THE RED EAGLE CYCLOTHEM
(Lower Permian)

by

Alistair William McCrone
B.A., University of Saskatchewan, 1953
M.S., University of Nebraska, 1955

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Advisory Committee:

R. C. Moore
Chairman

H. A. Ireland

Walter H. Hollingsworth

December, 1960

CONTENTS

Page

ABSTRACT 1

INTRODUCTION 3

Purpose and scope of investigation 3

Area of investigation 4

Stratigraphic position of the Red Eagle Cyclothem 7

Previous geologic work 9

Methods of investigation 12

Field procedures 12

Laboratory procedures 13

Acknowledgments 15

STRATIGRAPHY 16

Structural-Stratigraphic setting 16

General statement 18

Johnson Shale 21

Red Eagle Limestone 31

Glenrock Limestone 35

Bennett Shale 49

Howe Limestone 67

Roca Shale 72

MINERALOGY 77

PALEONTOLOGY 79

Paleobotany 79

Paleozoology 81

General statement 81

Stratigraphical paleontology 84

Page

PALEOECOLOGY 89

General statement 89

Marine plants 90

Calcareous algae 90

Marine and brackish-water plants 94

Charophytes 94

Spores 94

Carbonized terrestrial plant materials 94a

Marine animals 94a

Foraminifers 94a

Bryozoans 102

Brachiopods 105

Gastropods 108

Pelecypods 110

Worms 110

Ostracodes 111

Crinoids 115

Echinoids 116

Conodonts and fish remains 117

Fossil assemblages 118

PALEOSEDIMENTATION 122

Introductory remarks 122

Deposition of the Johnson Shale 124

Deposition of the Red Eagle formation 133

Glenrock Limestone 133

Bennett Shale 140

Howe Limestone 155

Page

Deposition of the Roca Shale 164

Cyclothemic nature of the deposits 169

DIAGENESIS 174

SYNTHESIS 178

Environmental history of the Red Eagle Cyclothem 178

CONCLUSIONS 185

APPENDIX I 190

Laboratory techniques 190

Insoluble residue technique 190

Acetate peel technique 192

Washed shale technique 195

APPENDIX II 196

List of observed Red Eagle Cyclothem outcrop localities 196

APPENDIX III 198

Detailed descriptions and graphic diagrams of sampled Red Eagle Cyclothem sections 198

Bennet section 199

Johnson section 202

Humboldt section 204

Pawnee section 206

Frankfort section 210

Manhattan section 212

Alma section 215

Paxico section 218

Keene section 221

Eskridge section 222

Eskridge Quarry section 224

Page

Eskridge South section 226

Judith section 227

Coffman Ranch section 229

Coffman West section 232

Allen section 233

Allen No. 2 section 235

Dunlap section 238

Saffordville section 240

Elmdale section 242

Turnpike section 245

Sallyards section 246

Piedmont section 247

Grand Summit section 248

Highway 38 section 253

Red Eagle section 257

Burbank section 258

REFERENCES 261

ILLUSTRATIONS

PLATE — Facing Page

1. Upper Johnson laminated calcisiltite and platestone at Johnson and Pawnee sections 22

2. Upper Johnson limestone and platestone at Pawnee and Keene sections 24

3. Red Eagle Limestone at Red Eagle section and limestone of Bennett Shale at Grand Summit section 31

4. Glenrock Limestone at Pawnee section 38

5. Uppermost Glenrock Limestone and top of Glenrock Limestone at Pawnee section. Lingula in basal Bennett Shale at Bennett section 38

Facing Page

6. Glenrock limestone at Manhattan section 40

7. Glenrock limestone at Coffman section 43

8. Glenrock limestone at Allen section 44

9. Johnson Shale - Red Eagle Limestone contact at Elmdale section. Sample of uppermost Johnson Shale at Elmdale 44

10. Allen section: showing Glenrock and Bennett members of Red Eagle Limestone 44

11. Algal limestones in Bennett member at Saffordville section 60

12. Algal crusts in Bennett limestones from Elmdale and Highway 38 sections 61

13. Bennett limestone from Piedmont section 62

14. Algal "buns" at top of Howe Limestone at Allen No. 2 section. Pelletoid Howe Limestone from Alma section 69

15. Vertical section of algal "bun" from Allen No. 2 section 70

16. Pelletoid Howe Limestone from Allen No. 2 section 70

17. Base of limestone bed in Roca Shale at Pawnee section 74

18. Stratigraphic position of Red Eagle Cyclothem fossils 84

19. Red Eagle Cyclothem correlations (chart) 198

20. Bennet section 199

21. Johnson section 202

22. Humboldt section 204

23. Pawnee section 206

24. Frankfort section 210

25. Manhattan section 212

26. Paxico section 218

27. Eskridge section 222

Facing Page

28. Eskridge Quarry section 224

29. Coffman Ranch section 229

30. Allen section 233

31. Allen No. 2 section 235

32. Saffordville section 240

33. Elmdale section 242

34. Grand Summit section 249

35. Highway 38 section 253

36. Burbank section 258

FIGURES

Page

1. Red Eagle Cyclothem outcrop belt showing locations of key sections and major structures 5

2. Location of and cross section through thick Bennett limestone facies in Eskridge-Coffman Ranch area 55

3. Composite section of Red Eagle Cyclothem and interpreted depths of deposition 172

4. Explanation of symbols used in plates 19 to 36 198

TABLES

TABLE

1. Stratigraphic placement of Red Eagle Cyclothem units in Lower Permian rock succession of Kansas..... 8

2. Animal remains recognizable in the Red Eagle Cyclothem 82

3. Idealized Lower Permian cycle of deposition in north-central Kansas, modified from Elias and Hattin 120

4. Units of the Red Eagle Cyclothem defined in terms of Elias (1937) but showing depths of deposition determined by this study 171

5. Summary of interpreted ecologic conditions during deposition of definitive faunal-lithologic phases in the Red Eagle Cyclothem 187

THE RED EAGLE CYCLOTHEM

by

A.W. McCrone

ABSTRACT

The Red Eagle Cyclothem, a Lower Permian marine sedimentary rock succession, includes rocks of the Johnson Shale, Red Eagle Limestone and Roca Shale formations. Despite facies changes these 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 basis for interpretations of its paleosedimentation and the paleoecology of its plant and animal mega- and microfossils. Acetate peels and insoluble residues studies were used to advantage.

Postulates concerning the approximate physical and chemical characteristics of the Red Eagle Cyclothem waters are attempted. The assembled evidence supports Elias's (1937) proposal that the depositional environments of the various faunal-lithologic phases of the cyclothem were most directly controlled by marine water depths which ranged between approximately 10 and 180 feet.

Accumulation of red muds in shallow waters 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 upper part of the Johnson Shale were similar to those which later produced the lower part of the Roca Shale. In the meantime the Red Eagle limestones and their shaly equivalents accumulated in the deepest, lime-rich waters of the cyclothem.

Fossil spores present in the Red Eagle Cyclothem seem similar to later Permian floral assemblages from other parts of the world.

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 of origin remain. The subject is still open, especially in the Lower Permian of Kansas, where many cyclothems remain to be studied in detail. Understanding of the broader aspects of the origin of cyclothems and of Permian cyclothemic history cannot be expected until most or all of the Lower Permian cyclothems have been examined carefully.

This investigation of the Red Eagle Cyclothem is the outgrowth of personal 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, because the Red Eagle Cyclothem extends from the Johnson Shale through the Red Eagle Limestone into the Roca Shale.

The present objective is to interpret the paleosedimentary and paleoecological setting that yielded lithofacies and biofacies recognizable as the Red Eagle Cyclothem in Kansas. This approach entails explanations

of certain facies patterns that hindered attempts by earlier stratigraphers to trace the cyclothems across Kansas. Moreover, the investigation supplies information which, in supplementing the work of others, may contribute to understanding of Permian cyclothems and geologic history in the classic Midcontinent region of Kansas and Nebraska. It is hoped that this study may contribute data toward a future report on Permian rocks such as that on the Pennsylvanian System in Kansas by Moore (1949).

Area of Investigation

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

Well-exposed sections are rare. Most limestone members form minor topographic benches, but shales commonly lie beneath shallow 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

Figure 1

RED EAGLE CYCLOTHEM OUTCROP BELT
SHOWING LOCATIONS OF KEY SECTIONS AND MAJOR STRUCTURES

NUMBERED KEY SECTIONS
1 Bennet
2 Johnson
3 Humboldt
4 Pawnee
5 Frankfort
6 Manhattan
7 Alma
8 Burlingame
9 Keene
10 Eskridge
11 Eskridge Quarry
12 Eskridge South
13 Judith
14 Coffman Ranch
15 Allen
16 Emporia
17 Duplan
18 Madison
19 Elmdale
20 Turnpike
21 Ballyards
22 Strong City
23 Grand Summit
24 Highway 56
25 Red Eagle
26 Burbank

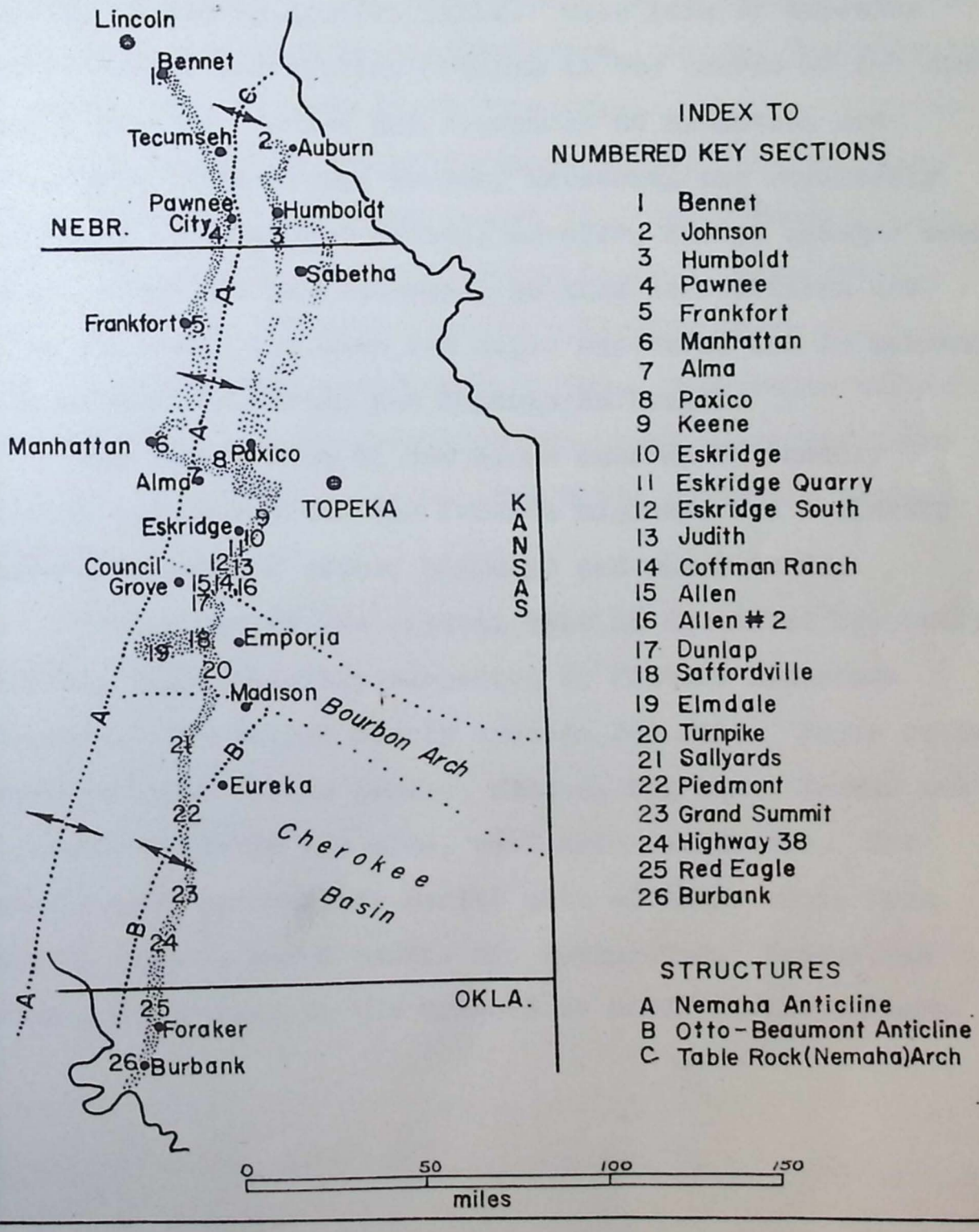
STRUCTURES
A Nemaha Anticline
B Otto-Beaumont Anticline
C Bourbon Arch

Lincoln
Tecumseh
Auburn
Pawnee
Humboldt
Sabetha
Frankfort
Marysville
Blue Rapids
Waterville
Alma
Eskridge
Council Grove
Emporia
Madison
Strong City
Foraker
Burbank
Barbour Basin
Bourbon Arch
TOPEKA
KANSAS
NEBR.
OKLA.
miles

Figure 1

RED EAGLE CYCLOTHEM OUTCROP BELT

SHOWING LOCATIONS OF KEY SECTIONS AND MAJOR STRUCTURES



INDEX TO
NUMBERED KEY SECTIONS

1 Bennet
2 Johnson
3 Humboldt
4 Pawnee
5 Frankfort
6 Manhattan
7 Alma
8 Paxico
9 Keene
10 Eskridge
11 Eskridge Quarry
12 Eskridge South
13 Judith
14 Coffman Ranch
15 Allen
16 Allen # 2
17 Dunlap
18 Saffordville
19 Elmdale
20 Turnpike
21 Sallyards
22 Piedmont
23 Grand Summit
24 Highway 38
25 Red Eagle
26 Burbank

STRUCTURES

A Nemaha Anticline
B Otto-Beaumont Anticline
C Table Rock(Nemaha)Arch

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 tills. This lack of exposure presented no correlation problem in the course of the Red Eagle studies because the sequences at Manhattan and Frankfort, Kansas, and Pawnee, Nebraska, are remarkably similar. 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 Nebraska and between Manhattan and Emporia in Kansas.

The entire belt of Red Eagle outcrop is readily accessible from state and federal highways and a closely spaced network of county highways and minor roads.

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, with 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.

Stratigraphic Position of the Red Eagle Cyclothem

The Lower Permian of Kansas contains many cyclic repetitions of lithologic sequence. Each cycle of rocks is called a cyclothem. Each cyclothem is named from its principal limestone formation. Thus, the Red Eagle Cyclothem is named from the Red Eagle Limestone.

The Red Eagle Cyclothem embraces the Johnson, Red Eagle and Roca 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 (Moore and Moss, 1934). Red shales within the Roca and Johnson formations mark 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 Geologic Work

The area of this investigation, famous for its distinctive Pennsylvanian and Permian rocks, for over 100 years has been visited and studied by geologists from all parts of the United States and several foreign countries.

Some of the earliest scientific explorers of America noted these rocks, sampled their profuse fossil remains, measured and described sections. Swallow and Hawn (1858) published the earliest reference to Permian rocks in Kansas. Meek and Hayden (1860) added more, 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 the literature. The newer 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 and Roca formations were named by Condra (1927) and 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 (1953, 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."

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 was greatly amplified by Elias (1937) when he described the faunas associated with the sequences of lithologic units making up the cycles of the Lower Permian ("Big Blue Series") of Kansas. Elias's principal postulate is 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.

Several recent county reports published by the State Geological Survey of Kansas and the United States Geological Survey contain brief general descriptions and measurements

of rocks of the Red Eagle Cyclothem. References to these reports appear in the bibliography.

Methods of Investigation

Field Procedures

During preliminary field reconnaissance for this project in the fall of 1956, primary interest in 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.

Most Red Eagle exposures are readily accessible by car, but some of the creek-bank outcrops must be reached on foot.

Approximately 50 exposures were examined. Of these, 22 were measured, sampled and described in detail.

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

Limestones were 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. More than a ton of shale and limestone samples were taken in the manner described.

Laboratory Procedures

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

Representative small limestone samples were broken to pea-size, using mortar and pestle. A weighed quantity of each broken sample was then digested in dilute (10 percent) hydrochloric acid, following procedures described by Ireland (1936, 1958). Insoluble residues from each digested sample were weighed, and later studied under the binocular microscope. Percentage (by weight) of insoluble material in each sample was computed and expressed in bar graphs beside a work sheet showing the graphic rock column (Appendix III). 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 insignificant, but conodonts were preserved in residues obtained with acetic acid and

not those using hydrochloric acid. Detailed description and evaluation of the special insoluble residues technique used in this study appears in Appendix I.

Microfossils were picked from the insoluble residues and identified as to genus.

Shale samples were boiled in a dispersant solution to liberate mega- and microfossils. Dispersed silts and clays were usually decanted. Some dispersed clays were 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. Detailed description of "washed-shale" technique is given in Appendix I.

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 dried, acetate film was pressed against them to obtain on the film an impression of the rock texture. These films were then used in a photographic enlarger to make magnified photographic prints (peel-prints) of the textural details. The technique used to prepare the acetate peels for this study differs in several respects from common procedures. It was faster, but results were approximately the same. (Detailed explanation of this technique appears in Appendix

I.) Later in the project the polished limestone surfaces were compared and studied alongside the magnified peel photographs.

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

Acknowledgements

To the several members of the Kansas Geological Survey who have helped me in this work I offer my sincere appreciation.

I wish to thank Profs. L.F. Dellwig, F.C. Foley, and H.A. Ireland for making special facilities available to me at critical times.

The help of Mr. H. Cousminer, who identified the fossil spores, is gratefully acknowledged.

To Prof. Raymond C. Moore who supervised this work from its inception, I extend my greatest thanks.

STRATIGRAPHY

Structural-Stratigraphic 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; 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 or had been initiated in Red Eagle time they might have influenced the cyclothemic sedimentary facies. Figure 1 shows significant structures.

In southern Kansas (Cowley and Elk counties) the Red Eagle Limestone crops out close to the axis of the Otto-Beaumont anticline. The outcrop belt is closely parallel to this structural trend.

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-Bourbon arch area of Chase County, and the Nemaha-Alma

arch areas 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 "extra-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.

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 Appendix III. Plate 19 (Appendix III) is a simplified north-south cross section through localities shown on Figure 1, showing fundamental correlations of rock units within the Red Eagle Cyclothem.

General Statement

The gray shales and mudstones 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. Where best exposed, near Manhattan, Kansas, the Red Eagle Limestone is a sort 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 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.

The Bennett member can be readily recognized by its basal "black" Orbiculoidea-bearing shale that rests on the distinctive Glenrock Limestone. The gray shales and rare

limestones of the Bennett member may also be identified by their relations to the overlying (equally distinctive) Howe Limestone.

The Howe member is a massive limestone unit 2 or 3 feet thick. In a number of localities it is uniquely pelletoid (pseudo-oolitic). The pellets are coatings of calcium carbonate around tiny nuclei such as foraminifers or ostracodes.

The Roca Shale is easily identified by its position above the Howe Limestone. The top of the Roca is equally well defined 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 shales are common in the midst of the principal gray and greenish-gray shales of the Roca Shale.

The three members of the Red Eagle "sandwich" merge to form the thick Red Eagle Limestone of southern Kansas and northern Oklahoma. In the same area, as farther north, Johnson and Roca Shales are readily recognizable by their relations to the distinctive Red Eagle Limestone and to other marker horizons above and below. Near Burbank, Oklahoma, 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 remain similar to those in

the outcrop belt. Well records of the Kansas Geological Survey yield little information about rocks in the Red Eagle part of the column. Marker beds above and below the Red Eagle Cyclothem are all that can be safely identified, and these are known chiefly from electric logs. Sample logs of rocks between the markers (especially the shales) are muddled because of cavings and the thinness and numerous alternations of the various lithic components. This precludes the reconstruction of accurate detailed sections from the few available cuttings samples. Hattin (1958, p. 107) reported similar difficulties.

The available electric logs and sample logs permit identification of the Red Eagle limestones, and provide a general impression of Johnson and Roca shales. A fundamental similarity of subsurface sections to outcropping sections is indicated. 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. These data indicate that, in the southeastern quadrant of Kansas, major facies patterns of the Red Eagle Cyclothem developed in roughly east-west belts. Well data reveal the presence of gray and red shales in the Roca Shale, and gray shales in the Johnson Shale. Traces of selenite seem to be present near the redbeds in the subsurface Roca. Only

the predominant limestone components of the Red Eagle formation are identifiable. The thin Bennett Shale is not recognized in the subsurface.

Johnson Shale

The Johnson Shale was named by Condra (1927, p. 86).

> "From exposures 1 1/2 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 is still well exposed in a creek bank north of Johnson, Nebraska, approximately where Condra indicated (Johnson section, Appendix III). However, Johnson is in Nemaha (not Johnson) County, Nebraska. This location is east of the axis of the Table Rock (Nemaha) anticline (Fig. 1).

At the type locality 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 comprised mainly of medium- to light-gray mudstones. Greenish-gray shales occur just above the middle of the unit, and medium-gray shales comprise the upper 2 feet. The medium-gray, moderately laminated, highly calcareous (50 percent), slightly silty shales of

the upper 2 feet weather to a light-buff color. Some of the shales seem to be vaguely ripple-marked. Laboratory examination reveals the presence of fish teeth, ostracodes, and small gastropods.

A thin, light brownish-gray, argillaceous limestone underlies the upper, fossil-bearing shales. In the field this limestone appears aphanitic or microcrystalline, but actually it is a laminated argillaceous calcisiltite with a few angular calcareous mudstone fragments (Pl. 1A). It shows vague small-scale diastems and graded bedding. Fragments of carbonized woody-plant detritus are present in the light greenish-gray mudstones that immediately underlie the aforementioned limestone.

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

At the northernmost exposure, near Bermet,[1] Nebraska, the Johnson Shale is similar to the type section, with only a few minor differences in general aspect. This location

1. The spelling "Bennet" is correct for the town but not for the rock unit named from this locality.

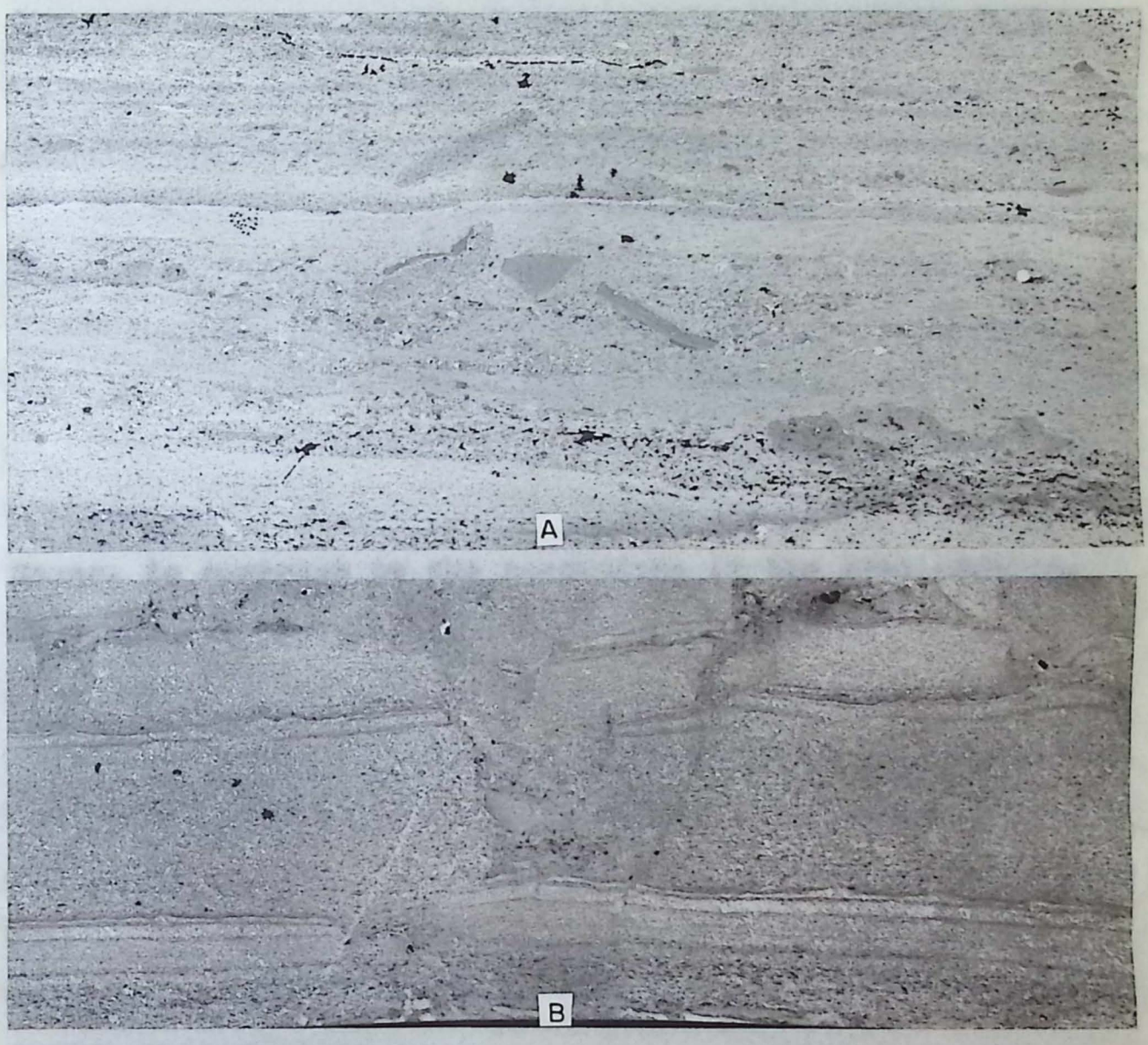


Plate 1

A. Enlarged (X3) peel-print of laminated argillaceous calcisiltite of upper Johnson Shale at Johnson section. Note the angular calcareous mudstone granules.

B. Peel-print (X3) of upper Johnson "platestone" at Pawnee section.

is about 25 miles northwest of the axis of the Table Rock (Nemaha) anticline. The Johnson Shale is about 16 feet thick at the Bennet section (Appendix III). The upper 2 feet of medium-gray, well-laminated shale is equivalent to the upper 2 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 shales. The lower half of these is somewhat more calcareous than the upper, in contrast to the conditions at the type section.

A thin, brick-red shale which seems to have no red equivalent anywhere else appears in the middle of the Johnson Shale at the Bennet section. Shales with limestone lenses near the base of the Bennet section (Appendix III) seem equivalent to the mudstones with limestone nodules near the base of the type 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) anticline axis (Pawnee section, Appendix III), the Johnson Shale is composed of mudstones, also very similar to those at the type locality. Rare fragments of carbonaceous plant remains occur in thin, shaly, medium-gray mudstones in the top foot of the unit. These fine-silty mudstones contain 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 noncalcareous 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 (Pl. 1B). This unit yields platy debris, and is called "platestone" for convenience in the following descriptions. Commonly this unit is calcareous. It can be traced southward at least as far as Eskridge, Kansas.

The remainder of the formation at the Pawnee section is mainly gray and greenish-gray mudstones and calcareous muddy siltstones. They rest on pitted, light-brown, sublithographic Long Creek Limestone. This uniform sequence is interrupted only by a massive foot of argillaceous limestone, vaguely nodular in some places, which occurs about 2 feet below the platestones. Megascopically this limestone appears uniformly microgranular to aphanitic. However, magnified peel-prints reveal that it contains minute wavy laminations associated with microscopic graded textures (Pl. 2A), suggesting faint diastems.

About 20 miles east of the Pawnee section, 0.5 miles east of the Humboldt fault, the upper portion of the Johnson Shale is exposed in a small road cut (Humboldt section,

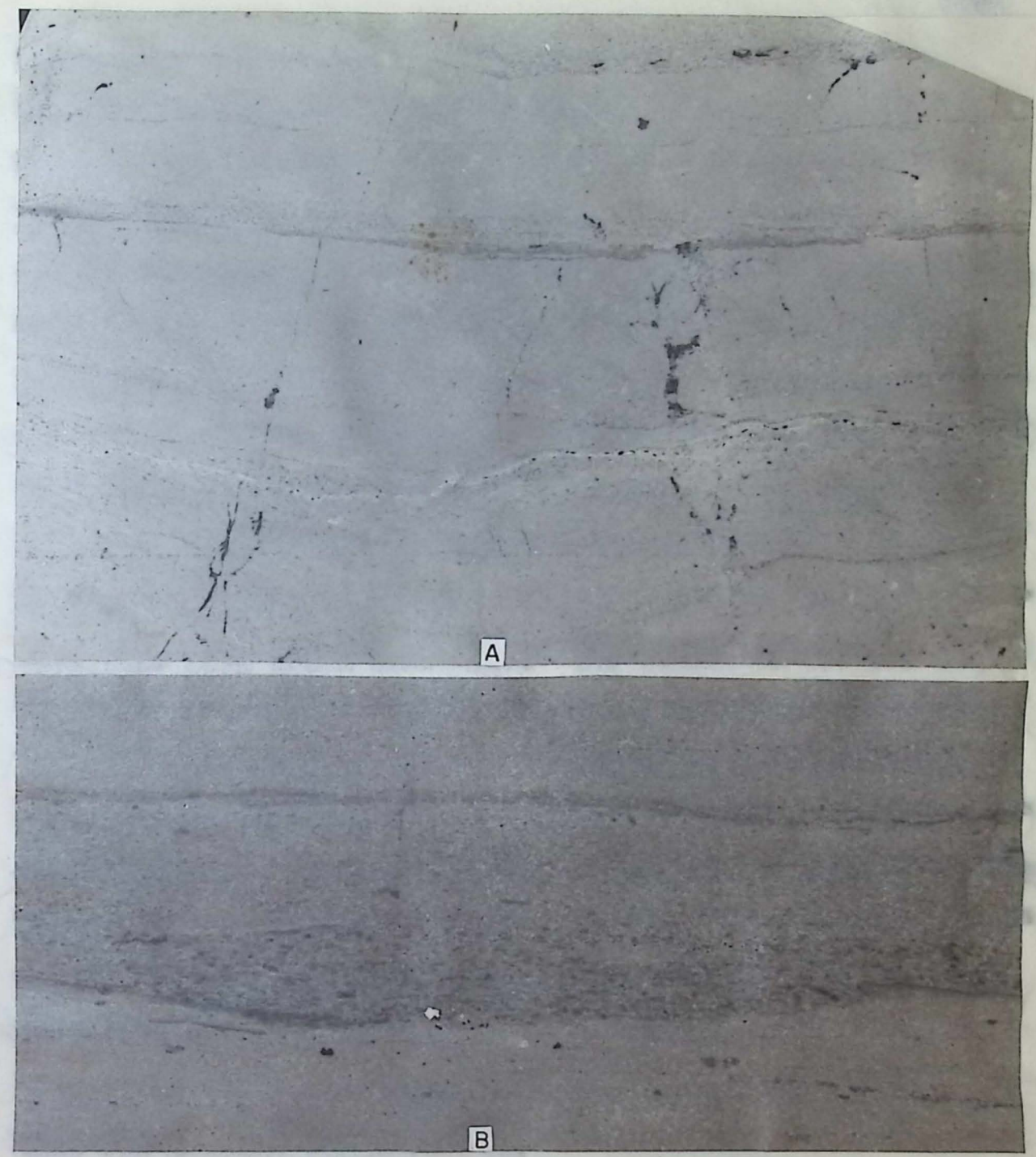


Plate 2

A. Peel-print (X3) of limestone in Johnson Shale at Pawnee section. Note wavy laminae and microscopic graded texture.

B. Peel-print (X3) of upper Johnson platestone at Keene section. Note laminae and microscopic graded textures.

Appendix III). The upper Johnson sediments resemble those at the Pawnee section in general appearance, but they are more calcareous. In carbonate content they resemble the upper Johnson at the type section. At the Humboldt section a thin uppermost shale unit of the Johnson Shale correlates with shales in analogous position at the other Nebraska sections. The difference at Humboldt is that these upper shales are deeply weathered from their original gray color to a light yellowish buff.

The Frankfort section lies just west of the axis of the Nemaha anticline, about 30 miles south of the Pawnee section. Only the upper portion 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 manifest farther north. Ostracodes occur in shales between these units. Here the platestone is a limestone, thinly laminated, yielding platy debris much more brittle than the argillaceous equivalents to the north. The bulk of the Johnson Shale at Frankfort consists of calcareous, light-gray and greenish-gray shales and mudstones typical of the Johnson Shale elsewhere.

At the Manhattan section the Johnson Shale is largely light-gray shales, with some light greenish-gray shales in the lower half. The section is as thick (16 feet) here as in Nebraska where other complete sections 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. Above it are the usual ostracode-bearing light-gray shales, topped by a foot of well-laminated shales containing traces of crinoid, bryozoan, brachiopod, and ostracode remains. These uppermost shales correlate with beds similar in position and lithology farther south. Beneath the platestone unit, the medial few feet of the formation contain light-buff to gray argillaceous limestones and highly calcareous light-gray shales. Greenish-gray and gray, slightly calcareous shales comprise the lower 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 III) 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 platestones occur here, overlain by the equally familiar ostracode-bearing gray shales of the uppermost Johnson. Slumping confuses suprajacent beds, but the fossils certify that the sampled shales are 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 portion of the Johnson Shale is well-exposed at the Paxico section (Appendix III). Three feet of the

typical gray, well-laminated, ostracode-bearing shales top the formation, and rest on 4 feet of calcareous mudstones. These in turn rest on the platestones. Thus, at the Paxico section, there is about twice the usual thickness of Johnson sediments above the platestone horizon. Moreover, the platestones themselves are comparatively even-textured and less argillaceous than at other sections. Light greenish-gray mudstones lie beneath the platestones.

At the Keene section (Appendix III), 10 miles southeast of Paxico, only the platestone part of the Johnson Shale is well exposed. Here the platestones are well laminated, with the usual microscopically graded textures (Plate 2B). Their low content of insoluble mud is similar to that of the platestones at Paxico. About 5 feet of upper Johnson shales above the platestones are not exposed.

The Eskridge section (Appendix III) is the southernmost exposure of the platestone facies in the Johnson Shale of Wabaunsee and Lyon counties. The platestone is faintly ripple-marked and shows channelling as deep as 2 mm. About 2.5 feet of ostracode-bearing shales lie above the platestone. Light-gray and greenish-gray calcareous mudstones and shales typical of the Johnson Shale lie below. These 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 formation.

At the Eskridge South section (Appendix III), 4 miles south of the Eskridge locality, the upper half of the Johnson Shale is partially exposed in a farmyard. Dark-gray, calcareous, ostracode-bearing shales, some with plant remains, comprise the upper 5 feet of the unit. These rest on muddy limestones equivalent to the platestone but somewhat thicker than normal. The lower part of the exposure shows greenish-gray shales below a thin local argillaceous limestone that contains traces of ostracodes.

The few feet of upper Johnson sediments exposed at the Coffman section (Appendix III) are quite similar to those at Eskridge South. Ostracodes and carbonaceous plant remains are common in the upper calcareous shales. Traces of carbonaceous remains are visible in the underlying laminated muddy limestones.

At the Allen section (Appendix III) carbonaceous remains and ostracodes are common in the upper shale of the Johnson Shale. These rest on vaguely laminated muddy limestones and limy mudstones very similar to their stratigraphic equivalents at the nearby Coffman locality.

About 40 miles to the southwest of Allen, at the Elmdale section (Appendix III), the upper two-thirds of the Johnson Shale are well-exposed. Here too, plants and ostracodes are present in the uppermost shales. A laminated platy argillaceous limestone unit, faintly ripple-marked, is the apparent equivalent of the so-called platestones farther

north in Kansas. Some of the laminations are extremely smooth and even. Greenish-gray mudstones, increasingly calcareous towards the base, comprise the remainder of the formation.

At the Saffordville section, 12 miles east of Elmdale (Appendix III), only platy limestones (platestones) bearing ostracodes are exposed below the Red Eagle formation.

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

At the Highway 38 section (Fig. 1) in Cowley County, the upper half of the Johnson Shale is similar to that at the Grand Summit locality (Appendix III). Here, in the upper 5 feet, similar shales with nodular limestones contain the same assemblage of ostracodes, plant remains, and common productid brachiopods observable at Grand Summit. They lie above 3 feet of barren calcareous gray shales.

Because it is complete, the Highway 38 exposure permits observation of the light-gray mudstones which comprise most of the lower part of the Johnson Shale. A thin maroon mudstone occurs near the base of the section. This is interpreted to mark the base of the Red Eagle Cyclothem. No good exposures of Johnson shales are known south of this locality.

Summary. The Johnson Shale is a distinct unit composed mainly of light-gray shales and mudstones immediately below the distinctive Red Eagle Limestone. In Nebraska it is at least 15 feet thick, and it thickens to a maximum of 18 feet southwards through Kansas. Workable exposures are rare. In most places, especially southern Kansas and northern Oklahoma, it forms gentle grass-covered slopes between thin limestone benches. Maroon mudstones have 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 are fossiliferous shales, containing aphanitic limestone nodules and lenticles. From central Kansas to the Nebraska border the upper few feet of the Johnson Shale consist of laminated gray shales with ostracodes and carbonized plant remains. The plant remains are rare in Nebraska. In the same area these shales are underlain by a horizon characterized by laminated muddy limestones yielding platy debris. In some places the purer platy brittle limestones may be conveniently

called platestones. The platy horizon is identifiable from a few miles north of the Nebraska-Kansas border, southward to Eskridge, Kansas. The lower half of the formation is almost invariably unfossiliferous.

Red Eagle Limestone

The Red Eagle Limestone was named by Heald (1916, pp. 24-25) from "excellent" exposures near Red Eagle School, about 3 miles west of Foraker, Osage County, Oklahoma.

> ".... a number of distinct beds of limestone, between which are beds of shale in some localities." (Heald 1916, p. 25)

The Red Eagle School mentioned by Heald was destroyed many years ago, and the limestone exposures in that neighborhood (Plate 3A) represent only a part of the total thickness.

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

The Burbank section exposes approximately 22 feet of Red Eagle limestone beds. The base is not visible. In the lower 6 feet of the exposed interval, brownish-gray aphanitic to microcrystalline, medium- to thin-bedded limestones grade laterally to similar but shaly laminated limestones. Somewhat wavy, laminated, calcareous shaly interbeds are

Plate 3

A. Red Eagle Limestone at Red Eagle section.
B. Limestone of the Bennett Shale at Grand Summit section.

characteristic of this part of the sequence. These beds contain common productid brachiopod fragments, crinoid columnals, and rare ostracodes, all oriented roughly parallel to bedding planes. Three feet of hard, dense, massive, medium- to thick-bedded, light brownish-gray limestone rest on the aforementioned shaly limestones. Common crinoid columnals and rare brachiopod and ramose-bryozoan remains are present in a dense microcrystalline matrix. Stringers of shaly calcareous material and calcareous shale intergrade laterally with the limestones. Shaly interbeds up to 0.5 inches thick emphasize the thick resistant limestone beds. Seven feet of light to medium greenish-gray, argillaceous, medium-bedded limestones overlie the massive limestones. The greenish-gray color accompanies 15 to 20 percent more clay content than in the lower limestones. Crinoid discs and brachiopod fragments are rare to common in aphanitic to microcrystalline, and argillaceous matrices. Some beds are vaguely laminated and argillaceous enough to appear shaly when deeply weathered. Half a foot of calcareous shale containing gastropods and bryozoans occurs near the base of this part of the sequence.

The three assemblages of strata just described from the Burbank section total about 16 feet in thickness. Their lithologies, bedding, and faunal content indicate that they represent a facies equivalent of the Bennett member of the Red Eagle Limestone. The more massive, resistant parts of

the Bennett member form subdued benches which can be mapped from air photos in northern Oklahoma and southern Kansas.

At the Burbank section, 4 feet of irregularly-bedded limestones rest on the limestones of the Bennett member. Their character is distinctive -- thick to thin beds, 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 correlated as equivalents of the Howe member of the Red Eagle Limestone, largely because of their position below red Roca shales and above Bennett limestones. Their faunal content only vaguely resembles the Howe Limestone fauna at the Coffman section. 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 partially 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 amid a 125-foot covered interval. In the Foraker area, at the Red Eagle section (Appendix III), about 1.5 miles east-southeast of the old type locality, the massive limestones of the medial Bennett member form a small hillside bench. This can be traced northward into Kansas and southward beyond Burbank,

Oklahoma. Depending upon the proportions of less-resistant argillaceous limestones, the ledge-forming beds of the Bennett member range 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 limestones (Pl. 3A). The assemblage of bryozoans, arenaceous foraminifers, crinoids, and brachiopod fragments indicate that these beds are equivalent to the medial, purer, resistant limestones 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 survive weathering any better than the softest of the Bennett limestones. 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 limestones.

In southern Kansas, at the Highway 38 section (Appendix III), the three 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 to and beyond their type localities in southeastern Nebraska.

Glenrock Limestone

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[1], Nebraska, the Glenrock member forms an inconspicuous ledge cropping out in the midst of long gentle grassy slopes which hide shales 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 a light gray color. 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 presents an "oatmealy" appearance on fresh surfaces. Fusulinids here are slightly smaller than in other parts of the Glenrock member.

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

O'Connor and Jewett (1952, p. 343) assert 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 Bennett section (Appendix III) the Glenrock Limestone is a massive ledge-forming unit 1.5 feet thick. The upper 0.5 feet of this rock contain numerous fusulinids, but the lower 1 foot contains few. Brachiopods, foraminifers, and ostracodes are common where fusulinids are scarce. 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 clays. The upper foot of the unit has a few random patches of muddy limestone somewhat similar to the overlying shales of the Bennett member. Some of the fusulinids in this part of the Glenrock member show a tendency toward orientation parallel to the bedding. Vague, wavy, clay-limestone seams much thinner than the subtlest of diastems share the vague preferential orientation. The lower part of the member is virtually structureless and even-textured. The Glenrock Limestone weathers light gray. The lower contact of the Glenrock is gently undulatory. It rests on the shales of

the uppermost Johnson Shale paraconformably but with only slight evidence of erosion. The upper contact is also slightly undulatory beneath the dark-gray Orbiculoidea-bearing Bennett shales. These contacts are unusually clear and sharp.

At the Tecumseh section (Appendix III) the Glenrock Limestone is also 1.5 feet thick. The upper 1.3 feet contain abundant fusulinids and common brachiopods in an aphanitic to microcrystalline matrix. Blotches of organically barren limestone occur at random. Aphanitic, somewhat dolomitic, limestone with random stringers of calcarenaceous and calcisiltaceous material comprise the lower 0.2 feet. Here the base is undulatory, as it is at the Pawnee section.

At the Johnson section (Appendix III) the Glenrock Limestone is 1 foot thick and resembles its equivalent at the type section. The upper 0.9 feet contain abundant fusulinids and rare to common brachiopod detritus. The basal 0.1 feet of the unit consists of hard, dense to microcrystalline limestone lacking fusulinids. The upper and lower contacts are faintly undulatory and typically sharp.

