periods when salinity was higher, and when less detritus was washing into the basin. Faunal and other evidence implies that Bennett waters were warm. Lowenstam's (1959) $0^{18}/0^{16}$ data might suggest that the upper Bennett shale beds (with *Neospirifer*) were deposited at temperatures commonly above 22° C (72° F).

The paucity of clay in limestone of the Bennett Member implies clear water. Although fossil shells are not abundant in these limestone beds, the faunal assemblages indicate deposition at generally shallow depths, some less than 10 feet. The bulk of the rock is aphanitic calcareous matrix. At a few localities the matrix displays traces of linear algal calcium carbonate ribbons, a few of which are broken. Some are clear, sparry, recrystallized replacements. It is believed that algae precipitated most of the nondescript aphanitic calcitic matrix material in very fine particulate form. Probably some of this material was brought down primarily as aragonite needles (Lowenstam, 1955). Where aphanitic calcite coincides with crustose or linear algae, the latter may have acted as filter traps for the finer material. It seems that such trapping of sediment might have given rise to calcilutaceous mud banks or shoals resembling those described by Ginsburg and Lowenstam (1958) and Harbaugh (1959, 1960).

The irregular bedding planes of the Bennett limestone are seams having slightly greater than average clay content. Such deposition of clay could have resulted from slight increase of noncarbonate clastic influx from the distant sources, or, as Keller (1936) suggested, it could result from sudden flocculation and settling of clay normally kept in suspension.

Within each limestone bed much of the matrix material contains extremely small fossil fragments, many randomly oriented but many showing moderate alignment parallel to bedding. Rare traces of scour and sorting are noticeable but developed on a very small scale. Some large delicate brachiopods are preserved intact with concave sides up. Other brachiopods, still articulated, are filled with aphanitic calcareous mud.

Johnson (1957) showed that such shells can be buried by scouring at velocities below those necessary to take the shells into suspension. The assembled evidence points toward gentle current activity during deposition of most of the Bennett limestone. Hence, in the absence of shell-shattering turbulence or currents, the finely fragmental condition of most fossil shells is attributed to scavengers, including both mud eaters and borers.

The fossils in the Bennett calcareous shale, although including the same genera as those in the southern limestone, seem larger, less finely comminuted, and scarcely abraded. They are scattered randomly throughout the shale. They seem to have been broken and transported short distances by currents somewhat stronger than those indicated by the limestone record. This interpretation is supported by the presence in the shale of a greater number of robust shells which supposedly reflect turbulent water. Some of the shells show evidence of boring by other organisms. Perhaps this facilitated their fragmentation. However, interpretation of apparent faunal differences may be slightly prejudiced, because fossils are easier to remove from shale than from limestone.

The regional pattern of Bennett deposition, after the initial black shale, was limestone in the south and shale in the north. Clastics seem to have come mainly from the north and east. Southern Kansas appears to have been beyond the reach of some of the clastic material. However, at the Burbank section the Bennett limestone beds contain considerable amounts of clay detritus, showing the additional effect in Oklahoma of a southern source area. The relative thinness of the Bennett part of the column, together with the interbedding of thin Bennett limestone and shale in Lyon and Greenwood Counties, seems to indicate slightly less subsidence in the Bourbon Arch and Otto-Beaumont Anticline areas and shows that the Bourbon Arch was (as in the Pennsylvanian) an area of "meeting and overlap of sediments from southerly and northerly directions" (Jewett, 1951). In fact, the Bourbon Arch might have been a barrier to free movement of clastics to southern Kansas from source areas to the north and east, thereby permitting the accumulation of the very pure Bennett limestone in Elk and Cowley Counties.

In these counties and in the Eskridge-Coffman Ranch area, the predominant carbonate deposition, once established, continued until the end of Bennett time. However, between these limestone areas the faunal-lithologic record reveals that after accumulation of 1 or 2 feet of Bennett limestone, clay drifted in and muddied the water so that calcareous mud (argillaceous limestone and very calcareous shale) deposition resumed and continued in slightly deeper water through late Bennett time.

At the Eskridge-Coffman Ranch area the lower Bennett limestone facies is not easily explained, for it begins suddenly amid shale on three sides. Nevertheless, it is markedly similar to the widespread platform limestone of southern Kansas. The limestone facies seem to represent a low-relief, shallow, marine bank development whereon upright algae may have trapped finer algal carbonates and other calcareous remains. Such a shoal condition may have been caused by local crustal upwarp. This idea is admittedly conjectural, but the available data permit no acceptable alternative hypotheses. In any event, the arriving clay clastics settled nearby so that clear water prevailed across the shoal. Deposition of algal calcium carbonate seems to have proceeded rapidly under such conditions and thus accounts for the somewhat thicker and nearly pure Bennett limestone accumulation in the Eskridge-Coffman Ranch area.

In this area the upper part of the Bennett consists of about 12 feet of rubbly, indistinctly thin-bedded, richly fossiliferous limestone. Profuse brachiopods, bryozoans, foraminifers, and especially crinoid columnals make up much of the rock. The purity of the limestone is evidence that late Bennett waters in this area must have been nearly clear. Moreover, it is known that crinoids enjoy clear, warm, gently agitated water, and bryozoans good oxygenation; so these conditions must have prevailed in the Eskridge-Coffman Ranch area during late Bennett time.

The crinoidal upper Bennett sediments seem to have been agitated by gentle currents, because many crinoid columnals and brachiopod shells are preserved undamaged and articulated. Severe currents would have shattered, disjointed, and abraded them.

It also should be noted that this crinoidal upper Bennett facies is developed only where the lower part of the Bennett limestone is thick. At the close of Bennett time the Eskridge-Coffman Ranch area was probably under 5 or 10 feet of water, while surrounding waters might have been slightly deeper. That is, the thick lower and middle Bennett limestone may have supported a broad platform perhaps a fathom higher than the neighboring sea floor, and the crinoids grew on the platform.

The crinoidal part of the Bennett contains about 2 or 3 percent more insoluble clay residue than either the osagitic Howe or the underlying Bennett limestone. This is attributed to the fact that the depositional environment had many stalked crinoids and fenestellate and ramose bryozoans which probably served as filter-traps for clay and calcareous algal particles that otherwise would have remained in suspension. The combination of ideal living conditions for calcareous shelled animals and the trapping of extra amounts of clay sediment might explain the thicker-than-normal Bennett limestone accumulation at Eskridge and Coffman Ranch.

All along the present outcrop belt the Bennett sequence above the black shale could have been deposited at water depths between low tide and 10 fathoms. It is postulated that the sea generally deepened after deposition of the basal Bennett black shale (Fig. 5C). During this deepening, the shores of the terrestrial source areas must have retreated considerable distances landward, if due recognition is given to the prevailing flatness of the depositional shelf. The relatively greater number of bryozoan genera, with many genera of brachiopods, in most of the medial shale, combined with stratigraphic evidence, suggests that the shale represents water possibly 50 feet or more in depth; that is, the sea was undoubtedly deeper than that of earliest Bennett time wherein the *Orbiculoidea* fauna thrived.

In central Kansas, shallower water seems to have produced the sparsely fossiliferous medial limestone beds of the Bennett Member. The uppermost Bennett shale and limestone units record the reestablishment of a mixed fauna (Elias, 1937, p. 410), indicating that toward the close of Bennett time the sea was somewhat deeper again (see Fig. 5). This set the stage for deposition of the Howe Limestone. The percentage of insoluble clastics in the upper part of the Bennett Shale decreases upward, and the Bennett-Howe transition is commonly gradational through less than a foot of column. The indication is that waters shallowed in latest Bennett time while the supply of clastics diminished. Although the relative decrease of clastics could mean lower source areas, it could have resulted from a drier climate in the source area (perhaps attended by increased salinity) or from the development of a submarine barrier. In any event, the change from Bennett to Howe sedimentation was marked by a rapid and great reduction of the supply of clastics. That is, clear shallow water attended the beginning of Howe deposition.

Howe Limestone Member

The Howe Limestone in Nebraska and northern Kansas has been described above as a fairly uniform, aphanitic, sparsely fossiliferous unit. The pelecypods *Allorisma* and *Aviculopinna* were found in this limestone in Nebraska. Tiny gastropods and traces of fenestellate bryozoans are randomly present. One coiled and several straight nautiloid cephalopods were found with the osagite at the top of the Howe Limestone in central Kansas.

From Manhattan, Kansas, to the vicinity of the Oklahoma-Kansas border, the Howe is an osagite containing much algal calcium carbonate. The paleontological record indicates that the Howe Limestone corresponds to the molluscan phase of Elias (1937). Lane (1958) presented evidence that similar osagite in the Grenola cyclothem also represents the molluscan phase of Elias' ideal cycle (1937, p. 411). According to Elias, the Howe Limestone would therefore record deposition in sea water 60 to 90 feet deep. However, Lane (1958) concluded that Grenola osagite beds probably formed at depths approximating 60 feet. The paleoecological evidence assembled in this study supports the postulate that the osagitic Howe Limestone accumulated in water much less than 60 (perhaps less than 10) feet deep. Imbrie and others (1959) interpreted *Osagia* facies as shallow nearshore deposits.

Lane (1958) indicated that algal incrustations throughout the Grenola osagite denote slow accumulation of the fragmental shell nuclei. Lane's (p. 153) reasoning is also valid for Howe osagite. The only significant difference in the occurrences is that the Howe Limestone contains sparse osagitic pellets near the base and these increase in number upward so as to dominate the texture at the top. Obviously, conditions favoring these algae improved with the passage of time. This might mean that the water shallowed from 2 or 3 fathoms to lesser depths wherein the algae flourished. The fact that algae did thrive implies, of course, that ecological factors other than depth and light were also favorable.

In central Kansas the algal coatings on the individual Howe osagite pellets are thicker near the top of the Howe Limestone than below. This is interpreted as additional evidence that water shallowed with the passage of Howe time. The osagitic facies of the Howe Limestone in southern Kansas is relatively thinner than that of the Howe in central Kansas, while the osagite pellets are very similar to those in the middle of the Howe in central Kansas. This suggests that Howe waters were slightly deeper in southern Kansas.

O'Connor and Jewett (1952) referred to the osagitic Howe texture as a "spergenite." Although this term is not used in this report, it is significant to note that Wolfenden (1958)—with reference to Carboniferous limestone in England—postulated a pH of about 8 for precipitation of spergenitic limestone. For this and other reasons it seems that a pH value of 8 might also be applied to the Howe osagitic limestone.

The evidence which shows that Howe waters were probably shallower than Bennett waters also implies, as a corollary, that Howe shorelines were nearer to the area of study than were Bennett shorelines. Yet the Howe Limestone rarely contains more than 10 percent of insoluble clastics (clay), whereas between central Kansas and Bennet, Nebraska, the upper Bennett deposits are quite argillaceous. The scarcity of Howe silicate clastics is therefore taken to indicate that Howe source areas must have worn to low relief by the end of Bennett time, or that the climate might have become warmer and drier so that relatively few clastics were washed to the sea, or both. If the Howe climate was comparatively warm and dry, salinity would have been slightly raised and precipitation of algal calcium carbonate doubtless would have been sufficient to account for the profuse Howe *Osagia*.

Neither the aphanitic nor osagitic facies of the Howe Limestone is distinctly bedded. The limestone is essentially a massive unit without diastems. This, as well as uniform texture, points to more or less continuous deposition in comparatively quiet water. Conditions of Howe Limestone deposition were probably similar to those on the present Bahama Bank. Cloud and Barnes (1948) stated that conditions similar to present-day limestone deposition on the Bahama Bank "probably existed in epeirogenic seas not receiving quantities of terrigenous sediments such as might be found far from shore, adjacent to land approaching sea level." It has already been pointed out that the Red Eagle sediments, particularly limestone, were deposited upon a great shelf under conditions much like those described in the above quotation.* However, because deep oceanic depressions surround the Bahama Bank, an exact comparison is not implied. Nonetheless, the great areal extent, flatness, warmth, sediments, shallowness, and subdued but free water circulation of the Bahama Bank correspond to some of the environmental conditions suggested by the faunal assemblage, stratigraphic pattern, and lithology of the Howe Limestone.

Whereas the Glenrock and Bennett regional depositional patterns seem to have been faintly governed by tectonic activity along structures such as the Nemaha Anticline and Bourbon Arch, the distribution and thickness of the Howe Limestone gives no evidence of similar control. In fact, the Howe Limestone seems to reflect a time of tectonic quiescence. It passes unchanged across all known major structural features in eastern Kansas.

The gentle currents mentioned for upper Bennett sedimentation in the Eskridge-Coffman Ranch area can be applied also to the unbedded Howe osagitic facies, wherein individual pellets are unabraded and only vaguely oriented parallel to bedding; so they apparently suffered only mild agitation. An occasional gentle rolling would permit algal calcium carbonate to surround the nuclei. Thus, the moderate sorting, the lack of bedding, and the implicit slow steady accumulation (Lane, 1958) suggest that gentle currents washed about the osagite pellets in Howe time.

A crude idea of the current velocity necessary to move the osagite pellets can be derived from Hjulstrom's (1939, p. 10) diagram. Most pellets are 0.2 to 1.0 millimeter in diameter and hence are of the size range of particles most easily moved by flowing water. According to Hjulstrom, particles in this size range could be moved by current velocities not significantly less than 10 centimeters per second. Obviously, the pellets began as small nuclei which would have required velocities periodically *greater* than 10 centimeters per second to move them enough to turn them over. Toward the top of the Howe the pellets increase in size and have thicker *Osagia* coatings. This distribution may signify that current velocity decreased during Howe time, while the water shallowed. Although the origin of the implied currents cannot be determined, the estimated velocities are nevertheless of the order of current velocities known to develop at or near wave base.* Moreover, it is almost certain that the Howe bottom was within reach of wave base. It is probable that mild tidal currents in Howe time were available to augment or counteract wave-induced currents and turbulence.

The regional pattern of Howe aphanitic limestone in the north and osagite to the south also requires consideration. The aphanitic facies commonly contains nearly 10 percent of insoluble clay, whereas the osagite contains less than 6 percent and is slightly thinner than the northern counterpart. Greater thickness and greater clastic content in Nebraska suggest that the

* The Glenrock and Howe Limestones also correspond to the "platform limestones" of Sloss (1947, p. 109); that is, they accumulated in areas "adjacent to positive areas either peneplained, submerged, or too far distant to supply significant quantities of clastics."

* Dietz and Menard (1951) pointed out that maximum current velocities at wave base are about 15 or 20 cm/sec.

principal source area of the scarce Howe clay was somewhere to the north and east of Nebraska.

The reason for the facies change from aphanitic to osagitic limestone is not certain. All that can be deduced is that in central and southern Kansas osagitic algal pellets developed on the floor of the Howe sea, indicating that the water was clear enough to transmit the sunlight necessary for benthonic algal photosynthesis. Small amounts of the calcareous material of the osagite pellets and their matrix may have originated as algal "dust" particles, but most of it seems to have been benthonically secreted by calcareous algae. Perhaps Howe waters were shallowest in central Kansas.

Although much of the Howe aphanitic limestone is thought to be consolidated algal particles, this does not exclude the presence of significant calcareous particles produced by near-surface warming or agitation (Emmons, 1928). The particles could have been in the form of aragonite needles (Revelle and Fairbridge, 1957, p. 258) later altered to calcite. Consistent with present-day requirements for carbonate deposition, this interpretation assumes that northern Howe waters were warm, normally saline or slightly hyperhaline, and saturated or slightly oversaturated with calcium carbonate (Pearse and Gunter, 1957, p. 133; Rogers, 1957). If planktonic lime-secreting algae were numerous enough, it is possible that the water could have been turned milky by fine algal carbonate particles (Revelle and Fairbridge, 1957, p. 258). This would interfere with passage of sunlight to the sea bottom, thereby directly or indirectly disfavoring benthonic organisms. This could explain the fact that the calcaphanitic Howe facies contains relatively few fossils and lacks benthonic *Osagia*.

The preceding comments about algal precipitation of calcareous particles also would imply diurnal production (Revelle and Fairbridge, 1957, p. 258). Consequently, if most of the calcareous material *is* algal, Howe time probably saw periods of water clear enough for sunlight to reach the bottom of the sea. It seems reasonable, therefore, to assume that a moderate number of benthonic animals and plants *did* thrive on the Howe sea floor. This is an obvious conclusion for the osagitic Howe facies wherein great numbers of foraminifers and tiny shell materials are nuclei for the algally coated pellets. However, the light color and insoluble residues of the Howe Limestone (and other Red Eagle limestone units) show it to be low in nonshelly organic residue content.

Why, then, is the Howe light colored and why are fossils and organic residue so scarce in the aphanitic Howe facies? A simple explanation is that organic detritus, had it existed, could have been destroyed or particle size reduced by soft-bodied scavengers and mud eaters and by decay in an oxidizing environment. This could also account for the Howe aphanitic texture and lack of bedding. Dapples (1938) and Ginsburg (1957) have drawn attention to the fact that a variety of scavengers, mud eaters, and shell borers are collectively capable of working over prodigious quantities of sediment in short periods of time. They destroy organic residues in sediments, reduce particle size, and efface stratification. Furthermore, Sloss (1947) noted that "light color reflects thorough decay and removal of organic material under shallow circulating waters," and Ginsburg (1957, p. 89) stated that "light color and low organic content suggest an oxidizing environment with pH's near 7.5."

Deposition of the Roca Shale

Rocks within the lower part of the Roca Shale record a pattern of changing environments similar to those of the upper part of the Johnson Shale but in reverse order. However, the Roca lacks the plant remains of the upper Johnson. After Howe deposition calcareous mud was deposited in progressively shallowing water until the redbeds of the medial Roca ended the Red Eagle cyclothem. Thereafter, the sea deepened again during the progressive (transgressive) half of the succeeding Grenola cyclothem (Lane, 1958). Preceding interpretations imply that all Roca (and analogous Johnson) waters were probably much less than 10 feet deep, and shallowest when the redbeds were deposited (see Fig. 5). All Roca sediments, including the redbeds, are judged to be marine, but they contain few fossils.

Roca deposition began with the sudden introduction of a large volume of muddy clastics. The bulk of the lower Roca shale and mudstone is composed of clay, with variable small amounts of silt. The silt particles are subangular to subrounded quartz grains and silt-size, buff-colored clay aggregates. The silt content is slightly greater than in upper Johnson.

Most of the lower Roca is light, faintly greenish-gray, and moderately calcareous shale. Few shale beds are noncalcareous. The Roca

Shale contains the same clay minerals as the marine Red Eagle Limestone formation.

The few fossils in the Roca Shale have little diagnostic value. The high clay content of the shale implies turbid water. It is believed that the small amounts of calcium carbonate common in these sediments fell from near-surface water as algal particles or were precipitated because of water agitation or rise in water temperature (Zeller and Wray, 1956). This suggests fairly warm waters saturated with calcium carbonate.

As previously mentioned, Trask (1937) found that commonly less than 5 percent of bottom sediment is carbonate beneath water wherein salinity at the time of deposition is less than 34‰. Although carbonate percentage is known to depend upon relative volumes of supplied silicate clastic and carbonate components, Trask's figure and the other evidence suggest that during much of early Roca time the moderately calcareous (more than 5 percent $CaCO_3$) mud of the lower Roca must have been deposited from water wherein salinity was probably near the modern ocean average of 35 to 36‰. In the same way it may be inferred that the few noncalcareous or slightly calcareous Roca shale beds indicate temporarily freshened water of less than 34‰ salinity.

A few ostracodes and fewer gastropods are almost the only fossils preserved in the Roca Shale. Therefore, Roca waters must have been inhospitable to most shelled animals. Had other fossils been present, at least a few of their hard structures should have survived diagenesis with the ostracodes, and the laminations of the Roca Shale would not be so well preserved.

Some of the lower shale contains up to 40 percent of carbonate, much of which is concentrated in secondary limestone nodules. In Nebraska and northern Kansas, aphanitic limestone is developed in the lower shale. Traces of ostracodes and arenaceous foraminifers have been found in some of these limestone beds. Their purity is evidence that the supply of clastics to the Roca sea occasionally dwindled until the water was clear. Explanations offered for the Howe aphanitic limestone and calcareous algal particles also may apply to the Roca limestone.

An overturned slump block of Roca limestone* (Pawnee section) revealed short partitionlike prominences on its base (Pl. 6C) which appear to have filled cracks in the top of underlying greenish-gray shale. The cracks may be subaerial and provide evidence that the shale accumulated at approximately intertidal depths. Desiccation could have occurred during an unusually prolonged exposure to the air (due to persistent unidirectional winds with exceptionally low tides?). The topmost mud beneath the limestone is only slightly calcareous and could have been deposited under abnormally low salinity conditions such as in extensive intertidal areas directly affected by rainwater.

The limestone records a temporary incursion of the sea and salinity possibly near 36 or 37‰. Accumulation probably took place below, but not far below, normal low-tide level.

The thin red shale of the Roca Shale in Nebraska and Kansas is taken to mark the terminal depositional event of the Red Eagle cyclothem. It is believed to be a very shallow marine deposit accumulated at intertidal depths at a time of maximum regression of the sea, when the shoreline was relatively close to the study area and the climate was moist and warm with periodic dry seasons. The only fossils in the red shale are scarce, tiny gastropod fragments similar to those in the Red Eagle Limestone and in the lower part of the Roca Shale. The possibility that they may be allochthonous pulmonate forms should not be dismissed. In one measured section near Burbank, Oklahoma, the lower Roca is nearly all red. This leads to the interpretation that southern source areas were near the study area during the first half of Roca deposition. That is, a major part of Oklahoma possibly was upwarped at the end of Howe deposition and was the principal source of southern Roca red sediments. The thin redbeds which reach into Nebraska are believed to reflect suddenly increased supply of red clastics from the southern, eastern, and northern sources during times of shallowest water; and they also reflect oxidizing conditions sufficient to maintain the original red color. Whether this would be due to tectonism or marked climatic change in the source areas is unknown. At other times, of cooler drier climate, the rate of supply of red clastics was slower, and they were reduced to a greenish-gray color on their way into and across Kansas.

The red color of these sediments is believed to have come from red soil. Although most of the red material probably washed into the area of study, it is likely that some of it blew in. Krumbein (1947) stated that red color is an

* The marine origin of the slumped limestone is revealed by traces of arenaceous foraminifers, ostracodes, gastropods, and faint traces of brachiopods at the top. The underlying shale is similar to other known marine shale.

indicator of the absence of organic material. Insoluble residue studies confirm this for Roca red shale. Some authors have implied that because of their common association with evaporites, redbeds generally reflect highly saline water. In the outcropping Red Eagle cyclothem, there is no such direct evidence that Johnson and Roca redbeds were deposited in highly saline water, but it is possible that weathering could have removed the evidence from the rock record.

Cyclothemic Nature of the Sedimentary Facies

The preceding discussion has shown that deposition of redbeds in very shallow water, with appropriate climatic conditions, in Johnson and Roca time, respectively, began and ended the Red Eagle cyclothem. Some beds between these markers show evidence of deposition in somewhat deeper water. However, presumed depositional depths considerably shallower than Elias' are applied herein to the principal lithofacies and biofacies recognizable in the Red Eagle cyclothem (see Tables 6 and 7). To explain the ecologic conditions suggested by the Red Eagle cyclothem record, maximum depths of deposition need not exceed 60 feet, whereas Elias suggested a maximum of 180 feet. Such a 60-foot figure is admittedly disputable. Perhaps a range between 50 and 100 would be preferred by many paleoecologists. Selection of such a figure is intended only to suggest a reasonable order of magnitude significantly different from Elias' figure and presumably more in

Table 6.—Depths of deposition postulated for facies types represented in the Red Eagle cyclothem.

Red shale facies	high intertidal
Green shale facies	low intertidal
Black shale facies	0 to 10 feet
Osagite limestone facies	0 to 10 feet
Aphanitic limestone facies	0 to 10 feet
Algal limestone facies	0 to 20 feet
Bioclastic limestone facies	10 to 20 feet
Conglomeratic-bioclastic facies	10 to 20 feet
Fusuline limestone facies	10 to 40+ feet
Shelly shale-limestone facies	10 to 50+ feet

harmony with current knowledge of modern sedimentary environments.

Figure 5A duplicates part of a figure shown by Elias (1937, p. 406) to illustrate his interpretation of depths of deposition of rocks now known as the Red Eagle cyclothem. Figure 5B is similar in form and purpose, but the depth curve was derived by applying Elias' interpreted depths of phase deposition (Table 4) to the sequence of his phases recognized by me and listed in Table 5. Figure 5C illustrates the depths of deposition of the Red Eagle cyclothem solely as interpreted in this report.

Summary of Major Facies Types in the Red Eagle Cyclothem

Imbrie and others (1959) and Laporte (1962) recognized and interpreted a number of distinct facies that reoccur vertically and laterally in several parts of the Beattie cyclothem, which is stratigraphically about 100 feet above the Red Eagle cyclothem in the Kansas Permian. Some of these facies types are also present in the Red

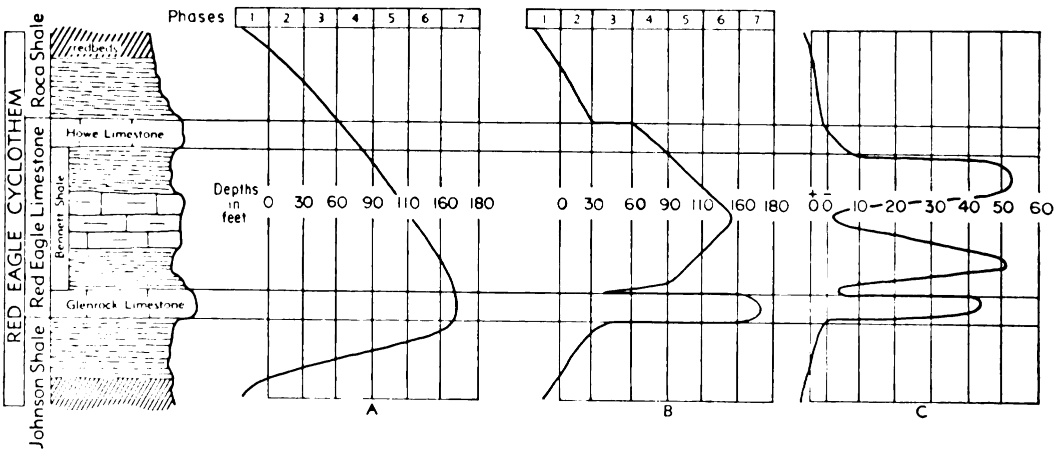
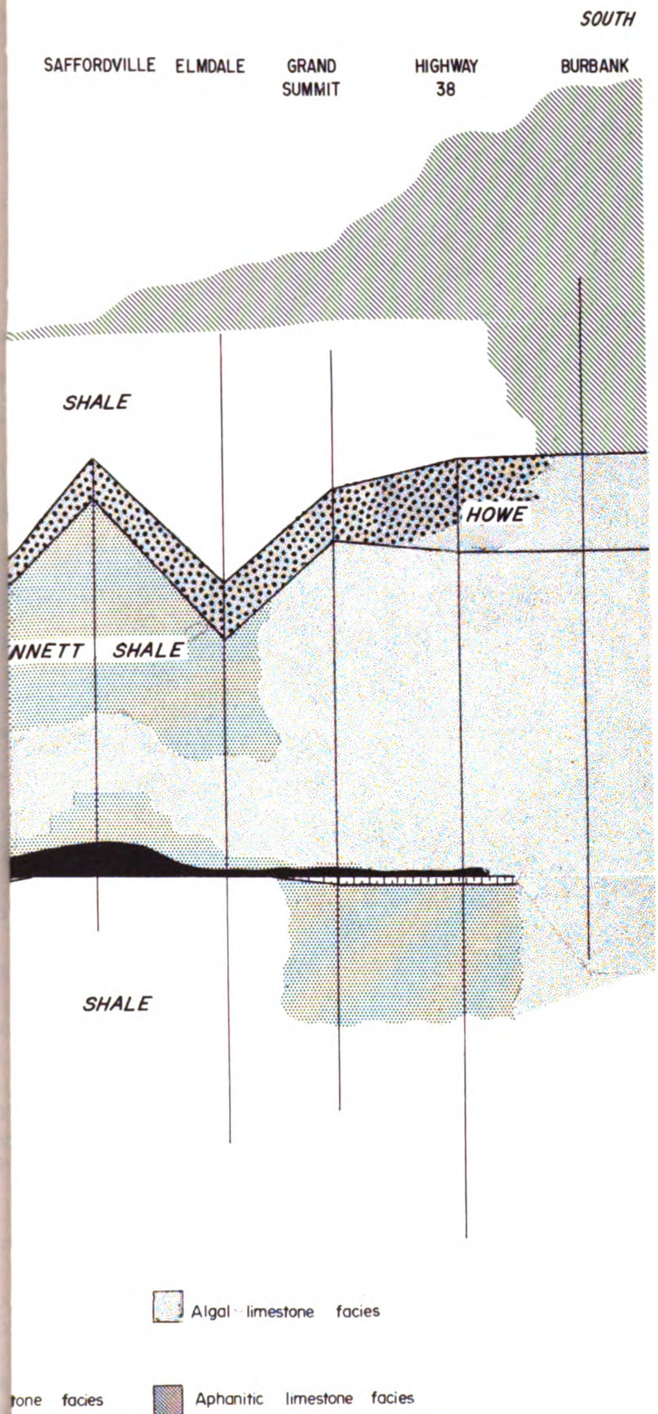


Figure 5.—Composite section of Red Eagle cyclothem in east-central Kansas and interpreted depths of deposition. A, Depths as diagrammed by Elias (1937, p. 407, fig. c). B, Depths adjusted according to Elias. Depth curve is based on Elias' phases now recognized in the Red Eagle cyclothem and interpreted using Elias' postulated depths of phase deposition. C, Postulated depths of deposition as interpreted in this study.



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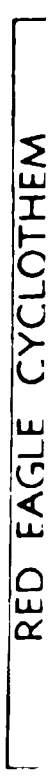

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TABLE 7.—Summary of interpreted ecologic conditions during deposition of definitive faunal-lithologic phases in the Red Eagle cyclothem.

Units of the Red Eagle cyclothem	Depth of deposition, feet	Phase (after Elias, 1937)	pH	Typical temperature, °F	Salinity, ‰	Oxygenation	Turbidity	Circulation	Current velocity, cm/sec.
Roca Shale									
medial red shale	high intertidal	1		>70	?>37	oxidizing conditions	turbid	?restricted	
lower greenish-gray shale	low intertidal	2r		<65	<30		turbid	free	
Red Eagle Limestone									
Howe Limestone Member	0-10	4r	>7.5	>70	?>37	oxidizing conditions	clear	free	>10
Bennett Shale Member									
upper gray shale	10-50+	5r	8.0-8.2	>72	35-37		turbid	free	
medial limestone	0-50+	6	8.0-8.2	>70	35-37	oxidizing conditions	clear	free	
lower gray shale	10-50+	5p	8.0-8.2	>70	35-37		turbid	free	
basal black shale	0-10	3p				low oxygen	turbid	restricted	
Glenrock Limestone Member	10-40+	7	8.0-8.2	>70	35-37	oxidizing conditions	clear	free	
Johnson Shale									
upper greenish-gray shale	low intertidal	2p		<65	<30		turbid	free	
medial red shale	high intertidal	1		>70	?>37	oxidizing conditions	turbid	?restricted	

Eagle and other Wolfcampian cyclothems. The system of facies interpretation introduced by Imbrie and others (1959) differs markedly from, and is in some respects superior to, the system employed by Elias (1937).

