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DIVISIONS OF THE PENNSYLVANIAN SYSTEM IN KANSAS

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By Raymond C. Moore

ABSTRACT

This report summarizes studies in the northern midcontinent region bearing on classification of rocks belonging to the Pennsylvanian System in Kansas. It does not review historical features in the development of classification, treated in 1936 (Kansas Geological Survey Bulletin 22), but takes account of work done since that date. In particular, it gives explanation of time-stratigraphic divisions of the Pennsylvanian rocks and embodies changes in the definition and naming of groups and subgroups which were adopted by agreement of the State geological surveys of Iowa, Kansas, Missouri, Nebraska, and Oklahoma at a conference held in May 1947. Except for definition of member subdivisions of formations belonging to the Marmaton group and a few revisions of formation and member names in the Shawnee and Wabaunsee groups, no changes in designation of lithologic units of the Kansas Pennsylvanian succession have been made during the last dozen years.

The Pennsylvanian rocks (including subsurface deposits which are not exposed in Kansas) are divided into five series (in upward order): Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian. The boundaries between these divisions are drawn at disconformities which are judged to denote important interruptions in sedimentation. Each of the designated series is characterized by paleontological distinctions, also. Deposits of Morrowan age (Kearny formation) and Atokan age (unnamed) are recognized in the subsurface of western Kansas but do not crop out. The Desmoinesian Series is well exposed in southeastern Kansas and widely distributed beneath the surface in the State. It comprises rocks of the Cherokee group, below, and Marmaton group, above. Paleontologically, the Desmoinesian rocks belong to the Zone of *Fusulina*. The Missourian Series contains important limestone formations and is divided, in upward order, into the Pleasanton, Kansas City, Lansing, and Pedee groups. It comprises the lower half of the Zone of *Triticites*. Rocks of Virgilian age are widely and excellently exposed in eastern Kansas. This uppermost main division of the Pennsylvanian rocks contains the Douglas, Shawnee, and Wabaunsee groups and comprises the upper part of the Zone of *Triticites*.

The interstate agreement on classification of Pennsylvanian rocks agreed to the name Pleasanton group for clastic deposits (formerly called Bourbon group by the Kansas Geological Survey). In the lower part of the Missourian Series, the conference adopted definition of the Kansas City group as extending from the top of Pleasanton beds to the base of the Plattsburg limestone. The rocks of this group were divided into three subgroups: Bronson

(base of Hertha limestone to top of Winterset limestone), Linn (base of Cherryvale shale to top of Iola limestone), and Zarah (base of Lane shale to top of Bonner Springs shale). In the Wabaunsee group, the conference recognized differentiation of subgroups, in upward order: Sacfox, Nemaha, and Richardson.

INTRODUCTION

Purpose of Report

It is the aim of this paper to record pertinent features of classification and nomenclature of rocks belonging to the Pennsylvanian System in Kansas. This subject was reviewed by me in detail (MOORE, 1936) in a report of the Geological Survey which traced the evolution of each stratigraphic division, including many names which have been abandoned, as well as those now generally employed. Three reasons may be cited for preparation of a new report defining the division of Pennsylvanian rocks which are recognized in Kansas and describing them briefly. (1) Demand for the 1936 report on Kansas Pennsylvanian rocks has been such that it has long been out of print; an up-to-date discussion of the subject is needed, not exactly as replacement of the older report, for the new one is not simply a new edition, but as supplement to it which will satisfy needs of almost anyone interested in the subject. (2) In May 1947, an interstate conference on Pennsylvanian classification in the northern midcontinent resulted in agreement by the geological surveys of Iowa, Kansas, Missouri, Nebraska, and Oklahoma on definitions of major and minor rock divisions belonging to this system which are recognized to extend from one of these States into another. The classification thus adopted involves some changes of official usage of the Kansas Geological Survey, and it is desirable to publish a statement of all such changes, with explanation. (3) The years 1936 to 1949 have brought a number of additions and a few revisions of names applied to minor rock units of the Pennsylvanian sequence in Kansas. These have already been incorporated in survey publications, but they have not been treated in a systematic report on Pennsylvanian rock units.

Nature and Distribution of Pennsylvanian Rocks in Kansas

Deposits belonging to the Pennsylvanian System which occur in Kansas are predominantly characterized by features of sedimentation on stable platform areas of the continent, as contrasted with sedimentation in the strongly subsiding troughs called geosynclines. Rock formations of the comparatively even-surfaced platform region are mostly thin but they have remarkable lateral uniformity throughout large areas. Marine deposits laid down in very shallow seas are very important components of the Kansas geologic section. ·Geosynclinal deposits, such as are well-developed in the southern Oklahoma region and in west-central Arkansas, are distinguished by thickness of formations measured in hundreds or thousands of feet and by general prominence of sandstone and shale deposits. Individual rock units are not traceable commonly for long distances because they have lenticular form or they grade laterally into different sorts of deposits. Marine strata occur in the geosynclines, but they are less prominent than nonmarine beds.

The Kansas Pennsylvanian rocks may be compared to a small stack of many-colored sheets of paper ranging in weights from thinnest onion-skin to cardboard. Each sheet of some specified color represents a certain kind of rock, such as black platy shale, light-gray calcareous shale, coal, a particular sort of limestone, and so on. The extreme relative thinness of the sheets as compared to their lateral dimensions suggests the small vertical measurements (ranging from less than 1 foot to not more than 25 feet generally) of Pennsylvanian rock units which can be traced 100 to 400 miles along the outcrop and similar distances at right angles to the outcrop underground. Of course, there are irregularities. Some layers vanish here and there, and they may show local pinching or swelling in the area where they persist. These are features which we should expect to find. The outstanding character of the Pennsylvanian rocks north of Oklahoma, nevertheless, is stratigraphic regularity and this makes possible application of the same classification and nomenclature of divisions (with very minor variations) throughout the States of Kansas, Missouri, Iowa, and Nebraska.

Pennsylvanian formations form the bed rock of eastern Kansas next below the soil, alluvium of stream valleys, glacial deposits (in northeastern Kansas), unconsolidated, wind-blown materials (loess), and the like (Fig. 1). In this area are many exposures of the Pennsylvanian bed rock, as in the walls of stream valleys, highway and railway cuts, and quarries. Collectively, the region

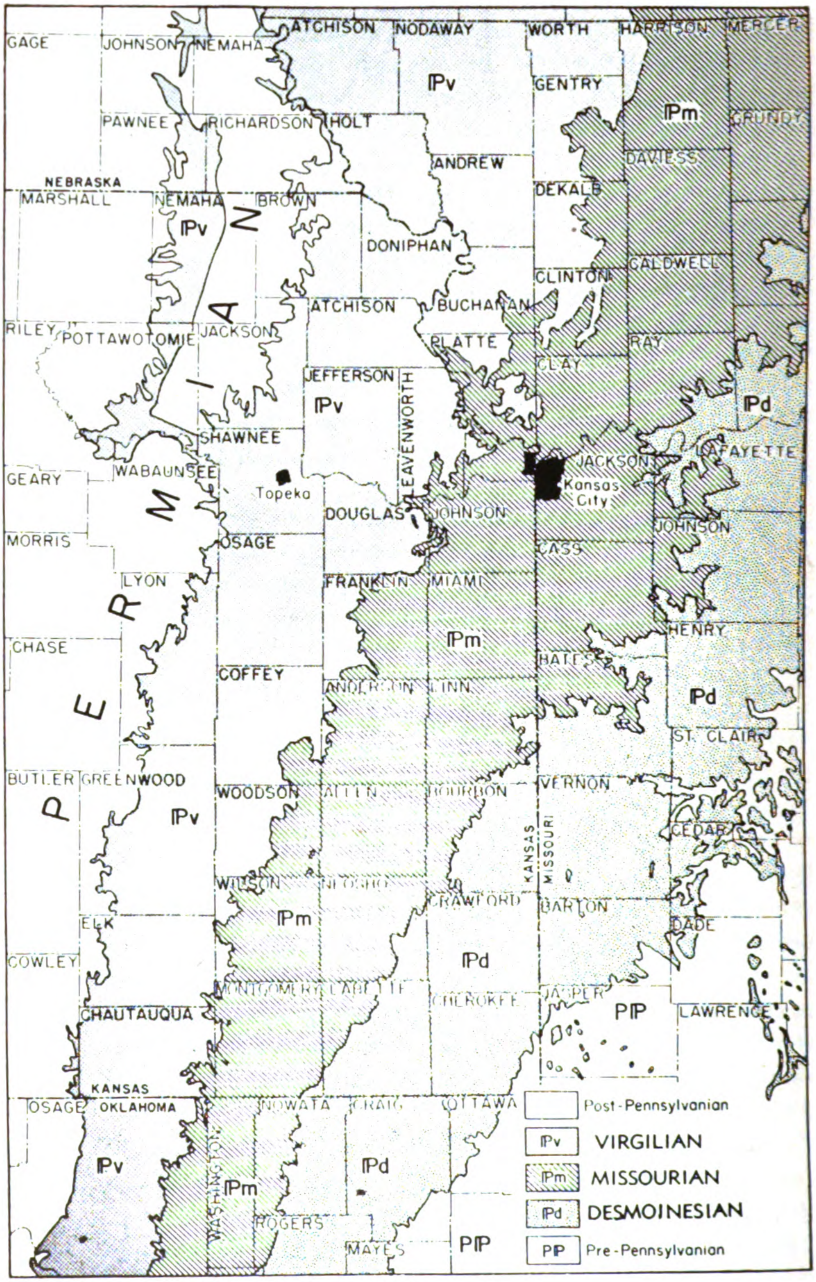

Figure 1. Outcrop of Pennsylvanian rocks in Kansas, and parts of adjoining states. The map shows main divisions termed Desmoinesian, Missourian, and Virgilian.

in which the Pennsylvanian strata are actually exposed and in which they are concealed only by the unconsolidated mantle of soil and other surficial materials, is called the outcrop area of these rocks. It includes approximately the eastern one-third of Kansas, reaching westward to the vicinity of the Flint Hills belt, which extends across the State from Nemaha County on the Nebraska line to eastern Cowley County on the Oklahoma line. All of the territory in Kansas east of the Flint Hills belongs to the Pennsylvanian outcrop area, except a few square miles in the southeastern corner of the State, where Mississippian rocks occur next below the surface.

The trend of outcrops (strike) of individual Pennsylvanian units in Kansas is mostly south-southwest. The rocks dip gently westward at an average rate of approximately 25 feet to the mile, and deposits belonging to this system underlie all of central and western Kansas. In this area where the Pennsylvanian is buried by younger formations, the thickness of the latter (and hence the depth to the top of Pennsylvanian deposits) ranges from a featheredge to nearly 4,000 feet. Average thickness of Pennsylvanian rocks at the outcrop in Kansas is approximately 2,500 feet.

The hard Pennsylvanian rocks, mostly limestone and sandstone, cap uplands and form escarpments or benches, some of which are prominent and can be traced for many miles. The general front of escarpments faces eastward. The weak Pennsylvanian rocks, chiefly shales, form gently rolling plains or lowlands, and commonly they occur in the lower slopes of escarpments beneath the protecting cap of hard strata which make the top of the escarpments.

The limestone and shale divisions of the Pennsylvanian System, together with less important sandstone and coal beds, are arranged in alternating succession. The limestone and part of the shales are marine; some of the shales, the coal beds, and most of the sandstones are nonmarine. These rocks occur in constant sequences which permit recognition of cyclic sedimentation. The cycles represent repeated inundations of the Kansas region by the Pennsylvanian shallow seas, some submergences being more extensive and long-enduring than others. These features have bearing on classification of the Pennsylvanian rocks, as discussed briefly in a later part of the report.

Previous Studies of Pennsylvanian Rocks in Kansas and Neighboring States

A beginning of systematic stratigraphical work on rocks of the Kansas region which now are classed as Pennsylvanian was made when MEEK & HAYDEN (1859) studied the Pennsylvanian section of the Kansas River Valley, and B. F. MUDGE (1866), first State Geologist of Kansas, described Carboniferous strata exposed in eastern Kansas. SWALLOW & HAWN (1865) and SWALLOW (1866) constructed a composite section of Pennsylvanian rocks observed in Kansas, in which geographic names such as Fort Scott, Stanton, and Plattsburg were first applied to stratigraphic divisions. In Missouri, work on the Pennsylvanian section exposed along the Missouri River was done by G. C. BROADHEAD (1866). During the 1860's the Geological Survey of Iowa made a general study of the so-called Coal Measures which are exposed in the central and southwestern part of that State (WHITE, 1870), and MEEK (1872) published descriptions of Pennsylvanian strata and fossils of eastern Nebraska.

No work of importance was done during the following two decades, but beginning in 1890, HAWORTH and associates of the reorganized Kansas Geological Survey made several traverses across the Pennsylvanian outcrops along selected lines and introduced many new stratigraphic names. Correlation of these sections showed that some strata were differently named in the various sections. A classification was developed (HAWORTH, 1894, 1895; HAWORTH & KIRK, 1894) in which all of the Pennsylvanian deposits were assigned to named groups and formations. In Iowa, surveys were made of counties in which Pennsylvanian rocks are exposed and various stratigraphic units were named. Some work was done on coal resources of Missouri and first efforts to classify Pennsylvanian rocks in northern Oklahoma are recorded in the work of DRAKE (1897).

The most important publications dealing with Pennsylvanian rocks in the northern midcontinent region in the period from 1900 to 1909 were a bulletin (ADAMS, GIRTY, & WHITE, 1903) of the U. S. Geological Survey on Upper Carboniferous rocks of Kansas, and a summary of the stratigraphy of these rocks published by the Kansas Geological Survey (HAWORTH & BENNETT, 1908). These describe the Pennsylvanian formations then known, and give observations on their paleontological characters (BEEDE & ROGERS, 1908).

The years 1910-19 witnessed activities in Pennsylvanian stratigraphic investigations throughout most of the midcontinent area. Chiefly important were reports by HINDS (1912) on coal and by HINDS & GREENE (1915) on stratigraphy of Pennsylvanian deposits in Missouri. The latter paper was accompanied by paleontological discussions on invertebrates by GIRTY (1915) and on plants by WHITE (1915). In Oklahoma, first effort to describe and classify Pennsylvanian strata in the northeastern part of the State (OHERN, 1910) and a series of oil and gas surveys by Federal geologists laid the foundation of classification and nomenclature of these rocks in northern Oklahoma. Summaries of the Pennsylvanian stratigraphy of Kansas (MOORE & HAYNES, 1917, pp. 78-107; MOORE, 1920), which include some modifications of HAWORTH's classification and incorporate features derived from the work of HINDS & GREENE, were published. The first modern work on Pennsylvanian rocks in Nebraska was recorded in a paper by CONDRA & BENGSTON (1915).

In the 1920's, work deserving special mention is the first comprehensive report on Pennsylvanian rocks of Nebraska (CONDRA, 1927), in which numerous subdivisions of previously defined formations were named. Although serious errors in interpretation of some units were made, especially in correlating the Platte Valley section, CONDRA's studies indicated the great persistence of many minor divisions of the rock succession and by introduction of formal nomenclature for them he laid groundwork for more detailed and precise stratigraphy of midcontinent Pennsylvanian deposits.

Partly from the impetus of CONDRA's work and partly from interest in exploring evidence of cylic sedimentation, study of Pennsylvanian stratigraphy was accelerated in the midcontinent area in the 1930's. In Kansas, stratigraphic sections and maps were gathered from oil companies and other sources for use in compiling a State geologic map (MOORE & LANDES, 1937). Field work was done by MOORE, N. D. NEWELL, J. M. JEWETT, W. H. SCHOEWE, M. K. ELIAS, and other survey members in every county having Pennsylvanian outcrops. Classification of rocks belonging to the system was revised in several ways, as by recognizing major time-rock divisions bounded by disconformities, by changing the assigned limits of some main lithologic units (groups) and by applying results of studies on cyclic sedimentation to definition of many formation and member units (MOORE 1932, 1936; NEWELL, 1935, JEWETT, 1933; JEWETT & NEWELL, 1935).

In Nebraska and Iowa, CONDRA and associates (CONDRA, 1930, 1933, 1935; CONDRA & UPP, 1933, 1933a; CONDRA & REED, 1937; CONDRA & SCHERER, 1939) published several papers giving information and new conclusions as to identification and stratigraphic classification of rock units, mostly of Missourian and Virgilian age. In 1932, D. G. STOOKEY and M. L. THOMPSON began studies of the Desmoinesian rocks of Iowa, working under direction of A. C. TESTER, but results are unpublished except for a paper by THOMPSON (1934) on fusulinids from some of the lower beds. Detailed work on upper Desmoinesian and lower Missourian strata of Iowa was carried on by L. M. CLINE during the years 1935-1941. Some of the stratigraphic results, including correlation of Iowa and Missouri units, have been reported by CLINE (1941). MCQUEEN & GREENE (1938) published a comprehensive report on oil and gas exploration in northwestern Missouri, with which a chart showing lithologic features and classification of the Pennsylvanian column of that State was offered. Several papers on stratigraphy of Pennsylvanian rocks in Oklahoma were published, and through collaboration of oil company geologists, numerous subsurface cross sections, showing the nature and correlation of Pennsylvanian rock units in Oklahoma and Kansas, were prepared.

The years from 1940 to the present have been somewhat less productive of advances in knowledge of northern midcontinent Pennsylvanian rocks than some previous equal periods, largely because of conditions imposed by World War II. In this period, however, two reports of continent-wide scope (MOORE *et al.*, 1944; CHENEY *et al.*, 1945) which treat classification and correlation of Pennsylvanian rocks in the midcontinent States have been issued. In less detail, the Pennsylvanian deposits were reviewed also in a survey of midcontinent stratigraphy (DOTT, 1941). An important paper by CLINE (1941) gives results of his studies on Pennsylvanian rocks in Iowa with indication of equivalent rock units in Missouri. A comprehensive summary of Pennsylvanian classification in Nebraska was published in 1943 by CONDRA &

REED and a similar one for Kansas, in 1944, by MOORE, FRYE & JEWETT. Studies of upper Desmoinesian (JEWETT, 1941, 1945) and lower Virgilian (BOWSHER & JEWETT, 1943) rocks in Kansas contain important new data and work in northeastern Oklahoma by OAKES (1940) makes additions to knowledge of Pennsylvanian rocks in this area.

A recently published paper (MOORE & THOMPSON, 1949) proposes recognition of three main divisions of the Pennsylvanian rocks, each composed of two lower-rank divisions, as follows: Lower Pennsylvanian rocks called the Ardian Series contain the Springeran Stage, below, and the Morrowan Stage, above; Middle Pennsylvanian deposits called the Oklan Series include the Atokan Stage, below, and the Desmoinesian Stage, above; Upper Pennsylvanian strata named the Kawvian Series are divided into the Missourian Stage, below, and the Virgilian Stage, above. This classification differs from prevailing usage mainly in emphasizing the importance of boundaries separating Morrowan from Atokan deposits and Desmoinesian from Missourian deposits. The greater significance of the boundaries which delimit Ardian, Oklan, and Kawvian, as compared with boundaries which are recognized within them, is supported by regional stratigraphic relations and paleontological distinctions.

Comparison of classification of Pennsylvanian rocks in the northern midcontinent States, particularly as represented by comprehensive papers published between 1930 and 1945, reveals many divergences, despite growing recognition of the identity of most rock units on opposite sides of State boundaries. Use of a different name for the same rock unit in two adjoining States (as Dennis limestone in Kansas, Hogshooter limestone in Oklahoma) represents lack of uniformity but is not a source of confusion. Use of the same name for different rocks on opposite sides of a State boundary (as Iola limestone and Kansas City group which have been defined in altogether different manner in Kansas and Missouri), is obviously objectionable.

Northern Midcontinent Interstate Conference on Pennsylvanian Classification

A meeting of State geologists representing Iowa, Kansas, Missouri, Nebraska, and Oklahoma, for the purpose of analyzing inter-State divergences in classification and nomenclature of Pennsylvanian deposits in the northern midcontinent area was held in offices of the Kansas Geological Survey at Lawrence on May 5-6, 1947. Those present were as follows: for Iowa, L. M. CLINE; for Kansas, R. C. MOORE, J. C. FRYE, and J. M. JEWETT; for Missouri, E. L. CLARK, F. C. GREENE, and W. V. SEARIGHT; for Nebraska, G. E. CONDRA and E. C. REED. WALLACE LEE, of the United States Geological Survey, attended the sessions as observer. R. H. DOTT, State Geologist of Oklahoma, was unable to be present, but on the basis of oral discussion with Moore on May 8 and examination of later written reports has expressed concurrence with qualifications based on differences in the nature of the Pennesylvanian rocks south of the Kansas-Oklahoma boundary.

Discussions at Lawrence extended from 8 a. m. to 6 p. m. on May 5. The following day was devoted to study in the field for the purpose of checking equivalence of Paola-to-Raytown beds in the Kansas City area to the Iola limestone at its type locality and for observations of overlying strata upward to the Plattsburg limestone in the area between Kansas City and Iola. Geologists participating in this field conference were CLARK, GREENE, JEWETT, MOORE, and SEARIGHT.

The May meeting reached essential accord on all points, subject to acceptance on the part of Missouri of correlations between Kansas City and Iola which had been made by Kansas. The field work on May 6 sufficed to remove doubts of the Missouri geologists on the correctness of identifying the Paola-to-Raytown strata of the Kansas City area with the type Iola limestone, and this permitted agreement of the Missouri Geological Survey to changes in stratigraphic nomenclature which depend on this identification (MOORE, 1948).

The substance of all changes adopted by the inter-State conference (Fig. 2) which affect classification of the Pennsylvanian rocks in Kansas will be outlined and explained in following parts of this paper.

Acknowledgments

I am indebted to associates of the Kansas Geological Survey for aid in preparing this paper, especially JOHN C. FRYE, BETTY

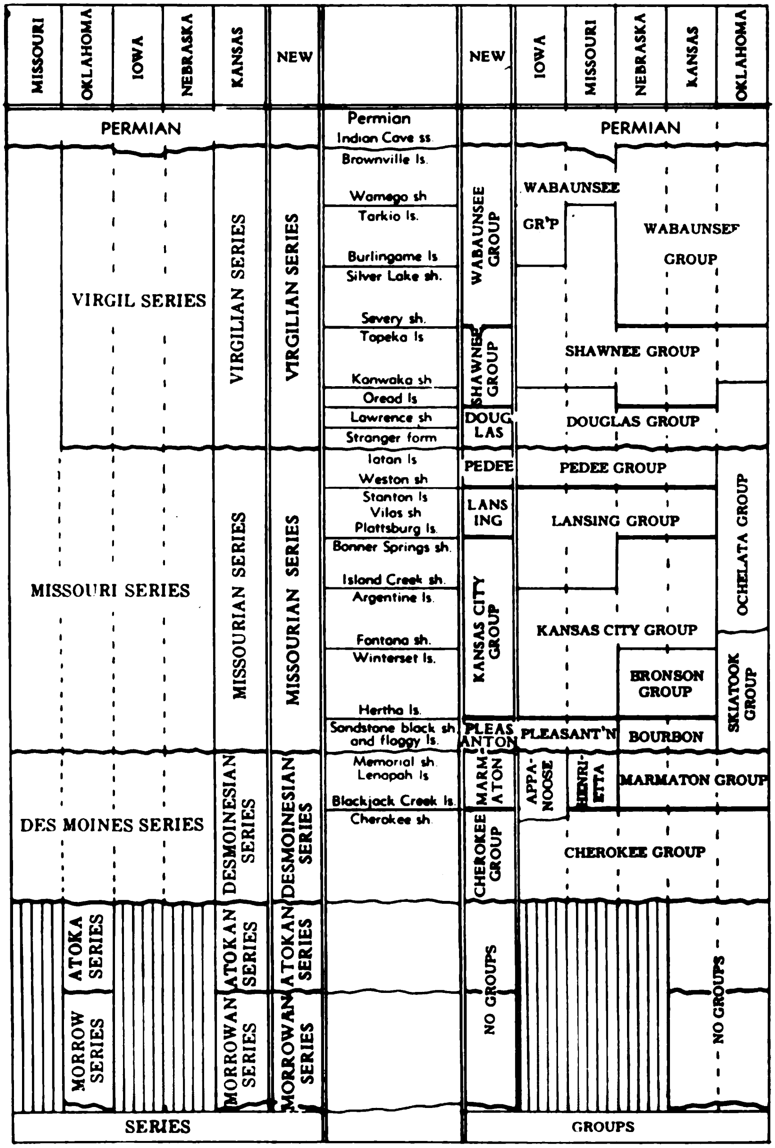

Figure 2. Main divisions of the Pennsylvanian System recognized by the northern midcontinent interstate conference of geological surveys. Accepted divisions are shown in the columns marked "new"; other columns indicate previously used divisions in the several States. Exception is to be noted, however, in that Oklahoma does not recognize Atokan and uses Skiatook and Ochelata groups as divisions of the Missourian rocks.