The Pawnee section (Appendix III) exposes a distinctive development of Glenrock Limestone. The thickness ranges from 0.7 to 1.0 feet. Fusulinids abound in the upper half of the unit together with a profusion of brachiopod fragments and traces of gastropods. The lower half lacks fusulinids. Acetate peel-prints reveal that many of these fossil fragments

(except the fusulinids) are coated with secondary calcite, similar to algal Osagia. The calcareous matrix of the detrital material is aphanitic and somewhat argillaceous, ranging to pure microcrystalline.

The base of the unit is gently undulatory (Pl. 4A) 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 on a small scale (1 inch) or "lumpy" and channelled. 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. 5C). The shales of the overlying Bennett member are impressed into these "trails" and, surprisingly, contain fusulinids. The top few inches of the limestone are randomly penetrated by tubes (worm burrows?) filled with black muddy material (Pl. 4B,5A,5B) continuous with the black shales of the basal Bennett member. Some of these black tubes also contain fusulinids.

The Glenrock Limestone at Pawnee South is similar to its equivalent at the Pawnee section.

In southwestern Richardson County, Nebraska, athwart the Nemaha anticline, the Glenrock Limestone is well-exposed at the Humboldt section (Appendix III). Here also, the base of the unit is undulatory, with relief of about 0.1 feet.

Plate 4

A. Glenrock Limestone at Pawnee section: showing undulatory base.
B. Glenrock Limestone at Pawnee section: closeup showing worm burrows (below face of hammer).

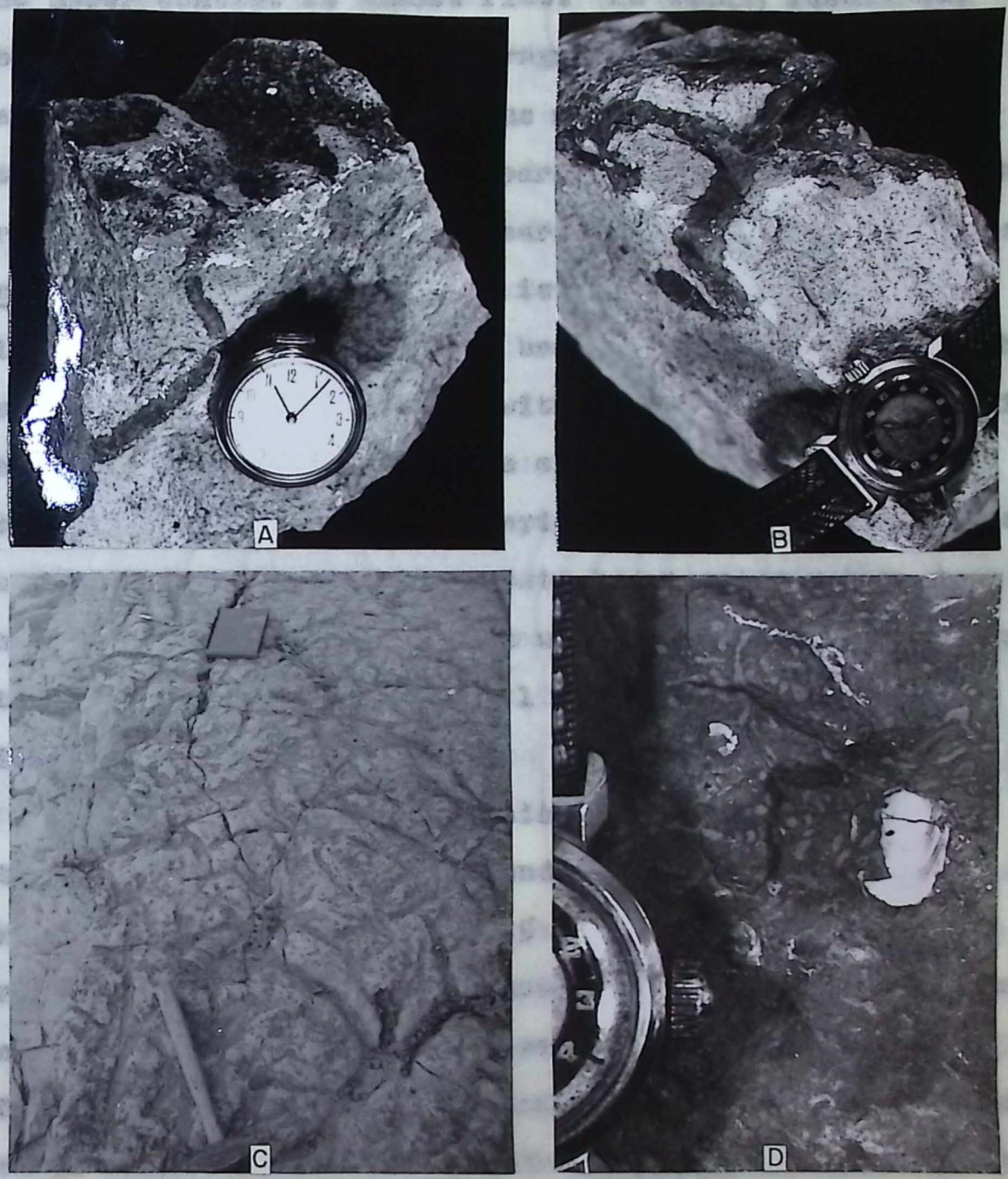


Plate 5

A.,B. Uppermost Glenrock Limestone at Pawnee section, showing black tubes interpreted as worm burrows.

C. Top of Glenrock Limestone at Pawnee section, showing channels and trails.

D. Lingula sp. in black basal Bennett Shale at Bennett section.

The upper contact is almost flat. As usual, fusulinids abound with many brachiopod fragments in an aphanitic to very finely granular calcareous matrix. Most of these fossils are oriented crudely parallel to the bedding. Some brachiopods are coated by calcareous deposits which suggest Osagia or other algae. There is also some evidence of "linear algae." Articulating 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 a medium rusty-brown color 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 (2 feet) than average at the Frankfort section (Appendix III). Fusulinids are extremely rare in the lower 0.5 feet of the unit but gradually increase in number upwards. Where fusulinids are scarce, brachiopods are quite common. The upper 0.5 feet of the Glenrock Limestone contains abundant fusulinids and scarce brachiopods which include Composita sp. Not all the shell detritus is broken. Traces of articulating brachiopod shells are visible in polished rock sections. A few ostracodes and uncrushed gastropods accompany the brachiopod detritus. Some 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 III) the Glenrock member (1.3 feet thick) is superficially "normal", but close examination reveals a distinctive local lithology (Pl. 6). The Glenrock member is comprised of 1.3 feet of fine conglomeratic, calcirudaceous, medium to light brownish-gray limestone. Randomly oriented granules and small pebbles of aphanitic buff argillaceous limestone are bound by a calcarenaceous and microcrystalline limy matrix containing many brachiopod shell remains. 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 in the matrix. The rock lacks fusulinids. Upper and lower contacts are relatively even and clearly defined.

At the Paxico section (Appendix III) the lithology of the Glenrock Limestone is intermediate between the material at Manhattan and the widespread fusulinid-rich rock found elsewhere. Aphanitic buff limestone granules occur in the calcisiltaceous to microcrystalline light creamy-gray matrix of the lower half of the unit. Both fusulinids and the granules are extremely sparse in similar but medium brownish-gray matrices of the upper half of the limestone. A few

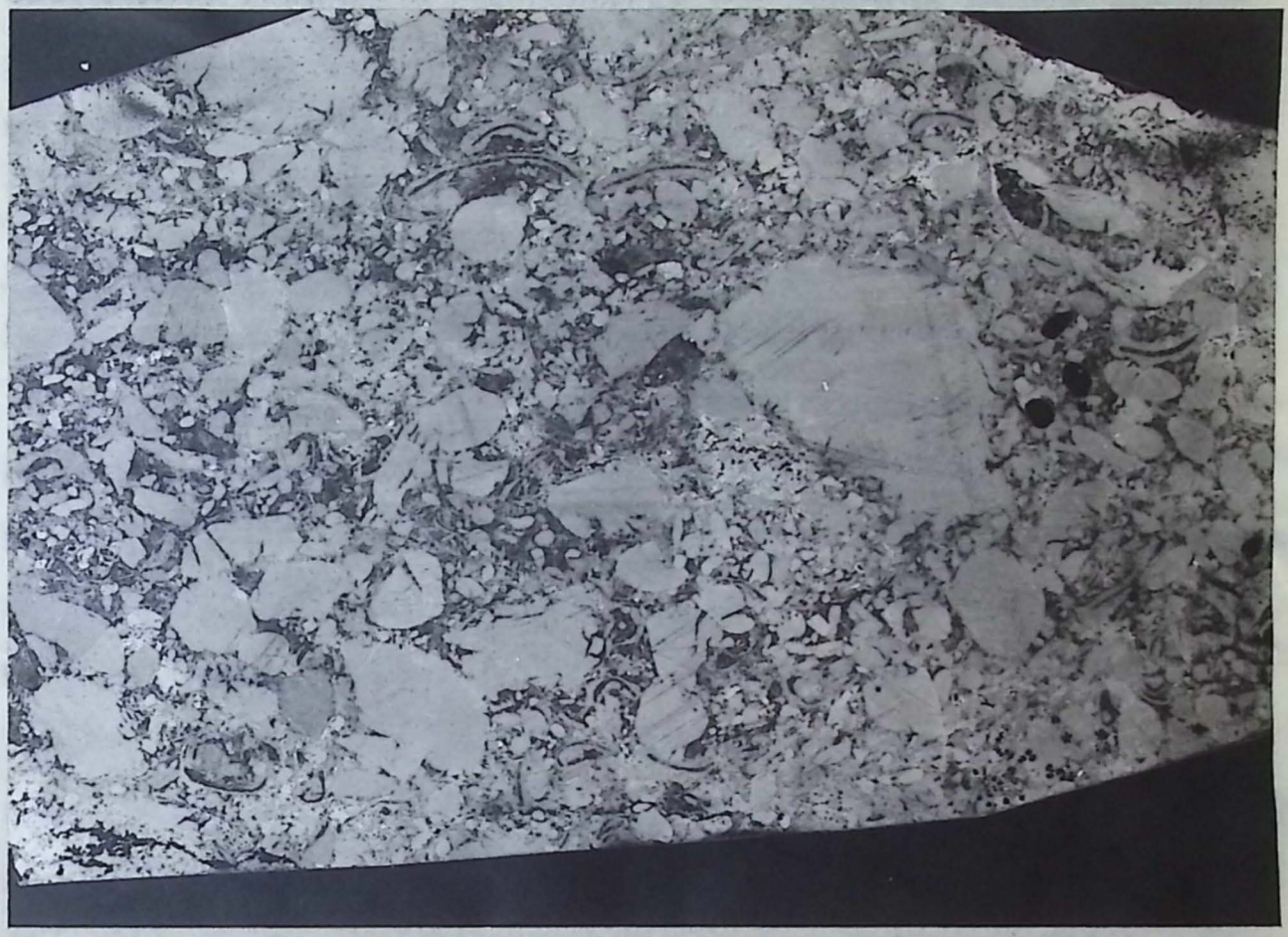


Plate 6

Peel-print (X3) from Glenrock Limestone at Manhattan section. Note three brachiopod shells, convex upward, coated by algal Osagia (in upper central part of picture) and oriented roughly parallel to bedding.

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 member is absent from the Alma area (Alma section, Appendix III). Shales of the Bennett member of the Red Eagle Limestone rest paraconformably on upper Johnson shales. Moreover, poor exposures make it impossible to determine whether the Glenrock is the only part of the Red Eagle Limestone which is missing. Paleosedimentological studies indicate that such absence is 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, the dark-gray shales contain ostracodes and carbonaceous remains characteristic of uppermost Johnson elsewhere. Hence the contact must be slightly higher in the Alma section than noted by O'Connor and Jewett. Precisely how much higher cannot be ascertained because of unsatisfactory exposures.

About 13 miles southeast of Alma and Paxico, at the Keene section (Appendix III), the Glenrock member is quite "normal" -- 1 foot of light brownish-gray calcareneaceous fusulinid-bearing limestone. The base of the unit is even. The upper contact, partly obscured be weathering, is somewhat lumpy and resembles that at the Pawnee section. In some

parts of the outcrop the top inch of Glenrock Limestone, lacking fusulinids, is medium gray in color, as though heralding the complete change to Bennett black shales at the top contact.

At the Eskridge section (Appendix III) the Glenrock is the usual fusulinid-bearing light brownish-gray limestone about one foot thick. Traces of argillaceous material bearing Orbiculoidea fragments are present in the uppermost 1 inch, vaguely similar to the relations at the Pawnee section. Upper and lower contacts are mostly clear and sharp but weathering has obscured details of the upper contact in some places.

The Glenrock member at the Judith section (Appendix III) is almost identical to that at the Eskridge section, except that the upper contact has not been weathered. Fusulinids abound, with many brachiopods and a few ostracodes and smaller foraminifers, in the calcarenaceous to microcrystalline matrix. The top is gradational to the Bennett member above through 0.5 inches 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 III) the Glenrock Limestone 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 gently lumpy and undulatory, (relief,

0.05 feet) and displays random patches of fusulinid coquina with traces of Orbiculoidea and fragments of bryozoans.

The section at Coffman Ranch (Appendix III) displays the Glenrock member as a medium brownish-gray limestone, considerably thinner than normal. It resembles Glenrock lithofacies in southern Kansas, and yet shows other features characteristic of Nebraska and northern Kansas facies. Thickness ranges from about 0.2 to 0.4 feet within 500 yards of exposure. The base is gently undulatory through about 0.1 feet of section. Fusulinids are extremely abundant in the calcarenitic and calcaphanitic matrix, accompanied by many or few brachiopods and smaller foraminifers. Many of the brachiopod fragments have coatings of algal calcium carbonate but other fossils do not. Some parts of the rock are faintly conglomeratic, containing granules of aphanitic limestone similar to, but much less numerous than, those at the Manhattan and Paxico sections. The difference may be that some of these aphanitic limestone granules are pieces of the aforementioned algal type of material. A solitary 1-inch aphanitic limestone pebble was seen in the normal fusulinid-bearing rock (Pl. 7). For this anomalous occurrence no explanation is offered.

Locally, the upper part of the unit is penetrated by "tubes" of Orbiculoidea-bearing medium to dark gray argillaceous material continuous with the Bennett shales above. These are much like the tubes at the Elmdale and Pawnee

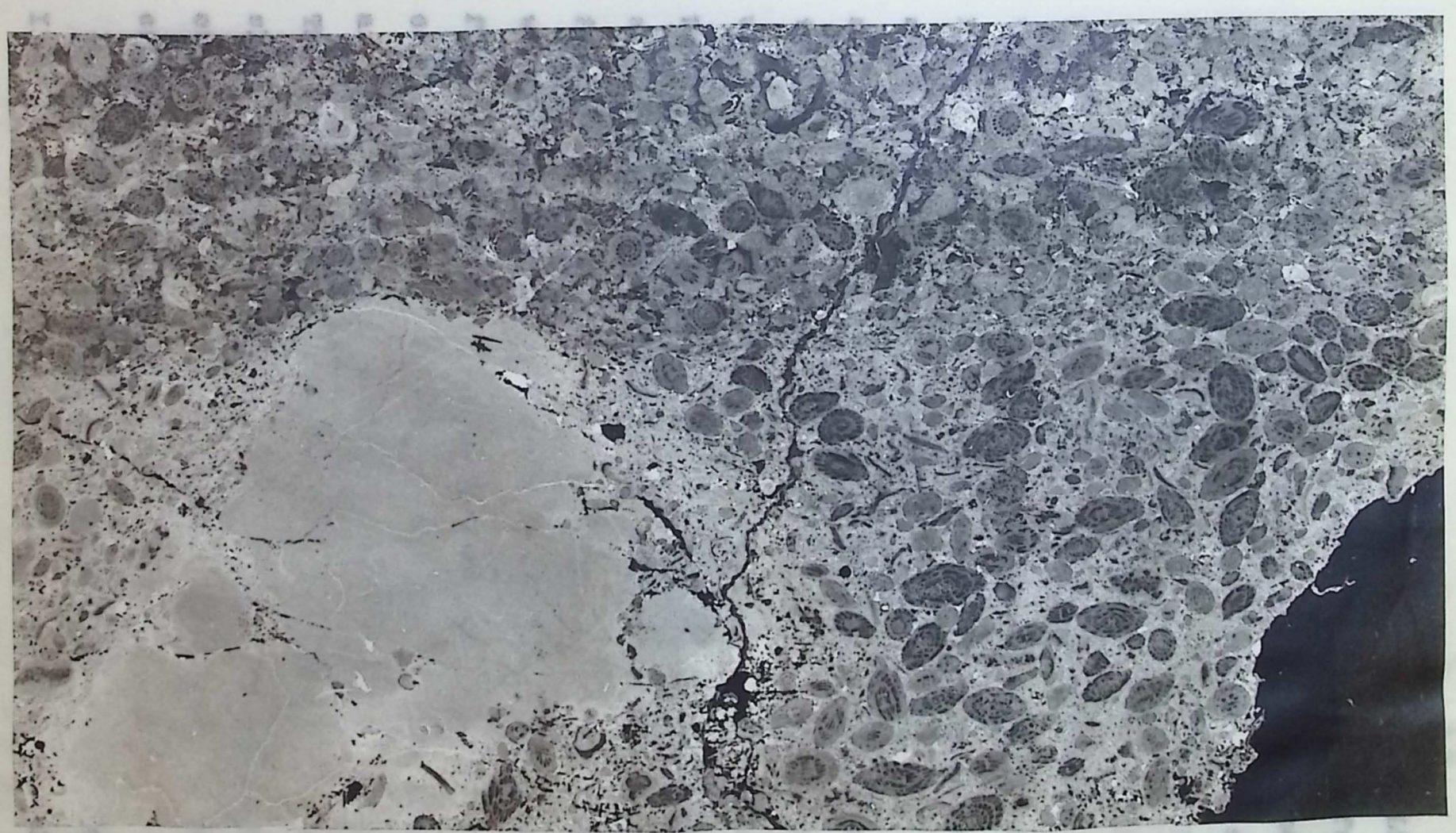


Plate 7

Peel-print (X30) of Glenrock Limestone at Coffman section. Note large aphanitic limestone pebble and faint preferential orientation of fusulinids parallel to bedding planes.

sections (Pl. 5, 9). At the top, the Glenrock Limestone grades upwards through 0.1 inch of rock from a fusulinid subcoquina to an Orbiculoidea subcoquina continuous with the overlying black Orbiculoidea-bearing shales of the Bennett member. That is, the top contact is typically sharp.

At the Allen section (Appendix III) 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. Downwards their numbers decrease, so that the lower 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. 8). Some of these (algal?) pebbles show shrinkage cracking. The pebbles are rarer and smaller in the lowest part of the unit. A variety of fragmental fossil remains, most of which are brachiopods, with a few tiny gastropods and ostracodes occur amid the fusulinids and lime granules. These fragments are more common where fusulinids are lacking. Many of the brachiopods are coated by deposits of calcium carbonate similar to Osagia. The matrix for the detritus is aphanitic to microcrystalline, slightly argillaceous, calcium carbonate. The top contact of the Glenrock member is gently undulatory but the lower contact is even (Pl. 10).

The Glenrock Limestone at Allen No. 2 section (Appendix III) is similar to the Allen No. 1 section. Fusulinids are

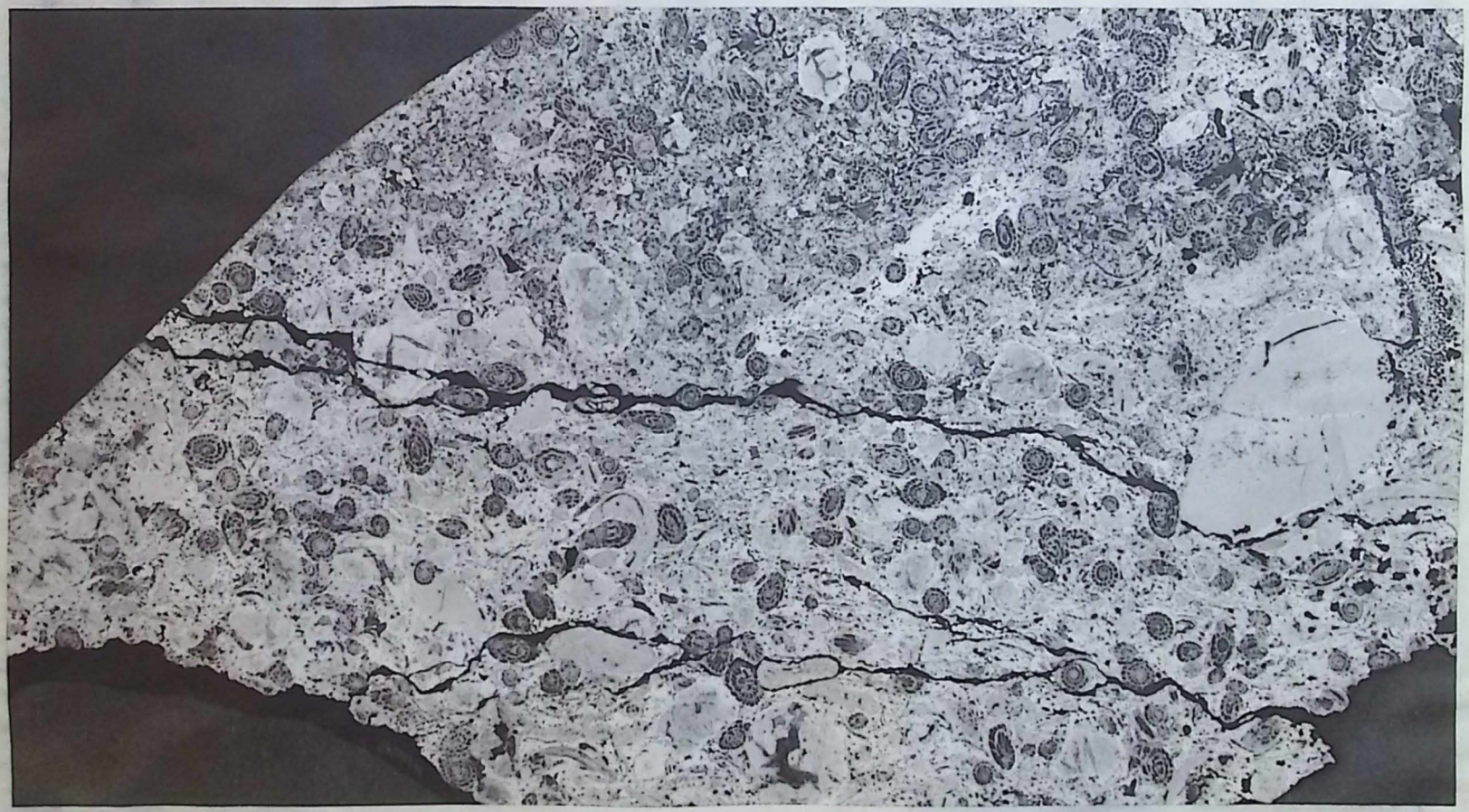


Plate 8

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

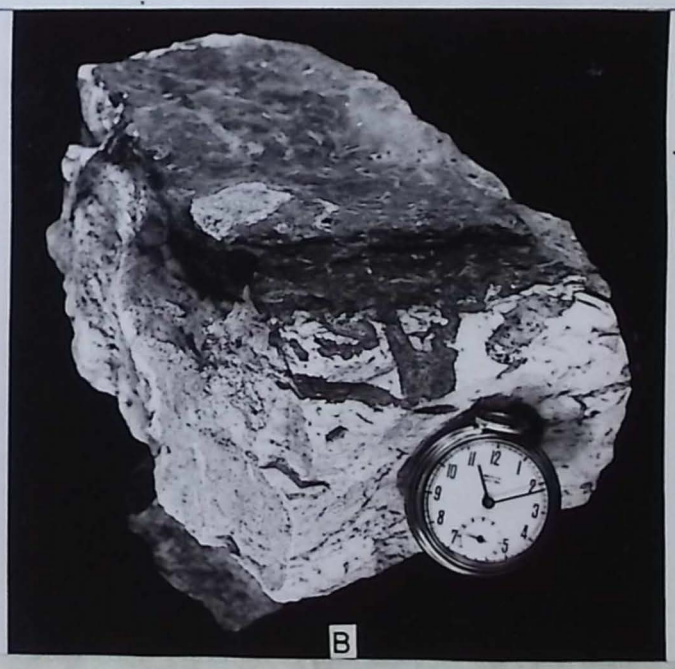


Plate 9

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 at Elmdale section. Note dark Orbiculoidea-bearing tubes near top.

Plate 10

Allen section: showing Glenrock and Bennett members of Red Eagle Limestone. Observer is touching top of Glenrock Limestone. Observer's eye level is at contact between lower shale and medial limestone facies of Bennett member.

abundant, with many brachiopods and a few gastropods in the usual calcaphanitic to calcarenitic matrix. Granules of aphanitic limestone and algally coated brachiopods are uncommon. Irregular tubes of gray argillaceous material containing Orbiculoidea (similar to those at the Pawnee and Coffman 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, 0.15 inches thick, of Orbiculoidea and Lingula fragments in a black argillaceous matrix continuous with the overlying Bennett shale (similar to the one at the Coffman section), is plastered upon the top of the Glenrock Limestone.

The Glenrock Limestone is not developed at the Saffordville section (Appendix III) where lower Bennett shales rest paraconformably on upper (not uppermost) Johnson shales.

A peculiar lithofacies is visible at the Elmdale section (Appendix III) below Bennett black shale. It is represented by 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 penetrate the upper 0.1 feet of the unit from the black Bennett shale above (Pl. 9B). A coquina of Orbiculoidea lies at the base of the overlying shale. These lithologies and structures are similar to those in the uppermost Glenrock Limestone at the Pawnee, Coffman, and Allen section. Thus, this unit might be mistaken as an argillaceous facies of the

Glenrock member. Whereas the top of the unit is clearly defined and somewhat undulatory, the less distinct base grades to shales below which contain plant remains and ostracodes typical of the upper part of the Johnson Shale. Moreover, the color of the unit, its softness, microstructure, insoluble clay content, and fossils ascertain it as part of the Johnson Shale. Thus, the combined evidence seems to demonstrate that the Glenrock member is absent at the Elmdale section.

At the Sallyards and Turnpike sections the Glenrock Limestone is absent. Fossils indicate that thin limestones exposed at these localities are correlatives of the Bennett member.

The Glenrock Limestone is about 1.5 feet thick at the Piedmont section (Appendix III). It consists of thin beds of limestone bearing abundant fusulinids in a microcrystalline matrix. Upper and lower contacts cannot be described in detail because they are badly weathered or buried. Nodules and blebs of milky and medium-gray chert are randomly present in the limestone.

At the Grand Summit section the Glenrock Limestone is thin (0.3 feet) but readily recognizable. Fusulinids are abundant and brachiopods rare in the usual aphanitic to microcrystalline 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 Bennett shale contains abundant Orbiculoidea.

The Highway 38 section (Fig. 1) is the southernmost exposure of the fusulinid-bearing Glenrock Limestone. As at the Piedmont section, the Glenrock Member is thin (0.5 feet) and is identified as much by its relation to the overlying Orbiculoidea-bearing Bennett Shale as by its own distinctive lithology. At the Highway 38 locality the Glenrock Limestone is softer and more argillaceous than its equivalents to the north, but contains the same fusulinids. Some brachiopods and crinoid discs accompany the fusulinids. Wormy tubes of black clay penetrate the top of the limestone. Upper and lower contacts are gently undulatory.

Summary. The Glenrock member of the Red Eagle formation is 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 hard enough to support minor topographic benches. It is readily identifiable in the field by means of its persistent characteristics, and by its position beneath black Orbiculoidea-bearing shales of the lower Bennett member. In localities where the Bennett limestone facies is thick, the Glenrock member is normally less than 0.5 feet thick. Where the Glenrock member is absent, the position of the corresponding paraconformity can be closely approximated at the base of the Orbiculoidea-bearing

black or gray Bennett shales where they lie directly on ostracode- and plant-bearing gray shales of the upper Johnson formation. The Glenrock Limestone commonly contains brachiopod fragments and spines, traces of gastropods and ostracodes, with 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 clays that are continuous with the basal Bennett shales penetrate the top of the Glenrock limestone 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 the Highway 38 locality 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.

The fusulinid-bearing Glenrock limestones, with the black Orbiculoidea-bearing Bennett shales resting directly upon them, are a reliable stratigraphic "marker", recognizable and useful from Bennet, Nebraska, to southern Kansas.

Bennett Shale

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[1] section, Appendix III) the Bennett member is approximately 14 feet thick. The lowermost 4 feet are slightly calcareous gray shales and mudstones containing Orbiculoidea and an abundant microfauna. The basal shales are dark gray to black. Many emit a fetid odor when treated with hydrochloric acid. A few frail specimens of Lingula (Pl. 5D) 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 5 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 shaly limestone, which looks more like shale and mudstone in weathered exposures. These beds lack conodonts and orbiculoids, but

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

some contain fish teeth and ostracodes. Three feet of massive hard aphanitic light-gray Howe Limestone rest on the tooth-bearing beds. The type locality is satisfactory for observation of the lower Bennett shales and their relations to the Glenrock member, but the relations of upper Bennett to the overlying Howe Limestone are much better observable in central Kansas.

Only 5 feet of light- and medium-gray shales and mudstones containing Orbiculoidea and other brachiopod fragments are exposed at the Tecumseh section (Appendix III). These beds contain a characteristic Bennett microfauna of conodonts and fish teeth in the blacker, less calcareous, shales; with ostracodes and foraminifers in the calcareous shales and mudstones.

About 2 feet of lower Bennett black, well-laminated, Orbiculoidea-bearing shales with abundant microfossils are exposed at the Johnson section (Appendix III). The contact with the Glenrock Limestone is sharp and gently undulatory.

Excellent exposures of the Bennett member are available at the Pawnee section (Appendix III). The lower contact of the basal black shales is impressed into peculiar channels (Pl. 5) and fills the tubes of 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 clays. Lingula accompanies Orbiculoidea in the lowermost 0.25 inches of shale resting on the Glenrock Limestone.

The lower 5 feet of the Bennett member at Pawnee consists of gray, and very dark-gray, almost black, slightly calcareous shales. These contain a varied microfauna and few, but conspicuous, articulate 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 a foot of calcareous siltstones and mudstones into the soft, pitted Howe Limestone.

The Bennett member at the nearby Pawnee South section (Appendix III) is quite similar to its equivalent at Pawnee, but it differs in the lesser abundance of the fauna.

Only the basal 3 feet of the Bennett member are exposed at the Humboldt section (Appendix III). These are the same as the dark-gray well-laminated Orbiculoidea-bearing shales 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 shales. At the very base, where many of the shells are only slightly flattened, rare Lingula accompany the orbiculoids.

Only the lower 2 feet of the Bennett Shale is exposed at the Frankfort section (Appendix III). The beds are almost identical with the slightly calcareous black shales 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 III) the Bennett member is 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 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 shales are well laminated, calcareous, and wafer-like.

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

Exposures are so poor at the Alma section (Appendix III) that they yield little information about the local characteristics of the Bennett member. The thickness is about 14 feet. The uppermost Bennett beds, beneath the Howe Limestone, are argillaceous calcisiltites somewhat similar to those in similar stratigraphic position at Paxico.

At the Eskridge section (Appendix III) the Bennett member is not exposed and the Howe Limestone is absent so that only an extrapolated estimate (6.5 feet) of Bennett Shale thickness is possible. This local thinning of the Bennett member shales might be overlooked were it not for the thick Bennett limestone development exposed less than 3 miles away (Eskridge Quarry section, Appendix III). Thus, the most abrupt facies change in the Bennett member is indicated.

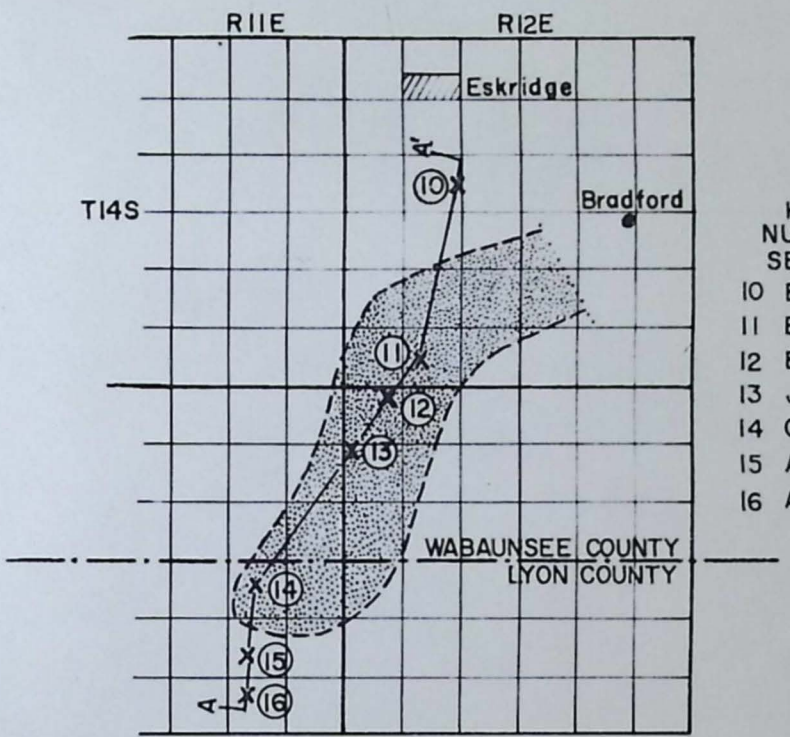
When quarrying is active, a complete section of Bennett member may be seen at the Eskridge Quarry. During suspension of quarry operations the excavations accumulate enough water to submerge the lower 7 feet of the Bennett member and so conceal the lower shales. At such times these lower beds may be sampled at the nearby Judith section (Appendix III) where the Bennett member is very similar to the Quarry Section.

At the Eskridge Quarry section and Judith section, the lower 3 feet of the Bennett member consist of typical black Orbiculoidea-bearing shales. The lowermost of these also contain traces of Lingula and conodonts. Medium-bedded very light brownish-gray limestones 15 feet thick rest upon the shales. Orbiculoidea and fusulinids are present in the lower foot or two of these Bennett limestones. Brachiopods, echinoid and brachiopod spines, crinoid discs, and foraminifers are rare to common in the aphanitic to microcrystalline calcareous matrix which comprises most of the rock.

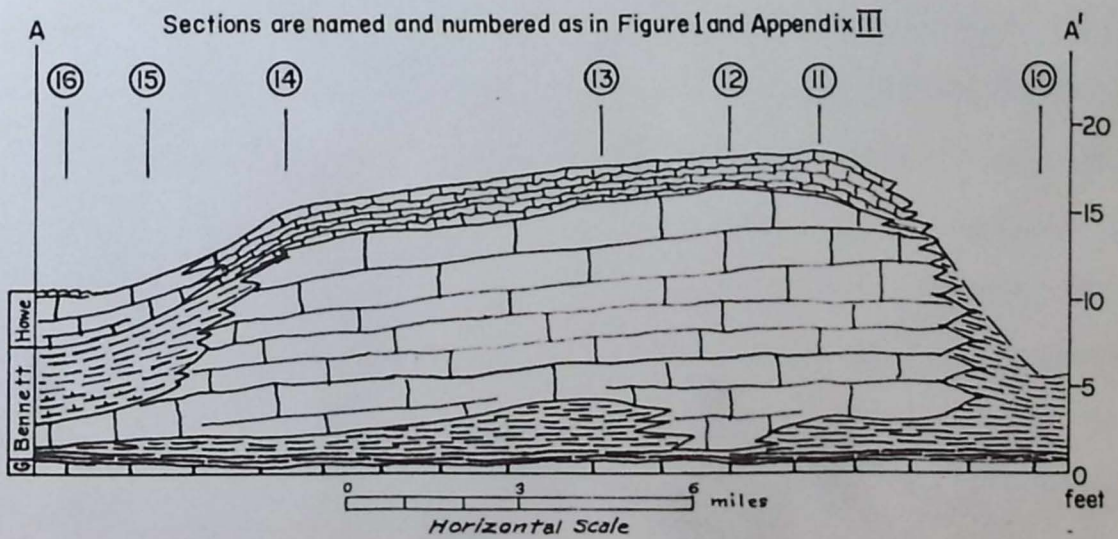
Laboratory analyses reveal that few of these limestones contain more than one percent insoluble clay residue. The sudden thickening, and the purity of these limestones suggest that they might be a part of a Bennett reef facies. This thickened limestone facies extends from the Eskridge Quarry through the Judith and Coffman Ranch areas where it forms a conspicuous bench on the local grassy hillsides. Shallow sink holes in the Bennett Limestones are common topographic features of this Eskridge-Coffman area.

O'Connor and Jewett (1952) noted this Bennett lithofacies (Fig. 2) and called it a "bioherm". The original definition of "bioherm" by Cummings (1932, p. 333) applies it to "reeflike, moundlike, lenslike or otherwise circumscribed structures of strictly organic origin, embedded in rocks of different lithology." In broad outline the Bennett limestones of the Eskridge-Coffman area faintly resemble part of a bioherm. However, the internal characteristics of these limestones (e.g. bedding) certainly are not reeflike, nor can their "strictly" organic origin be verified, although much of their mass is obviously organic shell detritus. Moreover, the Bennett limestone lithofacies of southern Kansas and Oklahoma are extremely similar to these of the Eskridge-Coffman area, except that they are too broadly distributed and uniform in thickness to permit the slightest suggestion that they are biohermal or reeflike in form.

Figure 2



Sections are named and numbered as in Figure 1 and Appendix III



TOP: Approximate locations of sampled sections, showing area (stippled) of thick Bennett limestone facies in Eskridge–Coffman Ranch area.

BOTTOM: Composite cross section A A' through numbered sections showing thick Bennett limestones in Red Eagle formation.

It must also be noted (Fig. 2) that whereas the western and northern margin of the Eskridge-Coffman area of limestones is bounded by shale ("rocks of different lithology", Cummings, 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, Saffordville, etc. sections.

The words of Moore (1957, p. 1240) seem to fit perfectly the observed Bennett stratigraphic conditions.

> "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 hereinafter presented indicates that these Bennett limestones probably were deposited in water at least 90 feet deep. Their maximum thickness is not much more than 15 feet where they are surrounded by contemporaneous shales at least 5 feet thick. Their minimum horizontal dimension is about 2 miles. Hence, the Bennett limestones in the Eskridge-Coffman area could not have been much more than a slight, flat, prominence on the sea floor. Such a low feature on the floor of waters 90 feet or more deep certainly should not be regarded as a "reef" or bioherm.

Mudge and Burton (1959, p. 60 and Pl. 9) also noted this feature of Bennett stratigraphy, but called it a "biostrome." Cummings (1932, p. 334) proposed the term

biostrome for "purely bedded structures, such as shell beds, crinoid beds, coral beds, etcetera, consisting of and built mainly be sedentary organisms, and not swelling into mound-like or lenslike form" and that, "Biostrome means literally an organic layer". As Weller (1958, p. 612) pointed out, "biostrome was intended as a structural term, in contrast to bioherm, for limestone deposits some of which have been called coral or other reefs but do not have biohermal form." The thickened Bennett limestones are bedded and are built in large degree by organisms. Perhaps this was the reason for Mudge and Burton to call them a biostrome. However, these limestones of the Eskridge-Coffman area certainly do "swell" somewhat, and cannot be certified as purely organic layers. That is, they do not fit the original definition of biostrome.

Apart from the fact the "biostrome" does not exactly fit the local Bennett stratigraphic relations described here, Moore (1957, p. 1789,1790) and Weller (1958, p. 612,613) have shown that there are good reasons why biostrome should be dismissed altogether from stratigraphic vocabulary. "Bioherm" and "biostrome" being inappropriate, there is no concise substitute term which, be definition, would describe the stratigraphic relationships manifested by the limestones and associated shales of the Bennett member in the Eskridge-Coffman area. Perhaps Bennett limestone "lithosome" might be tried as a last resort because the

original definition of lithosome (Wheeler and Malby 1956, p. 2719) accommodates the interfingering of the aforementioned Bennett limestones and shales. Moore (1957, p. 1789) pointed out that "A lithosome has lower and upper boundaries as well as lateral ones. Commonly, these coincide with bedding planes...". This implication that lithosomes are bedded further suggests that the bedded Bennett limestones may comprise a limestone lithosome. However, Moore (1957) also stated "Lithosome as a term does not belong to formal nomenclature of stratigraphic units as substitute for commonly recognized terms such as ..... facies." Hence, at Moore's suggestion lithosome is not used in this report. Nomenclatural difficulties are avoided by simply referring to thick or thin limestone or shale facies of the Bennett member or to the localities where such facies are best developed (e.g. the Eskridge-Coffman facies, or Grand Summit facies of the Bennett member), or to both facies and localities. The assumption is that shades of meaning will be quite clear from context. Moore (1957, p. 1782) and Weller (1958, p. 632) endorse the general practicality and clarity of this sort of facies nomenclature.

The thick (15 feet) limestone facies which comprise most of the Bennett member at the Eskridge Quarry continue through the Judith and Coffman Ranch sections. Southward, the limestones thin and give way to the thinner shaly facies visible at the Allen sections and beyond (Fig. 2).

The Bennett member is about 8 feet thick at the Allen section (Appendix III). Here, as elsewhere, the lowermost beds (1 foot thick) are dark-gray, Orbiculoidea-bearing shales. Only 2 feet of hard massive light-gray limestone similar to the Coffman Ranch limestones rest on these basal shales. 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. 10). It grades upwards into shaly light-gray limestones that contain a typical Bennett mixed fauna of brachiopods, horn corals, crinoids, and Orbiculoidea.

At the Allen No. 2 section the lowest Bennett shales are only 0.6 feet thick. One foot of Orbiculoidea-bearing massive limestone rests on the shales. The upper few inches of this limestone contain milky chert and silicified fossils. It grades upward through 2 feet of shaly limestone into 3 feet of gray and greenish-gray calcareous shales bearing Orbiculoidea and the Bennett mixed fauna. The upper 1 foot of the unit is a light-gray muddy limestone which contains a sparse Bennett fauna and lacks Orbiculoidea.

The Bennett limestone facies is only 5 feet thick at the Saffordville section (Appendix III) where it rests on about 3 feet of typical Orbiculoidea-bearing lower Bennett gray shales. Algal deposits of calcium carbonate occur at random throughout the limestones (Pl. 11). Some of these (Anchicodium) are called "linear algae," which appear in

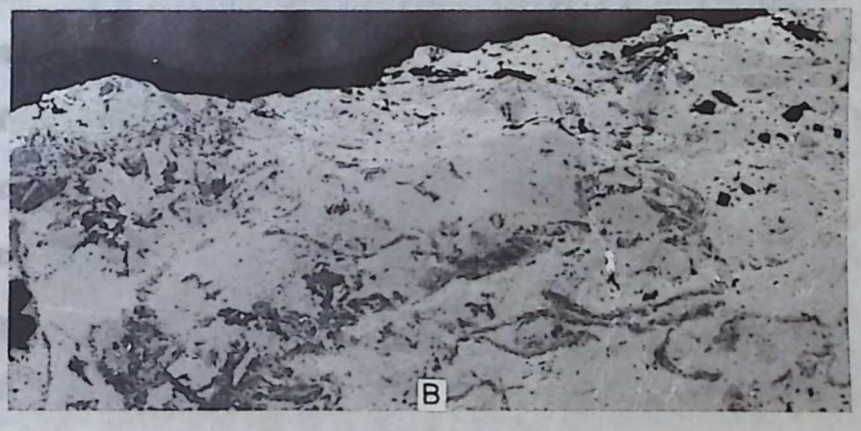


Plate 11

A. Peel-print (X3) of algal limestone in medial Bennett limestones at Saffordville section. Extended wavy lines are thin sheet-like algal crusts.