Figure 6 attempts to portray the major Red Eagle cyclothem facies after the fashion of Imbrie and others (1959, p. 73) and Laporte (1962, p. 526) but incorporates the green shale and red shale facies (phases) of Elias (1937) and the black shale and three other facies types recognized in this study.

Red Shale Facies

These rocks are the almost barren red shale defined by Elias (1937) as marking upper and lower boundaries of Kansas Permian cyclothems. Elias postulated that they were deposited above the littoral zone, but it is proposed here that although climatic influences causing red soil on land were most responsible for their red color, they were deposited at shallow, possibly intertidal, depths in slightly hyperhaline water resulting from warm, periodically dry climate. In the Red Eagle cyclothem these facies occur near the middle of the Johnson and Roca Shales.

Green Shale Facies

These facies are the sorts of greenish-gray and gray calcareous shale that, in the upper part of the Johnson Formation, contain ostracodes, plant remains, and a few charophytes. Similar shale in the lower Roca is nearly barren. A few random argillaceous limestone layers, some platy, others nodular, occur in these facies. The green shale facies are interpreted as the records of mainly intertidal (rarely deeper) deposition in slightly brackish water, possibly under moist climate. Elias (1937) viewed this "phase" as representing deposition at depths between 0 and 30 feet.

Black Shale Facies

Fresh exposures of this facies are characteristically dark gray to nearly black, and they almost invariably contain numerous *Orbiculoidea* and conodonts and rare *Lingula*. The black shale facies is interpreted as the record of deposition just below mean low-tide level within a poorly oxygenated basin having restricted internal circulation and lacking free communication with the open sea. Commonly the black shale facies grades vertically to lighter gray shale belonging to shelly facies. The black shale weathers to light brownish gray. In the Red Eagle cyclothem it occurs at the base of the Bennett Shale.

Fusuline Limestone Facies

These are essentially the same as the fusuline facies recognized by Imbrie and others (1959) and Laporte (1962), but they do not contain chert. They are equivalent to rocks of Elias' (1937) fusulinid phase, which he believed were deposited at depths between 160 and 180 feet. The upper part of the Glenrock Limestone typifies this facies in the Red Eagle cyclothem. At some localities the fusuline limestone facies grade downward to bioclastic limestone facies (containing few or no fusulinids) in the lower part of the Glenrock. Although numerous fusulinid foraminifers dominate the fusuline limestone facies, *Osagia* remains are also present in significant quantities. Laporte's (1962, p. 541) view that these facies were deposited at depths probably not greater than 50 feet is supported in this study.

Bioclastic Limestone Facies

In the Red Eagle cyclothem the lower part of the Glenrock Limestone, especially in Nebraska and northern Kansas, is bioclastic limestone facies. Finely broken carbonate shell materials and *Osagia* remains, much as described by Imbrie and others (1959, p. 72) and Laporte (1962), dominate the facies. In the Glenrock Limestone the bioclastic facies in the lower part grades upward to fusuline limestone facies, as in the Cottonwood Limestone (Laporte, 1962, p. 527). The bioclastic facies appears to have accumulated in freely circulating, normally saline warm water at depths slightly shallower than for fusuline limestone facies deposition.

Conglomeratic-Bioclastic Limestone Facies

Rocks of this facies have matrices similar to bioclastic limestone facies (with numerous *Osagia*), but the matrices are hidden amid numerous pebbles and granules of aphanitic, slightly argillaceous, soft limestone or highly calcareous mudstone. The conglomeratic-bioclastic facies in the Glenrock Limestone is best developed at Manhattan, Kansas, where the pebbles are interpreted as reworked upper Johnson deposits eroded from shoals near Alma, Kansas.

Shelly Shale-Limestone Facies

The thinly interbedded, shelly, fossiliferous calcareous shale and nodular limestone of the upper part of the Johnson Shale in southern Kansas is the best example of shelly facies in the Red Eagle cyclothem. Much of Imbrie and others' (1959) description of Beattie shelly facies could be applied equally well to Johnson shelly facies.

The shaly parts of the Bennett Shale Member lack thinly interbedded limestone but contain a shelly fauna of fewer unbroken shells than the Johnson shelly facies. Like the shelly facies of the Cottonwood Limestone (Laporte, 1962, p. 540), the Bennett shelly facies correspond to Elias' mixed phase and contain some fossils of his brachiopod and molluscan phases. Bennett shelly facies also contain sparse fragments of *Orbiculoidea*, which are numerous in, and characteristic of, the black shale facies.

Deposition of some shelly facies might have occurred in water slightly deeper than for fusuline limestone or bioclastic facies. This viewpoint resembles that of Laporte (1962, p. 540).

Algal Limestone Facies

Rocks of this facies commonly contain less than 5 percent of insoluble residue and they make up the major part of Bennett limestone. The common aphanitic calcareous matrices contain comparatively few fossil genera, most of which (including rare *Orbiculoidea* fragments and fusulinids) are represented in shelly facies. The few horn corals in the Red Eagle cyclothem are mostly confined to the algal limestone facies. Sparse *Osagia* beans and fragments are also present. Much of the aphanitic carbonate is judged to be of algal origin. In some parts of this facies, crustose algal remains (*Anchicodium?*) contribute up to 15 percent of the rock. Imbrie and others (1959) chose to identify the latter rocks separately as "*Anchicodium* facies." The algal limestone facies probably accumulated in warm water slightly shallower than that in which fusuline or shelly facies came to rest.

Osagite Limestone Facies

Pelletoid, oolitic, or pseudo-oolitic limestone characterizes this facies. The pellets or ooliths consist of calcareous nuclei such as tiny foraminifers, mollusks, and fragments thereof, surrounded by concentrically layered coatings of algal calcium carbonate (*Osagia*). Most pellets are subspherical, but many are bean or sausage shaped, depending mainly on the shape of the nucleus. The upper parts of some limestone beds of the osagite limestone facies contain up to 70 percent of pellets in a microcrystalline matrix. These textures have been called osagites. They grade downward to rock that contains fewer irregularly shaped *Osagia* bodies than the osagites proper. Bun-shaped, concentrically laminated, calcareous algal mounds (Pl. 6A) are associated with osagite at one locality. South of Manhattan, Kansas, the Howe Limestone is typical of the osagite limestone facies in the Red Eagle cyclothem. This is similar to the Type *a Osagia* facies defined by Imbrie and others (1959, p. 72). The facies is judged to represent warm, almost hyperhaline water and deposition at depths only a few feet below low-tide level, under turbulence and circulation conditions as suggested by Imbrie and others (1959).

Aphanitic Limestone Facies

Howe Limestone from Manhattan, Kansas, northward typifies the aphanitic limestone facies. The Howe is light-gray, uniform, aphanitic limestone commonly containing from 5 to 15 percent of insoluble residue (mostly clay) and few fossils. The limestone weathers to shades of rusty and yellowish light brown and is commonly vuggy. Much of the aphanitic calcium carbonate is thought to be of algal origin. The facies is believed to be the record of deposition in slightly hyperhaline warm water that was somewhat restricted from free interchange with open sea water. Depths of deposition were about the same as for osagite limestone facies.

DIAGENESIS

Diagenesis, as used here, corresponds to Sujkowski's (1958, p. 2692) definition as "changes occurring in a freshly deposited sediment, commonly while still in the sedimentary basin" and including the "processes which turn a fresh sediment into a stable rock of some hardness, under conditions of pressure and temperature not widely removed from those existing on the earth's surface."

The Johnson Shale affords little direct evidence of such diagenesis. Although the lamination and fissility of the shale is mostly ascribed to primary sedimentary processes, some of the shaly parting may have developed by compaction of the Johnson clay mud during diagenesis. Shepard and Moore (1955, p. 1587) observed that 8,500-year-old mud buried 69 feet beneath similar currently accumulating mud in the central Texas Gulf Coast shows shalelike parting planes. The younger deposits have not yet acquired these structures. Hence, it is suspected that some of the shaly partings in Bennett and Roca clay shale may be of similar diagenetic origin. In the same way, diagenesis probably accentuated the bedded or laminated structures produced by other means (Sujkowski, 1958, p. 2716).

Diagenesis in Glenrock, Bennett, and Howe limestone is demonstrated by fossil interiors and matrix interstices filled with secondary calcite and, rarely, pyrite. The most conspicuous fossil fillings occur in Glenrock fusulinids and in the Howe Limestone nautiloid cephalopod (Pl. 7). Calcite in the matrices of the limestone is commonly microcrystalline-aphanitic. The calcite is thought to have been derived mostly by solution of calcareous material within the limestone masses, and by nearly simultaneous reprecipitation in open spaces. Judging from the known composition of living animal shells, many of the shells found in the limestone originally may have been aragonitic. It is assumed that recrystallization of aragonitic materials gave rise to much of the secondary calcite recognizable in the Red Eagle Limestone. Traces of short, impressed or indented contacts between pellets in the Howe Limestone osagite may reflect solution and reprecipitation of calcite, probably aided by compactive pressure.

The few chert nodules in the Bennett limestone at the Allen sections are further evidence of diagenesis. The secondary origin of these siliceous materials is affirmed by their content of silicified fossils. Individually silicified, milky, chalcedonic fossil brachiopod fragments and beekite are associated with the chert nodules. No explanation is offered for the preferential replacement of these fossils. Sujkowski (1958, p. 2695) postulated a diagenetic mechanism to explain the concentration of silica necessary for such chert structures. Initially, his mechanism requires saline water of a pH near 8,* trapped with the sediments when they accumulate. The amount of this water is reduced by squeezing during compaction. To provide the required source of silica for the nodules, Sujkowski's explanation calls for organic and inorganic silica in the sediments. If silica was dispersed through Glenrock and Bennett sediments, the chert nodules constitute the only record.

* The fauna of Glenrock and Bennett limestone reflects normal marine conditions. Normal sea water has a pH about 8.1 or 8.3. If Suikowski's explanation is correct for silica in the Bennett limestone, his required pH lends support to the implication that Glenrock and Bennett pH values were near 8.0. Conversely, the implicit normal marine pH and presence of chert give support to the tenability of Suikowski's explanation.

Clay accumulations commonly undergo volume reduction of between 50 and 78 percent (Weller, 1960, p. 298) during diagenesis. Although it is certain that Johnson, Bennett, and Roca shale was compacted, the only direct evidence of compaction is visible in the black *Orbiculoidea*-bearing shale at the base of the Bennett Shale. Here, many specimens of cone-shaped *Orbiculoidea* have been crushed flat by compression under the weight of overlying sediments.

Traces of "muscovite" have been found with clay and fine quartz silt in many of the insoluble residues studied. It is believed that the "muscovite" is an alteration product of clay minerals such as illite, common in shale of the Red Eagle cyclothem. The small amounts of chlorite commonly present in many of these shale units could have been altered from the illite or from montmorillonite if appropriate ions were present during diagenesis. Some of the illite could have been altered from montmorillonite.

Evidence of oxidation of iron salts in shale is present where thin zones adjacent to fractures in greenish-gray shale are changed to a faint maroon-gray color. Some of the green coloration in Johnson and Roca shale is due to the presence of finely divided ferrous iron silicates.

The general light color of the Bennett limestone and the random orientation of its shell fragments may have resulted from the activities of mud-eating and scavenging organisms during early diagenesis. "The importance of living creatures as agents of early diagenesis in natural sedimentary environments can not be overstressed" (Shepard and Moore, 1955, p. 1586).

Much of the gray shale and some of the black shale of the Bennett Shale Member weather to light brownish gray or buff. This weathering is so deep in some places that the shale could be mistaken for unaltered buff shale. The light color is believed to be the result of oxidation, bleaching, or removal of dark carbonaceous and other rock-coloring materials during weathering.

ENVIRONMENTAL HISTORY OF THE RED EAGLE CYCLOTHEM

Necessarily, some episodes in this history rest on inference within a framework of conclusions that can be supported by observation. These conclusions are listed after the following summary of environmental history.

The Red Eagle cyclothem was deposited in Wolfcampian time in marine waters spread thinly over a wide, very flat, shelflike basin in the Midcontinent region of Kansas, Oklahoma, and Nebraska. The basin floor subsided slowly and permitted the accumulation of some 50 feet of sediments that now make up the Red Eagle cyclothem. Lowlands bordered this arm of the Wolfcampian sea on the north, east, and south. From time to time uplifts in southern Oklahoma supplied large quantities of clastics which were washed into the southern side of the basin and thence were spread northward by gentle currents. These sediments mingled with those from the lowlands to the north and east. The generally moist climate of the region varied from warm to cool, with dry, warm conditions occurring periodically.

During the first half of Johnson time, the sea shallowed until shorelines were comparatively near to the area of study. At the same time the climate became warm, with alternating wet and dry seasons, so that red soil developed on the land. When the waters were shallowest (high intertidal?), red soil detritus washed into the northern and southern margins of the basin. The Red Eagle cyclothem sequence began with accumulation of these red sediments in warm and possibly hyperhaline waters. While red detritus was carried toward the center of the basin, its ferric oxides were chemically reduced so that the sediment was deposited as a greenish-gray aggregate. After a few inches of red mud accumulated, the sea deepened very slightly, circulation with the ocean became freer, and the water became normally saline. Greenish-gray mud was deposited throughout the Kansas part of the basin. Little light could reach the sea bottom because waters were turbid from suspended mud. Hence, few benthonic plants and few animals inhabited the water, although planktonic algae were active near the surface. The algae precipitated calcium carbonate particles which settled with the suspended sediments to form moderately calcareous greenish-gray mud.

The sea cleared occasionally during the last of Johnson time because of: (1) short, warm, dry periods (which lessened runoff and inhibited subaerial erosion); (2) low relief and gradients in source areas; or possibly (3) development of submarine barriers to clay influx. During these times relatively more algal calcium carbonate was produced so that local layers of argillaceous lime mud accumulated within the preponderant calcareous clay mud. The water was less than 10 feet deep, so storms were able to stir up some of the bottom sediments. Tidal and wind-induced currents exerted daily smoothing and laminating action on bottom sediments and were an important agent of transportation of suspended clay detritus.

Near the end of Johnson time, rapid influxes of water from land during pluvial periods temporarily lowered the salinity. Ostracodes were the only shelled animals that flourished. Fragments of gymnosperm wood washed in from lands to the north and east. In southern Kansas (Cherokee Basin) the late Johnson waters were only slightly deeper than in the north. The land to the south was low. During relatively dry periods the supply of mineral and rock detritus from the south periodically diminished, and so allowed the waters to clear. During these periods a mixed shelly fauna developed in southern Kansas, while only ostracodes lived in the northern part of the basin. Small amounts of detritus regularly entered the Midcontinent basin, mainly from the north and east.

Johnson deposition terminated when the water deepened from less than 10, to 20 or 30 feet. Whether or not subsidence aided the rising water, the rise in sea level forced the shorelines to move considerable distances over the adjacent lowlands. Hence, in Glenrock time little clastic sediment from the land reached the area of study, so waters were very clear. The sea floor was extremely flat. Benthonic life thrived. Particulate algal calcium carbonate settled from near-surface waters amid a profusion of benthonic calcareous shelled invertebrates, of which many were fusulinids. The result was a richly bioclastic, clean, calcareous bottom ooze. During Glenrock time the basin floor subsided slightly less in southern Kansas than in the north, so that a lesser thickness of Glenrock lime mud accumulated there than in the north. However, in northern Kansas and Nebraska, Glenrock sediments were deposited at a remarkably uniform rate. Minor local uplifts occurred along the Nemaha Anticline, causing shoals near the Alma, Saffordville, and Elmdale localities just before or during Glenrock time, so that Glenrock sediments were scarcely deposited in these areas. Fragments of Johnson sediment were eroded from the Alma shoal and deposited in the Glenrock sediments at Manhattan and Paxico. At the end of Glenrock time, the depositional interface was a strikingly level, uniform surface over much of northeastern Kansas and southeastern Nebraska and parts of southeastern Kansas.

The sedimentary events that closed Glenrock time happened even more suddenly than those which began it. The sea shallowed quickly from 30 or 40 feet to less than 10 feet. The accumulation of clay clastics resumed in the area of study, and free circulation of water with the open ocean was restricted by an unknown barrier somewhere to the southwest. This change accounted for the euxinic sea floor at the beginning of Bennett time in Kansas and Nebraska. The top of the Glenrock Limestone was so flat that these changes occurred almost simultaneously throughout the area of study.

As the available oxygen was depleted, odorous Bennett mud began accumulating on the clean bioclastic Glenrock Limestone sediments. Black mud killed the last Glenrock fusulinids and washed into the open tubes of animals that burrowed into the upper Glenrock sediments. Organic matter and calcium carbonate settled from the surface waters to the toxic bottom (low in oxygen), where the organic matter was partly preserved and partly decayed by bacteria. This increased the toxicity. A few *Lingula* and *Orbiculoidea* were able to live in and on the black bottom, but they did not thrive.

During early Bennett time the water deepened slightly. The ensuing freer circulation improved oxygenation, reduced the toxicity, and encouraged the establishment of a mixed shelly benthonic fauna. Gray mud was deposited from moderately turbid water 40 or 50 feet deep. The southern supply of clastics to the area of study was reduced while waters shallowed in the middle of Bennett deposition. Faint upwarp of the Bourbon Arch further interfered with circulation and prevented northern clastics from reaching southern Kansas. Hence, lime mud was laid down in shallow clear water during the rest of Bennett time in southern Kansas, while calcareous clay mud was deposited from more turbid water in Nebraska and northern Kansas. Up to 5 feet of lime mud or ooze accumulated in central Kansas during medial Bennett time, some in calcareous banks stabilized by ramose crustose algae, but calcareous clay mud with a mixed shelly fauna followed when the water deepened in the latter part of Bennett time. In a small shoal area south of Eskridge, Kansas, double the normal thickness of lime mud accumulated in algal banks amid calcareous clay mud during medial and late Bennett time.

After the euxinic conditions which began Bennett time, all Bennett waters were mildly warm (about 70° F) and normally marine in salinity and pH. The bottom was swept by moderate to gentle currents. In medial and late Bennett time, calcareous crustose algae grew on the lime ooze in central and southern Kansas and helped to stabilize and accumulate fine particulate carbonate detritus.

Sedimentary events that concluded characteristic Bennett deposition were less abrupt and extreme than events at the beginning. Surrounding land masses were worn low by the end of Bennett time. The sea became very shallow again and the deposition of Howe calcareous sediments began in clear, warm, nearly hyperhaline water. A profuse benthonic fauna, rich in foraminifers, ostracodes, tiny gastropods, and small clams, was established south of the Manhattan area. Shortly after the beginning of Howe time the water was warm, shallow, and clear enough for algae to thrive on the bottom. The algae *(Osagia)* secreted calcareous coatings around shell fragments, thus forming the pseudo-oolites observable in the pelletoid Howe Limestone (osagite) of central and southern Kansas. Commonly gentle, but sometimes strong, currents swept the floor of the Howe sea. In Nebraska and northern Kansas, algal particles accumulated to form aphanitic calcareous ooze containing few shelly fossils.

After the water had shallowed to less than 10 feet by the end of Howe time, there followed a sudden influx of clastics and the establishment of water conditions similar to those of late Johnson time. Greenish-gray mud began to accumulate. Regional climatic changes and uplifts in the southern source area caused a flood of red clastics to move northward across the shelf-basin in early Roca time. Smaller quantities of red clastics washed in from sources to the north and east. Most of these were chemically reduced to a green color before they reached central Kansas. Greenish-gray calcareous clay mud similar to that deposited late in Johnson time settled from the turbid Roca waters. The water shallowed to nearly intertidal depths and the shorelines drew nearer to the area of study. Occasionally, as in late Johnson time, thin layers of lime mud accumulated during temporary incursions of deeper water. When the climate changed and the intertidal waters became slightly hyperhaline near the middle of Roca time, red clastics spread across the area. This return to conditions similar to those which caused deposition of the Johnson redbeds marked the end of the cycle of depositional events recorded within the Red Eagle cyclothem.

CONCLUSIONS

1. Rocks of the Red Eagle cyclothem can be traced through several facies changes from Bennet, Nebraska, to Burbank, Oklahoma. Most of the limestone in the northern Oklahoma Red Eagle type area is equivalent to the Bennett Shale Member of the Red Eagle Limestone formation in Kansas and Nebraska.

2. Rocks of the Red Eagle cyclothem accumulated in very shallow marine waters, upon an unusually flat shelf-basin. The floor of the basin was flattest at the end of Glenrock Limestone deposition.

3. Red Eagle cyclothem rocks contain the following fundamental faunal-lithologic facies types, recognizable both in the field and in the laboratory: red shale facies, green shale facies, black shale facies, fusuline limestone facies, bioclastic limestone facies, conglomeratic-bioclastic limestone facies, shelly facies, algal limestone facies, osagite limestone facies, and aphanitic limestone facies. These facies types, as well as others first recognized and interpreted by Imbrie and others (1959) and by Laporte (1962), are represented in most cyclothems of the Kansas Wolfcampian.

4. Depositional environments of the various faunal-lithologic cyclothemic phases were controlled principally by water depth (see Table 7). Regional climate, which modified the supply rate of silicate clastics and the chemistry and movements of the sea water, significantly modified and sometimes subordinated the effects of depth.

5. Uniform depositional environments prevailed contemporaneously over wide areas of the shelf-basin during Red Eagle cyclothem deposition. The remarkably level basin floor permitted transmittal of even slight changes of depth, and attendant environmental conditions, across the entire shelf within very short (geologically instantaneous) time intervals. Such events caused knife-sharp lithologic boundaries such as the Glenrock-Bennett contact, which is essentially a time plane within the Red Eagle cyclothem. Slight depth changes sometimes gave rise to major changes in circulation and depositional conditions by barrier breaching.

6. The Red Eagle cyclothem records a cycle of water depth changes (summarized in Figure 5C) ranging from intertidal depths to not more than 60 feet. Tidal, wave-induced, and other currents were gently active within the shallow Red Eagle cyclothem waters, and they served to spread the sediments uniformly over broad areas.

7. Accumulation rates were broadly uniform during deposition of individual sedimentary units or phases of the Red Eagle cyclothem in Kansas and Nebraska.

8. The silicate clastic sediments in the Red Eagle cyclothem came from the north, east, and south of the present outcrop belt. Tectonism to the south (southeastern Oklahoma?) periodically controlled the influx of clay clastics to the area. Changes of sea level (ultimate base level) and climatic changes also may have governed the supply of clastics.

9. Redbeds were deposited in the shallowest, most saline waters; they define the upper and lower boundaries of the cyclothem. Comparatively greater thickness of redbeds in Oklahoma indicates relative nearness to the southern source of red clastics. The red materials are believed to have been washed or blown into the area of study from red soil sources.

10. Regional climate during deposition of Red Eagle cyclothem sediments ranged from moist and cool (temperate), to warm and periodically dry.

11. Most of the limestone in the Red Eagle Limestone formation was formed from shell detritus and calcareous algal particles. Inorganically precipitated carbonates are negligible.

12. Formation of the Howe Limestone osagite required clear, gently agitated water probably less than 10 feet deep, with current velocities greater than 10 centimeters per second.

13. Stratigraphic marker fossils within the Red Eagle cyclothem are:

Howe limestone .... *Osagia* (alga)
Bennett limestone .... *Lophophyllidium?* (horn coral)
Bennett black shale .... *Lingula, Orbiculoidea* (inarticulate brachiopods)
Glenrock limestone .... *Triticites* (fusulinid foraminifer)
Upper Johnson shale .... *Trochiliscus* (charophyte)

14. Environmental index fossils within the Red Eagle cyclothem are:

Osagia: clear, shallow (0-10 feet), warm, gently agitated water.
Lingula, Orbiculoidea: shallow (0-10 feet), euxinic, somewhat turbid conditions; restricted circulation.
Triticites: clear, shallow (10-40+ feet), warm, normal marine water; gentle, free circulation.
Trochiliscus: shallow (0-10 feet), mildly brackish water rich in $CaCO_3$.

15. The gymnosperm? spores in the lower Bennett Shale resemble those of later Permian rocks elsewhere. In the Wolfcampian, mid-America may have been the cradle of development of a flora which did not reach other parts of the world until medial or later Permian time.

16. Faint crustal upwarps produced shoals in the Nemaha Anticline and Bourbon Arch areas of east-central Kansas, which exercised minor control over sedimentation in Glenrock and Bennett time but not during Howe time. Because of such upwarp, Glenrock Limestone is locally absent in east-central Kansas. A unique Glenrock facies near Manhattan, Kansas, may have been partly derived from upwarps near Alma, Kansas.

17. Chert and clear calcite pore fillings in Bennett limestone record diagenetic changes. The fine grain size of bioclastics, random particle orientation, light color, and lack of lamination in massive Bennett limestone are attributed to the activities of burrowing and mud-eating organisms.

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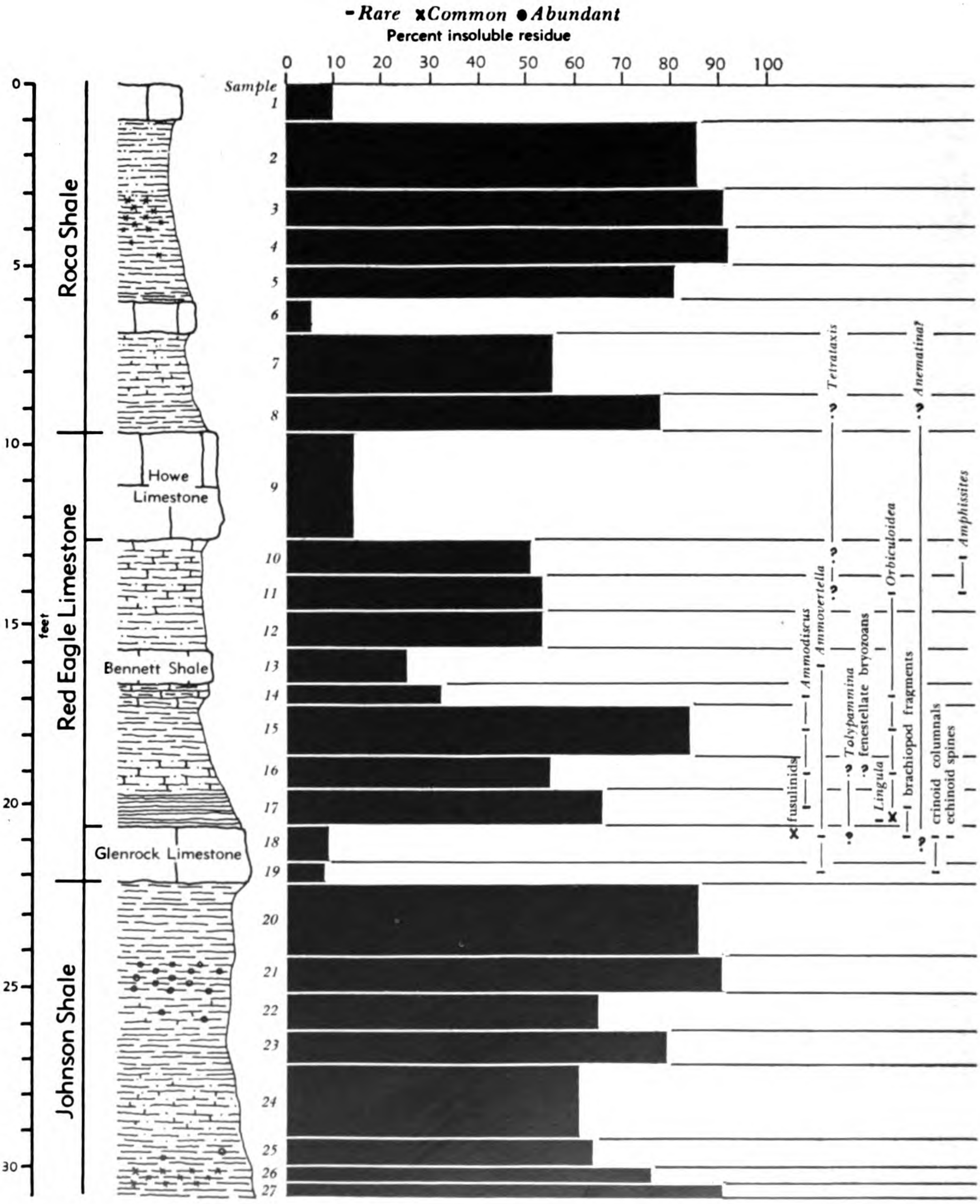
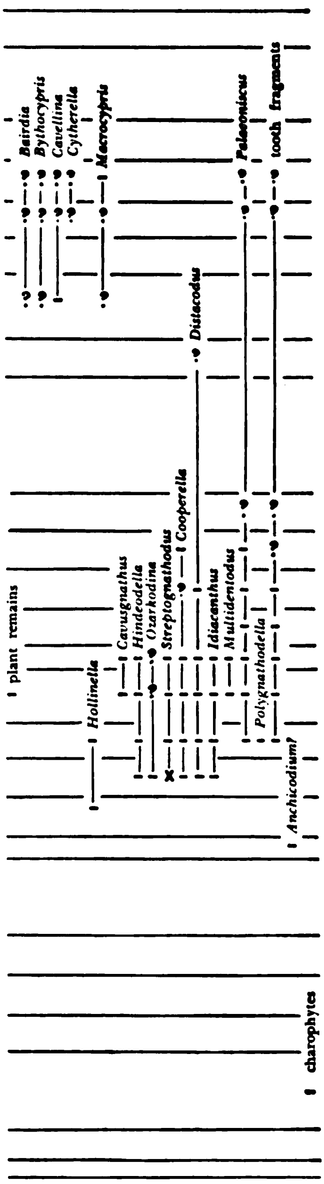


FIGURE 7.—Columnar section, insoluble residues, and fossils of the Bennet section.



APPENDIX

Descriptions of Sampled Red Eagle Cyclothem Sections

Bennet Section.—NE sec. 11, T. 8 N., R. 8 E. In south cut bank of Little Nemaha River, ½ mile southeast of Bennet, Lancaster County, Nebraska (Fig. 7).