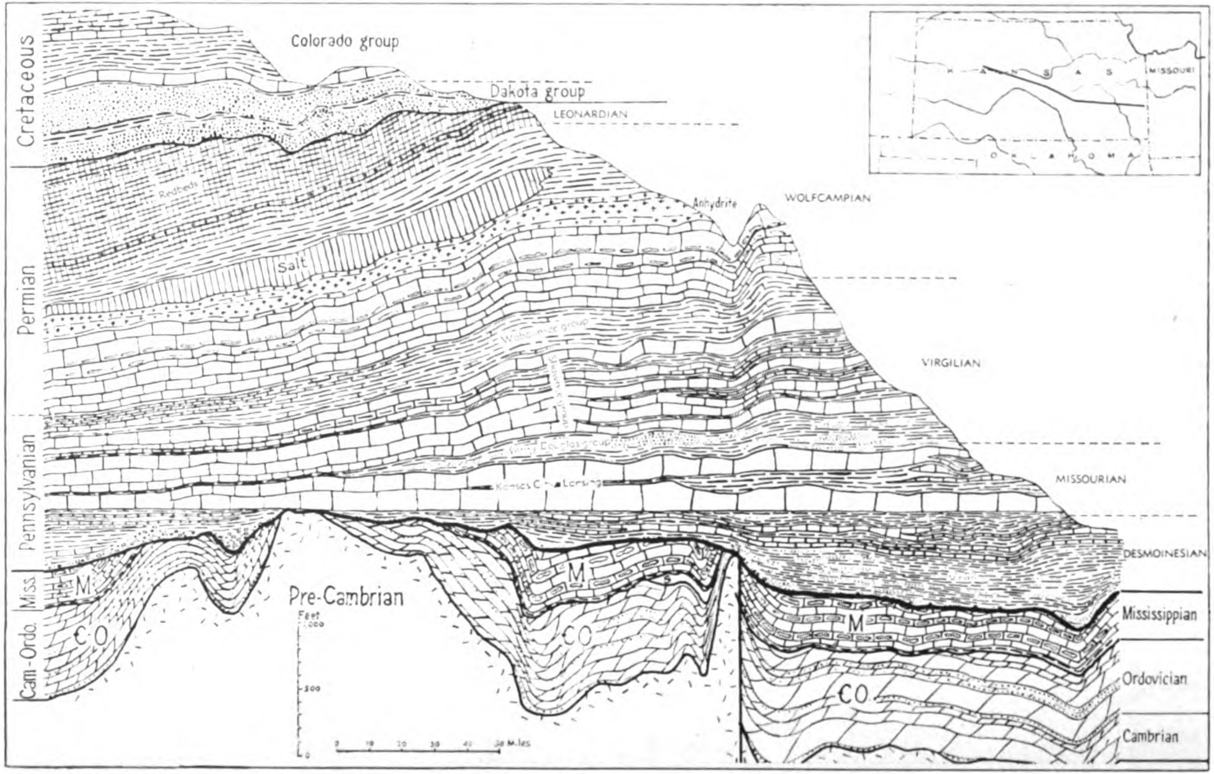

Figure 3. Diagrammatic east-west section of rocks in Kansas showing prominent unconformity at base of the Pennsylvanian System. The section, drawn on the base of the Kansas City group as a datum, shows essential conformity of succession from Pennsylvanian into Permian parts of the section. (*After Moore, Am. Assoc. Petroleum Geologists; data from section by Betty Kellett, Kansas Geol. Soc.*, 1932.)

HAGERMAN, and MARJORIE BRADLEY. Thanks are expressed also to JACK KOENIG and GRACE MUILENBURG for work on maps accompanying the report. The stratigraphic sections and charts have been drawn by me.

BOUNDARIES OF THE PENNSYLVANIAN SYSTEM IN THE KANSAS REGION

Mississippian-Pennsylvanian Boundary

In Kansas and throughout the northern midcontinent area, excepting parts of Oklahoma and Arkansas, definition of the lower limit of Pennsylvanian rocks is one of the most evident in the rock succession (Fig. 3). Not only are the types of sedimentary rocks on opposite sides of the boundary very dissimilar generally, but there is evidence of pre-Pennsylvanian erosion of the underlying strata and varyingly prolonged break in sedimentation. The basal Pennsylvanian rocks rest on different parts of the Mississippian succession, from high in the system down to the bottommost beds, and at many places, both at the outcrop in Missouri and in the subsurface of Kansas and Nebraska, the Pennsylvanian overlaps on to pre-Mississippian rocks. The oldest Pennsylvanian deposits in most of this territory are clearly much younger than rocks classed as belonging to the system elsewhere. Accordingly, there is no problem in marking the base of Pennsylvanian strata in the Kansas region.

Pennsylvanian-Permian Boundary

Definition of the boundary between rocks classed as Pennsylvanian and Permian in the Kansas region has led to much debate and disagreement. ULRICH (1911, p. 376, pl. 26) proposed to avoid the difficulty by not recognizing Permian at all and by defining as Pennsylvanian all of the rocks between Mississippian and Triassic. This procedure might be defended on the basis of the stratigraphic succession in the midcontinent area, but it is evidently unsuited to world-wide application. Because beds having Pennsylvanian and Permian fossils lie parallel and are seemingly conformable in Kansas and adjoining States, attempts to define the base of the Permian in this area have been based chiefly on study of fossils. Consideration has been given also to

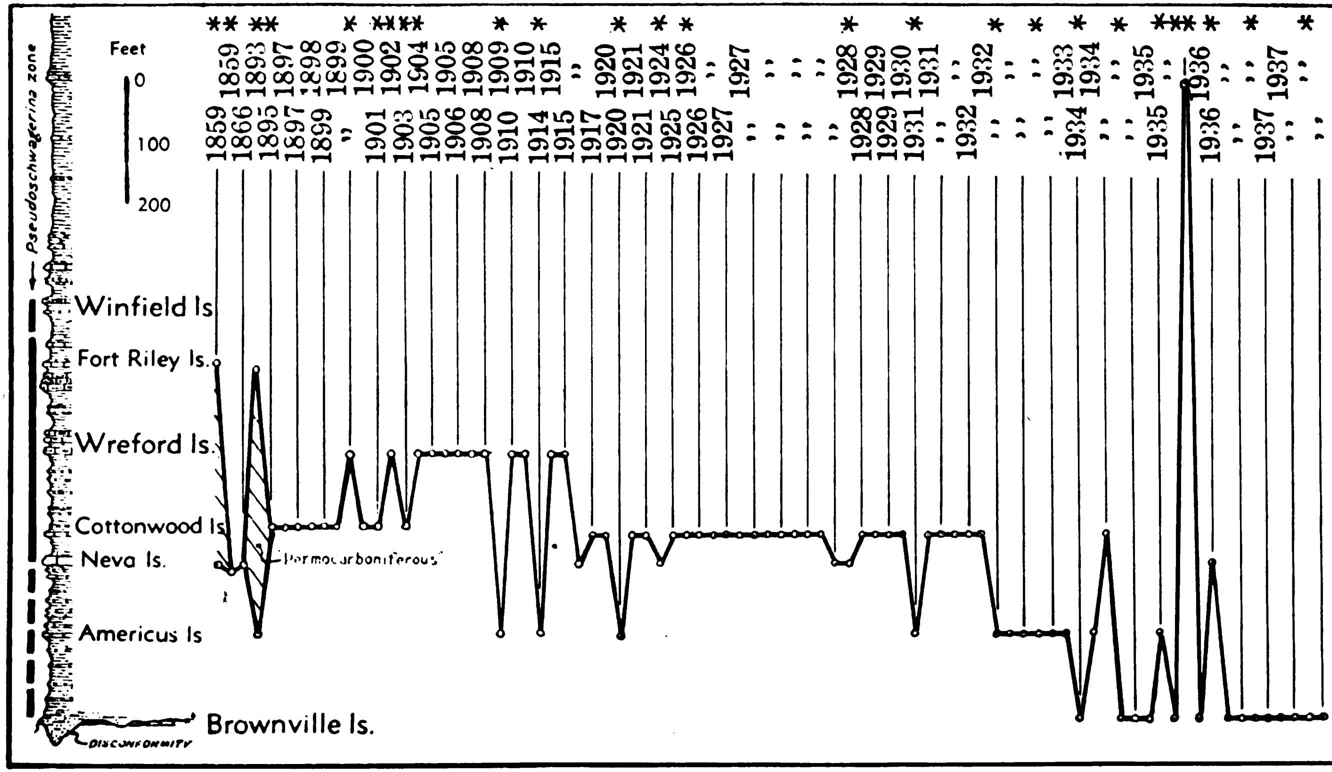

Figure 4. Placement of the Pennsylvanian-Permian boundary in Kansas. Asterisks denote papers in which special consideration is given to the problem of stratigraphic classification. (*After Moore, Am. Assoc. Petroleum Geologists.*)

lithologic features and the desirability of selecting a convenient cartographic datum. Judgment has been generally expressed that any adopted boundary is measurably arbitrary.

The general tendency during the 90 years since Permian deposits were first recognized in Kansas and in North Amrica as a whole has been to lower the boundary farther and farther (Fig. 4).

Mainly on account of the first appearance of the presumed Permian guide fossils *Callipteris conferta* and other plants at the horizon of the Wreford limestone in central Kansas, the lower Permian boundary was drawn at the base of the Wreford limestone by ADAMS, GIRTY, & WHITE (1903), PROSSER (1902, 1905), HAWORTH & BENNETT (1908), and others. Owing, however, to the very evident lithologic and faunal similarity of beds extending for a considerable distance below and above the Wreford limestone, the base of the Cottonwood limestone, about 125 feet below the Wreford, originally chosen by PROSSER (1895) as the basal boundary of the Permian, came later to be adopted generally. One reason for selection of this line seems to have been the fact that the Cottonwood is a persistent and distinctive stratigraphic datum that at a relatively early date had been traced entirely across Kansas into Nebraska and Oklahoma.

On the basis of discovery of species of "*Schwagerina*" (*Pseudoschwagerina*) in the Neva limestone, about 40 feet below the Cottonwood limestone, BEEDE & KNIKER (1925) judged that the base of the Permian should be lowered to the base of the Neva limestone. This conclusion was reached from an extensive examination of paleontological characters in Russian and other sections of the world, from which it appeared that the zone of "*Schwagerina*" marks the introduction of marine faunas which are considered generally characteristic of Permian time.

One of the distinctive fusulinids of the Lower Permian, as previously defined in Kansas, is "*Pseudofusulina*" (*Paraschwagerina*). Because this fossil and various other invertebrates which are typical of Lower Permian as previously defined range downward to the Americus limestone, 150 feet below the Cottonwood limestone, and because lithologic features of beds below the Cottonwood to a horizon at least as low as the Americus are much more closely similar to overlying beds than to those of the Wabaunsee group, below, MOORE (1932) concluded that if the

Cottonwood and Neva are classifiable as Permian, the lower boundary of the Permian rocks in Kansas should be placed at least as low as the base of the Americus limestone. Placement of the Pennsylvanian-Permian boundary at this horizon had previously been proposed by BEEDE (1909, 1914) (Fig. 4). In the course of detailed stratigraphic studies and mapping of beds belonging below the Americus, evidence of the existence of a stratigraphic break comparable to the disconformities which separate the Desmoinesian, Missourian, and Virgilian divisions of the Pennsylvanian System, was discovered and traced from southeastern Nebraska to northern Oklahoma (MOORE & MOSS, 1934). This disconformity belongs just above the Brownville limestone but in places depressions are carved into upper Wabaunsee strata reaching more than 100 feet below the horizon of the Brownville. Work by NEWELL and others in Oklahoma indicates that the horizons of this disconformity can be followed southward to the vicinity of the Arbuckle Mountains. Accordingly, this boundary, about 275 feet below the Cottonwood limestone, has been designated as the line of division between Pennsylvanian and Permian (MOORE, ELIAS & NEWELL, 1934). Evidence supporting the definition of this line as the lower boundary of rocks classed as Permian in the northern midcontinent area lies in conditions observed in western Texas where Wolfcampian beds, containing "*Pseudoschwagerina*" and "*Pseudofusulina*", rest with strong angular unconformity on upper Pennsylvanian beds (KING, 1934). A detailed review of the fluctuating placement of the Pennsylvanian-Permian boundary in the Kansas region and in the north-central Texas and Trans-Pecos Texas areas has been published by MOORE (1940) (Fig. 4).

Since the revision based on finding the disconformity just above the Brownville limestone, the Pennsylvanian-Permian boundary has been drawn uniformly by geologists of Kansas, Nebraska, and Oklahoma at this horizon. The boundary was recognized by the State geologists of Iowa, Kansas, Missouri, Nebraska, and Oklahoma in their conference of May 5-6, 1947, although basal Permian sandstone (Indian Cave) barely reaches into the northwestern corner of Missouri and the southwestern corner of Iowa.

DEFINITION OF PENNSYLVANIAN DIVISIONS BASED ON HISTORICAL GEOLOGY

Clear distinction is recognized between divisions of Pennsylvanian rocks in the midcontinent region that are based on relation to boundaries having significance as markers of geologic time, and those that are defined primarily by lithologic characters. The boundaries of time-rock units, which are determined primarily on the basis of sedimentation, interruptions of sedimentation, and other features of historical geology, are obscure but geographically extensive disconformities that separate successions of Pennsylvanian strata having different paleontological attributes. Greatest change in the components of fossil faunas and floras closely coincides with the horizons of these disconformities, which are inferred, therefore, to denote relatively prolonged interruptions in sedimentation. Erosion of previously accumulated deposits, which is indicated at many places as accompaniment of nondeposition, ranges from barely perceptible to quantitively very considerable.

The deposits occurring next above the disconformable surfaces, which mark boundaries between time-stratigraphic divisions of the Pennsylvanian System, are prevailingly clastic. They include much sandstone and there are local or widespread conglomerate beds. The clastic sediments increase in prominence as one proceeds outward from basin areas, as in the Forest City and Salina basins, and especially as source areas of sediments are approached. All known features of surface and subsurface stratigraphy of Pennsylvanian rocks in Kansas and neighboring States point to, or are in accord with, the recognition of at least four major time-rock units of equivalent rank, and the Pennsylvanian column in the whole region is judged to be divisible into six such time-rock elements. These have been named (in upward order): Springeran, Morrowan, Atokan (Derryan, or Lampasan), Desmoinesian, Missourian, and Virgilian. All except the first named are identified in Kansas at outcrops or buried beneath the surface.

The rank which should be assigned to the units just mentioned hinges on collateral observations and considerations. If Pennsylvanian rocks are designated as a system, as nearly all American geologists are agreed that they should be, divisions such as

Desmoinesian and Missourian may be treated appropriately as series; they have been so classified in previous reports of the Kansas Geological Survey and of surveys of adjoining States such as Missouri, Nebraska, and Oklahoma. The Nebraska Geological Survey (CONDRA & REED, 1943) treats Pennsylvanian as a subsystem of the Carboniferous System, which permits designation of divisions like Missourian and Virgilian as a series. On the other hand, if the Pennsylvanian rocks as a whole are classed as a series division of the Carboniferous System, in accord with usage of the U. S. Geological Survey, units having the span of Desmoinesian, Missourian, and Virgilian must be designated as subseries or stages. Likewise, if Pennsylvanian deposits are designated as a system and divided into series in the manner advocated by MOORE & THOMPSON (1949), it is necessary to treat main subdivisions of these series (Ardian, Oklan, Kawvian) as subseries or stages.

The Kansas Geological Survey, conforming to classification agreed to by the inter-State conference of May 1947, continues to designate Desmoinesian, Missourian, Virgilian, and units of similar rank as series (Fig. 2). Consequently, the divisions called Ardian, Oklan, and Kawvian are not employed, despite judgment as to their usefulness in taking account of major features of Pennsylvanian historical geology.

DEFINITION OF PENNSYLVANIAN DIVISIONS BASED LITHOLOGIC CHARACTERS

The succession of stratified deposits belonging to the respective series of the Pennsylvanian System, as seen in Kansas, is each composed of varied sorts of sedimentary materials, partly marine and partly nonmarine. The lithologic characters provide basis for classification that serves requirements for geological description and mapping. The named rock units are ranked as groups, formations, and members; two of the Pennsylvanian groups are divided into subgroups and there are a few named beds, subordinate to members.

Evidence of cyclic sedimentation is varyingly clear throughout the Pennsylvanian System in all the northern midcontinent region, but only in minor degree and rather exceptionally do boundaries of the deposits belonging to one cycle of sedimentation (called a *cyclothem*, Weller, 1931) coincide with the limits of rock units defined as members or formations (Moore, 1936). Reason for this is that precise delimitation of individual cyclothems in most places is impossible, either because the nature of well exposed beds between adjacent cyclothems does not afford conclusive indication of a boundary, or because critical parts of the section are concealed. Accordingly, the recognized rock units comprise lithologic entities having clearly marked physical limits, identification of which almost any two or more geologists can agree on readily. Commonly, these boundaries are well expressed topographically.

The general basis for differentiating an assemblage of beds classed together as a formation or group is dominance of a particular type of rock, at least in the area of the type section. Thus, a limestone formation, such as the Stanton, is composed predominantly of limestone members which are separated by thin shale members. A shale formation normally consists mostly of shale, but it may contain subordinate limestone or sandstone or both, and laterally the shale may diminish in importance as other rocks increase, until designation of the unit as a shale is no longer reasonable. The stratigraphic name may be retained because equivalence of span is definitely the same. The type Cherryvale shale section lacks limestone beds, whereas Cherryvale strata in Nebraska (as defined by inter-State classification) consist mostly of limstone. Likewise, two or more successive formations that stand apart from adjoining parts of the column because of contrasting lithologic features, topographic expression, and other attributes, may be defined as groups. The Shawnee group, characterized by relatively thick, escarpment-forming limestones, differs markedly from the underlying Douglas group and overlying Wabaunsee group.

In some parts of the Pennsylvanian succession of Kansas, cyclothems of different sorts are grouped by their arrangement and recurrence in constant order. Such sets of repeated cyclothems are called megacyclothems (Moore, 1936, pp. 26-38). Megacyclothem relationships as well as occurrence near together of similar kinds of rocks layers, are now understood as having importance in classifying the midcontinent Pennsylvanian deposits. For example, persistent thin limestone beds that characteristically underlie black platy shale are properly associated with limestone overlying the black shale, rather than treated as a minor element of a shale formation which includes the black shale.

Accordingly, formations are defined, as previously, to consist of an assemblage of rocks layers, which is judged to constitute a convenient and natural unit for purposes of description and geologic mapping. Generally, the strata thus classed together have similar composition or they are dominantly of similar lithology.

Members are subdivisions of formations which are found to be laterally persistent and are judged to be important enough for separate designation. They are not mapped as individual units.

Groups are assemblages of two or more formations which are judged to have similarities or a closeness of association sufficient to call for putting them together. They are a sort of super-formation. Subgroups are somewhat arbitrarily differentiated portions of a goup.

LOWER PENNSYLVANIAN ROCKS

General Description

Lower Pennsylvanian deposits of the midcontinent region are distinguished by paleontological and lithological characters and by widespread interruption of sedimentation associated with local crustal disturbances which set these rocks apart from younger formations. The Lower Pennsylvanian comprises strata which are assigned to the Springeran and Morrowan Series.

The magnitude of the hiatus at the base of Springeran deposits in the type area—the Ardmore Basin of southern Oklahoma—is not known. The type Morrowan section of northwestern Arkansas overlies the Pitkin limestone (Upper Mississippian), rocks of Springeran age being absent. Morrowan rocks (Kearny) unconformably overlie Mississippian limestone in western Kansas (Thompson, 1944; Maher, 1947) and in various parts of Colorado, Morrowan deposits unconformably overlie Leadville limestone (Lower Mississippian), erosional remnants of Upper Mississippian limestone, or Mississippian (?) black shales (Thompson, 1945).

One of the greatest diastrophic disturbances of Pennsylvanian time affected parts of North America near the close of Morrowan time. Deformation occurred in the Arbuckle area (Criner Hills) and the ancestral Rocky Mountains were uplifted. Isolated remnants of marine Morrowan rocks which remain after pre-Atokan or early Atokan erosion include deposits called Kearny formation in western Kansas, Glen Eyrie shale in Colorado, and Belden formation in western Colorado and Utah. Eroded Kearny and Glen Eyrie beds in western Kansas and eastern Colorado, respectively, are unconformably overlain by rocks of Atokan or Desmoinesian age (Cherokee shale in Kansas, Fountain formation of eastern Colorado). The type Morrowan rocks of Arkansas are overlain unconformably by Winslow sandstone (late Atokan), and the Wapanucka limestone (Morrowan) in eastern Oklahoma is overlain unconformably by middle Atokan shales. The Sloan limestone (Morrowan) of the Llano uplift occurs as erosional remnants unconformably below the Big Saline limestone (Atokan) with coarse conglomerate (Gibbon) at the base, on the east and the west sides of the uplift (PLUMMER, 1947; THOMPSON, 1947).

Few fossils are known from Springeran deposits but the Morrowan Series contains a rich marine fauna which resembles that of the upper part of the Chesteran (Late Mississippian) succession. Several groups of Mississippian fossils, particularly blastoids and certain bryozoans and brachiopods, are very similar to Morrowan forms. This invertebrate fauna contains several distinctive Pennsylvanian elements, however. Fusulinids are very abundant in early Pennsylvanian rocks of many areas, but all observed fossils of this group belong to *Millerella*. This genus occurs in rocks considered to be late Chesteran (upper Kinkaid formation) in Illinois (COOPER, 1947) and Mississippi (MELLEN, 1947). Also, *Millerella* occurs in post-Morrowan rocks. It is abundant in Atokan strata of many areas, less abundant in Desmoinesian rocks, and it occurs sparsely throughout higher Pennsylvanian formations. Since *Millerella* is the only known genus of fusulinids in pre-Atokan Pennsylvanian rocks, this part of the system is designated as the Zone of *Millerella* (Fig. 5). Deposits belonging in this part of the section can be recognized by common occurrence of *Millerella* and absence of other fusulinids (MOORE & THOMPSON, 1949).

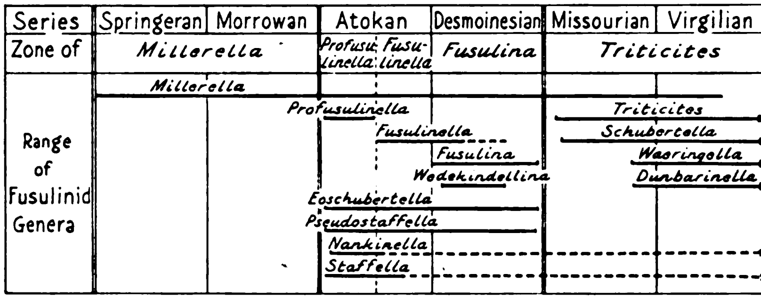

Figure 5. Fusulinid zones and ranges of fusulinid genera in Pennsylvanian rocks of Kansas and adjacent areas. (*Modified from Moore & Thompson, Am. Assoc. Petroleum Geologists.*)

Springeran Series

Springeran rocks are not known to be represented in Kansas. The time of Springeran sedimentation in other areas, during which thousands of feet of deposits were made in the southern Oklahoma and Arkansas geosyncline, was an age of weathering and erosion of exposed Mississippian and older rocks in the Kansas portion of the midcontinent region. If there was sedimentation in parts of Kansas during this earliest part of the Pennsylvanian Period, such deposits have not been discovered.

Morrowan Series

Deposits of Morrowan age are exposed in northeastern Oklahoma and are recognized under the name of Kearny formation in the subsurface of western Kansas (THOMPSON, 1944; MAHER, 1947). The Morrowan deposits belong in the Zone of *Millerella* (Fig. 5). Morrowan rocks are well exposed in northeastern Oklahoma but outcrops have not been discovered in other parts of the northern midcontinent region. This division of the Pennsylvanian is recognized in agreed classification as applicable to Kansas and Oklahoma. Probably throughout the northern midcontinent area, including Pennsylvanian deposits north of the latitude of Tulsa, the lower boundary of the Morrowan Series, where rocks of this age are present, coincides with the major unconformity that separates Pennsylvanian from older systems. The upper boundary is a well-marked disconformity in most places, but in parts of the subsurface there is indication that

Morrowan strata are limited above by a disconformity or nonconformity. The superjacent rocks seem definitely assignable to the Desmoinesian Series in parts of the region, but in other parts post-Morrowan-pre-Desmoinesian beds have been differentiated.

Kearny Formation

Rocks of Morrowan age which have been identified from well samples from southwestern Kansas are classed as belonging to the Kearny formation (THOMPSON, 1944). The type section (C, Fig. 6) is located in northwestern Kearny County, Kansas, and comprises 127 feet of alternating greenish gray finely crystalline limestone beds and dark greenish to black shale. Fossils are found in layers distributed throughout most of the section. Among them are fusulinids belonging to the genus *Millerella* (*M. marblensis, M. pressa, M. pinguis, M.? advena*, and *M.? advena ampla*), which are not associated with more advanced genera of fusulinids (THOMPSON, 1944, p. 415). The Kearny beds lie unconformably on Upper Mississippian (Ste. Genevieve) limestone. They are overlain unconformably by Desmoinesian deposits in the type section and presumably throughout the eastern border area of pre-Desmoinesian Pennsylvanian deposits in southwestern Kansas (Fig. 6), but westward the Morrowan rocks are separated from Desmoinesian strata by a varying thickness of Atokan deposits. The Atokan beds are judged to rest disconformably on the Kearny formation.

The thickness of Kearny deposits ranges from a featheredge along its eastern border to a maximum reported thickness of about 440 feet (A, Fig. 6) in southern Morton County, near the southwestern corner of Kansas (EDSON, 1947, Eason Oil Company's No. 1A Carver well in SW sec. 32, T. 34 S., R. 42 W.). At this place the top of the Morrowan rocks was penetrated at a depth of 4,260 feet. Thickness of Kearny beds in southern Hamilton County, Kansas (B, Fig. 6), is about 215 feet (MAHER, 1947) and in a well just west of the Kansas-Colorado boundary near the southwestern corner of Greeley County, 230 feet of rocks are assigned to the Morrowan (COLLINS, 1947).