B. Peel-print (X3) of uppermost Bennett algal limestone at Saffordville. Short wavy dark lines are fragments of crustose ribbon-like algae. Aphanitic matrix is believed to be consolidated algal calcium carbonate particles.

vertical sections as thin wavy lines oriented roughly parellel to bedding. In three-dimensions they are really ribbon-like or sheetlike crusts, but the term "linear" is retained because it is commonly used in field descriptions and defines the gross appearance of vertical sections of the structures. Other calcareous algal particles comprise much of the apparently structureless aphanitic matrix of the Bennett limestones. The top of the limestone assembly consists of 0.4 feet of unique moundlike limestone structures which seem to contain both of the above types of algal calcium carbonate, as well as fossil detritus (Pl. 11B). Rusty iron staining seems to favor the sheetlike algal structures. Rubbly, wavy-bedded limestones comprise most of the upper 2 feet of Bennett limestone at the Saffordville section. The remainder (3.7 feet) is a massive light-gray resistant, pure limestone containing scattered linear algae some of which are broken (Pl. 11A). In general aspect this limestone resembles equivalent limestones at the Allen section. It grades downward into fusulinid- and Orbiculoidea-bearing calcareous shales of the lower Bennett. About 7 feet of upper Bennett sediments, probably shales, are covered at the Saffordville section.

At the Elmdale section (Appendix III) the lower Orbiculoidea-bearing black shales of the Bennett member are reduced in thickness to about 1 inch. They lie below 5 feet of predominantly pure, massive, and resistant limestones

(Pl. 9A) which contain a few fusulinids at the base. These limestones are equivalent in thickness, position, and fauna to the Bennett limestones exposed at Saffordville. Within the upper foot of this limestone sequence at the Elmdale section are linear algal limestones (Pl. 12A). About 4 feet of medium-gray calcareous shales rest on the thick Bennett limestones. A typical Bennett fauna of common brachiopods (Neospirifer, Linoproductus, Crurithyris, Ambocoelia, Wellerella), bryozoans (Fenestella, Rhombopora, etc.), foraminifers, ostracodes, and fish teeth is abundantly represented in these upper Bennett shales.

Two feet of massive limestone enclosed by shales at the Turnpike section (Appendix III) superficially resemble Glenrock limestone. However, this designation is refuted by the presence in the limestone of Orbiculoidea, Fenestrellina and linear algae typical of the Bennett member. Moreover, fusulinids are absent. This evidence indicated that the limestone may be a thin, tongue-like extension of the Bennett limestone farther north. The Bennett limestone bed rests paraconformably on shales of the upper Johnson Shale. Calcareous shales immediately above the limestone contain a common Bennett fauna. Equivalents of the lower Bennett Orbiculoidea-bearing black shales are absent from the Turnpike section.

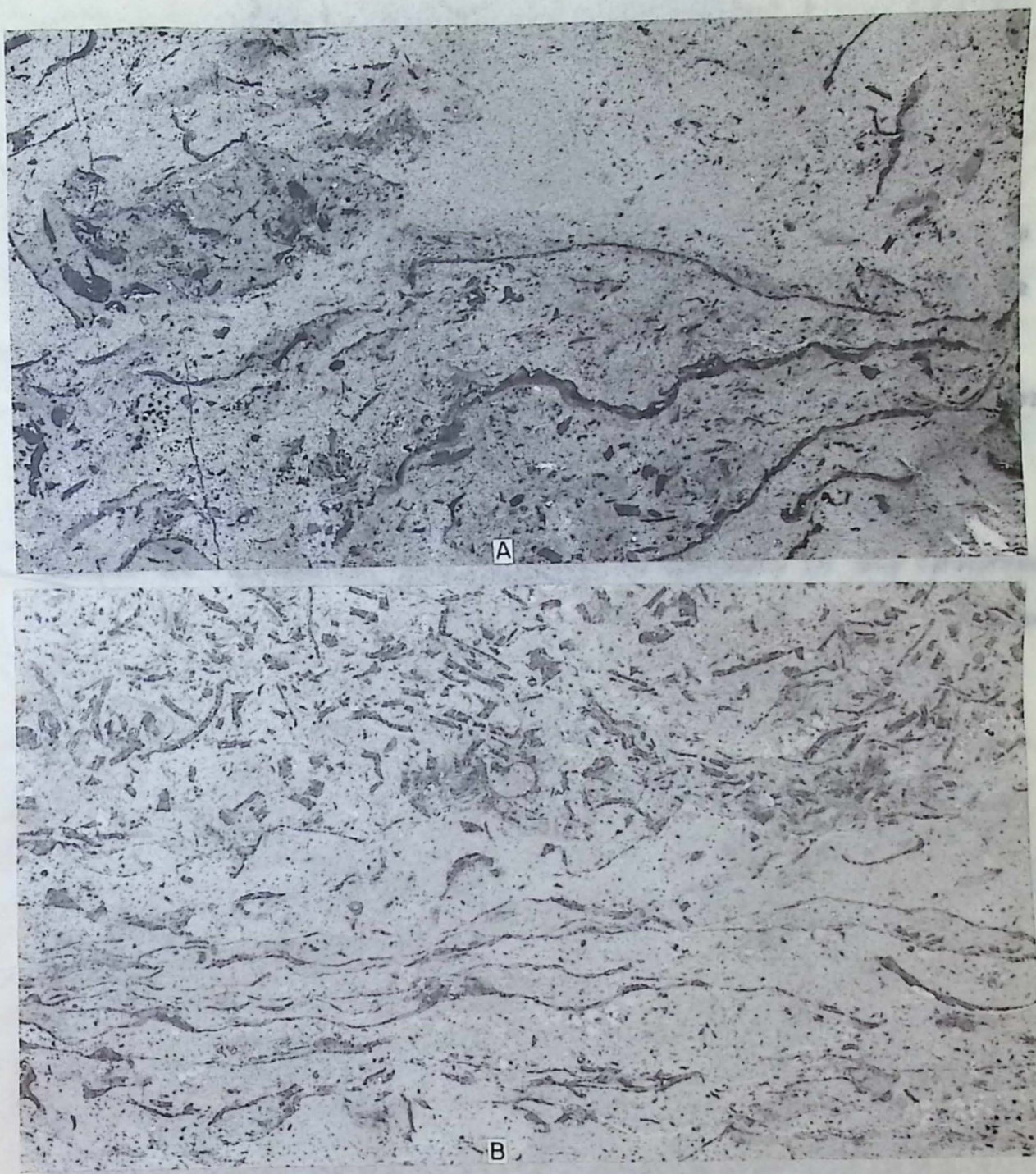


Plate 12

A. Peel-print (X3) of upper Bennett limestone at Elndale 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 at Highway 38 section. Note wavy sheetlike algal crusts in the lower half of picture, and broken algal crusts with brachiopod fragments in upper half.

Fossils in the limestone and shale exposed at the Sallyards section (Appendix III) indicate that these beds are also correlative with Bennett sediments farther north.

At the Piedmont section (Appendix III) only limestones of the Bennett member are exposed. The base of the unit is covered. Shaly light-gray limestones containing common fusulinids make up the lower 2 feet of the exposure. Eleven feet of massive, resistant, light-gray, medium- to thick-bedded limestones comprise the remainder of the Bennett member at Piedmont. Orbiculoidea is present in the lowermost of these limestones. Fusulinids are rare to common throughout the section, together with a typical Bennett fauna of brachiopods, ostracodes, crinoid discs, etc. (Pl. 13). Some of the limestones are vuggy; others contain secondary chert nodules surrounding silicified fossils. South from the Piedmont section the light-gray limestones of the Bennett member comprise most of the Red Eagle Limestone.

The basal Bennett shales are only 0.1 feet thick at the Grand Summit section (Appendix III). This resembles the conditions at Elmdale. Orbiculoidea abounds in these shales, together with many fusulinids, ostracodes, conodonts, and brachiopod fragments. The rest of the Bennett is all hard, light-gray, aphanitic limestone. The lower 4 feet of these limestones weather out as thin wavy beds in which linear algae are common. Five feet of massive thick- to medium-bedded limestone comprise the medial portion of the member.

Plate 13

Peel-print (X2.5) of fusulinid-bearing Bennett limestone from the Piedmont section. Note random orientation of fusulinids, and the articulating productid brachiopod filled with calcilutite.

Thinner beds make up the upper 3 feet. Brachiopods, crinoid columnals, ostracodes, and small gastropods are rare to common in an aphanitic matrix.

At the Highway 38 section (Fig.1) (Appendix III) the massive, light-gray, medium-bedded limestones which constitute the entire Bennett member are similar in thickness, purity, and lithology to their equivalents at the Grand Summit section. This is the southernmost section where correlations of the Red Eagle Limestone of Oklahoma with its members to the north can be recognized. Farther south the Glenrock Limestone disappears, whereas the Bennett limestones thicken and become more argillaceous towards the Burbank area where they comprise the bulk of limestones defined as Red Eagle Limestone formation.

Limestones of the Bennett member at the Highway 38 section embody 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. 12B) are present in limestones near the base of the Bennett member.

Summary. At the type area near Bennet, Nebraska, and southward to Manhattan, Kansas, the Bennett member is comprised mainly of calcareous (30 percent $CaCO_3$) medium-gray, moderately to well-laminated shales. Brachiopod

shells and spines are common, whereas bryozoans, conodonts, foraminifers, ostracodes, and crinoid discs are rare. The lower Bennett shales are fissile, dark gray or black, and characteristically contain numerous Orbiculoidea, a few conodonts and fish teeth, and even fewer fusulinids. They are easily identified in the field because they rest on the distinctive Glenrock Limestone. Sparse Orbiculoidea may occur throughout the Bennett member, regardless of lithology.

The Bennett member is about 7 feet thick at Bennet, Nebraska, and gradually thins southward to 4 feet at Manhattan, Kansas. Between Manhattan and Paxico the Bennett "shales" become thicker (8 feet) and more calcareous, until at the Paxico section only the lower, black fissile shales maintain the typical northern character (approximately 30 percent $CaCO_3$). In the same area the upper two-thirds of the Bennett member appear in the field to consist of light-gray, very calcareous mudstone and shales. Laboratory analyses reveal that these are laminated muddy limestones 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 Bennett facies change abruptly to the medium-bedded, very pure (95 to 98 percent $CaCO_3$) limestones, 15 feet thick, visible at the Eskridge Quarry. The thickest part of this limestone facies of the Bennett member trends in a band about 2 miles wide (Fig. 2) southwest from Bradford,

through the Eskridge Quarry to the Coffman Ranch section where it supports a conspicuous bench on local hillsides and creek banks. Sink holes are not uncommon in these limestones. Brachiopods, crinoid columnals, horn corals, bryozoans, and fusulinids are rare to common throughout the limestones. Between the Coffman Ranch section and the Allen section the entire Bennett member thins to about 9 feet. The pure limestone facies thin 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 to Allen No. 2 section the Bennett member thins to less than 8 feet, the pure limestone becomes slightly argillaceous, and the muddy limestones become shaly (45 percent $CaCO_3$).

The black and dark-gray shales of the lowest Bennett member maintain a thickness of about 1 foot below the aforementioned facies changes of the medial and upper Bennett.

Southwestward from Allen No. 2 to Elmdale, the Bennett member thickens slightly to 9 feet. The massive pure limestone facies of the Bennett member thicken to about 5 feet whereas the basal black shales thin to less than 0.1 feet at the Elmdale section. Some of the massive limestones contain wavy algae. Upper Bennett shales contain the same kind of mixed fauna visible in Nebraska.

There are few sections of the Bennett member suitable for sampling between Saffordville and Piedmont. Where it is visible, the member lacks black shales, and is comprised

of fossiliferous gray shales enclosing 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 limestone assemblage is relatively thick (10 to 15 feet) and continuous southward into Oklahoma, where it constitutes most of the Red Eagle Limestone. The basal Bennett black shales are scarcely an inch thick in southern Kansas but they are, nonetheless, readily recognizable at the base of the massive Bennett limestones. The black shales are absent in Oklahoma.

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

Bennett limestones are all quite pure (93 to 98 percent $CaCO_3$) in southern Kansas. In northern Oklahoma they are more argillaceous (60 to 80 percent $CaCO_3$). The limestones weather to shades of light gray with tints of rusty yellow and brown.

Wherever the Bennett member is shale it underlies grassy slopes between the minor hillside benches supported by Howe

and Glenrock Limestones. A few good shale outcrops have been found along creek banks. Fresh road cuts provide the best exposures. 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.

Howe Limestone

This upper member of the Red Eagle Limestone was named by Condra (1937, 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 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 which 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, no fossil-bearing Roca or Bennett beds are exposed above or below it, 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 feet thick. The commonly pitted and irregularly cellular (vuggy) Howe limestones have been partially dissolved by ground water in many places.

Near the Pawnee section springs 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 Bennett shales serve as an effective aquifuge or aquiclude preventing seepage of water downward from the Howe. Roca shales above are somewhat siltier and more porous than those of the Bennett.

The Howe Limestone is well exposed at the Bennett and Pawnee sections, either of which 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 shales of the topmost Bennett. This northern facies of the Howe Limestone contains few fossils (small foraminifers, gastropods) so that the Howe may 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 visible in the vicinity of Paxico and Alma (Pl. 14B). This distinctive texture characterizes the Howe Limestone of central and south-central Kansas between Paxico and Grand Summit. The Eskridge-Coffman area (where limestone of the Bennett member is thick) is the only part of central Kansas where the Howe does not display the pseudo-oolitic texture.

The pseudo-oolites are comprised of 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 pseudo-oolitic texture ("osagite") characteristic of the Howe Limestone in central Kansas. The rock weathers to a light gray color, 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 comprises the bulk of the unit, but the upper 2 or 3 inches is capped with bun-shaped or roughly hemispherical

Plate 14

A. Algal "buns" at top of Howe Limestone at Allen No. 2 section.

B. Pelletoid Howe Limestone (osagite) from Alma section, magnified (X50) from thin section. Pellets or pseudo-oolites are tiny fossil fragments (ostracodes, foraminifers, brachiopods) covered by layers of algal (Osagia) calcium carbonate.

masses of concentrically layered algal calcium carbonate (Pl. 14A,15). 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. 16). The nautiloid rests in the top of the pseudo-oolitic limestone. Greenish shales of the overlying Roca Shale are impressed into and around the tops of the algal "buns."

A fossiliferous Howe facies is developed on the thick Bennett Limestone at Eskridge Quarry and Coffman Ranch. Bryozoans, ostracodes, brachiopods, holothurian sclerites, foraminifers, and algae are common, and crinoid columnals are abundant in these unevenly thin-bedded "rubbly" limestones. Laboratory analyses show that these rocks contain about 5 percent less calcium carbonate than the underlying massive Bennett Limestone.

The distinctive pseudo-oolitic or pelletoid (osagite) Howe facies persists, with minor modification, southward to the vicinity of the Kansas-Oklahoma border. At the Highway 38 section the pellets or pseudo-oolites are smaller, less abundant, 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 pseudo-oolitic facies is absent, it is difficult to identify the Howe Limestone or its

Plate 15

Peel-print (X3.8) of vertical section of algal "bun" from Allen No. 2 section. Note vague definition of concentric laminations. Puffy material at top is argillaceous algal limestone.

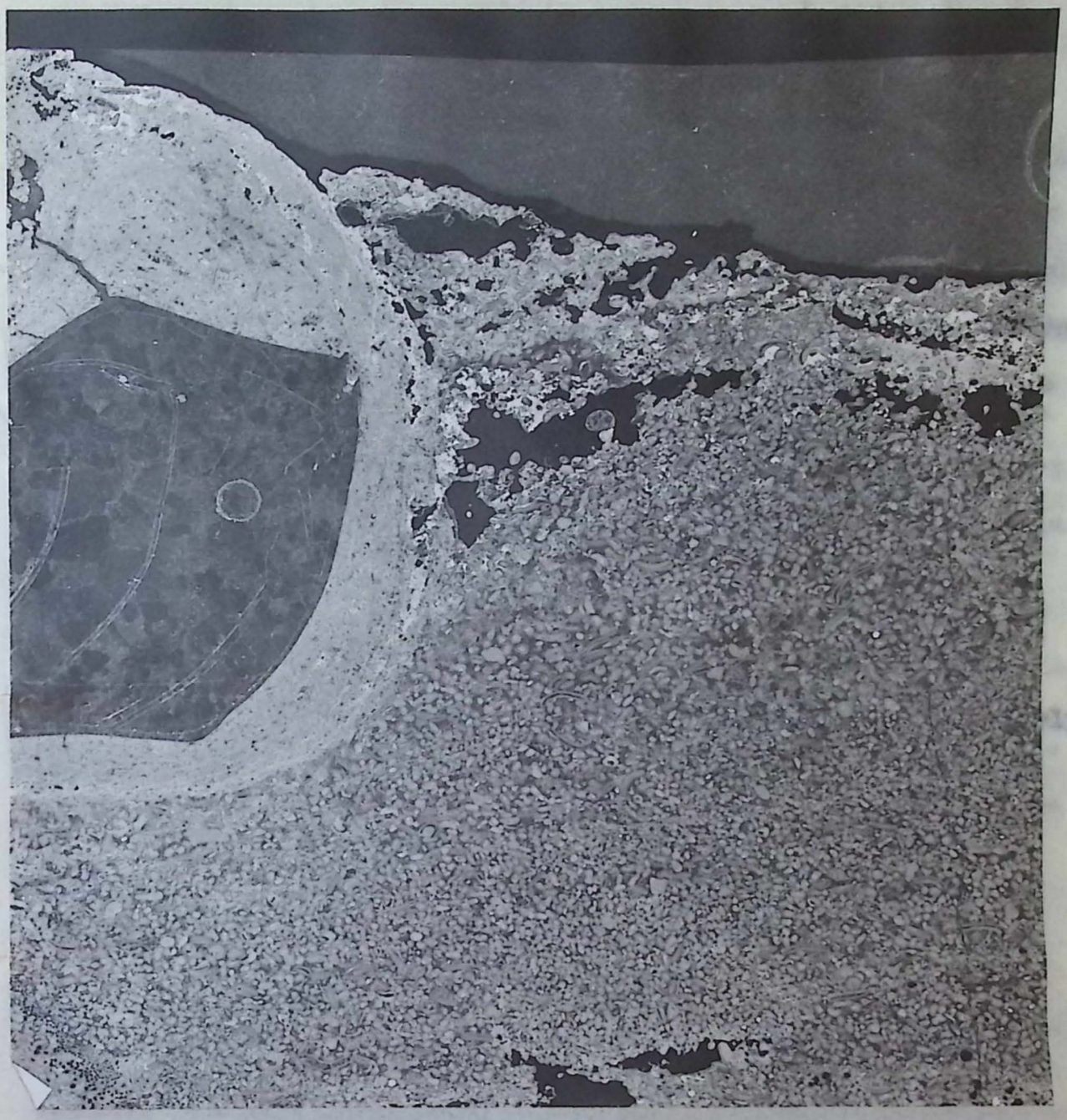


Plate 16

Peel-print (X30) of pelletoid Howe Limestone (pseudo-oolitic or osagite) from Allen No. 2 section. Large fossil at left of picture is a coiled nautiloid cephalopod filled with clear calcite and coated by Osagia type of algal calcium carbonate. Note that pellets are fossil fragments (ostracodes, foraminifers, brachiopods) coated by Osagia. (See also Pl. 14B.)

equivalents. Largely because of their stratigraphic position atop Bennett Limestone, and beneath red Rosa Shale, the irregularly thin-bedded, pitted, rusty, sparsely fossiliferous limestones at the top of the Burbank section are correlated with the Howe member of the Red Eagle Limestone. Additional support for this designation is provided by the sparse microfauna and observations that the thin wavy bedding resembles Howe bedding at the Eskridge Quarry, and the pitted, rusty condition is typical of Howe Limestone wherever it caps a section and is exposed to weathering and soil-forming processes.

Summary. The Howe 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 or 3 feet thick and it exhibits only one major facies change. In Nebraska and northern Kansas the Howe member is an aphanitic to microcrystalline light-gray limestone in places pitted and decayed by weathering. In central and southern Kansas the Howe Limestone is a brown to gray-brown pelletoid limestone. The pellets (pseudo-oolites) are composed of fragments of organic shell detritus coated by algal (Osagia) calcium carbonate. Fossils are rare to absent, but a few ostracodes, brachiopods, and arenaceous foraminifers can be seen in some fresh exposures.

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."

The pelecypod-bearing limestones ascribed by Condra to the upper portion of the Roca Shale are 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, 1957, 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 shales of the Roca Shale.

Thus, the Roca Shale is readily recognizable not only by its own red shale content, but by its position between the Howe Limestone below, and 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 recognizing 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 exposed at Roca, Nebraska. A few slopes in the town are reddish, after the fashion of weathered red shales of the Roca visible elsewhere, but they owe their color to red Pleistocene silts and loess.

At the nearby Bennet section (Appendix III) the lower 9 feet of the Roca Shale is well-exposed. The lowermost 3 feet consists of gray, and greenish-gray, slightly calcareous shale with traces of ostracodes and gastropods. One foot of hard, light-gray, aphanitic limestone separates the lower shale from overlying gray shale which includes approximately 1 foot of vivid brick-red shale. Gray shale below the red beds contains a few ostracodes and rare traces of fish teeth. Shales above the red beds are unfossiliferous. A thin, aphanitic, light-gray limestone caps the incomplete Roca exposure at the Bennet section. The complete Roca Shale thickness is estimated at 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 limestones of the overlying Grenola Limestone and underlying Red Eagle Limestone.

A partial exposure (lower 18 feet) of the Roca Shale occurs at the Pawnee section (Appendix III). The lowermost 9 feet consists of light greenish-gray calcareous mudstones barren of fossils. These are overlain by a foot 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 of the greenish-gray mudstones. This feature can be seen on the weathered base of the limestone where it is shown by overturned slump blocks (Pl. 17). The top of the limestone grades upwards through 0.2 feet of laminated, flaky, argillaceous limestone to calcareous shale with traces of tiny gastropods, brachiopod fragments, and arenaceous foraminifers. The brick-red mudstone next above is barren of fossils. Unfossiliferous light greenish-gray argillaceous limestone and shale comprise the uppermost beds. If unit thicknesses are disregarded, the sequence of green and red shales and limestones of the Pawnee section correlate satisfactorily with similar beds at the Bennet section despite the absence of fossils. Such correlation of subdivisions of the Rocs Shale is not possible in Kansas, because of numerous local inconspicuous changes in facies, lack of fossils, and wide separation of exposures.

The Rocs Shale is entirely exposed and accessible at the Manhattan section (Appendix III). Thickness of the unit here is 19 feet. Light greenish-gray, calcareous mudstone and shale are the principal rock types, but three levels of maroon and brick-red shales comprise nearly one-third of the sequence. Well-developed calcareous nodules occur in some of the calcareous red shales. Some of the maroon beds grade to light green color. A nodular microgranular limestone is

Plate 17

Base of limestone bed in the Roca Shale at Pawnee section. Raised angular wall-like structures fill cracks in top of underlying lower Roca Shale.

present just below the middle of the unit. Rare traces of brachiopods (Crurithyris?) are present in greenish-gray shales near the middle of the member.

At the Alma section (Appendix III) most of the Roca shale is medium to light gray and light greenish-gray, only slightly calcareous, and without fossils. The only red shale (noncalcareous) is near the top of the sequence and the only limestone is near the base.

The Roca contains several thin limestones at the Dunlap section (Appendix III). One of these, 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 brick-red shale occurs in the middle of the section.

The Roca Shale at the Elmdale section (Appendix III) is predominantly light greenish-gray or gray, and only faintly calcareous. A maroon shale near the top of the unit is noncalcareous.

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 shales and a lower one of brick-red and maroon shales 11 feet thick (Taylor, 1953, p. 57).

At the Burbank section (Appendix III) the lower 7 feet of the Roca Shale is comprised of brick-red shales. Pinkish-gray shales 4 feet thick lie between the lower red shale and 6 feet of buff-weathering gray shales 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 of the Roca Shale are the rarest of any in 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 shales about 15 feet thick. Brick-red shales 1 or 2 feet thick are 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 Oklahoma the lower third of the Roca Shale consists of brick-red shales, succeeded by an upper sequence of gray shales which weather light yellowish-gray or buff.

MINERALOGY

Study of insoluble residues obtained by acid treatment of rocks belonging to the Red Eagle Cyclothem shows that clays are the most abundant minerals. Clays comprise the bulk of the Johnson and Roca shales, regardless of their color, and are an important constituent of the Red Eagle Limestone. Differential thermal analyses and X-ray diffraction patterns from selected samples show that illite is the most common and abundant clay mineral. 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 shales, the major constituent of the small amounts of clay in the Red Eagle limestones is illite, with traces of chlorite.

Next to clays, calcite is the most abundant mineral in the Red Eagle Cyclothem. Finely-divided calcite is present in almost all shales and in all limestone matrices. Shell remains, some aragonitic originally but now changed to calcite, comprise a large portion of the calcium carbonate in the Red Eagle Limestone. Algal calcium carbonate is also significant. Traces of dolomite are present in some shales of the Red Eagle Cyclothem.

Insoluble residues also show 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 largely to have been built into the shells of arenaceous foraminifers. In the Johnson and Roca Shales the quartz silts are sparsely dispersed. Extremely rare traces of muscovite 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 limestones 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 the limestones of the Bennett member. Hematitic pyritohedral pseudomorphs are present in the limestones 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 shales in the Red Eagle Cyclothem.

PALEONTOLOGY

Paleobotany

Fragmentary carbonized plant remains and impressions are commonly present in the uppermost gray shales of the Johnson formation. Much of this material is quite vitreous and "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. Rare traces of fragmentary carbonized materials are also present in some gray shales in the lower part of the Bennett member, and in the uppermost shales of the Roca formation.

Evidence of the vital 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 "osagites." Limestones of the Bennett member contain traces of so-called "linear algae" at some localities (Pl. 11). These are really ribbon-like and thin, crustose, 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

comprise much of the matrix of Bennett limestones are believed to be largely algal in origin (consolidated algal 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 shales of the Roca in southern Kansas.

Several genera of spores are present in the lower black shales of the Bennett member. These include Pityosporites sp., Lueckisporites sp., Florinites sp., Punctatisporites sp., Nuskoisporites sp., and 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 in 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 up to now. 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,

and probably will be used to affirm or revise the presently recognised (Moore and Moss, 1944) position of the Pennsylvanian-Permian boundary in Kansas and adjoining states.

Paleozoology

General Statement

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 units of the Red Eagle Cyclothem. Other kinds of invertebrates are almost all confined to the Glenrock and Bennett members of the Red Eagle Limestone. Table 2 lists all animal fossils found in the Red Eagle Cyclothem.

TABLE 2. Animal Remains Recognizable in the Red Eagle Cyclothem.

FORAMINIFERS

Larger forms (fusulinids)

Triticites
Schwagerina

Smaller forms (mostly arenaceous)

Ammobaculites	Glyphostmella
Ammodiscella	Glomospira
Ammodiscina	Hyperammina
Ammodiscus	Nodosinella
Ammovertella	Nummulostigina
Bigenerina	Tetrataxis
Cornuspira	Tolypammina
Globivalvulina	Trochammina

COELENTERATES

Unidentified horn corals (lophophyllids)

BRYOZOANS

Cryptostomes	Acanthocladia	Polypora
	Bactropora	Rhabdomeson
	Chainodictyon	Rhombopora
	Fenestrellina	Safferdotaxis
	Fenestella	Septopora
	Megacanthopora	Syringoclemis
	Minilya	Thamniscus
	Pennirotopora	
Trepostomes	Leioclema?	

BRACHIOPODS

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

TABLE 2 (continued)

MOLLUSKS		
Pelecypods	Aviculopinna	
	Allorisma	
Gastropods	Anomatina?	
	Small unornamented forms	
Cephalopods	Unidentified coiled nautiloid	
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
	Geffonina	Youngiella
	Hollinella	
HOLOTHUROIDS	Small, wheel-shaped sclerites (Paleochiridota?)	
	Net like sclerites (Eocaudina?)	
	Achistrum	
CONODONTS	Cavusgnathus	Polygnathodella
	Hindeodella	Prioniodina
	Lonchodus	Streptognathodus
	Moreyella	Synprioniodina
	Ozarkodina	
Tooth fragments	Cooleyella	Multidentodus
	Cooperella	Paleoniscus
	Distacodus	Scolopodus
	Idiacanthus	
WORM BURROWS		

Stratigraphical Paleontology

Plate 18 shows the stratigraphic position of all fossils recognized in the Red Eagle Cyclothem. To some extent recognition of these fossils depends upon the efficiency and refinement of extraction methods. Most genera named were collected from shales of the Bennett member of the Red Eagle Limestone.

The fusulinid foraminifer Triticites is the most abundant fossil in the entire Red Eagle Cyclothem (Pl. 18). It is mainly confined to the Glenrock Limestone, where at many places its large numbers constitue a major part of the rock. A few Triticites are present in lowermost shales and the limestone facies of the Bennett member and in uppermost beds of the Johnson Shale only at the Highway 38 section.

With five exceptions only, 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 them in beds younger than Red Eagle and states that they are indistinguishable from Upper 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.

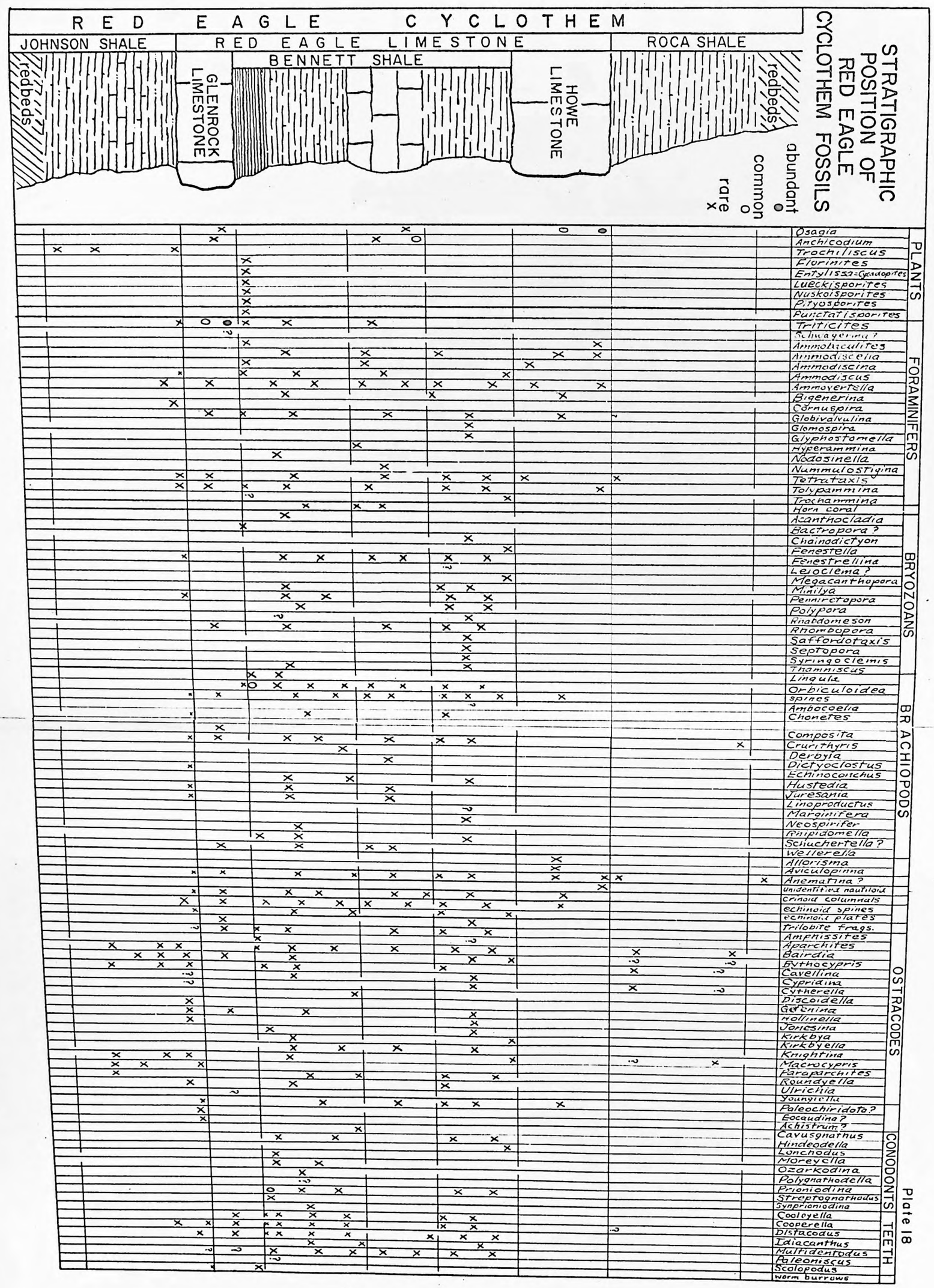

RED EAGLE CYCLOTHEM
JOHNSON SHALE
RED EAGLE LIMESTONE
ROCA SHALE
BENNETT SHALE
redbeds
GLENROCK LIMESTONE
HOWE LIMESTONE
redbeds?
STRATIGRAPHIC POSITION OF RED EAGLE CYCLOTHEM FOSSILS
abundant
common
rare
Osagia
Anchicodium
Trochiliscus
Florinites
Entylissa=Cycadopites
Lueckisporites
Nuskoisporites
Pityosporites
Puncatisporites
Triticites
Schwagerina?
Ammobaculites
Ammodiscella
Ammodiscina
Ammodiscus
Ammovertella
Bigenerina
Cornuspira
Globivalvulina
Glomospira
Glyphostomella
Hyperammina
Nodosinella
Nummulostigina
Tetrataxis
Tolypammina
Trochammina
Horn coral
Acanthocladia
Bactropora?
Chainodictyon
Fenestella
Fenestrellina
Leioclema?
Megacanthopora
Minilya
Pennireteropora
Polypora
Rhabdomeson
Rhombopora
Saffordotaxis
Septopora
Syringocleimis
Thamniscus
Lingula
Orbiculoidea
spines
Ambocoelia
Chonetes
Composita
Crurithyris
Derbyia
Dictyoclostus
Echinoconchus
Hustedia
Juresania
Linoproductus
Marginifera
Neospirifer
Ripidomella
Schuchertella?
Wellerella
Allorisma
Aviculopinna
Anematina?
unidentified nautiloid
crinoid columnals
echinoid spines
echinoid plates
trilobite frags.
Amphissites
Aparchites
Bairdia
Bythocypris
Cavellina
Cypridina
Cytherella
Discoidella
Geisinina
Hollinella
Jonesina
Kirkbya
Kirkbyella
Knightina
Macrocypris
Paraparchites
Roundyella
Ulrichia
Youngiella
Paleochiridota?
Eocaudina?
Achistrum?
Cavusgnathus
Hindeodella
Lonchodus
Moreycla
Ozarkodina
Polygnathodella
Prioniodina
Streptognathodus
Synprioniodina
Cooloyella
Cooperella
Distacodus
Idiacanthus
Multidentodus
Paleomiscus
Scolopodus
worm burrows
PLANTS
FORAMINIFERS
BRYOZOANS
BRACHIOPODS
OSTRACODES
CONODONTS
TEETH

Plate 18

Bryozoans (mostly cyclostomes) are largely confined to the Bennett and Glenrock members of the Red Eagle formation. Fenniretopora, characteristic of the Bennett member, is also found at the top of the Johnson Shale and in the upper part of the Roca Shale. All bryozoan genera were washed from shales. 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 shales than in the lower part of the Bennett Shale.

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 common in the black shales of the lower Bennett, and rare in gray shales and buff limestones 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 common 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 shales and rare to common in Bennett shales. Crurithyris, the only brachiopod found in all three formations, is 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 shales of the Johnson formation contain many ostracodes, in company with 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 shales of the lower part of the Bennett. Streptognathodus is the most common genus. Minute fish teeth (?) (Idiacanthus, Distacodus, etc.) which 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 Anomatina, 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 and in Howe Limestone at one locality, and in the Bennett Shale and Howe Limestone at another.

One nautiloid cephalopod was found at the top of the Howe Limestone (Pl. 16).

Crinoid columnals are fairly common in the Bennett member of the Red Eagle Limestone, but a few may 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.

Echinoid spines are rare to common throughout the Red Eagle Limestone, and very rare in the upper beds of the Johnson Shale. Cidaroid interambulacral plates are very scarce in the Bennett member. A single plate was found in the upper part of the Johnson calcareous shales.

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

Holothuroids or scleritos may be found only in the upper part of the Johnson Shale and in the Bennett member of the Red Eagle Limestone. Achistrum, a hooked form, and Eocaudina?, a net like sclerite, occur exclusively in the upper part of the Johnson Shale. Wheel-shaped scleritos (Palaechiridota?) are present in the Bennet 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

General Statement

Rocks of the Red Eagle Cyclothem are believed to have been deposited in warm shallow marine waters, sometimes clear, sometimes turbid, sometimes teeming with organisms, sometimes almost lifeless. Marine animals are the only fossils in the Red Eagle Cyclothem.

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

Danger lies in depending on fossils alone for paleoecological interpretation. The enclosing sediments may show that fossils were moved from their original positions and came to rest in a different environment (Weller, 1960, p. 204). 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.

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

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

Marine Plants

Calcareous Algae

All three members of the Red Eagle formation contain calcium carbonates of algal origin. They are recognizable as the Osagia (Johnson, 1946) coatings on shell fragments in the Glenrock and especially Howe Limestones. Another type appears as long, roughly horizontal, ribbon- or sheet-like crustose layers (Pl. 12), commonly called linear algae (Anchicodium?) in limestones of the Bennett member. Intact

specimens are presumably *in situ*. Some of the ribbon-like material is broken and randomly oriented (Pl. 12). It may have come from encrusted upright-growing algal forms (Harbaugh, 1959, pp. 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 limestones containing obvious algal deposits suggests that there was very little muddy material in the waters.

If it is assumed that the earth's crust of the Midcontinent region has not shifted appreciably since Permian time, present day observations (Hedgpeth 1957, p. 18) support the additional assumption that in clear waters, the base of the photic zone and the compensation depths, in Kansas latitudes at noon, on a cloudless calm June 21 during Wolfcampian time, would have been at least 200 feet below the surface. Elias (1936) postulated that limestones such as the Glenrock were 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 limestones in the Kansas Lower Permian. Possibly 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." Certainly, algal growth involves more than mere

presence of light. Intensity and wave length of light are 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 or 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) are 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 (Ginsberg and Lowenstam, 1958). Accordingly, it seems justifiable to assume that the profuse algal (Osagia) carbonates in the Howe Limestone were probably deposited in waters less than 60 feet deep.

The few algally-coated shell fragments within the Glenrock Limestone show no signs of abrasion or other suggestion of damage due to transportation. This indicates that although they must have been turned over by gentle currents from time to time in the Glenrock lime oozes (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 where fusulinids lived. Hence, the question arises as to whether such light penetration was because of shallow waters in Glenrock time, or merely because of exceptionally clear, deeper waters, free of suspended detritus. The latter seems most likely.

A large part of the calcareous matrices of the Red Eagle Limestone is aphanitic and microcrystalline. Johnson (1946) suggested that such very fine-grained calcite is an accummulation of dust-like algal particles. In these matrices traces of the same sort of algal threads described by Johnson (1946, p. 1107) are rarely observable, possibly because of effacement by recrystallization. Thus, it seems reasonable to believe that a large proportion of the structureless, aphanitic calcium carbonate in the Red Eagle limestones (especially Bennett limestone facies) is of algal origin. Bacteria also 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. 11) it can be suggested that if the algal ribbons grew in the upright position, they may have served as filter traps for the algal detritus. Moreover, as Harbaugh (1954, 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.

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 waters, Paleozoic forms seem to have lived in shallow marine waters. They appear to have thrived in clear, lime-rich waters.

The oogonia of charophytes in calcareous mudstones of the Johnson formation support the conclusion that these beds were deposited in shallow marine, limy waters of less than normal salinities. Perhaps this is why fossils are so rare in the Johnson formation. Tentative explanations for such abnormal conditions are given on page 114.

Spores

Spores are present in a number of the shales of the Red Eagle Cyclothem, especially the black Bennett shales. They are of no use in marine environmental interpretations because they must have blown or washed into the Red Eagle Cyclothem sediments from terrestrial sources. However, the assemblage seems to indicate a cool climate in the lands which surrounded the seas of earliest Bennett time.

Waxy plant residues are also present in the black Bennett shales. Presumably much of this unidentifiable material is of terrestrial origin similar to the spores.

Its presence merely demonstrates that the Bennett black-mud environment preserved plant material.

Carbonized Terrestrial-Plant Materials

The only significant black carbonaceous plant remains occur in the uppermost shales of the Johnson formation. Plant materials are randomly distributed through the mudstones and shales. They must have been buried quickly under accumulating Johnson clastics to avoid destruction by physical or organic agencies. Some are gymnospermous, but other fragments, which might be seaweed, look "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 (Cushman, 1937). Elias (1936, 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 comprise a major proportion 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 little damaged. This is usual with fusulinids (Dunbar, 1957). Their shape, size, and cellular internal structure all tend to resist breakage, but their undamaged surfaces are nonetheless surprising, 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 pointed randomly. This could be expected, because spindle-shaped objects would be in unstable equilibrium in any other position than "on their sides." Their random orientation in the Glenrock Limestone might be explained by a sea-floor 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 character of the fusulinids in limestones 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 substrate where algae were depositing calcium carbonate on and around broken shell detritus of several kinds. Perhaps they were 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 enjoyed clear water. They are numerous only in limestones containing less that 15 percent of insoluble clay and silt detritus. Moreover, the pure calcium-carbonate tests of fusulinids can comprise up to 60 percent (by volume) of the rock. Thus, if a limestone containing 50 percent (by volume) of fusulinid tests yields, say, 5 percent (by weight) of insoluble reside, 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 containing abundant fusulinids contain slightly less calcium carbonate than where they are sparse.

The association of fusulinids with algal carbonates also indicates warm, clear waters, shallow enough to permit light penetration sufficient for algal photosynthesis. This evidence suggests that Elias (1936) was approximately correct in estimating that fusulinids in Lower Permian rocks of Kansas (including the Red Eagle formation) lived in waters less than 180 feet deep.