Sample	*Thickness, feet*
Soil	
Roca Shale	
1. Limestone, light yellowish to brownish gray, argillaceous, traces of random clear calcite flecks	1.0
2. Mudstone, light gray and greenish gray with yellowish mottling, silty, calcareous, moderately laminated	2.0
3. Mudstone, brick red, calcareous, moderately laminated	1.0
4. Shale, light gray with pale-maroon tint, moderately to well laminated, slightly calcareous, compact	1.0
5. Shale, light gray, slightly calcareous, compact, well to moderately laminated, traces of small tan calcareous shell? fragments	1.0
6. Limestone, light brownish gray, aphanitic, hard, traces of medium to fine clear calcite crystals in veinlets or in random blebs, very rare ostracodes	0.9
7. Shale, light gray, silty, slightly calcareous, moderately to well laminated, rare ostracodes	1.7
8. Shale, light gray with greenish tint, calcareous, well laminated, traces of buff frail gastropod? fragments	1.0
Thickness Roca Shale exposed	9.6
Red Eagle Limestone	
Howe Limestone Member	
9. Limestone, light to medium brownish gray, aphanitic, rare large vugs, some pinpoint porosity in lower 1.0 foot, thick bedded	3.0
Bennett Shale Member	
10. Shale, medium to light gray, traces of yellowish mottling, moderately to slightly calcareous, compact, moderately to well laminated	1.0
11. Mudstone, light yellowish rusty gray, calcareous, poorly to moderately laminated, compact	1.0
12. Mudstone, buff, probably weathered from medium to light gray, calcareous, moderately to poorly laminated, trace of pale-rusty yellowish mottling	1.0
13. Limestone, light brownish gray, muddy, resistant, hard, traces of flecks of dark-brown (possible bituminous or plant) material	1.0
14. Mudstone, argillaceous calcilutite, aphanitic, similar to above, trace of dark-brown flecks in light-yellowish-gray mottled matrix, microgranular, trace of fish teeth and small shell fragments	0.5

15. Shale, medium to dark gray, compact, well laminated, slightly calcareous, traces of frail shell fragments and black threadlike plant remains 1.5
16. Mudstone, light gray, calcareous, some rusty-yellow mottling, compact, poorly laminated 1.0
17. Shale, dark gray, well laminated, complete *Orbiculoidea* with fragments 1.0

Thickness Bennett Shale Member 8.0

Glenrock Limestone Member

18. Limestone, light brown to grayish green, aphanitic matrix for common fusulinids, hard, massive, trace of brachiopod fragments, rare flecks of brown bituminous? material, upper 0.2 feet has patches of muddy gray material suggestive of Bennett shale; lower 0.5-foot free of fusulinids but contains common brachiopods, foraminifers, and ostracodes 1.0
19. Limestone, medium to light brownish gray, aphanitic to microgranular faint undulatory (algae?) laminations, undulatory base and top, very hard 0.5

Thickness Glenrock Limestone Member 1.5

Thickness Red Eagle Limestone 12.5

Johnson Shale

20. Shale, medium gray, some light greenish gray, well laminated 2.0
21. Shale, light greenish gray, calcareous 1.0
22. Claystone, light gray to bluish gray, slightly calcareous, poorly to moderately laminated 1.0
23. Shale, light bluish gray, calcareous, moderately laminated 1.0
24. Mudstone, light gray, calcareous, poorly to moderately laminated 2.0
25. Shale, light gray to olive green in places, calcareous, soft, well laminated 0.8
26. Mudstone, brick red, calcareous 0.5
27. Shale, light greenish gray, calcareous, moderately laminated; 0.1-foot brick-red shale 0.5 foot above base 1.7
28. Siltstone, light gray, very finely and evenly laminated, resistant, platy debris, slightly calcareous, grades downward to similar silty shale in lower 0.5 foot and to shale as below 1.0
29. Shale, light gray to brownish gray, moderately to very well laminated as above, slightly calcareous, traces of foraminifers, snails, and fish teeth 1.0
30. Limestone, shaly, medium gray, weathers light yellowish gray to light brownish gray, moderately to well laminated, slightly calcareous, slightly silty along laminae; 0.3-foot lens of aphanitic argillaceous medium-gray limestone 1.0 foot from base 2.5
31. Shale, light brownish gray, similar to above, slightly silty 1.1

Thickness Johnson Shale 15.6

Foraker Limestone

Long Creek Limestone Member

32. Limestone, argillaceous to coquinoid, medium to light gray; exposed 2.0

Johnson Section.—NW NE sec. 6, T. 5 N., R. 13 E. In west bank of creek, 1¼ miles north of Johnson, Nemaha County, Nebraska (Fig. 8).

Sample — *Thickness, feet*

Soil

Red Eagle Limestone

Bennett Shale Member

1. Shale, dark gray, weathers buff, well laminated, fish teeth, *Orbiculoidea;* exposed 2.0

Glenrock Limestone Member

2. Limestone, light brownish gray, aphanitic matrix for abundant fusulinids, oatmealy subcoquinoid-calcarenitic texture 1.0

Thickness Red Eagle Limestone exposed 3.0

Johnson Shale

3. Shale, light buff, weathered from medium gray, calcareous, slightly silty, moderately laminated, trace mica? and minute brown flecks of phosphatic material, possibly vague ripple marks, fairly hard 0.5
4. Shale, similar to above, trace of brown phosphatic tooth? remains, common plain ostracodes along coarser textured laminae or very thin beds 0.5
5. Shale, similar to above 0.5
6. Limestone, medium to light brownish gray with some pale-rusty-yellow stain, slightly resistant, argillaceous, aphanitic matrix for ostracodes, possible linear algae 0.5
7. Mudstone, light greenish gray, calcareous, silty, blocky debris, more resistant than below 1.0
8. Mudstone, light olive green to gray, calcareous, similar to above, traces of possible plant remains, not laminated 1.0
9. Mudstone, light greenish gray, moderately laminated, calcareous, rare very fine grains of tan $CaCO_3$, less resistant than 7 and 8 .. 1.0
10. Shale, laminated, medium greenish gray, clayey laminae alternate with off-white marly laminae; all laminae are lenticular on a very minute scale, calcareous, and more resistant than beds above and below .. 0.3
11. Shale, light olive green to gray, moderately laminated, compact 0.7
12. Shale, light yellowish green to gray, calcareous, moderately to poorly laminated; some mudstone 0.3
13. Mudstone, light greenish gray with yellowish cast, calcareous, fairly resistant 1.0
14. Mudstone, similar to above but lighter greenish gray, calcareous 1.0
15. Mudstone, medium to light olive green, not calcareous, fairly resistant, compact, olive tint modified by limonite 1.0
16. Shale, light greenish gray, calcareous, (similar to 14), poor wavy laminae, varies to mudstone 1.0
17. Mudstone, medium olive green, somewhat calcareous, random rusty flecks 0.8
18. Limestone, light brownish gray, very argillaceous, laminated, varies to limy shale, some laminae are pure tan $CaCO_3$ 0.1

19. Mudstone, medium gray, calcareous, some rare vague laminae, blocky debris 1.0
20. Mudstone, medium greenish gray, very calcareous, nodular weathering 1.0
21. Mudstone, light greenish gray with pale-yellowish tint, calcareous, nodular, soft to hard where nodular 1.0
22. Mudstone, light greenish gray, somewhat chalky 1.0
23. Mudstone, similar to above, varies to very light greenish buff 1.0
24. Mudstone and shale, variegated, very light green, pink, and buff, calcareous 0.8

Thickness Johnson Shale 17.0

Pawnee Section.—C NW NW sec. 11, T. 1 N., R. 10 E. In south bank of West Branch Creek, 100 yards from small bridge, Pawnee County, Nebraska (Fig. 9).

Sample	*Thickness, feet*
Roca Shale	
1. Shale, medium to light gray and greenish gray, slightly silty, rare rusty mottling, poorly laminated, varies to mudstone	1.5
2. Shale, light greenish gray, slightly silty, varies to mudstone, random crude light-gray argillaceous limestone boxwork	1.5
3. Limestone, light greenish gray, argillaceous, grades to shale above, top undulatory (2 inches relief)	1.5
4. Siltstone, light greenish gray, argillaceous ..	0.5
5. Siltstone, brick red, argillaceous, varies to mudstone, slightly calcareous, small blocky debris	1.5
6. Shale, light gray to light greenish gray, calcareous, poorly laminated, varies to calcareous mudstone, trace of fossils, sinistrally coiled high-spired smooth-shelled gastropod fragments	0.2
7. Limestone, light gray to very light brownish gray, argillaceous, laminated, flaky	0.2
8-9. Limestone, light brownish gray with horizontal small discontinuous medium- to light-gray streaks, vugs rare, trace of MnO_2 dendrites, sublithographic to microcrystalline, hard, even textured, massive, thick to medium bedded, bedding planes undulatory (3 inches) to even, traces of crack fillings at base recorded on overturned slumped block, weathers light gray to buff	2.0
10. Shale, very light greenish gray, finely silty, clayey, varies to calcareous mudstone, slightly calcareous	0.05
11. Shale, very light greenish gray, finely silty, calcareous, well to poorly laminated, varies to calcareous mudstone, somewhat blocky, more resistant than below	0.55
12. Mudstone, very light greenish gray, soft, calcareous, trace of mica?	1.9
13. Shale, brownish gray, silty, well laminated, trace of mica along laminae, not calcareous, compact, gray to rusty along some laminae	1.5

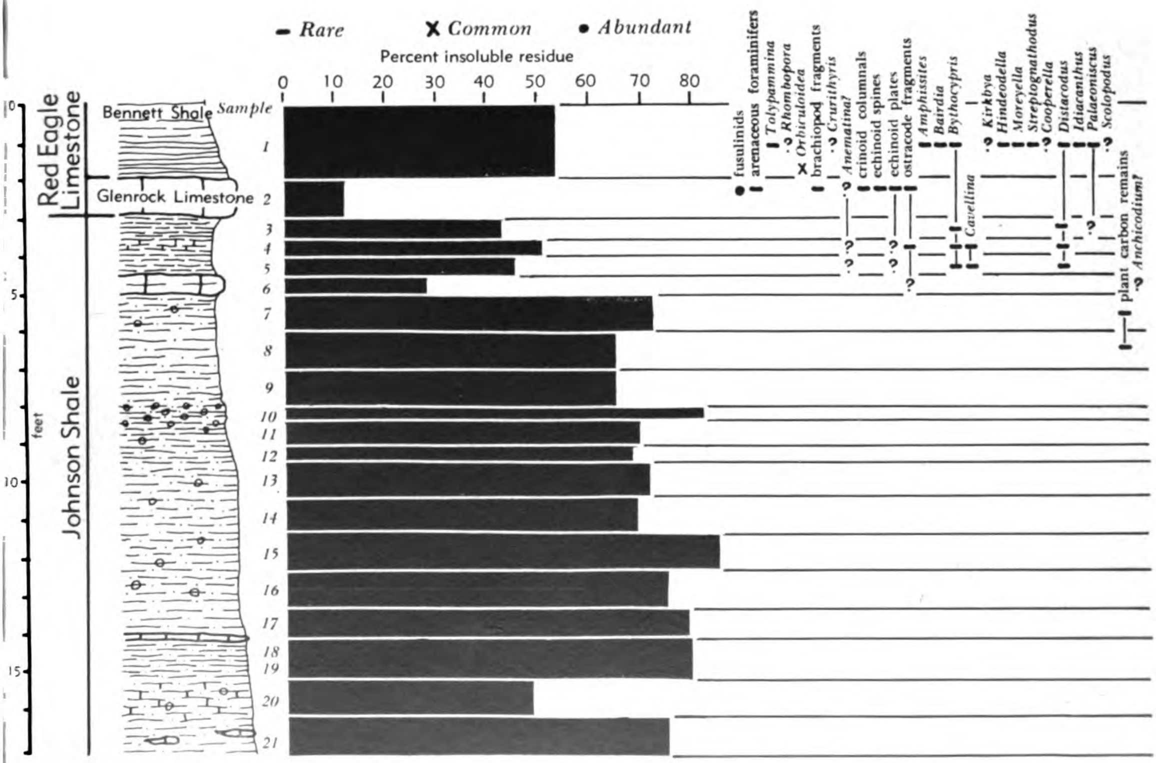


FIGURE 8.—Columnar section, insoluble residues, and fossils of the Johnson section.

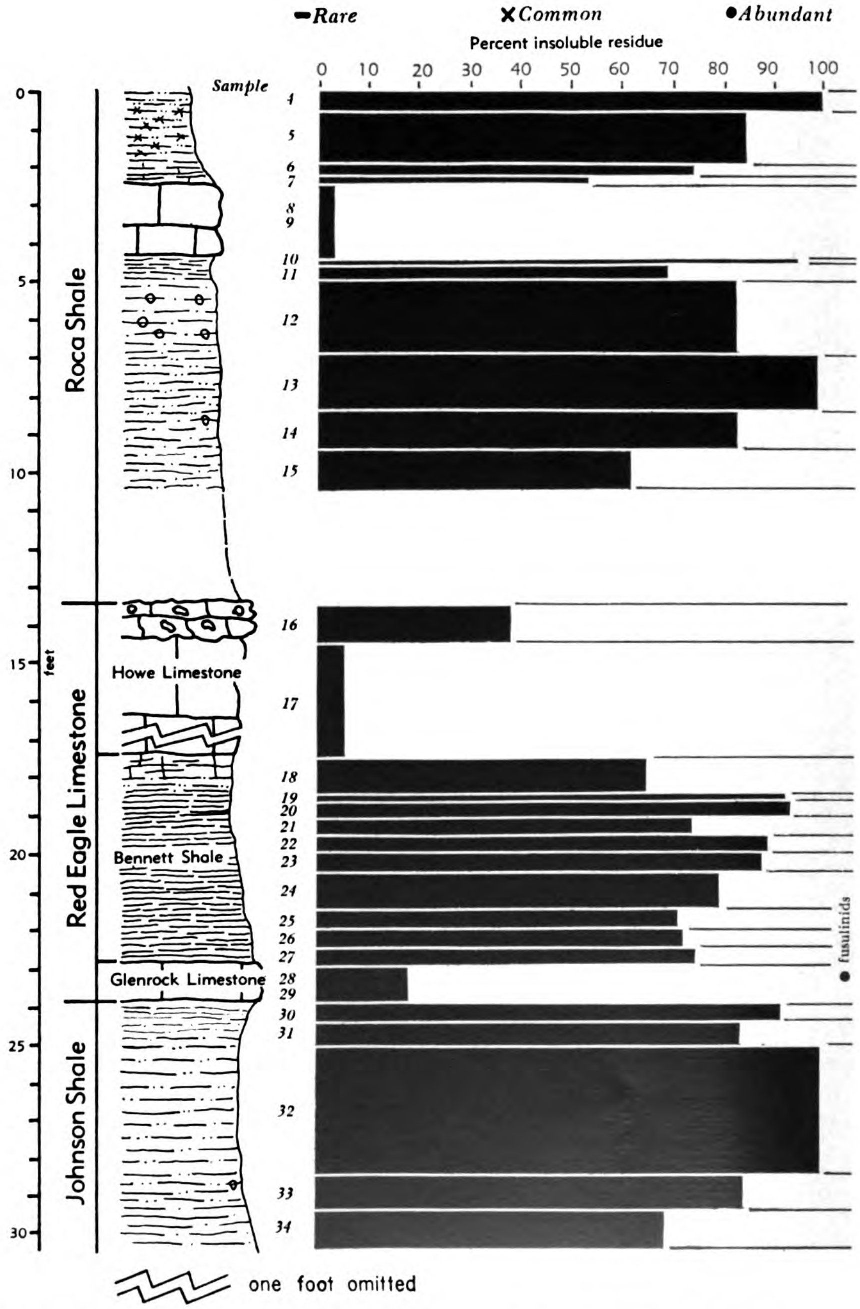
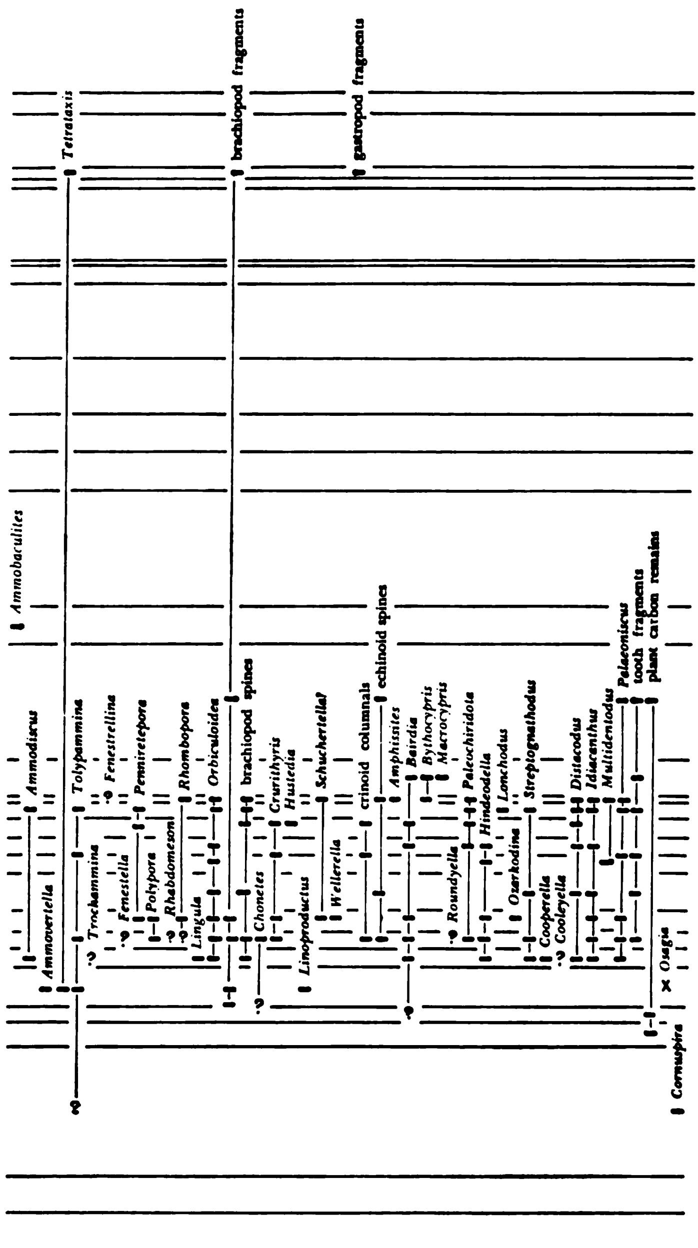


FIGURE 9.—Columnar section, insoluble residues, and fossils of the Pawnee section.


Tetrataxis
brachiopod fragments
gastropod fragments
Ammobaculites
Ammodiscus
Ammovertella
Tolypammina
Trochammina
Fenestrellina
Fenestella
Penniretepora
Polypora
Rhabdomeson
Rhombopora
Lingula
Orbiculoidea
brachiopod spines
Chonetes
Crurithyris
Hustedia
Linoproductus
Schuchertella?
Wellerella
crinoid columnals
echinoid spines
Amphissites
Bairdia
Bythocypris
Macrocypris
Roundyella
Paleochiridota
Hindeodella
Lonchodus
Ozarkodina
Streptognathodus
Cooperella
Cooleyella
Distacodus
Idiacanthus
Multidentodus
Palaeoniscus
tooth fragments
plant carbon remains
Osagia
Cornuspira

14. Claystone, light greenish gray, calcareous, compact, uncommon vague laminae, trace of very fine silt, varies to mudstone 1.0
15. Claystone, very light greenish gray, calcareous, compact, poor uncommon laminae, similar in general appearance to above 1.0
Covered 3.1

Thickness Roca Shale 18.0

Red Eagle Limestone

Howe Limestone Member

16. Limestone, light gray and greenish gray, microcrystalline, hard, slightly argillaceous, varies at random to clayey compact clay-filled vugs and pits, very irregular boundary, fairly resistant 1.0
17. Limestone, light rusty gray to buff, very calcilutaceous to very finely silty, badly decayed, soft, little resistance to erosion, vaguely laminated in places 4.0

Thickness Howe Limestone Member 5.0

Bennett Shale Member

18. Siltstone, very light gray to buff or yellowish gray, slightly to moderately calcareous, very fine to fine, grades into above 1.0
19. Shale, medium to light brownish gray, calcareous, moderate to good fissility, contains many calcareous fossil fragments (brachiopods, *Orbiculoidea*, productid spines) oriented roughly parallel to fissility, trace of interstitial dark-gray MnO_2, transitional between 18 and 20 .... 0.1
20. Shale, very dark gray, moderately laminated, varies to mudstone, very slightly calcareous, varies to noncalcareous, trace of *Orbiculoidea*, compact 0.5
21. Shale, similar to 19, many brachiopod fragments, *Crurithyris*, productid spines 0.5
22. Shale, medium to dark gray and brownish gray, moderately laminated, slightly calcareous, compact, weathers to medium brownish gray 0.5
23. Shale, similar to above, moderately to well laminated, silt-size fragments of dark-brown corneous fossil remains (*Orbiculoidea*? or fish fragments?), compact 0.5
24. Shale, very dark gray, compact, noncalcareous to very slightly calcareous, well laminated to moderately laminated 1.0
25. Shale, medium gray, calcareous, well laminated, large calcareous brachiopod fragments parallel to laminae, traces of dark-brown corneous fossil fragments 0.5
26. Shale, medium to dark gray, calcareous, emits fetid odor when attacked by HCl, well laminated, rare traces of brachiopod fragments (*Crurithyris*) 0.5
27. Shale, medium to dark gray, calcareous, similar to above but lacking visible fossils, well laminated, moderately fissile, compact, *Orbiculoidea* and *Lingula* fragments occur in the basal ¼ inch 0.5

Thickness Bennett Shale Member 5.6

Glenrock Limestone Member

28. Limestone, medium to light gray and brownish gray, very finely granular to very finely crystalline matrix, very fossiliferous, common fusulinids especially in upper 0.6 foot, brachiopod fragments and lesser foraminifers, hard, compact, trace of pyrite in fusulinids, a single massive bed, locally top 0.2 foot penetrated by tubes of dark-gray calcareous mud from Bennett Shale above, upper 0.1 foot undulatory with abrupt gradation upward to dark-gray calcareous tubes (containing fusulinids and *Orbiculoidea* fragments) in random pattern suggesting worm trails, random lumps and small accumulations of fusulinid-bearing lime mash material associated with the dark mud, rare larger brachiopods (*Linoproductus*?), smaller tubes of medium-gray silty material in dark mud suggest small worm activity, lower 0.3 foot contains identified foraminifers *Tolypammina*, *Ammovertella*, and *Tetrataxis*; nearby outcrops have only shallow penetrating tubes but transition to Bennett mud is abrupt .. 0.7 to 1.0
29. Limestone, medium to light gray and brownish gray, abundant brachiopod fragments and common lesser foraminifers in very fine crystalline matrix, brachiopods coated with algal? $CaCO_3$, rough random orientation of shells parallel to bedding, base roughly parallels bedding planes, varies to silty limestone and calcareous siltstone with small brachiopod and foraminifer fragments; a local feature occurring in lenticular masses up to 2 inches thick which seem to have grown as small lumps on the Johnson and over which the Glenrock was deposited, thus contributing to the undulatory base of the Glenrock .... 0 to 0.2

Thickness Red Eagle Limestone approximately 11.5

Johnson Shale

30. Shale, medium gray, very finely silty, calcareous, faint trace of glossy carbonaceous plant remains, moderately to poorly laminated, varies to mudstone, crudely defined clay-filled tubes suggest worm burrows, trace of mudstone pebble breccia, trace of ostracodes 0.4
31. Mudstone, medium gray with flecks of lighter gray, varies to clay granule conglomerate, calcareous flattish claystone granules roughly parallel to bedding planes, finely silty, calcareous, rare traces of pyrite, rare traces of carbonaceous remains, compact .... 0.5 to 0.7
32. Siltstone and mudstone, medium to light gray, some microbrecciation, moderately to well laminated, compact; paper-thin laminae are light gray, calcareous, massive; lower 1.0 foot is well laminated and weathers to tough brittle plates and slabs up to 1 inch thick (platestone) 3.5
33. Siltstone, light greenish gray, even textured, weathers to irregular lumps of crude blocky shape, slightly calcareous 1.0
34. Mudstone, medium gray, trace of dark-gray flecks, even textured, weathers somewhat blocky in upper part, lower 0.5 foot poorly laminated, calcareous 1.0

35. Limestone, light gray, microgranular to aphanitic, somewhat argillaceous, massive, uniform, varies to somewhat nodular 1.0
36. Shale, medium to light greenish gray, faint trace of very fine sand, calcareous, poorly laminated or crudely bedded in places, but usually even textured, weathers to crude blocky debris 0.5
37. Siltstone, light greenish gray, argillaceous, faint trace of very fine sand, calcareous, crudely laminated 3.0
38. Siltstone, as above but varies to light greenish buff, weathers light brownish gray 2.0
39. Siltstone, as above but softer and lacks laminae, calcareous 2.0

Thickness Johnson Shale approximately 15.0

Humboldt Section.—SE SE sec. 16, T. 1 N., R. 13 E. West side of road cut in crest of small hill in Richardson County, Nebraska (Fig. 10).

Sample — *Thickness, feet*

Red Eagle Limestone

Bennett Shale Member

1. Shale, dark to medium brownish gray, calcareous, well laminated, emits fetid odor when attacked by HCl 0.5
2. Shale, medium brownish gray, calcareous, well laminated, trace of *Orbiculoidea* fragments, compact, similar to above 0.5
3. Shale, dark to medium gray and brownish gray, traces of yellowish to buff weathering, compact, contains thin *Orbiculoidea* coquina layer (shell fragments are flattened and crushed along the laminae) but otherwise free of fossils 0.8
4. Shale, medium to dark brownish gray, calcareous, well laminated, contains *Lingula* and *Orbiculoidea* well preserved and slightly flattened 0.7

Thickness Bennett Shale Member exposed 2.5

Glenrock Limestone Member

5. Limestone, medium grayish brown, hard, aphanitic matrix for abundant fusulinids and brachiopod fragments, trace of yellow iron stain, rusty-brown weathering, single massive bed, ledge-former, undulatory base (relief 0.1) 0.9

Thickness Red Eagle Limestone exposed 3.4

Johnson Shale

6. Shale, light yellowish brown, calcareous, well laminated, compact 0.5
7. Limestone, boxwork, light yellowish brown, very clayey, randomly pitted 1.0
8. Limestone, very light gray to brownish yellowish gray, very argillaceous and silty, poorly laminated in upper 0.5 foot grading downward to massive, even textured, hard, resistant 1.0

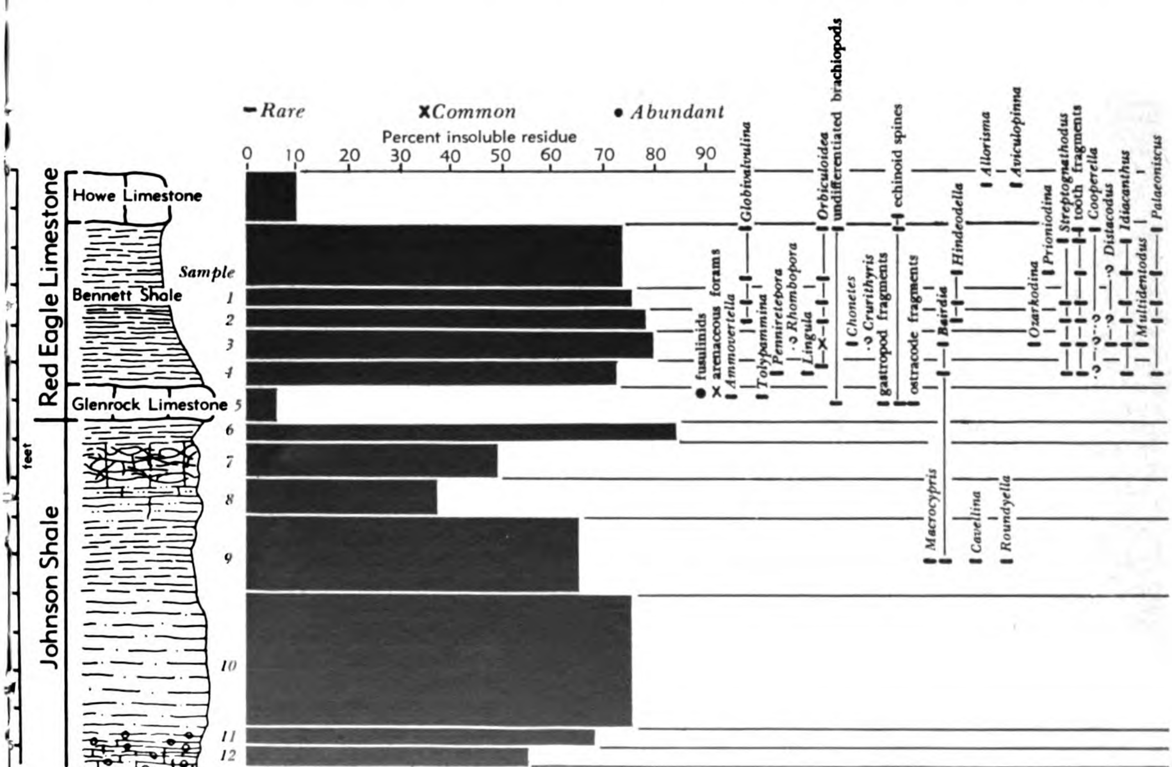


FIGURE 10.—Columnar section, insoluble residues, and fossils of the Humboldt section.

9. Shale, very light gray, very calcareous, silty, moderately to well laminated, grades downward to more resistant moderately to poorly laminated mudstone and shale 2.0
10. Mudstone, very light greenish gray with slight yellowish-brown tint, silty, calcareous, moderately to poorly laminated, fairly massive, soft 3.5
11. Shale, light greenish gray, silty, calcareous, well laminated 0.5
12. Limestone, very light greenish gray, poorly laminated, very muddy 0.5

Thickness Johnson Shale exposed 9.0

Frankfort Section.—NE NW sec. 21, T. 4 S., R. 9 E. In west side of Kansas Highway 99 road cut south of railroad, ¼ mile south of Frankfort, Marshall County, Kansas (Fig. 11).

Sample — *Thickness, feet*

Red Eagle Limestone

Howe Limestone Member

1. Limestone, medium to light brown and brownish gray, fine to microcrystalline where intact, badly decayed and pitted, much recrystallized with traces of opaline silica; lower 0.2 foot is a light-yellowish-gray, porous, soft, clayey, microcrystalline limestone with much leached-oolite type of porosity; ghosts of fossils (foraminifers, high-spired gastropods) 1.3

Bennett Shale Member

Covered 1.5

2. Shale, medium to dark gray, weathers to light brownish gray, well laminated, traces of *Orbiculoidea* fragments, rare trace of carbonaceous remains 2.0
3. Shale, medium to light brownish gray with yellowish clayey mottling, poorly to well laminated, common *Orbiculoidea* fragments, calcareous, soft 0.2

Thickness Bennett Shale Member 3.7

Glenrock Limestone Member

4. Limestone, medium to light gray and brownish gray, some limonitic yellow stain, hard, microgranular matrix for abundant fusulinids and rare brachiopods in upper 0.5 foot, rare larger brachiopods (*Composita*?), middle 0.5 foot has few fusulinids but contains common brachiopod fragments in aphanitic to microgranular light- to very light brown matrix, lower 0.7 foot similarly rich in smaller brachiopod fragments but matrix is light brown and aphanitic, several kinds of foraminifers, tiny snails and ostracodes, trace of limonite 1.8

Thickness Red Eagle Limestone 6.8

Johnson Shale

5. Shale, clayey, medium brown, moderately laminated, calcareous, traces of (plant?) carbonaceous remains, compact 0.5
6. Limestone, very light gray to brownish gray, argillaceous, varies to very calcareous mudstone, moderately laminated 1.0
7. Shale, similar to above, calcareous, occasional $CaCO_3$ seams or stringers, well laminated 1.4
8. Shale, medium brownish gray, silty, calcareous, mostly weathers to buff, well laminated, tough and brittle, ostracodes and small brachiopod fragments common, fossils oriented parallel to laminae 0.6
9. Limestone, medium to light gray, very finely silty, microgranular to microcrystalline, well laminated, platy and flaggy debris, platestone, weathers to light brownish gray 1.0
10. Shale, light yellowish gray, calcareous, moderately laminated, silty, debris somewhat blocky 1.0
11. Shale, light to medium greenish gray with rusty mottling, some shale pebble breccia with rusty-weathering granules in shale matrix, compact, calcareous 1.1
12. Shale, light greenish gray with some rusty-yellow clay mottling, well to poorly laminated, varies to mudstone, calcareous 0.9
13. Mudstone, medium to light greenish gray, vaguely laminated, blocky irregular debris 0.5
14. Shale, varies to mudstone, very light gray to greenish gray, rare trace of very fine sand grains at random, calcareous, poorly laminated 2.0

Thickness Johnson Shale exposed 10.0

Manhattan Section.—NE sec. 7, T. 10 S., R. 8 E. In west bank of road cut on Kansas Highway 13 near northeastern outskirts of Manhattan along northeast side of Bluemont Hill, Manhattan, Riley County, Kansas (Fig. 12).