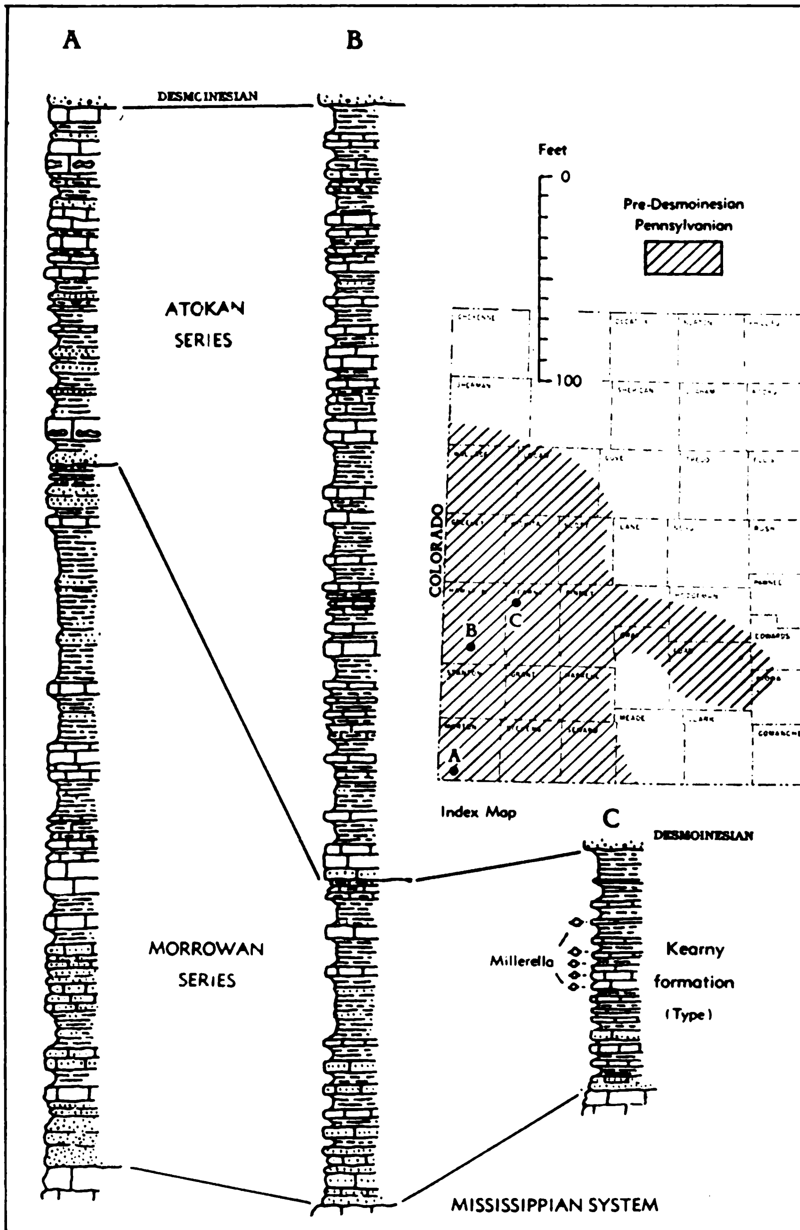

Figure 6. Sections of Morrowan and Atokan rocks encountered in wells in southwestern Kansas. These strata are not exposed anywhere within the borders of Kansas but are represented by outcrops in Oklahoma.

MIDDLE PENNSYLVANIAN ROCKS

General Description

Rocks classified as Middle Pennsylvanian comprise the oldest deposits of the system having very widespread geographic distribution. They occur not only in the belt of thick sedimentation of the southern Oklahoma and Arkansas geosyncline but extend uninterruptedly northward across the stable platform area in Oklahoma into Kansas and States farther north. Evidence for segregation of this part of the system, classed as the Oklan Series by MOORE & THOMPSON (1949), consists of well-marked physical breaks below and above and excellent paleontological testimony. The rocks of Middle Pennsylvanian age are here classed as belonging to the Atokan Series, below, and the Desmoinesian Series, above.

Important crustal deformation belongs to the time just preceding the beginning of Atokan sedimentation. This deformation is best recorded in the southern Oklahoma geosynclinal area. The occurrence of similar crustal movements at the close of Middle Pennsylvanian time is inferred from the important paleontological aspects of the Desmoinesian-Missourian boundary, but no mountain-making disturbance of this date is known in any part of North America. Comparative study of the late Paleozoic succession in North America and Europe, however, indicates that the post-Desmoinesian break corresponds to the Asturian orogeny in western Europe (MOORE, 1935, p. 1303).

Rocks of Atokan age are dominantly clastic deposits, which are confined chiefly to the geosynclines but include thin overlapping upper portions which extend over parts of the adjoining platform areas. The Desmoinesian rocks are also thick in the geosynclinal belt of Oklahoma and Arkansas, but unlike the Atokan, are spread with thickness of 1,000 feet or more throughout all the northern States, including Kansas. In the south, the Desmoinesian deposits are chiefly of clastic nature, but in the north, the upper part of the series contains several persistent comparatively thick limestones, which alternate with intervening shale and some sandstone. Cyclic sedimentation is evident in the Desmoinesian rocks of the northern area but is less evident in the geosynclinal region.

Rocks of Middle Pennsylvanian age are more widespread in North America than those of either older or younger parts of the Pennsylvanian System. They unconformably overlie Lower Pennsylvanian rocks in almost all areas where these occur. Not only is the present extent of Middle Pennsylvanian deposits considerably greater than that of Morrowan and Springeran, but its original spread is judged to be much larger than that of earlier Pennsylvanian rocks. Pre-Atokan or pre-Desmoinesian erosion undoubtedly reduced the areal extent of older Pennsylvanian deposits, for the latter are now found in some regions only as large or small patches beneath younger Pennsylvanian rocks. Atokan and Desmoinesian deposits also have been eroded away, both in pre-Missourian or pre-Virgilian and post-Pennsylvanian time, but they are still the most extensively distributed part of the Pennsylvanian System. It seems evident that Atokan beds chiefly occupy the deeper parts of the Pennsylvanian basins in the Rocky Mountain and midcontinent regions. The Desmoinesian seas, however, spread widely in the basins, extended over much territory not previously covered by Pennsylvanian deposits (Moore & Thompson, 1949).

The Desmoinesian Series is overlain by Upper Pennsylvanian strata at many places, but it is more widespread in North America than Missourian and Virgilian deposits. An unconformity is recognized between the Desmoinesian and Missourian divisions in many areas. Erosion along this contact locally removed at least 100 feet of Desmoinesian rocks in parts of Iowa, Missouri, and Kansas (Moore, 1936, p. 43). In the basin areas of the southern Rocky Mountains, however, Missourian strata overlap older Pennsylvanian deposits and are found on pre-Pennsylvanian rocks of the basin margins. It seems evident, however, that late Pennsylvanian seas did not extend as far northward in the Rocky Mountain area as did those of late Middle Pennsylvanian time.

Disturbances of less importance than those preceding Atokan and following Desmoinesian time also resulted in major interruptions of sedimentation within the Pennsylvanian Period. One of these occurred near the end of Atokan time and it determines the boundary between the Atokan and Desmoinesian Series. The boundary between the Atokan and Desmoinesian is identified in some areas by structural disturbances affecting Atokan rocks but not Desmoinesian (as on the flanks of the Llano uplift in Texas) and in most places by gaps in the stratigraphic section and paleontological discontinuities. Atokan rocks are much more restricted in geographic distribution than Desmoinesian rocks. In Oklahoma, on the flanks of the Arbuckle Mountains, Desmoinesian rocks (McAlester and younger) overlap beveled and folded or faulted Atokan rocks, and Desmoinesian conglomerates resting on Atokan rocks contain pebbles and cobbles derived from the mountain area. In northeastern Oklahoma, north of Muskogee, faulting disturbed Atokan deposits and beveled fault-blocks of Atokan rocks are overlain by lower Desmoinesian beds.

The paleontological hiatus between Middle and Upper Pennsylvanian rocks is pronounced, especially among the fusulinids. None of the many index genera and species of fusulinids which characterize the Atokan and Desmoinesian Series are known to extend into Missourian rocks. Also, diagnostic Middle Pennsylvanian brachiopods, such as *Mesolobus*, do not persist into Missourian Series, which contains prolific faunas of *Triticites*. Atokan and Desmoinesian deposits contain several readily identified faunal zones which have world-wide distribution. The fusulinid foraminifers are abundant throughout the Middle Pennsylvanian succession, and are generally recognized as among the most reliable of the zone fossils belonging to the system. The genera *Profusulinella*, *Fusulinella*, *Fusulina*, and *Wedekindellina* are confined in America to rocks of Atokan and Desmoinesian age, with possible exception of a questionable *Wedekindellina* found in the Bethany Falls limestone.

The Atokan Series is divisible faunally into fusulinid zones called (1) Zone of *Profusulinella* (lower Atokan) and (2) Zone of *Fusulinella* (middle and upper Atokan). Rocks of the Desmoinesian Series are referred to the (3) Zone of *Fusulina* (Fig. 5). The Subzone of *Wedekindellina* comprises the central part of the Zone of *Fusulina*. Many individual species of these four genera are recognized as excellent index fossils for identification of smaller units of the rock succession. *Profusulinella* is confined to the lower part of the Atokan. *Fusulinella* is also restricted to the Atokan Series, except for a few forms associated with species of *Fusulina*, which are found in Desmoinesian strata. Definite forms of *Fusulina* are unknown in America in rocks older or younger than Desmoinesian, and this genus ranges throughout practically all of this division. The Zone of *Fusulina* is well represented in the

Desmoinesian rocks of Kansas and has been recognized in the United States from Ohio on the east, Kentucky on the southeast, to Idaho and Arizona on the west. Faunas of this zone are abundant and prolific at many places. Perhaps the most nearly complete fauna of this zone is in the highly marine and calcareous section of Desmoinesian rocks of New Mexico. Fusulinids belonging unquestionably to *Wedekindellina* are confined to the middle part of the Desmoinesian section (MOORE & THOMPSON, 1949).

Atokan Series

General Description

This name (SPIVEY & ROBERTS, 1946) has been introduced in classifying buried Pennsylvanian deposits of western Kansas and eastern Colorado (MAHER, 1947). The Atokan comprises the Zones of *Profusulinella* and *Fusulinella*. If deposits younger than Morrowan and older than Desmoinesian are differentiated in Oklahoma, Nebraska, Missouri, and Iowa, their nomenclature remains to be considered. L. M. CLINE reports that there is a prominent disconformity below the horizon of the Munterville limestone, not far above the base of the Iowa Pennsylvanian, and beds below this disconformity, which contain *Fusulinella* (MOORE *et al.*, 1944, p. 691), may be pre-Desmoinesian, but they are insufficiently studied. Geologists of the Iowa Geological Survey are not ready to propose any change in definition of the Desmoinesian rocks, the base of which lies on Mississippian strata in the type area.

The rocks in the subsurface of western Kansas and eastern Colorado which are identified as belonging to the Atokan Series have not been given a formation name.

Unnamed Subsurface Atokan Rocks in Western Kansas

Deposits identified as post-Morrowan and pre-Desmoinesian are reported from several deep wells in southwestern Kansas. No formation name has been applied to these rocks but they are referred to the Atokan Series (MAHER, 1947; COLLINS, 1947). They do not extend as far eastward as the type section of the Kearny formation in northwestern Kearny County but probably are present in southern Kearny County and in Grant and Seward Counties farther south. In the westermost tier of counties in Kansas, the Atokan rocks have a thickness of 240 feet in southwestern Morton

County (A, Fig. 6) (EDSON, 1947); 490 feet in southern Hamilton County (B, Fig. 6) (MAHER, 1947); and about 75 feet near the southwestern corner of Greeley County (COLLINS, 1947). According to EDSON (1947), a well in sec. 10, T. 33 S., R. 39 W., in western Stevens County, Kansas, penetrated 550 feet of Atokan rocks without reaching the Kearny formation. Maximum reported thickness of Atokan beds in this region is 860 feet, in a well located in southern Bent County, Colorado, about 50 miles west of the Kansas-Colorado boundary in a direction west-southwest from Garden City (MAHER, 1947, p. 7, well 2).

In Kansas, the Atokan deposits consist of alternating beds of brown to black cherty limestone and black shale in the upper part of the section, and thin gray to black limestone interbedded with thick hard black shale in the lower part. Inasmuch as fusulinids found in the well samples are not distributed in manner to define the boundaries of the Atokan part of the section definitely, the identification of stratigraphic divisions has been based largely on lithologic features, boundaries being dawn also on the basis of unconformities indicated by the samples.

Desmoinesian Series

General Description

The type locality of this time-rock division, which is designated paleontologically as the Zone of *Fusulina*, is in Iowa. In some parts of northern midcontinent States, Desmoinesian deposits are separable from underlying pre-Desmoinesian Pennsylvanian rocks, but in large areas, especially in the subsurface of northern Oklahoma and Kansas along the Nemaha ridge and bordering the Central Kansas uplift, Desmoinesian beds rest on pre-Pennsylvanian formations with angular unconformity. The upper boundary of the Desmoinesian Series is defined by a disconformity which is very inconspicuous in most places but, on the basis of paleontological changes, is judged to be a division line of much importance. Beds next above the break belong to the Upper Pennsylvanian Missourian Series.

The disconformity at the top of Desmoinesian rocks in the midcontinent region has been traced for hundreds of miles (JEWETT, 1941, p. 298). In Oklahoma, the disconformity at the top of the series is at the base of the Seminole formation (MOORE, 1936, p.

53; Oakes & Jewett, 1943). In Kansas, the break occurs at the base of the Hepler sandstone, which is the basal part of the Pleasanton group and is correlated with the upper part of the Seminole formation. That is, Missourian rocks overlap Desmoinesian strata from the south. The Chariton conglomerate in Iowa

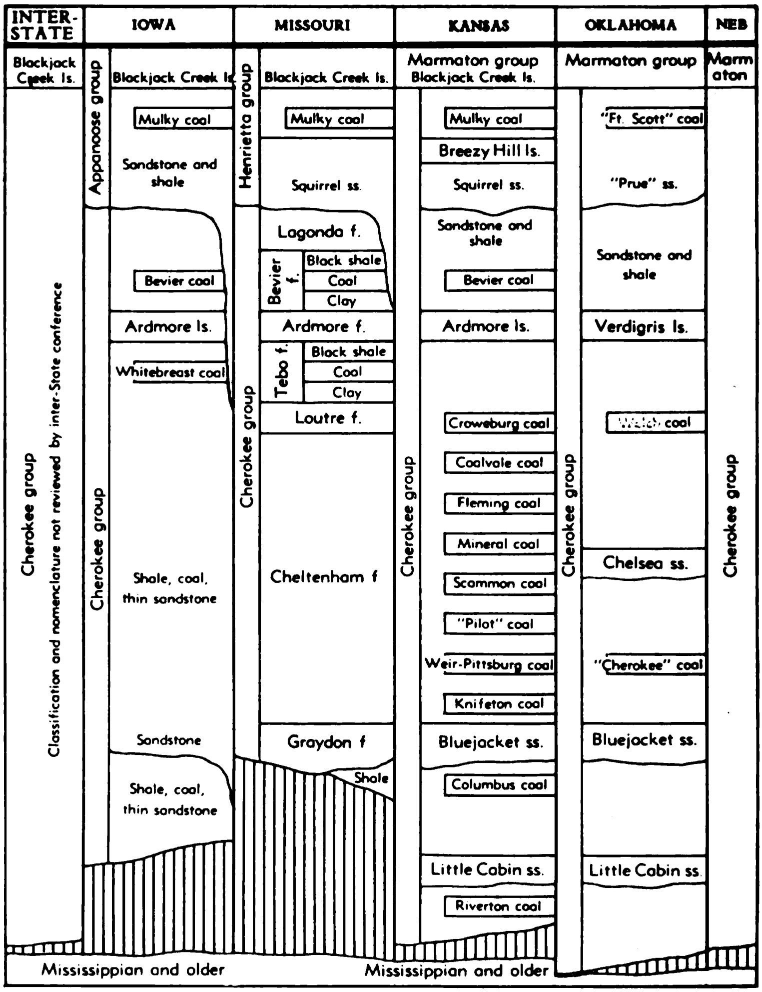

Figure 7. Classification of lower Desmoinesian rocks in the northern midcontinent region. Placement of stratigraphic units in columns (excepting Ardmore and Verdigris limestones, Mulky, Fort Scott, and Bevier coals, Graydon, Bluejacket and Little Cabin sandstones) does not indicate correlation.

is believed to be the northward extension of the Hepler sandstone and of about the same age.

Deposition of Pennsylvanian sediments is believed to have taken place largely in the form of transgressive overlap away from the eastern and southern positive area, Appalachia-Llanoria. By the close of Desmonesian time and probably earlier, this transgression was met by similar transgression from other directions and from other positive areas that were being eroded. Diastrophic movements within the basins were of differential nature. The presence of many local hiatuses and the occurrences of overlap are probable.

The inter-State conference has recognized the Desmoinesian Series as having the limits here indicated (Fig. 2, 7). This merely confirms previous common definitions of the boundaries. At many places in Kansas all pre-Missourian rocks of Pennsylvanian age are classed as Desmoinesian.

The Desmoinesian rocks of Kansas are divided into two groups, called Cherokee (below) and Marmaton (above). The Cherokee deposits are distinguished in character from Marmaton deposits by relative prominence of sandstone and coal beds and unimportance of limestone; both groups have thick shale formations. The Desmoinesian rocks crop out in southeastern Kansas (Fig. 1). They are the surface beds in most of Cherokee, Labette, Crawford, and Bourbon Counties. The total thickness of rocks belonging to the series in this region is approximately 700 feet.

The Desmoinesian formations are widely distributed in the subsurface of Kansas. They underlie all of the State west of the outcrops of these rocks except over northern parts of the Nemaha granite ridge and locally over the Central Kansas uplift. The deposits of this division are thickest in basin areas like the Forest City and Salina basins; they overlap against buried "highs" of older rocks and where they extend across them, they are generally thin.

Cherokee Group

Definition and Thickness

The Cherokee group is defined to include strata from the base of the Pennsylvanian north of the Kansas-Oklahoma line upward

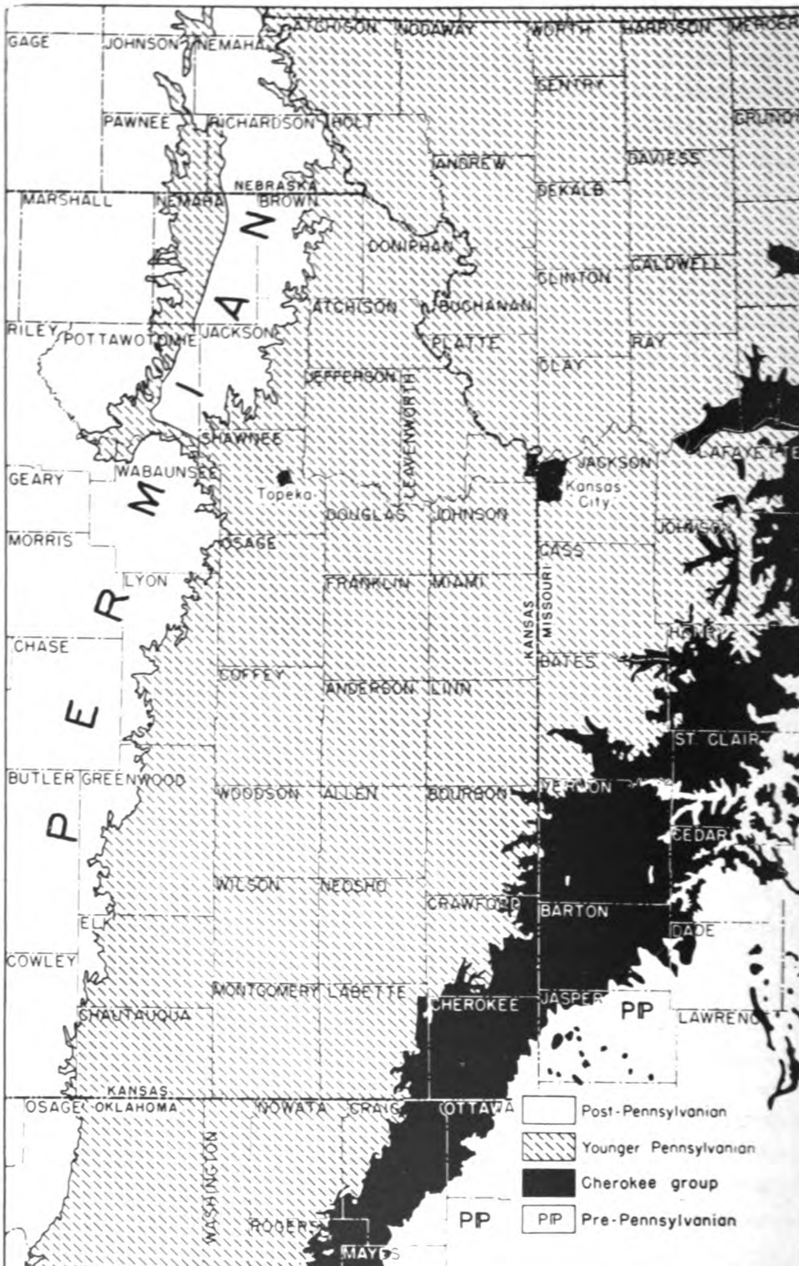

Figure 8. Distribution of Cherokee outcrops in Kansas and parts of adjoining States. The Cherokee group comprises the lower part of the Desmoinesian Series in the Kansas region.

to the base of the Fort Scott limestone (MOORE, 1936, p. 55; HAWORTH & KIRK, 1894, p. 105).

The maximum known thickness of Cherokee rocks north of Oklahoma is in the Forest City basin, in northeastern Kansas and in northwestern Missouri, where this division slightly exceeds 700 feet. The average thickness in southeastern Kansas is about 400 feet. The thickest section in southeastern Kansas is in Labette County where about 500 feet has been measured. On the low structural arch between the Forest City basin and the Cherokee basin the thickness is about 350 feet. Rocks of the Cherokee group overlap older beds on the Ozark uplift giving rise to a much smaller thickness of Cherokee rocks in several Missouri counties (HINDS, 1912, p. 4).

Distribution

The outcrop belt of Cherokee rocks in Kansas is about 20 miles wide, extending northeast and southwest across the southeast corner of the State (Fig. 8). Its area is about 1,000 square miles, in Cherokee, Crawford, Bourbon, and Labette Counties. Outcrops of Mississipian rocks lie to the south and east and Marmaton strata are exposed on the west and north.

Cherokee rocks are generally absent or are very thin beneath the surface in Kansas west of the Nemaha ridge. Basal Pennsylvanian rocks in the Sedgwick basin in south-central Kansas and a part of the "Sooy" conglomerate in much of western Kansas, however are believed to be equivalent to the upper part of the Cherokee shale of eastern Kansas.

Lithologic Character

Cherokee rocks are chiefly clastic; the amount of limestone is very minor. Shale is strongly predominant, gray clayey and silty micaceous shale being most common, but there is also much sandy shale and sandstone. Very dark or black carbonaceous shale occurs at several horizons. Sandstones in the Cherokee rocks commonly occur in lenticular bodies but the lenses are arranged in definite stratigraphic zones. "Shoestring sands," long narrow channel fillings or bar deposits, are numerous and many of them are important oil and gas reservoirs. Fifteen coal beds have been identified in the Kansas Cherokee section (Fig. 9).

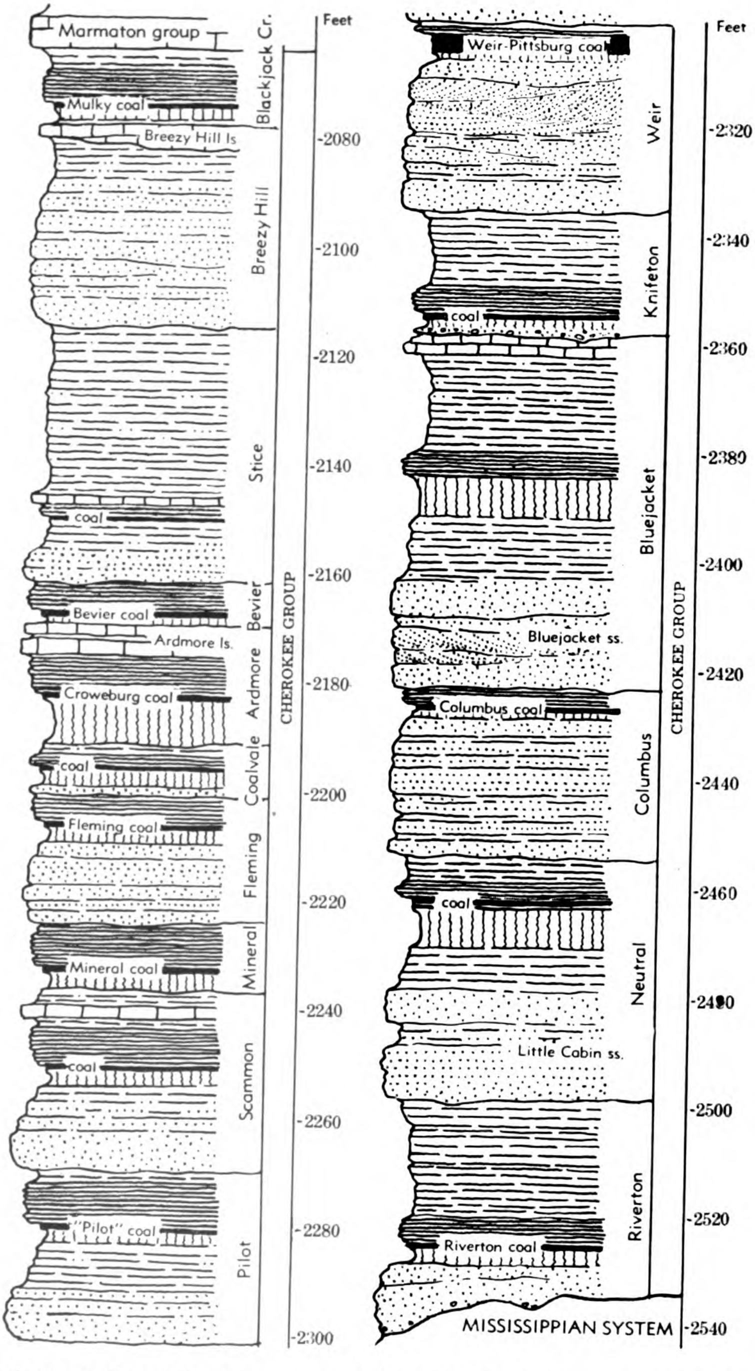

Figure 9. Generalized columnar section of rocks belonging to the Cherokee group in Kansas. Cyclic divisions are indicated. (*Modified from Abernathy.*)

The amounts of marine and nonmarine material in Cherokee rocks are about equal. Limestones and other rocks containing marine fossils are rare, whereas fossil land plants are plentiful. All detailed descriptions of Cherokee deposits in southern Iowa, western and northern Missouri, eastern Kansas, and eastern Oklahoma indicate that they were laid down under cyclical conditions.