Normally, temperature is a major control of the distribution of foraminifers (Glaessner, 1955; Myers and Cole, 1957) but it does not influence zonation in shallow waters (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 for the foraminifers' diet.

During Glenrock time clear, marine, fusulinid-rich waters, of uniform depth and faunal content, covered most of eastern Kansas. That is, deposition of the Glenrock Limestone was uniform over a broad area 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 the black tubes near the top of the Glenrock Limestone at the Pawnee section 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 muds into loosely consolidated Glenrock lime muds. The few loose fusulinids that lie atop the Glenrock Limestone (slightly impressed into it) and that are largely engulfed by black Bennett muds were probably killed by the first incursion of toxic Bennett muddy conditions.

If the sparse fusulinids which are present in some Bennett limestones are approximately in situ, they must have lived under conditions close to the tolerance limits of fusulinids. The implication of their small numbers, their faunal association, and their association with large volumes of algally-deposited limestones, would be that these fusulinids lived in quite shallow waters (?≤140-150 feet). A corollary to this would be that the algae possibly used up a large portion of nutrients that would be necessary to support fusulinid life. Perhaps some critical nutrient was in short supply, so that only a sparse fusulinid population could develop. Moreover, the particulate algal calcium carbonate that was probably precipitating rapidly might have interfered with the food-intake mechanisms of the fusulinids, perhaps killing them before they could proliferate.

On the other hand, it is remotely possible that the fusulinids could have washed into the area of study from unknown sources, or 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 abasion to suggest erosion or transportation.

The very rare fusulinids in the top part of the Johnson Shale at the Highway 38 section are broken and abraded, betokening damage during long transportation from an unknown source area.

The smaller foraminifers of the Red Eagle Cyclothem are almost all 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 is incomplete, 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 a variety of lithologies ranging from very pure limestone to moderately calcareous shales and mudstones. 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 residues. Thus, their preference for clear waters is indicated. 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 Mattin (1957) noted that certain specimens of Osagia studied by them 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 in the Bennett member as well. However, the Ammovertella are so few that these coincidences of occurrence are not construable as indicating definite organic associations (e.g., commensal, symbiotic, etc.). That is, considering the variety of calcareous materials on which it encrusts, Ammovertella in the Red Eagle Cyclothem simply seems 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 interelatives of algae and active contributors to Osagia.

Insoluble residues from limestones in all parts of the Red Eagle Cyclothem commonly contain traces of quartz silt

most of which probably came directly from arenaceous foraminiferal tests similar to (or actually belonging to) Ammovertella and Tolypammina.

Little definite opinion about the paleoecology of the smaller foraminifers is forthcoming from the available evidence. Their presence 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 the paleosedimentation of the Red Eagle Cyclothem.

Johnson waters seem to have been generally inhospitable to foraminifers. Only Ammovertella and Tolypammina were able to establish themselves during periods of clearer waters in later Johnson time, represented by limestone layers in the upper part of the Johnson Shale. Large and small foraminifers thrived in the clear waters of Glenrock time. Foraminifers did not live in the toxic waters 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 joined the other marine invertebrates which teemed in the calcareous, sometimes turbid, waters represented by Bennett limestones and shales.

The clear, shallow-water environment represented by the sparsely fossiliferous aphanitic Howe Limestone seems to have been favorable enough for a foraminifer population somewhat reduced in number of genera and individual as compared to the Bennett 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 portions 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 waters, probably in the shallower reaches of the neritic type of environment, where waters were warm and life 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 raising the question of 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 without also removing the others. Thus, it seems that bryozoans were

absent from the Johnson and Roca environments because of some unfavorable ecologic factors. 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 the 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, 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 sea water averages about 35°/oo.) are unfavorable to bryozoans. Thus, the absence of bryozoans from upper shales of the Johnson and Roca formations lends support to the possibility that abnormally low salinity 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's range of depths should

not be construed as the depth limits outside of which bryozoans could not have lived during Early Permian time. The assumption is 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 protected places in water shallower than 75 feet where they would not be destroyed by turbulence. However, there is no evidence of bottom relief sufficient to afford such protection. If Elias's figures are correct, it might be suggested that in the flat-bottomed shallow sea indicated by the Red Eagle Cyclothem most turbulence (e.g., lowering of wave base) was shallower than 75 feet. That is, bryozoans favored bottoms below a normal wave base of about 75 feet. Broken bryozoans in the calcareous Bennett shales suggest that turbulence during unusually severe storms occasionally shattered the bryozoans living below normal wave base.

One specimen of Rhombopora (?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 limestones. However, they are found at random throughout a

variety of fossiliferous calcareous mudstones, indicating that they could tolerate a good deal of mud in waters of approximately normal marine salinity. Their faunal and sedimentary associations demonstrate that they thrived below normal wave base in shallow water, probably less than 150 feet deep. The scarcity of bryozoans in any part of the Red Eagle sequence may be due to shallow water or other unfavorable and physically severe conditions (Duncan, 1957, p. 786). The euxinic environment of the Bennett black muds 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

As with other calcareous invertebrate remains, brachiopods are most numerous in the Red Eagle formation and rare in the Johnson and Ross formations. There is no doubt that the articulate brachiopods preferred the clear calcareous environments represented by Red Eagle limestones, but many genera also occur in a variety of muddy lithologies. Only the inarticulates Orbiculoidea and Lingula are present in the black Bennett shales (conodonts are the only other fossils present). These delicate fossils are commonly found unabraded and almost unbroken or gently crushed by pressure in the vertical direction, so that their in situ occurrence

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 limestones, 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 waters, much as it was during Red Eagle time. In 1902, Morse (Cooper, 1957, p. 265) stated that Lingula has always dwelt in a shallow-water shore zone and therefore has not felt the affect 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 waters and is rarely present at depths greater than 60 feet. In fact, Lingula is commonly found in the littoral zone (Cooper, 1957, p. 1113-1116).

The Lingula-Orbiculoidea association in the black shales at the base of the Bennett member is therefore thought to indicate that these beds were deposited in warm marine waters shallower that 60 feet. Moreover, the nature of the

sediments as a whole indicates that the early Bennett waters were low in oxygen content and rather toxic, so that benthonic invertebrates could not live there. This further suggests that Lingula and Orbiculoidea had broad tolerance ranges for oxygen supply and salinity, but were sensitive to depths greater than 60 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 common 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, normal marine waters under both turbid and clear conditions, on calcareous muddy bottoms. Many shells were broken or without their spines. This could be the result of turbulent waters, or the masticatory activities of mud-ingesting animals and nectonic and benthonic predators. The shell fragments are not worn or rounded.

Theories that shape, ornamentation, and thickness of bivalve shells reflect the rigor of their living conditions, are well known. The variety of brachiopod shell shapes, thicknesses, and sizes, present (broken and unbroken) in the Red Eagle sediments indicates that they lived in waters 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 shales. Lowenstam (1959) indicated, from geochemical data, that the shells of Lower Permian Neospirifer probably formed in marine waters at about 74°F.

Crurithyris, in a variety of lithologies, and in all three formations of the Red Eagle Cyclothem, seems to have been the 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 Johnson shales are quite calcareous.

Gastropods

Small, smooth, spired and planispiral evolute gastropods are present, but few in number, in all units of the Red Eagle Cyclothem. They occur in all lithologies of the cyclothem, except the Bennett black shales. This suggests that although they could have lived in most sedimentary environments in waters less than 200 feet deep, they were among the many animals unable to tolerate the euxinic Bennett conditions. A slight preference for the more calcareous environments is indicated by somewhat greater numbers of gastropods in limestones.

Gastropods in osagite of the Howe Limestone are not coated by algal calcium carbonate. This may signify that the gastropods were moving about while the algae were growing, or that the geochemistry of their shells was distasteful to algae.

Cephalopods

Modern Nautilus lives in depths from near low tide to almost 2,000 feet.

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

Pelecypods

Molds of Aviculopinna are present 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 limestones were probably preserved because the limes were 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 muds. Perhaps some of the broken Bennett shell materials belong to (comparatively frail) Aviculopinna. Allorisma is more robust than Aviculopinna and is only rarely found in the Bennett shales and in the Howe Limestone.

Worms

Explanation as worm burrows is one interpretation of the peculiar flattened clay-filled tubes in the Glenrock Limestone (Pl. 5A). Apparently the worms burrowed into the Glenrock lime sands from the overlying black Bennett muds. 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 materials by secreting acids. Thus, it is not known whether the tubes were made in the Glenrock

sediments before or during consolidation. However, individual fusulinids, Orbiculoidea fragments and Bennett muds trapped in the tubes suggest that the sediment was firm enough for the tubes to remain open[1]. Flattened parts of

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

the tubes indicate that consolidation and compression was completed after the time of burrowing. The tubes had to be open to allow the fragments of Orbiculoidea, fusulinids, and mud particles to fall to the bottom of the tubes from the Bennett muds at their upper ends.

Other, smaller and somewhat different, worm tubes are present in upper Johnson calcareous mudstones and upper Roca limestone. Some might be phoronid tubes.

The assumption that the tubes were made by worms does not preclude the possibility of their making 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 shales of the Johnson formation and in the Red Eagle formation, but rare

in the Roca formation. They occur in almost all calcareous rock types in the Red Eagle Cyclothem, but not in red or black shales.

Sediments enclosing the ostracodes and their numerous and varied faunal associates indicate that some sorts of ostracodes could survive in almost every calcareous marine environment within the Red Eagle Cyclothem. They are thus independent of sedimentary facies. They thrived best in somewhat turbid, calcareous, waters of normal salinity. The toxic conditions indicated by the black Bennett shales and high salinities suggested by Roca red shales were inimical to 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 wider variety of 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 accumulate along laminae of shales. In view of their molting habits, delicate shells, easy transport, and association with coarse detritus, it seems clear that these almost undamaged ostracodes had not been transported far. Soft and muddy bottom sediments may account partly for their preservation. If some ostracodes died in their burrows, the bottom muds could have protected

them from abrasion. Also, the muddy bottom would cushion them against the effects of tumbling by gentle currents. Many ostracodes present in the nonlaminated mudstones, 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 (Segandares-Bernal, 1955; personal communication).

Within the Red Eagle Limestone, especially the limestone members, many ostracodes are randomly oriented. In Bennett shales 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 very frail, smooth ostracode shells occur along laminae in uppermost Johnson gray shales and mudstones. In fact, these layers of ostracodes are planes of textural difference and hence,

of weakness or parting which are recognized as "laminations." Their frailty and lack of damage indicate that they are probably *in situ*. Ostracodes are few and randomly-oriented in the interlaminar mudstones. Perhaps these were burrowing forms.

Periodical mass mortality of ostracodes in late Johnson waters could have caused the rain 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 waters bearing plant detritus. This combination of events is admittedly hypothetical. However, sporadic fluctuations of regional climate offer a tentative explanation for the phenomena recorded in the uppermost Johnson shales. If low salinity had been the prevailing condition during late Johnson deposition, and if the waters cleared and became more normally saline 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 waters carrying plant detritus and mud. This could explain both the mass mortality of ostracodes and traces of carbonaceous plant remains in mudstones and shales 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 wide range of salinity conditions.

Crinoids

Within the Red Eagle Cyclothem columnal remains of crinoids are present almost exclusively in the Red Eagle Limestone. The only exception is in calcareous upper Johnson sediments at the Grand Summit section. 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.

The Howe Limestone at the Coffman Ranch section contains common crinoid columnals; many still articulated. This indicates that they remained in situ, where they accumulated to form a local crinoid shell bank. Such delicately stalked animals may have grown near the lower limit of normal wave base, where currents and water turbulence were usually gentle. Moreover, decaying epidermal binding of crinoid stems might allow the columnals to disjoint and fall apart with very little water agitation. Thus the articulating columnals which do occur probably reflect gentle water agitation.

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

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 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 with 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.

Conodonts and Fish Remains

A somewhat arbitrary distinction is drawn between conodonts and fish teeth. As well as 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 shales of the basal Bennett member and rare in other Bennett shales. Fish teeth (e.g., Idiacanthus, Paleoniscus, Distacodus) are rare in upper Johnson gray shales, common in all Bennett shales, and extremely rare in the Howe Limestone, Glenrock Limestone and lower Roca shales. Lower Johnson shales and upper Roca shales lack conodonts and fish teeth. Conodonts are thought to be part of the dental structures of vagrant nektonic animals similar in habit to, if not truly, fishes (Schmidt, 1950: in; Ellison, 1957). Such habit explains the fact that they occur in black shales (barren of other fossils) indicative of toxic living conditions, as well as in fossiliferous shales and limestones 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 shales 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 where 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), would seem quite unlikely.

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

Fossil Assemblages

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 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.

Elias (1937) asserted that depth of deposition seems to have been the factor that controlled the sedimentation and fauna of the rock sequence of the Red Eagle Cyclothem. He postulated that certain faunal assemblages lived in certain phases of the repetitious marine sedimentary environments which resulted from rhythmic changes of water depth during Early 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 regressive half-cycle, which presumably reflect deepening and shallowing of the seas, respectively. In the regressive part of a theoretically complete cycle, faunas and lithologies are repeated one above the other in sequence exactly opposite to that in which they accumulated during the progressive part. Elias (1937, p. 411) recognized seven faunal-lithological "phases" in each half of a complete, or ideal, cycle. However, he was careful to point out that no known single cycle of rocks possesses all phases of the ideal cycle. Elias's phases and their postulated depths of deposition appear in Table 3.

TABLE 3. Idealized Lower Permian Cycle of Deposition in North-Central Kansas (Modified from Elias, and Hattin).

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

Only five such basic faunal assemblages (phases) are present in rocks of the Red Eagle Cyclothem. A fusulinid fauna is characteristic of, and dominates, the Glenrock Limestone. This corresponds to Elias's phase 7 ("fusulinid phase"), which he described as indicating depositional depths between 150 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 shales of the lower Bennett Member. Elias's 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.

A fauna rich in productaceans and spiriferids dominates the gray shales 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 interpreted as the "mixed phase" (5) of Elias, which he stated was deposited at depths between 90 and 110 feet. Bennett limestones exhibit a sparse brachiopod fauna (Elias's phase 6), including some horn corals.

A mixed faunal assemblage (Elias's phase 5) of brachiopods, bryozoans, foraminifers, gastropods, crinoid, mollusks, and ostracodes is repeated in the upper portion 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's "molluscan phase" (phase 4), and thereby suggests depositional depths between 60 and 90 feet. Elias's (1937) phases and postulated depths appear in Table 3.

PALEOSEDIMENTATION

Introductory Remarks

The cyclic repetition of rock units similar in lithology, sequence, and thickness, one above the other, in the Lower Permian of Kansas is well known since Elias's (1937) 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 interpretations of cyclothems 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 in the light of what is observable in the Red Eagle Cyclothem. This will set the stage for interpretations in the following chapters.

The sharp Glenrock-Bennett contact is, for all practical purposes, a "time plane" within the Red Eagle Cyclothem. Although this contact is chosen for detailed discussion, 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 major intracyclothemic units are sharp and reflect sudden widespread changes in depositional conditions, whereas,

within major units sedimentary conditions must have changed more gradually, because most lithologic boundaries are gradational through an inch or two of column.

Another matter of interest is the proportion of noncalcareous clastic material to calcium carbonate in these rocks. Few clastic rocks in the Red Eagle Cyclothem are free from calcareous matter, and so indicate a measure of continuous carbonate deposition. Clastic carbonates complicate the situation. 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 are mainly due to abrupt changes of water depth. Current opinion acknowledges that the cause of 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, and helped produce the different lithologies.

Because no cyclothem is complete or symmetrical, in the "ideal" sense of Elias (1937) it is obvious that these depth changes were neither uniform in rate nor continuous. Within any cycle there were temporary reversals of direction of depth change subservient to the over-all deepening or shallowing of the seas and general subsidence of the shelf-basin (Fig. 3B, 3C).

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 Johnson formation were somewhat similar to those that later produced the Roca formation. In the meantime, sedimentation that yielded the Red Eagle formation was unique within the Red Eagle Cyclothem.

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

Deposition of the Johnson Shale

The several types of shales and mudstones which comprise most of the Johnson Shale show no regularity of habit or stratigraphic position except in the upper few feet of the formation.

All the shales and mudstones are calcareous. Many are greenish-gray in color. The majority contain about 30 percent of calcium carbonate, but the distribution is not systematic. Many beds contain 10 to 40 percent of calcium carbonate and a few contain less than 10 percent. These proportions vary abruptly from bed to bed. Almost all this carbonate material is extremely fine-grained. Only a small amount in uppermost Johnson shales is attributed to calcareous ostracode shells.

The origin of these shales and mudstones required an interpretation of the method of precipitation of the calcium carbonate, and its relation to the preponderant muddy clastics which obscure it.

Interpretation of the mechanics of precipitation of calcium carbonate has been reviewed at length by many authors (Cloud and Barnes, 1946; Rodgers, 1947; Zeller and Wray, 1956; Emmons, 1928; Revelle and Fairbridge, 1957; etc.). Two good possibilities seem available to explain the origin of the aphanitic calcium carbonate in the Johnson Shale. Inorganic precipitation resulting from liberation of CO_2 from sea waters saturated with carbonate by agitation or rise in temperature (Emmons, 1928; Zeller and Wray, 1956) is one possibility. Organic precipitation as the familiar "algal particles" is another. In either circumstance, precipitation probably would have occurred mainly in the upper levels of the Johnson waters, and would have mingled with clastic materials while descending to the depositional interface.

The preponderance of clay clastic materials in the Johnson sediments suggests fairly turbid waters. The paucity of silt probably indicates deposition far from the source, although source rocks may have been sediments containing few coarse clastics. Deposition may have occurred near or below a very shallow effective wave base during Johnson time, because many of the mudstone sediments are scarcely

laminated. On the other hand, a few of the laminated shales suggest a lowering of wave base, and accumulation in 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 flocculos (Keller, 1936). Difficulties of thin-sectioning such shales prevent certification of the textural nature of the laminae. However, in the laminated argillaceous limestones (platestones) 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, e.g., Pl. 2) probably records lowerings of wave base, which occasionally stirred up accumulated sediments.

Faint scour effects and faint ripples are present in the platestones near the top of the Johnson Shale. A few indistinct ripples are also evident in some of the laminated gray shales at the top of the formation. These occurrences are also interpreted as the record of deposition in fairly shallow waters where tidal currents associated with lowering of wave base manipulated bottom sediments.

The carbonized gymnosperm wood and spore assembly in the upper few feet of Johnson shales seem to indicate that the regional climate was temperate to cool (Cousminer, 1960; personal communication) as Johnson time drew to a close.

Accordingly, it is suggested that the shallow Johnson waters also may have been cool to "temperate."

A few laminae in upper Johnson shales comprise 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 season) might have caused such vigorous carbonate production. It has been suggested 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. Perhaps heavy regional rainfall could have suddenly freshened the shallow marine water both directly (beginning in the near-surface waters where algae live) and indirectly by increased inflow from terrestrial rivers. In either circumstance the implications may be manifold, for even if salinity or temperature change is granted to be the cause, it may have been by way of control over inorganic and organic nutrients in the water rather than by direct effects on the physiology of the perished animals. Moreover, if the laminae are particulate algal calcium carbonate, it may be implied that the same sort of indirect controls over nutrients might have stimulated the algal activity temporarily. To carry the idea to the extreme, the fortuitous introduction, concentration, or combination of critical ions in the waters may have influenced precipitation of calcium carbonate either

organically or inorganically, or the settling of organic colloidal detritus to produce laminae in the Johnson muds.

The generally low content (20 percent) of calcium carbonate in the upper part of the Johnson shales is attributed to reduced vigor of carbonate-secreting algae. Presumable the algae preferred warm waters. Moreover, carbonate content of sea water is known to vary directly with temperature (Revelle and Fairbridge, 1957). Hence, in the suggested cool to temperate late Johnson waters neither the carbonate concentration nor the disposition of the algae would have favored vigorous carbonate precipitation.

Biostratigraphic evidence accumulated in this study, suggests that Johnson waters progressively deepened after the redbeds were deposited. Low concentration of upper Johnson carbonates may have been partly the result of freshening of sea waters by an increased volume of inflowing waters from land. Some of the smooth, delicate ostracodes in the upper Johnson shales may well be brackish-water forms. If so, they would give support to the idea that waters of later Johnson time were less saline than those of the medial part of the Johnson when the redbeds were deposited.

The few red shales that appear in the middle part of the Johnson formation at opposite ends of the Red Eagle outcrop belt are difficult to explain. There is no evidence that they are nonmarine. They contain exactly the same clay minerals as the other clearly marine Johnson shales. It

seems reasonable to believe that the redbeds are shallow marine deposits probably derived from nearby red soils. Their position at the northernmost and southernmost ends of the outcrop belt, hence probably closer to land, supports the possibility of terrestrial derivation. It is conceivable that green shales in areas between the redbeds might have lost their original red color by reduction of iron during long transportation towards the central part of the basin. Had they been deposited in the red condition the chances are they would still be red, because as Grim (1951) pointed out, red sediments, once deposited, tend to stay red.

The origin of red terrestrial source materials calls for 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 soils as the source material is favored. This leads toward the possibility of warm, moist (Krynine, 1949) regional climates (periodically dry) at least for a short duration near the middle of Johnson time.

The Red Eagle Cyclothem began with Johnson redbeds. As Johnson time drew toward a close, the waters deepened slightly and freshened while the climate cooled. The Johnson redbeds and those of the Rocs Shale seem to be forewarning of the greater number of redbeds which followed in the Middle and Upper Permian.

In southern Kansas the uppermost Johnson shales, which elsewhere have no fossils other than ostracodes and plant remains, are more calcareous than usual and have interbedded with them thin nodular aphanitic argillaceous limestones. The shale beds contain common productid brachiopods and other fossils much like the Bennett Shale fauna. Thus, in late Johnson time, conditions hospitable to few animals other than ostracodes obtained from central Kansas to Nebraska. At the same time southern Kansas seems to have undergone conditions favorable to establishment of a mixed fauna associated with periodic deposition of argillaceous limestone and abnormally limy muds. Apparently limestones were deposited in temporarily clear waters when the omnipresent lime deposition outweighed the clastics. That is, the clay clastics seem to have settled from time to time before reaching Cowley County in southern Kansas. Perhaps this reflects temporarily dry climates and less erosion of source areas. The surface and subsurface distribution of the Johnson Shale implies that source areas of upper Johnson clastics were located at some distance to the north, east and south of Kansas.

Altogether, the combined evidence suggests that the Bourbon Arch area may have been faintly active in late Johnson time, so that it interfered with continuous passage of clastics from the northeast into the slightly deeper waters[1]

1. Indicated by the mixed fauna.

of the Cowley County area. 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 (Jewett, 1951, p. 127) which was sometimes out of reach of clastics from low source areas far to the north or northeast, but accessible to clastics from the south. This concept is not new. Jewett (1951, p. 127) suggested that during Late Pennsylvanian time the sediments from areas to the north and south mingled in the Cherokee basin. Such conditions seem to have persisted during the Johnson part of the Early Permian. Apparently, upper Johnson sediments were not deposited in the area at the northern end of the Otto-Beaumont anticline (Jewett, 1951). This gives further indication of a faint physical barrier to the migration of sediments from the northeast. Accordingly, it is to be assumed that much of the Johnson clastics of Cowley County must have been transported from a land mass to the south and east of Kansas. The fact that the Highway 38 section (closer to the postulated southern source) has more upper Johnson clastics than the Grand Summit section (Fig. 1) 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. To attain their present distribution the plant remains must have drifted all over the late Johnson sea. Land masses generally to the northeast, east, and southeast could have been the source 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 shallow turbid warm waters during the medial part of Johnson time. Deposition from turbid waters continued while depths slowly increased to nearly 100 feet by the end of Johnson time. At the same time the regional climate became cooler than when the redbeds were deposited. Clastics came from probably low land masses to the northeast and south. Tectonically active localities in the Ozark and Ouachita regions also 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. Deposition was patchy until the latter part of Johnson time. Late in Johnson time the Cherokee basin was occasionally separated from clastic sources to the northeast by faint positive barriers in the area of the Bourbon arch. At the same time waters began to deepen slightly in the Cherokee basin and a mixed fauna developed. Land plant fragments and, possibly, seaweed drifted over the entire area during late Johnson time.

Judging from the uniformity of thickness of the Johnson beds, absolute rates of sediment accumulation were essentially uniform over the Midcontinent shelf during deposition of the Johnson portion of the Red Eagle Cyclothem.

Deposition of the Red Eagle Formation

Glenrock Limestone

The sharp basal contact of the Glenrock Limestone marks an abrupt change in depositional conditions. The muddy, sparsely populated, waters suddenly cleared, and so provided the habitat for the prolific benthonic fauna of the Glenrock Limestone. This is inferred from insoluble residues, which show a decrease of 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 upwards. In these few places, fusulinids seem to have been late arrivals which slowly proliferated later in Glenrock time. The Glenrock sediments wherein fusulinids are sparse contain a slightly larger amount 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 does not overlook the fact that percentages of insoluble residues may be controlled by relative rates of carbonate versus clastic deposition. However, upon consideration of the generally uniform character of Glenrock composition, thickness etc., there is no evidence of marked changes in rate of carbonate deposition during Glenrock time. That is, the slight variations of the percentage of insolubles content are thought to be the result of changed rates of clastic supply and indicate a remote, northern or northeastern source of clastics.

The Glenrock Limestone is remarkably uniform in thickness (approximately 1 foot) and lithology through some 150 miles of outcrop between Bennet, Nebraska, and Allen, Kansas. Although its basal contact is gently undulatory (Pl. 4), the top is remarkably flat and clearly defined. Thus, at the close of Glenrock time the floor of the Red Eagle sea must have been even flatter than at its beginning. During Glenrock time, sediments must have accumulated evenly over this shelf area or the unit would not be so uniformly thin. Similarly, south of Allen, Kansas, where the Glenrock is yet thinner, accumulation must have been slower or of lesser duration. Uniform accumulation is easier to explain for lime materials than for clastics. The small amount of clastic materials in the Glenrock Limestone consists of clays, which, because of their slow rate of settling, may well have drifted far from their source in only mildly

agitated waters. 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 to deposit such a widespread, uniform unit the same uniform depth and limy conditions must have obtained over a great area of the Midcontinent shelf basin.

It is clear that a sudden change of depth would be effective almost simultaneously over all parts of such a flat area. This should be followed instantaneously by changes in animal growth and sedimentation over the entire shelf. This would explain the ubiquitous sharp (0.1-inch) contact between the Glenrock Limestone and overlying black Bennett shales. This phenomenon establishes the Glenrock-Bennett contact as a distinct time plane. If not, the contact must be a plane which crosses time planes "at an almost infinitely small oblique angle" (Moore, 1959). This refinement of definition is necessary for general theoretical discussions of cyclothems, but it is of minor practical use in this study.

The paleoecological evidence, derived principally from the fusulinids and traces of Osagia, suggests that the Glenrock Limestone probably was deposited in waters slightly more than 150 feet deep. Sedimentological evidence seems to verify this, because the Glenrock shows no traces of scour, or breaks in depositional continuity. That is, the Glenrock was deposited below effective wave base, which is

usually much shallower than 150 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 tidal currents must have been active in such shallow waters. It is emphasized that in most 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 articulating brachiopod shells are preserved, the fusulinids are essentially undamaged, and there is no evidence of scour. Slight textural variations of Glenrock matrix suggest 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 the face of the other evidence and in view of probabilities suggested by studies of present-day sediments, the breakage and comminution of these materials is probably 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. Another possibility is that the shells were weakened by boring organisms to the point where the gentlest of currents would have been 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"[1], affected

1. Such aphanitic calcium carbonates have been attributed by some authors to purely physiochemical 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.

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 depths is unknown. The latter possibility is mentioned because of the implied clarity of the waters, which could have permitted photosynthesis, however slight, even at the bottom of the Glenrock sea.

It is stated earlier that 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 the chemistry of their shells or individual microenvironments was unfavorable to algae.

The Glenrock Limestone in the Manhattan and Paxico areas is known to contain common Osagia and fragments of detrital material somewhat similar to upper Johnson muddy limestones in the Alma area, where the Glenrock is absent. Osagia suggests that Glenrock waters in the Manhattan area might have been slightly shallower than normal. Apparently the Glenrock Limestone was not deposited at Alma. It is suspected that a local rise of the Nemaha anticline (Jewett, 1951) may have been responsible for these lithologic features. That is, some of the pebble-like aphanitic Glenrock detritus at Manhattan may have been derived from uplifted Johnson deposits near Alma and deposited in waters somewhat less than 150 feet deep.

The Glenrock Limestone is also absent at the Elmdale and Saffordville sections and in Greenwood County. This also suggests that gentle uplift of the Nemaha anticline area at the western end of the Bourbon arch, and in the northern part of the Bemmont anticline (Fig. 1) may have controlled the depositional patterns during Glenrock time. Indeed, it is possible that these areas were almost emergent from late Johnson to early Bennett time, so that no Glenrock Limestone was deposited.

Where the Glenrock Limestone reappears to the south of these structural features, just east of the trend of the Otto-Beaumont anticline (Fig. 1) it is comparatively thin and full of fusulinids, and somewhat similar to its local development at the Coffman Ranch in central Kansas. The weight of evidence accumulated in this study suggests that these areas 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.

These suggestions point to probable shallow waters in the vicinity of the western part of the Bourbon and Beaumont arches during Glenrock time, and account for the apparent absence of the Glenrock Limestone at the Elmdale section.

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.

The Glenrock fauna suggests nearly normal salinity and pH in clear waters.

It can be assumed that while Glenrock waters deepened shorelines receded, so that terrestrial clastics could have settled long before they reached the area of study. This would account for the comparative purity of Glenrock

Limestone. The slightly greater than average amount of Glenrock clastics in southernmost Kansas (Highway 38 section) may indicate closeness of source areas in Oklahoma or uplifts in the source areas, or both. It is believed that southward in Oklahoma, the Glenrock Limestone grades to a shale facies indistinguishable from Johnson Shale

Bennett Shale

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 basal Bennett shales suggest deposition at depths less than 60 feet. Thus, it is evident that the change from Glenrock carbonates to Bennett clastics attended a very rapid shallowing of the Red Eagle sea from depths of approximately 150 to 60 feet or less.

The basal Bennett shale is black because it is charged with finely divided carbonaceous organic residues and traces of pyrite. Hydrofluoric acid residues from the black shales contain small amounts of dark-brown, waxy plant materials, together with spores. This brown substance also contributes to the dark color. Conditions at, or soon after, the deposition of the organically rich muds must have been such that the organic material was only partially decomposed because of insufficient oxygen. It seems likely that this decomposition was effected principally by anaerobic bacteria.

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. 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 shales 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 scarce in the black Bennett shales.

The concentration of Orbiculoidea (with Lingula) at the base of the Bennett black shales, with few specimens above, suggests 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 survived. These may have been the only animals actually able to live on the black muddy bottom of the earliest Bennett sea. The conodonts and rare 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 and forthwith perished. The scarce arenaceous foraminifers and traces of 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 almost all of even the blackest shales contain 20 to 30 percent of calcium carbonate. Certainly, the calcareous material did not originate in the black muddy bottom waters; and because very little of it is shell material, it must have fallen from near-surface waters where algae or agitation could have caused precipitation of calcareous particles.

The bulk of the black shales, and in fact all Bennett shales, is composed of illite, with traces of calcium montmorillonite. Such mineralogy seems typical of black shales 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). High percentage of clay content indicates that the Bennett-shale waters were rather turbid.

A number of the black sediments are claystones, rather than shales. This indicates essentially uniform conditions of deposition for certain portions of early Bennett time.

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

The preservation of many of the black shale laminae indicates not only the absence of mud-working organisms, but also the probable absence of anything more than gentle currents, because no traces of scour or disrupted bedding are present. This is somewhat anomalous, because Orbiculoidea and Lingula indicate water shallow enough to be above normal wave base. This, and the many unbroken Lingula and Orbiculoidea, may suggest that strong winds must have been uncommon in early Bennett time.

Although the black shales reflect euxinic deposition, there is no ready explanation of the means by which the Bennett waters could have been restricted. Shallowing waters could have left shoals between the area of study and the open sea to the south and west. By an unexplained coincidence 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 show that the same regional basin patterns persisted during the accumulation of the two, despite their different lithologies, and that the changes of conditions across the Glenrock-Bennett contact were uniformly widespread.

There is no doubt that the supply of clastic materials to the Red Eagle seas increased suddenly at the beginning of Bennett time. The fusulinids at the top of the accumulated Glenrock deposits appear to have been suffocated by the Bennett black muds or poisoned by the increasingly toxic waters. The death of the fusulinids was followed by an influx of Orbiculoidea with a few Lingula. This may have been the shallowest part of the Red Eagle deposition. Accordingly, it is 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 shales too few orbiculoids are broken to admit the same possibility. The water seems to have deepened after the beginning of Bennett time so that deposition of most of the shales took place not

far below wave base. Lingula in the basal Bennett black shales indicates that these beds probably were deposited in waters less than 60 feet deep.

The shallowed waters of earliest Bennett time must have exposed extensive mud flats near the source area. Their loosely consolidated deposits could have been eroded easily and dispersed by waves. Much of the argillaceous material of the lower Bennett may have been thus derived. As time advanced, it could be expected that, as the near-shore materials were removed, erosion would become slower and less detritus would be available for transport. If waters deepened again, shorelines would withdraw and the supply of local detritus should diminish even more. Although these remarks emphasize the role of changing depths in governing the proportions of detrital materials in the Bennett shales, uplift or climatic change in distant source areas may have been the major control. However, the sedimentary record seems to indicate the deepening with the passage of Bennett time, because black basal Bennett shales grade upward into gray[1] shales of the middle part of the Bennett which contain

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

a variety of shelly fossil remains but few conodonts. The medial Bennett fauna indicates that waters deepened to more than 100 feet. Some of the gray shales contain 10 to 20 percent more carbonate and are less closely laminated than

the black shales. Some of the gray shale laminations are tiny diastems. The combined faunal and sedimentologic evidence suggests that medial Bennett waters circulated more freely than when euxinic bottom conditions obtained. In central Kansas, the shales give way to very pure medial Bennett limestones. Apparently, while the supply of clastics dwindled, the water cleared in central Kansas and carbonate deposition (largely by algae) overwhelmed the few clastics that did arrive.

Where the Glenrock Limestone is missing (e.g., at Saffordville), gray calcareous Bennett shales rest on upper Johnson shales. This demonstrates a local paraconformity representing Glenrock and earliest Bennett time, and suggests uplift in the contiguous Nemaha and Bourbon arch areas. Perhaps such elevation restricted the circulation of the early Bennett seas, and so led to euxinic bottom conditions.

Some gray Bennett shales contain traces of glauconite. Although much has been written about the origin of glauconite, few conclusions are definite. Glauconite in the Bennett shale suggests conditions such as those outlined by Lochman (1957)[1], that is, slow sedimentation, much putrefying organic

1. See also: Cloud and Barnes (1948)

material, and a large and varied fauna. Lochman also noted that glauconite forms in marine waters away from the freshening influences of large rivers, free of coarse detritus originating in crystalline source areas, and under somewhat

anaerobic conditions. That is, glauconite forms under conditions similar to those postulated on the basis of other evidence for Bennett Shale deposition.

Cloud (1955) affirmed Lochman's basic requisites and also suggested that glauconite usually forms at depths of less than 200 feet and at temperatures greater than 15°C (60°F). Faunal evidence places the deposition of Bennett Shale in waters less than 150 feet deep with temperatures above 20°C (68°F). Accordingly, glauconite in the Bennett shales lends support to these estimates.

The chapter dealing with stratigraphy has described the considerable accumulation of medium-bedded limestones in the lower half of the Bennett member in Nebraska and northern Kansas. These limestones comprise almost all of the Bennett member, indeed, almost all of the Red Eagle Limestone in southern Kansas and northern Oklahoma. The stratigraphic evidence shows that while carbonate deposition predominated in the southern regions throughout Bennett time, tongues of limestone deposition 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 render muds in Nebraska extremely calcareous.

This might lead to the erroneous suggestion that in the Permian Period times of mud deposition were times of comparatively rapid accumulation, whereas accumulation of calcium carbonate was abnormally slow. However, because many of the Bennett carbonates are algal, it must be expected that in clearer waters during times of less suspended clay, the absolute rate of such carbonate deposition would have accelerated considerably. Indeed, the thickness of limestone facies of the Bennett member is somewhat greater than contemporaneous accumulation of shale facies, suggesting that, on the average, rates of sedimentary accumulation of limestone was slightly more rapid than mud. However, when the diagenetic compaction of the two types of sediments is considered, it can be concluded that their rates of sedimentary accumulation were approximately similar over broad areas. The absolute thickness and accumulation rate of all sediments is, of course, controlled by regional subsidence of the basin floor.

Southern Kansas, where the section is thicker and calcareous facies predominates, appears to have experienced slightly greater regional subsidence than Nebraska and northern Kansas. This coincides with the generally greater regional thickness of the Council Grove Group in Oklahoma as compared with Nebraska.

The physical, chemical, and biological controls of carbonate deposition are well known. Emmons (1928), Cloud

and Barnes (1948), Twenhofel (1950), and Fairbridge (1958) 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 degree of oversaturation, and he noted that, with a few special exceptions, marine organisms acquire most of the calcium carbonate before chemical precipitation can occur. This concept, with the field and laboratory evidence, lends weight to the belief 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 water temperature. He also observed a direct correlation between the calcium carbonate content of bottom sediments and the salinity of overlying surface waters. Where salinities are below 34 parts per thousand (normal marine salinity is about $35^{o}/_{oo}$) the sediments contain less than 5 percent calcium carbonate. Because all Bennett sediments contain more than 10 percent calcium carbonate, it seems likely that the salinity of normal marine Bennett waters exceeded 35 parts per thousand. Faunal evidence implies that the waters were warm. Lowenstam's (1959) O^{18}/O^{16} data suggest that the upper Bennett shales (with Neospirifer) were deposited at temperatures above 22°C (72°F).

Paucity of clay in the limestones of the Bennett member indicates clear waters. Fossil shells are not abundant in the limestone. Faunal assemblages indicate depths between 60 and 150 feet (Elias 1936, p. 410). The bulk of the rocks is comprised of aphanitic to very fine granular and microcrystalline calcareous matrix. At some localities the matrices display traces of ("linear") algal calcium carbonate ribbons, a few of which are broken. Some are clear, recrystallized replacements. It is believed that algae precipitated most of the nondescript calcitic matrix material, in very fine particulate form. Probably some of this material was brought down primarily as aragonite needles (Lowenstam, 1956).

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

Within each 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 notable, 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 mud (Pl. 13).

Johnson (1957) showed that such shells can be buried by scouring, at velocities below those necessary to take the shells into suspension. This evidence points towards gentle current activity during deposition of most of the Bennett limestones. Hence, in the absence of shell-shattering currents, the fine fragmental condition of most of the fossil shells is attributed to scavengers including both mud-eaters and borers (Dapples, 1938).

The fossils in the calcareous Bennett shales, although including the same genera as in the southern limestones, seem larger than normal, less finely comminuted, and scarcely abraded. They are scattered randomly throughout the shales. They seem to have been broken and transported short distances by currents somewhat stronger than those indicated by the limestone record. This is supported by the presence in the shales of a greater number of robust shells which supposedly reflect turbulent water. Some of the shells show evidence of borings by other organisms. Perhaps this facilitated their fragmentation. The combined evidence of proportion and size of clastics, fauna, and sedimentary structure, suggests that the Bennett shales were deposited in waters slightly shallower than those in which the Bennett limestones accumulated. Interpretation of apparent faunal differences may be slightly prejudiced, because fossils are easier to obtain from shale than from limestone.

The regional pattern of Bennett deposition, after the initial black shales, was limestones in the south and shales in the north. Clastics seem to have come mainly from the north and east. Southern Kansas appears to have been out of reach of these clastic materials. 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 interfingering of thin Bennett limestone and shale, in Lyon and Greenwood counties seems to indicate less subsidence in the Bourbon and Beaumont anticline areas, and shows that the Bourbon arch was (as in the Pennsylvanian) as area of "meeting and overlapping of sediments from southerly and northerly directions" (Jewett, 1951). In fact, the Bourbon arch may have been a barrier to free circulation of clastics to southern Kansas from source areas to the north and east, thereby permitting the accumulation of the very pure Bennett limestones in slightly shallower waters in Elk and Cowley counties.

In southern Kansas and in the Eskridge-Coffman 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 in waters over 100 feet deep, clastics drifted in and muddied

the waters. Thus, calcareous mud deposition resumed, and continued in shallowing waters through late Bennett time. The insoluble residues show that the upper Bennett shales in these intermediate areas are more calcareous than similar shales beneath the limestone (a condition best demonstrated at the Allen No. 2 section). This is interpreted as showing that while there was slight activation of the source area, the influx of northern clastics which produced the higher Bennett shales was not as great as earlier. For some reason clastics did not reach southern Kansas and the small Eskridge-Coffman area of central Kansas. Probably southern Kansas was too far away from the northeastern source, and was further protected by slight uplift of the Bourbon arch.

The Eskridge-Coffman facies are less easily explained, for they begin suddenly, amid shales on three sides. Nevertheless, they are markedly similar to the widespread platform limestones of southern Kansas. The evidence indicates that the depth of deposition of these beds was only slightly less than adjacent contemporaneous calcareous shaly facies.

The only explanation that appears to account for most of the observed features of the Eskridge-Coffman facies is that it was deposited in an area of quiet waters, perhaps protected by some unknown relief feature of the sea bottom, probably located east of the outcrop belt, or produced by a fortuitous combination of interacting currents of unknown origin. In either circumstance, the entering clastics were

settled nearby so that clear waters prevailed. Deposition of algal calcium carbonate seems to have proceeded rapidly under such conditions, and so accounts for the somewhat thicker than normal limestone accumulation.

All along the present outcrop belt, the Bennett sequence above the black shales appears to have been deposited at water depths between 60 feet and 150 feet. It is postulated that waters generally deepened after deposition of the basal Bennett black shales (Fig. 30). 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. Upon withdrawal of the source areas, and ignoring other factors, the supply of clastics to the area of study could be expected to diminish, so that proportion of clastics to carbonates in the Bennett would decrease upward. This is, in fact, recorded by the general gradation of lower Bennett calcareous gray shales upward to highly calcareous upper Bennett shales in northern Kansas, and to the pure limestones in central and southern Kansas. The relative greater number of bryozoan genera, with many genera of brachiopods, in most of the medial Bennett shales, combined with stratigraphic evidence, suggests that the shales represent waters somewhat deeper than 100 feet (brachiopod phase of Elias, 1936, p. 410); that is, waters were undoubtedly deeper than those of earlier Bennett time wherein a mixed fauna thrived.