Sample — *Thickness, feet*

Roca Shale

1. Shale, light greenish gray, varies to mudstone, slightly calcareous, trace of calcareous mudstone stringers 1.7
2. Shale and mudstone, light greenish gray to olive green, noncalcareous 1.5
3. Limestone, very light brownish gray, marly, argillaceous 0.5
4. Shale, light greenish gray 1.5
5. Shale and mudstone, maroon with greenish-gray mottling, slightly calcareous, compact 1.5
6. Mudstone, very light brownish gray, marly, trace of calcite crystals, soft to compact and resistant, trace of pale-greenish tint, slightly nodular 1.0
7. Shale, light greenish gray varying to maroon tint, noncalcareous 1.5
8. Shale, brick red with buff lime nodules, varies to poorly laminated mudstone, slightly calcareous 1.2
9. Shale, similar to above but lacking lime nodules 0.9
10. Mudstone, light greenish gray, compact blocky debris, minute traces of calcareous shell fragments (*Crurithyris*?), moderately laminated 0.6
11. Limestone, light brownish gray, microgranular with fine- to medium-crystalline

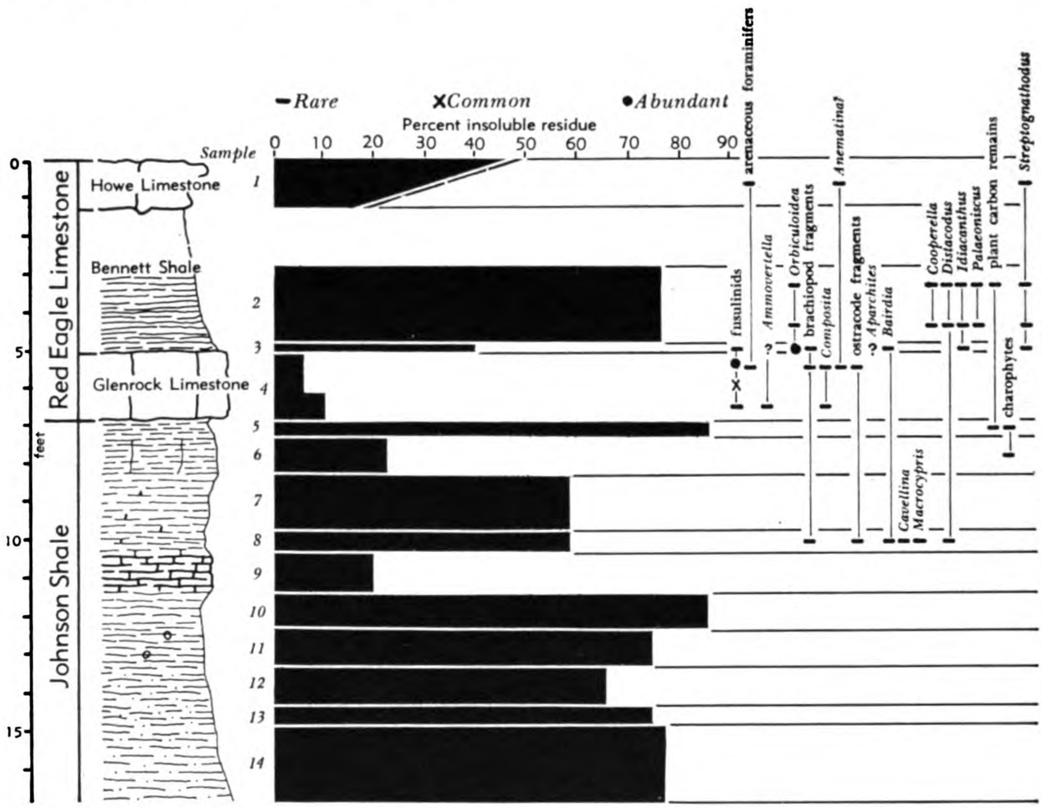


FIGURE 11.—Columnar section, insoluble residues, and fossils of the Frankfort section.

clear calcite blebs and stringers of pale-green calcareous mudstone, nodular	0.9
12. Shale, light greenish gray, calcareous, well laminated, minute nodular blebs of amorphous calcareous material	1.2
13. Shale, medium maroon to grayish maroon in lower 1.0 foot, silty, noncalcareous where compact, extremely well laminated especially in upper 1.0 foot, calcareous where color is redder and shale is softer	2.0
14. Shale and mudstone, light gray, noncalcareous, extremely well laminated within thicker more blocky units, trace of micro-cross laminations, laminae are silty	1.0
15. Mudstone, light greenish gray to grayish olive green, calcareous, chalky	0.5
16. Mudstone, light gray, calcareous, vaguely laminated, chalky to silty	1.0
Thickness Roca Shale	18.5

Red Eagle Limestone

Howe Limestone Member

17. Limestone, light yellowish brown, clayey, somewhat vuggy, massive, thick bedded, some rusty iron stain	1.5
18. Limestone, similar to above, grayish tint	1.5
19. Limestone, light brownish gray with yellowish tint, very similar to above, base grades through 0.2 foot to underlying shale	0.6
Thickness Howe Limestone Member	3.6

Bennett Shale Member

20. Shale, light gray and brownish gray with yellow and rusty mottling, moderately to well laminated, calcareous, very fossiliferous (brachiopods and spines, fish teeth?), possibly weathered from medium gray color	1.0
21. Shale, light greenish brown with rusty and gray yellowish tints, very fossiliferous (brachiopod fragments, *Derbyia*?), calcareous, well laminated, trace of fenestellate bryozoans	1.0
22. Shale, medium to light gray (probably weathered from dark gray), possible *Lingula*? molds, calcareous, moderately laminated, slightly silty, compact, somewhat wafery	1.0
23. Shale, medium to dark gray, moderately laminated, brachiopod fragments (*Composita*?), calcareous	1.2
Thickness Bennett Shale Member	4.2

Glenrock Limestone Member

24-25. Limestone, medium to light gray and brownish gray, granule breccia, fragments

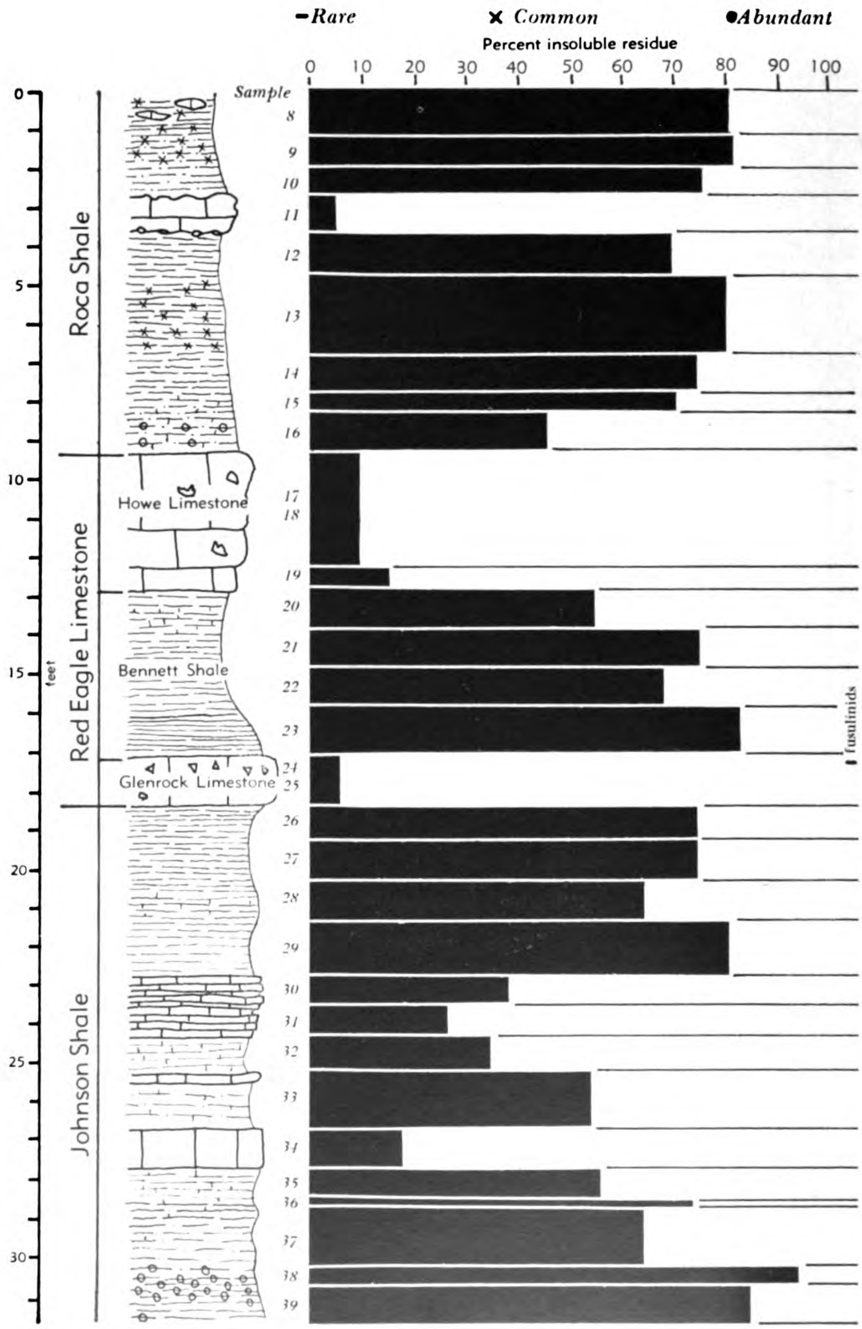
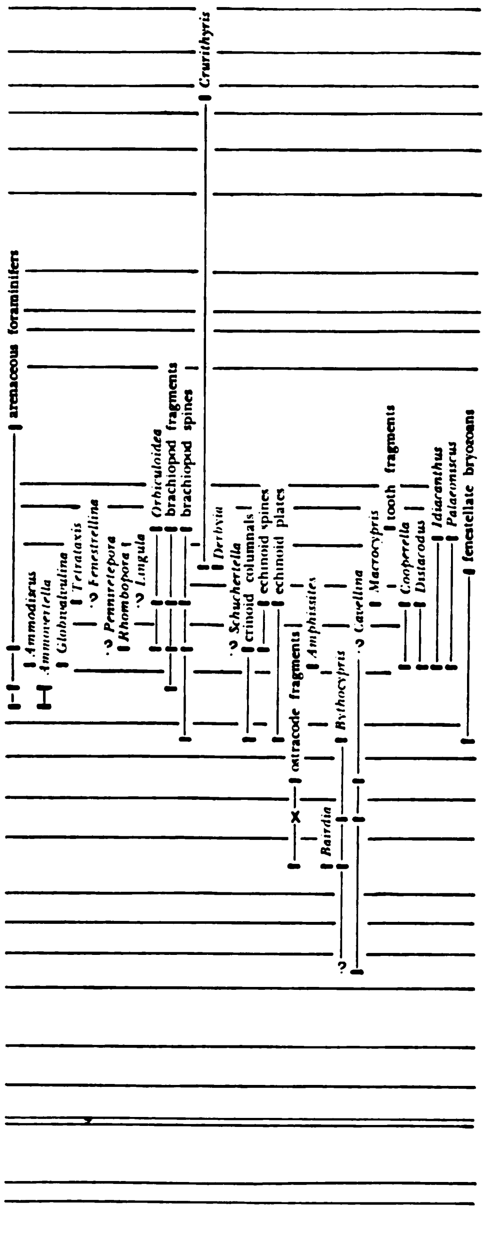


FIGURE 12.—Columnar section, insoluble residues, and fossils of the Manhattan section.

of aphanitic limestone in microcrystalline and calcarenitic matrix containing trace of foraminifers and brachiopod fragments, similar to Paxico section but slightly more conglomeratic near base 1.3

Thickness Red Eagle Limestone 9.1



Johnson Shale

26. Shale, medium to light gray, weathers to light brownish gray, well laminated, calcareous, some laminae are dark gray 0.9
27. Shale, medium to slaty gray, weathers to light gray, well laminated, frail ostracodes along some laminae, calcareous 1.0
28. Shale, light brownish gray, probably weathered from medium gray, common ostracodes especially along some laminae, trace of mud-crack fillings and possibly subtle ripple marks, slightly resistant 1.0
29. Shale, medium slaty gray, weathers buff, well laminated, compact, wafery, minute frail ostracodes along laminae appear as white flecks, slightly calcareous 1.5
30. Limestone, medium to light gray, weathers buff, aphanitic, moderately to well laminated, platestone, compact, muddy 0.7
31. Limestone, similar to above but laminated within thicker more flaggy units, muddy .. 0.8
32. Marl, very light grayish brown, probably weathered from darker gray, moderately laminated, very argillaceous 0.9
33. Mudstone, light to very light brownish gray, well to moderately laminated, slightly wavy laminae, top has a light-rusty-brown to gray-brown irregular argillaceous limestone 0.1 foot thick 1.5
34. Limestone, light brownish gray, grades to shale above and below, aphanitic with traces of microcrystalline to medium crystals of clear calcite, hard 1.0
35. Shale, light gray, calcareous, compact 0.7
36. Shale, very light gray with some greenish tint, chalky, laminated 0.2
37. Shale and mudstone, medium gray in upper 0.5 foot grading to light gray in lower 1.0 foot, calcareous, moderately laminated 1.5
38. Shale, light grayish green, compact, noncalcareous, moderately laminated 0.5
39. Shale, similar to above, slightly calcareous 1.6
40. Limestone, light greenish gray, wavy laminae, argillaceous, varies to calcareous mudstone 1.2
41. Shale, medium to light gray with slight greenish tint, moderately laminated, calcareous 1.2
42. Shale, light grayish green, varies to light greenish gray and gray, clayey at top, muddy downward, minute grains of tan calcareous material in upper 0.4 foot 1.0
43. Shale, medium to light gray, muddy, slightly calcareous 0.6

Thickness Johnson Shale 17.8

Paxico Section.—SW sec. 30, T. 11 S., R. 12 E. North side of abandoned U.S. Highway 40 road cut, in crest of hill, Wabaunsee County, Kansas (Fig. 13).

Sample	Thickness, feet
Red Eagle Limestone	
Howe Limestone Member	
1. Limestone, light gray and brownish gray, pitted, decayed and vuggy, random blebs of secondary opaline silica, vugs contain yellowish clay, mainly medium to finely crystalline pure to argillaceous matrix, hard	0.3
2. Limestone, light brownish gray, clayey, soft, very badly decayed, vague ghosts of pseudo-oolites and possibly ostracodes and foraminifers	0.7
3. Limestone, similar to above but slightly harder and with clearer ghosts of pseudo-oolites, rare high-spired gastropods, pelecypod casts in argillaceous fine-grained limestone, poorly preserved brachiopods, trace of iron oxides	0.7
Thickness Howe Limestone Member	1.7
Bennett Shale Member	
4. Limestone, very light gray to brownish gray, minute flecks of yellowish clay and dark-brown shell material with possible very fine silt, compact, pitted in places, unfossiliferous	0.9
5. Limestone, varies to calcilutite, light yellowish gray, very fine grained, argillaceous, vague trace of lirate costate brachiopods (possibly *Derbyia*)	0.5
6. Limestone, similar to 3 and 4 but lacking flecks, trace of secondary chert, trace of brown cutaneous shell fragments (*Orbiculoidea*?)	1.0
7. Limestone, light brownish gray, muddy, vague lirate brachiopod molds, very slightly calcareous, occasional small vugs and yellowish clay, possibly finely silty	2.0
8. Limestone, argillaceous to finely silty, microcrystalline, compact, rare trace of brown *Orbiculoidea* fragments, trace milky chert	1.5
9. Shale, very dark gray, weathers buff, well laminated, trace of *Orbiculoidea* fragments	2.0
10. Shale, buff, weathered from dark gray, well laminated, *Orbiculoidea* fragments common, ¼-inch *Orbiculoidea* coquina along some laminae, trace of *Lingula*, fragments randomly oriented but somewhat compressed parallel to bedding plane	0.5
Thickness Bennett Shale Member	8.4
Glenrock Limestone Member	
11. Limestone, medium brownish gray to brown with some yellowish-rusty iron stain, weathered light brownish gray at top, fusulinids sparse in upper 0.5 foot, trace of brachiopod fragments and spines, *Crurithyris* at top, hard, ghosts of fossils (vague foraminifers?); lower 0.5 foot is granule breccia of light-brownish-gray aphanitic limestone fragments and fossil remains (e.g., brachiopods, fusulinids, ostracodes, brachiopod spines, bryozoans, tiny spired gastropods) in light-creamy-gray aphanitic matrix, fossils oriented vaguely parallel to bedding plane	2.0
Thickness Red Eagle Limestone	12.1
Johnson Shale	
12. Shale, dark to medium gray, weathered to mottling of light gray buff, well laminated, somewhat flakey, clayey, slightly calcareous	0.9
13. Shale, dark to medium gray, weathered to mottling of light gray, similar to above, slightly calcareous	1.0
14. Shale, dark to medium gray, weathered to light brownish gray, well laminated, flaky, rare trace of carbonaceous? remains, trace of delicate ostracode fragments along laminae, slightly calcareous	1.0
15. Mudstone, very light brownish gray, calcareous, argillaceous, varies to calcareous poorly laminated mudstone and shale	1.2
16. Shale, medium gray, weathered to light yellowish gray, calcareous, laminated varying to poorly laminated mudstone	1.0
17. Mudstone, medium to light brownish gray, calcareous, poorly to moderately laminated with some shale as in above	1.2
18. Siltstone, medium to light brown and grayish brown, argillaceous, calcareous, well laminated; varies to very finely silty shale, calcareous, well laminated, brittle waferlike debris	1.1
19. Siltstone (or calcisiltite), medium to light brownish gray, hard, well laminated, calcareous, weathered to platy debris, platestone	2.1
20. Mudstone, very light greenish gray, calcareous	1.5
Covered	14.0
Thickness Johnson Shale	25.0

Alma Section.—SW NE sec. 11, T. 12 S., R. 10 E. In east bank of Mill Creek, north of bridge, Wabaunsee County, Kansas.

Sample	Thickness, feet
Grenola Limestone	
Sallyards Limestone Member	
1. Limestone, very light gray, silty to chalky, porous, spongy, grades upward to calcareous wavy-bedded shale, irregular rubbly weathering, *Pseudomonotis*	1.5
Roca Shale	
2. Shale, light greenish gray, slightly silty, varies to mudstone, moderately to poorly laminated, calcareous, compact, arenaceous foraminifers	0.9
3. Shale, similar to above	0.9
4. Shale, maroon, varies to mudstone, poorly to moderately laminated, very slightly calcareous	1.2
5. Shale, medium to light gray and brownish gray, calcareous, moderately to well laminated, somewhat blocky debris	1.0
6. Shale, similar to above	0.8
7. Shale, similar to above, well laminated, watery debris, random lenticular nodules	

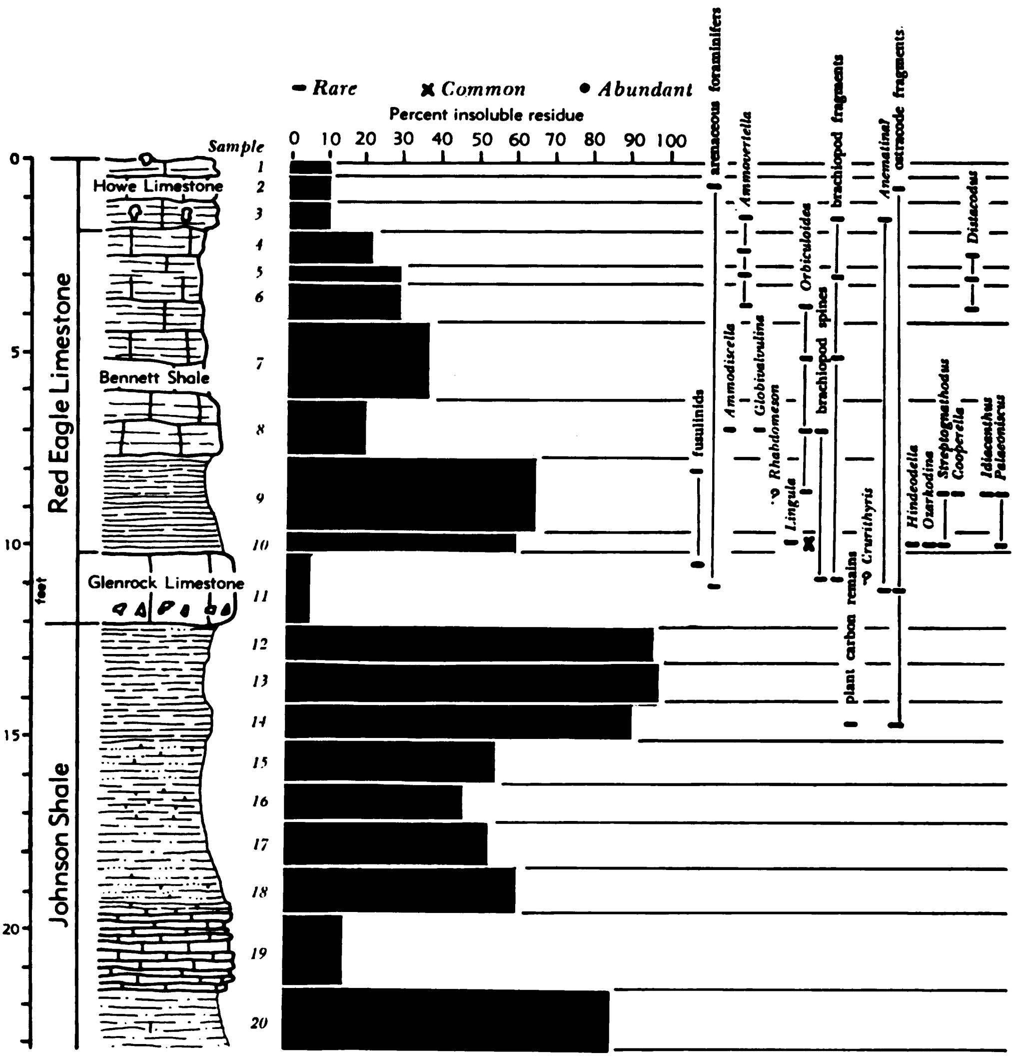


FIGURE 13.—Columnar section, insoluble residues, and fossils of the Paxico section.

of medium-gray fine-granular to microcrystalline slightly argillaceous limestone .. 0.6

8. Shale, medium gray, silty, contains traces of black carbonaceous remains, calcareous, well laminated 0.8
9. Shale, medium to light gray, finely silty, well laminated, varies in some places to poorly laminated mudstone, calcareous, ripple marks suspected 1.0
10. Limestone (calcisiltite), light to very light gray and brownish gray, very finely silty to clayey, varies to mudstone, slightly calcareous, a few vugs, even textured 0.9
11. Limestone, very light brownish gray, similar to above, some vague laminae within thicker beds, very finely silty to clayey, varies to mudstone 1.0
12. Shale, light greenish gray, moderately to poorly laminated, varies to mudstone, noncalcareous to slightly calcareous 1.0

Thickness Roca Shale 10.1

Red Eagle Limestone

Howe Limestone Member

13. Limestone, light gray to very light yellowish gray, argillaceous, pitted, weathers yellowish chalky gray 0.7
14. Limestone, medium to light brownish gray, pseudo-oolitic (osagite), microcrystalline matrix, rare small vugs 0.5
15. Limestone, very light gray mottled with very light yellowish-gray clayey material, flecks of brown-rusty clay throughout,

microgranular to microcrystalline, trace of ghosts of oolites 0.4

Thickness Howe Limestone Member 1.6

Bennett Shale Member

16. Siltstone, light gray with brown flecks as above, calcisiltite varying to calcareous mudstone 1.2
Covered 17.8

Thickness Bennett Shale Member, as much as 19.0

Thickness Red Eagle Limestone, as much as 20.6

Johnson Shale

17. Shale, dark gray to light brown where weathered, similar to below but ostracodes are less obvious, slightly calcareous 0.5
18. Shale, dark gray, very well laminated to very fissile, calcareous, rare to common ostracodes cf. *Bairdia* along laminae, very rare trace of fish teeth?, rare carbonaceous remains, some laminae are covered almost entirely by ostracodes in a fine-grained calcareous matrix 0.5
19. Shale, very light brownish gray, calcareous, moderately to well laminated, slightly silty to argillaceous, varies to claystone, rare trace of $CaCO_3$ grains of silt size, ostracode? shell fragments 0.5
20. Limestone, very light brownish gray, microgranular, even textured, trace of silt, similar to below but slightly softer and not laminated 0.5
21. Limestone, very light brownish gray, microgranular, trace of silt, believed to be a weathered variety of below, well laminated, platy 0.5
22. Limestone, medium gray, microcrystalline to microgranular, brittle, hard; very thin bedded to laminated, platy, or slightly argillaceous platestone 0.6
Covered 6.9

Thickness Johnson Shale, estimated 10.0

Foraker Limestone

Long Creek Limestone Member

23. Limestone, light brown and gray, pitted, microgranular to microcrystalline, argillaceous, weathers to light yellowish gray brown 3.0

Keene Section.—SE sec. 24, T. 13 S., R. 12 E. In bank of stream north of small bridge on east-west road, Wabaunsee County, Kansas.

Sample *Thickness, feet*

Red Eagle Limestone

Glenrock Limestone Member

1. Limestone, very light brownish gray with some yellowish clayey iron oxides, hard, compact, aphanitic matrix for abundant fusulinids and common brachiopod fragments and smaller foraminifers, top exposed and weathered but change to darker gray at top suggests similarity to Pawnee section, top lumpy with dark gray in the lows between lumps 1.2

Johnson Shale

Covered 5.0
2. Limestone, medium brownish gray, very hard, very even textured, moderately to well laminated, platy to flaggy, argillaceous?, unfossiliferous, platestone varies to flagstone 1.0
Covered interval, not measured ....
Shale, greenish gray, calcareous, moderately to well laminated, badly slumped, mostly covered, seen in random patches on slopes ½ mile north of above ....

Eskridge Section.—SE NE sec. 17, T. 14 S., R. 12 E. In south bank of small creek just west of Kansas Highway 99, Wabaunsee County, Kansas (Fig. 14).

Sample *Thickness, feet*

Red Eagle Limestone

Glenrock Limestone Member

1. Limestone, light brownish gray, microgranular matrix for common to abundant fusulinids and a few foraminifers and brachiopod fragments, top 0 to 1 inch is coquinoid fusulinid limestone with trace of shaly material (as in Bennett) and *Orbiculoidea* fragments in a slightly argillaceous matrix 0.9

Johnson Shale

Covered 1.5
2. Shale (slumped), varies to mudstone, buff, poorly to moderately laminated, even textured 1.0
3. Shale, buff, probably weathered from medium gray, well laminated, waferlike, calcareous 0.6
4. Limestone, medium gray, weathered buff, argillaceous to silty, well laminated, compact, platestone, minute textural differences from layer to layer, trace of very shallow channelling (1-2 mm), trace of fucoids, vague ripple marks 0.6
5. Limestone, medium gray weathered medium buff, argillaceous to silty, vague rare laminae, essentially a massive unit 0.5
6. Shale, medium to light brownish gray, very finely silty, calcareous, rare trace of carbonaceous remains up to ¼ inch, well laminated, flaky to waferlike debris, laminations are slightly undulatory 1.0
7. Shale, light greenish gray, moderately to poorly laminated, varies to mudstone yielding blocky debris, noncalcareous 1.0
8. Shale and mudstone, very calcareous, very light to light brownish gray, moderately to poorly laminated 1.0
9. Mudstone, light greenish gray, calcareous, poorly laminated, varies to shale 2.0
10. Shale, light gray with greenish tint, calcareous, moderately to well laminated 1.0
11. Shale, medium to light gray and greenish gray, calcareous, varies to argillaceous

limestone and mudstone of same color, trace of carbonaceous remains, some silt, vague tubes and blebs of greenish clayey material 1.0

12. Shale and mudstone, light greenish gray, calcareous, moderately to rarely laminated, trace of silt 1.0

Thickness Johnson Shale exposed 12.2

Eskridge Quarry Section—NW sec. 32, T. 14 S., R. 12 E. In large quarry ⅞ mile west of Kansas Highway 99. Large spoil heap can be seen for several miles. Wabaunsee County, Kansas (Fig. 15).

Sample *Thickness, feet*

Red Eagle Limestone

Bennett Shale Member

1. Limestone, light greenish gray, argillaceous to pure crystalline, weathered to light yellowish brown, aphanitic to medium crystalline and coarsely (clear) crystalline where recrystallized, uneven rubbly bedding 3 inches, rough debris, trace of stylolites, very fossiliferous; common crinoid columnals with fragments of productid brachiopods, echinoid spines, ostracodes, and chambered foraminifers in crystalline and greenish-gray lime matrix .. 1.0
2. Limestone, similar to above with slightly fewer fossils, crinoid debris common 1.0
3. Limestone, as above but with more aphanitic matrix for fewer fossils, brachiopod fragments common, *Crurithyris*? seen essentially undamaged 1.0
4. Limestone, light brownish gray, weathered light rusty gray, massive, medium to thick beds, hard, aphanitic to microcrystalline matrix for abundant fossil detritus, brachiopods, foraminifers, crinoid discs, spines, some clear medium to coarse calcite crystals, somewhat wavy irregular bedding planes, very rare greenish-gray clayey limestone in random wisps 1.0
5. Limestone, light brownish gray, some microvugular pores, aphanitic matrix for common fossil detritus as above, trace foraminifers, *Tolypammina*? 1.0
6. Limestone, as above, some vugular porous development in association with solution of fossils 1.0
7. Limestone, light brownish gray, aphanitic matrix for rare fossil detritus as above, random microvugular pores, trace of stylolites, thick massive beds, hard 1.0
8. Limestone, as above with slightly more crystalline calcite fossil detritus, some vugs 1.0
9. Limestone, light brownish gray, aphanitic to microcrystalline matrix for rare fossil detritus as above, trace of stylolites 1.0
10. Limestone, as above, with crinoid discs, medium to thick massive beds 1.0
11. Limestone, as above with vugs and common clear calcite crystalline fossil detritus 1.0
12. Limestone, as above with large vugs, some vugs border on calcite-lined geodes, trace of stylolites 1.0
13. Limestone, as above; exposed above water 1.0

Thickness Bennett Shale Member exposed 13.0

Thickness Red Eagle Limestone exposed 13.0

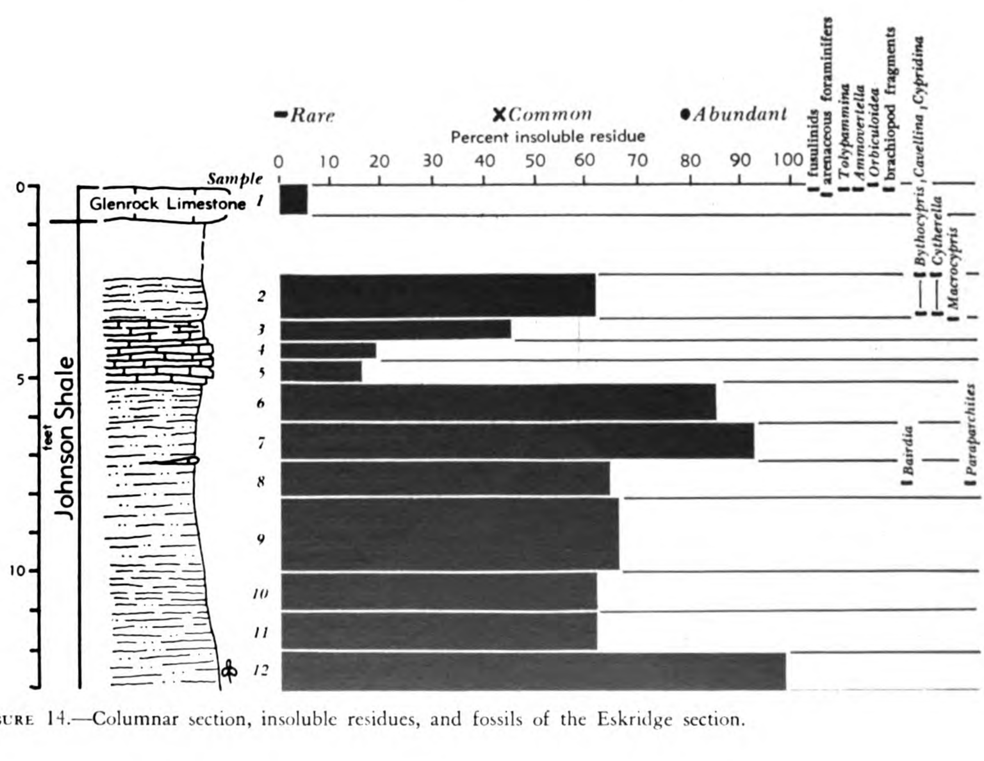


FIGURE 14.—Columnar section, insoluble residues, and fossils of the Eskridge section.