The Ardmore limestone, 80 to 100 feet below the top of the Cherokee shale, is the most prominent limestone in the Kansas, Missouri, and northeastern Oklahoma section of Cherokee beds (Fig. 7, 9). It has been identified by several geologists with the "Verdigris limestone" of eastern Oklahoma. ABERNATHY (1937) states that the Ardmore limestone belongs to the second cyclothem below the Fort Scott (Mulky) cyclothem, but in the type locality of the "Verdigris limestone", this unit seems to be separated from the Fort Scott limestone by several cyclical units.

Classification

Cherokee rocks, although containing the most important coal beds and some of the chief oil and gas reservoirs in the State, have not been studied as thoroughly as some of the younger Pennsylvanian strata. Although they are not yet divided into named formations, it is deemed proper to regard Cherokee beds as comprising a group, partly because of similar treatment in neighboring States and partly because continuation of stratigraphic studies promises to allow differentiation into well-defined formational units.

In the east-central Missouri MCQUEEN (1943, pp. 29-93) recognized the following formations in the Cherokee section (in ascending order): (1) Unnamed sandstone and shale, principally cavern and sink fillings; (2) Graydon, basal chert conglomerate and sandstone; (3) Cheltenham, chiefly fire clay; (4) Loutre, limestone and clay; (5) Tebo, coal and shale; (6) Ardmore, limestone and shale; (7) Bevier, coal, clay, and shale; and (8) Lagonda, sandstone and shale. According to MCQUEEN, a pronounced unconformity separates the Cheltenham and Loutre formations and unconformities occur within the Cheltenham. Because of the persistence of coal and limestone beds, the higher formations can be correlated with subdivisions of the Cherokee group in southeastern Kansas. According to GREENE & POND (1926, p. 44) and MCQUEEN (1943, p. 38), the Graydon formation is equivalent to

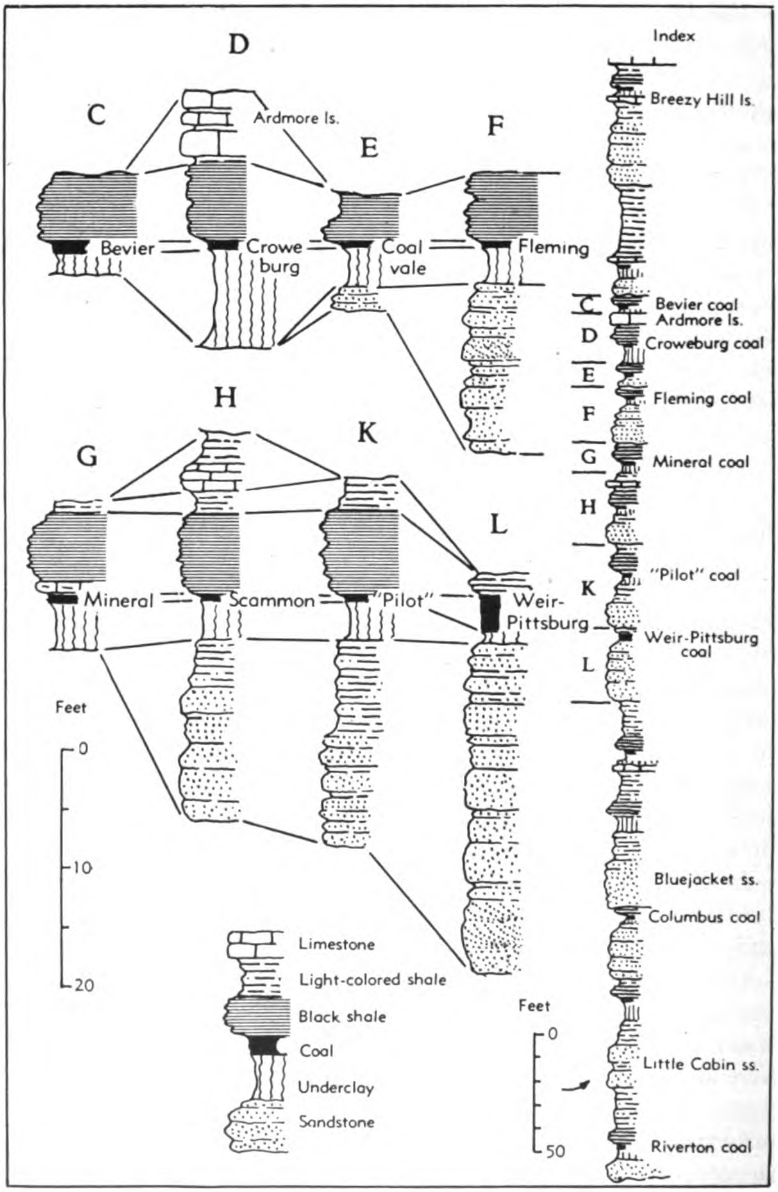

Figure 10. Representative Cherokee cyclothems showing correlation of similar types of sedimentary deposits. The identity of stratigraphic sequence belonging to different cyclothems is indicated even though some of the cyclic units lack certain sorts of rock. The index section at right shows the position of the cyclothems illustrated.

the "Clear Creek" (Bluejacket) sandstone in southwestern Missouri.

Cyclic Sedimentation

ABERNATHY (1937 p. 19) recognized 15 cyclothems in outcropping Cherokee rocks in Kansas and proposed that each be classed as a formation. In ascending order these are named: (1) Riverton, (2) Neutral, (3) Columbus, (4) Bluejacket, (5) Knifeton, (6) Weir, (7) Pilot, (8) Scammon, (9) Mineral, (10) Fleming, (11) Coalvale, (12) Croweburg, (13) Ardmore, (14) Bevier, and (15) Mulky. The names, except Ardmore (a limestone) and Bluejacket (a sandstone), are the names of coal beds.

The cyclothems, where fully developed, contain in ascending order the following types of sedimentary deposits: (1) sandstone, (2) sandy shale, (3) underclay, (4) coal, (5) black shale, (6) gray shale, (7) limestone, and (8) calcareous shale. Figure 10 shows the correlation of these similarly arranged deposits in several representative Cherokee cyclothems as observed in southeastern Kansas.

It seems that the Croweburg and Ardmore cyclothems, as designated by ABERNATHY are really a single cyclothem, and that the Breezy Hill limestone and adjacent calcareous shale beds, occurring a short distance below the Mulky coal, which with sandy deposits were assigned by him to the Mulky cyclothem, constitute a distinct cyclic unit, which may be called the Breezy Hill cyclothem. In Oklahoma, arenaceous beds between the Breezy Hill limestone and the Mulky coal and black shale are interpreted as the lower phases of the cyclothem which includes the Mulky coal.

Also, a definite cyclic succession which includes (in upward order sandstone, light-colored clayey to sandy shale, coal (Stice), black platy shale, limestone, and relatively thick light-colored shale, occurs between the Bevier and Breezy Hill cyclothems (Fig. 9). It is designated as the Stice cyclothem.

Definition of practically useful formational subdivisions of the Cherokee group depends on studies which are not yet completed. Prospectively, the Kansas Geological Survey will adopt a classification based on lithological features of the Cherokee deposits which are judged to be most persistent and to be best suited for objective differentiation of the rock succession. The Survey does not treat the units called cyclothems as formations. Geologists of the Missouri and Kansas Geological Surveys are now at work on the problem of stratigraphic classification of the Cherokee rocks and it is desirable that the recognized formational units in this part of the section shall be defined in identical manner on opposite sides of the State boundary.

Following paragraphs, based primarily on studies by ABERNATHY (1937), summarize characters of cyclic units which have been recognized in the southeastern Kansas Cherokee section (Fig. 9). They are designated in upward order.

Riverton cyclothem. The lowest Cherokee cyclothem, called Riverton, comprises a basal sandstone followed by underclay and coal (Riverton coal), which lies below black shale and gray shale. The average thickness of the cyclothem is about 38 feet.

Neutral cyclothem. The next higher cyclothem of the Cherokee succession has no observed basal sandstone, but contains the succession: underclay, coal, underclay, coal, black shale, and gray shale. The two coal beds, which are separated by about 3 feet of underclay, are called the Neutral coal.

Columbus cyclothem. The third cyclic assemblage includes the Columbus coal near the top. At the base is about 28 feet of sandstone, followed by about 1 foot each of coal and black shale.

Bluejacket cyclothem. This is the oldest cyclothem of the Cherokee rocks in which marine fossils are reported. It contains a thick basal sandstone (Bluejacket) and shows all phases of fully developed Cherokee cyclothems except coal and calcareous shale. Fossil marine invertebrates occur in about 3 feet of limestone at the top. The thickness of the cyclothem is about 68 feet.

Knifeton cyclothem. Conglomerate in the lower part distinguishes the Knifeton cyclothem. The conglomerate is followed by underclay, coal (Knifeton), black shale, and gray shale. The thickness is about 24 feet. The Knifeton coal is about 8 inches thick.

Weir cyclothem. This consists of sandstone, underclay, coal, and black shale. It is characterized by persistent coal (Weir-Pittsburg) which is one of the most important mined beds in southeastern Kansas. This bed carries a "blackjack" clay parting about 2 feet thick. Abundant fossil plants are found at the coal-black shale contact. The thickness of the cyclothem is about 36 feet.

Pilot cyclothem. The Weir is overlain by the Pilot cyclothem, which contains all the typical phases except two, limestone and calcareous shale. The average thickness is about 35 feet.

Scammon cyclothem. The next higher cyclic sequence, called Scammon, has an average thickness of about 35 feet. In most of its exposures it is fully developed, containing all eight phases. Limestone near the top and black shale overlying the Scammon coal are fossilferous. Mollusks are fairly abundant.

Mineral cyclothem. This cyclic unit consists of underclay, coal, black shale, and gray shale. The black shale is calcareous and abundantly fossiliferous, especially where thin beds of black limestone occur in the shale. The thickness of the cyclothem is about 12 feet.

Fleming cyclothem. This seemingly unfossiliferous cyclothem contains basal sandstone, sandy shale, underclay, coal (Fleming or Lightning Creek), black shale, and gray shale. The total thickness is about 24 feet.

Coalvale cyclothem. The next unit comprises about 11 feet of beds which contain all the elements of a fully developed Cherokee cyclothem except the upper calcareous parts.

Ardmore cyclothem. Although ABERNATHY (1937, pp. 19-20) separated the Croweburg coal and underclay below it and black shale above from the Ardmore limestone and underlying shale as separate cyclothems, these beds seem to represent a single cycle. The average thickness of the Ardmore cyclothem is about 22 feet. The Croweburg coal is correlated with the Broken Arrow coal of northeastern Oklahoma and the Ardmore limestone corresponds to the Verdigris limestone of the same area.

Bevier cyclothem. The Bevier cyclothem, about 10 feet thick, contains underclay, coal, and black shale of a typical Cherokee cycle.

Stice cyclothem. Approximately 45 feet of beds occurring next above the Bevier cyclothem in southeastern Kansas are here designated as the Stice cyclothem. These strata underlie the persistent, relatively prominent sandstone called "Squirrel", which is interpreted as part of the Breezy Hill cyclothem.

Breezy Hill cyclothem. The Breezy Hill limestone (PIERCE & COURTIER, 1938, p. 33) seemingly is the calcareous phase of a cyclothem occurring next above the Stice cycle. Sandstone occurring above the black shale which overlies the Stice coal consti-

INTER-STATE [1]	NEBRASKA [4]	IOWA [5]	MISSOURI [8]		KANSAS [12]		OKLAHOMA [14]
Memorial sh.		Shale	Memorial sh.		Memorial sh.		Memorial sh.
Lenapah formation [2, 3]		Exline ls. [6, 7]	Lenapah ls. [9]	Idenbro ls. mem.	Lenapah ls.	Idenbro ls. mem.	Lenapah ls.
				Perry Farm sh. mem.		Perry Farm sh. mem.	
		Cooper Creek ls. [6]		Norfleet ls. mem.		Norfleet ls. mem.	
Nowata formation [3]	Nowata sh.		Nowata sh. [9]		Nowata sh.	Walter Johnson ss. mem.	Nowata sh.
Altamont formation [3]	Altamont ls.	Worland ls. [7]	Altamont ls.	Worland ls. mem. [9]	Altamont ls.	Worland ls. mem.	Altamont ls.
				Lake Neosho sh. mem.		Lake Neosho sh. mem.	
				Tina ls. mem. [10]		Tina ls. mem. [10]	
Bandera formation	Bandera sh.	Coal Creek ls.	Bandera sh.	Bandera Quarry ss. mem.	Bandera sh.	Bandera Quarry ss. mem.	Bandera sh
				Mulberry coal		Mulberry coal	
Pawnee formation	Pawnee ls.	Pawnee ls.	Pawnee ls.	Laberdie ls. mem.	Pawnee ls.	Laberdie ls. mem.	Pawnee ls
				Mine Creek sh. mem.		Mine Creek sh. mem.	
				Myrick Station ls. mem.		Myrick Station ls mem.	
				Anna sh. mem.		Anna sh. mem. [13]	
Labette formation	Labette sh.	Mystic coal	Labette sh.	Lexington coal	Labette sh.	Lexington coal	Labette sh.
		Labette sh.		Englevale ss. mem.		Englevale ss. mem.	
Fort Scott formation [3]	Fort Scott ls.: Higginsville ls. mem.	Higginsville ls.	Fort Scott ls.	Higginsville ls. mem.	Fort Scott ls.	Higginsville ls. mem.	Fort Scott ls.
	Little Osage sh. mem.	Houx ls.		Houx ls. mem. [11]		Little Osage sh. mem.; Houx ls.	
		Summit coal		Summit coal		Summit coal	
	Blackjack Creek ls. mem.	Blackjack Creek ls.		Blackjack Creek ls. mem.		Blackjack Creek ls. mem.	

Figure 11. Classification of upper Desmoinesian rocks in the northern midcontinent area adopted by interstate conference of geological surveys. The agreed classification, shown in the column at left margin, is compared with classification previously used in the several States.

[1] Classification and nomenclature of subdivisions of formations not reviewed by interstate conference.

[2] Not recognized in Nebraska.

[3] Not recognized in Iowa.

[4] Condra and Reed (1943).

[5] Cline and Stookey (unpublished chart); Cline (1941).

[6] Correlation with Lenapah limestone not established.

[7] Recognized by Cline (1941) in northern Missouri, also; placed in Pleasanton by Clair (1943).

[8] Mainly based on unpublished chart by W. V. Searight (1948).

[9] McQueen and Greene (1938) report that Nowata and Lenapah beds are absent in Missouri and class Worland as subdivision of Bandera shale.

[10] Type Tina limestone is now known not to belong in Altamont; new name is to be substituted.

[11] Clair (1943).

[12] Moore, Frye, and Jewett (1944).

[13] Includes thin limestone at base.

[14] Newell (1937); Oakes and Jewett (1943).

tutes the basal clastic phase of the Breezy Hill cyclothem. No coal or underclay is observed between the sandstone and the Breezy Hill limstone. The thickness of strata assigned to this cyclic unit is 50 to 70 feet.

Blackjack Creek cyclothem. Sandy shale, underclay, coal (Mulky bed), black shale, and limestone (Blackjack Creek limestone) belonging in the lower part of the Fort Scott limestone comprise a widely distributed cyclic sequence which may be termed the Blackjack Creek cyclothem. Average thickness of this unit is about 15 feet.

Marmaton Group

Definition and Thickness

Strata from the base of the Fort Scott limestone to the disconformity which marks the upper limit of the Desmoinesian Series are designated as the Marmaton group (Figs. 2, 11). The Marmaton is set apart from the underlying Cherokee group because the former contains prominent limestones. There are four limestone formations and four shale formations which are identified along their outcrop from the Akansas River Valley in Oklahoma to Iowa and Illinois. Formations that comprise the Marmaton group (in ascending order) are: (1) Fort Scott limestone, (2) Labette shale, (3) Pawnee limestone, (4) Bandera shale, (5) Altamont limestone, (6) Nowata shale, (7) Lenapah limestone, and (8) Memorial shale.

The combined average thickness of these formations in Kansas is about 250 feet. The type locality of the Marmaton group is along Marmaton River, from Uniontown to Fort Scott, Bourbon County, Kansas.

The Marmaton group has been defined in the sense here indicated during many years in Kansas, northeastern Oklahoma, and Nebraska, being employed extensively in subsurface nomenclature as well as in classification of outcropping beds (Fig. 11). The term Henrietta group, which was formerly applied to beds from the base of the Fort Scott limestone to the top of the Pawnee limestone, has been used previously in Missouri (McQueen & Greene, 1938; Grohskopf, Hinchey, & Greene, 1939; Clair, 1943) and Iowa (Cline, 1941) as an exact synonym of Marmaton, but Cline (1939) and McQueen (1943, p. 90) altered the stratigraph-

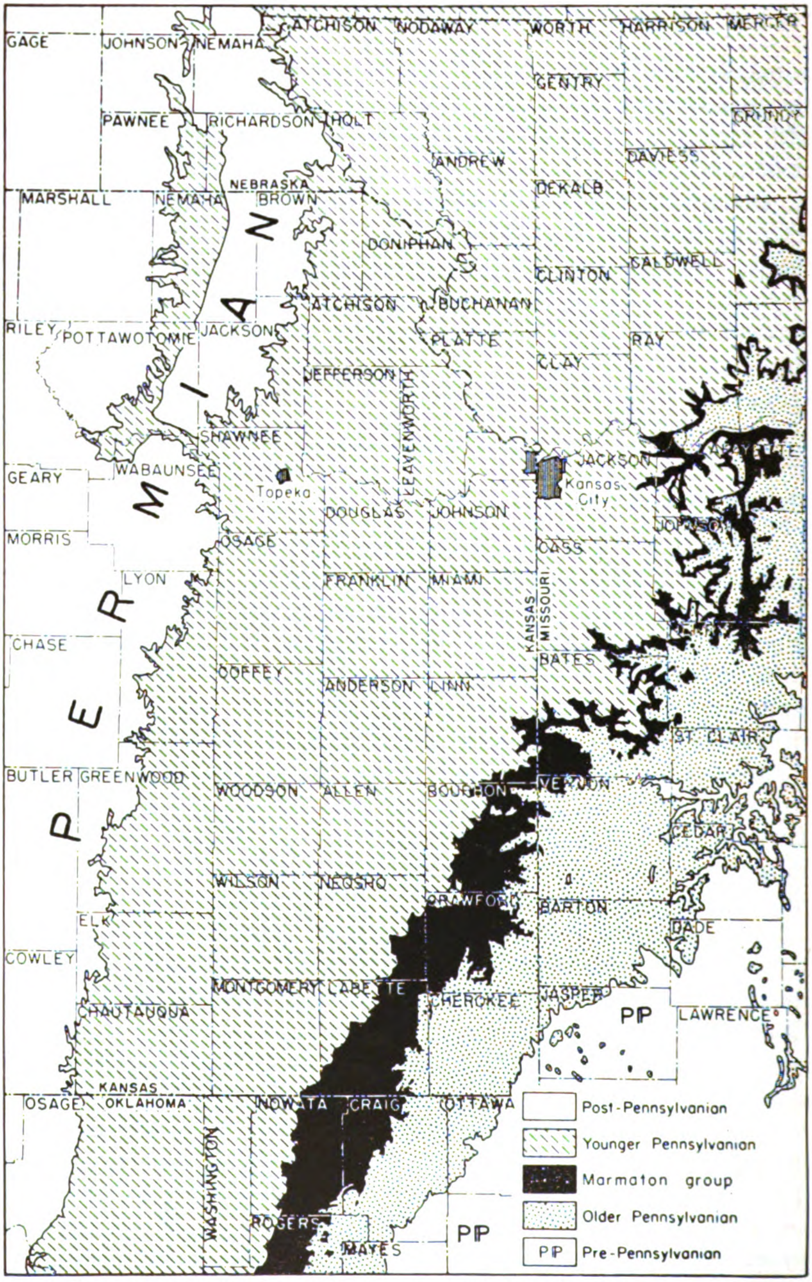

Figure 12. Distribution of Marmaton outcrops in Kansas and parts of adjoining States. The Marmaton group comprises the upper part of the Desmoinesian Series of Pensylvanian rocks in the northern midcontinent region.

ic span of Henrietta by including in it upper beds of the Cherokee as previously classified (Fig. 7). This name is now abandoned both bacause in common later usage it duplicates Marmaton and because formations overlying the Pawnee limestone are not well developed near Henrietta. The name Appanoose, which was introduced by BAIN (1896) for deposits in Iowa that approximate the span of the Marmaton group (Fig. 7), was used by CLINE (column 31 of chart in MOORE *et al.*, 1944) for upper Desmoinesian beds, classed as a group, extending downward to a somewhat prominent disconformity that is recognized in Iowa between the Ardmore and Blackjack Creek limestones. Thus, the Appanoose includes some upper Cherokee strata and corresponds to Henrietta group as treated by CLINE in 1939 (p. 1905) and as redefined by MCQUEEN (1943). The Iowa and Missouri geological surveys have joined Kansas, Nebraska, and Oklahoma in recognizing Marmaton group.

Distribution

Marmaton rocks crop out in Kansas in a belt ranging in width from about 10 miles to 25 miles (Fig. 12). The outcrop belt extends from Linn and Bourbon Counties on the Kansas-Missouri boundary to Montgomery and Labette Counties on the Kansas-Oklahoma boundary. The general strike is about 30° east of north and the dip, which is westerly, averages about 20 feet to the mile. The prevalent dip locally is interrupted by minor flexures.

Lithologic Character

The Marmaton group comprises the upper and more calcareous part of the stratigraphic section assigned to the Desmoinesian Series. In Kansas the Marmaton rocks are dominantly shale, limestone being second in quantitative importance, and sandstone third. There is a minor amount of coal.

Desmoinesian limestones differ in lithologic characteristics from those of younger parts of the Pennsylvanian section. The most noticeable difference is the absence of certain lithologies, such as flinty limestone, which is plentiful in the Kansas City group, that are common in higher beds. Marmaton limestones are only locally and very sparsely flint bearing. Massive cross-bedded oölitic limestone, which is mostly a mass of algal pellets, is characteristic of the Kansas City group, but is absent from Marmaton rocks. Fusulines, although present in several Desmoinesian limestones, are not important rock makers in this part of the section. Most of the limestone in these rocks is light gray and weathers into a rock of even lighter color. This contrasts with most of the limestone of younger groups, which develops a rusty brown coating when exposed for a few years. Brown-weathering limestone beds are not absent from the Marmaton group, however. One type of finely crystalline brownish-gray limestone characteristically weathers into a dark-brown-coated rock. The most common limestone type in the Marmaton group is a light-gray, rather coarsely crystalline rock, which has the appearance of being a breccia. Small limestone fragments of irregular outline are imbedded in a matrix of slightly different color and texture.. Coralline limestone, which is dominantly composed of *Chaetetes* colonies, is a distinctive rock in the Marmaton group.

The thicker shale units include sandstones which consist of channel fills in clay shale and sheetlike bodies that grade laterally into sandy shale. In general, the sandstone channel fills are not more than 25 feet in greatest thickness.

Shale members of the limestone formations are partly, if not wholly, marine. They contain brachiopods, bryozoans, crinoid remains, and locally, mollusks and corals. Black carbonaceous shale and small amounts of coal are characteristic of some of the thinner shale units. Where fossiliferous, the black shales contain a sparse fauna in which thin-shelled brachiopods are the most conspicuous element; conodonts are present locally. Small dark phosphatic concretions are common in the black shales. The thin fossiliferous shales are more finely bedded than the thicker nonmarine shales.

Coal beds are mostly thin and discontinuous, but a few beds are persistent and locally attain minable thickness.

Cyclic Sedimentation

The Marmaton group is composed of alternate nonmarine and marine deposits which clearly reflect successive oscillations of the strand line in eastern Kansas during late Desmoinesian time. Repetition of rock sequences, in which the types of lithological and paleontological characters characterizing various strata are arranged in constant order, is seen both in the nonmarine and marine sedimentary accumulations and although some kinds of deposits found in the most complete sequences are missing here and there, the regularity of the repeated stratigraphic pattern demonstrates the cyclic nature of Marmaton sedimentation (Fig. 13). As in the Cherokee group, there are beds of the following types, one overlying another in upward order: (1) nonmarine sandstone, commonly uneven at the base, occupying channels cut in subjacent rocks, (2) sandy, silty, and clayey shale, unfossiliferous or containing land plant remains, (3) underclay, (4) coal, (5) black platy shale containing conodonts, and commonly bearing small spheroidal phosphatic concretions, (6) gray to brownish clayey or calcareous shale, or limestone containing a varied assemblage of marine invertebrates. Such a rock sequence represents a simple sort of progression from nonmarine to marine deposition associated with advance of a shallow sea. Retreat of the sea followed by re-advance is indicated by stratigraphically higher layers having similar arrangement.

The Marmaton group also offers evidence of a more complex arrangement of repeated sequences of rock layers in which cyclic deposits of somewhat differing sorts are disposed one above another in regular order. Such a cycle of cycles has been termed a megacyclothem (Moore, 1936, p. 29). Seemingly, it represents an oscillatory transgressive movement of the seas on which Pennsylvanian marine deposits of the Kansas region were laid down. Minor retreats of the strand line separated advances of the sea margin and at any one locality this is recorded by the shifting nature of limestone, shale, sandstone, and carbonaceous materials (including coal) which accumulated.