In central Kansas, the deep (100 to 150 feet) waters seem to have produced the sparsely fossiliferous medial limestones of the Bennett member. The uppermost Bennett shales and limestones record the reestablishment of a mixed fauna (Elias, 1937, p. 410) indicating that toward the close of Bennett time the seas were shallowing again (Figure 3 illustrates these changes). This set the stage for deposition of the Howe Limestone. The percentage of insoluble clastics in the upper part of the Bennett shales decreases upward and the top of the Bennett grades through somewhat less than a foot of column to the overlying Howe Limestone. The indication is that waters shallowed steadily in late Bennett time while the supply of clastics diminished. Although the decrease of clastics could mean lower source areas, it may also result from a drier climate in the source area or the development of a submarine barrier. In any event, the change from Bennett to Howe deposition was marked by a rapid and great reduction of the supply of clastics. That is, clear waters began the Howe.

Howe Limestone

The Howe Limestone in Nebraska and northern Kansas has been described as a fairly uniform aphanitic, sparsely fossiliferous unit. The pelecypods Allorisma and Aviculopinna were found in the Howe Limestone in Nebraska. Tiny gastropods and traces of fenestellate bryozoans are randomly present. One nautiloid cephalopod was found in the osagite at the top of the Howe Limestone.

South of 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 osagites in the Grenola Cyclothem also represent the molluscan phase of Elias's ideal cycle (1937, p. 411). According to Elias, the Howe Limestone would therefore record deposition in sea water 60 to 90 feet deep. Lane (1958) concluded that Grenola osagite beds probably formed at depths approximating 60 feet. Paleoecological evidence assembled in this report shows that the osagitic Howe Limestone probably accumulated in water less than 60 feet deep.

Lane (1958) indicated that algal incrustations throughout the osagite denote slow accumulation of the fragmental shell nuclei. Lane's (p. 153) reasoning leads to the same conclusion here for Howe osagite. The only difference 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 algae improved with the passage of Howe time. This might mean that the water shallowed from depths in excess of 60 feet to lesser depths where 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. In southern Kansas, osagitic facies of the Howe Limestone is relatively thinner than, and the osagite pellets are very similar to those in the middle of, the Howe in central Kansas. This suggests that Howe waters were always 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 (1948) (with reference to Carboniferous limestones in England) postulated a pH of about 8 for precipitation of spergenitic limestones. It seems reasonable that this pH value might also be applied to the Howe osagitic limestones.

The evidence (p. 92, 121) which shows that Howe waters were probably shallower than Bennett waters implies that Howe shore lines were probably nearer to the area of study than in Bennett time. Yet, the Howe Limestone rarely contains more than 10 percent of insoluble clastics (clays), whereas between central Kansas and Bennet, Nebraska, the upper Bennett deposits are quite argillaceous. The scarcity of Howe clastics is therefore taken to indicate that Howe source areas must have worn to low relief by the end of Bennett time, or the climate might have become warmer and

drier so that relatively few clastics were washed to the sea, or both. If Howe climates were comparatively warmer, precipitation of algal calcium carbonate would doubtless have been invigorated enough to account for the profuse Howe Osagia.

Neither the aphanitic nor osagitic facies of the Howe Limestone is bedded. The limestones are massive units without diastems. This, and their uniform textures, points to deposition in comparatively quiet waters undisturbed by violent lowering of wave base. Conditions of Howe Limestone deposition were probably similar to those on the present Bahama Bank. Cloud and Barnes (1948) stated that conditions similar to the 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 the limestones, were deposited upon a great shelf under conditions much as described in the above quotation.[1] However, because deep oceanic depressions

1. The Glenrock and Howe Limestones 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."

surround the Bahama Bank an exact comparison is not implied. Nonetheless, the great areal extent, flatness, warmth, shallowness, and subdued water circulation of the Bahama

Bank correspond to some of the environmental conditions suggested by the faunal assemblages, stratigraphic position and lithology of the Howe Limestone.

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

The Eskridge-Coffman area is the only one where an anomalous Howe facies is developed. Here the Howe consists of about 5 feet of rubbly, indistinctly thin-bedded, richy fossiliferous limestone. Crinoid columnals make up much of the rock, together with profuse brachiopods, bryozoans, and foraminifers. The purity of the limestones is evidence that Howe waters must have been nearly clear. Moreover, it is known that crinoids enjoy clear, warm, gently agitated waters, and bryozoans good oxygenation; so these conditions must have prevailed in the Eskridge-Coffman area.

It also should be noted that this fossiliferous Howe facies is developed only where the Bennett limestone is thick. It quickly grades to osagite where the Bennett thins. At the close of the Bennett time, the Eskridge-Coffman area was probably under some 50 or 60 feet of water, while surrounding areas were under 60 feet or more in depth.

The thick Bennett limestones may have supported a broad platform some 10 feet higher than the neighboring sea floor. The Howe crinoids grew on the platform.

The crinoidal Howe Limestone contains about 2 or 3 percent more insoluble clay residue than either the osagitic Howe or the underlying Bennett limestones. This is attributed to the fact that the Howe environment had many stalked crinoids and fenestellate and ramose bryozoans, which probably served as filter-traps for clays and calcareous algal particles which 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 led to the slightly thicker-than-normal Howe accumulation at Eskridge-Coffman.

The Howe waters 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. A similar setting of gentle currents in the Eskridge-Coffman area can be applied also to the unbedded osagitic facies. The individual osagite pellets are unabraded and only vaguely oriented parallel to bedding, so that they apparently suffered little agitation. An occasional gentle rolling would permit algal calcium carbonate to surround the nuclei. Thus, the moderate sorting, lack of bedding, and the implicit slow steady accumulation (Lane, 1958) suggests that gentle currents washed the osagite pellets in Howe time.

A crude idea of current velocity necessary to move the osagite pellets can be derived from Hjulstrom's (1939) diagram. Most pellets are 0.2 to 1.0 millimeters in diameter and hence are of the size range of particles most easily moved by flowing water. According to Weller (1960, p. 165; following Hjulstrom) particles in this size range could be moved by current velocities of probably not 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. The pellets increased in size, and acquired thicker Osagia coatings toward the top of the Howe. This distribution may signify that current velocities decreased during Howe time, while the waters shallowed. Although the origin of the implied currents cannot be determined, the estimated velocities are nevertheless in the order of current velocities known to develop at or near wave base[1]. Moreover, it is almost certain that the Howe bottom was within reach of wave base. It is probable that, as today, tidal currents in Howe time were available to augment or counteract wave-induced currents.

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

The regional pattern of Howe aphanitic limestone in the north and osagite to the south also requires consideration. The aphanitic facies commonly contain nearly 10 percent of insoluble clays, whereas the osagites contain less than 6

percent and are slightly thinner than their northern counterparts. Greater thickness, combined with greater clastic content in Nebraska, suggests that the source area of the scarce Howe clays was somewhere to the north and east of Nebraska.

The reason for the facies change between the aphanitic and osagitic Howe limestones 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 waters were 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 particles but most seems to have been benthonically secreted by calcareous algae.

Although much of the Howe aphanitic limestone is thought to be consolidated algal particles, this does nor exclude calcareous particles produced by near-surface warming or agitation (Emmons, 1928) as a significant contributor. The particles could have been in the form of aragonite needles (Revelle and Fairbridge, 1957, p. 258) later altered to calcite. In the light of present-day requirements for carbonate deposition, this interpretation assumes that Howe waters were warm, normally saline, and nearly saturated, or slightly oversaturated, with calcium carbonate (Rogers, 1957; Pearse and Gunther, 1957, p. 133). If planktonic

algae were numerous enough, it is possible that the waters could have been turned milky by fine algal particles (Revelle and Fairbridge, 1957, p. 258). This would interfere with passage of sunlight to the sea bottom, thereby disfavoring benthonic organisms either directly or indirectly. This could explain the fact that the aphanitic Howe facies contain few fossils and lack benthonic Osagia.

The preceding comments about algal precipitation of calcareous particles would imply their diurnal production (Revelle and Fairbridge, 1957, p. 258). Because most of the calcareous material is algal, Howe time probably witnessed 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 wherin great numbers of foraminifers and other shell materials are nuclei for the algaly-coated pellets. However, the light color and insoluble residues of the Howe limestones (and other Red Eagle limestones) show them to be low in nonshelly organic residue content.

Why is the Howe light-colored and why are fossils and organic residues so scarce in the aphanitic Howe facies? The simplest explanation is that organic detritus, had it existed, could have been destroyed, and particle size reduced by soft-bodied scavengers and mud-eaters and by

decay in an oxidizing environment. This would also account for the Howe aphanitic textures and lack of bedding. Dapples (1938) and Ginsberg (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) has noted that "light color reflects thorough decay and removal of organic material under shallow circulating waters," and Ginsberg (1957, p. 89) has stated that "light color and low organic content suggest an oxidizing environment with pH's near 7.5."

Deposition of the Roca Shale

The 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. After Howe deposition, calcareous muds were deposited in progressively shallowing waters until the redbeds of the medial Roca ended the Red Eagle Cyclothem. Thereafter, waters deepened again during the progressive half of the succeeding Grenola Cyclothem (Lane, 1957). In view of preceding interpretations, this implies that all Roca waters were less than 60 feet deep, and shallowest when the redbeds were deposited.

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 shales and mudstones are composed of clays, with variably small amounts of silt. The silt particles are subangular to subrounded quartz grains and silt-sized, buff-colored clay aggregates. The silt content is slightly greater than in upper Johnson shales.

Most of the lower Roca shales are light, faintly greenish-gray, and moderately calcareous (5 to 20 percent $CaCO_3$). Few are noncalcareous. They contain the same clay minerals as the marine Red Eagle Limestone.

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

As previously mentioned (p. 149), Trask (1937) found that commonly less than 5 percent of bottom sediment is carbonate beneath waters wherein salinities are less than 35 parts per thousand. Although carbonate percentage is known to reflect relative volumes of supplied clastic and

carbonate components, Trask's figure suggests that during much of early Roca time the moderately calcareous (more than 5 percent $CaCO_3$) muds of the lower Roca must have been deposited where salinities were probably near the present average (i.e. 35°/₀₀, Pearse and Gunter, 1957). In the same way it may be inferred that the few noncalcareous or slightly calcareous Roca shales indicate temporarily freshened water, with salinities less than 34 parts per thousand.

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

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

An overturned slump-block of Roca limestone (Pawnee section) revealed short partition-like prominences on its base (Pl. 17) which appear to have filled cracks in the top of underlying greenish-gray shales. Submarine mudcracks can develop under certain conditions (Twenhofel, 1925), so the question of submarine or subaerial origin of the crack fillings arises. They might be submarine cracks because all Roca deposits are thought to be marine[1].

1. The marine origin of the limestone is revealed by traces of arenaceous foraminifera, ostracodes, gastropods, and faint traces of brachiopods at the top. The underlying shales are similar to other known marine shales and show no evidence of dessication or erosion.

On the other hand, the cracks may be subaerial, because marine sedimentation could have been interrupted by an interval of littoral non-deposition (brief exposure to the air), followed by limestone deposition. The topmost mud beneath the limestone is only slightly calcareous, and could have been deposited under abnormally low salinity conditions. During deposition of the limestone, volumes of clastics supplied diminished for some unknown reason, while the accumulation of carbonate continued. Perhaps tectonic pulsations or climatic changes in the source area were responsible; perhaps uplifts along structural trends such as the Bourbon arch interfered with continuously free dispersal of clastics over the entire area.

The clays and uniform fine silts generally present in the Roca Shale suggest remoteness or low relief of the source

areas; but this would not preclude the possibility that the silts may have been reworked from older, finely clastic rocks.

The thin red shales of the Roca Shale in Nebraska and Kansas are taken to mark the terminal depositional event of the Red Eagle Cyclothem. They are believed to be shallow marine deposits which accumulated near but below lowest tide level at a time of maximum regression of the seas, when shore lines were relatively close to the study area. The only fossils in these red shales are tiny gastropod fragments similar to those in the Red Eagle Limestone and in the lower part of the Roca Shale.

In Oklahoma the lower Roca is all red. This leads to the interpretation that southern source areas were nearby during the first half of Roca time. That is, a part of Oklahoma was upwarped at the end of Howe time. This southern area was the principal source of red sediments. The extended thin redbeds which reach into Nebraska are believed to reflect suddenly increased supply of clastics from the southern source during times of shallowest waters, and also, oxidizing conditions sufficient to maintain the red original color. Whether this would be due to tectonism or climatic change in the source area is unknown. At other times, the supply of red clastics was slower, and they were reduced to a greenish-gray color on their way northward across Kansas.

The red color of these sediments is believed to have come from red soils. Krumbein (1947) has stated that red color is an indicator of the absence of organic material. Insoluble residues studies confirm this for red Roca shales.

Some authors have implied that because of their common association with evaporites, redbeds generally reflect highly saline waters. There is no such direct evidence in the outcropping Red Eagle Cyclothem that Johnson and Roca redbeds were deposited in saline waters, but it is possible that weathering could have removed the evidence from the rock record.

Cyclothemic Nature of the Deposits

The preceding chapters have shown that deposition of redbeds in shallow waters of Johnson and Roca time respectively began and ended the Red Eagle Cyclothem. Beds between these markers show evidence of deposition in deeper water.

Elias (1937) showed that the Lower Permian cyclothems of Kansas are divisible into phases, each characterized mainly by its distinctive fauna, and by lithology. Each phase is named from its most characteristic fossil group (Table 3, p. 120). Elias interpreted each phase as the record of a certain type of depositional environment controlled principally by water depth. Elias (1937) also noted that in the lower part of each cycle these phases appear in a

succession which is reversed in the upper half of the cycle. When interpreted, these sequences were seen to record progressively deepening waters in the early (lower) half of the cycle and progressively shallower in the later (upper) half.

Table 3 (p. 120) is a modification of Elias's "idealized" list of 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 to 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." The Red Eagle Cyclothem lacks several of the ideal phases. Table 4 shows units of the Red Eagle Cyclothem and their appropriate phase designation (following Elias) as determined in this study. The progressive (transgressive) and regressive phases within the Bennett member are noteworthy. Depths of deposition listed in Table 4 are based on interpretations in this report. The overlap of depth ranges allows for gradational lithologic changes and intermingling faunas.

TABLE 4. Units of the Red Eagle Cyclothem Defined in Terms of Elias (1937) but Showing Depths of Deposition Determined by this Study.

Units of the Red Eagle Cyclothem	Depths of Deposition	Elias's Phases	No.
Roca Shale			
medial red shales	0-20	Red shale	1
lower greenish shales	10-40	Green shale	2r
Red Eagle Limestone			
Howe Limestone	50-90	Molluscan phase	4r
Bennett Shale			
upper gray shales	80-110	Mixed phase	5r
medial limestones	100-160	Brachiopod phase	6
lower gray shales	80-110	Mixed phase	5p
basal black shale	30-60	Lingula phase	3p
Glenrock Limestone	150-180	Fusulinid phase	7
Johnson Shale			
upper greenish shales	10-40	Green shale	2p
medial red shales	0-20	Red shale	1

Figure 3A is an enlarged redraft of 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 3B is similar in form and purpose, but the depth curve was derived by applying Elias's interpreted depths of phase deposition (Table 3) to the sequence of phases (listed in Table 4) recognized by this study. Figure 3C similarly illustrates the depths of deposition of the Red Eagle Cyclothem, as interpreted in this report. The diagram is constructed in the same way as 3B, except that depths of phase deposition interpreted in this report (Table 4) are used instead of those interpreted by Elias (Table 3).

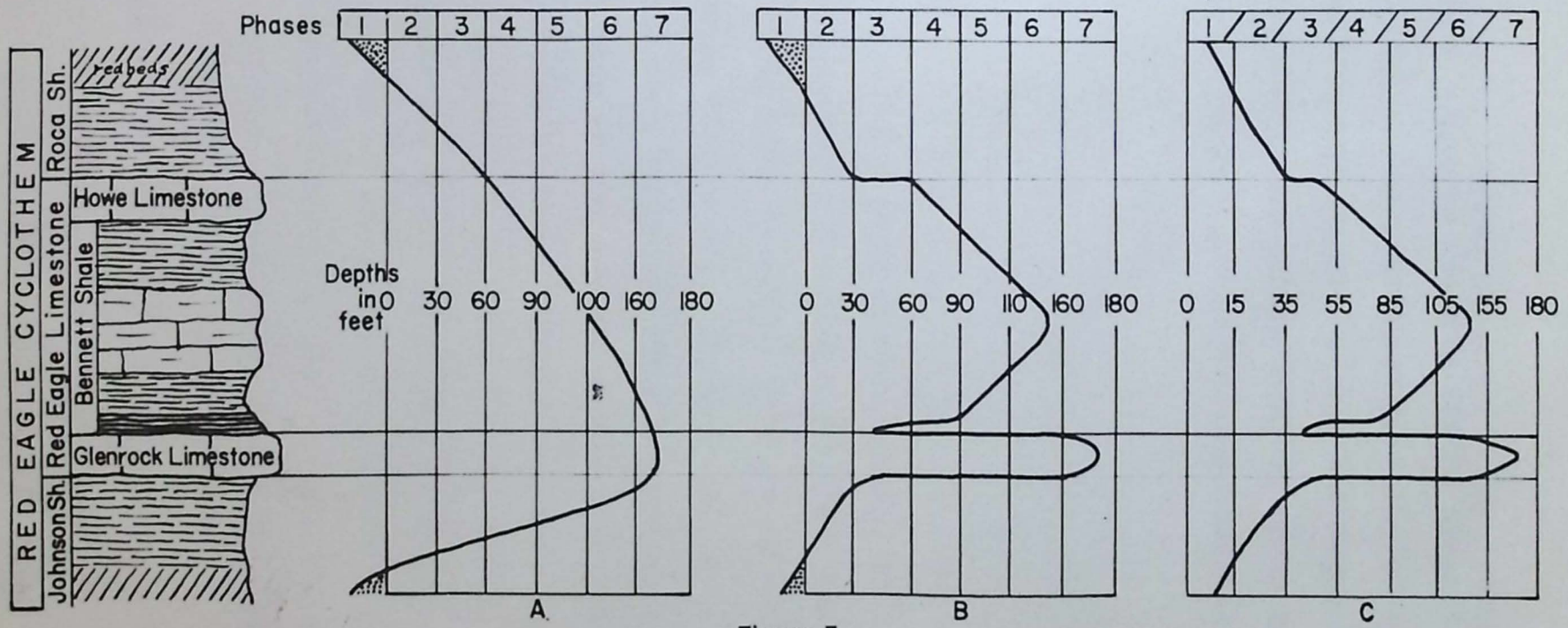


Figure 3

Composite section of Red Eagle Cyclothem in northern Kansas and interpreted depths of deposition

A. Depths of deposition as diagrammed by Elias (1937, Fig. C, p. 407).

B. Depths adjusted according to Elias (1937). The depth curve is based on Elias's phases now recognized in the Red Eagle Cyclothem and interpreted using Elias's postulated depths of phase deposition.

C. Postulated depths of deposition as interpreted in this study.

This study supports Elias's (1937) concept that water depth during deposition was the major control exerted upon the marine sedimentary facies of the Red Eagle Cyclothem. Regional marine climate, supply rate of muddy clastics, and chemistry of the waters appear to have modified the depth effects.

DIAGENESIS

Diagenesis, as used here, accepts Sujkowski's (1958, p. 2142) definition which states that it consists of "changes occurring in a freshly deposited sediment, commonly while still in the sedimentary basin" and includes 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 evidence of diagenesis. Although the lamination and fissility of Johnson shales is largely ascribed to primary sedimentation, it is inferred, following Shepard and Moore (1955, p. 1587) that some of the shaly parting may have developed by compaction of the Johnson clay muds during diagenesis. Shepard and Moore observed that 8,500-year-old muds buried 69 feet beneath similar currently-accumulating muds in the central Texas coast area show shale-like parting planes. Younger deposits above them have not yet acquired these structures. Hence, it is suspected that some of the shaly partings in Bennett and Roca clay shales 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 limestones is demonstrated by fossil interiors and matrix interstices filled with secondary calcite. The most conspicuous fossil fillings

occur in Glenrock fusulinids, and in the Howe Limestone nautiloid cephalopd (Pl. 16). Calcite in the matrices of the limestones is commonly microcrystalline to aphanitic. The calcite is thought to have been derived largely by solution of calcareous materials within the limestone masses, and nearly simultaneous reprecipitation in open spaces (Sujkowski, 1958, p. 2696). Judging from the known composition of living animal shells, many of the shells found in the Red Eagle limestones 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.

The few chert nodules in the Bennett limestones 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 in the same limestones. 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 for such chert structures. His explanation begins with saline waters of pH near 8[1], trapped with the sediments

1. The fauna of the Glenrock and Bennett Limestones reflects normal marine conditions. Weller (1960, p. 216) pointed out that normal sea waters have pH about 8.1 or 8.3. If Sujkowski's explanation is correct for the Bennett limestones, his required pH lends support to the implication that Glenrock and Bennett pH's were near 8.0. Conversely, the implicit normal marine pH's and presence of chert, give support to the tenability of Sujkowski's explanation.

when they accumulated. 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.

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

Traces of muscovite have been found with clays and fine quartz silts 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 shales of the Red Eagle Cyclothem. The small amounts of chlorite commonly present in many of these shales, 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 shales is present where thin zones alongside fractures in greenish-gray shales are changed to a faint maroon-gray color. Some of the green

coloration in Johnson and Roca shales is due to the presence of finely divided ferrous iron silicates.

The random orientation of shell fragments in the Bennett limestone and part of their light color have been explained (p. 163) as resulting 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).

Traces of short, impressed or indented contacts between pellets in the Howe Limestone reflect solution and reprecipitation of calcite, probably aided by compactive pressure.

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

SYNTHESIS

This synthesis outlines the environmental history of the Red Eagle Cyclothem. Necessarily, some episodes in the 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.

Environmental History of the Red Eagle Cyclothem

The Red Eagle Cyclothem was deposited in Wolfcampian time. It was laid down in marine waters spread thinly over a wide, very flat, shelflike basin in the Midcontinent region of Kansas, Oklahoma, and Nebraska. The basin floor slowly subsided and permitted the accumulation of some 50 feet of sediments that comprise 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 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 moist climate of the region varied from warm to temperate or cool.

During the first half of Johnson time, waters shallowed until shore lines 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 soils developed. When the waters were shallowest (10 to 20 feet deep) red detritus entered the northern and southern margins of the basin. The Red Eagle Cyclothem sequence began with accumulation of these redbeds in warm and possibly saline water. While red detritus was carried northward 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 basically red muds accumulated, the sea began to deepen, shore lines retreated, and the water became normally saline. Then, greenish-gray muds were 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 slightly calcareous greenish-gray mudstones.

Waters cleared occasionally during the last quarter of Johnson time, either because of short, warm, dry periods which inhibited subaerial erosion, low relief and gradients in source areas, or development of submarine barriers. During these times relatively more algal calcium carbonate was produced so that local layers of argillaceous lime muds accumulated within the preponderant slightly calcareous muds. The water was less than 40 feet deep so that storms were

able to stir up some of the bottom sediments. Tidal currents exerted daily smoothing action on bottom sediments and were an important agency of transportation of suspended detritus.

Near the end of Johnson time, rapid influxes of water from land during a fluvial period temporarily lowered the salinity. Ostracodes were the only shelled animals that flourished. Fragments of gymnosperm wood floated in from lands to the north and east. In southern Kansas the late Johnson waters were slightly deeper than in the north. The land to the south was low. Periodically the supply of detritus from the south diminished, and so allowed the waters to clear. During these short times a mixed fauna developed in southern Kansas while only ostracodes lived in the northern part of the basin. Detritus entered the basin mainly from the north and east.

Johnson deposition terminated when the water deepened suddenly from 40 to nearly 150 feet. Whether or not subsidence aided the rising water, the 100-foot rise in sea level forced the shorelines to retreat great distances over the adjacent lowlands. Hence, in Glenrock time, little clastic sediment from the distant sources reached the deep waters of the area of study. Thus, Glenrock waters were very clear. The sea floor was very flat. Benthonic life thrived. Particulate algal calcium carbonates settled from near-surface waters amid a profusion of benthonic calcareous shelled invertebrates most of which 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 muds accumulated there than in the north. However, in northern Kansas and Nebraska, Glenrock sediments were laid down at a remarkably uniform rate. Minor local uplifts occurred along the Nemaha anticline near the Alma and Elmdale localities during or at the close of Glenrock time, so that the Glenrock sediments were not deposited in these areas. At the end of Glenrock time, the depositional interface was a strikingly level, uniform, surface over much of northeastern Kansas and southeastern Nebraska.

The events which closed Glenrock time happened even more suddenly than those which began it. Waters shallowed quickly from more than 160 feet to less than 60 feet. The abundant supply of clastics was resumed and areal circulation of waters from the open ocean was restricted by an unknown barrier somewhere to the southwest. This change accounts for the turbid waters and toxic euxinic floor of 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.

Black odorous Bennett muds began accumulating on the clean bioclastic Glenrock Limestone. Black mud killed the last Glenrock fusulinids and washed into the open tubes of animals which had burrowed into the upper part of the

Glenrock sediments. Organic matter and calcium carbonate settled from the surface waters to the toxic bottom where the organic matter was partly preserved and partly decayed by anaerobic bacteria. This increased the toxicity. A few Lingula and Orbiculoidea were able to live in and on the black bottoms, but they did not proliferate.

During early Bennett time the waters deepened. The ensuing freer circulation reduced the toxicity and encouraged a mixed benthonic fauna. Gray muds were deposited from moderately turbid waters. The southern supply of clastics was reduced while waters continued to deepen in the middle part of Bennett time. Faint upwarp of the Bourbon arch prevented northern clastics from reaching southern Kansas. Hence, lime muds were laid down in clear water during the rest of Bennett time in southern Kansas while calcareous clay muds were deposited from turbid waters in Nebraska and northern Kansas. Up to 5 feet of lime muds or oozes accumulated in central Kansas during medial Bennett time, but calcareous clay muds with a mixed fauna followed when waters began shallowing in the latter part of Bennett time. The same faunal change occurred in the contemporaneous lime facies of southern Kansas and the shale facies of Nebraska.

In a small area south of Eskridge, Kansas, double the normal thickness of lime muds accumulated amid calcareous clay muds, during medial and late Bennett time.

After the euxinic conditions which began in Bennett time, all Bennett waters were mildly warm (above 70°F.) and

normal-marine in salinity and pH. Their bottoms were swept by gentle currents. In late Bennett time, calcareous crustose algae formed on the lime oozes in southern Kansas.

The end of Bennett deposition was less abrupt than the beginning. Surrounding land masses were worn low by the end of Bennett time. While the late Bennett waters shallowed, less and less clastic materials were carried into the area. Thus, the deposition of Howe bioclastics began in clear, warm, normal-marine waters, wherein a profuse "molluscan" benthonic fauna, rich in foraminifers, ostracodes, gastropods, and small clams was established. Shortly after the beginning of Howe time waters were shallow (less than 90 feet), warm, and clear enough for algae, even on the bottom. These algae (Osagia) secreted calcareous coatings around shell fragments, thus forming the pseudo-oolites in the pelletoid Howe Limestone (osagite) of central and southern Kansas. Gentle currents swept the floor of the Howe sea. In Nebraska and northern Kansas algal particles accumulated to form calcareous ooze.

After the depth had shallowed rapidly to about 35 feet by the end of Howe time, came the sudden influx of clastics and establishment of fresher water conditions similar to those of the late Johnson.

Uplift or climatic change in the southern source area was responsible for a flood of red clastics northward across the shelf-basin in early Roca time. Smaller quantities of

red clastics came from sources to the north and east. Most of these were reduced to a green color before they reached Kansas. Greenish-gray calcareous clay muds similar to those of late Johnson time settled from the turbid Roca waters. The water continued to shallow and shorelines drew nearer to the area of study than in early Roca time. Occasionally, as in late Johnson time, thin layers of lime muds accumulated. When the water shallowed to 10 or 20 feet and became abnormally saline near the middle of Roca time, red clastics spread across the area. This return to conditions similar to those which produced Johnson redbeds marks 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, despite facies changes, from Bennet, Nebraska, to Burbank, Oklahoma. Most of the Red Eagle limestones in the type area are equivalent to the Bennett member of the Red Eagle Limestone.
2. The Red Eagle Cyclothem accumulated in shallow marine waters, upon an unusually flat shelf-basin. The floor of the basin was flattest at the end of Glenrock time.
3. Regional climates during Red Eagle Cyclothem time ranged from cool or temperate, to warm and periodically arid.
4. Depositional environments of the various faunal-lithologic phases were controlled principally by water depth. Regional climate, supply rate of clastics, and chemistry of the sea waters, modified the effects of depth.
5. The clastic sediments in the Red Eagle Cyclothem came from the north, east, and south of the present outcrop belt.
6. Uniform depositional environments prevailed contemporarily over wide areas of the shelf-basin during Red Eagle Cyclothem time. The level floor permitted transmittal of sudden changes of depth and other environmental conditions across the entire shelf within very short time intervals (geologically instantaneous). Such events caused knife-sharp lithologic boundaries such as the

Glenrock-Bennett contact which is essentially a time plane within the Red Eagle Cyclothem.

7. The Red Eagle Cyclothem records a cycle of water depth changes (summarized in Figure 30) ranging from 10 feet to nearly 180 feet and returning to nearly 10 feet. Thus, all depths were within the inner neritic range as defined by Hedgepeth (1957, p. 18). Tidal currents were gently active within the shallow Red Eagle Cyclothem waters.

8. Accumulation rates were generally uniform during deposition of individual sedimentary units or phases of the Red Eagle Cyclothem in Kansas and Nebraska. The somewhat thicker succession in Oklahoma indicates a slightly greater rate of regional subsidence.

9. Redbeds in northern Kansas were deposited in the shallowest waters, and mark 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.

10. Table 5 summarizes postulated environmental conditions during deposition of the various faunal-lithologic units of the Red Eagle Cyclothem.

11. Most of the limestones in the Red Eagle Limestone formation were formed from shell detritus and calcareous algal particles. Inorganically precipitated limes are negligible.

Units of the Red Eagle Cyclothem	D	Pse	pH	Tp	S	O_2	Tb	C	CV
Roca Shale									
medial red shales	0-20	1		w	n	o	t	f	
lower greenish-gray shales	10-40	2r		c	n		t	f	
Red Eagle Limestone									
Howe Limestone	50-90	4r	>7.5	w	n	o	c	f	>10
Bennett Shale									
upper gray shales	80-110	5r	n	>72	n		t	f	
medial limestones	100-160	6	n	w	n	o	c	f	
lower gray shales	80-110	5p	n	w	n		t	f	
basal black shales	30-60	3p				lo	t	r	
Glenrock Limestone	150-180	7	n	w	n	o	c	f	
Johnson Shale									
upper greenish-gray shales	10-40	2p		c	n		t	f	
medial red shales	0-20	1		w	n	o	t	f	

EXPLANATION

D	depth of deposition (feet)	n	normal
Pse	phases of deposition (after Elias, 1937)	>	greater than
pH	hydrogen ion concentration (n=8.0-8.2)	<	less than
Tp	typical temperature (°F)	t	turbid
Tb	turbidity	c	clear
S	salinity (n=35-36°/oo)	lo	low
O_2	oxygenation	w	warm (>70°F)
C	circulation	c	cool (<65°F)
CV	current velocity (cm/sec)	r	restricted
		f	free
		o	oxidizing conditions

Table 5
Summary of interpreted ecologic conditions during deposition of definitive faunal-lithologic phases in the Red Eagle Cyclothem.

12. Formation of the Howe osagites required clear waters probably less than 60 feet deep and current velocities greater than 10 centimeters per second.

13. Stratigraphic index fossils within the Red Eagle Cyclothem are:

Howe limestone - Osagia (alga)

Bennett limestone - (Lophophyllidium?) (horn corals)

Bennett black shale - Lingula, Orbiculoidea (inarticulate brachiopods)

Glenrock limestone - Triticites (fusulinid foraminifers)

Upper Johnson shales - Trochiliscus (charophyte)

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

Osagia - clear, shallow (50-90 feet), warm, normal-marine, gently agitated waters, gentle circulation.

Lingula, Orbiculoidea - shallow (30-60 feet), euxinic, turbid conditions, restricted circulation.

Triticites - clear, shallow (150-180 feet), warm, normal-marine waters, gentle free circulation.

Trochiliscus - brackish waters rich in $CaCO_3$.

15. The gymnosperm spores in the lower Bennett shales 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 and Late Permian time.

16. Faint crustal upwarps in the Nemaha and Bourbon arch areas of east-central Kansas exercised minor control over sedimentation in Glenrock and Bennett time, but not during Howe time. Glenrock limestone is absent in central Kansas because of such upwarp.

17. Tectonism in a southern source (southeastern Oklahoma?) periodically controlled the influx of clastics to the area. Changes of sea level (ultimate base level) and climatic changes also governed the supply of clastics.

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

APPENDIX I

Laboratory Techniques

Insoluble Residue Technique

1. Weigh desired amount (10 grams for this study) of crushed rock sample.
2. Place sample in 500 cc beaker. Add water until sample is immersed to depth of one inch.
3. Slowly add dilute (10%) HCl until mild effervescence develops. Effervescence can thus be controlled, to avoid dangerous "bubbling-over" and loss of sample. Slow effervescence avoids disintegration of delicate fossils such as arenaceous foraminifers.
4. When effervescence stops, add another small amount of dilute acid. If effervescence resumes, wait until it stops.
5. Repeat step 4 until effervescence does not resume when acid is added. At this stage all acid-soluble carbonates will be dissolved, leaving an insoluble residue commonly consisting of mixed clays, silts and coarser materials.
6. Allow acid to stand until clear.
7. Carefully siphon off supernatant acid.
8. Gently fill beaker with water to wash residue.
9. Allow liquid to stand until clear, then siphon off water.
10. Repeat steps 8 and 9 until residue is free from acid. This can be checked with litmus paper.
11. Carefully wash residue onto filter paper of known weight.
12. Dry and weigh filter paper and residue.
13. Compute percentage by weight of insoluble residue.
14. Re-wet residue in beaker of water.
15. Add dispersing agent (a pinch or two of sodium hexametaphosphate) and heat (do not boil) the residue until it is again in suspension.
16. Allow suspension to cool.
17. Agitate by repeated gentle inversion.

17a. At this stage, suspended clays can be removed with an eyedropper and applied on glass slides for X-ray diffraction studies. Pipette analyses of silt and silt sizes may also be done.

18. Let stand until silts settle, then decant the suspended clays.
19. Gently refill the beaker and put residue into suspension again.
20. Repeat steps 16 and 17 until clays are removed, leaving a silt-size and coarser residue.
21. Carefully wash residue into filter paper.
22. Dry and store residue in glass vials pending study.

Residue may be sieved to separate sand from silt, or put into suspension for pipette analyses of silt sizes (Krumbein, 1932).

12. Dry and weigh filter paper and residue.
13. Compute percentage by weight of insoluble residue.
14. Re-wet residue in beaker of water.
15. Add disperaing agent (a pinch or two of sodium hexameta-phosphate) and heat (do not boil) the residue until it is again in suspension.
16. Allow suspension to cool.
17. Agitate by repeated gentle inversion.
17a. At this stage, suspended clays can be removed with an eyedropper and applied on glass slides for X-ray diffraction studies. Pipette analyses of clay and silt sizes may also be done.
18. Let stand until silts settle, then decant the suspended clays.
19. Gently refill the beaker and put residue into suspension again.
20. Repeat steps 18 and 19 until clays are removed, leaving a silt-size and coarser residue.
21. Carefully wash "clayless" residue into filter paper.
22. Dry and store residue in glass vials pending study.

Residue may be sieved to separate sand from silt, or put into suspension for pipette analyses of silt sizes (Krumbein, 1932).

Acetate Peel Technique

1. Cut rock specimen perpendicular to the bedding planes, or in any other desired plane. Be sure the top of the sample is indelibly marked.
2. Polish the cut face with successively finer abrasives until a smooth, flat surface is obtained. Rotating lap wheels are useful, but the final finish is obtained best by polishing the flat face upon plate glass with very fine abrasive.
3. Etch the surface with one percent hydrochloric acid for 5 to 10 seconds. The severity of the etch effect varies with the material. The most desirable etch must be achieved empirically. After practice, a second etching is seldom necessary. Acetic acid may be used, but it leaves a fine white deposit of calcium acetate on the polished surface. This will not wash off completely, and sometimes interferes with the clarity of the peels.
4. Wash the etched surface with distilled water and dry thoroughly. Special care must be taken to protect the etched surface.
5. Cut a piece of single-matte-finish commercial acetate film (.005-inch thickness) to a size slightly larger than the polished face of the specimen.
6. Support the specimen with the etched surface up and approximately level. Specimens may be oriented properly by placing them in the desired position in a flat tray

filled with 3 or 4 inches of clean coarse sand or medium gravel. A gentle downward, and slightly rotational, pressure is sufficient to fix the specimen in place with the polished and etched surface about one inch above the surface of the gravel.

7. Cover the etched surface with a mixture of 95 percent acetone and 5 percent amyl acetate. Allow this to soak into the rock for a few moments, then apply more.

8. Quickly, but gently, apply the matte (dull) side of the acetate film against the moist rock surface. It is not necessary to press the film against the rock. Rapid evaporation of the acetone is apt to produce gas bubbles beneath the film, but this is partially eliminated by the amyl acetate which inhibits evaporation of the acetone. More than 5 percent amyl acetate may be added to further inhibit bubbles, but more than 10 percent is undesirable, because it interferes with the adhesion of the film, and results in undue cloudiness of the reproduction.

9. Let dry for 20 to 30 minutes.

10. Carefully peel the film off, starting at one corner.

11. Trim away the excess peripheral film.

12. Label the film and retain for study under a binocular microscope using oblique illumination. For some films a combination of reflected and transmitted illumination yields the strongest contrasts of shading. This must be determined empirically.

13. Contact photographs of the peels ("peel-prints") may be made using the peels directly as negatives. Also, the peels may be mounted between plates of glass and (1) used in a photographic enlarger to obtain enlarged negative peel-print reproductions (e.g., Pl. 6, 7, 8) or (2) subjected to 30-degree oblique illumination and photographed against a black background (Easton, 1942) to obtain positive peel-print reproductions.

Washed Shale Technique

1. Prepare a half pound sample of roughly crushed shale. Remove silt-size and finer particles by sieving.
2. Immerse a quarter pound of screen sample in a pan of water and add a small amount of sodium hexametaphosphate (Tchillingarian, 1952) to aid decomposition.
3. Gently boil the sample until the shale begins to decompose and water becomes muddy.
4. Remove from heat and allow to settle for 20 minutes.
5. Remove the muddy liquid by decantation.
6. Re-immerse the residue, add more deflocculating agent, and bring to a gentle boil.
7. Repeat steps 3, 4, 5 and 6 until essentially all clay-size materials have been removed, leaving a residue of organic and inorganic clastics of silt-size and larger.
8. Air-dry and store the residue for study. Do not attempt to hasten drying by heating directly. Drying over a steam bath will safely hasten drying.

APPENDIX II

List (continued)

List of Observed Red Eagle Cyclothem Outcrop Localities

Bennet, Nebraska. NE Sec.11, T.8N., R.8E., Lancaster County.

Tecumseh, Nebraska. NE Sec.33, T.5N., R.10E., Johnson County.

Pawnee, Nebraska. NW NW Sec.11, T.1N., R.10E., Pawnee County.

Pawnee South, Nebraska. SW Sec.23, T.1N., R.10E., Pawnee County.

Pawnee North, Nebraska. NW Sec.26, T.2N., R.10E., Pawnee County.

Glen Rock, Nebraska. NW SW Sec.30, T.6N., R.14E., Nemaha County.

Howe, Nebraska. NE Sec.15, T.4N., R.14E., Nemaha County.

Johnson, Nebraska. NW NE Sec.6, T.5N., R.13E., Nemaha County.

Richardson West, Nebraska. SW Sec.27, T.1N., R.13E., Richardson County.

Humboldt, Nebraska. SE SE Sec.16, T.1N., R.13E., Richardson County.

Richardson East, Nebraska. NW Sec.19, T.1N., R.14E., Richardson County.

Frankfort, Kansas. NE NW Sec.21., T.4S., R.9E., Marshall County.

Manhattan, Kansas. NE Sec.7, T.10S., R.8E., Riley County.

Manhattan East, Kansas. CNL Sec.20, T.10S., R.8E., Riley County.

Manhattan West, Kansas. SW NW Sec.34, T.10S., R.7E., Riley County.

Paxico, Kansas. SW Sec.30, T.11S., R.12E., Wabaunsee County.

Alma, Kansas. SW NE Sec.11, T.12S., R.10E., Wabaunsee County.

Keene, Kansas. SE Sec.24, T.13S., R.12E., Wabaunsee County.

Eskridge, Kansas. SE NE Sec.17, T.14S., R.12E., Wabaunsee County

Eskridge Quarry, Kansas. NW Sec.32, T.14S., R.12E., Wabaunsee County.

Eskridge South, Kansas. NE Sec.6, T.15S., R.12E., Wabaunsee County.

Judith, Kansas. NW NW Sec.7, T.15S., R.12E., Wabaunsee County.

Coffman Ranch, Kansas. NE SW Sec.23, T.15S., R.11E., Lyon County.

List (continued)

Coffman West, Kansas. NW Sec.23, T.15S., R.11E., Lyon County.

Allen, Kansas. NW SW Sec.36, T.15S., R.11E., Lyon County.

Allen No.2, Kansas, SW NW Sec.35, T.15S., R.11E., Lyon County.

Dunlap, Kansas. SE SE Sec.23, T.17S., R.9E., Morris County.

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

Elmdale, Kansas. C Sec.26, T.19S., R.7E., Chase County.

Saffordville, Kansas. NW SW Sec.30, T.19S., R.9E., Chase County.

Sallyards, Kansas. SW NW Sec.11, T.26S., R.8E., Greenwood County.

Piedmont, Kansas. NE SW Sec.30, T.27S., R.8E., Greenwood County.

Grand Summit, Kansas. SE Sec.3, T.31S., R.8E., Elk and Cowley counties.

Highway 38, Kansas. SE Sec.21, T.32S., R.8E., Cowley County.

Red Eagle, Oklahoma. SW SE Sec.25, T.28N., R.6E., Osage County.

Burbank, Oklahoma. C Sec.25, T.26N., R.5E., Osage County.

APPENDIX III

Detailed Descriptions and Graphic Diagrams of Sampled Red Eagle Cyclothem Sections.