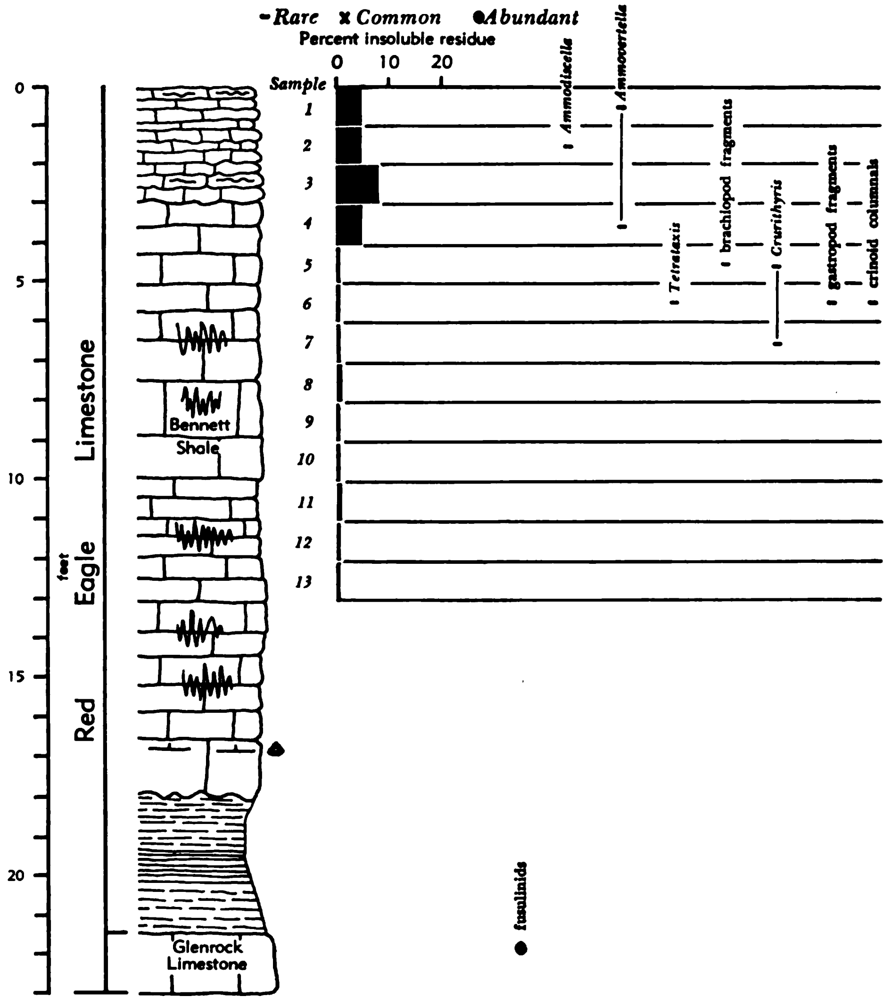


FIGURE 15.—Columnar section, insoluble residues, and fossils of the Eskridge Quarry section.

Eskridge South Section.—NE sec. 6, T. 15 S., R. 12 E. On northeast side of road leading into farmyard, Wabaunsee County, Kansas.

Sample	*Thickness, feet*
Red Eagle Limestone	
Glenrock Limestone Member	
1. Limestone, light grayish brown, aphanitic matrix for abundant fusulinids with rare brachiopod fragments and other foraminifers, upper ½ inch argillaceous with patches of dark-gray shaly material, clusters of fusulinids at top form coquina with trace to rare *Orbiculoidea* and bryozoan fragments and yellow weathered clay in matrix, top gently undulatory, weathered, lower 0.3 feet has fewer fossils	0.8
Johnson Shale	
Covered	5.0
2. Shale, buff, weathered from dark gray, well laminated, calcareous, frail plain ostracodes and delicate plant remains along laminae, compact, flaky to waferlike	1.0
3. Siltstone, varies to mudstone, light yellowish to brownish gray, calcareous, moderately to well laminated	1.0
4. Limestone, light yellowish to brownish gray, very muddy, well laminated within medium to thin beds, resistant	3.0
Covered	2.5
5. Limestone, light yellowish to brownish gray, weathered from medium gray, muddy, well laminated, platy to flaggy, very evenly laminated and even textured between laminae	0.7
6. Limestone, similar to above but poorly laminated, even textured	0.8
7. Mudstone and shale, moderately to well laminated, light greenish gray with some yellowish tint, slightly to moderately cal-	

careous, possibly weathered from darker shale or mudstone 1.0

Thickness Johnson Shale exposed 15.0

Judith Section.—NW NW sec. 7, T. 15 S., R. 12 E. In east gutter of road up hillside, Wabaunsee County, Kansas.

Sample	Thickness, feet
Red Eagle Limestone	
Bennett Shale Member	
Limestone, not sampled, very similar to Eskridge Quarry	16.0
1. Limestone, medium to light brownish gray, microgranular, slightly argillaceous matrix for common *Orbiculoidea* debris (some almost intact), trace of spines, crinoid discs, brachiopods, foraminifers	0.5
2. Limestone, medium to light gray and brownish gray, microgranular, somewhat argillaceous matrix for common *Orbiculoidea* fragments, trace of fish teeth, thin to medium bedded, massive, base of resistant cliff-forming unit	0.5
3. Shale and mudstone, medium brownish gray, weathered from dark gray, calcareous, *Orbiculoidea* nearly intact but flattened	0.5
4. Shale, dark gray, weathered buff, moderately to well laminated, trace of *Orbiculoidea* fragments, slightly calcareous	1.0
5. Shale, dark gray, weathered buff, poorly to well laminated varying to fissile, *Orbiculoidea* commonly preserved nearly intact or as debris, trace of *Lingula*, rare trace of carbonaceous remains, calcite crystals along some laminae	0.5
6. Shale, dark gray, weathered medium brownish gray, very well laminated, fissile, flaky to waferlike, calcareous, rare trace of *Orbiculoidea* and *Lingula*? fragments, compact	0.5
7. Shale, dark gray, fissile, waferlike, varies to crudely laminated mudstone in places, trace of minute *Orbiculoidea* fragments possibly reworked from base, rare trace of conodonts and fish teeth, weathered buff, compact, brittle and tough, slightly calcareous	1.0
Thickness Bennett Shale Member	20.5
Glenrock Limestone Member	
8. Limestone, light brownish gray, massive, matrix weathered faint light yellowish gray in places, microgranular to aphanitic matrix for abundant fusulinids throughout, trace of foraminifers, brachiopods, ostracodes, top grades through ½ inch of medium- to light-brown shale and argillaceous limestone with abundant *Orbiculoidea* and rare brachiopods (*Lingula*?, *Crurithyris*?) and fish teeth	0.9
Thickness Red Eagle Limestone	21.4

Coffman Ranch Section.—S/2 NW sec. 23, T. 15 S., R. 11 E. In quarry and along creek bank on Coffman Ranch property, Lyon County, Kansas (Fig. 16).

Sample	Thickness, feet
Red Eagle Limestone	
Howe Limestone Member	
Limestone, light brownish gray and grayish brown, typical fine osagite, foraminifers common, rare large bellerophontid gastropods and straight nautiloid cephalopods near top, undulatory lower contact, weathers light rusty brown along joints, light- to medium-gray weathering in exposed hillside benches, some deep surficial pitting in field exposures	5 to 6
Bennett Shale Member	
1. Limestone, light gray to light brownish gray, aphanitic with some clear fine to coarse calcite crystals at random, stringers of greenish clay, trace of crinoid discs and brachiopod fragments and fenestrate bryozoans, nodular bedding planes, rubbly debris, medium to thin bedded, some silicified fossils	6.5
2. Limestone, light brownish gray, aphanitic to microcrystalline with crystalline calcite fossil remains, crinoid discs, productid spines, foraminifers, hard, compact, massive unit with irregular boundaries	0.5 to 1.0
3. Limestone, similar to 1 but more greenish clay associated with stylolites, greenish clay interbedded material	1.0
4. Limestone, similar to 1 but less green clay	1.0
5. Limestone, light gray to greenish gray and brownish gray, aphanitic matrix for common fossils (intact crinoid columnals, brachiopods, fenestrate and ramose bryozoans, and foraminifers), some fossils especially brachiopods replaced by milky opaline silica, similar to above	1.0
6. Limestone, light gray to greenish gray, aphanitic matrix, some parts fossiliferous, crystalline, light brownish gray, brachiopods, echinoid and productid spines, brachiopod fragments, rubbly, thin bedded, hard, some fossils silicified	0.5
7. Limestone, similar to above, secondary calcite stringers and aphanitic brachiopod fillings produce pseudobrecciated appearance in some places	0.5
8. Limestone, light brownish gray, aphanitic to medium crystalline, similar to above, very fossiliferous, crinoid columnals abundant (articulated), fragments of branching structureless algal? material, fenestellate and ramose bryozoans, spines as above, weathered light gray	0.5
9. Limestone, light brownish gray with some faintly rusty yellow tint, medium to thick bedded, hard, massive; aphanitic to microcrystalline matrix for common fossil detritus ranging from normal sizes of crinoid discs (mainly disarticulated) and brachiopods to minute microscopic debris of great variety including bryozoans, ostracodes, foraminifers, ?rare trace *Orbiculoidea* fragments	2.0
10. Limestone, matrix similar to above, randomly vuggy, trace of white opaline-replaced brachiopod shells, few megafossils	2.0

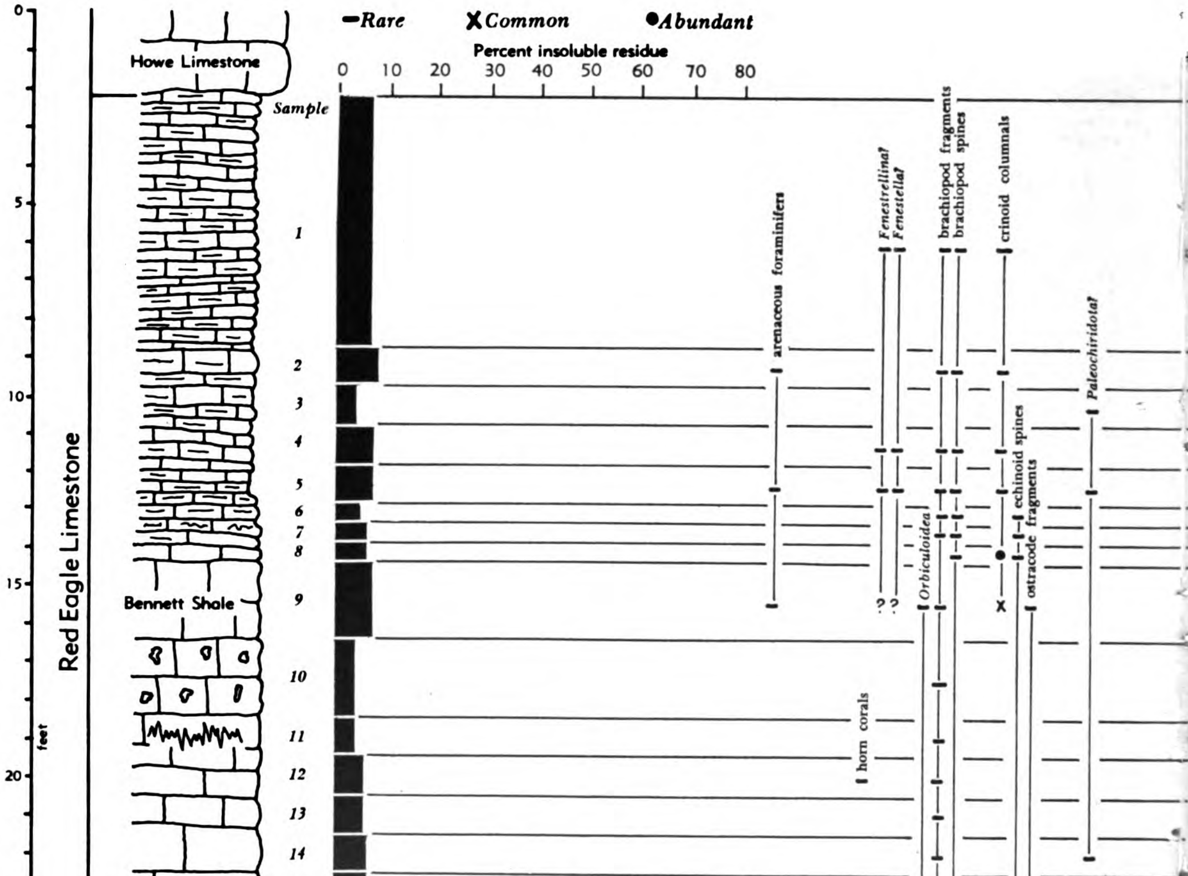


FIGURE 16.—Columnar section, insoluble residues, and fossils of the Coffman Ranch section.

11. Limestone, similar to above, columnar stylolites up to 2 inches 1.0
12. Limestone, similar to above, light brownish gray, aphanitic matrix for rare medium crystals of calcite and common small nodules, horn corals rare, hard 1.0
13. Limestone, similar to above, a few small vugs, harder than below (possibly owing to less clay) 1.0
14. Limestone, similar to above, medium bedded, vugs developing at solution cavities associated with interiors of articulated brachiopod shells 1.0
15. Limestone, similar to above, stylolites 1.0
16. Limestone, similar to above, trace of rusty yellow stain at weathered surface, rare trace of *Orbiculoidea* fragments 1.0
17. Limestone, similar to above 1.0
18. Limestone, similar to above, seems more clayey, abundant microfossils 1.0
19. Limestone, similar to above, rare trace of *Orbiculoidea*, fish tooth seen 0.5
20. Limestone, similar to above, microfossil debris abundant, productid and echinoid spines, trace of *Orbiculoidea* fragments seen 0.5
21. Shale, dark gray to medium brownish gray, well laminated, calcareous, *Orbiculoidea* fragments common, rare trace of frail *Lingula*? fragments, some *Orbiculoidea* well preserved but flattened (apical one-third seems to resist flattening), intact specimens in place?, minute flecks of black carbonaceous matter, conodonts, trace of calcareous nodules or lenticles in upper 0.5 foot 1.0
22. Shale, similar to above, some weathered to light brownish gray, softer than below, moderately to well laminated, some microgeodes, interlaminated with below through 1 inch 0.5
23. Shale, black to dark gray, compact, brittle, much harder than above, very slightly calcareous but calcareous where weathered to medium to light brownish gray and along slightly silty laminae of same color, not visibly fossiliferous 0.5

Thickness Bennett Shale Member 27.0

Glenrock Limestone Member

24. Limestone, medium brownish gray, massive, moderately hard, aphanitic matrix for profuse fusulinids (almost a fusulinid coquina in places), common small brachiopods, foraminifers, spines; evidence of worm tubes composed of medium-gray clayey material from Bennett above and containing *Orbiculoidea* fragments to the bottoms of the tubes, no tubes reach the base of this limestone; at top lithology changes through less than ⅛ inch from fusulinid subcoquina to *Orbiculoidea* subcoquina and thence upward to dark-gray *Orbiculoidea*-bearing shale of the Bennett, lower ¼ inch of shale contains rare fusulinids (probably detrital), fossils here show crude orientation parallel to bedding plane; base gently undulatory through 1 inch 0.4

Thickness Red Eagle Limestone 33.4

Johnson Shale

25. Shale, light yellowish gray brown, well laminated, trace of carbonaceous plant remains and greenish-gray and dark-gray shale granules in calcareous clay matrix, weathered light grayish yellow 0.5
26. Shale, light brownish gray, trace of rusty yellow tint, well laminated, probably weathered from medium gray, slightly silty, trace of carbonaceous plant remains, rare trace of frail ostracodes associated with medium-gray shale remnants, calcareous 0.5
27. Shale, light brownish gray, probably weathered from medium to dark gray, frail ostracodes common along laminae and abundant in thin laminar beds, well laminated, slightly silty, calcareous, rare trace of carbonaceous plant remains 1.0
28. Shale, medium to light brownish gray, well laminated, calcareous, vague but abundant frail ostracodes as above 1.0
29. Shale, light brownish gray, well laminated, probably weathered from medium gray, similar to above, rare trace of carbonaceous remains and ostracodes 1.0
30. Limestone, very argillaceous (possibly calcimudite), microgranular, massive, vaguely laminated, rare trace of black carbonaceous remains, microgeodes 3.0
31. Limestone, similar to above, light brownish gray, very argillaceous, well laminated, not visibly fossiliferous 0.5

Thickness Johnson Shale exposed 7.5

Allen Section.—NW SW sec. 36, T. 15 S., R. 11 E. In south cut bank of small stream east of bridge on north-south county road, Lyon County, Kansas (Fig. 17).

Sample *Thickness, feet*

Red Eagle Limestone

Bennett Shale Member

1. Limestone, medium to light gray, moderately laminated, muddy and shaly, slightly silty, trace of spine fragments and minute brown phosphatic remains (*Orbiculoidea* fragments) 1.0
2. Limestone, medium to light gray, shaly, trace of brown *Orbiculoidea* fragments, spine remains, more massive in upper 0.5 foot, common crinoid stems intact 1.3
3. Limestone, similar to above with spines and rare horn corals, trace of opaline creamy chert, trace of MnO_2 .... 0.7
4. Limestone, light gray with faint brownish tint, weathered light yellow gray, aphanitic, light- and medium-gray secondary opaline and porcellaneous chert nodules and silicified fossil fragments, *Linoproductus*, *Dictyoclostus* and other brachiopod fragments and spines, rare trace of fusulinids and ostracodes and crinoid discs, trace of *Orbiculoidea* fragments, some fusulinids in chert (cf. *Triticites rockensis*) 1.0

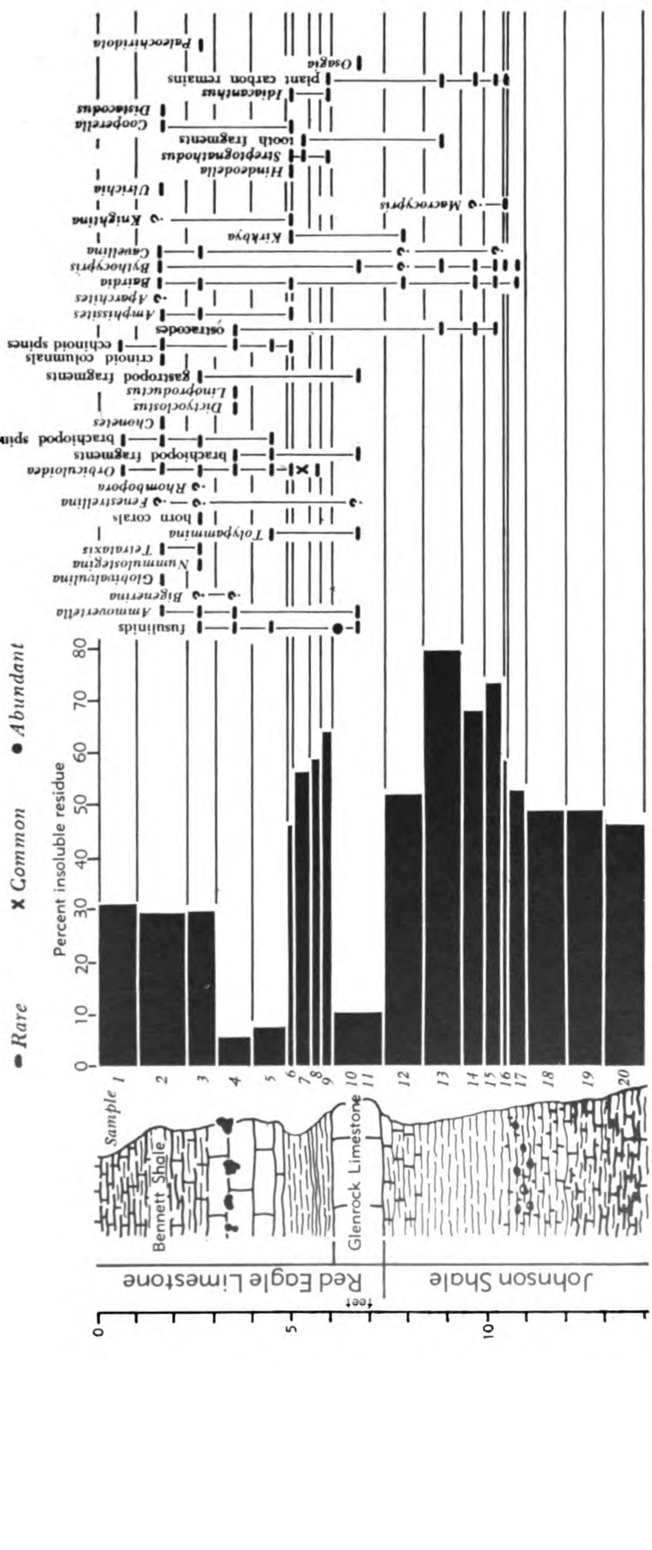


FIGURE 17.—Columnar section, insoluble residues, and fossils of the Allen section.

5. Limestone, similar to above, common *Orbiculoidea* and trace of other brachiopod fragments and spines most obvious, some fossils silicified, some parts contain abundant *Orbiculoidea* fragments, very rare fusulinids 0.9
6. Shale, medium to light gray brown, clayey, calcareous, common *Orbiculoidea* fragments (some parts subcoquinoid), moderately laminated 0.05
7. Shale, medium to light brownish gray, clayey to very finely silty, calcareous, well laminated, trace of *Orbiculoidea* fragments 0.5
8. Shale, dark gray, calcareous, well laminated, soft, fissile 0.3
9. Shale, medium grayish brown, well laminated, calcareous 0.3

Thickness Bennett Shale Member exposed 6.05

Glenrock Limestone Member

10-11. Limestone, light brownish gray; microcrystalline matrix for abundant fossil detritus including fusulinids, foraminifers (cf. *Tolypammina*), brachiopod fragments, ostracodes, and algally coated brachiopod fragments; fossils oriented roughly parallel to bedding, top has high-spired gastropods and algal blebs, a single massive unit, fragments of aphanitic limestone material give rare brecciation effect in lower 0.6 foot, fusulinids rare to absent in lower part of unit 1.3

Thickness Red Eagle Limestone exposed 7.35

Johnson Shale

12. Shale and mudstone, light yellowish gray, probably weathered from medium gray, vaguely laminated, calcareous, chalky 1.0
13. Shale, medium to light grayish brown, weathered from medium gray, well laminated, soft to compact, calcareous, frail white ostracodes along laminae, rare trace of carbonaceous (plant?) remains and fish teeth 1.0
14. Shale, light brownish gray, calcareous, well laminated, common fragmental carbonaceous plant remains along laminae with frail ostracodes 0.5
15. Shale, medium brownish gray, weathered from dark gray, calcareous, well laminated, frail small ostracodes, mostly broken along laminae, finely divided black carbonaceous remains 0.5
16. Shale, medium to light brownish gray, similar to above with rare plant remains along some laminae 0.1
17. Shale, medium to light greenish gray with some yellowish tint, calcareous, lacks plant remains 0.5
18. Shale, light yellowish to brownish gray, well laminated, compact, harder than above, very calcareous 1.0
19. Limestone, very light brownish gray, argillaceous, aphanitic, massive with vague papery laminae, vague ripple marks near top 1.0
20. Limestone, similar to above but harder and more resistant, vaguely laminated 1.0

Thickness Johnson Shale exposed 6.6

Allen No. 2 Section.—SW NW sec. 35, T. 15 S., R. 11 E. Beside bridge on north-south county road, Lyon County, Kansas (Fig. 18).

Sample — *Thickness, feet*

Roca Shale

1. Limestone, light gray with brownish tint, aphanitic, hard, dense, rare clear calcite crystals at random 0.7
2. Shale, medium to light greenish gray, calcareous, well laminated, soft to moderately compact, slightly silty, subtle green-gray and buff intralaminations 0.5
3. Shale and mudstone, medium to light greenish gray, noncalcareous, grades upward into above 1.0

Thickness Roca Shale exposed 2.2

Red Eagle Limestone

Howe Limestone Member

4. Limestone, in algal buns topped and surrounded by greenish mudstone as above, osagitic, tan oolites and pseudo-oolites in green clay (with some $CaCO_3$) matrix, some portions foraminiferal with tan aphanitic to microcrystalline matrix and vague to well-defined concentric laminar structure forming the buns, some small high-spired gastropods seen, one nautiloid cephalopod found beneath a bun 0.2
5. Limestone, light brownish gray, foraminiferal and pseudo-oolitic with some tiny gastropods as above, matrix medium to aphanitic tan $CaCO_3$, some leached oolite porosity, hard 1.0
6. Limestone, transition between above and below, some medium vugs 1.0
7. Limestone, light brownish gray with greenish-gray clay seams, vugs, microcrystalline to medium-crystalline matrix for abundant crystalline fossil fragments, brachiopods, foraminifers, spines 0.5
8. Limestone, similar to above, richly fossiliferous, brachiopods, crinoid discs, spines, rare gastropods, rare fenestellate bryozoans, rare ostracodes, trace of milky opaline chert 0.5

Thickness Howe Limestone Member 3.2

Bennett Shale Member

9. Limestone, light gray, argillaceous, poorly laminated, varies to calcareous mudstone, trace of brachiopods, ostracodes, spines 1.0
Covered 1.0
10. Shale, light gray with pale-green cast, possibly weathered from medium gray, calcareous, rare trace of fish teeth?, ostracodes, *Orbiculoidea*, well laminated 1.0
11. Shale, light brownish gray, calcareous, well laminated, trace of *Orbiculoidea*, ostracodes, brachiopod fragments 1.0
12. Shale, medium gray, weathered buff, calcareous, well laminated, trace of ostracodes, brachiopod fragments, trace of spines, grades to below 0.5
13. Limestone, medium to light gray, very

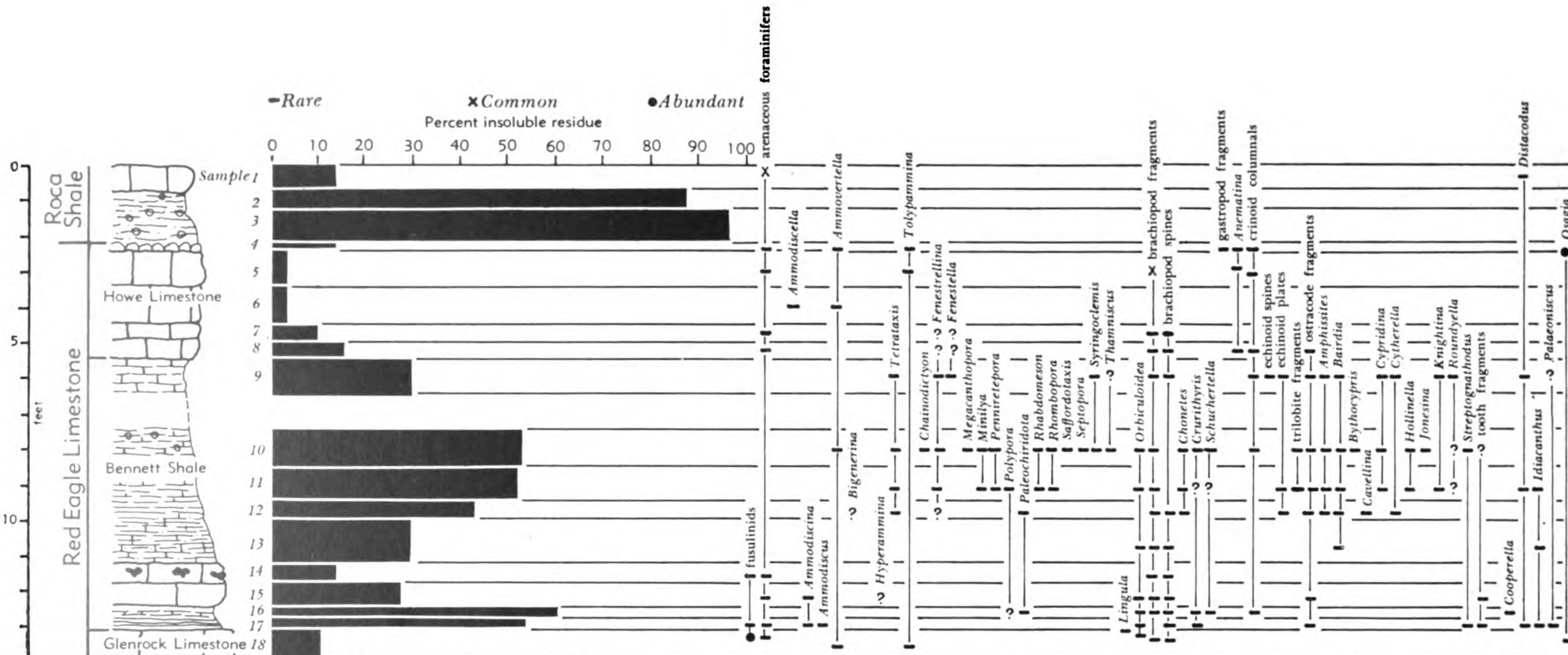


FIGURE 18.—Columnar section, insoluble residues, and fossils of the Allen No. 2 section.

muddy, varies to calcareous mudstone, fossiliferous, brachiopods, rare *Orbiculoidea*, spines ... 1.2

14. Limestone, medium gray, argillaceous, weathered light buff, some buff secondary porcellaneous chert concretions, fossiliferous; aphanitic matrix for fusulinids, foraminifers, brachiopod fragments, and spines; massive, resistant, hard ... 0.6
15. Limestone, light brownish gray, hard, similar to above but lacks chert, some milky opaline chert replacements of fossil fragments; aphanitic matrix for profuse fossil detritus including brachiopod fragments, spines, small foraminifers, and *Orbiculoidea* ... 0.7
16. Shale, medium gray, mostly weathered to gray buff, moderately to well laminated, calcareous, *Orbiculoidea* fragments common, trace of spines and brachiopod fragments (cf. *Crurithyris*), slightly silty ... 0.3
17. Shale, very dark gray, very well laminated, very slightly calcareous, rare laminar lenticles of marly clay and subcoquina of *Orbiculoidea* fragments, very rare fish teeth, small spines, very frail ostracodes, disclike foraminifers (*Ammodiscus?*), dark-brown possible fish bones? 0.3

Thickness Bennett Shale Member 7.6

Glenrock Limestone Member

18. Limestone, medium gray to brownish gray, aphanitic to microcrystalline matrix for abundant fossils, fusulinids (*Triticites?*) and brachiopod fragments common, rare frail coiled or wormlike foraminifers (*Tolypammina?*), spines, some subrounded fragments of medium-gray or bluish-gray aphanitic limestone give sparse conglomeratic effect; top undulatory, distinct, and coated with subcoquina of *Orbiculoidea* and *Lingula?* fragments in a very dark gray clay matrix; crude worm burrows similar to Pawnee locality which contain *Orbiculoidea* fragments are 2 inches below top of this unit, some algal $CaCO_3$ coatings on brachiopod fragments, rare trace of pyrite, one or two broken fusulinids at base of overlying *Orbiculoidea* subcoquina ... 0.9

Thickness Red Eagle Limestone 11.7

Dunlap Section.—SE SE sec. 23, T. 17 S., R. 9 E. In west bank of road cut just south of bridge, Norris County, Kansas.