Each of the four limestone formations of the Marmaton group, combined with adjacent parts of the relatively thick intervening shale formations, is composed of three or four individual cyclothems representing distinct, though in many places incompletely expressed, marine invasions and retreats. Thus, four megacyclic groupings of the Marmaton strata may be recognized. In these, the limestone formations comprise records of dominant marine conditions whereas the shale formations furnish records of dominant nonmarine conditions. Minor, and somewhat local, marine invasions are recorded in cyclothems included in the shale formations, and minor, somewhat local emergent, or near-emergent conditions are recorded by shale members of the limestone formations.

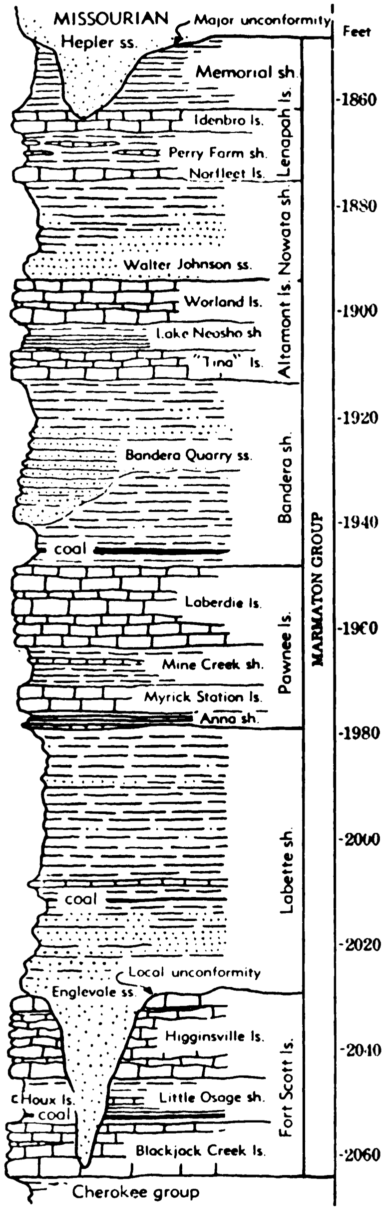

Figure 13. Generalized columnar section of rocks belonging to the Marmaton group in Kansas. This group is mainly distinguished from adjoining groups by prominence of limestones.

Classification

The Marmaton rocks contain some persistent formational units which are recognized in Kansas, Oklahoma, Missouri, Iowa, and Nebraska. Classification has differed, however, in a few features in the different States (Fig. 11) and it continues to lack complete uniformity. The divergence is largely a reflection of stratigraphic differences. For example, the assemblage of limestones and shales from Blackjack Creek to Higginsville limestones, inclusive, which comprises the unit called Fort Scott formation in Kansas, is judged to be unnatural in Iowa; accordingly, Fort Scott is not recognized and the rock divisions which are classed as members of the Fort Scott in Missouri and Kansas are treated in Iowa as independent formational units. The Coal Creek limestone, which is found in northern Missouri and Iowa, has not been identified in western Missouri, Kansas, and northeastern Oklahoma. Relations of the Cooper Creek and Exline limestones to the Lenapah fomation are undetermined. Marmaton strata are buried in Nebraska.

Fort Scott Limestone

The lowermost formation of the Marmaton group is known as the Fort Scott limestone (SWALLOW, 1866; BENNETT, 1896) (Fig. 13). The formation is composed of two main limestone units and an intervening shale which contains thin, persistent limestone beds and a coal (Fig. 11). The lower limestone, commonly known as the "Cement rock", now is called the Blackjack Creek limestone member and the upper limestone, sometimes termed "Lexington bottom rock," is the Higginsville limestone member. The intervening beds are designated as the Little Osage shale member. It contains the Houx limestone and Summit coal.

The Fort Scott has been identified along its outcrop line from Arkansas River Valley in Oklahoma to southern Iowa, but in Iowa, the individual limestone and shale components are classed as formations. Equivalent beds are recognized in Illinois (WELLER & Others, 1942, p. 1586, fig. 1).

Blackjack Creek limestone member. The lower Fort Scott or Blackjack Creek limestone (CLINE, 1941, p. 36) rests on black shale which is classed as the uppermost part of the Cherokee group. At the outcrops in Kansas, this limestone ranges in thickness from about 4 feet to 17.5 feet.

The lower part of the member is sparsely fossiliferous limestone called "Cement rock." It weathers brown but in fresh exposure, appears tan, brownish, or dark dove gray. The rock is mostly somewhat earthy and dense but locally it has a fine crystalline texture. Conchoidal fracture is common. The "Cement rock," which ranges in thickness fom 1.5 to 10 feet, has thicker and more regular bedding than the upper part of the Blackjack Creek limestone.

The upper part of the Blackjack Creek limestone is easily distinguished from the "Cement rock" by its lighter gray color, more coarsely crystalline texture, and thinner, more irregular bedding. Locally it is separated from the "Cement rock" by a thin shale parting. The upper unit disappears north of Bourbon County, Kansas, for at outcrops in northern Bourbon and Linn Counties and in eastern Missouri, the Little Osage shale rests directly on the "Cement rock". Similar conditions prevail locally in northeastern Oklahoma. The upper part of the Blackjack Creek limestone ranges from a featheredge to 13 feet in thickness.

Except for the rock-building coral, *Chaetetes*, which is mostly confined to the upper part, fossils are rather scarce in the Blackjack creek limestone. Fusulines occur more commonly in the upper part. Mollusks are plentiful in the "Cement rock" portion of this member in Oklahoma.

Little Osage shale member. The middle member of the Fort Scott formation, called Little Osage shale (JEWETT, 1941, p. 306), is persistent. In its lower part is the Summit coal, named from Macon County, Missouri (McGEE, 1888, p. 331), and in the middle part is the thin but very persistent Houx limestone (CLINE, 1941). The thickness of the Little Osage shale at its outcrops in Kansas ranges from 4 to 12 feet, but it becomes thicker northeastward in Missouri.

The light to dark-gray, locally calcareous shale beneath the Summit coal is about 3 feet thick in Kansas. Maximum thickness of the Summit coal is about 1 foot. The shale overlying the Summit bed is black and fissile, or gray in the lower part and black in the upper part. The black shale attains a thickness of 10 feet and commonly contains spheroidal phosphatic concretions. The Houx limestone bed is about 1 foot thick in western and northern Missouri but only a few inches in Kansas. The uppermost part of the Little Osage shale consists of gray calcareous shale, 1 to 4.5

feet thick, the greatest known thickness being in Missouri. The Summit coal and Houx limestone beds extend southward to Fort Scott, in Bourbon County, Kansas, and possibly farther. Locally in southeastern Kansas and northeastern Oklahoma, the Little Osage shale consists almost entirely of black fissile shale. Fossils are rather scarce in this member but horn corals occur in the upper few inches at some outcrops in western Missouri and conodonts are rather abundant in the black shale.

Higginsville limestone member. The upper member of the Fort Scott limestone, called the Higginsville limestone (CLINE, 1941, p. 36), is 12 to 15 feet thick along most of its outcrop belt in Kansas (Fig. 13). The limestone is a light to dark gray rock which commonly has a medium-grained crystalline texture and displays a brecciated appearance. The lower part is thicker bedded than other parts generally, but the whole unit displays irregular wavy beds, which are thinnest in the middle of the member. At many places, the upper beds are largely made up of the coral *Chaetetes*. Large fusulines and large crinoid stems also are common.

Labette Shale

The Labette shale (HAWORTH, 1898) includes beds, mostly shale and sandstone, occurring between the Fort Scott and Pawnee limestones (Figs. 11, 13).

Average thickness of this formation along the outcrop in Kansas is about 40 feet but changes in thickness are rather abrupt, the range being from about 30 to 100 feet. In general, thickness increases southward

The Labette includes clayey and silty shale, sandstone, and minor amounts of limestone and coal. A persistent limestone occurs in the upper-middle part in southeastern Kansas and in northeastern Oklahoma. Coal beds, which are rather local, seem to represent parts of different cyclothems. A black shale and coal zone occurs in the upper part of the Labette next below the persistent thin limestone that marks the base of the Pawnee limestone.

Sandstone lenses, consisting partly of channel fillings, are common in the Labette shale, but they are less numerous in Kansas than in Missouri and Oklahoma. A channel sandstone in the lower part of the formation, which is locally prominent in southeastern Kansas, is named the **Englevalle sandstone** (PIERCE &

Courtier, 1935, p. 1061). Locally, the sandstone extends downward into depressions eroded in the Fort Scott limestone (Fig. 13). Sandstone bodies which are encountered in subsurface parts of the Labette shale are generally designated as "Peru sand"; some of these bodies are sources of oil and gas production.

Thin limestone beds and calcareous shale belonging to the Labette formation contain brachiopods and other marine fossils. Most beds are poorly fossilferous or barren of fossils, however.

Pawnee Limestone

The Pawnee limestone (Swallow, 1866; Moore, 1936), which lies between the Labette and Bandera shales, is the first prominent limestone assemblage above the Fort Scott formation. In Kansas the following members (in ascending order) are recognized: (1) Anna shale, (2) Myrick Station limestone, (3) Mine Creek shale, and (4) Laberdie limestone (Figs. 11, 13). The inclusion of a shale member at the base of a limestone formation is explained by the presence of a thin slabby, somewhat lenticular limestone at the base of this shale throughout a wide area. This limestone thickens northeastward in Missouri and southward in Oklahoma, where it comprises a major part of the Oologah limestone (Jewett, 1941, p. 290). Logically, the limestone and the overlying shale, which are mostly shale in Kansas, belong in the Pawnee limestone assemblage. Moore (1936, p. 62) has amended definition of the Pawnee limestone to include these beds.

In Oklahoma, beds equivalent to the Pawnee limestone compose the main part of the Oologah limestone, which crops out a few miles east of Tulsa. It has been traced across Missouri into Iowa (Cline, 1941 p. 37; Jewett, 1941, p. 312) and its equivalent is recognized in Illinois (Weller & Others, 1942, pp. 1591-1592). A graphic section of the Pawnee limestone and adjacent rocks in Kansas is given in Figure 8.

Anna shale member. The Anna shale member, at the base of the Pawnee formation, lies below the Myrick Station limestone member. It includes the Lexington coal of Missouri. At outcrops in Kansas, the Anna shale ranges in thickness from 2 feet to 13 feet and consists chiefly of black fissile shale. The upper few inches consists of gray shale. Commonly it contains small, black, nearly spherical phosphatic concretions imbedded in the black shale. A thin bed of slabby black crystalline or earthy limestone occurs below the black shale. The black limestone is widely distributed in Missouri where it has been identified just below the Lexington coal. In Crawford County, Kansas, the upper middle part of the Anna shale is very coaly. The Anna shale contains fragments of crinoids and other fossils in the basal limestone and flattened brachiopod shells in the black shale.

Myrick Station limestone member. The Myrick Station limestone (CLINE, 1941, p. 37) is the so-called "Lexington cap-rock" near Lexington, Missouri, and at its type locality near Myrick Station, Missouri. This limestone is easily identified in numerous outcrops in Missouri and Kansas. Its thickness ranges from less than 1 foot to approximately 8.5 feet. Where the member is thickest, the limestone is found to be composed largely of colonies of *Chaetetes*, which occur mostly in the upper part. The lower part of the limestone is characteristically a dark brownish-gray or dove-gray, massive, regularly bedded rock which weathers tan or brown. This division has a fairly uniform thickness of 3 to 4 feet. *Chaetetes* colonies, crinoid fragments, brachiopods (especially *Squamularia*), and fusulines are common fossils in the Myrick Station limestone.

Mine Creek shale member. North of Marmaton River in Kansas and in Missouri, the Pawnee limestone includes a well-defined shale unit next above the Myrick Station member. This is called the Mine Creek shale member (JEWETT, 1941, p. 318). South of Marmaton River, the shale is thin but can be identified in many exposures. The thickness of the Mine Creek member ranges from a featheredge to about 17 feet, the thickest sections occurring in the northern part of the outcrop belt. In northeastern Oklahoma, the thickness is commonly less than 1 foot.

The Mine Creek shale consists of gray, black, greenish-gray and yellow shale and a little limestone. In Linn and Bourbon Counties, Kansas, the Mine Creek is divisible into three parts: a lower yellowish to greenish-gray limonitic shale, a thin limestone in the middle, and an upper calcareous shale which contains an extensive fossil zone. Locally this becomes a coquina of brachiopods. Chonetids are the most plentiful fossils. In southern Kansas the Mine Creek shale is identified as a thin parting between the Myrick Station and Laberdie limestones, which are distinguishable by lithologic differences.

Laberdie limestone member. The uppermost member of the Pawnee formation is the Laberdie limestone (JEWETT, 1941, p. 320). It is approximately 10 feet thick in the northern part of the outcrop area in Kansas and 20 feet on the average in the southern part. The limestone is light gray, crystalline, and brecciated. It occurs in rather thin wavy beds or beds of irregular thickness, although the lower part is somewhat more massive. Locally, *Chaetetes* is plentiful, especially in the upper part. Fossils commonly are silicified, but chert nodules are rare.

The upper part of the Laberdie limestone weathers into a "cotton rock" having an irregular hummocky surface, which is pitted and flecked with brown. Sparse fusulines, crinoid and echinoid fragments, and brachiopods, in addition to abundant *Chaetetes*, are characteristic fossils and in Oklahoma silicified specimens of *Cystauletes mammilosus* King, a cylindrical sponge, are locally abundant.

Bandera Shale

The Bandera shale (ADAMS, in ADAMS, GIRTY, & WHITE, 1903, p. 32) comprises relatively thick shale and sandstone occurring above the Pawnee limestone and below the Altamont limestone (Figs. 11, 13). A rather persistent flaggy sandstone member called **Bandera Quarry sandstone** (JEWETT, 1941, p. 292) appears in the upper part (Fig. 8). Near the base, the Mulberry coal (HINDS, 1912, p. 75), which is more than 2 feet thick in many places, is traced from southern Bourbon County, Kansas, far northward into Missouri. It is mined extensively. The thickness of the Bandera shale ranges from about 35 to 75 feet at the outcrop in Kansas. Well records in eastern Kansas show 45 to 100 feet of Bandera shale.

Shale of the Bandera formation is mostly light in color, but a very persistent maroon shale occurs in the upper part. The shale beneath the Mulberry coal is clayey and carbonaceous.

Sandy deposits of the Bandera shale include channel fiillings and evenly layered sandstone sheets. Locally in Missouri some channel sandstone cuts out upper beds of the Pawnee limestone. The Bandera Quarry sandstone member comprises fine-grained micaceous flagstones which attain a thickness of 30 feet or more. Bedding planes are marked commonly by abundant trails and castings, probably made by marine worms.

A thin bed of nearly black limestone occurs in Bourbon County, Kansas, in the lower part of the Bandera shale just above the Mulberry coal. A limestone is noted at the same horizon in wells farther north in Kansas and in western Missouri.

The Bandera shale contains few invertebrate fossils, but fragments of land plants are abundant, especially in the lower part of the formation just above the Mulberry coal.

Altamont Limestone

The Altamont limestone (Adams, 1896) lies next above the Bandera shale. It comprises limestone and shale beds which are best developed in southeastern Neosho and Labette Counties, Kansas, and Bates County, Missouri (Fig. 11, 13). The formation is identified from northeastern Oklahoma to southern Iowa (Cline, 1941, pp. 26-27; Jewett, 1941, p. 326) and is recognized in the subsurface of much of eastern Kansas. Subdivisions of the formation are designated (in upward order) as "Tina" limestone member, Lake Neosho shale member, and Worland limestone member. The type section of the Tina limestone (Cline, 1941, p. 43), has recently been found to belong well below the Altamont and consequently, until a new name for the lower Altamont is chosen, this limestone is called "Tina".

"Tina" limestone member. The lowest member of the Altamont limestone ranges in thickness from a featheredge to slightly more than 10 feet. Like several other Marmaton limestones, it is largely made up of *Chaetetes* colonies at many places. The member generally is thicker in the south than in the north. At several places it contains three limestones separated by thin shale beds. The uppermost limestone, which is a gray crinoidal bed, is the most persistent part of the member.

Lake Neosho shale member. The middle member of the Altamont limestone, called Lake Neosho shale, is a widely distributed, distinctive unit, which can be identfied in exposures where the underlying limestone member is absent. The characteristic thickness of the shale is about 2 feet, but locally it is nearly 6 feet. The shale is yellowish gray and black, the latter occurring uniformly in the lower or middle part. A characteristic feature of the black shale is the presence of irregularly shaped, slightly elongated, dark phosphatic nodules. Commonly they contain fish teeth and bone fragments.

Worland limestone member. The upper member of the Altamont limestone, called Worland (CLINE, 1941, p. 29; JEWETT, 1941, p. 334), is known from Oklahoma to Iowa. This limestone has a rather uniform thickness of about 8 feet in Kansas, but generally it is somewhat thinner in the northern part of its outcrop area. It is a light bluish-gray, massive, fine-grained rock; in some places the lower part is brecciated. Chemically, the Worland limestone is purer than other Marmaton rocks, many samples being found to contain approximately 97 percent $CaCO_3$. Fossils of the member include chonetids, *Squamularia*, *Composita*, other brachiopods, and fusulines.

Nowata Shale

Shale and sandstone between the Altamont and the Lenapah limestones are called Nowata shale (OHERN, 1910, p. 23) (Figs. 11, 13). Along its outcrop in Kansas, the thickness of this formation ranges from almost nothing to approximately 50 feet and locally changes in thickness are abrupt. The Nowata includes light and dark gray to yellow, limonitic clay shale, sandy shale, and sandstone; no coal beds have been found in this part of the section in Kansas. Black shale at the top of the formation commonly contains small smooth dark phosphatic concretions. At most places the Nowata shale is sandy and commonly contains massive, abundantly micaceous sandstone bodies. Lenses of sandstone ranging in thickness to 10 feet or more are locally prominent in the lower Nowata of southern Kansas. Such deposits are differentiated as the **Walter Johnson sandstone** (JEWETT, 1941, p. 335) (Fig. 13). Generally the Nowata shale is unfossiliferous, but brachiopods, including *Mesolobus*, are common in places in the dark shale.

Lenapah Limestone

The Lenapah limestone (OHERN, 1910) which overlies the Nowata shale, is named from the town of Lenapah in Nowata County, Oklahoma. It is divisible into members named (in upward order) Norfleet limestone, Perry Farm shale, and Idenbro limestone (Fig. 11, 13). In Iowa, the Cooper Creek limestone, Exline limestone, and intervening shale are correlated with Lenapah beds.

Norfleet limestone member. The lower part of the Lenapah limestone, below nodular, locally fossilferous shale in the middle part, is called the Norfleet limestone member (JEWETT, 1941, p. 338). This lower member is absent or very poorly developed along much of the outcrop in southeastern Kansas, but it can be identified readily at various places from northeastern Oklahoma northeastward to Bates County, Missouri, and it may be represented in Iowa by the Cooper Creek limestone. In southern Kansas, the Norfleet limestone has a maximum known thickness of 3 feet, but near Lenapah, in northeastern Oklahoma, it is 14 feet thick. Throughout most of the northern part of the Kansas outcrop area, this limestone is about 0.5 foot thick. Where best developed, as in northeastern Oklahoma, the limestone is a light-gray, sandy, hard massive rock which contains few fossils. In Labette County, Kansas, it varies from massive limestone bearing abundant productid brachiopods (*Dictyoclostus*) to slabby limestone which is partly crinoidal, partly characterized by numerous land plant remains. Farther north, is consists of interbedded dark-gray sandy limestone and calcareous shale. The Norfleet limestone is seemingly absent from nearly all the outcrop belt in Bourbon County, but it occurs locally there and in Linn County.

Perry Farm shale member. The middle member of the Lenapah formation includes calcareous fossiliferous shale above the Norfleet limestone and below the Idenbro limestone (JEWETT, 1941, p. 339). It is characterized by irregular limestone nodules in gray shale. At its upper boundary the Perry Farm shale grades into the overlying Idenbro limestone. The thickness of this member in Kansas ranges from a featheredge to about 20 feet. Nodules and discontinuous lenses of gray dense limestone which occur in the Perry Farm shale member commonly range in thickness from a fraction of an inch to 6 inches, but just south of the Kansas-Oklahoma boundary, nodular, mottled limestone belonging to this member attains a thickness of 2 or 3 feet. Locally in Bourbon County, Kansas, and in western Missouri, the Perry Farm shale includes black shale.

At some places the Perry Farm shale contains abundant fossils including corals, mollusks, and brachiopods, especially *Marginifera*.

Idenbro limestone member. The upper, most prominent member of the Lenapah limestone, called the Idenbro limestone (JEWETT, 1941), forms a low escarpment in Labette and Montgomery Counties, Kansas. Thickness of this limestone ranges from 1 to 7 feet in Kansas, the greater thickness prevailing toward the south. The member is thin and inconspicuous north of Labette County.

The Idenbro limestone is generally a light-gray nodular rock. Analysis of typical samples indicates a silica content of 35 percent. The lower part of the member generally is massive and the upper part thin-bedded. In northern outcrops the rock is more sandy, darker in color, and generally more limonitic than in the south. Although it is a thin ledge in Linn and Bourbon Counties, Kansas, the rock is massive, showing no tendency to weather into thin slabs as it does elsewhere.

Algal remains, corals, and bryozoans are common in the Idenbro limestone. Among the corals are *Aulopora* and horn corals; *Chaetetes* has not been observed. Brachiopods, including *Mesolobus*, are common. Fragments of crinoids and bryozoans, such as *Prismopora* and *Fistulipora*, stand out in relief on weathered slabs of the rock.

Memorial Shale

The Memorial shale (Dott, 1936, 1941) includes all observed Desmoinesian beds in the northern midcontinent region above the Lenapah limestone (Figs. 11, 13). In Kansas and western Missouri, it embraces shale between the Idenbro limestone and the Hepler sandstone (Jewett, 1941, p. 340), which lies next above the post-Desmoinesian disconformity. The Memorial beds are generally present above the Lenapah limestone in Kansas, except locally where they have been removed by pre-Missourian erosion. The shale is absent in northeastern Oklahoma (Oakes & Jewett, 1943, p. 633), in an area extending 20 miles or more southward from the Kansas-Oklahoma boundary. In parts of Linn County, basal Missourian sandstone rests directly on the eroded surface of the Lenapah limestone or lower beds. The Memorial shale in Kansas ranges from a featheredge to about 30 feet in thickness.

In most outcrops the Memorial consists of well-bedded, slightly blocky gray clay shale. Some red shale is present locally in the lower part. Small lenses of limonite are common. In a few places the shale is slightly sandy. A coal bed underlain by black shale occurs near the base of the Memorial shale in southern Kansas.

The Memorial shale is barren of fossils along most of its outcrop area in Kansas, but corals and brachiopods are common near Mound Valley in Labette County. There the corals *Striatopora austini* and *Aulopora* occur very abundantly. The brachiopod *Mesolobus* ranges upward nearly to the base of the Hepler sandstone.

UPPER PENNSYLVANIAN ROCKS

General Description

Upper Pennsylvanian rocks of the northern midcontinent region have become widely known as the Missourian and Virgilian Series. The deposits of these divisions were classed together by MOORE & THOMPSON (1949) as the Kawvian Series. Many characters which belong in common to Missourian and Virgilian formations, especially their lack of strongly marked paleontological differentiation, served to link them. Together they form the Zone of *Triticites* and they are readily distinguished on the basis of their fusulinid content from underlying Middle Pennsylvanian rocks belonging to the Zones of *Profusulinella, Fusulinella,* and *Fusulina* (Fig. 5).

The Upper Pennsylvanian rocks of Kansas, here treated as containing the Missourian and Virgilian Series, are bounded below by the disconformity and prominent paleontological break which separates Desmoinesian from Missourian deposits. Their upper boundary is defined by the disconformity or angular unconformity which marks the line between Pennsylvanian and Permian rocks throughout most of North America. The Kansas region contains a well-exposed, nearly complete section of these Upper Pennsylvanian formations, both marine and continental, in which are found innumerable richly fossiliferous zones. The Missourian and Virgilian deposits are remarkably displayed in the regular succession of evenly dipping strata in this area. The many hard rock units form east-facing escarpments one after another in roughly even spacing until that formed by the Brownville limestone at the top of the Pennsylvanian is reached, beyond which are other escarpments formed by the Permian limestones. The weak rocks make plains between the escarpments.

Upper Pennsylvanian rocks show less disparity of development in the geosynclinal belt and stable platform region farther north, as represented by the thickness of deposits found in southern Oklahoma and spread over northern Oklahoma, Kansas, Missouri, Iowa, and Nebraska. This is true even though Missourian deposits are represented by several thousand feet of strata in the Ardmore basin area.

Upper Pennsylvanian rocks exhibit somewhat more marked facies variation than the older part of the system. In eastern Kansas and neighboring territory of the northern midcontinent, in north-central Texas, and parts of New Mexico, the Missourian and Virgilian deposits are characterized by dominance of marine strata and prominence of limestones. The Oklahoma region and part of Texas near the Red River Valley, on the other hand, contain Upper Pennsylvanian rocks among which nonmarine clastics, including prominent red sandstone and shale, predominate. Marine deposits are relatively unimportant and limestones are almost lacking. Similar to the Oklahoma Upper Pennsylvanian in the prevailing nonmarine character of sedimentation, but differing in unimportance of redbeds and presence of numerous coal beds, are formations of the Conemaugh and Monongahela groups in the Appalachian region; here fresh-water limestones are common.