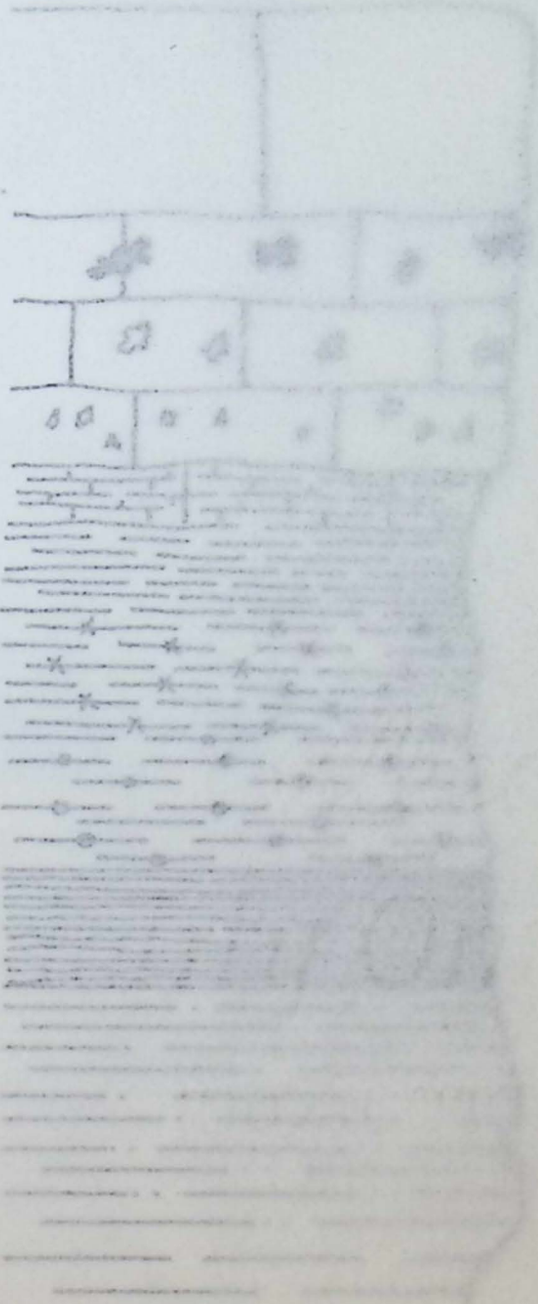
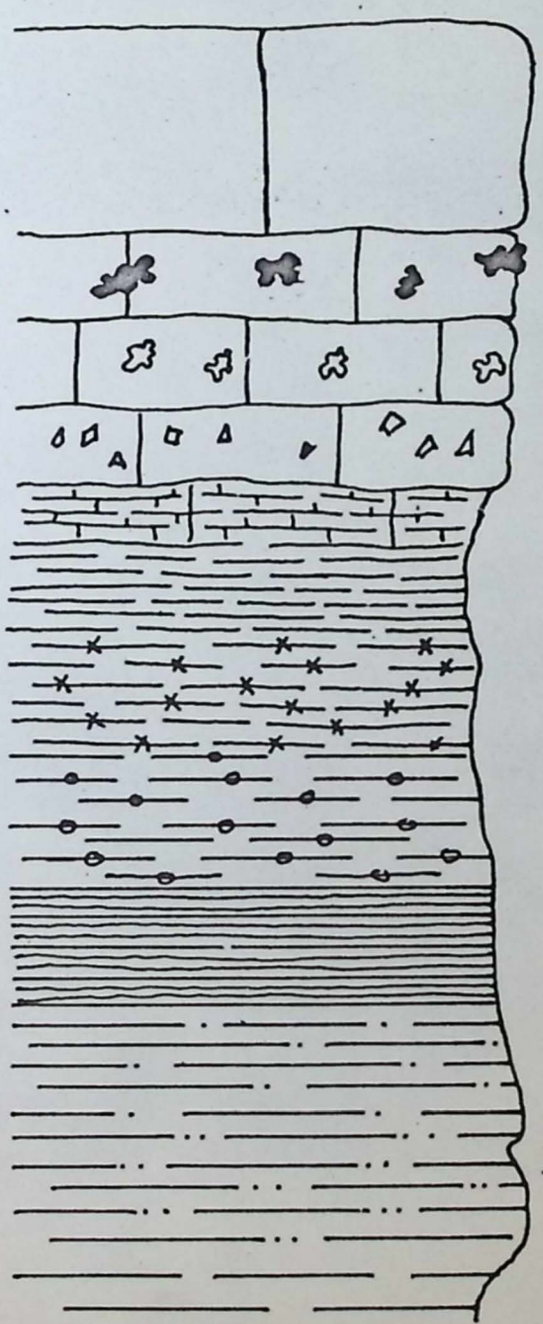


Figure 4

EXPLANATION OF SYMBOLS USED IN PLATES 19 TO 36



Limestone, massive

Limestone, cherty

Limestone, vuggy

Limestone, breccia

Limestone, shaly

Shale, gray

Shale, red

Shale, green

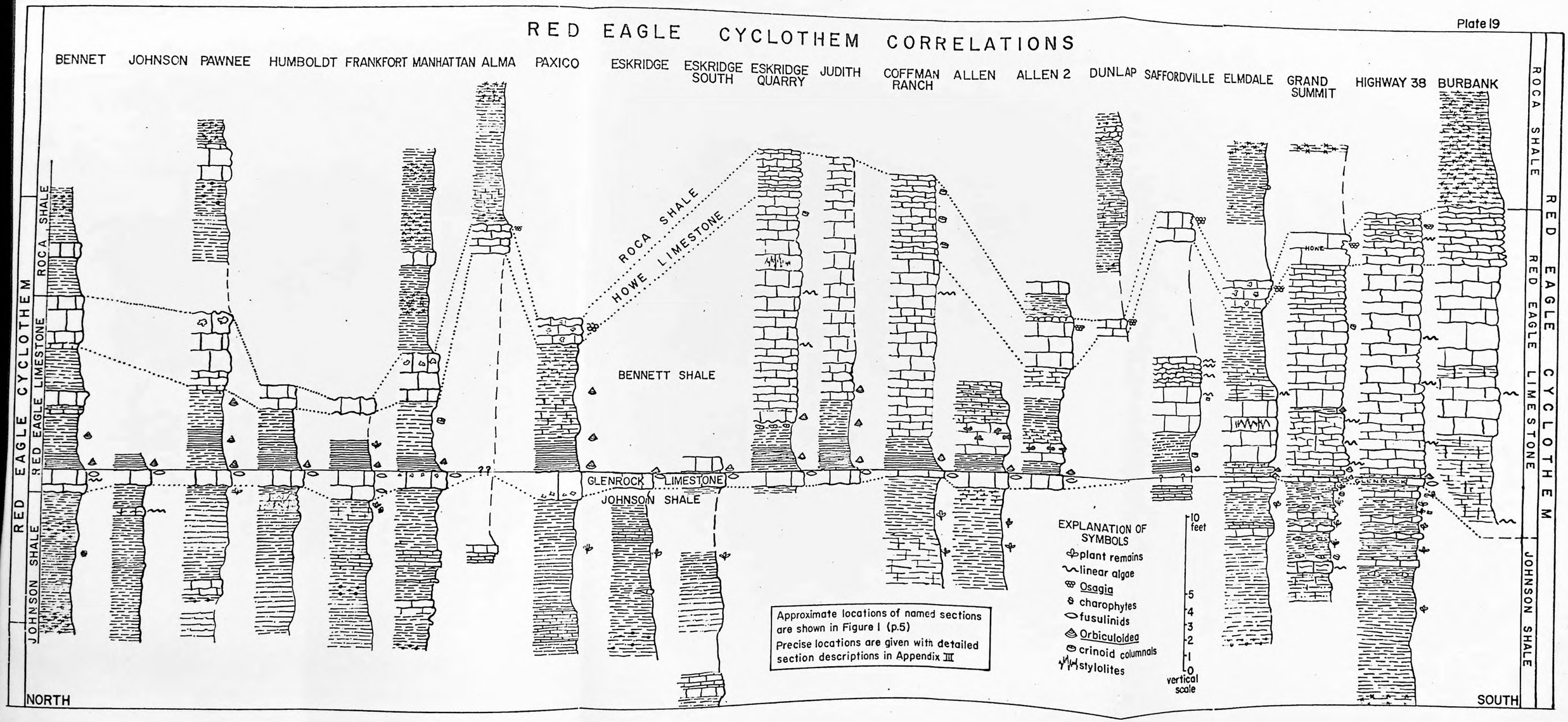
Shale, black

Mudstone

Siltstone

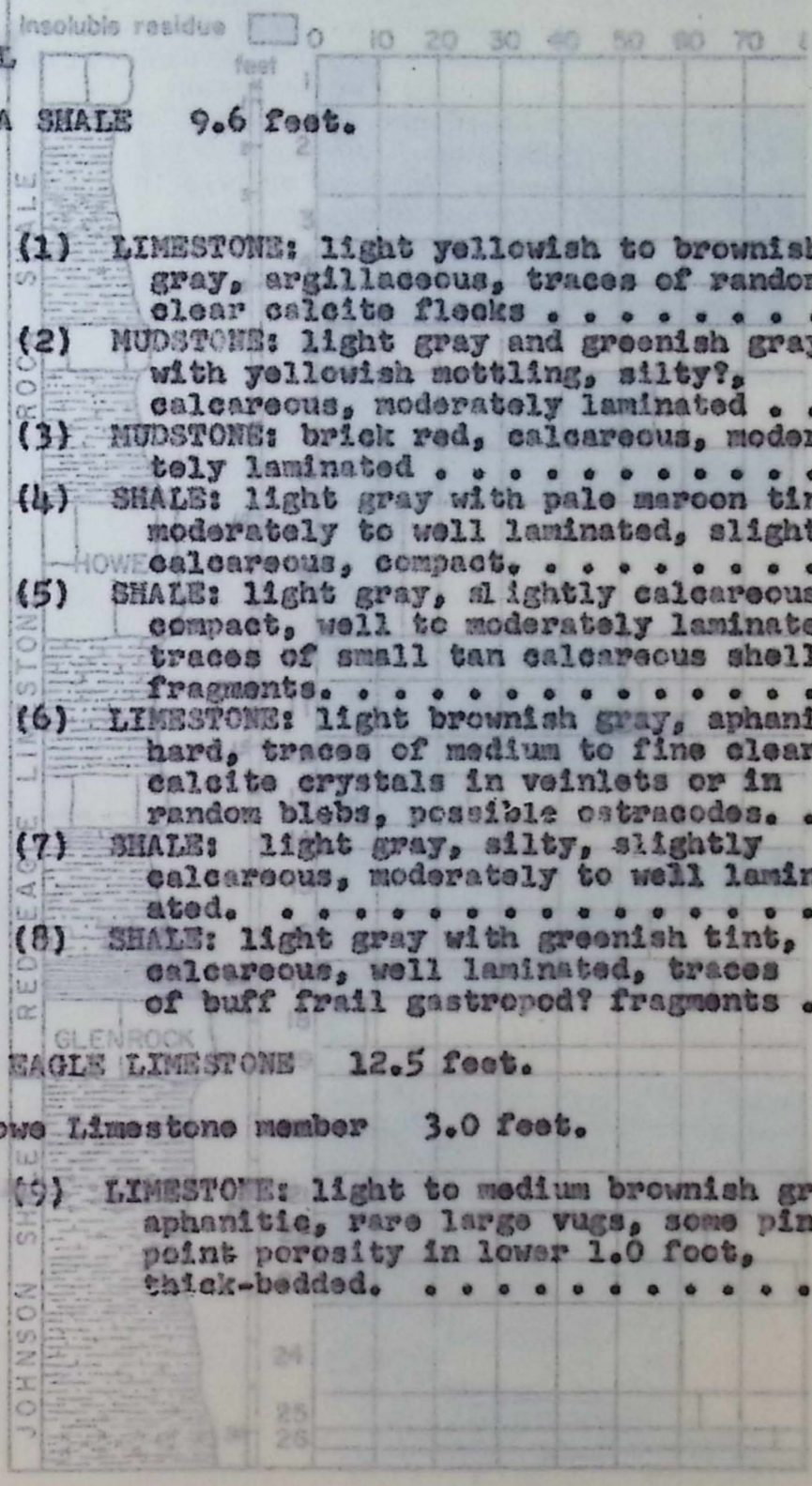
Claystone

RED EAGLE CYCLOTHEM CORRELATIONS



BENNET SECTION

NE Sec.11, T.8S., R.8E.
In south cut-bank of Little Nemaha River, 1/2 mile southeast of Bennet, Lancaster County, Nebraska.



SOIL

ROCA SHALE 9.6 feet.

	Thickness, feet
(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, possible ostracodes. .	0.9
(7) SHALE: light gray, silty, slightly calcareous, moderately to well laminated.	1.7
(8) SHALE: light gray with greenish tint, calcareous, well laminated, traces of buff frail gastropod? fragments .	1.0

RED EAGLE LIMESTONE 12.5 feet.

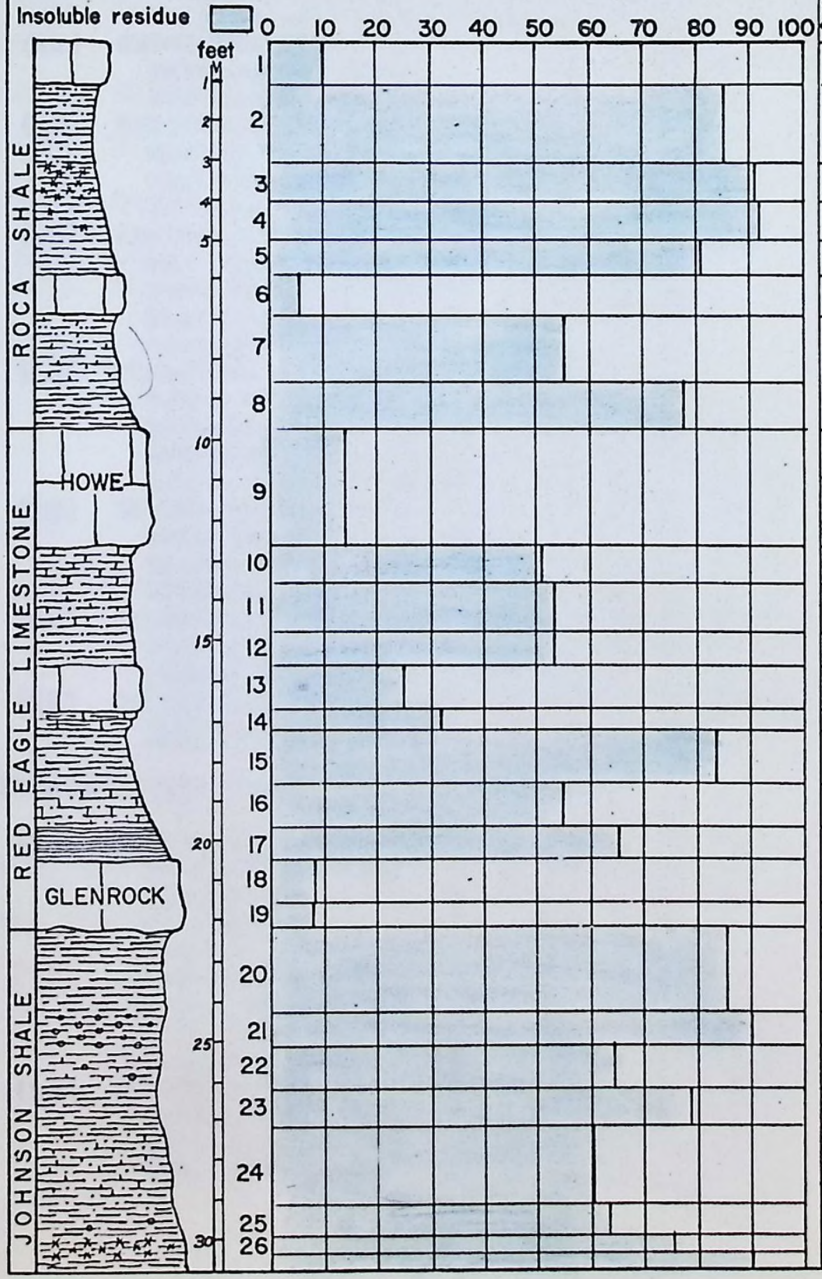
Howe Limestone member 3.0 feet.

(9) LIMESTONE: light to medium brownish gray, aphanitic, rare large vugs, some pinpoint porosity in lower 1.0 foot, thick-bedded.	3.0

BENNET SECTION

NE Sec. 11, T.8N., R.9E.
Lancaster County, Nebraska

x rare
o common
● abundant



Bennett Limestone member 8.0 feet.

(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, microcrystalline to microgranular 1.0

(14) MUDSTONE: calcareous, similar to 13, 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 thread-like plant remains . . . 1.5

(16) MUDSTONE: light gray, slightly calcareous, some rusty yellow mottling, compact, poorly laminated. 1.0

(17) SHALE: dark gray, well laminated, complete Orbiculoidea with fragments 1.0

Glenrock Limestone member 1.5 feet.

(18) LIMESTONE: light brown to grayish green, microcrystalline matrix for common fusulinids, upper 0.2 feet has patches of muddy gray material suggestive of Bennett shale, hard, massive, trace of brachiopod fragments, rare flecks of brown bituminous? material, lower 0.5 feet free of fusulinids but with common brachiopods, foraminifers, and ostracodes 1.0

(19) LIMESTONE: medium to light brownish gray, aphanitic to microcrystalline, undulatory laminations, undulatory base and top, very hard. 0.5

JOHNSON SHALE 15.6 feet.

(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, slightly 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 feet brick red shale 0.5 feet above base.	1.7
(28)	SILTSTONE: light gray, very finely and evenly laminated, resistant, platy debris, slightly calcareous, grades downward to similar silty shales in lower 0.5 feet and to shale as below	1.0
(29)	SHALE: light gray to brownish-gray, moderately to very well laminated as above, slightly calcareous.	1.0
(30)	LIMESTONE: shaly, medium gray, weathering light yellowish-gray to light brownish-gray, moderately to well laminated, slightly calcareous, slightly silty along laminae, one foot from base is a 0.3 lens of aphanitic argillaceous medium gray limestone	2.5
(31)	SHALE: light brownish-gray, similar to above, slightly silty.	1.1

FORAKER LIMESTONE

Long Creek Limestone member

(32)	LIMESTONE: argillaceous to coquinoid, medium to light gray	2.0

JOHNSON SECTION

NW NE Sec.6, T.5N., R.13E.

In west bank of creek, 1 1/4 miles north of Johnson, Nemaha County, Nebraska

SOIL

RED EAGLE LIMESTONE 3.0 feet exposed.

	Thickness, feet
Bennett Shale member 2.0 feet.	
(1) SHALE: dark gray, weathers buff, well laminated, fish teeth, Orbiculoidea. .	2.0
Glenrock Limestone member 1.0 feet.	
(2) LIMESTONE: light brownish-gray, fine crystalline matrix for abundant fusulinids, oatmealy subcoquinoid-calcarenitic texture	1.0
JOHNSON SHALE 17 feet.	
(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 (3), trace of brown phosphatic tooth? remains, common plain ostracodes along coarser textured laminae or very thin beds	0.5
(5) SHALE: similar to (4).	0.5
(6) LIMESTONE: medium to light brownish-gray with some pale rusty yellow stain, slightly resistant, argillaceous, aphanitic to microcrystalline matrix for ostracodes, possible linear algae. . .	0.5
(7) MUDSTONE: light greenish-gray, calcareous, silty, blocky debris, (7) and (8) more resistant than below	1.0
(8) MUDSTONE: light olive green to gray, calcareous, similar to (7), vague 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,	

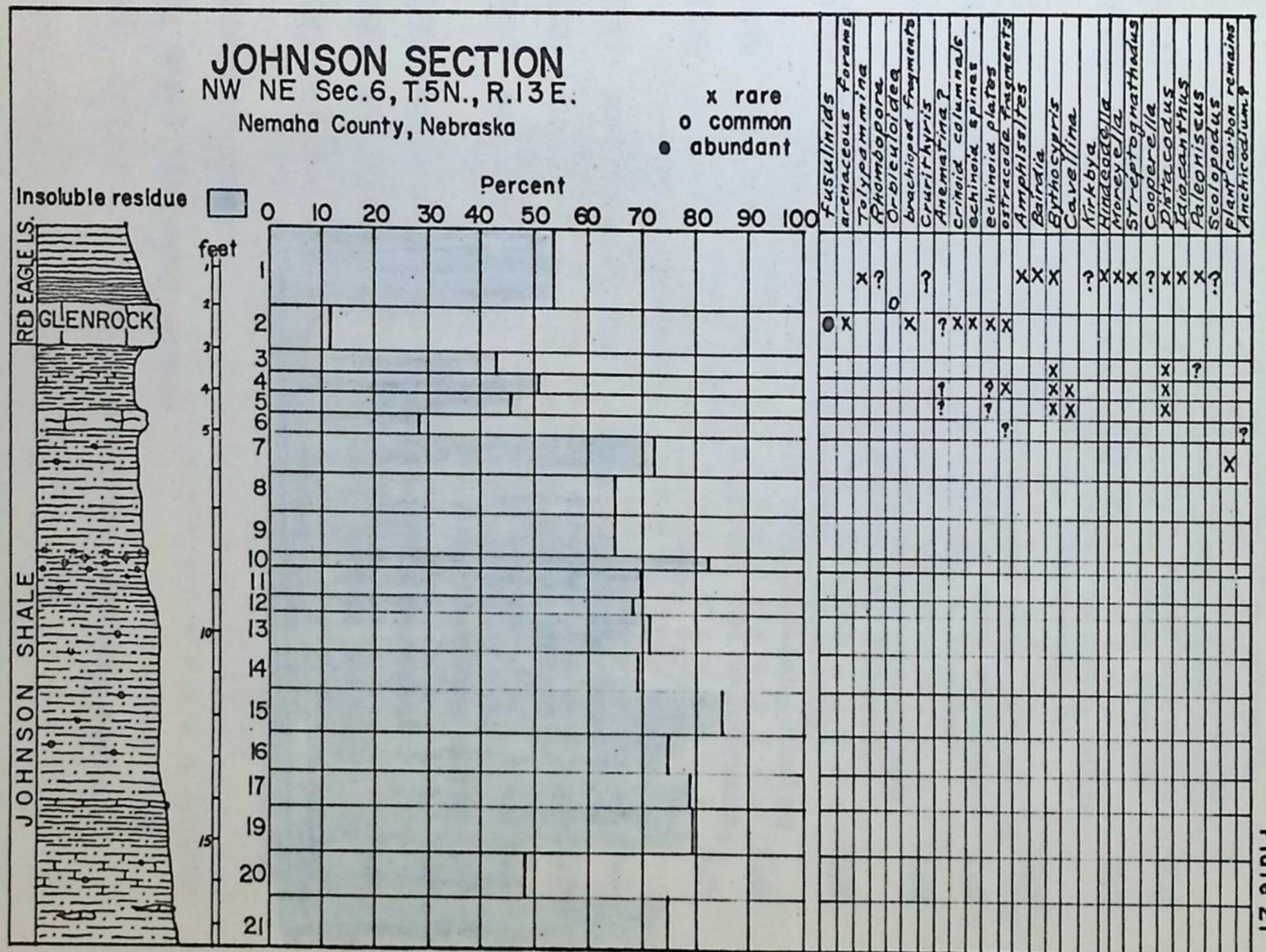

JOHNSON SECTION
NW NE Sec.6, T.5N., R.13E.
Nemaha County, Nebraska
x rare
o common
● abundant
Insoluble residue
Percent
0 10 20 30 40 50 60 70 80 90 100
feet
RED EAGLE LS.
GLENROCK
JOHNSON SHALE
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 19 20 21
Fusulinids
arenaceous Forams
Tolypammina
Rhombopora
Orbiculoidea
brachiopod fragments
Crurirhyris
Anematina ?
crinoid columnals
echinoid spines
echinoid plates
ostracode fragments
Amphissites
Bairdia
Bythocypris
Cavellina
Kirkbya
Hindeodella
Moreyella
Streptognathodus
Cooperella
Dasycladus
Idiocanthus
Paleoniscus
Scolopodus
Plant carbon remains
Anchicodium ?

Plate 21

clayey laminae alternate with off-white marly laminae, all layers are lenticular on a very minute scale, very calcareous, 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, some mudstone, moderately to poorly laminated. 0.3

(13) MUDSTONE: light greenish-gray with yellowish cast, calcareous, slightly more resistant 1.0

(14) MUDSTONE: similar to (13) but a lighter shade of 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, not 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, slightly 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, softer than usual 1.0

(23) MUDSTONE: similar to (22), varies to very light greenish-buff 1.0

(24) MUDSTONES and SHALES: variegated, very light greens, pinks, and buffs, calcareous 0.8

FORAKER LIMESTONE

Long Creek Limestone member

(25) LIMESTONE: light rusty-green, chalky, soft.

HUMBOLDT SECTION

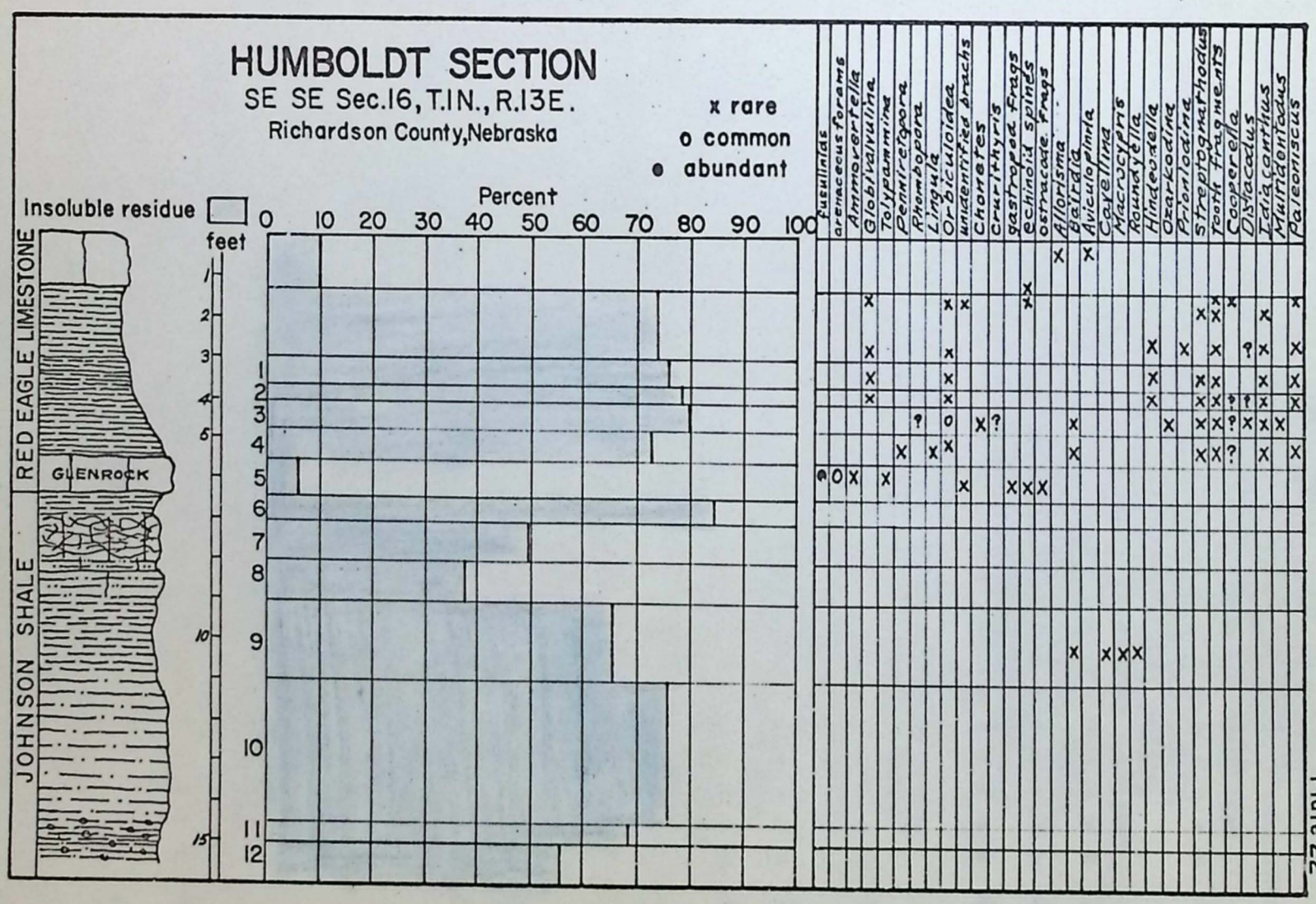
SE SE Sec.16, T.1N., R.13E.
West side of road cut in crest of small hill.
Richardson County, Nebraska.

RED EAGLE LIMESTONE 6.4 feet exposed.

		Thickness, feet
	Bennett Shale member 5.5 feet.	
	Covered below soil profile.	3.0
(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 (1). . . .	0.5
(3)	SHALE: dark to medium gray and brownish-gray, with 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
	Glenrock Limestone member 0.9 feet.	
(5)	LIMESTONE: medium grayish-brown, hard, microcrystalline to aphanitic matrix for abundant fusulinids and brachiopod fragments, trace of yellow iron stain, single massive, rusty-brown weathering ledge-former, undulatory base (relief 0.1).	0.9

JOHNSON SHALE 9.0 feet exposed.

(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 feet grading downward to massive, even-textured, hard, resistant	1.0


HUMBOLDT SECTION
SE SE Sec.16, T.1N., R.13E.
Richardson County, Nebraska
x rare
o common
● abundant
Insoluble residue
Percent
0 10 20 30 40 50 60 70 80 90 100
feet
RED EAGLE LIMESTONE
GLENROCK
JOHNSON SHALE
Fusulinids
arenaceous forams
Ammovertella
Globivalvulina
Tolypammina
Pennireticpora
Rhombopora
Lingula
Orbiculoidea
unidentified brachs
Chonetes
Crurithyris
gastropod frags
echinoid spines
ostracode frags
Allorisma
Betrida
Aviculopinna
Cayeliina
Macrocypris
Roundyella
Hindeodella
Ozarkodina
Prioniodina
Streptognathodus
Tooth fragments
Cooperella
Dyscacodus
Edmondia
Multidentatus
Paleonisciis
Plate 22

(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 slightly 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

PAWNEE SECTION
C NW NW Sec.11, T.1N., R.10E.
In south bank of West Branch Creek, 100 yards from small bridge. Pawnee County, Nebraska.

ROCA SHALE 18.0 feet exposed

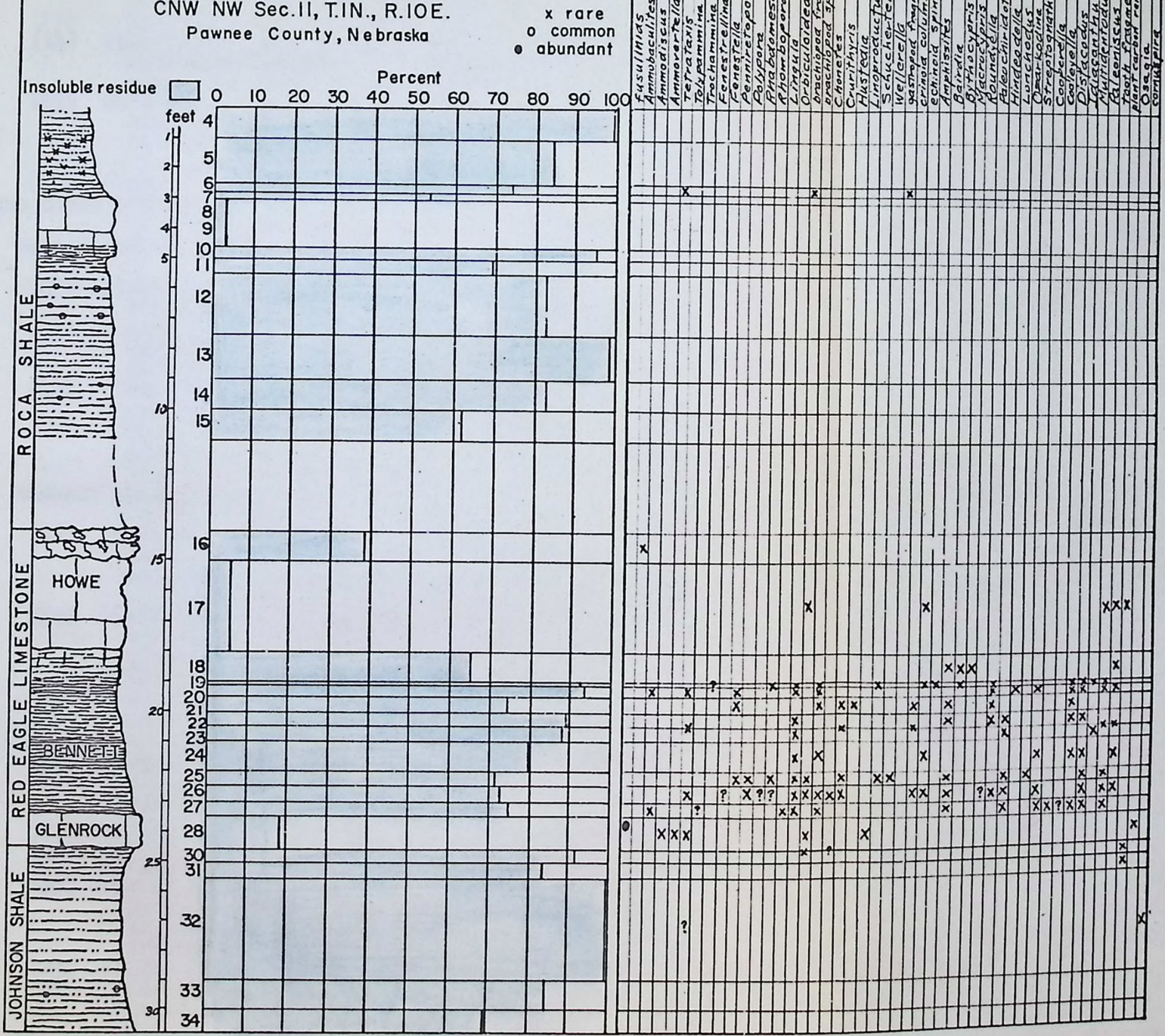
		Thickness, feet
(1)	SHALE: medium to light gray and greenish-gray, slightly silty, rare rusty mottling, poorly laminated, varies to mudstone	1.5
(2)	SHALE: light greenish-gray, slightly silty, varies to mudstone, random crude light gray argillaceous limestone boxworks	1.5
(3)	LIMESTONE: light greenish-gray, 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 (12)	0.55
(12)	MUDSTONE: very light greenish-gray, soft, calcareous, trace of mica?.	1.9

PAWNEE SECTION

CNW NW Sec.11, T.1N., R.10E.

Pawnee County, Nebraska

x rare
o common
● abundant



(13) SHALE: brownish-gray, silty, well laminated, trace of mica along laminae, not calcareous, compact, gray to rusty along some laminae 1.5

(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 (14) . . 1.0

(15a) Covered . . . . . 3.1 — ?

RED EAGLE LIMESTONE 22.1 feet.

Howe Limestone member 5.0 feet.

(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

Bennett Shale member 5.6 feet.

(18) SILTSTONE: very light gray to buff or yellowish gray, slightly to moderately calcareous, very fine to fine, grades up into (17). 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, Cyrithyris?, 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 (22), 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 (26), but lacking visible fossils, well laminated, moderately fissile, compact 0.5

Glenrock Limestone member 0.7 to 1.0 feet.

(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 feet, brachiopod fragments and lesser foraminifers, hard, compact, trace of pyrite in fusulinids, a single massive bed, locally top 0.2 feet penetrated by tubes of dark gray calcareous mud from Bennett Shale above, upper 0.1 feet undulatory with abrupt gradation upwards 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 muds, rare larger brachiopods (Linoproductus?), nearby outcrops have only shallow penetrating tubes, but transition to Bennett muds is abrupt, Orbiculoidea and Lingula fragments occur in the first ½ inch above the top of the Glenrock, smaller tubes of medium gray silty material in dark mud suggests small worm activities, lower 0.3 feet contains identified foraminifers: Tolypammina, Ammovertella, Tetrataxis . . 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. This occurs 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. Base roughly parallels bedding planes, varies to silty limestone and calcareous siltstone, with small brachiopod and foraminifer fragments, a local feature. . 0 to 0.2

JOHNSON SHALE 15.0 feet.

(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 feet is well laminated and weathers to tough-brittle plates and slabs up to 1 inch thick, a "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 portion, lower 0.5 feet 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

FRANKFORT SECTION
NE NW Sec.21, T.4S., R.9E.
In west side of Highway 99 roadcut south of railroad, ½ miles south of Frankfort, Marshall County, Kansas.

RED EAGLE LIMESTONE 6.8 feet.

	Thickness, feet
Howe Limestone member 1.3 feet.	
(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 feet 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 3.7 feet.	
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
Glenrock Limestone member 1.8 feet.	
(4) LIMESTONE: medium to light gray and brownish-gray with some limonitic yellow staining, hard, microgranular matrix for abundant fusulinids and rare brachiopods in upper 0.5 feet, rare larger brachiopods (Composita?), middle 0.5 feet has few fusulinids but contains common brachiopod fragments in microcrystalline to microgranular light to very light brown matrix, lower 0.7 feet similarly rich in smaller brachiopod fragments but matrix is light brown microcrystalline, several kinds of foraminifers, tiny snails and ostracodes, trace of limonite	1.8

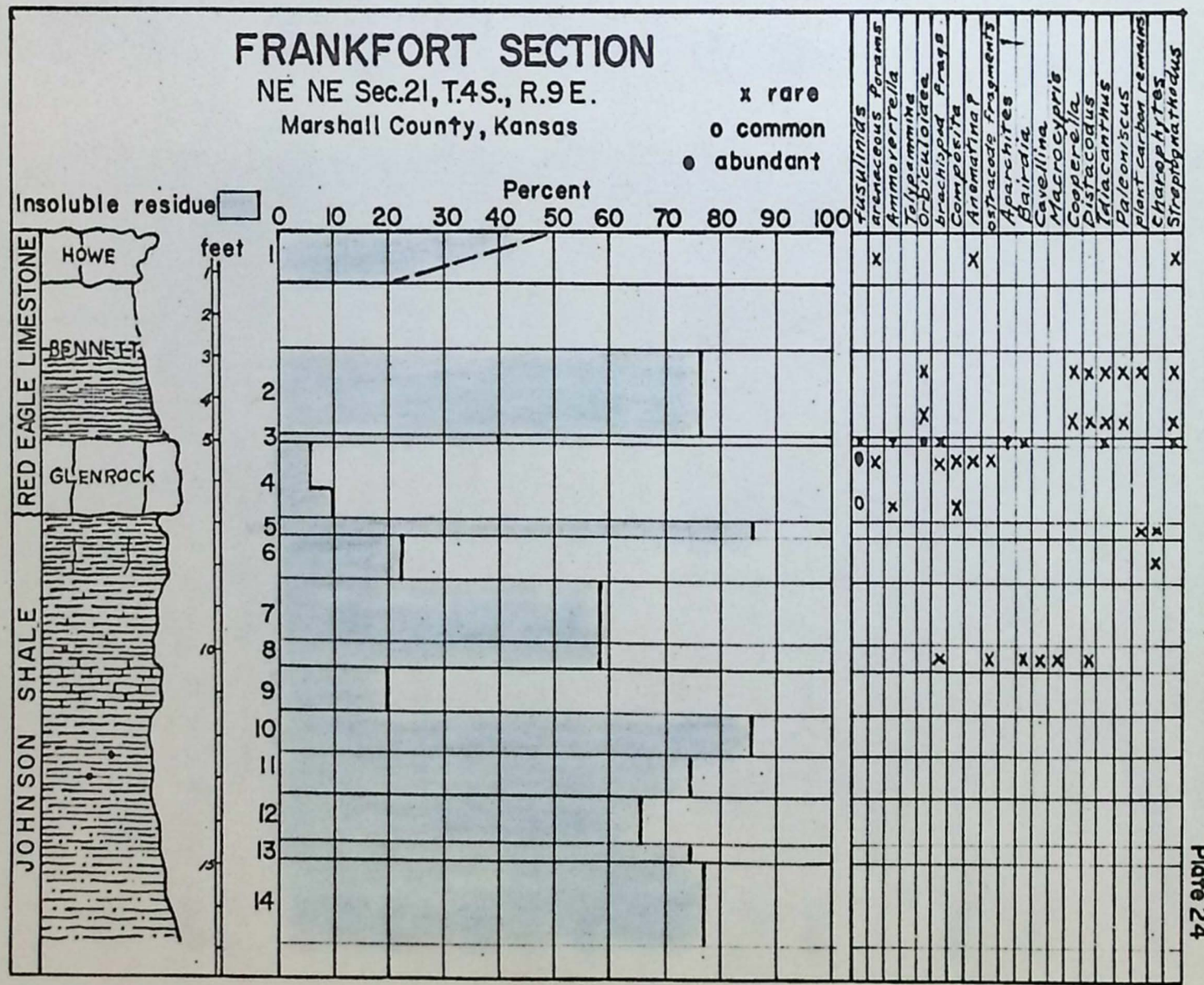

FRANKFORT SECTION
NE NE Sec.21, T.4S., R.9E.
Marshall County, Kansas
x rare
o common
● abundant
Insoluble residue
Percent
0 10 20 30 40 50 60 70 80 90 100
feet
RED EAGLE LIMESTONE
JOHNSON SHALE
HOWE
BENNETT
GLENROCK
fusulinids
arenaceous forams
Ammovertella
Tetrataxis
Orbiculoidea
brachiopod frags
Composita
Anemantina?
ostracode fragments
Aparchites
Bairdia
Cavellina
Macrocypris
Cooperella
Distacodus
Polacanthus
Paleoniscus
plant carbon remains
Chaetetes
Stereostrathodus

Plate 24

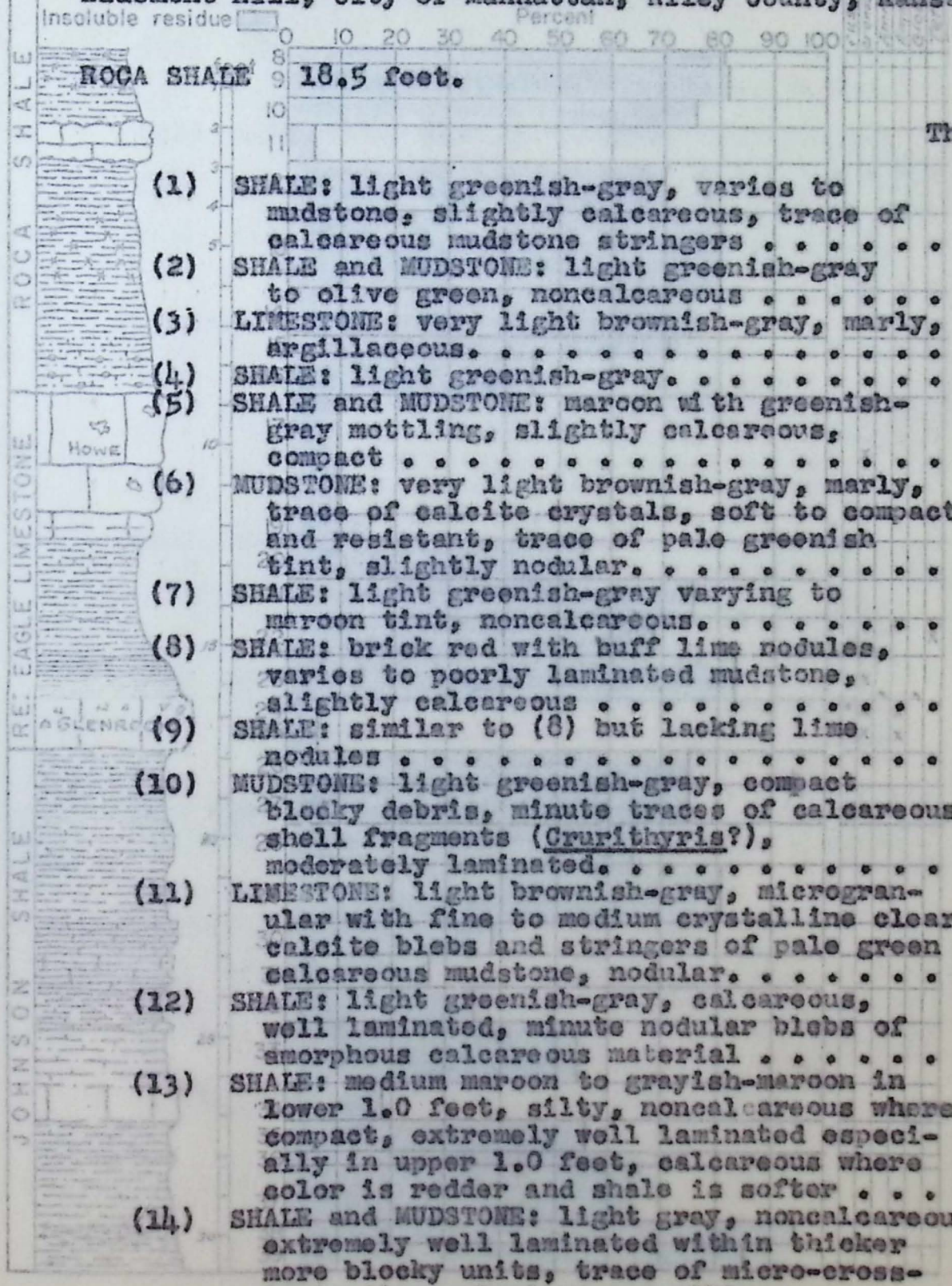
JOHNSON SHALE 10.0 feet exposed

(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 (6), 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-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

MANHATTAN SECTION

NE Sec.7, T.10S., R.8E.