Sample — *Thickness, feet*

Roca Shale

1. Mudstone and shale, light greenish yellowish gray, calcareous, moderately to poorly laminated, arenaceous foraminifers 1.0
2. Mudstone, similar to above, rare patches of light greenish gray associated with rusty yellow flecks ... 1.0
3. Shale, light gray, faintly greenish, flecks of rusty weathering, well laminated, calcareous, some laminae are wavy ... 1.0
4. Limestone, light gray, faintly greenish, shaly, poorly to nonlaminated, calcareous .. 0.2
5. Mudstone, light gray, faintly greenish, calcareous, vaguely laminated in some places, chalky ... 1.5
6. Shale and mudstone, medium to light greenish gray, green in patches, calcareous, compact, rubbly debris ... 0.8
7. Limestone, medium to light greenish gray, argillaceous, green clay in wormy tubes up to 1/16 inch diameter, trace brachiopod fragments, one ostracode seen ... 0.3
8. Shale, medium to light grayish green, calcareous, nonuniform mixture of green clay and light-grayish-brown calcareous material, moderately wavy laminae ... 0.5
9. Shale, varies to mudstone, medium green with grayish cast, noncalcareous, irregular blocky debris ... 1.5
10. Shale, medium gray to bluish gray, varies to mudstone, compact, irregular blocky debris, noncalcareous ... 0.5
11. Limestone, light brownish gray, argillaceous, pitted, vague broken small buns at top suggest algal origin ... 1.0
12. Shale, light gray, faintly brownish, chalky, poorly laminated, noncalcareous ... 0.5
13. Shale and mudstone, dark brick red, silty, poorly to moderately laminated, blocky debris, noncalcareous ... 0.5
14. Shale, brick red, softer than above, irregular blocky debris, calcareous, moderately to poorly laminated ... 1.0
15. Shale and mudstone, medium to light gray with pale-brick-red cast, silty, blocky debris, very calcareous ... 1.0
16. Shale, medium gray with brownish tint, blocky debris, noncalcareous, compact ... 0.3
17. Shale, medium greenish gray to gray, compact, very slightly calcareous, moderately laminated ... 0.2
18. Limestone, light brownish gray, argillaceous, wavy thin bedding, aphanitic ... 1.0
19. Limestone, light gray, shaly, very thin wavy beds, faintly brownish, aphanitic 1.0
20. Shale, light gray, faintly greenish, very calcareous, well laminated, waferlike debris, compact, rare trace of faint interference ripples, silty ... 1.0
21. Shale, similar to above but slightly harder and more resistant ... 1.0
22. Shale, light gray, some pale-brick-red mottling, well laminated, softer than above, silty, calcareous ... 1.0

Covered ... 3.5

Thickness Roca Shale 21.3

Red Eagle Limestone

Howe Limestone Member

23. Limestone, medium grayish brown, weathered light rusty yellowish brown to light brown, pseudo-oolitic, foraminiferal, common microcrystalline clear calcite matrix for oolites; foraminifers, ostracodes?, small brachiopods?, or clams? coated by algal $CaCO_3$ yield pseudo-oolites; exposed ... 0.5

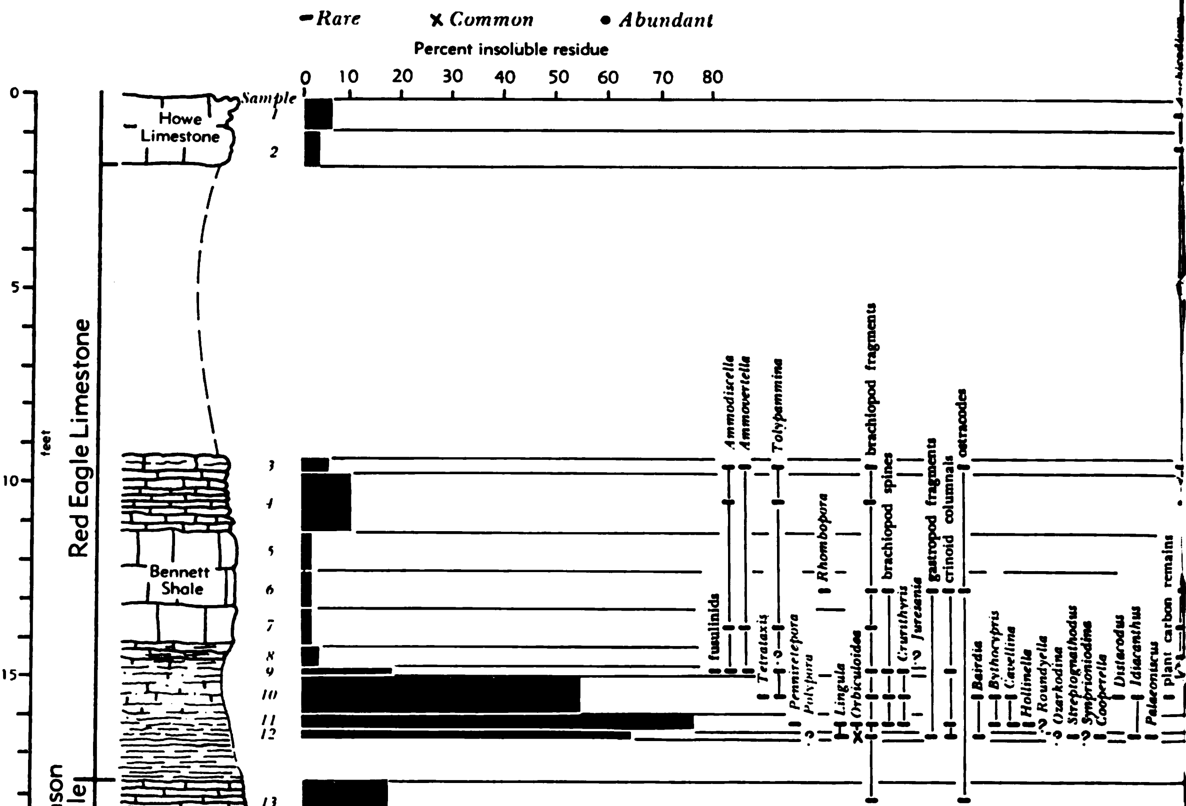


FIGURE 19.—Columnar section, insoluble residues, and fossils of the Saffordville section.

Saffordville Section.—NW SW sec. 30, T. 19 S., R. 9 E. In south bank of Cottonwood River east of stone bridge, Chase County, Kansas (Fig. 19).

Sample		*Thickness, feet*
	Red Eagle Limestone	
	Howe Limestone Member	
1.	Limestone, medium brownish gray, microcrystalline, badly pitted and weathered	0.8
2.	Limestone, medium brownish gray, microcrystalline matrix for extremely abundant foraminifers of several kinds, some ostracodes, some fossils coated with secondary algal calcite giving pseudo-oolitic effect, typical osagite	1.0
	Thickness Howe Limestone Member	1.8
	Bennett Shale Member	
	Covered, weathered fossil remains in soil suggest similarity to shale at Elmdale	7.5
3.	Limestone, light-gray aphanitic matrix for a few clear crystalline brachiopod fragments and rusty-brown stringers of possible algal origin, traces of random clear calcite crystals, algal? mounds, rare traces of ostracodes and coiled foraminifers	0.4
4.	Limestone, light buff, similar to above, thin and wavy-laminated rubbly beds, aphanitic matrix, linear algae	1.5
5.	Limestone, light buff, aphanitic to microcrystalline matrix, some vugs, random clear medium calcite crystals, hard; this is upper part of 3.0-foot massive unit with medium intrabeds	1.0
6.	Limestone, similar to above, rare crinoid discs, brachiopod fragments and spines, rare traces of ostracodes, rare stringers of linear algae, traces of vugs along stylolites, a rare trace of *Rhombopora*?, one high-spired tiny gastropod	1.0
7.	Limestone, similar to above, vuggy, some large broken bilobate brachiopods (*Juresania*?), some linear algae	1.0
8.	Limestone, buff and rusty brown, aphanitic to medium crystals, peculiar wavy and brecciated layers of hard and soft lime suggesting a combination of algal deposition and shrinkage-crack filling, *Ammovertella* along algal sheets, somewhat similar to 5	0.5
9.	Limestone, medium to light brownish gray, aphanitic, calcareous to argillaceous matrix for small brachiopod fragments and	

spines, rare crinoid discs and rare fusulinids, softer and more shaly than above, grades downward into calcareous mudstone barren of fusulinids 0.2

10. Mudstone, medium gray, calcareous, very clayey, traces of brachiopods and spines, traces of brown plant? remains and/or fish? remains, moderately laminated 1.0
11. Shale, medium gray, moderately laminated, calcareous, rare trace of fenestellate bryozoans, frail brachiopods, ostracodes 0.5
12. Shale, dark gray, well laminated with intrabeds of shale as in above containing abundant *Orbiculoidea* fragments (subcoquina) with fewer frail *Lingula* oriented parallel to laminae, traces of fish teeth and brachiopod spines 0.2

Shale, same as above 1.0

Thickness Bennett Shale Member 15.8

Thickness Red Eagle Limestone exposed 17.6

Johnson Shale

13. Limestone, medium gray, aphanitic, hard, moderately laminated, rough platy debris, trace of very delicate brachiopods, ostracodes common 1.0

Elmdale Section.—Near C sec. 26, T. 19 S., R. 7 E. Road cut in hillside above bridge 1 mile east of Elmdale, Chase County, Kansas (Fig. 20).

Sample — *Thickness, feet*

Roca Shale

1. Shale, light greenish gray, calcareous, moderately laminated, very finely silty 1.0
2. Shale, light olive green to gray, calcareous, moderately laminated, rare trace of black carbonaceous? remains 1.0

Covered 2.0

3. Mudstone, medium maroon to greenish gray and gray, slightly calcareous, blocky debris 1.0

Limestone, light gray and greenish gray, very muddy 0.2

4. Mudstone, medium gray to greenish gray with maroon tint along microfractures, similar to above, noncalcareous to slightly calcareous 1.0
5. Shale, light gray to greenish gray, very calcareous, compact, trace of silt, argillaceous lime nodules near base 0.8
6. Mudstone, medium greenish gray, calcareous in fractures, similar to 3 and 4, poorly laminated 1.0
7. Shale, medium to light gray, slightly calcareous, trace of pale-greenish-maroon tint 1.0
8. Shale, medium to light gray and greenish gray, slightly calcareous, moderately laminated 1.0

Covered, presumably shale 4.0

Thickness Roca Shale 14.0

Red Eagle Limestone

Howe Limestone Member

9. Limestone, medium brownish gray to light yellowish gray, massive, pelletoid, pseudo-oolitic (osagite), some algae-coated brachiopods or clams? with encrusting foraminifers as below, matrix of clear calcite varying to clayey microcrystalline calcite .. 0.3
10. Limestone, medium to light brownish gray, microcrystalline matrix for abundant arenaceous foraminifers, rare "osagia," medium to thin bedding 0.7
11. Limestone, light rusty yellow, badly pitted and vuggy, decayed, clayey, fairly even textured, microcrystalline matrix where intact 1.5

Thickness Howe Limestone Member 2.5

Bennett Shale Member

12. Clay, light yellow, calcareous, marly, varies to soft pitted clay limestone 0.3
13. Shale, light brownish gray, faintly yellowish, well laminated, rare ostracodes, trace of spine fragments 1.0
14. Shale, light gray, calcareous, fossiliferous, well laminated, rare thin limestone wafers containing abundant fossils, trace of ostracodes and spine fragments, brachiopods 1.0
15. Shale, light brownish gray, faintly yellowish, calcareous, fossiliferous, *Neospirifer*, bryozoans, productid spines, brachiopods, well laminated 0.5
16. Shale, light brownish gray, similar to above, calcareous, grades to below 1.0
17. Limestone, light brownish gray, aphanitic to microcrystalline; rare to common foraminifers with brachiopods, linear algae and productid spines; compact, a single unit with wavy intrabeds 1.0
18. Limestone, very light brownish gray, aphanitic to microcrystalline, hard, medium bedded, some microvugs and small vugs .. 1.0
19. Limestone, similar to above, more vuggy .. 1.0
20. Limestone, similar to 18, some stylolites .. 1.0
21. Limestone, similar to 18, abundant microfossil detritus vaguely preserved 1.0
22. Limestone, medium gray to light brownish gray with rusty yellow tint, shaly, well to moderately laminated, wavy laminae, fossiliferous, common brachiopod fragments and spines oriented roughly parallel to the laminae, some fusulinids, bryozoans, crinoid discs .... 0.3 to 0.4
23. Limestone, medium grayish brown to brownish gray, composed largely of very fine well-broken fossil detritus, brachiopods, spines, foraminifers, very rare fish teeth, some dark brown carbonaceous? remains, rare trace of *Orbiculoidea* fragments and fusulinids, aphanitic to microcrystalline matrix .... 0.3 to 0.4
24. Shale, dark gray to medium brownish gray at top, calcareous, grades from fossiliferous limestone above downward into argillaceous limestone below, fills worm burrows in 25, vague ripple marks, trace of *Orbiculoidea*, rare fish teeth, base is almost a coquina of *Orbiculoidea* 0.1

Thickness Bennett Shale Member 9.7

Thickness Red Eagle Limestone 12.2

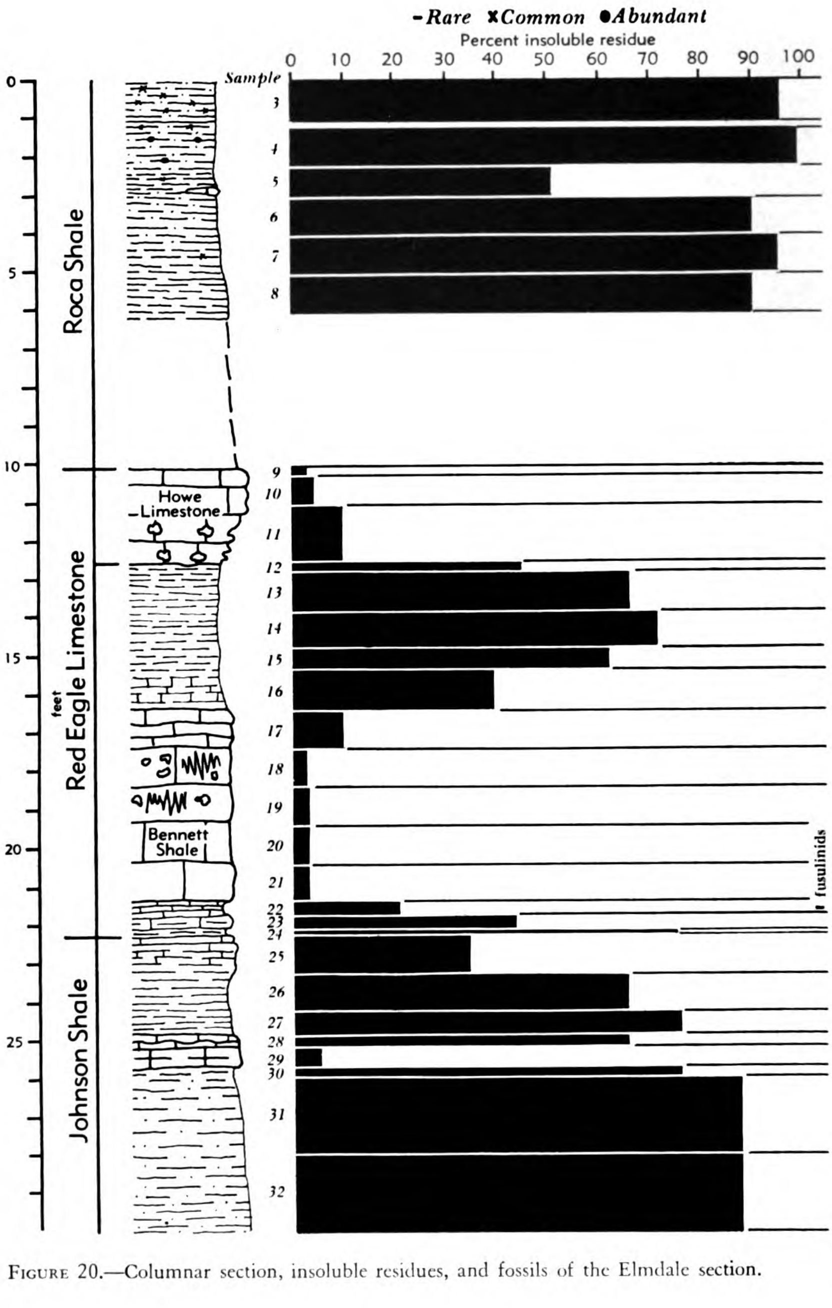
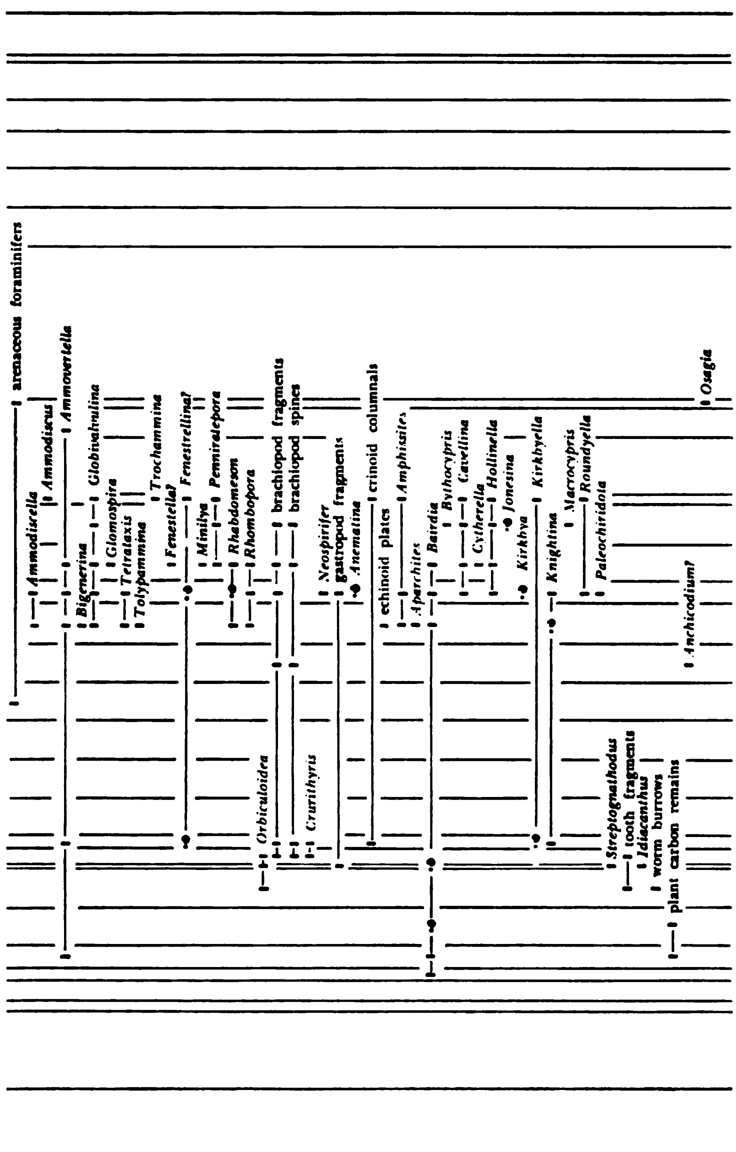


FIGURE 20.—Columnar section, insoluble residues, and fossils of the Elmdale section.


arenaceous foraminifers
Ammodiscella
Ammodiscus
Ammovertella
Bigenerina
Globivalvulina
Glomospira
Tetrataxis
Tolypammina
Trochammina
Fenestella?
Fenestrellina?
Minilya
Penniretepora
Rhabdomeson
Rhombopora
Orbiculoidea
brachiopod fragments
brachiopod spines
Crurithyris
Neospirifer
gastropod fragments
Anematina
crinoid columnals
echinoid plates
Amphissites
Aparchites
Bairdia
Bythocypris
Cavellina
Cytherella
Hollinella
Jonesina
Kirkbya
Kirkbyella
Knightina
Macrocypris
Roundyella
Paleochiridota
Anchicodium?
Osagia
Streptognathodus
tooth fragments
Idiacanthus
worm burrows
plant carbon remains

Johnson Shale

25. Limestone, light gray, faintly brownish, very argillaceous, vaguely laminated, thin worm burrows in upper 0.1 foot filled with *Orbiculoidea*-bearing black clay and black muddy limestone from 24, tubes also contain fish teeth, grades to calcareous shale below, massive in upper part, even textured, top slightly undulatory below cap of black *Orbiculoidea* shale, trace of black phosphatic bone? remains, top contains random rare roughly tubular 1- to 2-inch lumps of fusulinid-bearing limestone similar to Glenrock lithology, lumps appear to be decapitated burrow fillings 1.0
26. Shale, light brownish gray, calcareous, moderately to well laminated, trace of black plant remains and plant molds 1.0
27. Shale, light brownish gray, weathered from medium gray, well laminated, calcareous, trace of plant remains and ostracodes 0.6
28. Limestone, light brownish gray, laminated, vaguely ripple marked, hard, argillaceous, aphanitic, common ostracodes along laminae near top (platestone equivalent) 0.3
29. Limestone, medium to light brownish gray, even textured, some small vugs and microgeodes, argillaceous, aphanitic 0.5
30. Clay, light yellowish gray, marly 0.3
31. Mudstone, medium to light brownish gray, calcareous, trace of pale-greenish-gray silt granules, moderately to poorly laminated, blocky debris 2.0
32. Shale, light gray, faintly greenish and brownish, calcareous, finely silty 2.0
33. Mudstone, medium greenish gray, faintly bluish, clayey, noncalcareous, irregular blocky debris, fairly hard 2.0
34. Shale, similar to above, medium to light greenish gray, noncalcareous 1.0
35. Shale, light brownish gray, calcareous, moderately to well laminated, clayey to very finely silty 1.3
36. Limestone, light yellow gray, argillaceous and shaly, grades to below 1.4
37. Mudstone, medium to light yellow gray, very calcareous, similar to above 1.0

Thickness Johnson Shale exposed 14.4

Turnpike Section.—(Mile 118.1) sec. 17, T. 20 S., R. 10 E. Lyon County, Kansas.

Sample — *Thickness, feet*

Red Eagle Limestone

Howe Limestone Member

1. Limestone, very light brownish gray, microcrystalline matrix for abundant foraminifers, hard, exposed 0.5

Bennett Shale Member

Covered 5.5

2. Shale, buff, weathered from medium gray, very calcareous, moderately to well laminated, *Tetrataxis, Bigenerina,* ostracodes, *Amphissites, Bairdia, Bythocypris, Minilya, Penniretopora, Fenestellina, Rhombopora,* trace of brachiopod fragments, *Crurithyris, Chonetes,* productid spines, echinoid spines and plates, holothurian wheels, gastropods (*Anematina?*) 1.0
3. Limestone, light buff, fossiliferous, microcrystalline to aphanitic matrix for brachiopod fragments, linear algae, trace of ostracodes (*Amphissites*), hard to moderately hard, weathered yellowish 0.9
4. Limestone, light brownish gray, aphanitic to somewhat microcrystalline matrix for common brachiopod fragments, *Crurithyris,* very rare *Orbiculoidea,* crinoid discs, *Fenestella?,* somewhat argillaceous along wavy shaly stringers, some thick and thin linear algae 1.2

Thickness Bennett Shale Member 8.6

Johnson Shale

5. Shale, medium to light yellowish buff, well laminated, calcareous, rare fossils 0.5
6. Limestone, argillaceous, and shale, calcareous; medium to light grayish brown, moderately to well laminated, wavy laminae, rare to common delicate ostracodes, brachiopod fragments, rare black carbonaceous plant remains 0.3
7. Shale, medium brownish gray with pale-yellow to greenish cast, brown carbonaceous remains, *Ammodiscus, Tetrataxis, Bairdia, Bythocypris, Cavellina,* holothurian "wheels," *Crurithyris? Distacodus* 1.0

Thickness Johnson Shale exposed 1.8

Sallyards Section.—SW NW sec. 11, T. 26 S., R. 8 E. At turn of the road 1 mile south of Sallyards, Greenwood County, Kansas.

Sample — *Thickness, feet*

Red Eagle Limestone

Bennett Shale Member

1. Limestone, medium gray, aphanitic matrix for crinoid discs, bryozoans, brachiopods, *Schuchertella* 1.0
2. Shale, mottled buff to olive gray, clayey, calcareous, soft, crinoid discs, bryozoans, *Fenestrellina, Distacodus, Streptognathodus, Orbiculoidea, Bigenerina, Tetrataxis* .. 1.0

Thickness Bennett Shale Member exposed 2.0

Piedmont Section.—NE SW sec. 30, T. 27 S., R. 8 E. 5 miles west and 3½ miles north of Piedmont, Greenwood County, Kansas.

Sample — *Thickness, feet*

Red Eagle Limestone

Bennett Shale Member

1-2. Limestone, light gray to brownish gray, some yellowish-rusty clay in vugs and leached fossils, aphanitic to microcrystalline matrix for abundant fusulinids, rare crinoid discs and brachiopod spines, medium indistinct beds, heavily pitted, detached from limestone ledge below (floating) 1.5

3. Limestone, light brownish gray or buff, yellowish clayey material in vugs, microcrystalline matrix for very rare brachiopod fragments, ostracodes, fusulinids, much vugular and leached fossil porosity .. 1.0
4. Limestone, light gray buff, much less porosity than above, microcrystalline matrix for rare brachiopod fragments, spines, ostracodes, foraminifers?, very rare fusulinids 1.0
5. Limestone, similar to above, rare small vugs, tighter than above, some pitting at surface, medium bedded 1.0
6. Limestone, similar to above with extremely rare traces of *Orbiculoidea* fragments, medium bedded 1.0
7. Limestone, similar to above with common fusulinids, lacks *Orbiculoidea* fragments .. 1.0
8. Limestone, similar to above, trace of chert nodules; upper part of a 4-foot massive unit with medium to thick intrabeds 1.0
9. Limestone, similar to above, crinoid discs, dark gray chert nodules containing fusulinids 1.0
10. Limestone, similar to above, crinoid discs, brachiopod fragments, rare ostracodes, common fusulinids 1.0
11. Limestone, similar to above, medium to thick beds with undulatory (relief 2 inches) bedding planes 1.0
12. Limestone, medium to light gray and brownish gray, similar to above, aphanitic to microcrystalline matrix for abundant *Orbiculoidea* fragments and common fusulinids, brachiopod fragments, spines, small crinoid discs, common rusty stains in pores throughout, hard, resistant 0.6
13. Limestone, similar to above but fewer fossils 0.5
14. Limestone, medium grayish brown, fossil content similar to above, extremely rare presence of ramose bryozoans 0.5
15. Limestone, medium to light gray, argillaceous?, common fusulinids, rare brachiopod fragments, some linear algae, uniform texture, microcrystalline to microgranular .. 1.0
16. Limestone, grades to above, medium gray, argillaceous, extremely rare trace of pyrite, abundant fusulinids 0.5

Covered 10.5

Thickness Bennett Shale Member 24.1

Glenrock Limestone Member

17. Limestone, medium gray brown and brownish gray, contains abundant fusulinids, thin bedded, weathered rusty brown, microcrystalline matrix, hard, medium-gray chert blebs, fusulinids contain milky opaline chert, rare *Dunbarinella*?, common *Triticites*?, lower part contains very abundant fusulinids 1.5

Thickness Red Eagle Limestone 25.6

Grand Summit Section.—SE sec. 3, T. 31 S., R. 8 E. Along railroad cut 4 miles west and 2 miles north of Grenola, Elk County, Kansas (Fig. 21).