The stratigraphic relationship of the Missourian Series to underlying rocks has been discussed. The upper limit of the Pennsylvanian System has been drawn at more than a half-dozen different horizons during the last twenty-five years (Moore, 1940) (Fig. 4). Agreement is now general among American geologists that the Pennsylvanian-Permian boundary belongs at the base of the Zone of *Pseudoschwagerina* (Wolfcampian, Sakmarian) and equivalent Zone of *Callipteris* (Autunian, lower Rotliegende), and this view has concurrence of various Europeans. Consequently, the upper Virgilian boundary is placed at a widespread disconformity near the Brownville limestone of Kansas and at the base of the Pueblo formation as now defined in north-central Texas. In western Texas there is an angular unconformity between Upper Pennsylvanian deposits of the Gaptank formation and Wolfcampian rocks classed as Lower Permian. This unconformity is evidently associated with mountain-building disturbances which occurred in the Marathon region of western Texas at or near the close of Virgilian time. Wolfcampian rocks overlie the beveled edges of the entire Pennsylvanian section and overlap onto the Pre-Cambrian in extreme western Texas and southern New Mexico.

The upper part of the Gaptank formation in the Glass Mountains of Texas, which is in contact with Lower Permian, is of middle Virgilian age. Therefore, the upper part of the Virgilian is missing in this area. An unconformity of similar magnitude is recognized at Abo Canyon and in the northern Oscura Mountains of New Mexico. In the southern Oscura Mountains, however, the stratigraphic break at the top of Virgilian deposits seems to have much smaller magnitude. The break at the top of the Virgilian Series in Kansas does not seem to have had long duration.

Most Upper Pennsylvanian faunas are distinctive assemblages when compared with the fossils known from adjacent older and younger strata. Although the upper Paleozoic ammonoids are distributed in more or less gradational sequence (MILLER & FURNISH, 1940), the ammonoid zones of *Prouddenites* and *Uddenites* characterize Missourian and Virgilian strata in various parts of North America. The Canyon formation (Missourian) of Texas locally contains abundant ammonoids, including *Prouddenites* and Cisco (Virgilian) rocks also yield numerous ammonoids, including *Uddenites*. Brachiopods are abundant throughout the Upper Pennsylvanian succession but they have not been studied in sufficient detail to permit satisfactory use of them for paleontological zonation.

Fusulinids are abundant throughout the Missourian and Virgilian section above the Bethany Falls limestone or equivalent horizons. These fusulinids, particularly species of *Triticites*, seem to be among the most reliable fossils for local, as well as interregional, correlations of different parts of the two series. Most fusulinids in the Upper Pennsylvanian are referable to *Triticites*, and together, the Missourian and Virgilian rocks comprise the Zone of *Triticites* (Fig. 5). Other fusulinid genera represented in these rocks include *Dunbarinella*, *Schubertella*, *Waeringella*, and *Millerella*. Although forms of *Triticites* are present in the overlying Wolfcampian rocks, the faunas of the Wolfcampian are dominated by species belonging to more advanced fusulinid genera (MOORE & THOMPSON, 1949).

The early Missourian forms of *Triticites* have highly elongate shells similar to and including *T. irregularis* (Staff). These forms are surely not primitive representatives of the genus and this suggests incompleteness in the record of evolving fusulinid forms as seen in Pennsylvanian rocks of North America. Indication of the magnitude of the pre-Missourian break in the Kansas region is obtained from Russia where a large fauna of primitive *Triticites* is found associated with advanced *Fusulina* or *Quasifusulina*. These fusulinids occur in a thick section of Pennsylvanian rocks, equivalents of which are not recognized in North America. They belong in the hiatus which is observed in the American section between youngest known Desmoinesian and oldest known Missourian rocks (MOORE & THOMPSON, 1949). *Triticites* exhibits progressive and rapid evolution throughout the Missourian-Virgilian section, becoming modified in several different directions. The most pronounced evolutionary break in the succession of species belonging to *Triticites* is at the unconformity between the Missourian and Virgilian Series. This paleontological break can be recognized in most parts of America where this part of the Upper Pennsylvanian section contains fusulinid-bearing marine deposits.

Abundant faunas of Missourian and Virgilian fusulinids are known from Utah, Arizona, New Mexico, Texas, Oklahoma, Kansas, Nebraska, Iowa, Illinois, Missouri, Indiana, and Ohio. Less abundant fusulinid faunas belonging to Upper Pennsylvanian zones are known from Wyoming, Idaho, and Colorado. The largest and most nearly complete sequence of these fusulinids found in a continuous section is from rocks exposed along the Kansas River Valley in Kansas.

Missourian Series

General Description

The Missourian rocks are named from outcrops in northwestern Missouri, the best sections being in the vicinity of Kansas City and along the Missouri River near Leavenworth, Kansas. Formations belonging to this series are also very well exposed at many places in eastern Kansas, southward from the Kansas River Valley. Indeed, most of the stratigraphic subdivisions of Missourian rocks are named from localities in eastern Kansas. Among type localities of Missourian units recognized in midcontinent States north of Oklahoma, 36 are located in Kansas, 10 in Missouri, 3 in Nebraska, and 2 in Iowa. The formations are more widely exposed in eastern Kansas than in territory farther north, where a thick cover of Pleistocene deposits conceals the bed rocks except locally.

The Missourian rocks of Kansas are mainly characterized by prominence of limestones. Calcareous marine deposits are much more predominant in this part of the section in Kansas than among Desmoinesian rocks. Between the limestones are persistent shale units, some having very uniform thickness both along the outcrops and beneath the surface, and others showing abrupt variations in thickness from a featheredge to 100 feet or more. Sandstone is a minor constituent of the Missourian part of the Upper Pennsylvanian column in Kansas, and coal beds are unimportant, even though one bed (Thayer) is mined. Conglomerate is lacking.

The outcrop of Missourian formations in Kansas forms a belt slightly more than 50 miles in maximum width which trends south-southwestward from the Kansas City area to Montgomery County, adjoining the Oklahoma-Kansas boundary (Fig. 1). The belt narrows southward, being only 25 miles across in Montgomery County. The thickness of the Missourian deposits is greatest in the south—about 800 feet near the Oklahoma line, 600 feet in the latitude of Iola, and 500 feet near Kansas City. The northward thinning continues into Missouri, Nebraska, and Iowa; the total Missourian section along the Platte in southeastern Nebraska measures only 260 feet.

For many years all Pennsylvanian strata in the northern mid-continent area above the so-called Des Moines group, or Lower Coal Measures, were known as the Missouri group, or Upper Coal Measures. The boundary between these "groups" was drawn at the base of the Hertha limestone, or base of the Kansas City formation of Missouri Geological Survey usage. Moore (1932) relocated this boundary to coincide with the regional disconformity occurring 5 to 100 feet below the Hertha and he classed the redefined Des Moines as a series; the former Missouri group, with addition of strata below and removal of beds above, was designated as the "Missouri series". Studies shortly prior to 1932 had brought to attention the existence of a widespread disconformity in the middle part of the old "Missouri group" and this seemed to rank in importance with other main time-rock boundaries in the Pennsylvanian System. It is less emphasized paleontologically

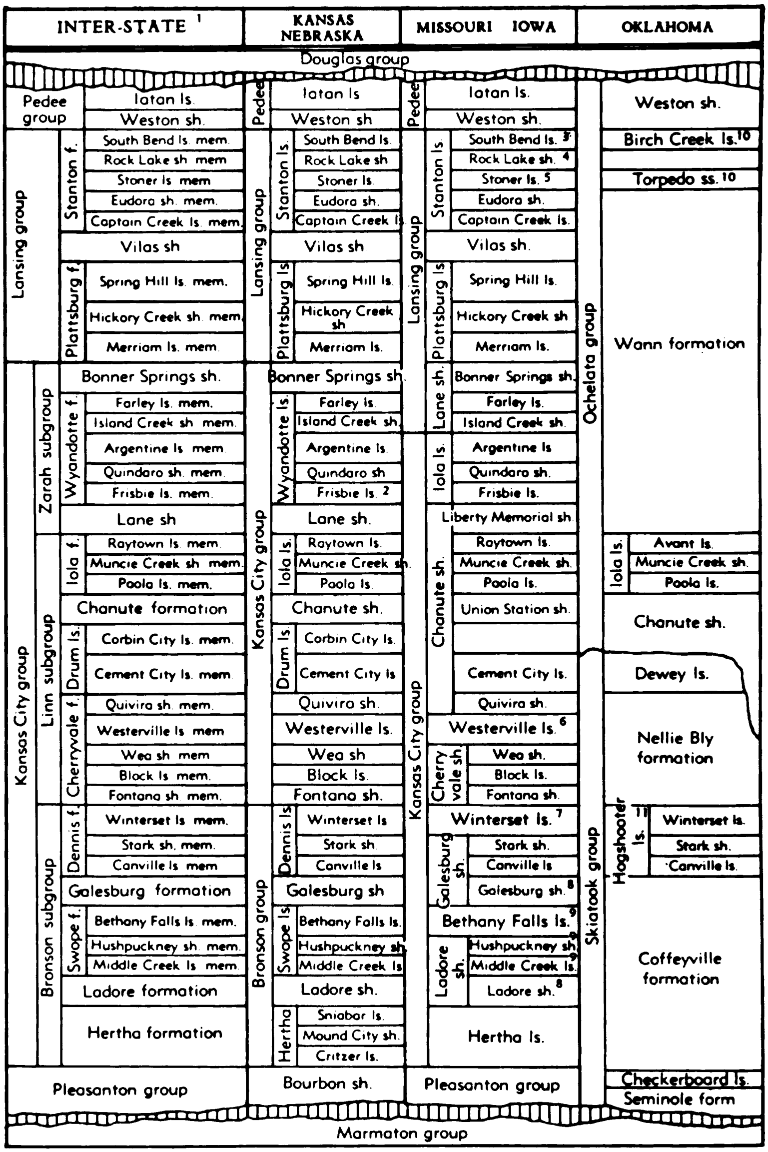

Figure 14. Classification of Missourian rocks in the northern midcontinent area adopted by interstate conference of geological surveys. The agreed classification is compared with those previously used in the several States.

[1] Recognition of subgroups of Kansas City is optional. Also, units such as Stanton, Plattsburg, Chanute, and others having composite lithologic characters, may be designated as formations or as limestone, shale, *et cetera*, according to predominant type of constituent rock.

[2] Frisbie limestone not recognized in Nebraska.

than the boundary marking the top of the Desmoinesian strata, however. The deposits occurring between the post-Desmoinesian disconformity and that in the mid-part of the Upper Pennsylvanian, just mentioned, are here classed as belonging to the Missourian Series. This time-rock division comprises the lower part of the Zone of *Triticites*.

Rocks of the Missourian Series in States north óf Oklahoma are classed in four groups: Pleasanton, Kansas City, Lansing, and Pedee (Fig. 14).

Pleasanton Group

Definition

Lowermost deposits of Missourian age, mostly of clastic nature, are called Pleasanton, a name first used in a stratigraphic sense by HAWORTH (1895) for rocks between the uppermost Pawnee limestone and base of the Hertha formation. Pleasanton was similarly used in Missouri until 1938 (MCQUEEN & GREENE), when it was revised to exclude Desmoinesian strata. In Kansas (MOORE, 1932) and Nebraska (CONDRA, 1935) the name was dropped.

Despite previous variation in the span of beds defined as Pleasanton, recent agreement of the State surveys of Iowa, Kansas, Missouri, and Nebraska at the Lawrence conference should stabilize future application of this name to the interval from the basal Missourian disconformity to the base of the Hertha formation (Fig. 14). The now-accepted definition, which was first used by MCQUEEN & GREENE (1938), precisely corresponds to "Bourbon formation" or group as previously recognized in Kansas and Nebraska. Priority in application to the stratigraphic span that here is assigned to the revised Pleasanton and consistency in numerous publications make Bourbon preferable to Pleasanton,

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[3] Called South Bend or Little Kaw limestone by McQueen and Greene (1938).

[4] Called Rock Lake or Victory Junction shale by McQueen and Greene (1938).

[5] Called Stoner or Olathe limestone by McQueen and Greene (1938).

[6] Westerville limestone included in Cherryvale shale by Clair (1943).

[7] Winterset limestone classed as members of Dennis limestone by Clair (1943).

[8] Galesburg and Ladore shale classed both as formation and member by McQueen and Greene (1938).

[9] Bethany Falls, Hushpuckney, and Middle Creek classed as members of Swope limestone by Clair (1943).

[10] Oakes (1940); stratigraphic placement of beds above Wann formation uncertain.

[11] Oakes (1940) includes Lost City limestone member locally instead of Stark and Canfield, but in many places only Winterset member is present.

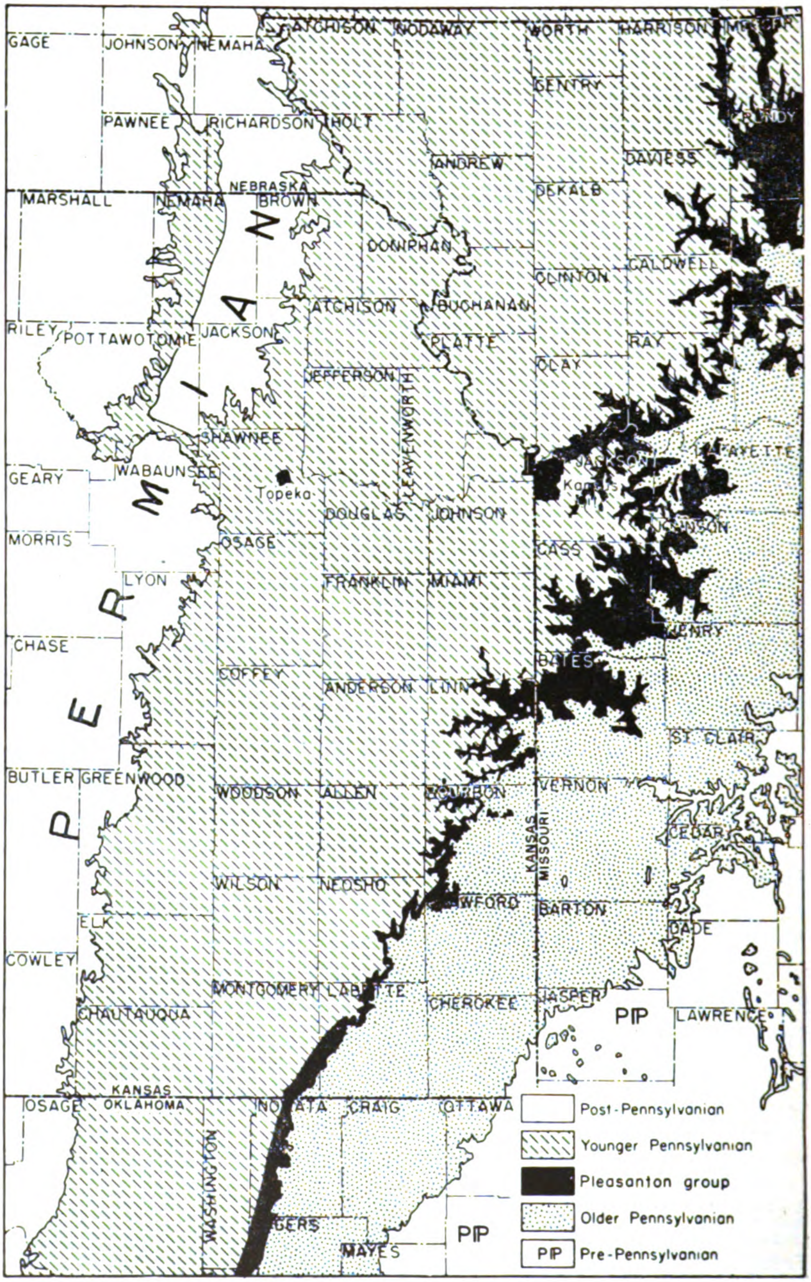

Figure 15. Distribution of outcrops of the Pleasanton group in Kansas and part of Missouri. Southward from northern Labette County, Kansas, the Pleasanton beds are not differentiated as a unit owing to disappearance of the Hertha limestone, which marks the top. Equivalent strata in this region are classed as the Seminole formation and lower part of the Coffeyville formation.

but the latter name has been accepted in the interest of obtaining uniform inter-State nomenclature. It is deemed acceptable on the basis of the unanimous agreement as to revised definition. The name Bourbon, which has been used by the Kansas Geological Survey since 1932, will be suppressed. The Pleasanton deposits are classed as a group.

Distribution and Thickness

The outcrop of strata belonging to the Pleasanton group is distributed as a south-southwest trending belt which crosses southeastern Kansas from Linn County to Montgomery County (Fig. 15). The width of this belt ranges from two to six miles. In northwestern Missouri, the mapped width of Pleasanton outcrops becomes considerably greater, especially in Bates, Cass, and Grundy Counties.

Inasmuch as most of the strata belonging to the Pleasanton group are fine-grained clastic sediments, which are non-resistant to weathering, the outcrop belt generally is covered by soil and vegetation; it forms a slope beneath the escarpment formed by lower limestone beds of the Kansas City group.

In southern Kansas (most of Labette County and southeastern Montgomery County) and in northeastern Oklahoma, the Pleasanton group cannot be differentiated from shaly and sandy beds which are equivalent to part of the Kansas City group. The Hertha limestone, which forms the base of the Kansas City group northward from Labette County, disappears southward. Rocks equivalent to the Pleasanton beds in this southern area are classed as the Seminole formation, below, and part of the Coffeyville formation, above.

The thickness of the Pleasanton group along its outcrop in Kansas ranges from 35 to 150 feet. Both exposed and buried parts of the group in eastern Kansas have greater thickness in the north than in the south. West of the Nemaha anticline (Marshall County to Sumner County) this rock division is reduced in thickness and seems to pinch out not far from the uplift. In eastern Nebraska, a few feet of clastic rocks which separate Marmaton and Kansas City beds are recognized as Pleasanton (Condra & Reed, 1943, p. 53); in its outcrop belt in western Iowa, the Pleasanton group ranges in thickness from a few to about 15 feet (Cline, 1941).

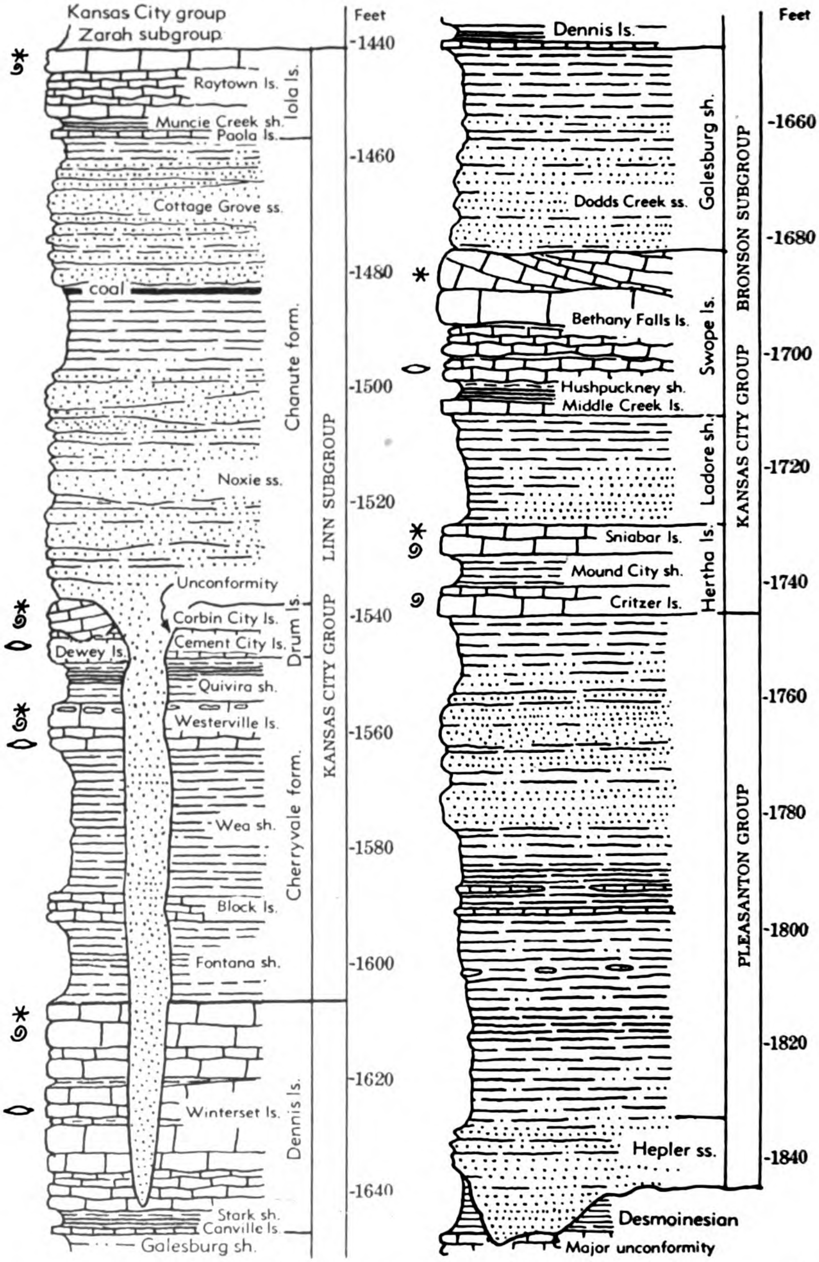

Figure 16. Generalized columnar section of the Pleasanton group and lower part of the Kansas City group in Kansas. These rocks comprise the lower part of the Missourian Series in eastern Kansas.

Lithologic Character

At the base of the Pleasanton rocks, lying unconformably on uppermost Desmoinesian strata, is the fairly persistent **Hepler sandstone** (JEWETT, 1940, p. 8) (Fig. 16). This sandstone is believed to be the northward extension of the upper part of the Seminole formation of northeastern Oklahoma (MOORE, *et al.*, 1937, fig. 13; OAKES & JEWETT, 1943, fig. 1). Probably it is nearly the time equivalent of the Chariton conglomerate of northern Missouri and southern Iowa (WELLER, WANLESS, CLINE & STOOKEY, 1942, fig. 1). Although the Hepler sandstone is persistent along its outcrop, it is replaced by shale or is very thin beneath the surface a short distance west of the Pleasanton exposures. In general, the Hepler is a sheetlike deposit and only locally in the northern part of the outcrop area and in near-by subsurface occurrence, this sandstone is found to fill sharply cut channels. Some of the channel fills are asphaltic where exposed, and some contain oil not far west of the outcrops.

Several thin limestones are included in the lower part of the Pleasanton group. The lowermost of these in southern Kansas has been found to be the **Checkerboard limestone** (OAKES & JEWETT, 1943), a thin but prominent marker bed which has been traced more than 150 miles southward in Oklahoma. In Kansas, the Checkerboard has not been identified north of Labette County but one of several thin limestones, which occur as far north as Bourbon or Linn Counties, may represent this unit. In Labette County, the Checkerboard limestone and underlying beds, including a thin deposit of coal and the Hepler sandstone, closely resemble a typical Cherokee cyclothem.

The lithologic character of the middle and upper parts of the Pleasanton group is highly variable. Thick black, carbonaceous shale, having characteristics of oil shale and containing dark limestone concretions to 2 feet in diameter, appears in southeastern Kansas. Farther north, in northern Bourbon and southern Linn Counties, alternating layers of dark shale and dark flaggy limestone occupy the same position in the Pleasanton group; they range in total thickness to approximately 50 feet. Still farther north, in Linn and Miami Counties, massive sandstone beds, some of which fill channels as much as 40 feet deep, are exposed. These sandstones collectively are called **Knobtown sandstone** (GREENE, 1933, p. 13). In some areas the upper part of the Pleasanton contains very fine-grained, greenish sandstone, which is unlike most Pennsylvanian sandy deposits in the northern midcontinent. Such sandstone, together with carbonaceous shale and flaggy limestone, comprises a relatively minor portion of the Pleasanton group as a whole. Gray and brownish shale, some of which is unusually free from sand and contains marine fossils, is the dominant rock type.

In general, rocks of the Pleasanton group are more dominantly marine in southeastern Kansas than farther north in the State, a condition opposite to that of the overlying Kansas City and younger Pennsylvanian deposits. Locally in southern Kansas, the basal sandstone has a sandy limestone facies and contains marine invertebrates. The thick black shale accumulations and the alternating deposits of dark shale and flaggy limestone are seemingly nonfossiliferous, but marine fossils occur somewhat sparsely in the lighter-colored shale. The Knobtown sandstone in northeastern Kansas and western Missouri is judged to be a marine deposit which was transported to this area from an easterly source. It is significant that shale beds adjacent to and below channel fillings are almost entirely free of sand. Locally, a slight erosional disconformity is found at the top of the Pleasanton rocks, separating them from the Hertha limestone.

Marine invasions of eastern Kansas during early Missourian time when Pleasanton deposits were formed, probably came from the west and southwest. Land-derived clay and sand accumulated rather rapidly, and occasionally marine plants and animal remains formed calcareous beds east of the Nemaha anticline. Farther west, in the more open sea, deposition took place more slowly.

Kansas City Group

Definition

The Kansas City group was named (Hinds, 1912, p. 7) from exposures in the bluffs of the Missouri River and tributaries at Kansas City, Missouri. A revised definition of the group was adopted by the conference of State geological surveys at Lawrence in May 1947 (Fig. 14). The term is to be used in Iowa, Kansas, Missouri, and Nebraska but is not applicable to Missourian deposits in Oklahoma. The lower boundary of the group is placed at the base of the Hertha formation and the upper limit is drawn at the base of the Plattsburg formation. This modifies the originally designated limits by addition of the "Lane shale" of Missouri usage (Island Creek shale, Farley limestone, and Bonner Springs shale) at the top of the group, and to the same extent changes usage which has been followed by the Missouri Geological Survey since 1912. The new upper boundary of the Kansas City group coincides with definition of this line employed during the past 15 years in Kansas (MOORE, 1932) and Nebraska (CONDRA, 1935), but the lower limit of the group (top of the Dennis formation) used by the Kansas and Nebraska surveys in recent years differs from the new definition which follows original Missouri survey usage and that followed in Iowa. Subdivisions of the Kansas City group, as previously defined and as now recognized, are shown in Figure 14.