In west bank of roadcut on Kansas Highway 13 near northeastern outskirts of Manhattan along northeast side of Bluemont Hill, City of Manhattan, Riley County, Kansas.



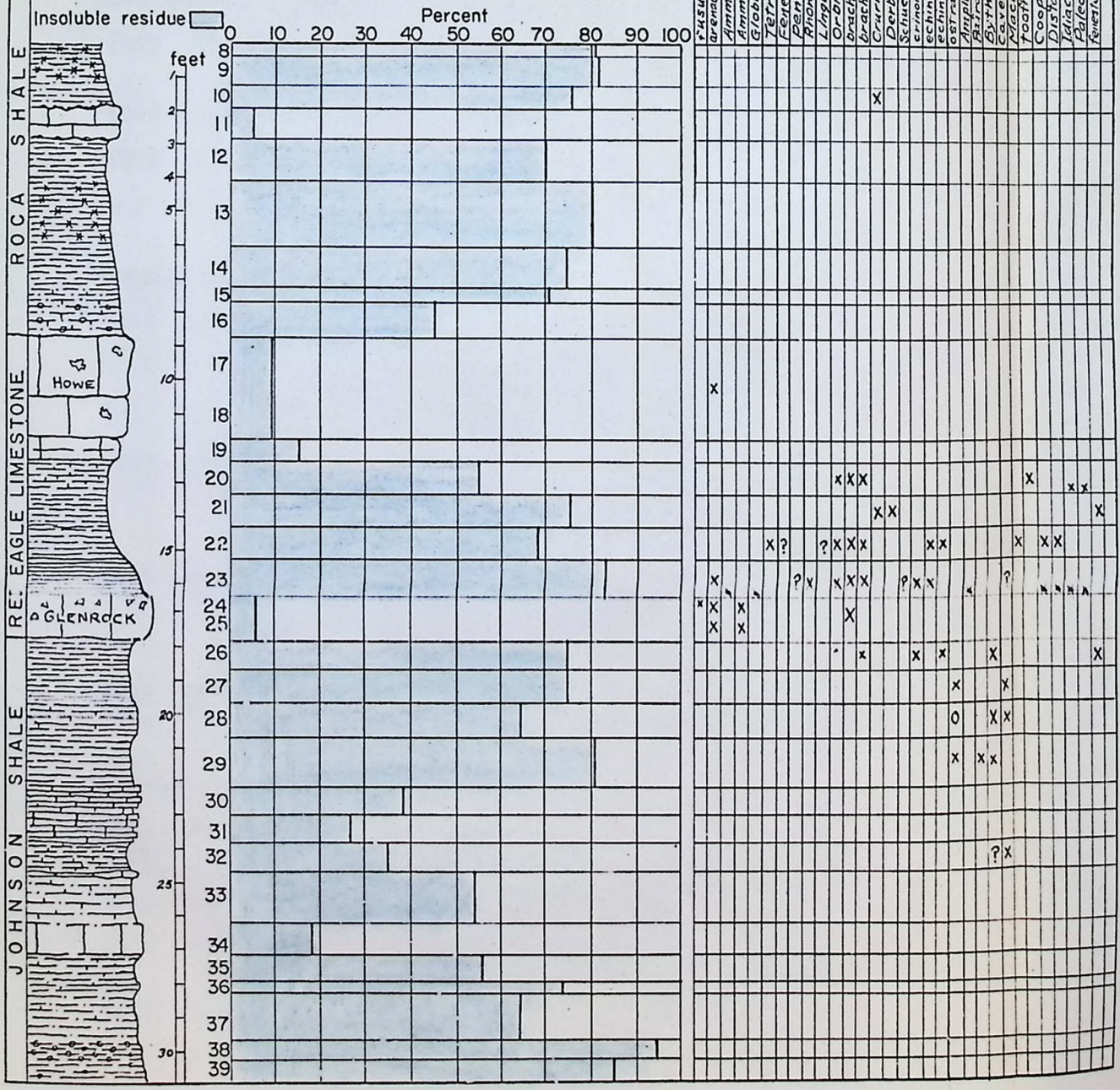
ROCA SHALE 18.5 feet.

		Thickness, feet
(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 (8) 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 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 feet, silty, noncalcareous where compact, extremely well laminated especially in upper 1.0 feet, 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

MANHATTAN SECTION

NE Sec. 7, T. 10S., R 8E.
Riley County, Kansas

x rare
o common
● abundant



(16) MUDSTONE: light gray, calcareous, vaguely laminated, chalky to silty. 1.0

RED EAGLE LIMESTONE 9.1 feet.

Howe Limestone member 3.6 feet.

(17) LIMESTONE: light yellowish-brown, clayey, somewhat vuggy, massive, thick-bedded, some rusty iron stain 1.5

(18) LIMESTONE: similar to (17), with grayish tint. 1.5

(19) LIMESTONE: light brownish-gray with yellowish tint, very similar to (18), base grades through 0.2 feet to underlying shale 0.6

Bennett Shale member 4.2 feet.

(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

Glenrock Limestone member 1.3 feet.

(24-25) LIMESTONE: medium to light gray and brownish-gray, granule breccia fragments of aphanitic limestone in microcrystalline and calcarenitic matrix containing trace of foraminifers and brachiopod fragments, similar to Paxico section, slightly more conglomeratic near base . . 1.3

JOHNSON SHALE 17.8 feet.

(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, trace of frail ostracodes along some laminae, calcareous. 1.0

(28) SHALE: light brownish-gray, probably weathered from medium gray, abundant 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 (30) 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 inch thick. 1.5

(34) LIMESTONE: light brownish-gray, grades to shales 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 feet grading to light gray in lower 1.0 feet, calcareous, moderately laminated 1.5

(38) SHALE: light grayish-green, compact, non-calcareous, moderately laminated. 0.5

(39) SHALE: similar to (38) , slightly calcareous

(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 downwards, minute trains of tan calcareous material in upper 0.4 feet . . 1.0

(43) SHALE: medium to light gray, muddy, sl.calc. 0.6

ALMA SECTION
SW SW NE Sec.11, T.12S., R.10E.
In east bank of Mill Creek, north of bridge, Wabaunsee County, Kansas

GRENOLA LIMESTONE

		Thickness, feet
Sallyards Limestone member 1.5 feet.		
(1)	LIMESTONE: very light gray, silty to chalky, porous, "spongy", grades upwards to calcareous wavy-bedded shale, irregular rubbly weathering, Pseudomonotis	1.5
ROCA SHALE 10.0 feet.		
(2)	SHALE: light greenish-gray, slightly silty, varies to mudstone, moderately to poorly laminated, calcareous, compact.	0.9
(3)	SHALE: similar to (2)	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 (5)	0.3
(7)	SHALE: similar to above, well laminated, wafery debris, random lenticular nodules 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 (10), some laminae within vague 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

RED EAGLE LIMESTONE 13.6 feet.

Howe Limestone member 1.6 feet.

(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 (oosagite), 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

Bennett Shale member 19.0 feet estimated.

(16) SILTSTONE: light gray with brown flecks as above, calcisiltite to varying to calcareous mudstone 1.2

Covered 17.8

JOHNSON SHALE 10.0 feet estimated.

(17) SHALE: dark gray to light brown where weathered, similar to (18) 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, minute (ostracodes?) shell fragments 0.5

(20) LIMESTONE: very light brownish-gray, microgranular, even-textured, trace of silt, similar to (21) 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 (22), 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

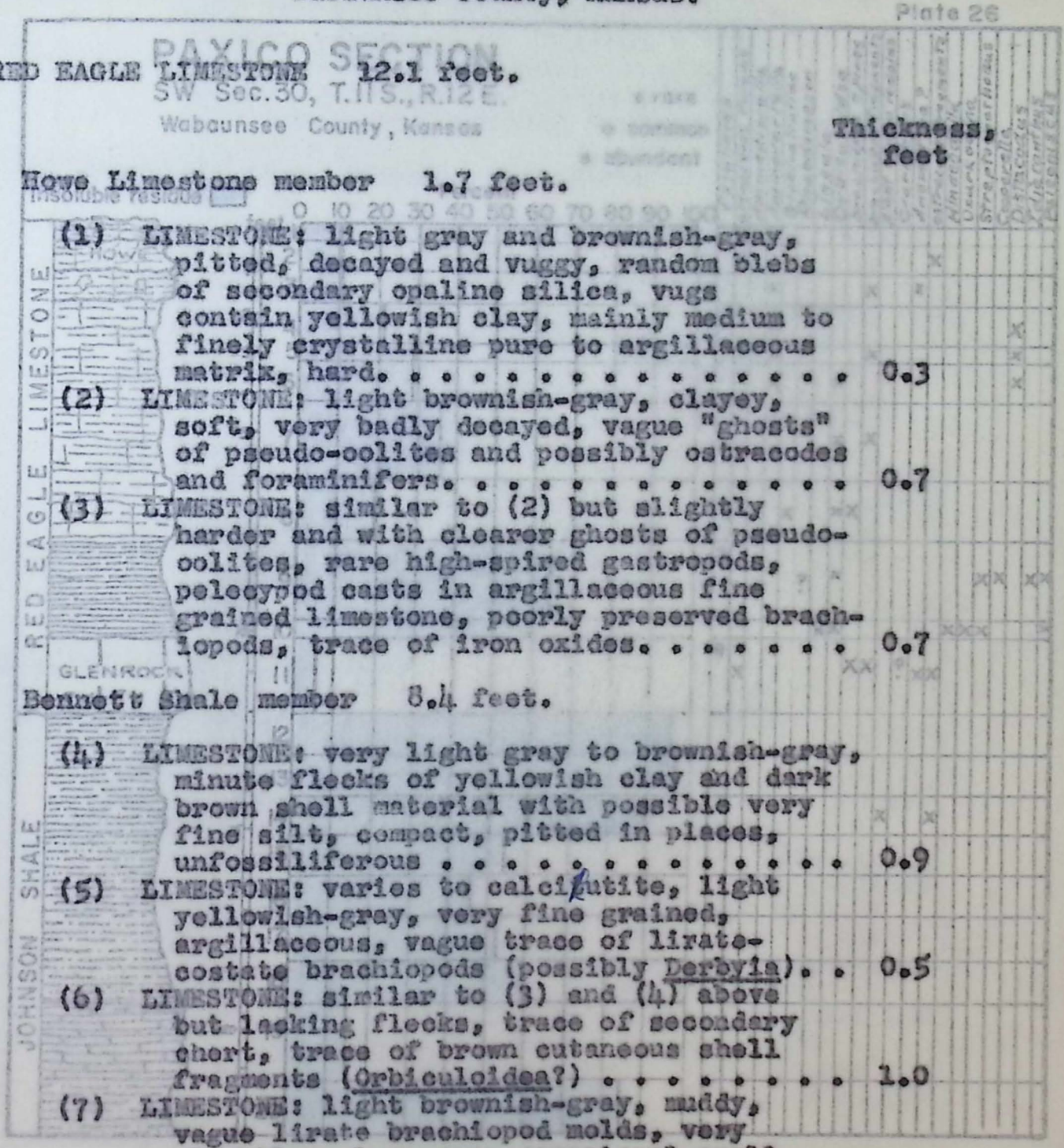
FORAKER LIMESTONE

Long Creek Limestone member

(23) LIMESTONE: light brown and gray, pitted, microgranular to microcrystalline, argillaceous, weathers to light yellowish gray-brown. 3.0

PAXICO SECTION

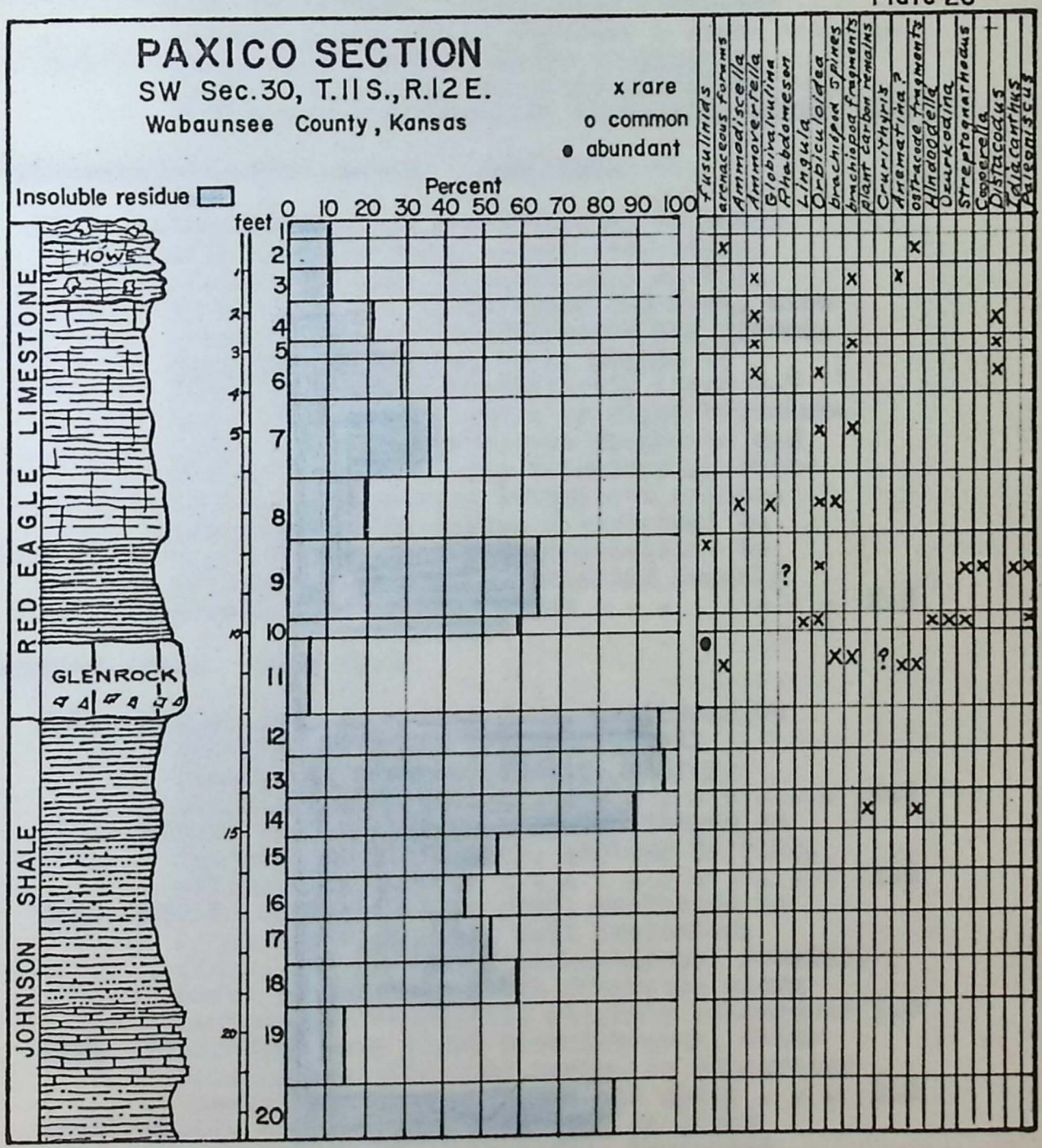
SW Sec.30, T.11S., R.12E.
North side of abandoned Highway 40 roadcut, in crest of hill,
Wabaunsee County, Kansas.



RED EAGLE LIMESTONE 12.1 feet.

		Thickness, feet
	Howe Limestone member 1.7 feet.	
(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 (2) 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
	Bennett Shale member 8.4 feet.	
(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) above 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, and microcrystalline, compact, rare trace of brown Orbiculoidea fragments, trace milky chert	1.5

Plate 26


PAXICO SECTION
SW Sec. 30, T. 11 S., R. 12 E.
Wabaunsee County, Kansas
x rare
o common
● abundant
Insoluble residue
Percent
0 10 20 30 40 50 60 70 80 90 100
feet
RED EAGLE LIMESTONE
HOWE
GLENROCK
JOHNSON SHALE
Fusulinids
arenaceous forams
Ammodiscella
Ammoveriella
Globivalvulina
Rhabdomesen
Lingula
Orbiculoidea
brachiopod spines
brachiopod fragments
plant carbon remains
Cruziythyris
Arenatina?
ostracode fragments
Almadaella
Deurkodina
Streptognathodus
Gondolella
Distacodus
Idiognathus
Neogondolella

(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, Orbiculoidea coquinas ¼ inch along some laminae, trace of Lingula, fragments randomly oriented but somewhat compressed parallel to bedding plane 0.5

Glenrock Limestone member 2.0 feet.

(11) LIMESTONE: medium brownish-gray to brown with some yellowish-rusty iron stain, weathered light brownish-gray at top, fusulinids common in upper 0.5 feet, also trace of brachiopod fragments and spines, Crurithyris at top, hard, ghosts of fossils: vague foraminifers?, lower 0.5 feet 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 microcrystalline to microgranular matrix, oriented vaguely parallel to bedding plane 2.0

JOHNSON SHALE 25.0 feet

(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 (12), 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 shell fragments along laminae (ostracodes?), slightly calcareous 1.0

(15) SILTSTONE: 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 (16). 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 wafer-like 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

KERNE SECTION
SE Sec.24, T.13S., R.12E.
In bank of stream north of small bridge on east-west road, Wabaunsee County, Kansas.

RED EAGLE LIMESTONE 1.2 feet.

	Thickness, feet
Glenrock Limestone member 1.2 feet	
(1) LIMESTONE: very light brownish-gray with some yellowish clayey iron oxides, hard compact, microcrystalline to aphanitic matrix for abundant fusulinids and common brachiopod fragments and smaller foraminifers, top exposed and weathered, but change to darker gray at top suggests similarities to Pawnee section, top "lumpy" with dark gray in the lows between the lumps	1.2
JOHNSON SHALE thickness not determined	
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 SHALES: greenish-gray, etc., calcareous, moderately to well laminated, badly slumped, mostly covered, seen in random patches in slopes ¼ mile north of samples (1) and (2) above.	

ESKRIDGE SECTION
SE NE Sec.17, T.14S., R.12E.
In south bank of small creek just west of Highway 99,
Wabaunsee County, Kansas.

RED EAGLE LIMESTONE 0.9 feet.

		Thickness, feet
	Glenrock Limestone member 0.9 feet.	
(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 a coquinoid fusulinid limestone (with trace of shaly material as in Bennett and Orbiculoidea fragments in a slightly argillaceous matrix)	0.9
	JOHNSON FORMATION 12.2 feet.	
	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, wafer-like, 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 (1-2mm.), trace of fucoids, vague faint ripple marks	0.6
(5)	LIMESTONE: medium gray weathered medium buff, argillaceous to silty, vague rare laminae, more of a massive unit	0.5
(6)	SHALE: medium to light brownish-gray, very finely silty, calcareous, trace of carbonaceous remains, rare up to ¼ inch, well laminated, flaky to wafer-like 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

ESKRIDGE SECTION

SE NE Sec. 17, T. 14 S., R 12 E.
Wabaunsee County, Kansas

x rare
o common
● abundant

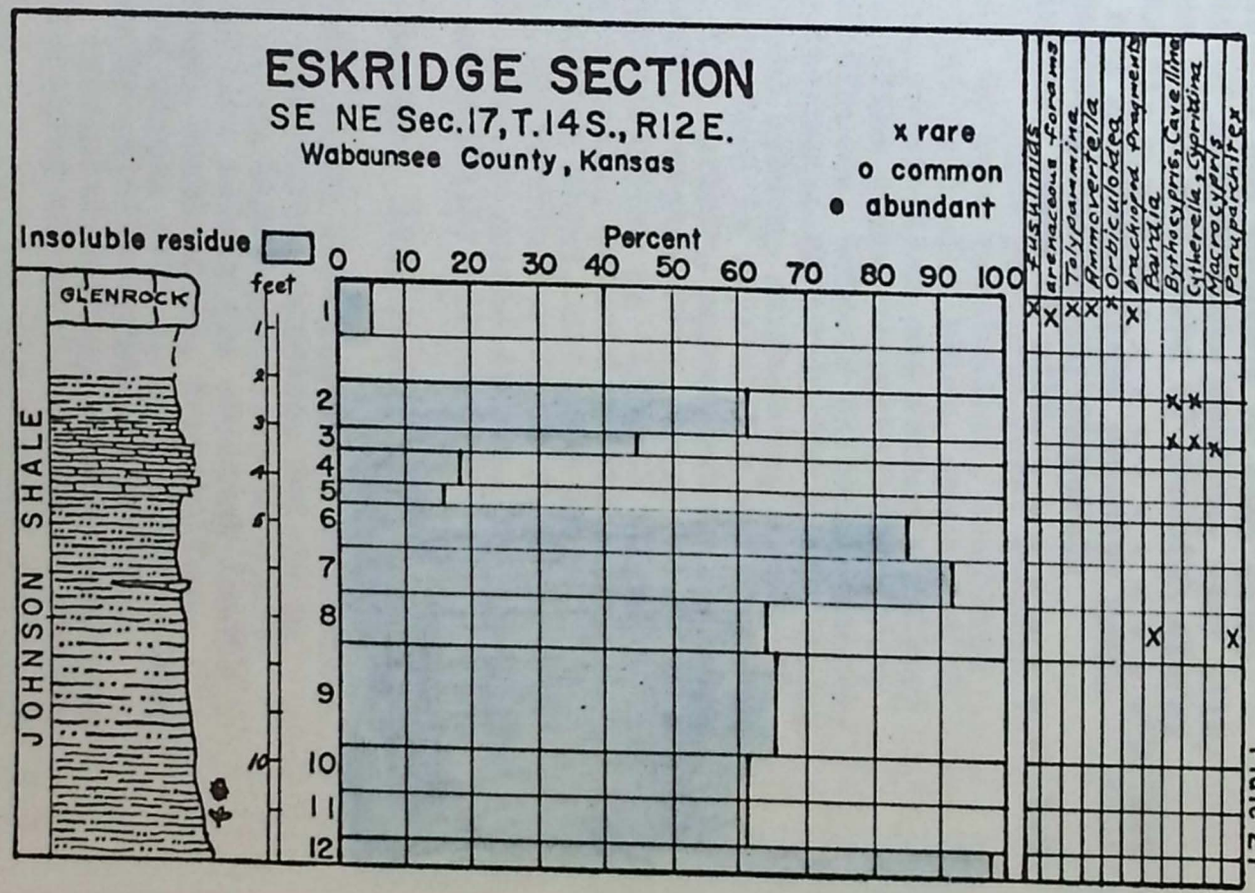


Plate 27

(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

ESKRIDGE QUARRY SECTION
NW Sec.32, T.14S., R.12E.
In large quarry 7/8 miles west of Kansas Highway 99. Large spoil heap can be seen for several miles. Wabaunsee County, Kansas.

RED EAGLE LIMESTONE 13.0 feet exposed

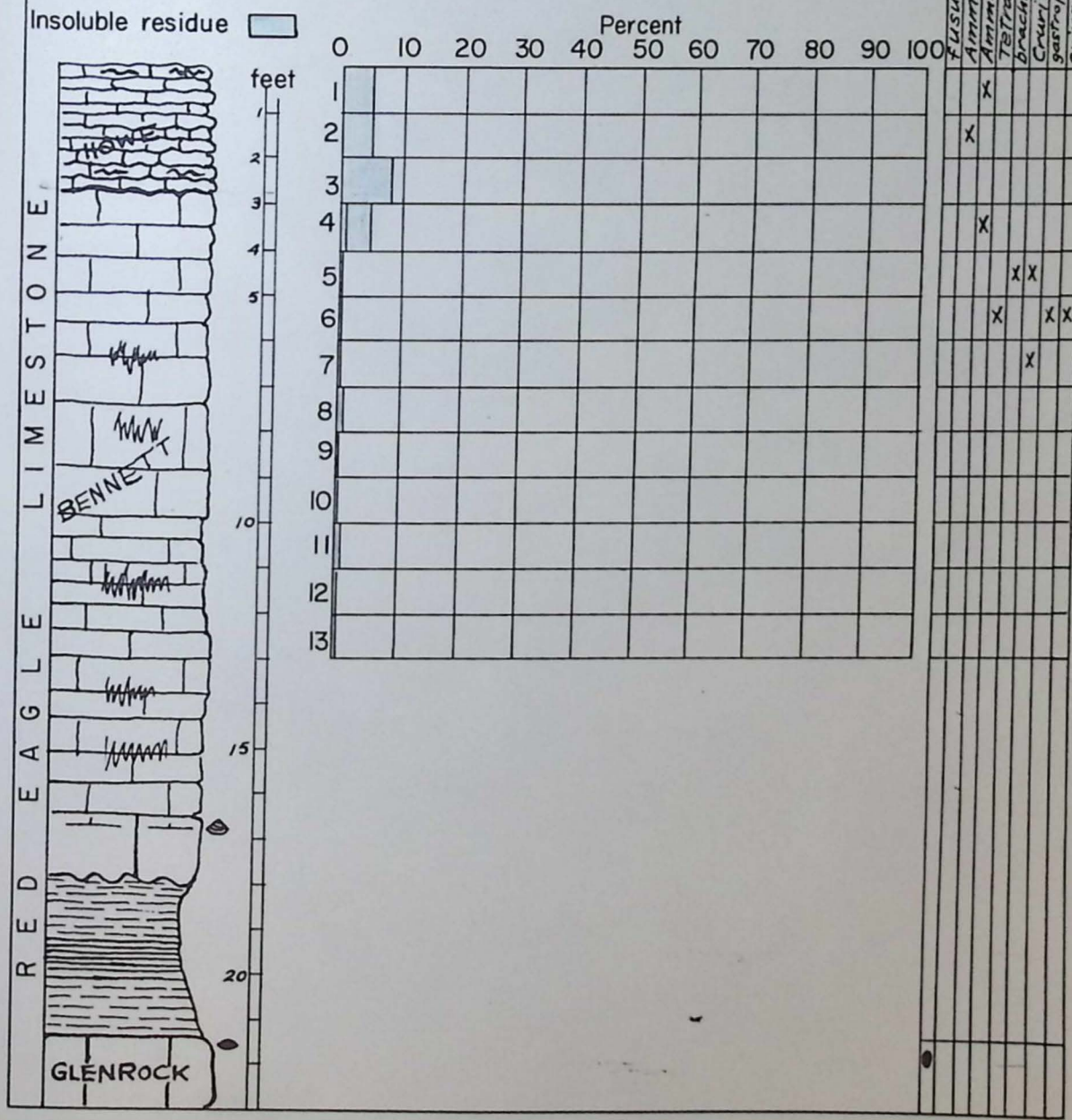
	Thickness, feet
Howe Limestone member 3.0 feet exposed	
(1) LIMESTONE: light greenish-gray, argillaceous to pure crystalline, weathered to light yellowish brown, aphanitic to medium crystalline and coarsely (clear) crystalline where recrystallized, very fossiliferous, crinoid columnals common, also fragments of productid brachiopods, echinoid spines, ostracodes, chambered foraminifers in crystalline and greenish-gray lime matrix, uneven rubbly bedding 3 inches, rough debris, trace of stylolites	1.0
(2) LIMESTONE: similar to (1) with slightly fewer fossils, crinoid debris common. . .	1.0
(3) LIMESTONE: as above, but more of an aphanitic matrix for fewer fossils, brachiopod fragments common, Cruirithyris? seen essentially undamaged.	1.0
Bennett Shale member 10.0 feet	
(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 seen Tolypammina?.	1.0
(6) LIMESTONE: as above, some vugular porous development in association with solution of fossils.	1.0

Plate 28

ESKRIDGE QUARRY SECTION

NW Sec.32, T.14S., R.12 East
Wabaunsee County, Kansas

x rare
o common
● abundant



(7) LIMESTONE: light brownish-gray, aphanitic to microgranular and microcrystalline 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 matris 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 bordering on calcite-lined geodes, trace of stylolites 1.0

(13) LIMESTONE: as above 1.0

Base below water.

ESKRIDGE SOUTH SECTION
NE Sec.6, T.15S., R.12E.
In northeast side of road leading into farmyard, Wabaunsee County, Kansas.

RED EAGLE LIMESTONE 0.8 feet.

		Thickness, feet
	Glenrock Limestone member 0.8 feet.	
(1)	LIMESTONE: light grayish-brown, aphanitic to microcrystalline matrix for abundant fusulinids with rare brachiopod fragments and other foraminifers, upper 0.05 feet argillaceous with patches of dark gray shaly material, clusters of fusulinids form coquinas at top, 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 15.0 feet.

	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 wafer-like . .	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
(5)	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 (5) 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 calcareous, possibly weathered from darker shales or mudstones	1.0

JUDITH SECTION
NW NW Sec.7, T.15S., R.12E.
In east gutter of road up hillside, Wabaunsee County, Kansas.

RED EAGLE LIMESTONE 20.4 feet.

Thickness, feet

Bennett Shale member 19.5 feet

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, poor 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 wafer-like, calcareous, rare trace of Orbiculoidea and Lingula? fragments, compact. 0.5

(7) SHALE: dark gray, fissile, wafer-like, 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-tough, slightly calcareous 1.0

Glenrock Limestone member 0.9 feet.

(8) LIMESTONE: light brownish-gray, microgranular to microcrystalline matrix for abundant fusulinids throughout, trace of foraminifers, brachiopods, ostracodes, massive, matrix weathered faint light yellowish-gray in places, top grades through ½ inch of medium to light brown shale, argillaceous limestone with abundant Orbiculoidea and rare brachiopods (Lingula?, Crurithyris?) and fish teeth. 0.9

COFFMAN RANCH SECTION
NE SW Sec.23, T.15S., R.11E.
In east bank of creek ½ mile southeast of bridge on north-south road, Lyon County, Kansas.

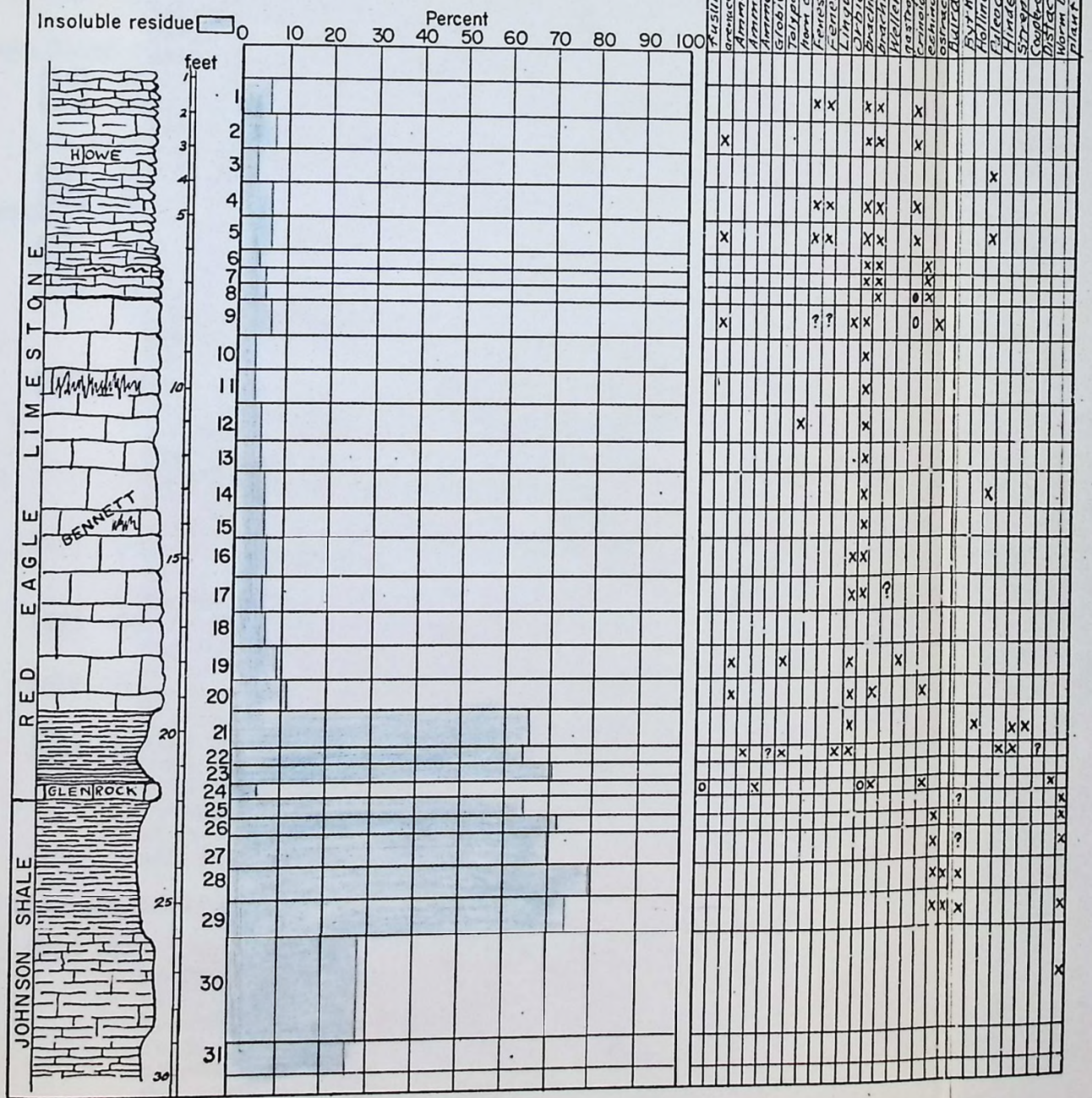
RED EAGLE LIMESTONE 14.9 feet exposed.

	Thickness, feet
Howe Limestone member 1.5 exposed.	
(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 bedding, hard, some fossils silicified.	0.5
(7) LIMESTONE: similar to (6), secondary calcite stringers, and aphanitic brachiopod fillings produce pseudo-brecciated appearance in some places.	0.5
(8) LIMESTONE: light brownish-gray, aphanitic to medium crystalline, similar to above, very fossiliferous, crinoid columnals abundant (articulate), fragments of branching structureless algal? material, fonestellate and ramose bryozoans, spines as above, weathered light gray, ...	0.5
Bennett Shale member 13.0 feet.	
(9) LIMESTONE: light brownish-gray with some faintly rusty yellow tint, 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, medium to thick bedded, hard, massive	1.0
(10) LIMESTONE: similar to (9), randomly vuggy, trace of white opaline replaced brachiopod shells, few megafossils	1.0
(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

COFFMAN RANCH SECTION

NE SW Sec.23, T.15S., R.11E.
Lyon County, Kansas

x rare
o common
● abundant



(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 articulating 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 1/3 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 feet 1.0

(22) SHALE: similar to above, some weathered to light brownish-gray, softer than below, moderately to well laminated, some micro-geodes, interlaminated with (9) through 1 inch at lower boundary. 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

Glenrock Limestone member 0.4 feet.

(24) LIMESTONE: medium brownish-gray, aphanitic matrix for profuse fusulinids (almost a fusulinid coquina in places), common small brachiopods, foraminifers, spines etc., evidence of worm tubes from Bennett above, composed of medium gray clayey material and containing Orbiculoidea fragments to the bottoms of the tubes, no tubes reach

the base of this limestone, massive, moderately hard. At the top, the lithology changes through 1/8 inch from fusulinid subcoquina to an Orbiculoidea subcoquina and thence upwards to dark gray, Orbiculoidea-bearing shales of the Bennett, the lower ½ inch os these contains rare fusulinids probably detrital, fossils here show crude orientation parallel to bedding plane, base gently undulatory through 1 inch 0.4

JOHNSON SHALE 7.5 feet exposed.

(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, common frail ostracodes 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 (30), light brownish-gray, very argillaceous, well laminated, not visibly fossiliferous 0.5

COFFMAN WEST SECTION
NW Sec.23, T.15S., R.11E.
1/4 mile southeast of bridge on county road, Lyon County, Kansas

RED EAGLE LIMESTONE 5.0 feet

		Thickness, feet
Howe Limestone member 5.0 feet		
(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 discsand brachiopod fragments and fenestrate bryozoans, nodular bedding plane, rubbly debris, medium to thin bedded, some silicified fossils	1.0
(2)	LIMESTONE: light brownish gray, aphanitic to microcrystalline with crystalline calcite fossil remains, crinoid discs, productid spines, foraminifers, hard, compact, a 0.5 to 1.0 massive unit with irregular boundaries	1.0
(3)	LIMESTONE: similar to (1) above with more greenish clay associated with stylolites, greenish clay interbedded material. . . .	1.0
(4)	LIMESTONE: similar to (1) above, less green clay.	1.0
(5)	LIMESTONE: light gray to greenish-gray and brownish-gray, aphanitic matrix for common fossils: crinoid columnals (intact), brachiopods, fenestrate and ramose bryozoans, foraminifers, some fossils especially brachiopods replaced by milky opaline silica, similar to above.	1.0

ALLEN SECTION
NW SW Sec.36, T.15S., R.11E.
In south cutbank of small stream east of bridge on north-south county road. Lyon County, Kansas.

RED EAGLE LIMESTONE 7.35 feet.

		Thickness, feet
Bennett Shale member 6.05 feet.		
(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 feet, 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, ostracodes and crinoid discs, trace of Orbiculoidea fragments, some fusulinids in chert (cf. Triticites rockensis).	1.0
(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

ALLEN SECTION

NW SW Sec.36,T.15S.,R.11E.

Lyon County, Kansas

x rare
o common
● abundant

Plate 30

Glenrock Limestone member 1.3 feet.

(10-11) LIMESTONE: light brownish-gray, microcrystalline matrix for abundant fossil detritus including fusulinids, foraminifers (cf. Tolypammina etc.), 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 feet (11), fusulinids rare to absent in lower part of unit. . . 1.3

JOHNSON SHALE 6.6 feet.

(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 (15) 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 (17), 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 (19) but harder and more resistant, vaguely laminated 1.0

ALLEN NO. 2 SECTION
SW NW Sec.35, T.15S., R.11E.
Beside bridge on north-south counth road, Lyon County, Kansas.

ROCA SHALE 2.2 feet.

		Thickness, feet
(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 (2)	1.0

RED EAGLE LIMESTONE: 11.7 feet.

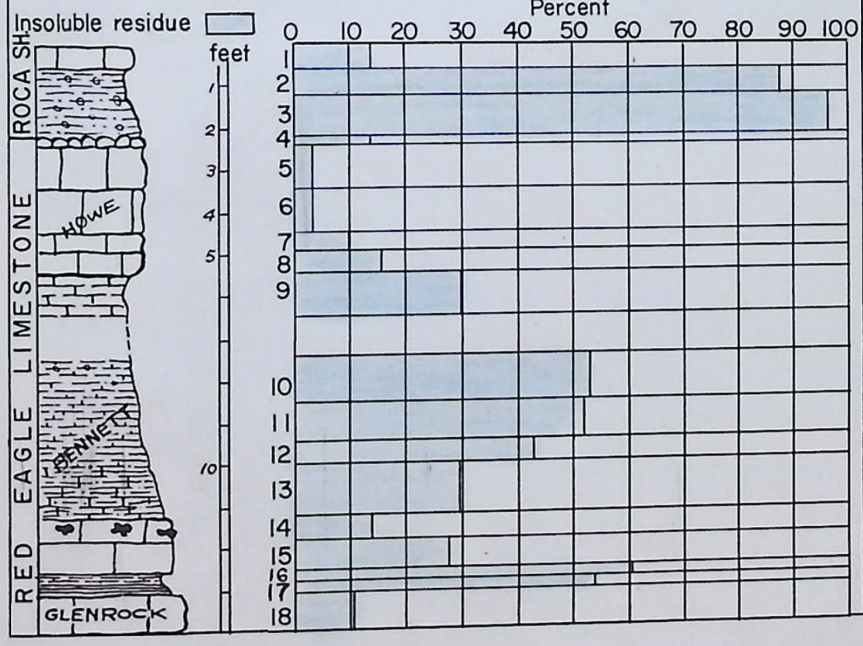
Howe Limestone member 3.2 feet.

(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 microcrystalline aphanitic tan $CaCO_3$, some leached oolite porosity, hard. . . .	1.0
(6)	LIMESTONE: transition between (5) and (7), 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 (7), richly fossiliferous, brachiopods, crinoid discs, spines, rare gastropods, rare fenestellate bryozoans, rare ostracodes, trace of milky opaline chert	0.5

ALLEN NO.2 SECTION

SW NW Sec.35,T.15S.,R11E.
Lyon County, Kansas

x rare
o common
● abundant



Bennett Shale member 7.6 feet.

(9) LIMESTONE: light gray, argillaceous, poorly laminated, varies to calcareous mudstone, trace of brachiopods, ostracodes, spines. 1.0

(10) 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 (13). 0.5

(13) LIMESTONE: medium to light gray, very 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, spines; massive, resistant, hard. 0.6

(15) LIMESTONE: light borwnish-gray, hard, similar to (14) but lacks chert, some milky opaline chert replacements of fossil fragments, aphanitic to microcrystalline matrix for profuse fossil detritus including brachiopod fragments, spines, small foraminifers, 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 grey, 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, disc-like foraminifers (Ammodiscus?), dark brown possible fishbones? 0.3

Glenrock Limestone member 0.9 feet.