Sample	*Thickness, feet*
Grenola Limestone	
Sallyards Limestone Member	
Limestone, *Aviculopecten* and other fossils	
Roca Shale	
1. Shale and limestone, interlaminated; calcareous shale, light brownish to yellowish gray, moderately to well laminated, soft; thin light-gray aphanitic limestone interlaminated up to 0.5 inch thick; trace of fenestrate bryozoans	0.5
2. Mudstone, very light to light brownish gray, marly, some small lime nodules	0.5
3. Mudstone, very light brownish gray, shaly, chalky	1.0
4. Mudstone, light pinkish gray, calcareous, chalky	1.0
5. Mudstone, light pinkish gray, calcareous, chalky, poorly laminated	1.0
6. Mudstone, very light greenish gray, chalky	0.5
Covered, presumably shale	4.0
7. Claystone, brick red, somewhat chopped up by slumping	0.5
Covered, presumably shale	5.5
Thickness Roca Shale	14.5
Red Eagle Limestone	
Howe Limestone Member	
8. Limestone, light yellowish gray, typical osagite, foraminiferal?, some ostracodes, small gastropods and brachiopods, deeply pitted, yellowish weathering	2.0
Bennett Shale Member	
9. Limestone, buff, microcrystalline matrix for medium crystalline rare fossil remains such as brachiopod fragments, hard, medium bedded, massive	1.0
10. Limestone, light brownish gray, some yellowish limonitic clay tint, medium to thin bedded within massive thicker unit	1.0
11. Limestone, similar to above, medium to thin bedded	1.0
12. Limestone, light brownish gray, thin bedded, microcrystalline, trace of ostracodes and brachiopod fragments, some microvugs and leached fossil porosity, similar to above but lacking yellowish stain	1.0
13. Limestone, light brownish gray to gray brown, medium bedded, microcrystalline matrix for common brachiopod fragments and spines and trace of crinoid discs, some yellowish stain, medium crystalline clear calcite fossil remains and some leached fossil pores	1.0
14. Limestone, similar to above with fewer brachiopod fragments	1.0
15-16. Limestone, similar to 13 but no yellow stain and almost no pores, hard, dense	2.0
17. Limestone, light brownish gray with some limonitic yellow clay stains in leached fos-	

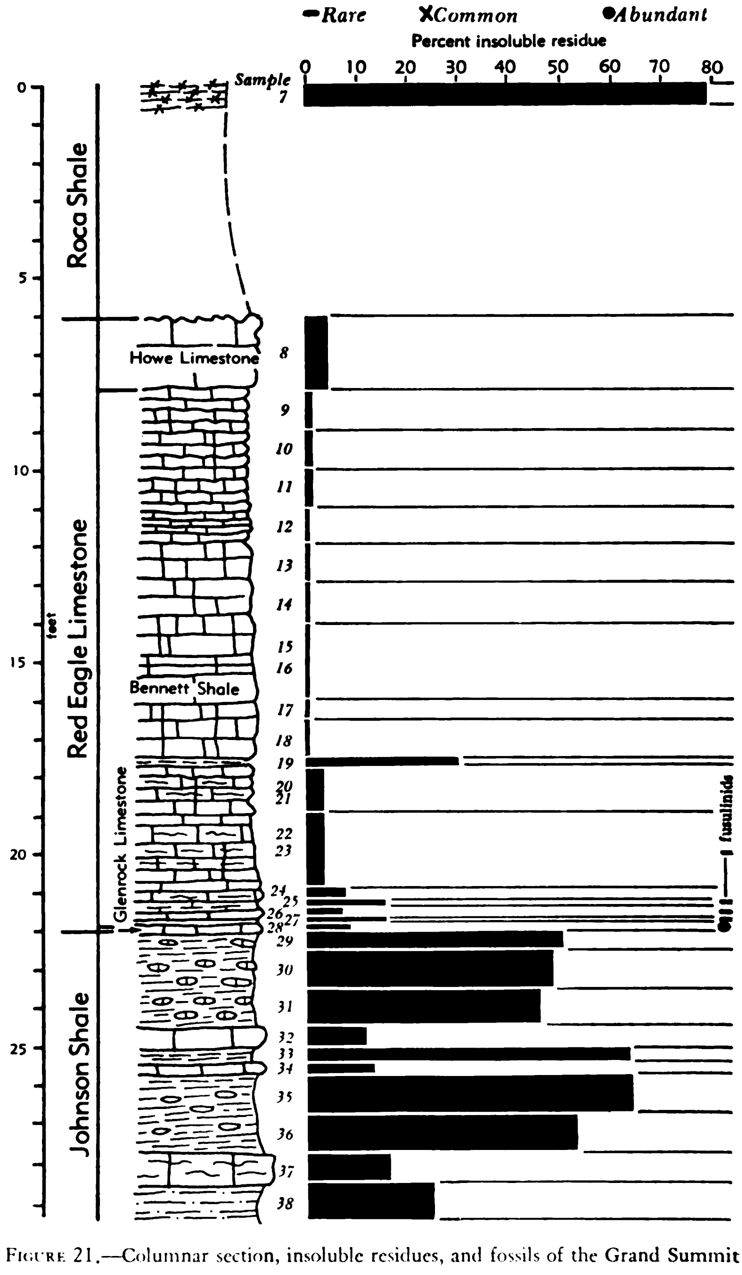
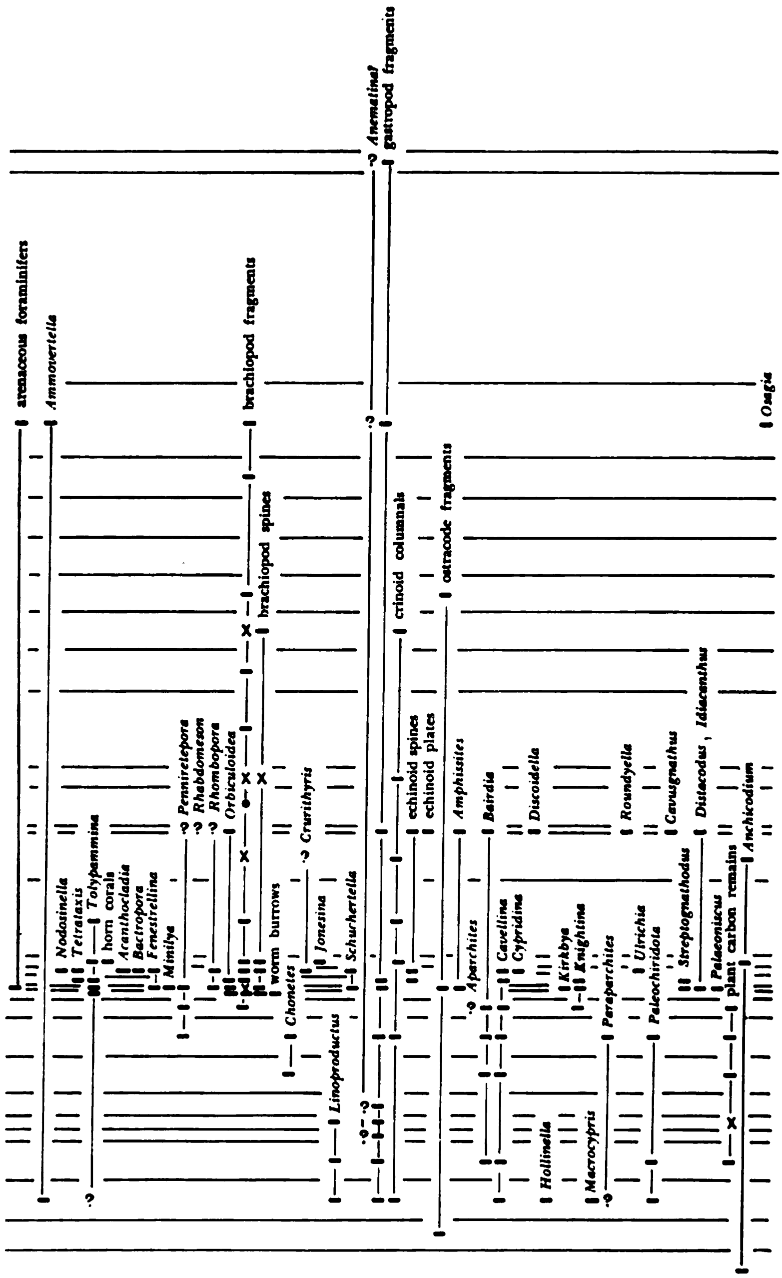


FIGURE 21.—Columnar section, insoluble residues, and fossils of the Grand Summit



arenaceous foraminifers
Ammovertella
Nodosinella
Tetrataxis
Tolypammina
horn corals
Acanthocladia
Bactropora
Fenestrellina
Minilya
Penniretepora
Rhabdomeson
Rhombopora
Orbiculoidea
brachiopod fragments
brachiopod spines
worm burrows
Chonetes
Crurithyris
Jonesina
Linoproductus
Schuchertella
Anematina?
gastropod fragments
crinoid columnals
echinoid spines
echinoid plates
ostracode fragments
Amphissites
Aparchites
Bairdia
Cavellina
Cypridina
Discoidella
Hollinella
Kirkbya
Knightina
Macrocypris
Paraparchites
Roundyella
Ulrichia
Paleochiridota
Cavusgnathus
Streptognathodus
Distacodus, Idiacanthus
Paleoniscus
plant carbon remains
Anchicodium
Osagia

section.

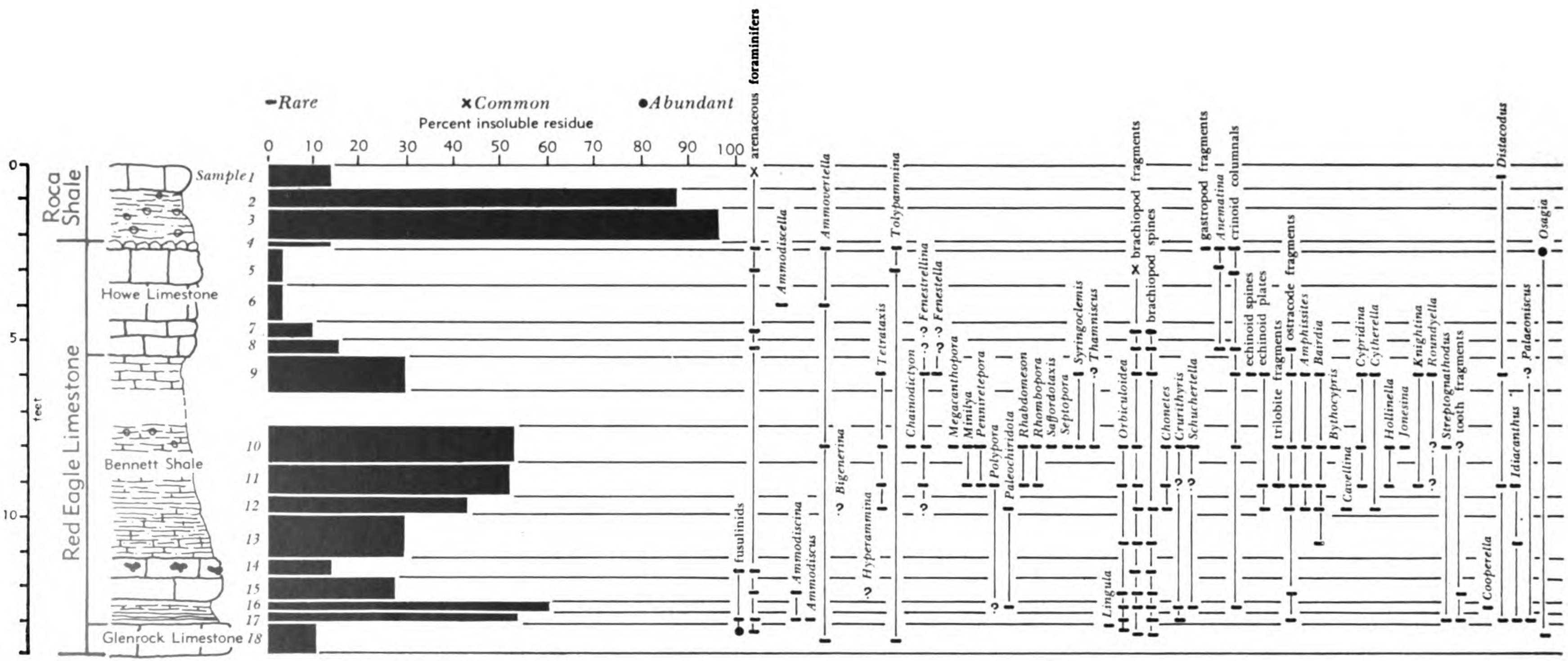


FIGURE 18.—Columnar section, insoluble residues, and fossils of the Allen No. 2 section.

muddy, varies to calcareous mudstone, fossiliferous, brachiopods, rare *Orbiculoidea*, spines 1.2

14. Limestone, medium gray, argillaceous, weathered light buff, some buff secondary porcellaneous chert concretions, fossiliferous; aphanitic matrix for fusulinids, foraminifers, brachiopod fragments, and spines; massive, resistant, hard 0.6
15. Limestone, light brownish gray, hard, similar to above but lacks chert, some milky opaline chert replacements of fossil fragments; aphanitic matrix for profuse fossil detritus including brachiopod fragments, spines, small foraminifers, and *Orbiculoidea* 0.7
16. Shale, medium gray, mostly weathered to gray buff, moderately to well laminated, calcareous, *Orbiculoidea* fragments common, trace of spines and brachiopod fragments (cf. *Crurithyris*), slightly silty 0.3
17. Shale, very dark gray, very well laminated, very slightly calcareous, rare laminar lenticles of marly clay and subcoquina of *Orbiculoidea* fragments, very rare fish teeth, small spines, very frail ostracodes, disclike foraminifers (*Ammodiscus*?), dark-brown possible fish bones? 0.3

Thickness Bennett Shale Member 7.6

Glenrock Limestone Member

18. Limestone, medium gray to brownish gray, aphanitic to microcrystalline matrix for abundant fossils, fusulinids (*Triticites*?) and brachiopod fragments common, rare frail coiled or wormlike foraminifers (*Tolypammina*?), spines, some subrounded fragments of medium-gray or bluish-gray aphanitic limestone give sparse conglomeratic effect; top undulatory, distinct, and coated with subcoquina of *Orbiculoidea* and *Lingula*? fragments in a very dark gray clay matrix; crude worm burrows similar to Pawnee locality which contain *Orbiculoidea* fragments are 2 inches below top of this unit, some algal $CaCO_3$ coatings on brachiopod fragments, rare trace of pyrite, one or two broken fusulinids at base of overlying *Orbiculoidea* subcoquina 0.9

Thickness Red Eagle Limestone 11.7

Dunlap Section.—SE SE sec. 23, T. 17 S., R. 9 E. In west bank of road cut just south of bridge, Norris County, Kansas.

Sample — *Thickness, feet*

Roca Shale

1. Mudstone and shale, light greenish yellowish gray, calcareous, moderately to poorly laminated, arenaceous foraminifers 1.0
2. Mudstone, similar to above, rare patches of light greenish gray associated with rusty yellow flecks 1.0
3. Shale, light gray, faintly greenish, flecks of rusty weathering, well laminated, calcareous, some laminae are wavy 1.0
4. Limestone, light gray, faintly greenish, shaly, poorly to nonlaminated, calcareous .. 0.2
5. Mudstone, light gray, faintly greenish, calcareous, vaguely laminated in some places, chalky 1.5
6. Shale and mudstone, medium to light greenish gray, green in patches, calcareous, compact, rubbly debris 0.8
7. Limestone, medium to light greenish gray, argillaceous, green clay in wormy tubes up to 1/16 inch diameter, trace brachiopod fragments, one ostracode seen 0.3
8. Shale, medium to light grayish green, calcareous, nonuniform mixture of green clay and light-grayish-brown calcareous material, moderately wavy laminae 0.5
9. Shale, varies to mudstone, medium green with grayish cast, noncalcareous, irregular blocky debris 1.5
10. Shale, medium gray to bluish gray, varies to mudstone, compact, irregular blocky debris, noncalcareous 0.5
11. Limestone, light brownish gray, argillaceous, pitted, vague broken small buns at top suggest algal origin 1.0
12. Shale, light gray, faintly brownish, chalky, poorly laminated, noncalcareous 0.5
13. Shale and mudstone, dark brick red, silty, poorly to moderately laminated, blocky debris, noncalcareous 0.5
14. Shale, brick red, softer than above, irregular blocky debris, calcareous, moderately to poorly laminated 1.0
15. Shale and mudstone, medium to light gray with pale-brick-red cast, silty, blocky debris, very calcareous 1.0
16. Shale, medium gray with brownish tint, blocky debris, noncalcareous, compact 0.3
17. Shale, medium greenish gray to gray, compact, very slightly calcareous, moderately laminated 0.2
18. Limestone, light brownish gray, argillaceous, wavy thin bedding, aphanitic 1.0
19. Limestone, light gray, shaly, very thin wavy beds, faintly brownish, aphanitic 1.0
20. Shale, light gray, faintly greenish, very calcareous, well laminated, waferlike debris, compact, rare trace of faint interference ripples, silty 1.0
21. Shale, similar to above but slightly harder and more resistant 1.0
22. Shale, light gray, some pale-brick-red mottling, well laminated, softer than above, silty, calcareous 1.0

Covered 3.5

Thickness Roca Shale 21.3

Red Eagle Limestone

Howe Limestone Member

23. Limestone, medium grayish brown, weathered light rusty yellowish brown to light brown, pseudo-oolitic, foraminiferal, common microcrystalline clear calcite matrix for oolites; foraminifers, ostracodes?, small brachiopods?, or clams? coated by algal $CaCO_3$ yield pseudo-oolites; exposed 0.5

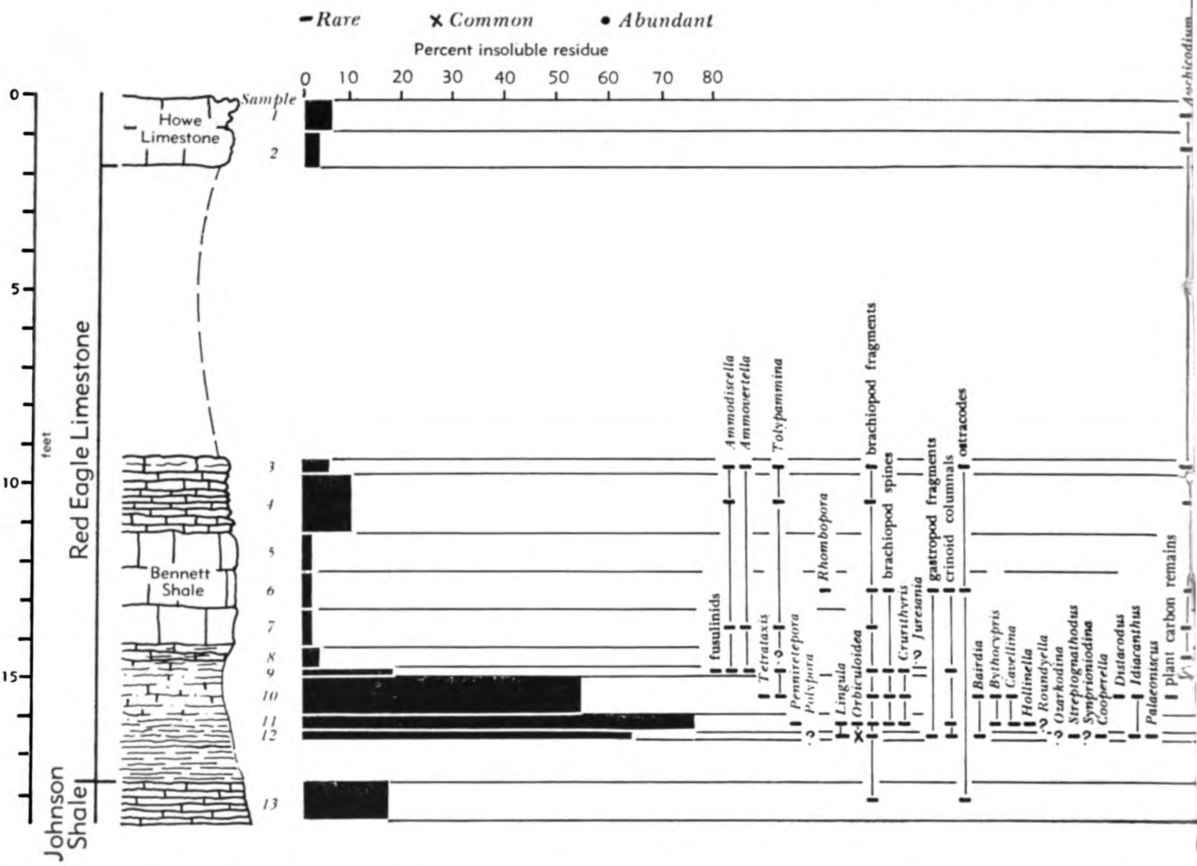


FIGURE 19.—Columnar section, insoluble residues, and fossils of the Saffordville section.

Saffordville Section.—NW SW sec. 30, T. 19 S., R. 9 E. In south bank of Cottonwood River east of stone bridge, Chase County, Kansas (Fig. 19).

Sample	*Thickness, feet*
Red Eagle Limestone	
Howe Limestone Member	
1. Limestone, medium brownish gray, microcrystalline, badly pitted and weathered	0.8
2. Limestone, medium brownish gray, microcrystalline matrix for extremely abundant foraminifers of several kinds, some ostracodes, some fossils coated with secondary algal calcite giving pseudo-oolitic effect, typical osagite	1.0
Thickness Howe Limestone Member	1.8
Bennett Shale Member	
Covered, weathered fossil remains in soil suggest similarity to shale at Elmdale	7.5
3. Limestone, light-gray aphanitic matrix for a few clear crystalline brachiopod fragments and rusty-brown stringers of possible algal origin, traces of random clear calcite crystals, algal? mounds, rare traces of ostracodes and coiled foraminifers	0.4
4. Limestone, light buff, similar to above, thin and wavy-laminated rubbly beds, aphanitic matrix, linear algae	1.5
5. Limestone, light buff, aphanitic to microcrystalline matrix, some vugs, random clear medium calcite crystals, hard; this is upper part of 3.0-foot massive unit with medium intrabeds	1.0
6. Limestone, similar to above, rare crinoid discs, brachiopod fragments and spines, rare traces of ostracodes, rare stringers of linear algae, traces of vugs along stylolites, a rare trace of *Rhombopora*?, one high-spired tiny gastropod	1.0
7. Limestone, similar to above, vuggy, some large broken bilobate brachiopods (*Juresania*?), some linear algae	1.0
8. Limestone, buff and rusty brown, aphanitic to medium crystals, peculiar wavy and brecciated layers of hard and soft lime suggesting a combination of algal deposition and shrinkage-crack filling, *Ammovertella* along algal sheets, somewhat similar to 5	0.5
9. Limestone, medium to light brownish gray, aphanitic, calcareous to argillaceous matrix for small brachiopod fragments and	

spines, rare crinoid discs and rare fusulinids, softer and more shaly than above, grades downward into calcareous mudstone barren of fusulinids 0.2

10. Mudstone, medium gray, calcareous, very clayey, traces of brachiopods and spines, traces of brown plant? remains and/or fish? remains, moderately laminated 1.0
11. Shale, medium gray, moderately laminated, calcareous, rare trace of fenestellate bryozoans, frail brachiopods, ostracodes 0.5
12. Shale, dark gray, well laminated with intrabeds of shale as in above containing abundant *Orbiculoidea* fragments (subcoquina) with fewer frail *Lingula* oriented parallel to laminae, traces of fish teeth and brachiopod spines 0.2

Shale, same as above 1.0

Thickness Bennett Shale Member 15.8

Thickness Red Eagle Limestone exposed 17.6

Johnson Shale

13. Limestone, medium gray, aphanitic, hard, moderately laminated, rough platy debris, trace of very delicate brachiopods, ostracodes common 1.0

Elmdale Section.—Near C sec. 26, T. 19 S., R. 7 E. Road cut in hillside above bridge 1 mile east of Elmdale, Chase County, Kansas (Fig. 20).

Sample — *Thickness, feet*

Roca Shale

1. Shale, light greenish gray, calcareous, moderately laminated, very finely silty 1.0
2. Shale, light olive green to gray, calcareous, moderately laminated, rare trace of black carbonaceous? remains 1.0

Covered 2.0

3. Mudstone, medium maroon to greenish gray and gray, slightly calcareous, blocky debris 1.0

Limestone, light gray and greenish gray, very muddy 0.2

4. Mudstone, medium gray to greenish gray with maroon tint along microfractures, similar to above, noncalcareous to slightly calcareous 1.0
5. Shale, light gray to greenish gray, very calcareous, compact, trace of silt, argillaceous lime nodules near base 0.8
6. Mudstone, medium greenish gray, calcareous in fractures, similar to 3 and 4, poorly laminated 1.0
7. Shale, medium to light gray, slightly calcareous, trace of pale-greenish-maroon tint 1.0
8. Shale, medium to light gray and greenish gray, slightly calcareous, moderately laminated 1.0

Covered, presumably shale 4.0

Thickness Roca Shale 14.0

Red Eagle Limestone

Howe Limestone Member

9. Limestone, medium brownish gray to light yellowish gray, massive, pelletoid, pseudo-oolitic (osagite), some algae-coated brachiopods or clams? with encrusting foraminifers as below, matrix of clear calcite varying to clayey microcrystalline calcite .. 0.3
10. Limestone, medium to light brownish gray, microcrystalline matrix for abundant arenaceous foraminifers, rare "osagia," medium to thin bedding 0.7
11. Limestone, light rusty yellow, badly pitted and vuggy, decayed, clayey, fairly even textured, microcrystalline matrix where intact 1.5

Thickness Howe Limestone Member 2.5

Bennett Shale Member

12. Clay, light yellow, calcareous, marly, varies to soft pitted clay limestone 0.3
13. Shale, light brownish gray, faintly yellowish, well laminated, rare ostracodes, trace of spine fragments 1.0
14. Shale, light gray, calcareous, fossiliferous, well laminated, rare thin limestone wafers containing abundant fossils, trace of ostracodes and spine fragments, brachiopods 1.0
15. Shale, light brownish gray, faintly yellowish, calcareous, fossiliferous, *Neospirifer*, bryozoans, productid spines, brachiopods, well laminated 0.5
16. Shale, light brownish gray, similar to above, calcareous, grades to below 1.0
17. Limestone, light brownish gray, aphanitic to microcrystalline; rare to common foraminifers with brachiopods, linear algae and productid spines; compact, a single unit with wavy intrabeds 1.0
18. Limestone, very light brownish gray, aphanitic to microcrystalline, hard, medium bedded, some microvugs and small vugs .. 1.0
19. Limestone, similar to above, more vuggy .. 1.0
20. Limestone, similar to 18, some stylolites .. 1.0
21. Limestone, similar to 18, abundant microfossil detritus vaguely preserved 1.0
22. Limestone, medium gray to light brownish gray with rusty yellow tint, shaly, well to moderately laminated, wavy laminae, fossiliferous, common brachiopod fragments and spines oriented roughly parallel to the laminae, some fusulinids, bryozoans, crinoid discs .... 0.3 to 0.4
23. Limestone, medium grayish brown to brownish gray, composed largely of very fine well-broken fossil detritus, brachiopods, spines, foraminifers, very rare fish teeth, some dark brown carbonaceous? remains, rare trace of *Orbiculoidea* fragments and fusulinids, aphanitic to microcrystalline matrix .... 0.3 to 0.4
24. Shale, dark gray to medium brownish gray at top, calcareous, grades from fossiliferous limestone above downward into argillaceous limestone below, fills worm burrows in 25, vague ripple marks, trace of *Orbiculoidea*, rare fish teeth, base is almost a coquina of *Orbiculoidea* 0.1

Thickness Bennett Shale Member 9.7

Thickness Red Eagle Limestone 12.2

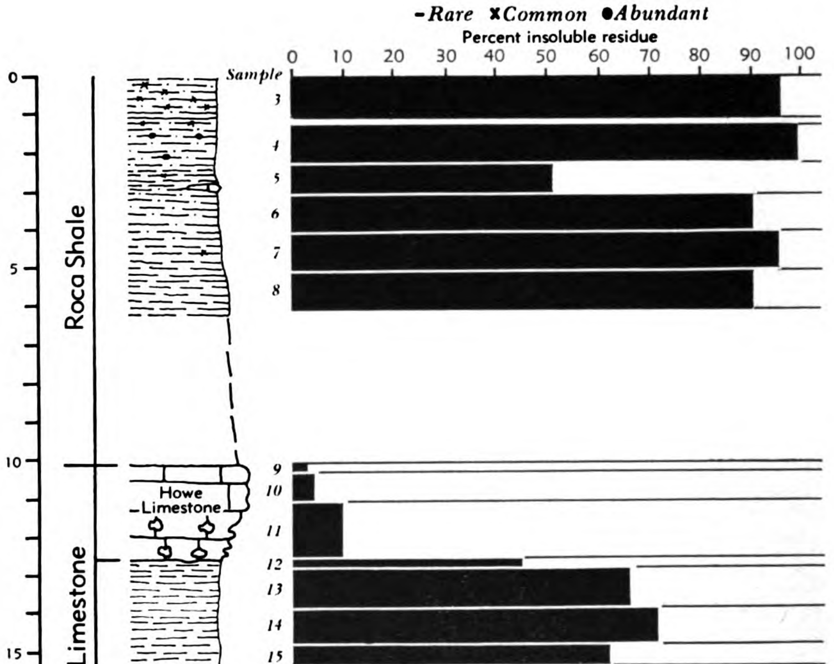
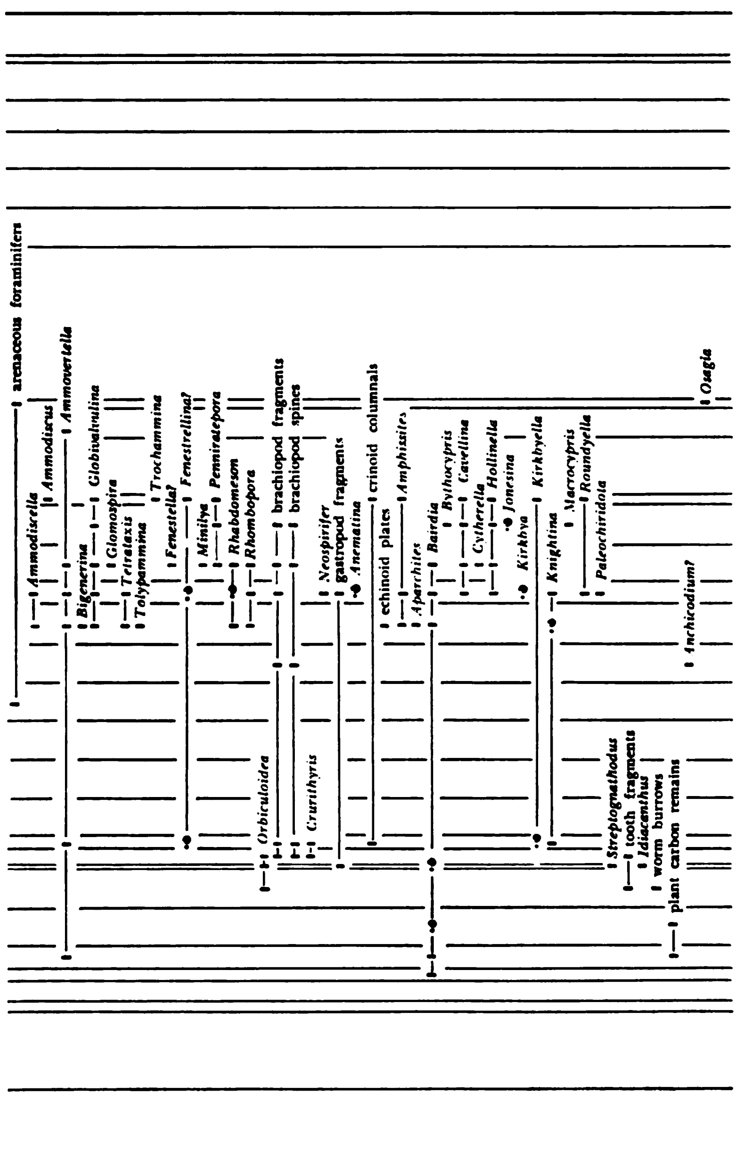


FIGURE 20.—Columnar section, insoluble residues, and fossils of the Elmdale section.


arenaceous foraminifers
Ammodiscella
Ammodiscus
Ammovertella
Bigenerina
Globivalvulina
Glomospira
Tetrataxis
Tolypammina
Trochammina
Fenestella?
Fenestrellina?
Minilya
Penniretepora
Rhabdomeson
Rhombopora
Orbiculoidea
brachiopod fragments
brachiopod spines
Crurithyris
Neospirifer
gastropod fragments
Anematina
crinoid columnals
echinoid plates
Amphissites
Aparchites
Bairdia
Bythocypris
Cavellina
Cytherella
Hollinella
Jonesina
Kirkbya
Kirkbyella
Knightina
Macrocypris
Roundyella
Paleochiridota
Streptognathodus
tooth fragments
Idiacanthus
worm burrows
plant carbon remains
Archicodium?
Osagia

sil pores, microcrystalline matrix for common brachiopod fragments and spines, trace of crinoid discs, some microvugular pores 0.5

18. Limestone, medium to light brownish gray, lower part of a 1.5-foot bed, microcrystalline matrix for medium crystals of clear calcitic fossil remains, abundant brachiopod fragments 1.0

19. Shale, light yellowish gray brown, very calcareous, clayey, rare trace of *Orbiculoidea* fragments 0.1

20-21. Limestone, medium to light brownish gray and gray with wavy rusty stringers undulating parallel to bedding plane, massive unit which weathers to thin wavy beds owing to very thin shaly intrabeds or partings, microcrystalline matrix for common brachiopod fragments (*Crurithyris*?) and rare crinoid discs, but some aphanitic parts are free of fossils, much fine to medium crystalline clear calcite shell remains or leached fossil fillings, wavy algal material similar to that seen at Saffordville section, hard 1.4

22-23. Limestone, massive unit which weathers to thin wavy intrabeds, similar to above with fewer brachiopods and no rusty stringers, some linear algae? in aphanitic wavy portion, very rare fusulinids seen, trace of crinoids 2.0

24. Limestone, medium to light brownish gray, microcrystalline matrix for rare brachiopod fragments and spines, hard, rare crinoid discs, possibly linear algae, *Juresania*, horn corals 0.3

25. Limestone, light to medium yellowish gray, moderately to well laminated, shaly, brachiopod fragments and spines, rare trace of fusulinids 0.2

26. Limestone, medium to light gray and brownish gray, microcrystalline hard to softer argillaceous matrix for common *Orbiculoidea* fragments, rare trace of glauconite grains, brachiopod fragments, very rare fusulinids 0.25

27. Shale, medium to light brownish gray with limonitic yellow cast, abundant *Orbiculoidea* fragments, trace of conodonts and ostracodes, larger brachiopod fragments and glauconite grains rare, very rare fusulinids, rare trace of gastropods, very fossiliferous, calcareous, undulatory boundaries, well laminated 0.1

Thickness Bennett Shale Member 13.85

Glenrock Limestone Member

28. Limestone, medium brownish gray, aphanitic to microcrystalline matrix for common fusulinids (*Triticites* sp.), rare brachiopod fragments and spines, some medium- to dark-gray round spots that suggest worm burrows and contain some small *Orbiculoidea* fragments 0.25

Thickness Red Eagle Limestone 16.1

Johnson Shale

29. Shale, light brownish gray with light-gray argillaceous chalky lime nodules containing fusulinids and small brachiopods, earthy, calcareous, trace of carbonaceous plant remains, ostracodes, brown phosphatic remains 0.5

30. Shale, very light brownish gray with yellowish cast, well laminated, calcareous, trace of minute carbonaceous plant remains, lime nodules of similar color rarely contain tiny spinose brachiopods cf. *Chonetes*? 1.0

31. Shale, similar to above 1.0

32. Limestone, medium gray, nodular, up to 0.5 foot thick, aphanitic, very rare high-spired gastropods cf. *Leptoptygma* or *Anematina*?, weathered light buff, hard 0.5

33. Shale, medium gray, weathered light to medium buff, well laminated, trace of brachiopod fragments cf. *Linoproductus* (flattened), common black plant remains along some laminae 0.4

34. Limestone, similar to 32, hard 0.3

35. Shale, similar to 33, some small nodular aphanitic limestone with trace of gastropods 1.0

36. Shale, similar to above with *Linoproductus* commonly associated with limestone nodules 1.0

37. Limestone, light yellowish gray, hard, appears earthy, somewhat similar to mudstone below, aphanitic to microcrystalline, trace of ostracodes, possibly algal crystalline limestone in small 1-inch waves 0.8

38. Mudstone, light brownish gray, calcareous 1.0

Thickness Johnson Shale exposed 7.5

Highway 38 Section.—S-line sec. 21, T. 32 S., R. 8 E. In Kansas Highway 38 road cut, Cowley County, Kansas (Fig. 22).