The term Kansas City, especially in combination with the overlying Lansing as Kansas City-Lansing, has been very widely used by geologists in the northern midcontinent for designation of subsurface beds extending from Hertha to Stanton. Surface nomenclature adopted by the State surveys thus accords with that which has come to be accepted as best suited to subsurface requirements.

Distribution and Thickness

Rocks of the Kansas City group are very well exposed in and around Kansas City, Missouri, the type locality, and Kansas City, Kansas (Fig. 17). Outcrops appear in the bluffs of the Missouri and Kansas River Valleys and along tributary streams as far northwestward as Leavenworth and westward to the vicinity of De Soto, Kansas. The very irrergular eastern margin of Kansas City outcrops in this region is marked by a prominent escarpment which trends northeastward across southern Clay County, Missouri, north of the Missouri River, and obliquely across Jackson and Cass Counties, Missouri, east and south of Kansas City. From the Kansas City area the outcrop belt trends southwestward across eastern Kansas, the most important exposures of rocks belonging to the Kansas City group being found in Johnson, Miami, Linn, Anderson, Bourbon, Allen, Neosho, Wilson, Montgomery, and Labette Counties. Along most of this trend, the belt is 25 or more miles in width. Its eastern edge is topographically defined by the escarpment of lower Kansas City limestone beds. The west-

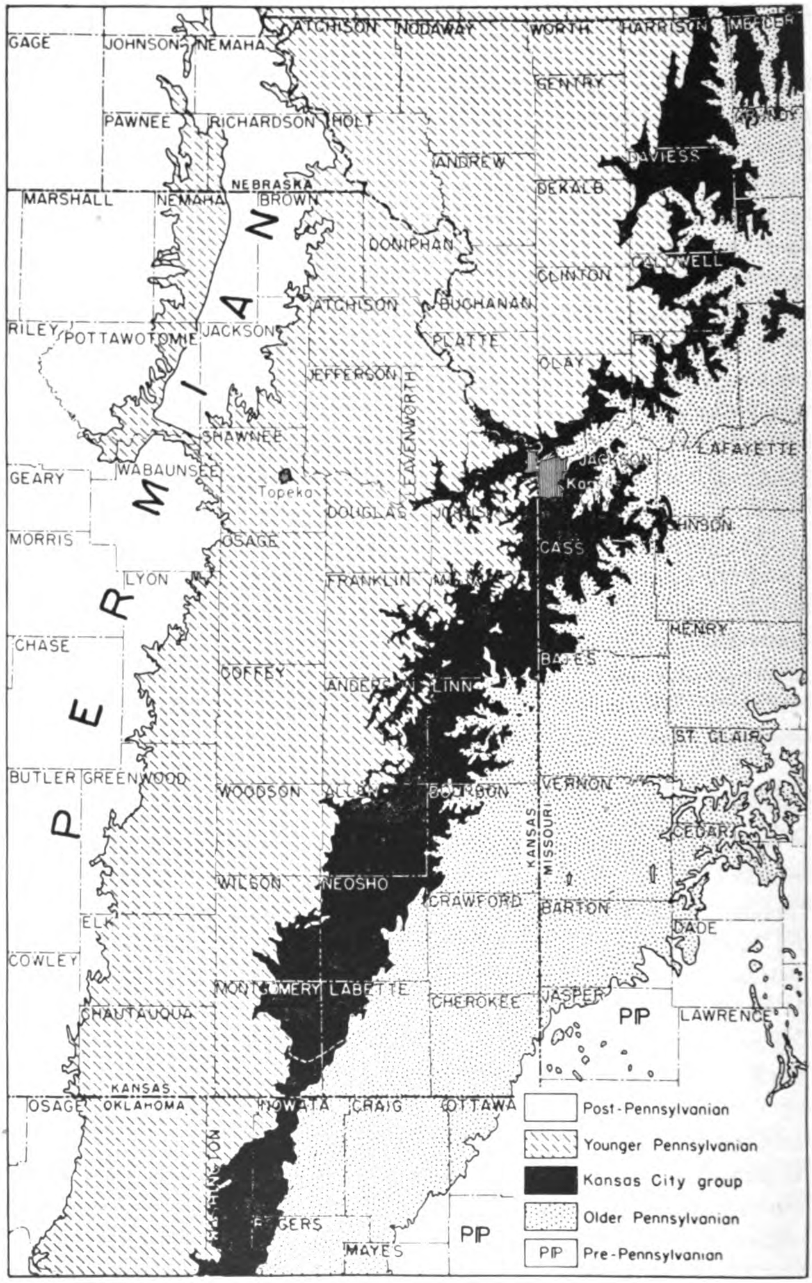

Figure 17. Distribution of outcrops of the Kansas City group in Kansas and parts of adjoining States. This group consists of escarpment-forming limestone formations and intervening shales and sandstones. South of central Montgomery County, Kansas, the outcrops shown on the map belong to the upper part of the Skiatook group (upper Coffeyville, Hogshooter, Nellie Bly, and Dewey formations) and lower part of the Ochelata group (Chanute, Iola, and lower Wann beds).

ern margin is similarly marked by the escarpment made by the Lansing limestones.

Southward from east-central Montgomery County, Kansas, the rocks equivalent to the Kansas City group are not differentiated lithologically or topographically from strata below and above in such manner as to make recognition of the group readily possible. It is not a natural assemblage of beds. The rock succession of Missourian age in this region near the Kansas-Oklahoma boundary and southward across eastern Oklahoma, accordingly, is classed in two groups called Skiatook, below, and Ochelata, above. Equivalents of the Kansas City group are mainly clastic deposits. Their stratigraphic classification is shown in Figure 14.

The Kansas City group is the thickest division of the Missourian Series. It is about 350 feet thick in the latitude of Iola and 275 to 325 feet thick in the Kansas City area. Northward thinning of beds belonging to the group is shown by measurements of 165 feet in Richardson County, southeasternmost Nebraska, and 100 feet in the Platte Valley, south of Omaha.

Lithologic Character

As a whole, the Kansas City group is characterized by prominence of relatively thick, persistent limestones (Fig. 16). Between the limestones are shales of varying thickness, predominantly light-colored and clayey to sandy in composition. Thin but very persistent black platy shale units are associated with most of the limestone formations of the Kansas City group. Sandstone is not a prominent constituent of this division of the Pennsylvanian rocks in northeastern Kansas but it increases in abundance southward to such extent that between the latitude of Iola and the Kansas-Oklahoma boundary sandstone is quantitatively as great or greater than limestone in the Kansas City group. Most of the sandy deposits are thin-bedded and fine-grained but some deposits are fairly thick-bedded and medium- to coarse-grained. Coal beds are found in the middle part of the Kansas City group. Most layers are very thin and impersistent, but the Thayer coal, which attains a thickness of 29 inches (SCHOEWE, 1944, p. 97) in Montgomery County, Kansas, is mined at several places.

Some of the rock subdivisions of the Kansas City group are amazingly uniform in lithology and thickness, whereas others are decidedly variable in physical features and show somewhat erratic

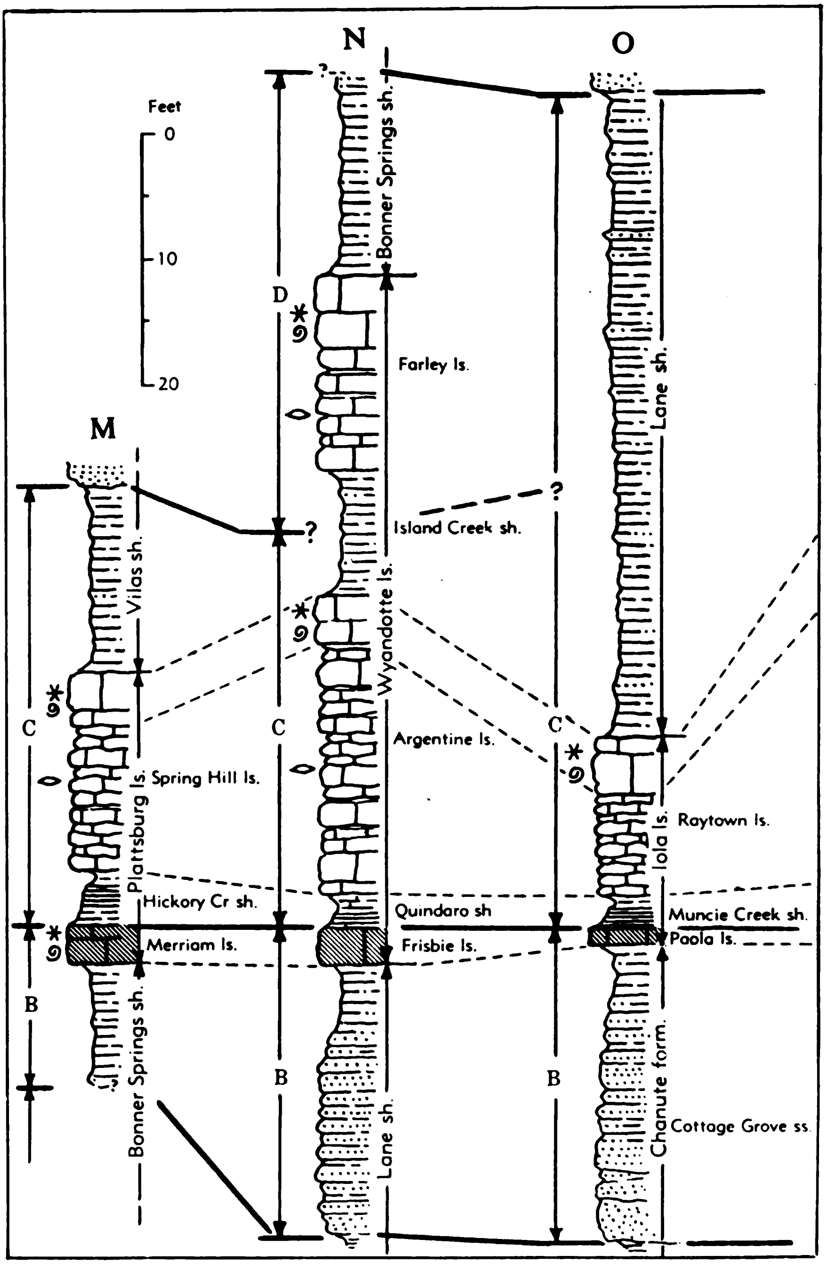

Figure 18. Sections of lower Lansing and upper Kansas City beds showing cyclothems grouped in megacyclothems. The individual cyclothems are indicated by the letters B, C, and D. Megacyclothems comprise the entire sequence of beds in any one of the three plotted sections, M, N, O. Stratigraphic position of the sequences is shown on the index section in Figure 19.

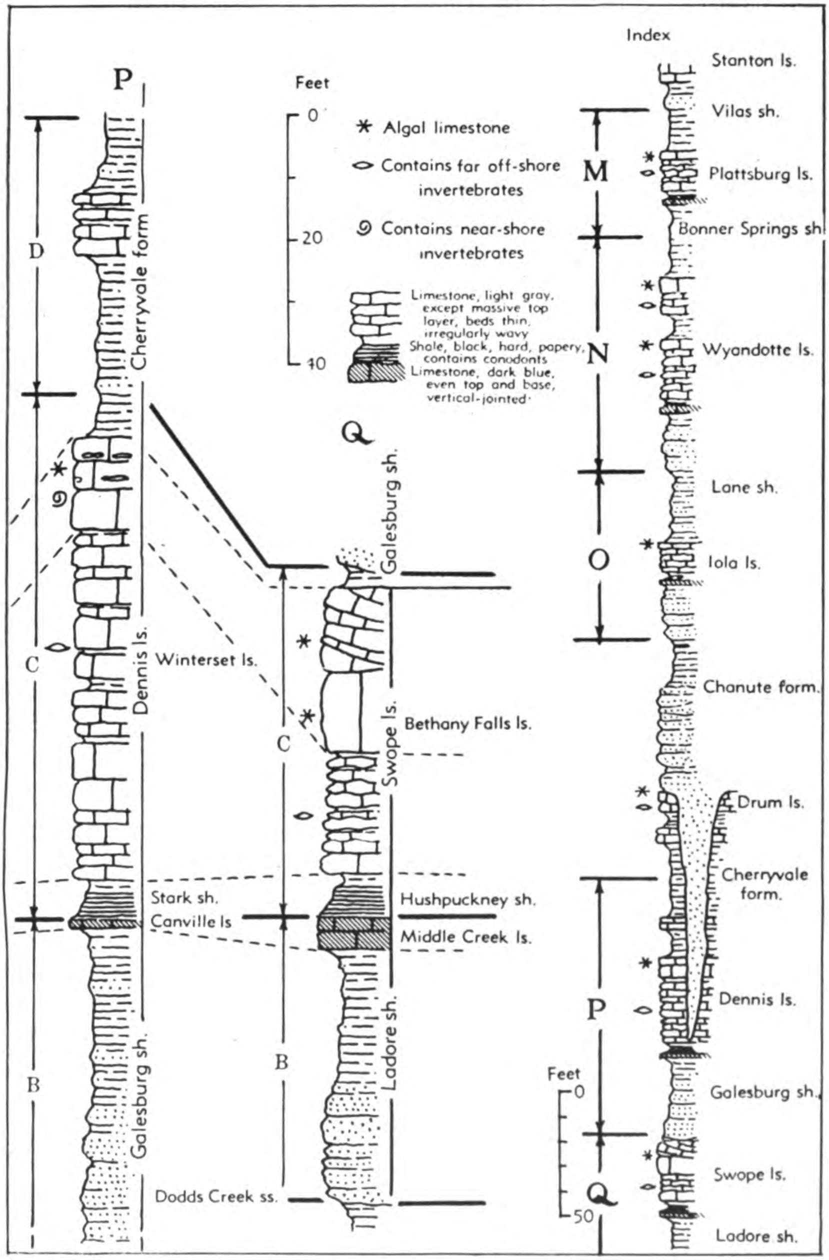

Figure 19. Sections of lower Kansas City beds showing cyclothems and megacyclothems. These units are differentiated as explained in description of Figure 18.

changes of thickness. Physiographically, the group is characterized by well-defined escarpments which mark the outcrop of limestone formations, especially the Dennis, Iola, and Wyandotte.

Much of the variability of Kansas City beds, including especially southward change of facies, seems to be correlated with successive uplifts in the area of the Chautauqua arch (Barwick, 1928, p. 177), which is a pre-Mississippian westward-trending extension of the Ozark uplift in southern Kansas and northern Oklahoma. The more striking structural features of the arch were formed by warping before Mississippian sedimentation, for the Mississippian rocks progressively overlap the truncated older Paleozoic formations of the arch. Movements occurred at intervals throughout middle Missourian time and culminated in regional warping late in the Missourian Epoch. There has long been such difficulty in tracing Oklahoma equivalents of Kansas City beds (for example, the Hogshooter, Dewey, and Avant limestones) into the standard Kansas section, that the question of correlation has come to be known as the "State Line Problem". Many of the difficulties lie in the existence of overlaps, long unrecognized, in connection with which key horizons are cut out locally, and in the abnormal thinning of many units over the high area along the State boundary. Features of middle Missourian sedimentation which show definite relation to the Chautauqua arch include: (1) overlaps from the south and north across higher parts of the arch, (2) thinning of marine units in this area, (3) greater proportion of nonmarine and channel deposits over the arch, and (4) a striking duplication of facies in northeastern Kansas and northeastern Oklahoma areas, which are separated by rocks showing very different lithologic facies in the intervening territory near the Kansas- Oklahoma boundary.

Cyclic Sedimentation

Deposits included in the Kansas City group exhibit regularities of sequence which denote both cyclothems and the arrangement of successive cyclothems of differing character which belong to so-called megacyclothems (Moore, 1936, p. 29). Simple cyclic sequences are represented by nonmarine sandstone, overlain by sandy to clayey shale containing land plant remains, underclay, a coal bed, and shale or limestone containing marine fossils. Some of the marine beds contain invertebrates interpreted as representing a very near-shore assemblage; in such faunas are inarticulate brachiopods, certain types of calcareous brachiopods (*Derbyia, Juresania*) in abundance, thick-shelled clams (especially *Myalina*) and radially ribbed scallops (*Aviculopecten* and other genera), associated with more or less common snails (especially bellerophontids) and some bryozoans. Off-shore faunal assemblages are characterized by a varied group of marine invertebrates and particularly the wheat-grain foraminifers called fusulinids (*Triticites* in Kansas City beds). Algal limestones occur at the top of several limestone formations of the Kansas City group, and these beds evidently represent the shallow-water deposits of retreating phases of the marine inundations.

Features of cyclic sedimentation observed in part of the Kansas City group of eastern Kansas and in lower Lansing beds are indicated graphically in Figures 18 and 19, which show correlation of elements belonging to a number of different cyclothems. The stratigraphic position of the respective cyclothems is recorded by the index section on Figure 18.

The cyclothems designated by the letter "B" are mostly distinguished by presence of sandstone at the base and medium-to dark-blue dense brittle vertical-jointed massive limestone at the top. Invariably, the upper limestones of the "B" cyclothems are characterized by thinness—a few inches to 4 or 5 feet maximum. A coal bed occurs between the basal sandstone and the upper limestone of some of these cyclothems.

The cyclothems which are marked by the letter "C" are characterized by the distinctive carbonaceous black platy shale layer, a few inches to 3 or 4 feet thick, at the base. The black shale is overlain by thin light-colored shale and this in turn by thick light-gray to nearly white fine-textured limestone which typically occurs in thin uneven beds separated by wavy shale partings. The thin-bedded wavy limestone contains a varied assemblage of marine invertebrates, generally including fusulinids. The top portion of the limestones is massive or thick-bedded, nodular or even-textured, and commonly somewhat siliceous; it contains algal remains and where invertebrates are found, the assemblage is dominated by mollusks, a few brachiopods belonging to certain genera (especially *Composita*), and some bryozoans. Oölite occurs in the position of this algal limestone and in no other part of the section. The thick light-colored limestone is overlain by clayey to sandy shale which is mostly unfossiliferous.

Cyclothems indicated by the letter "D" are differentiated less definitely and they are not characterized generally by the distinctive peculiarities of the "B" and "C" sequences. Wherever recognized, they are clearly separable from subjacent and superjacent cyclothems by deposits which denote retreat of marine waters, whereas the central part of such cyclothems records more or less off-shore sedimentation during marine submergence.

The index letters employed for designation of cyclothems shown in Figures 18 and 19 correspond to those used in drawing the Shawnee megacyclothems. Correspondence of the "B" and "C" cyclothems in the Missourian and Virgilian parts of the Upper Pennsylvanian section respectively, is obvious. It is interesting to observe that nowhere in the Kansas City and Lansing groups are known to exist distinct equivalents of the "A" cyclothems of Shawnee megacyclothems, although these are strongly marked features of the latter.

Classification

The strata included in the Kansas City group are judged to be divisible advantageously into three main parts of subequal thickness, which are treated as subgroups. In upward order, these are called Bronson, Linn, and Zarah (Fig. 14). They differ in dominant lithologic characteristics and are bounded by unusually persistent marker beds.

The Bronson beds are distinguished by prominence of persistent limestone formations, in upward order called Hertha, Swope, and Dennis. Between these units are predominantly shaly deposits named the Ladore and Galesburg formations, which increase in thickness southward and contain a good deal of sandstone.

The Linn subgroup forms the middle part of the Kansas City group in which shale, associated with mostly rather thin limestones, is a characteristic lithologic feature. Formations recognized in this part of the section, in upward order, are named Cherryvale, Drum, Chanute, and Iola. The limestone units tend to thicken locally. Shale and sandstone predominate toward the south.

The Zarah portion of the Kansas City group contains the Lane shale at the base, Wyandotte formation (mainly limestone) in the middle, and Bonner Springs shale at the top. The Wyandotte beds are prominent in the Kansas City region and northward but disappear about 75 miles southwest of Kansas City. Where the Wyandotte is absent, the Zarah subgroup comprises the Lane-Bonner Springs shale.

Bronson Subgroup

General Description

The lower main division of the Kansas City group, as now defined, consists of the old "triple limestone" (Haworth, 1895, p. 458), which was named Bronson by Adams (1904). It extends from the base of the Hertha formation to the top of the Dennis formation (Fig. 16). Along the outcrop from central eastern Kansas into Iowa, the Hertha, Swope, and Dennis formations are repectively separated by relatively thin shales and they form a well-defined escarpment which rises above the Pleasanton lowland belt.

The uppermost Bronson unit (Winterset limestone) extends as far southward as T. 8 N. in Oklahoma, some 60 miles south of Tulsa, but the Hertha disappears before the Kansas-Oklahoma State line is reached. Where the normal lower boundary of the subgroup (and group) can be followed no longer, classification must be modified by reducing the stratigraphic span so as to include only units that can be recognized and traced, or nomenclature suited to northern territory must be discarded in favor of different terminology that is adapted to southern Kansas and northeastern Oklahoma. The latter course has been followed. South of the point where the Hertha disappears, lower Missourian deposits are referred to the **Skiatook group.** Rocks equivalent to the Bronson subgroup are named, in upward order, Coffeyville formation and Dennis formation (Hogshooter limestone in Oklahoma).

Bronson rocks are partly marine and partly nonmarine. In the north, where the total thickness is less than 100 feet, almost the entire section is composed of sediment that accumulated on the shallow sea floor. In this area considerably more than half of the subgroup consists of limestones separated by thin shales, which seemingly are mostly marine. Farther south, the shale formations are thicker and they merge into largely nonmarine deltaic deposits, which extend far southward into the Oklahoma basin. The Bronson limestones are calcareous tongues which divide the clastic deposits.

Chert is present in nearly all limestone units of the Bronson subgroup. It is conspicuous in the Winterset and Bethany Falls limestones and is not confined to any one type of limestone. Cross-bedded oölitic (algal) limestone replaced by chert furnishes evidence of the secondary origin of some of the chert. Also, the chert in some limestones is most plentiful in places where the rocks have been longest exposed.

The thickness of the Bronson subgroup ranges from about 55 feet in the Platte Valley of Nebraska to about 175 feet in southern Kansas. The average thickness of this division in the vicinity of Kansas City is about 80 feet and in the latitude of Iola, about 100 feet.

Bronson rocks, associated with a few underlying and overlying beds, comprise three megacyclothems which may be designated Hertha, Swope, and Dennis. Each is composed of two or more cyclothems in which individual phases generally are not as distinct as in some other parts of the section.

Hertha Limestone

The lowest formation of the Kansas City group, which is called Hertha (Adams, in Adams, Girty, & White, 1903, p. 35), is divisible into three members, in upward order called Critzer limestone, Mound City shale, and Sniabar limestone (Fig. 16).

The limestone members vary somewhat in lithologic features from place to place, and each may exhibit characters seen in the others. Accordingly, they are distinguished most readily and definitely by their position below and above the distinctive Mound City shale member. The Sniabar limestone is more persistent than the Critzer member, but locally the latter is by far the most conspicuous part of the Hertha formation. The three members are identified as far south at T. 32 S., R. 19 E., Labette County, Kansas, and as far north as southern Jackson County, Missouri. The southernmost exposure in which identifiable Hertha beds have been seen is in southwestern Labette County (sec. 19, T. 33 S., R. 18 E.), 11 miles north of the Kansas-Oklahoma boundary. Calcareous shale equivalent to part of the Hertha formation is recognized, however, in a zone about 135 feet below the top of the Coffeyville formation in southeastern Montgomery County, near the Oklahoma border. Along its outcrop in Kansas, the formation ranges in thickness from a few inches to about 30 feet.

The Hertha formation is identified at various points in northwestern Missouri and is known to extend into Iowa, where it is overlapped by Cretaceous beds. In eastern Nebraska, the Hertha is exposed in the Platte Valley and along the Missouri River at Jones Point near the mouth of Weeping Water Creek, north of Nebraska City (CONDRA, 1930). The formation can be identified in cuttings from wells west of its outcrop area in eastern Kansas, northwestern Missouri, southwestern Iowa, and eastern Nebraska.

Critzer limestone member. The Critzer limestone (JEWETT, 1932, p. 99) lies next above uppermost Pleasanton beds and is overlain by the Mound City shale. Locally, it is separated from the Pleasanton group by a disconformity. As seen in most exposures, the Critzer is a light-gray, sandy, impure, massive limestone ranging from 2 to 5 feet in thickness. In southern Kansas. where it becomes thinner, this member is composed of nodular, hard, dark limestone, probably of algal origin.

Normally, the lower part of the Critzer limestone contains a molluscan fauna characterized by large bellerophontid gastropods; the middle part commonly bears corals and brachiopods; and the upper part consists of algal limestone. In many northern outcrops, the molluscan facies comprises the whole member and the rock appears as a single massive bed. At some places, it is almost entirely made up of thin-and-wavy bedded gray limestone containing corals and brachiopods, the lower molluscan and upper algal phases being inconspicuous or absent.

The thickness of the Critzer limestone ranges from a few inches to about 11 feet along its outcrop in Kansas. Where thick, it commonly forms a rimrock above steep slopes developed on Pleasanton beds.

Mound City shale member. The middle member of the Hertha formation, called the Mound City shale (JEWETT, 1932, p. 99), ranges in thickness from a featheredge to 8 feet, the average being about 5 feet. The greatest thickness is in the northern part of the outcrop area. Where well developed and well exposed, this shale is divisible into three parts: (1) a lower nonfossiliferous, blocky gray shale, which locally is black; (2) a thin bed of crinoidal limestone or zone of limestone nodules; and (3) an upper blocky gray shale rich in chonetid brachiopods, ramose bryozoans, and (locally) small horn corals and crinoid fragments. A thin bed of coal, which is observed in western Missouri in the lower part of the Mound City shale, probably corresponds to the black shale. The lower gray shale contains chonetid brachiopods and some other fossils; pectinoid clams and phosphatic-shelled brachiopods (*Orbiculoidea, Lingula*) have been found in the black shale.