(18) LIMESTONE: medium gray to brownish-gray, aphanitic to microcrystalline matrix for abundant fossils, fusulinids (Triticites?) and brachiopod fragments common; rare frail coiled or worm-like 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 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

DUNLAP SECTION
SE SE Sec.23, T.17S., R.9E.
In west bank of road cut just south of bridge, Morris County, Kansas.

ROCA SHALE 17.8 feet.

		Thickness, feet.
(1)	MUDSTONE and SHALE: light greenish-yellowish-gray, calcareous, moderately to poorly laminated	1.0
(2)	MUDSTONE: similar to (1), 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	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 (13), 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 to finely microcrystalline. 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, wafer-like debris, compact, rare trace of faint interference ripples, silty 1.0

(21) SHALE: similar to (20) but slightly harder and more resistant 1.0

(22) SHALE: light gray, some pale brick-red mottling, well laminated, softer than (21), silty, calcareous 1.0

Covered 3.5

RED EAGLE LIMESTONE 0.5 feet exposed

Howe Limestone member 0.5 feet exposed

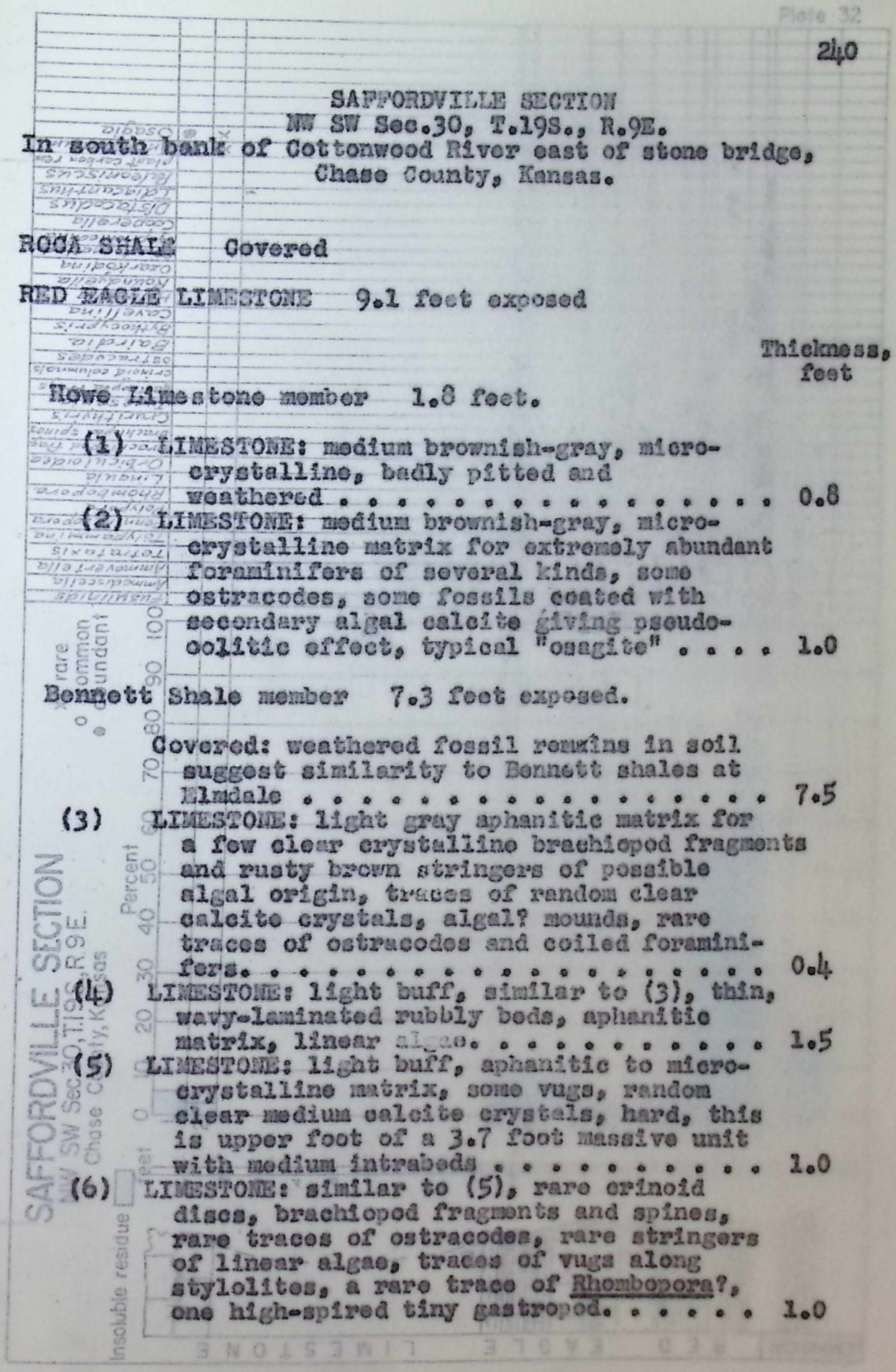
(23) LIMESTONE: medium grayish-brown, weathered light rusty yellowish-brown to light brown, pseudo oolitic: foraminiferal, common microcrystalline clear calcite matrix for oolites, foraminifers, ostracodes?, small brachiopods?, or clams? coated by algal $CaCO_3$ yield pseudo oolites. 0.5

SAFFORDVILLE SECTION
NW SW Sec.30, T.19S., R.9E.
In south bank of Cottonwood River east of stone bridge,
Chase County, Kansas.

ROCA SHALE Covered

RED EAGLE LIMESTONE 9.1 feet exposed

		Thickness, feet
	Howe Limestone member 1.8 feet.	
(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
	Bennett Shale member 7.3 feet exposed.	
	Covered: weathered fossil remains in soil suggest similarity to Bennett shales 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 (3), thin, 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 foot of a 3.7 foot massive unit with medium intrabeds	1.0
(6)	LIMESTONE: similar to (5), 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



SAFFORDVILLE SECTION

NW SW Sec.30, T.19S., R.9E.
Chase County, Kansas

x rare
o common
● abundant

Insoluble residue

Percent 0 10 20 30 40 50 60 70 80 90 100

feet

JOHNSON | RED EAGLE LIMESTONE

HOWE

BENNETT

Fusulinids
Ammodiscella
Ammovertella
Tetrataxis
Tolypammina
Pennireteopora
Polypora
Rhombopora
Lingula
Orbiculoidea
Brachiopod frag.
brachiopod spines
Crurithyris
Juresania
gastropod frags
crinoid columnals
ostracodes
Bairdia
Bythocypris
Cavellina
Hollinella
Roundyella
Ozarkodina
Streptognathodus
Synonniodina
Cooperella
Distacodus
Talacanthus
Paleoniscus
plant carbon rem.
Anchicodium
Osagia

Plate 32

(7) LIMESTONE: similar to (6), 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, 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 (11) containing abundant Orbiculoidea fragments (subcoquina) with fewer frail Lingula oriented parallel to laminae; traces of fish teeth and brachiopod spines 0.2

Covered 1.0

JOHNSON SHALE 1.0 feet.

(13) LIMESTONE: medium gray, aphanitic, hard, moderately laminated; rough platy debris; very delicate brachiopods, ostracodes common. 1.0

ELMDALE SECTION
Near C, Sec.26, T.19S., R.7E.
Road cut in hillside above bridge 1 mile east of Elmdale,
Chase County, Kansas.

ROCA SHALE 14.0 feet.

		Thickness, feet.
(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, noncalcareous, blocky debris.	1.0
(3a)	LIMESTONE: light gray and greenish-gray, very muddy.	0.2
(4)	MUDSTONE: medium gray to greenish-gray with maroon tint along micro-fractures, similar to (3), noncalcareous	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) above, poorly laminated	1.0
(7)	SHALE: medium to light gray, noncalcareous, 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

RED EAGLE LIMESTONE 12.1 feet.

- Howe Limestone member 2.5 feet.

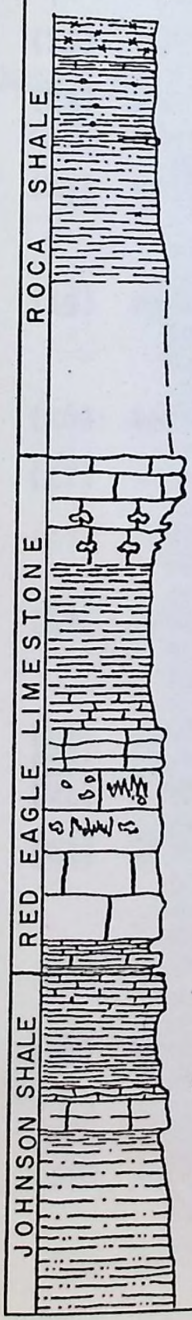
(9)	LIMESTONE: medium brownish-gray to light yellowish-gray, massive, pelletoid, pseudo-oolitic ("osagite"), some algae-coated brachiopods or clams? with encrusting foraminifers as below, matrix of clear calcite varying to clayey microcrystalline calcite.	0.3
(10)	LIMESTONE: medium to light brownish-gray, microcrystalline matrix for abundant arenaceous foraminifers, trace of "osagia", medium to thin bedding.	0.7

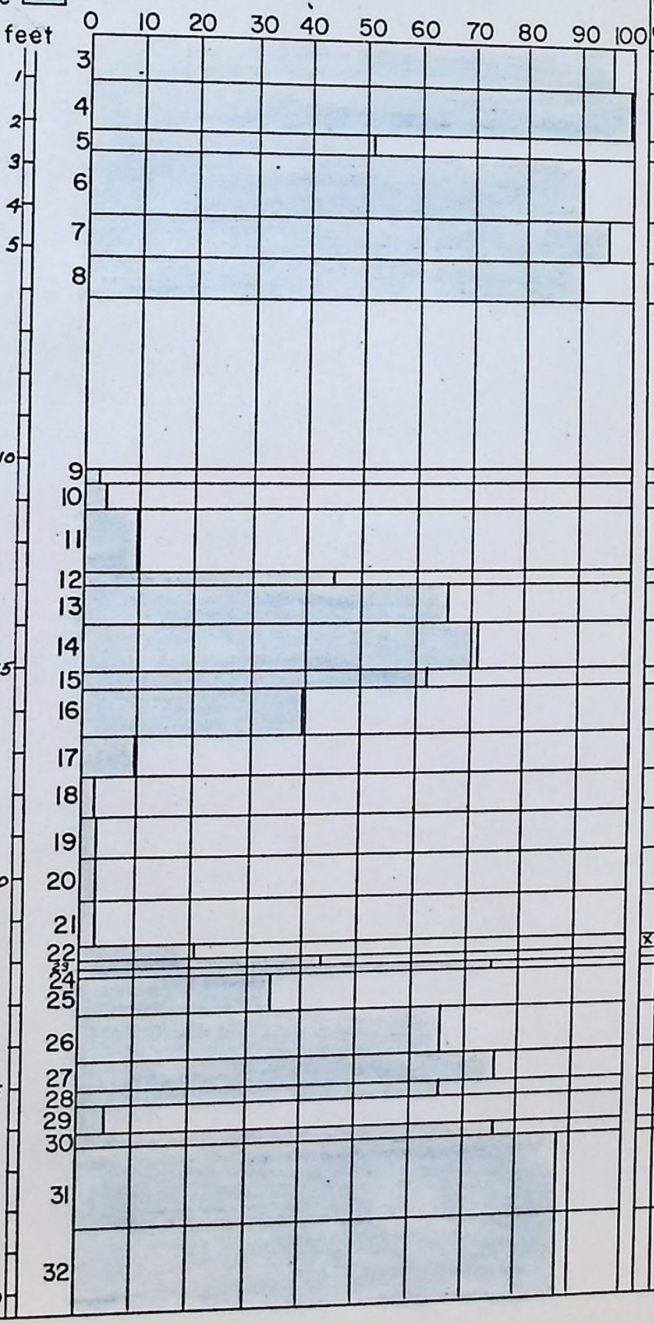
ELMDALE SECTION

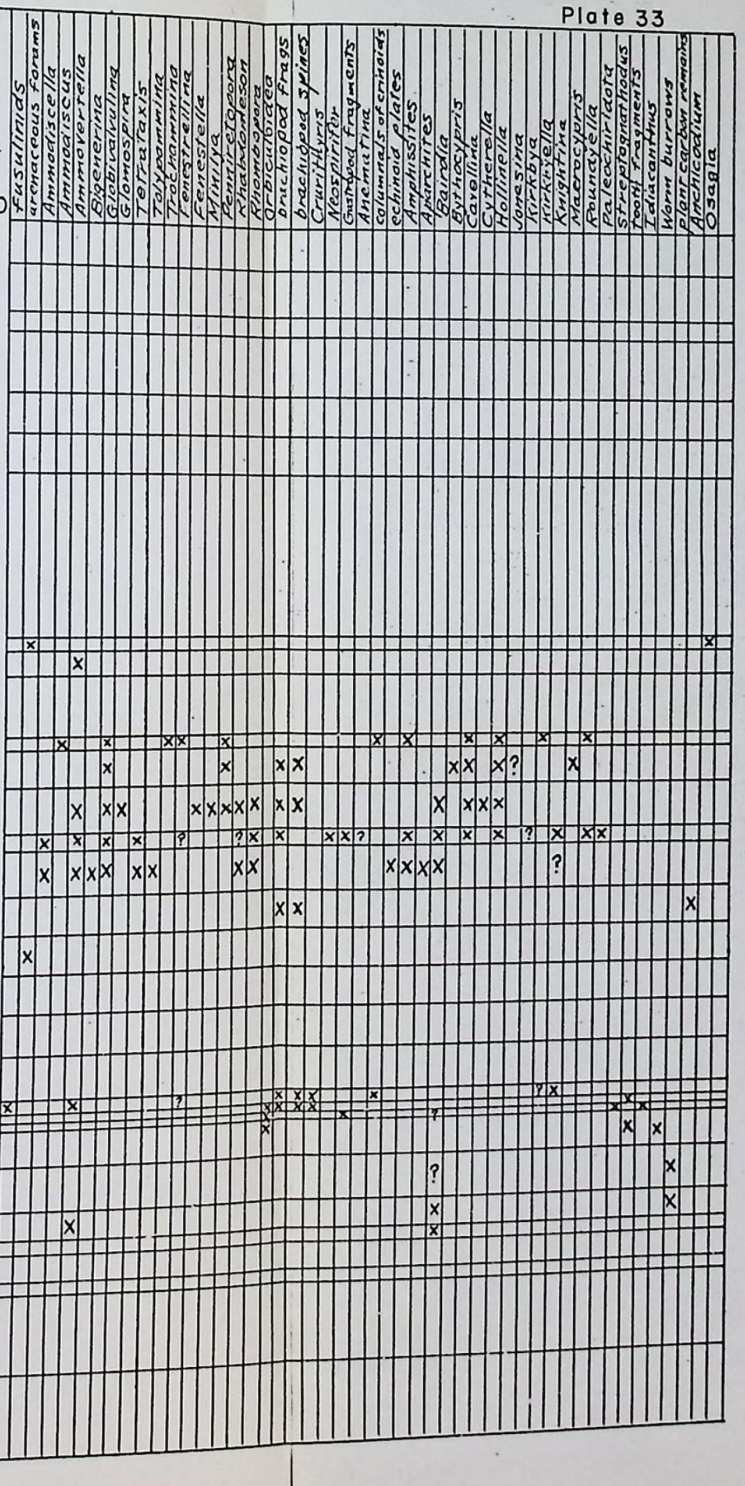
C Sec. 26, T. 19S., R. 7E.
Chase County, Kansas

x rare
o common
● abundant

Insoluble residue







(11) LIMESTONE: light rusty yellow, badly pitted and vuggy, decayed, clayey, fairly even-textured, microcrystalline matrix where intact 1.5

Bennett Shale member 9.6 feet.

(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 (15), calcareous, grades to (17). 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 (18), 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 0.3-0.4

(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. 0.3-0.4

(24) SHALE: dark gray to medium brownish-gray at top, calcareous, grades from fossiliferous limestone above downward into argillaceous limestone, fills worm burrows in (25), vague ripple marks, trace of Orbiculoidea, rare fish teeth; base is almost a coquina of Orbiculoidea. 0.1

JOHNSON SHALE 14.4 feet.

(25) LIMESTONE: light gray, faintly brownish, very argillaceous, vaguely laminated, worm burrows in upper 0.1 feet filled with Orbiculoidea-bearing black clay and black limestone from (24) above, tubes also contain fish teeth, grades to calcareous shale below, massive in upper portion, even-textured, top slightly undulatory below cap of black Orbiculoidea shale, trace of black phosphatic bone? remains 1.0

(26) SHALE: light brownish-gray, calcareous, moderately to well laminated, trace of 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 (33), 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 down to (37). 1.4

(37) MUDSTONE: medium to light yellow-gray, very calcareous, similar to (36) 1.0

Covered 8.6

TURNPIKE SECTION (MILE 118.1)
Sec.17, T.20S., R.10E.
Lyon County, Kansas

RED EAGLE LIMESTONE 10.9 feet.

		Thickness, feet
Howe Limestone member 0.5 feet exposed.		
(7)	LIMESTONE: very light brownish-gray, microcrystalline matrix for abundant foraminifers, hard.	0.5
Bennett Shale member 8.6 feet.		
	Covered	5.5
(6)	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
(5)	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

JOHNSON SHALE 1.8 feet exposed

(3)	SHALE: medium to light yellowish buff, well laminated, calcareous, rare fossils . . .	0.5
(2)	LIMESTONE: argillaceous, and SHALE: calcareous; medium to light grayish-brown, moderately to well laminae, wavy laminae, profuse delicate ostracodes, brachiopod fragments, rare trace of black carbonaceous plant remains	0.3
(1)	SHALE: medium brownish-gray with pale yellow to greenish cast, brown carbonaceous remains, Ammodiscus, Tetrataxis, Bairdia, Bythocypris, Cavellina, holothurian "wheels", Crurithyris? Distacodus.	1.0

SALLYARDS SECTION
SW NW Sec.11, T.26S., R.8E.
At turn of the road 1 mile south of Sallyards, Greenwood County, Kansas.

RED EAGLE LIMESTONE 2 feet exposed.

		Thickness, feet
Bennett Shale member 2 feet exposed.		
(1)	LIMESTONE: medium gray, aphanitic to microcrystalline 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

PIEDMONT SECTION
NE SW Sec.30, T.27S., R.8E.
5 miles west and 3½ miles north of Piedmont, Greenwood County, Kansas.

RED EAGLE LIMESTONE 25.6 feet. Exposed

		Thickness, feet
Bennett member	24.1 feet	
(1-2)	LIMESTONE: light gray to brownish-gray, some yellowish-rusty clay in vugs and leached fossils, aphanitic to microcrystalline 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 (3), microcrystalline matrix for rare brachiopod fragments, spines, ostracodes, foraminifers?, very rare fusulinids	1.0
(5)	LIMESTONE: similar to (4), rare small vugs, "tighter" than above, some pitting at surface.	1.0
(6)	LIMESTONE: similar to (5) with extremely rare traces of Orbiculoidea fragments, (5) and (6) are medium bedded	1.0
(7)	LIMESTONE: similar to (6) with common fusulinids, lacks Orbiculoidea fragments.	1.0
(8)	LIMESTONE: similar to (7), trace of chert nodules	1.0
(9)	LIMESTONE: similar to (8), crinoid discs, dark gray chert nodules containing fusulinids etc.	1.0
(10)	LIMESTONE: similar to (9), crinoid discs, brachiopod fragments, rare ostracodes, common fusulinids, (8) to (11) are a 4 foot massive unit with medium to thick intrabeds	1.0
(11)	LIMESTONE: similar to (10), medium to thick beds with undulatory (relief 2 inches) bedding planes.	1.0

(12) LIMESTONE: medium to light gray and brownish-gray, similar to (11), 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 (12) 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 up to (15), medium gray, argillaceous, extremely rare trace of pyrite, abundant fusulinids 0.5

Covered 10.5

Glenrock Limestone member 1.5 feet.

(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 portion contains very abundant fusulinids. 1.5

GRAND SUMMIT SECTION
SE Sec.3, T.31S., R.8E.
Along railroad cut 4 miles west and 2 miles north of Grenola,
Elk County, Kansas

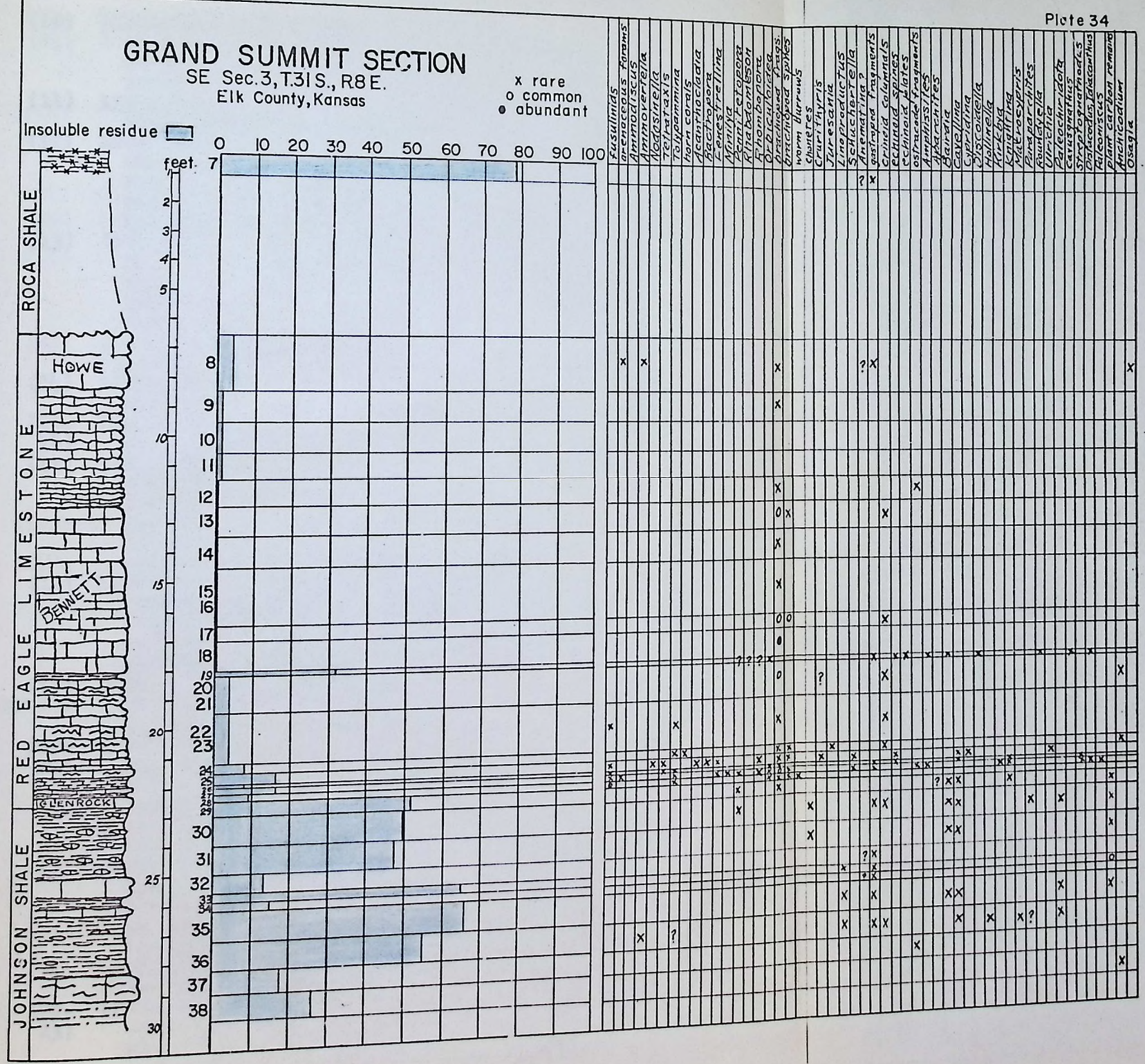
GRENOLA LIMESTONE

	Thickness, feet
Sallyards Limestone member	
Limestone with Aviculopecten etc.	
ROCA SHALE 14.5 feet	
(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 inches thick, trace of fenestrate bryozoans.	0.5
(2) MUDSTONE: very light to light brownish-gray, marly, some small lime nocules. . .	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
RED EAGLE LIMESTONE 16.1 feet.	
Howe Limestone member 2.0 feet	
(8) LIMESTONE: light yellowish-gray, typical osagite, foraminiferal?, some ostracodes, small gastropods and brachiopods, deeply pitted, yellowish weathering.	2.0
Bennett member	
(9) LIMESTONE: buff, microcrystalline matrix for medium crystalline rare fossil remains such as brachiopod fragments, hard, medium bedded, massive, ...	1.0

GRAND SUMMIT SECTION

SE Sec. 3, T. 31 S., R 8 E.
Elk County, Kansas

x rare
o common
● abundant



(10) LIMESTONE: light brownish-gray, some yellowish limonitic clay tint, medium to thin bedded within massive thicker unit. 1.0

(11) LIMESTONE: similar to (10), 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 (11) 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 (13) 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 fossil 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 portion of a thick 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 portions are free of fossils, much fine to medium crystalline clear calcite shell remains or leached fossil fillings, wavy algal material similar to those seen at Saffordville section, hard. 1.4

(22-23) LIMESTONE: upper part of a 2 foot 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 (see:pool), very rare

fusulinids seen, trace of crinoids. . . . 2.0

(24) LIMESTONE: medium to light brownish-gray, microcrystalline matrix for rare brachiopod frements 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

Glenrock Limestone member 0.25 feet

(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, containing some small Orbiculoidea fragments 0.25

JOHNSON SHALE 7.5 feet

(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

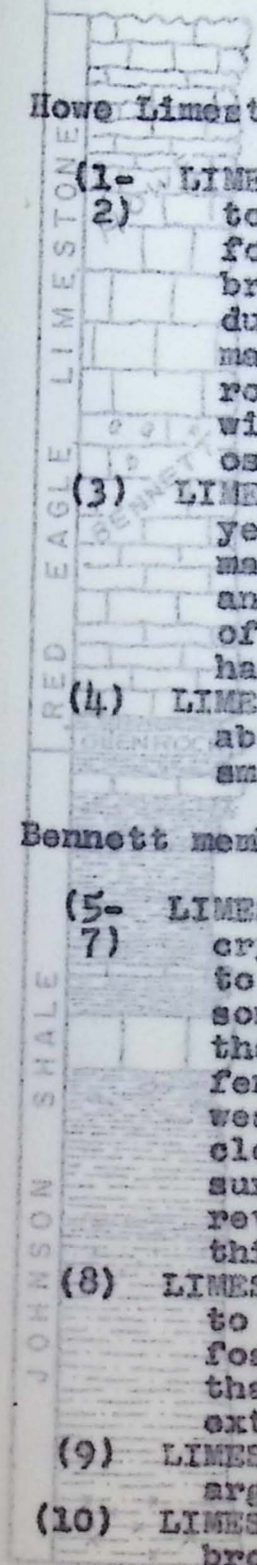
(31) SHALE: similar to above 1.0

(32) LIMESTONE: medium gray, nodular, up to 0.5 feet thick, aphanitic, very rare high-spired gastropods cf. Leptotygma or Anematina?, weathered light buff, hard. . 0.5

(33) SHALE: medium gray, weathered light to medium buff, well laminated, trace of brachiopod fragments of. 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 limestones, with trace of gastropods. 1.0
(36) SHALES: similar to (35) 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 limestones in small 1 inch waves. 0.8
(38) MUDSTONE: light brownish-gray, calcareous . 1.0

HIGHWAY 38 SECTION
Southline Sec.21, T.32S., R.8E.
In Kansas Highway 38 road cut, Cowley County, Kansas.

RED EAGLE LIMESTONE 17.7 feet

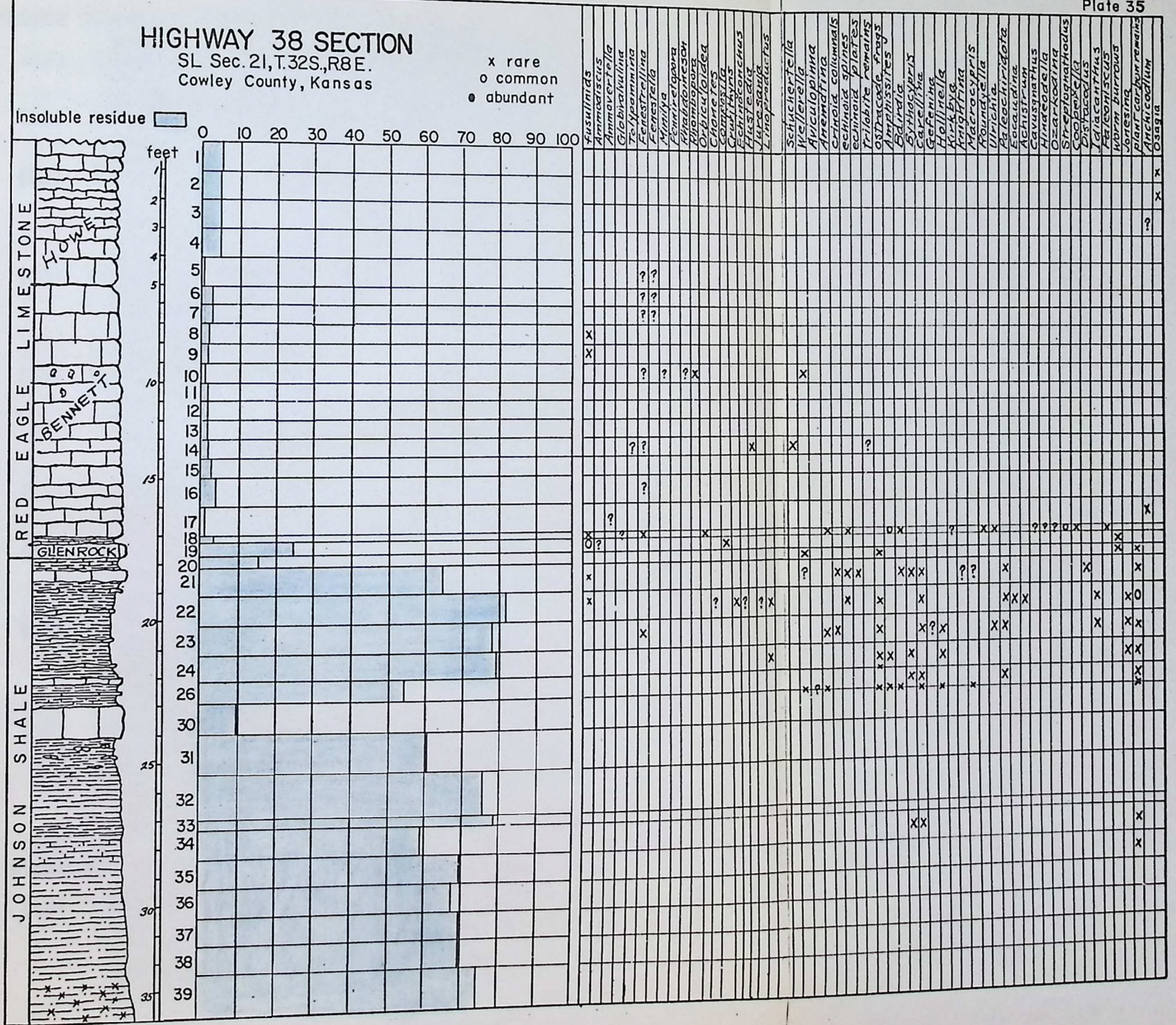


	Thickness, feet
Howe Limestone member 4.0 feet	
(1-2) LIMESTONE: light yellow-brown, aphanitic to microcrystalline matrix for rare fossil fragments such as ostracodes, brachiopod fragments and spines, color due to finely divided limonitic material throughout, pitted and rounded top, medium to thin bedded within thicker major beds, slightly asagitic.	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 (3), bedding as above, trace of ramose bryozoans and small brachiopods	1.0
Bennett member 13.2 feet	
(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 (8), slightly more argillaceous.	1.0
(10) LIMESTONE: medium grayish-brown to light brownish-gray, pitted to vuggy with	

HIGHWAY 38 SECTION

SL Sec. 21, T. 32S., R8E.
Cowley County, Kansas

x rare
o common
● abundant



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 (10), 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 etc., interbedded are argillaceous limestones with fossil fragments, linear algae?. 1.0

(14) LIMESTONE: light gray with medium to dark gray wavy clay seams cf. Bennett shales as interbeds, aphanitic to microcrystalline matrix for profuse fossils similar to above, 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 (16) 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

Glenrock Limestone member 0.5 feet

(19) LIMESTONE: medium gray, very argillaceous, soft, contains abundant fusulinids, some crinoid discs and brachiopod fragments, Composita seen, rare wormy tubes of black clay, up to 0.5 feet thick, uneven. . . . 0.5

JOHNSON SHALE 22.15 feet

(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 feet 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 in (21), 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 laminae 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 grey with rare plant remains and tiny ostracodes, calcareous; limestone is aphanitic, light gray. 1.0

(23a) LIMESTONE: nodular, as above. 1.0

(24) SHALE: medium gray, well to moderately laminated, calcareous, frail ostracodes, rare trace of very finely divided plant remains, Linoproductus? 0.8

(25) 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

(27) LIMESTONE: medium to light gray, very even thickness, some crude intralaminations, aphanitic, even-textured, hard, ... 0.1

(28) 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

(29) SHALE: light brownish-gray, calcareous, common carbonaceous plant remains, trace of Wellerella, rare trace of brown phosphatic remains, grades up to (28) . . 0.1

(30) LIMESTONE: light brownish-gray, aphanitic, some random blebs of fine to medium crystalline calcite, argillaceous 0.7

(31) SHALE and MUDSTONE: with some off-white limy marly nodules, light yellowish-gray, weathered from pale light greenish-gray, calcareous. 1.5

(32) SHALE: light to medium yellowish-gray, very well laminated, calcareous, some off-white marly interlaminations. 1.5

(33) SHALE: similar to (32) with slightly more laminations, calcareous, clayey 0.5

(34) MUDSTONE: light brownish-gray, calcareous, vaguely laminated, some carbonaceous plant remains common along the laminae, rare trace of ostracodes 1.0

(35) 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

(36) MUDSTONE: similar to (35) with some greenish-gray lime and shale grains and sands well rounded to angular 1.0

(37) MUDSTONE: similar to (36) with some angular mud granules. 1.0

(38) MUDSTONE: light brownish-gray, very calcareous, marly, somewhat similar above but rare sand grains 1.0

(39) MUDSTONE: maroon, calcareous. 1.0

(40) MUDSTONE: maroon-gray, calcareous, vaguely laminated, some granules of greenish-gray shale. 1.0

(41) MUDSTONE: light greenish-gray, calcareous with granules of brown limestone as below 0.5

(42) MUDSTONE: similar to (41) with brown aphanitic microcrystalline medium to dark brown limestone in nodules and crude networks, this limestone is what appears in granules above 0.7

(43) LIMESTONE: similar to meterial 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

(44) SHALE: light greenish-gray to olive greenish-gray, vaguely laminated, some random buff aphanitic lime nodules. 0.5

(45) SHALE: light gray, calcareous, vaguely laminated, somewhat chalky, trace of brachiopods and ramose bryozoans. 0.5

Covered 1.9

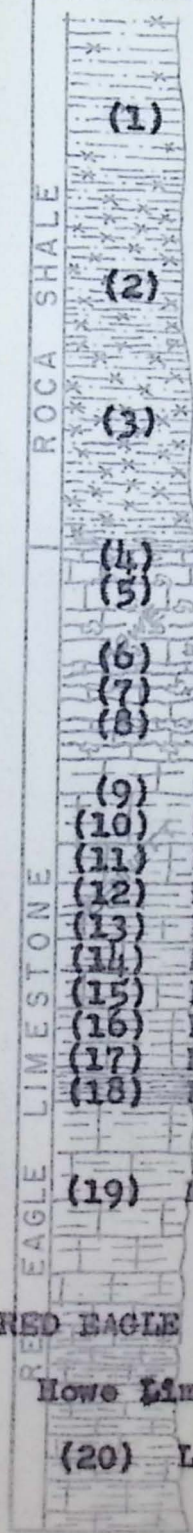
RED EAGLE SECTION
SW SE Sec.25, T.28N., R.6E.
In south wall of road cut on east-west road 2 miles west of Foraker, Osage County, Oklahoma.

RED EAGLE LIMESTONE 5.0 feet

		Thickness, feet
Bennett member 5.0 feet		
(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 (2) but few vugs, aphanitic to microcrystalline matrix for finely crystalline clear calcitic brachiopod fragments.	1.0
(4)	LIMESTONE: similar to (2)	1.0
	Covered	

BURBANK SECTION
Near center Sec.25, T.26N., R.5E.
In quarry just north of Highway 66, ½ mile east of Burbank,
Osage County, Oklahoma.

ROCA SHALE 17.5 feet



		Thickness, feet
(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. Anomatina	1.0
(3)	MUDSTONE: light brownish-gray, contains round granules of crystalline limestone, also 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 (9).	1.0
(11)	MUDSTONE: light brick red	1.0
(12)	MUDSTONE: similar to (11)	1.0
(13)	MUDSTONE: brick red	1.0
(14)	MUDSTONE: medium to light brick red	1.0
(15)	MUDSTONE: similar to (14)	1.0
(16)	MUDSTONE: medium to dark brick red.	1.0
(17)	MUDSTONE: similar to (16)	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

RED EAGLE LIMESTONE 21.0 feet exposed

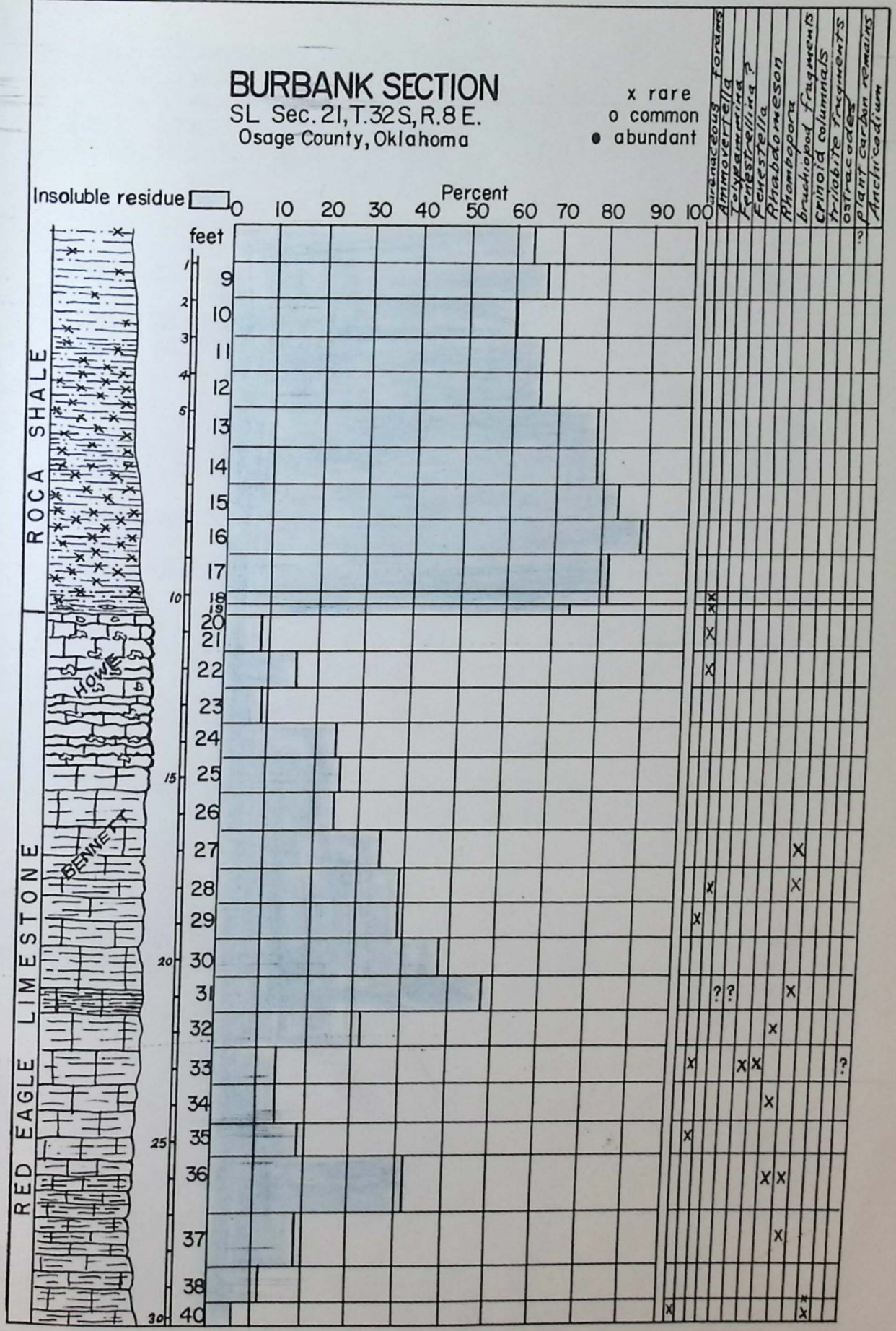
Howe Limestone member 4.0 feet

(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

BURBANK SECTION

SL Sec. 21, T. 32 S., R. 8 E.
Osage County, Oklahoma

x rare
o common
● abundant



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 shales above, aphanitic to finely crystalline, trace of crinoid discs, weathers to light rusty yellow. 0.5

(22) LIMESTONE: similar to (21) with 50 percent brick red argillaceous limestone stringers 1.0

(23) LIMESTONE: similar to (22). 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

Bennett member 17.0 feet

(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 (25), some small dark brick red wormy stringers, trace of coated shell fragments (Osagia?). 1.0

(27) LIMESTONE: similar to (26), 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 (28) but harder . . . 1.0

(30) LIMESTONE: similar to (28). 1.0

(31) LIMESTONE: light to medium greenish-gray, fine grained to aphanitic to microcrystalline matrix for common crinoid remains, rare brachiopod fragments and very rare fenestellate bryozoans; crude orientation parallel to bedding planes, hard. 1.0

(32) LIMESTONE: similar to (31). 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 grades in and out laterally: possibly linear algae, trace of fenestellate bryozoans 1.0

(34) LIMESTONE: light brownish-gray, hard, resistant, microcrystalline to aphanitic matrix for brachiopod fragments, more argillaceous interbeds. 1.0

(35) LIMESTONE: medium to light brownish-gray, similar to (34) but slightly more argillaceous as in (31) 1.0

(36) LIMESTONE: similar to (35), medium brownish-gray, microcrystalline to 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 (36). 1.5

(38) LIMESTONE: medium brownish-gray, somewhat shaly, crudely laminated, similar to above, aphanitic to microcrystalline. . . 1.0

(39) LIMESTONE: similar to (38), some thin wavy dark gray calcareous shale interbeds containing productid spines, rare ostracodes, brachiopod fragments. 1.0

(40) LIMESTONE: similar to (39). 1.0

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