Sample	Thickness, feet

Red Eagle Limestone

Howe Limestone Member

1-2. Limestone, light yellow brown; aphanitic to microcrystalline matrix for rare fossil fragments such as ostracodes, brachiopod fragments and spines; color due to finely divided limonitic material throughout, pitted and rounded top, medium to thin bedded within thicker major beds, slightly osagitic 2.0

3. Limestone, light buff with some pale-yellow tint, aphanitic to microcrystalline matrix for rare brachiopod fragments and small wavy algal sheets?, rare blebs of fine to medium clear calcite crystals, hard, some vugs 1.0

4. Limestone, similar to above, bedding as above, trace of ramose bryozoans and small brachiopods 1.0

Thickness Howe Limestone Member 4.0

Bennett Shale Member

5-7. Limestone, light brownish gray, microcrystalline matrix for fossils similar to above, some brachiopods nearly intact, some vugs, very hard, less weathered than above, some fragments of unidentified fenestrate bryozoans and ostracodes on weathered surface, random fine to medium clear calcite crystals throughout, fresh surface does not reveal the fossil material revealed on weathered surface, medium to thick beds, wavy to nodular bedding planes 3.0

8. Limestone, light brownish gray, aphanitic to microcrystalline matrix for obscure fossil debris much more finely broken than above, rare brachiopods and spines, extremely rare fusulinids 1.0
9. Limestone, similar to above, slightly more argillaceous 1.0
10. Limestone, medium grayish brown to light brownish gray, pitted to vuggy with medium secondary calcite crystals, varies to microcrystalline and aphanitic, weathered surface reveals brachiopod fragments and bryozoans not observable on fresh surface, *Wellerella*? 1.0
11. Limestone, similar to above, heavily pitted and weathered in this sample, only brachiopods seen 1.0
12. Limestone, light yellowish to brownish gray, aphanitic to microcrystalline matrix for common small brachiopod and ostracode fragments and spines, some limonite-lined leached-fossil pores 1.0
13. Limestone, medium grayish brown to light brownish gray, microcrystalline matrix for brachiopod fragments, interbedded argillaceous limestone with fossil fragments, linear algae? 1.0
14. Limestone, light gray with medium- to dark-gray wavy clay seams cf. northern Bennett shale as interbeds, aphanitic to microcrystalline matrix for profuse fossils similar to above but more finely divided, *Schuchertella*?, bryozoans, *Hustedia* 1.0
15. Limestone, light brownish gray, microvugular porosity, microcrystalline matrix for fossil fragments 1.0
16. Limestone, medium gray, aphanitic to microcrystalline matrix for fossils as above, some fenestrate bryozoans seen on weathered surface 1.0
17. Limestone, similar to above with some wavy linear algae, some weathered to light brown, wavy dark-gray clay interbeds, much secondary calcite crystals as in all units above 1.0
18. Limestone, medium to dark gray, weathered medium to light grayish brown, very shaly, sometimes varies to similar calcareous shale, moderately to well laminated, rare *Orbiculoidea* fragments and common brachiopod fragments of other types 0.2

Thickness Bennett Shale Member 13.2

Glenrock Limestone Member

19. Limestone, medium gray, very argillaceous, soft, abundant fusulinids, some crinoid discs and brachiopod fragments, *Composita* seen, rare wormy tubes of black clay, uneven, up to 0.5

Thickness Red Eagle Limestone 17.7

Johnson Shale

20. Marl, varies to soft very calcareous shale, light yellowish to brownish gray, trace of brown and black plant remains and brown or waxy plant remains, trace of frail lirate brachiopods and ostracodes 0.4
21. Limestone and shale; limestone medium gray, microcrystalline, up to 0.4 foot in place, argillaceous, fairly even textured, nodular lime lenticles in shale at random and in definite thin horizons; shale buff, probably weathered from medium gray, moderately to well laminated, calcareous, rare trace of brown carbonaceous material 1.0
22. Limestone and shale, as above, limestone is aphanitic, shale contains frail lirate brachiopod fragments and rare to common carbonaceous broken grassy plant fragments, long unbroken productid spines, trace of ostracodes, one lamina has profuse brachiopod and spine fragments with some ostracodes and common black plant remains, productid brachiopods common 1.0
23. Limestone and shale; shale light gray with rare plant remains and tiny ostracodes, calcareous; limestone aphanitic, light gray 1.0
24. Limestone, nodular, and shale, as above .. 1.0
25. Shale, medium gray, well to moderately laminated, calcareous, frail ostracodes, rare trace of very finely divided plant remains, *Linoproductus*? 0.8
    Limestone, medium gray, aphanitic, very tight, some rare vugs, hard 0.15
26. Shale and limestone, medium gray, interlaminated, trace of black plant remains, one possible fish scale seen and fragments of other brown phosphatic material, moderately to well laminated, trace of ostracodes 0.7
    Limestone, medium to light gray, very even thickness, some crude interlaminations, aphanitic, even textured, hard 0.1
    Conglomerate, calcareous and argillaceous granule- and sand-size particles of shale and fossil detritus in silty to microcrystalline calcareous matrix, ostracodes, microbrachiopods, possibly foraminifers, rare trace of vitreous coal material, rare trace of pyrite, conglomerate fragments come from unit below 0.2
    Shale, light brownish gray, calcareous, common carbonaceous plant remains, trace of *Wellerella*, rare trace of brown phosphatic remains, grades up to above 0.1
27. Limestone, light brownish gray, aphanitic, some random blebs of fine to medium crystalline calcite, argillaceous 0.7
28. Shale and mudstone, some off-white limy marly nodules, light yellowish gray, weathered from pale light greenish gray, calcareous 1.5
29. Shale, light to medium yellowish gray, very well laminated, calcareous, some off-white marly interlaminations 1.5
30. Shale, similar to above with slightly more laminations, calcareous, clayey 0.5
31. Mudstone, light brownish gray, calcareous, vaguely laminated, some carbonaceous plant remains common along the laminae, rare trace of ostracodes 1.0

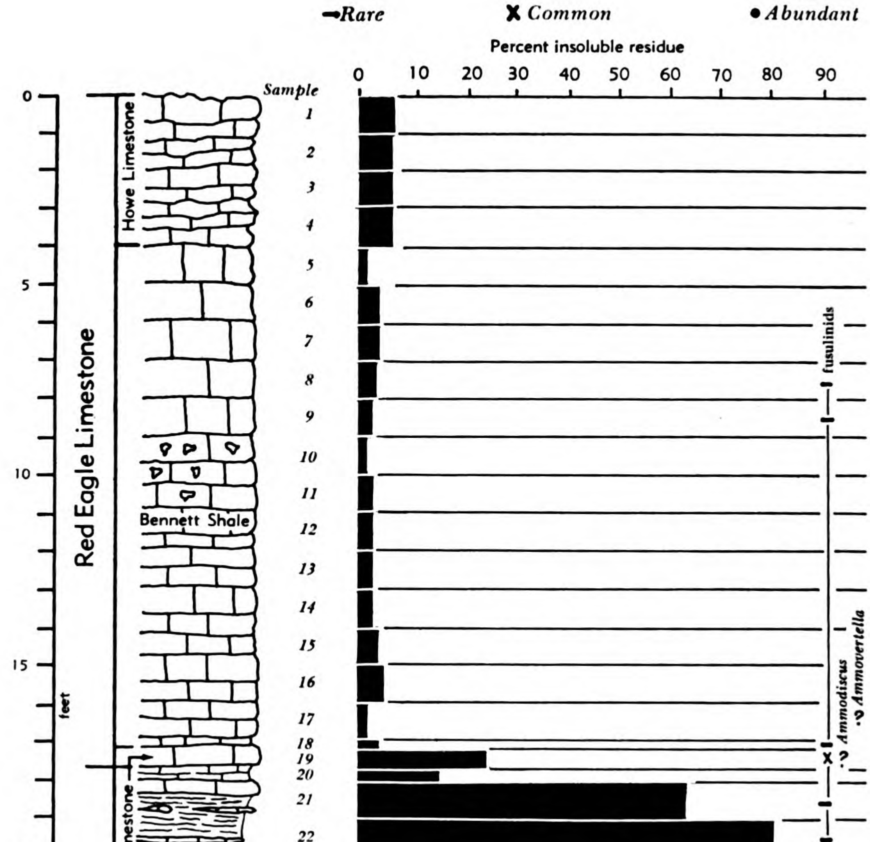
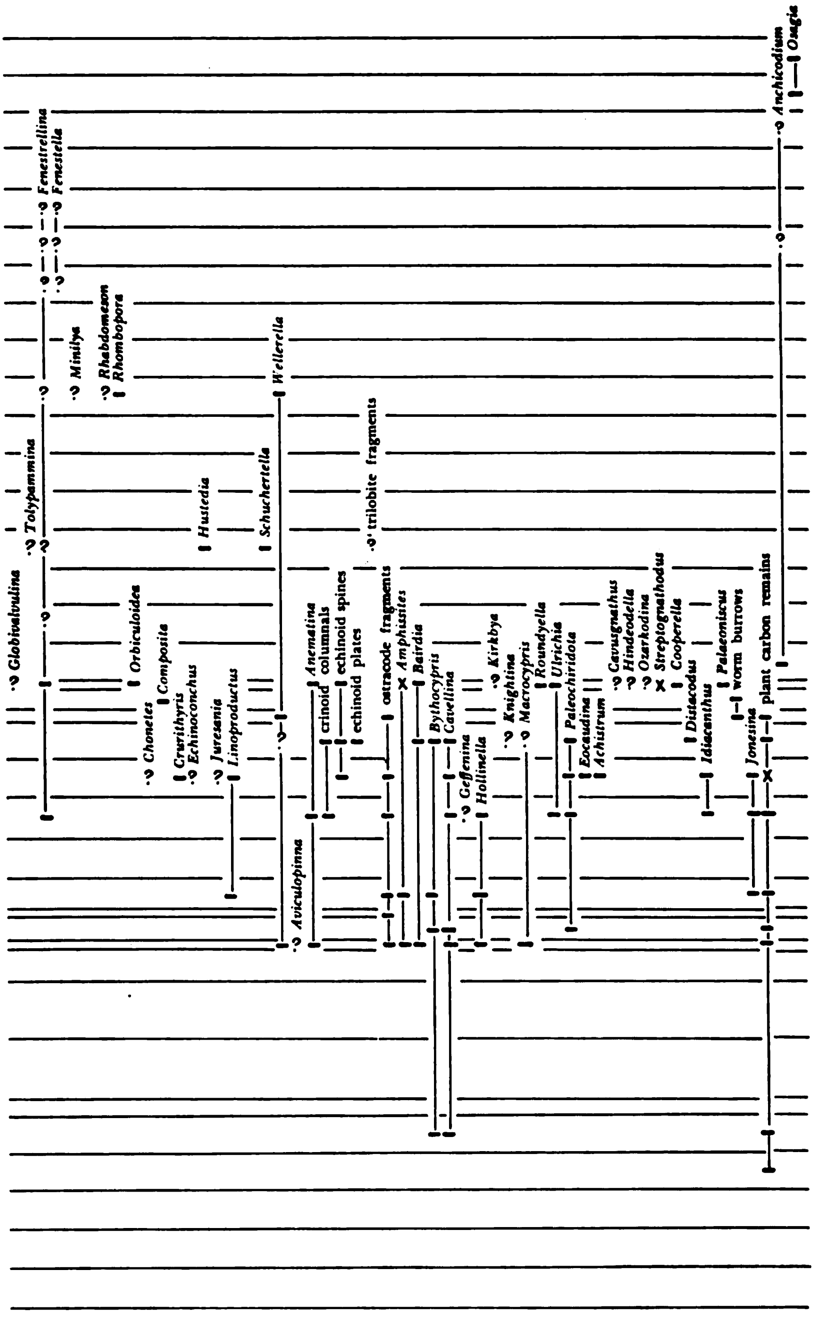


FIGURE 22.—Columnar section, insoluble residues, and fossils of the Highway 38 section.


Globivalvulina
Tolypammina
Fenestrellina
Fenestella
Minilya
Rhabdomeson
Rhombopora
Orbiculoidea
Chonetes
Composita
Crurithyris
Echinoconchus
Hustedia
Juresania
Linoproductus
Schuchertella
Wellerella
Aviculopinna
Anematina
crinoid columnals
echinoid spines
echinoid plates
trilobite fragments
ostracode fragments
Amphissites
Bairdia
Bythocypris
Cavellina
Geffenina
Hollinella
Kirkbya
Knightina
Macrocypris
Roundyella
Ulrichia
Paleochiridota
Eocaudina
Achistrum
Cavusgnathus
Hindeodella
Ozarkodina
Streptognathodus
Cooperella
Distacodus
Idiacanthus
Palaeoniscus
worm burrows
plant carbon remains
Jonesina
Anchicodium
Osagia

32. Mudstone, light to medium brownish gray, calcareous, very rare trace of plant fragments, very rare small sands and granules of crystalline tan limestone 1.0
33. Mudstone, similar to above with some greenish gray lime and shale grains and sands well rounded to angular 1.0
34. Mudstone, similar to above with some angular mud granules 1.0
35. Mudstone, light brownish gray, very calcareous, marly, somewhat similar above but rare sand grains 1.0
36. Mudstone, maroon, calcareous 1.0
Mudstone, maroon gray, calcareous, vaguely laminated, some granules of greenish gray shale 1.0
37. Mudstone, light greenish gray, calcareous with granules of brown limestone as below 0.5
38. Mudstone, similar to above with brown aphanitic microcrystalline medium- to dark-brown limestone in nodules and crude networks 0.7
39. Limestone, similar to material in nodules above, medium to dark brown and brownish gray, aphanitic to microcrystalline, trace of pale-green clay blebs, rare trace of ostracodes 1.3
40. Shale, light greenish gray to olive greenish gray, vaguely laminated, some random buff aphanitic lime nodules 0.5
41. Shale, light gray, calcareous, vaguely laminated, somewhat chalky, trace of brachiopods and ramose bryozoans 0.5
Covered 1.9

Thickness Johnson Shale 23.05

Red Eagle Section.—SW SE sec. 25, T. 28 N., R. 6 E. In south wall of road cut on east-west road 2 miles west of Foraker, Osage County, Oklahoma.

Sample	*Thickness, feet*
Red Eagle Limestone	
Bennett Shale Member	
1. Limestone, light brownish gray, microcrystalline matrix for clear calcitic brachiopod fragments, some limonite-lined vugs, hard, medium bedded, resistant	1.0
2. Limestone, light brownish gray, microcrystalline to medium crystalline matrix for brachiopod fragments, similar to above but larger vugs, medium bedded	2.0
3. Limestone, similar to above but few vugs, aphanitic to microcrystalline matrix for finely crystalline clear calcitic brachiopod fragments	1.0
4. Limestone, similar to 2	1.0
Thickness Bennett Shale Member exposed	5.0
Thickness Red Eagle Limestone exposed	5.0

Burbank Section.—Near center sec. 25, T. 26 N., R. 5 E. In quarry just north of Highway 66, ½ mile east of Burbank, Osage County, Oklahoma (Fig. 23).

Sample	*Thickness, feet*
Roca Shale	
1. Shale, light yellowish gray brown, probably weathered from medium gray, calcareous, trace of dark-gray carbonaceous remains, some light-gray chalky lime nodules, silty?	1.0
2. Shale, buff, weathered from medium gray, rare traces of carbonaceous grassy plant remains, ostracodes at random, gastropods cf. *Anematina*	1.0
3. Mudstone, light brownish gray, round granules of crystalline limestone, off-black nodules and other possible shale detritus, calcareous	1.0
4. Mudstone, light brownish gray, calcareous	1.0
5. Mudstone, light yellowish to brownish gray, calcareous, moderately to poorly laminated	1.0
6. Mudstone, light yellowish brown	1.0
7. Mudstone, light pinkish gray, calcareous ..	1.0
8. Mudstone, light pinkish gray, calcareous, chalky	1.0
9. Mudstone, light pinkish gray, calcareous ..	1.0
10. Mudstone, similar to above	1.0
11. Mudstone, light brick red	1.0
12. Mudstone, similar to above	1.0
13. Mudstone, brick red	1.0
14. Mudstone, medium to light brick red	1.0
15. Mudstone, similar to above	1.0
16. Mudstone, medium to dark brick red	1.0
17. Mudstone, similar to above	1.0
18. Mudstone, light greenish gray to olive green with some brick-red flecks, grading to brick-red mudstone, calcareous	0.2
19. Mudstone, red and green as above with small light-gray chalky lime nodules, some greenish and brownish-red weathering	0.3
Thickness Roca Shale	17.5
Red Eagle Limestone	
Howe Limestone Member	
20. Limestone, light brownish gray, hard, thick to thin very irregular bedding, pitted, weathers light rusty to yellowish gray, microcrystalline to fine crystalline matrix for possible fossil fragments, trace wormy brick-red argillaceous stringers at random which probably yield pitting when weathered	0.5
21. Limestone, medium to light brown and yellowish and grayish brown, brick-red stringers of argillaceous material similar to shale above, aphanitic to finely crystalline, trace of crinoid discs, weathers to light rusty yellow	0.5
22. Limestone, similar to above with 50 percent brick-red argillaceous limestone stringers	1.0
23. Limestone, similar to above	1.0
24. Limestone, light brownish gray; microcrystalline matrix for traces of ostracodes, brachiopod fragments, and crinoid discs; some brick-red argillaceous limestone stringers, probably 22 and 23 were similar before weathering turned them yellow	1.0
Thickness Howe Limestone Member	4.0

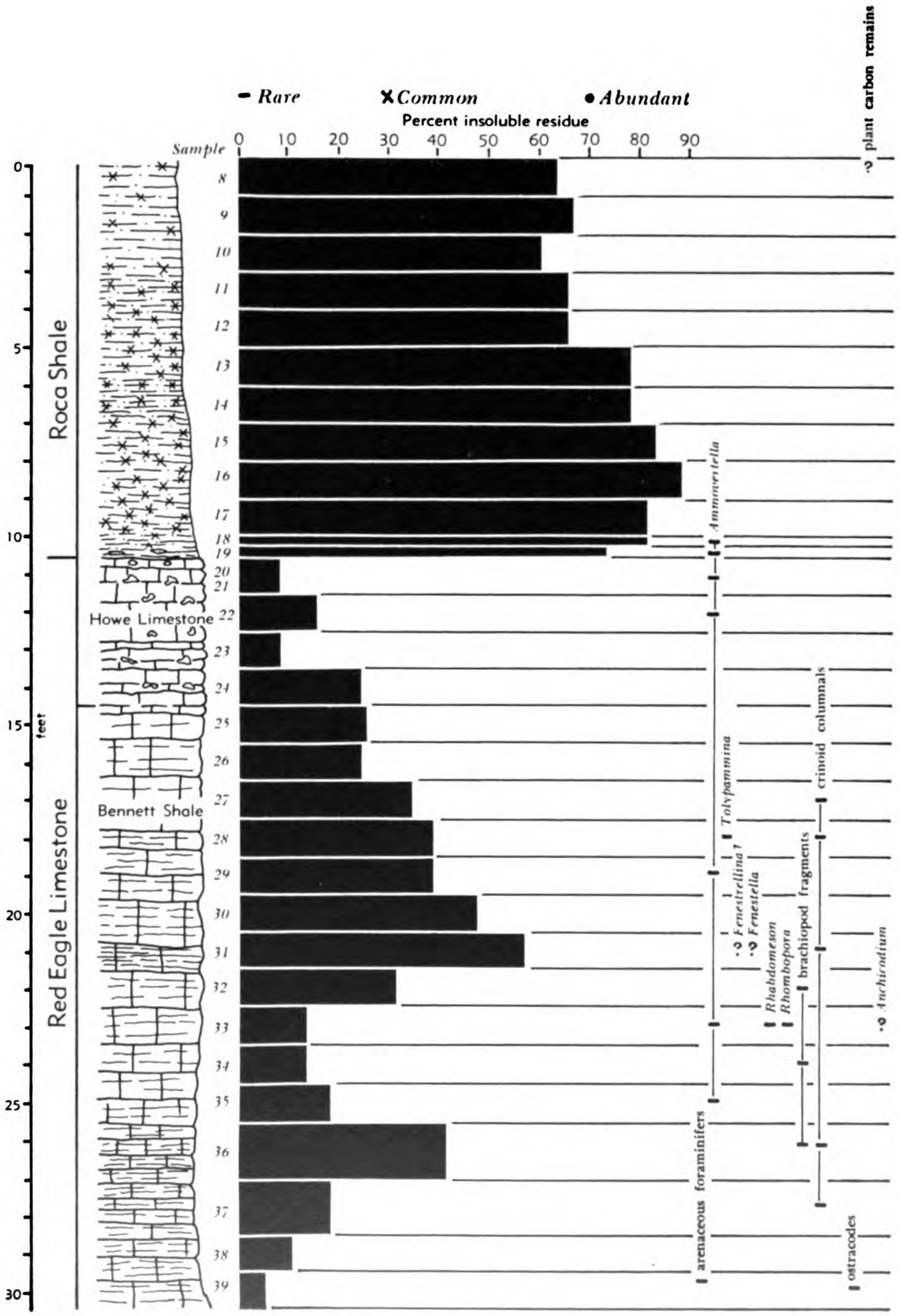


FIGURE 23.—Columnar section, insoluble residues, and fossils of the Burbank section.

Bennett Shale Member

25. Limestone, medium to light greenish gray, somewhat argillaceous, aphanitic to microcrystalline matrix for rare crinoid discs and brachiopod fragments, medium bedded, locally more or less argillaceous along beds, almost shaly in some places 1.0
26. Limestone, similar to above, some small dark-brick-red wormy stringers, trace of coated shell fragments (*Osagia*?) 1.0
27. Limestone, similar to above, large brachiopod fragments (*Neospirifer*?) 1.0
28. Limestone, medium to light greenish gray, microcrystalline to aphanitic-argillaceous matrix for common crinoid discs, some discs single, some discs articulated, fairly soft, grades to harder laterally 1.0
29. Limestone, similar to above but harder 1.0
30. Limestone, similar to 28 .... 1.0
31. Limestone, light to medium greenish gray, fine grained to aphanitic matrix for common crinoid remains, rare brachiopod fragments and very rare fenestellate bryozoans with crude orientation parallel to bedding planes, hard 1.0
32. Limestone, similar to above 1.0
33. Limestone, light brownish gray, hard, microcrystalline matrix for fossils as above, stringers and intrabeds of shaly lime material and limy shale which grade in and out laterally, possibly linear algae, trace of fenestellate bryozoans 1.0
34. Limestone, light brownish gray, hard, resistant, microcrystalline-aphanitic matrix for brachiopod fragments, more argillaceous interbeds 1.0
35. Limestone, medium to light brownish gray, similar to above but slightly more argillaceous as in 31 .... 1.0
36. Limestone, similar to above, medium brownish gray, argillaceous aphanitic matrix with crinoid stems common in crude preferred orientation; grades in and out laterally into medium-gray very shaly laminated limestone with traces of brachiopod fragments, more argillaceous with shaly interbeds below this bed 1.5
37. Limestone, similar to above 1.5
38. Limestone, medium brownish gray, somewhat shaly, crudely laminated, similar to above, aphanitic 1.0
39. Limestone, similar to above, some thin wavy dark-gray calcareous shale interbeds, contains productid spines, rare ostracodes, brachiopod fragments 1.0
40. Limestone, similar to above 1.0

Thickness Bennett Shale Member exposed 17.0

Thickness Red Eagle Limestone exposed 21.0

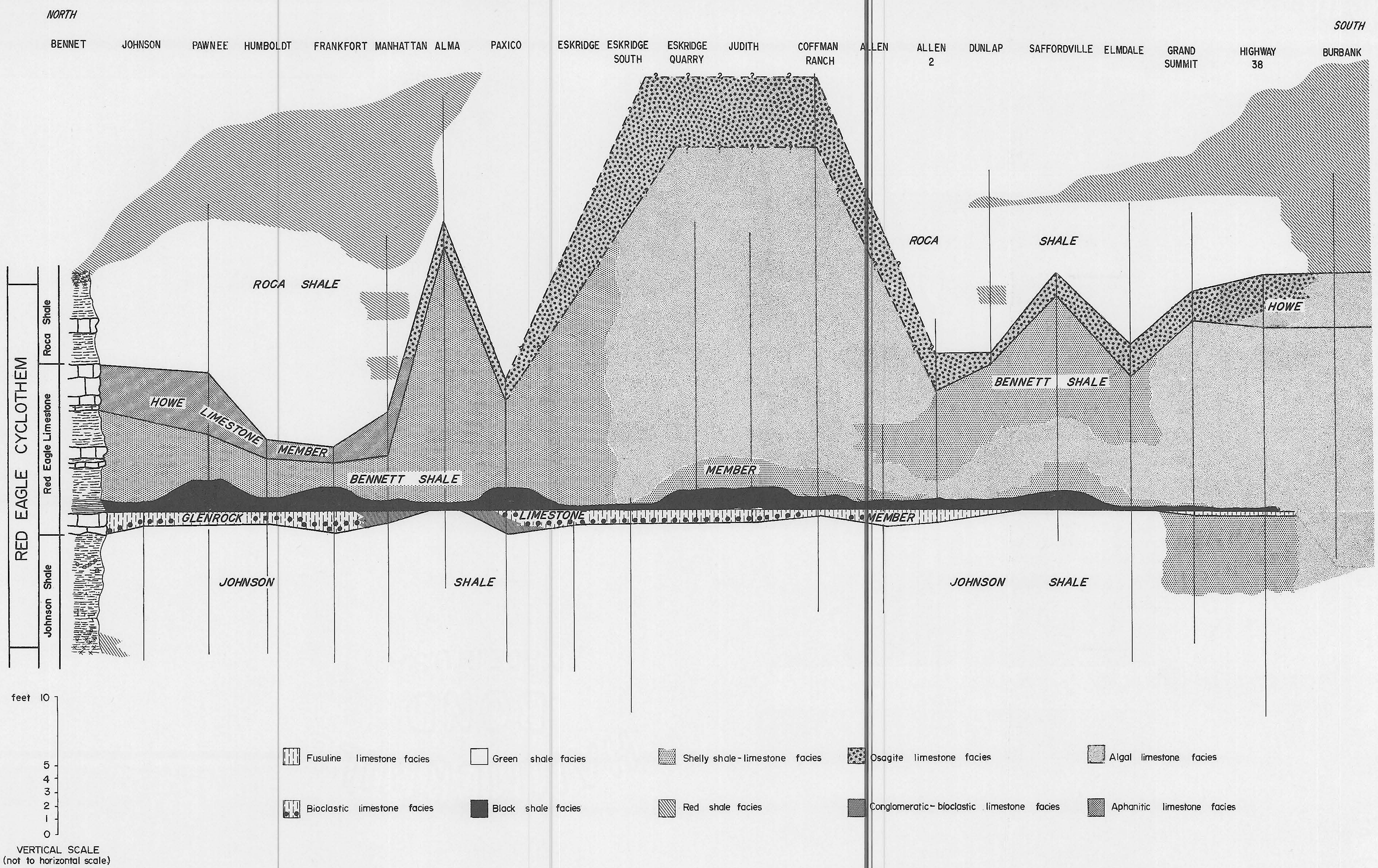


Figure 6—Diagrammatic cross section showing arrangement of Red Eagle cyclothem facies along line from Bennett, Nebraska, to Burbank, Oklahoma. Diagram corresponds to correlated columnar sections in Figure 2.