Sniabar limestone member. The upper member of the Hertha formation called the Sniabar limestone (JEWETT, 1932, p. 99), includes all limestone and shale beds in the formation above the Mound City shale. In places where the Critzer member is absent and the Mound City shale cannot be differentiated from upper Pleasanton beds, this limestone comprises the entire Hertha formation.

The Sniabar is dominantly a fine-grained gray limestone which weathers brown. Along most of its outcrop in Kansas, this limestone is a massive resistant ledge, but locally it is a thinly wavy-bedded rock which breaks down into slabs. In southern Kansas, silty layers alternate with purer limestone, and shale partings are common.

Coralline limestone, bearing abundant *Aulopora*, locally comprises nearly the entire thickness of the Sniabar member, but corals are more characteristic of the basal part. In some places, however, the lower few inches is composed almost wholly of crinoid fragments. Productid brachiopods (*Marginifera*) are very common in this limestone at places in southern Kansas. Algal limestone commonly forms the uppermost part of the member.

In Kansas the thickness of the Sniabar limestone ranges from a few inches to about 11 feet.

Ladore Shale

The Ladore (ADAMS, 1904, p. 18) is a clastic formation between the Hertha and Swope limestones (Figs. 14, 16). It lies above the Sniabar and below the Middle Creek limestone, but south of central Neosho County, where the Middle Creek disappears, the Ladore shale is overlain by the middle shale member (Hushpuckney) of the Swope formation. Since such a contact of shale-on-shale generally cannot be distinguished, the combined beds are designated as Ladore-Hushpuckney. The Ladore beds are the northward equivalent of part of the Coffeyville formation, which is recognized southward from west-central Labette County, Kansas.

A strikingly abrupt change in thickness and lithology of the Ladore shale is observed in southeastern Allen County, Kansas. North of the line between T. 25 S. and T. 26 S. it is marine shale containing locally limestone nodules and nodular limestone, the thickness of the entire Ladore being only 2 feet or a little more. Much of the limestone shows evidence of algal origin. Southward from the line mentioned, the shale expands rapidly to 20 feet or so of sandy deltaic deposits, in which sandstone and coal appear. In southern Neosho County and farther south, these sandy Ladore deposits are 60 to 70 feet thick.

Swope Limestone

The Swope formation (Moore, 1932, p. 90) includes beds above the Ladore shale from the base of the Middle Creek limestone to the top of the Bethany Falls limestone (Figs. 14, 16). The expression of cyclothem units arranged in megacyclic sequence is closely comparable to that seen in limestone formations of the Shawnee group, Virgilian Series. The lower Swope limestone (Middle Creek) has typical lithologic features of the thin, dense, vertical-jointed limestone which belongs to the cyclothem next above the lowermost cyclothem of Shawnee megacyclothems and the black platy middle Swope shale (Hushpuckney) and the upper Swope limestone (Bethany Falls) match corresponding strata of the third cyclothem of the Shawnee megacyclothems. No other equivalents of Shawnee cyclic units are distinguished.

The thickness of the Swope limestone at the type locality, in the southeast part of Kansas City, Missouri, is about 30 feet. This is the average thickness of the formation northeastward into Iowa and southward to Bourbon County, Kansas, east of Chanute. Farther south, the limestone gradually becomes thinner and disappears a few miles south of Mound Valley, in Labette County.

Middle Creek limestone member. Named from outcrops near LaCygne in eastern Linn County, the Middle Creek limestone member (Newell, in Jewett, 1932, p. 101) of the Swope formation conformably overlies the Ladore shale and is overlain by black fissile shale of the Hushpuckney shale member of the Swope (Fig. 19). It is a dark bluish, dense, hard, brittle, even-textured limestone, which in most outcrops shows vertical joints. The thickness of the member ranges from a few inches to about 8 feet, the maximum being observed in western Bourbon County. The thickness in any one region shows very slight change. The limestone is identifiable in northwestern Missouri and Iowa, but disappears southward in central Neosho County, Kansas.

Hushpuckney shale member. Very persistent shale between the two limestone members of the Swope formation has been named the Hushpuckney shale (NEWELL, in JEWETT, 1932, p. 101). The lower part of the shale is black and fissile; it contains few observed fossils other than conodonts and other microfossils. The upper half to two thirds of the member consists of bluish or bluish-gray clay shale (Fig. 19). The thickness of the Hushpuckney shale ranges from 3 to 6 feet, the average being 4 feet. The member is distinguishable in northwestern Missouri and across eastern Kansas as far as Erie, where the Middle Creek limstone, which separates it from the Ladore shale, disappears.

Bethany Falls limestone member. The Bethany Falls limestone (BROADHEAD, 1866, p. 320) is the main limestone unit of the Swope formation, occurring above the Hushpuckney shale and beneath the Galesburg shale. The name is derived from the vicinity of Bethany, county seat of Harrison County, in northwestern Missouri. It is somewhat variable from place to place, but can be identified at most outcrops very readily and definitely. The Bethany Falls is traced from south-central Iowa to southern Kansas not far from the Oklahoma boundary.

Two chief subdivisions of the member are recognized—(1) a lower unit consisting of light-gray, dense, thin-bedded limestone, which occurs in uneven, somewhat wavy layers separated by shale partings and (2) an upper unit consisting of very light gray massive, nodular or oölitic limestone. The lower unit which ranges in thickness from less than 1 foot to about 20 feet (average about 12 feet) contains fairly abundant fossils consisting mostly of brachiopods and bryozoans (Figs. 16, 19). The upper subdivision of massive nodular limestones ranges in thickness up to about 7 feet, and where it is represented by oölite, to about 13 feet. This unit is mostly unfossiliferous and is judged to be algal in origin. At many places the oölitic part of the Bethany Falls, which may show cross-bedding, is weathered so that the oölitic granules are removed by solution, leaving the material between the oölites behind; accordingly, the rock is very porous. The oölitic phase of the upper Bethany Falls limestone is widely developed in Kansas south of the Kansas River, but is not common northeastward. The total thickness of the Bethany Falls limestone ranges from about 12 to 27 feet, the average in eastern Kansas being about 18 feet.

The outcrop of the Bethany Falls limestone is marked in many places by the occurrence of large joint blocks, 10 to 20 feet in diameter, which have moved various distances down hillsides owing to creep. No other limestone of the Missourian section exhibits this feature so commonly as the Bethany Falls limestone. It is well shown in many ravines near Kansas City.

Galesburg Shale

The Galesburg shale (Adams, in Adams, Girty, & White, 1903, p. 36) includes predominantly shaly strata between the Swope and Dennis limestones (Figs. 14, 16). Type exposures are near Galesburg in southern Neosho County, Kansas. The Bethany Falls limestone member of the Swope occurs everywhere next below the Galesburg. Throughout east-central Kansas, rock next above the Galesburg shale is the Canville limestone which is the basal member of the Dennis formation, but in northeastern Kansas and northwestern Missouri, the Galesburg is directly overlain by the Stark shale member of the Dennis. In southern Kansas and northern Oklahoma, the only recognizable member of the Dennis is the Winterset limestone. The upper boundary of the Galesburg formation, therefore, shows more varied relationships than the lower.

The Galesburg formation near Galesburg, Kansas, comprises about 70 feet of unfossiliferous gray and brown clayey to sandy shale, and near the top, some sandstone. Sandstone becomes increasingly prominent southward, and there are several fairly persistent thin coal beds. It is worthy of notice that the nonmarine facies of the Galesburg formation extends farther northward than nonmarine deposits of the Ladore shale. In western Bourbon County, near Uniontown, the Galesburg shale is about 10 feet thick. At Kansas City, it consists of 2 to 3 feet of buff calcareous nodular shale which is readily separated from the overlying black, fissile Stark shale, even though no limestone (Canville) intervenes.

Although very thin in northeastern Kansas and northwestern Missouri, the Galesburg shale is traceable into Iowa. The southern limit of the Galesburg as a distinct stratigraphic unit is in southern Labette County, Kansas, for the Swope limestone disappears in this region. To the south the Galesburg merges with the upper part of the Coffeyville rocks.

Dennis Limestone

The Dennis limestone (Adams, in Adams, Girty, & White, 1903, p. 36) is the uppermost formation of the Bronson subgroup. It overlies the Galesburg shale and is succeeded conformably by the Cherryvale shale. (Figs. 14, 16, 19). Near Dennis, in northwestern Labette County, and for a considerable distance northward, the formation contains three members: (1) the thin blue dense blocky Canville limestone at the base, (2) the black fissile and gray or buff Stark shale in the middle, and (3) the thick gray or blue, thin-bedded or in part massive, oölitic Winterset limestone at the top. Along many miles of Dennis outcrop, the upper limestone not only constitutes the main element of the formation, amounting to 90 percent or more of the total thickness, but it includes all limestone beds belonging to the Dennis; the Canville limestone member at the base is missing. In such areas, the stratigraphic span of the Dennis formation commonly is not restricted to that of the Winterset member, because the Stark shale can be distinguished readily from the underlying Galesburg shale. The Dennis limestone, in many places may thus consist of two members, the Stark shale, below, and the Winterset limestone, above.

The thickness of the Dennis limestone ranges from 5 or 6 feet, in an area a few miles southwest of Coffeyville, to more than 70 feet. The Winterset and Stark members are continuous to south-central Iowa, and the Winterset extends to southern Oklahoma, where it is the main (or only) component of the formation called Hogshooter limestone.

Canville limestone member. The Canville limestone (Jewett, 1932, p. 102), named from a locality in Neosho County, overlies the Galesburg shale and is next beneath the Stark shale (Figs. 16, 19). It is a fine-grained, dense, hard rock which shows prominent vertical joints. As seen at some outcrops, it is a single layer about 1 foot thick, but where the thickness is greater, up to an observed maximum of about 3 feet, two or three beds may occur. The member becomes thin southward from the type region and is not known in Kansas south of Erie, in central Neosho County, although it reappears locally in Oklahoma. The Canville disappears also near the Linn-Miami County line, some 40 miles south of Kansas City and is not seen farther north. The known area of its development, therefore, is confined to Neosho, Bourbon, and Linn Counties, Kansas. In terms of relation to cyclic sedimentation, the Canville member is exactly homologous to the Middle Creek limestone, representing the same part of the Dennis megacyclothem that the Middle Creek is in the Swope megacyclothem. Both of these limestones are dense blue vertical-jointed strata occurring next below black platy shales.

Stark shale member. The middle member of the Dennis limestone is named Stark shale (Jewett, 1932, p. 102), from a village in Neosho County, Kansas. It occurs above the Canville limestone wherever the latter is present and lies below the Winterset limestone (Figs. 16, 19). North of the point in Linn County where the Canville limestone disappears, the Stark shale rests directly on Galesburg shale, but because the lower part of the Stark member is hard, black, fissile shale, which is very unlike the soft, light-colored, nonfissile Galesburg, the contiguous shales are differentiated easily. The contact between them is sharp.

The Stark shale normally consists of two parts—a lower unit of black fissile shale, 1 to 3 feet thick, and an upper unit consisting of gray or buff, calcareous to clayey shale, 2 to 5 feet thick. At Kansas City, the total thickness of the Stark member is about 4 feet. The black shale contains conodonts and macerated plant remains. Small phosphatic concretions occur commonly. The upper shale contains a varied brachiopod and pelecypod fauna in many places. The most common fossils are *Derbyia crassa* and *Aviculopecten*. The distinctive brachiopod *Liorhynchus rockymontanum* is found in this shale at Kansas City.

Winterset limestone member. The uppermost member of the Dennis limestone, named the Winterset limestone (Tilton & Bain, 1897, pp. 517-519), is defined from outcrops in Iowa a few miles southwest of Des Moines. In normal sequence, the Winterset rests on the Stark shale and is overlain by shale belonging to the Cherryvale formation (Figs. 16, 19). From central Neosho County, Kansas, northeastward to Iowa, the Winterset rests on the Stark shale, which along this part of the outcrop can be identified as a distinct stratigraphic unit, whether the Canville limestone underlies it or not. In territory south of Neosho County, except locally, roughly coincident with disappearance of the Canville, the Stark loses its diagnostic physical characters so that a boundary between it and the underlying Galesburg shale cannot be defined. Inasmuch as field observations indicate that the few feet of shale occurring next below the Winterset limestone unquestionably is continuous laterally with Stark beds, the Galesburg shale, combined with Stark shale equivalents, may be designated appropriately as Galesburg-Stark shale. Because a definite boundary cannot be drawn at the base of presumed Stark beds, the Dennis formation may be defined as composed of one member—the Winterset limestone. Underlying shale equivalent to the Stark, is, in effect, classified as uppermost part of the Galesburg formation.

The Winterset limestone is typically a light bluish-gray to bluish, fine-grained limestone which occurs in somewhat uneven to distinctly wavy thin beds separated by thin shale partings. In places the lower part is thick-bedded, dark-gray limestone which contains abundant fine, very irregular primary calcite "veins", which probably represent algal structures. Beds of shale, including some black platy beds a foot or more thick, occur in a number of sections of the Winterset limestone. Near the top a prominent zone of very dark-gray to black chert concretions is found commonly, and in places this type of chert occurs in the middle part of the member. The associated limestone beds may be distinctly siliceous. Light-gray oölitic limestone is present at the top or in the upper half of the member locally, especially in east-central Kansas. Farther south, irregularly bedded, pseudo-brecciated and "veined" light-gray limestone is prominent in the upper part of the member. This rock, which is probably algal in origin, has a thickness of more than 50 feet in some areas. Near Cherryvale and Coffeyville, the typical Winterset limestone is succeeded by very dense dark-blue, fine-grained siliceous to sandy limestone beds interbedded with shale. These beds are unfossiliferous flagstones.

Fossils are abundant at many places in the Winterset limestone. The thin wavy-bedded strata commonly contain numerous brachiopods, including especially abundant shells of small productids (*Marginifera*), and bryozoans. The siliceous and oölitic beds contain numerous pelecypods and gastropods. Large nautiloid cephalopods and some ammonoids have been collected in the Winterset limestone of the Kansas City area (MILLER, LANE, & UNKLESBAY, 1947). Fusulinids of the *Triticites irregularis* type are numerous in some of the brachiopod-bearing beds. Well-preserved land plant remains have been collected from shaly beds of the member.

The equivalence of the Winterset limestone to the Hogshooter limestone of Oklahoma has been determined by tracing outcrops and by comparison of sections at frequent intervals along the outcrops.

Linn Subgroup

General Description

The middle portion of the Kansas City group, from the base of the Cherryvale formation to the top of the Iola formation, is defined as the Linn subgroup (MOORE, 1948), named from Linn County, Kansas, which contains excellent exposures of all constituent units (Fig. 14, 16). The subgroup is characterized by relative prominence of shale, but there are persistent limestones, mostly only a few feet thick, and locally much sandstone. A main reason for this segregation of beds is the regularity of stratigraphic units belonging to it, in contrast to variability of limestone and shale subdivisions belonging to the upper part of the Kansas City group. Also, the top of the Linn division has been found to be one of the best datum planes for structural mapping. It is thus employed in oil and gas exploration, especially in western Missouri and parts of eastern Kansas. The Linn subgroup comprises the Cherryvale formation, the Drum limestone, the Chanute formation, and the Iola limestone. The average thickness in Kansas is approximately 110 feet.

A prominent disconformity occurs within the subgroup (at the base of the Chanute shale), and at several places it extends down to or into the Bronson beds. No seemingly significant faunal change is associated with this break but it indicates unusual physical changes incident to the close of one megacycle (Drum) and the beginning of another (Iola). Irregularities in sedimentation in beds next above this disconformity are most strikingly seen from the vicinity of Chanute southward. They are associated with warping of the Chautauqua arch in southern Kansas. In northeastern Oklahoma and extending a short distance into Kansas, this disconformity is designated as the boundary between the Skiatook group, below, and the Ochelata group, above.

Cherryvale Formation

The Cherryvale formation (HAWORTH, 1898, p. 47) includes beds from the top of the Winterset limestone to the base of the Drum limestone (Figs. 14, 16). At its type locality, in the vicinity of Cherryvale, Montgomery County, Kansas, the section consists entirely of bluish-gray, clayey to silty shale, but farther north there are persistent limestones (Block, Westerville) which extend into Iowa and Nebraska. These limestones and the shale subdivisions lying below and above them are classed as members of the Cherryvale formation. The average thickness of the Cherryvale formation in Kansas is about 60 feet.

Fontana shale member. The basal part of the Cherryvale formation is the Fontana shale member (NEWELL, in MOORE, 1932, p. 91), named from a village in Miami County. It conformably overlies the Winterset member of the Dennis limestone and underlies the Block limestone (Figs. 16, 19). It is a fairly uniform clay shale of greenish-gray to buff color, which contains scattered calcareous nodules. Locally, ferruginous calcareous shale occurs at the base. The member is mostly barren of fossils, but near the top, abundant specimens of the small brachiopod *Chonetina flemingi* var. *plebeia* are common in many places.

The Fontana shale is 15 feet thick near Fontana and about 5 feet thick in the vicinity of Kansas City. Southward the shale thickens to 25 feet in Linn County. Since the Winterset and Block limestones are found at various places in northwestern Missouri and southern Iowa, the Fontana shale can be recognized from Linn County, Kansas, to Iowa, but it is not differentiated from other Cherryvale beds south of Linn County.

Block limestone member. The Block limestone (NEWELL in MOORE, 1932, p. 91), named from a small settlement in Miami County, occurs conformably between the Fontana shale, below, and the Wea shale, above (Figs. 16, 19). It is a blue-gray, fine-grained, hard limestone which occurs in moderately thick even beds, commonly intersected by vertical joints. At some outcrops the beds are thin and wavy or nodular, and near Kansas City this member is composed of several thin dense blue limestones separated by a few inches to a foot or two of shale. Fusulinids are common in the Block limestone and the brachiopod *Marginifera wabashensis* is abundant at many places.

The thickness of the member ranges in most places from 3 to 8 feet, the average being about 4 feet. The unit has been identified at exposures from Linn County, Kansas, northward to Iowa, but has not been traced south of Linn County.

Wea shale member. The Wea shale (Newell, in Moore, 1932, p. 91), named from outcrops in northeastern Miami County, occurs next above the Block limestone and is overlain by the Westerville limestone. The shale is mostly olive-green in color and clayey, but a persistent thin zone of maroon silty to clayey shale occurs near the top. The shale is more calcareous to the north.

The thickness of the Wea shale in eastern Kansas ranges from about 10 to 30 feet, the greatest thickness being observed in eastern Johnson County, a few miles southwest of Kansas City. The unit is traceable across northwestern Missouri into Iowa, but south of the type region, the Westerville limestone is mostly missing, so that the shales below and above this limestone are not clearly separable. The stratigraphic relationships of the shales can be determined in well-exposed sections because of lithologic distinctions between the Wea and Quivira shales. It is not practicable, however, to draw a boundary at the top of the Wea shale where the Westerville limestone is absent, and the shale between the Block and Drum limestones is designated as Wea-Quivira shale. Likewise, this member cannot be differentiated from the underlying Fontana shale in mapping where the Block limestone is absent.

Westerville limestone member. A persistent and distinctive stratigraphic unit in the vicinity of Kansas City and northward to the type area in Iowa, a few miles southwest of Des Moines, is the Westerville limestone (Bain, 1898a, pp. 276-277). It is identified in Nebraska, but seems to be absent south of Miami County, Kansas. The Westerville member occurs next above the Wea shale and underlies the Quivira shale.

The lithologic characters shown by Westerville beds in northeastern Kansas and northwestern Missouri are much more variable than those of adjacent limestone units. Commonly, a lower and upper division can be distinguished, the former by its fine texture and moderately thin, somewhat uneven bedding, and the latter by prominence of massive or cross-bedded oölite-like algal limestone. This algal limestone has been extensively used as building stone in the Kansas City area, and is known as the "Kansas City oölite". Both parts of the member are light bluish-gray to nearly white, and weather gray or buff, but their appearance, nevertheless, is quite different one from the other. In places the upper Westerville is dense, siliceous, chert-bearing rock, which weathers light brown. In the Kansas City area fossils are uncommon except in the oölite, which yields a rich fauna of mollusks, brachiopods, bryozoans and various other invertebrates. Many fossils described by SAYRE (1931) from the Kansas City area were obtained from oölitic limestone which was thought to be Drum limestone (equivalent to the oölitic, richly fossilferous Corbin City member of southern Kansas), but actually came from the Westerville limestone. In northern Missouri, Iowa, and Nebraska, oölite is not common in the upper Westerville and the fine-grained light blue-gray rock which generally makes up most of this member contains very abundant small fusulinids.

The thickness of the Westerville limestone averages about 8 feet.

Quivira shale member. The Quivira shale (NEWELL, in MOORE, 1932, p. 91) comprises strata between the Westerville limestone, below, and the Drum limestone, above. Type outcrops occur a few miles west of Kansas City, in Johnson County, Kansas. It consists mostly of unfossilferous olive-green clay shale, but in most sections about 1 foot of black carbonaceous shale containing corneous brachiopods is found in the upper part and in some outcrops about the same thickness of maroon clay shale occurs at the base. The middle part of the Quivira shale in the Kansas City area contains a rather inconspicuous nodular light gray limestone. The upper part contains nonmarine deposits, including underclay and coal, which are overlain by a thin dense limestone, calcareous, fossilferous shale, and black platy shale, which bears *Orbiculoidea* and *Lingula*. These are characteristic phases in normal order representing parts of two successive cyclothems.

The thickness of the Quivira shale in northeastern Kansas ranges from 4 to 11 feet. In the Kansas City area, the thickness averages 7.5 feet. The Quivira is differentiated only in the region from Miami County northward across Johnson and Wyandotte Counties, Kansas; in Jackson and Platte Counties, Missouri; and in southeastern Nebraska.

Drum Limestone

In central Montgomery County, Kansas, where the type locality of the Drum limestone (ADAMS, in ADAMS, GIRTY, and WHITE, 1903, p. 37) occurs, this formation rests conformably on the Cherryvale shale, and it is overlain conformably or disconformably in different places by the Chanute formation (Figs. 14, 16). In northeastern Kansas and northwestern Missouri, the Drum limestone lies conformably on the Quivira shale member of the Cherryvale formation.

The Drum limestone is composed partly of fine-grained, dense, somewhat thinly and unevenly bedded limestone; partly of granular, more or less crystalline, crinoidal limestone; and partly of oölite, probably of algal origin. Locally there are deposits of fine to coarse limestone conglomerate. Fossils are very abundant at many places in the fine-grained thin-bedded part and in the oölite, especially the latter. The fauna is rich in its variety of species. Many fossils from the Drum oölite of the type area near Independence, Kansas have been described and figured by SAYRE (1931), but fossils from various other oölitic limestones, which were miscorrelated with Drum, are included, unfortunately, in the "Drum" fauna.

The thickness of the Drum limestone ranges from less than 2 feet to a known maximum of about 60 feet, found locally east of Independence. The average thickness is about 5 feet. The Drum has been identified at many places from the Oklahoma line northward to Kansas City and it extends through northern Missouri to Iowa and Nebraska. The limestone was removed by pre-Chanute erosion in parts of southern Kansas, and therefore the outcrop is discontinuous.

Two subdivisions of the Drum limestone are recognized, the Dewey (Cement City) limestone member below, and the Corbin City limestone member above. At some exposures these units are separated by a few inches of shale but elsewhere they are in disconformable contact.

Dewey (Cement City) limestone member. The Dewey limestone was named by OHERN (1910, p. 30) from Dewey, Oklahoma, where this rock is quarried extensively for manufacture of cement. Field studies in southern Kansas and northern Oklahoma have established beyond reasonable doubt the equivalence of Dewey limestone exposures in the type area of that unit to the lower part of the type Drum, which is the fine-grained, dense, light bluish-gray thinly bedded rock described as one type of lithology observed in the Drum beds. The Dewey limestone may be identified, therefore, as comprising the lower member of the Drum limestone. It is overlain disconformably near Independence, Kansas, by the oölitic Corbin City limestone, which is absent at Dewey and, indeed, in most other places outside of Montgomery County, Kansas.

Limestone, which is called Cement City (HINDS & GREENE, 1915, p. 27), occurs in the Kansas City section next above the shale (Quivira) that overlies the Westerville limestone. Field mapping and extensive stratigraphic studies by the Kansas Geological Survey have shown that the Cement City limestone (not the rock now called Westerville) is properly correlated with part of the type Drum limestone. The Cement City corresponds to the fine-grained, dense lower Drum and is judged to be the same as Dewey. Inasmuch as Dewey is the older name in stratigraphic usage and is widely recognized by geologists in Oklahoma, this term must be chosen in preference to Cement City for designation of the most persistent part of the Drum formation. Missouri geologists and others are not certain of the accuracy of statements as to identity of Dewey, lower Drum, and Cement City, and accordingly, they prefer to use Cement City as the name of the lower member of the Drum limestone. This name is accepted by the inter-State conference of May 1947, and accordingly, the unit is here indicated as Dewey (Cement City) limestone.

The Dewey (Cement City) member is less prominent in exposures of the Drum near Independence than the overlying oölitic Corbin City member, but it is the most persistent and really most important of the two units. At most outcrops in Kansas, Oklahoma, and Missouri, it is the only member present. The fresh limestone is blue-gray to pale-drab in color and on weathering the rock becomes light-gray, somewhat mottled with brown, or the member may become entirely brown. The texture of the rock is typically very fine and dense. Thin wavy bedding may be observed, especially on weathered outcrops, but in many places the member tends to appear as a single massive ledge which breaks along widely spaced joint planes to make large blocks. In southern Kansas, the wavy thin shale partings between the dense nodular limestone beds are somewhat more evident than to the north, and they yield a profusion of finely preserved bryozoans. A persistent zone of *Caninia torquia* is found near the top of the Dewey (Cement City) limestone in northeastern Kansas, and since this fossil is not observed in adjacent beds it is an aid in identifying the member. A variety of brachiopods, bryozoans, and, less commonly, other invertebrates occurs in this limestone.

The thickness of the Dewey (Cement City) in most of the Kansas outcrop and near Kansas City ranges from 2 to 10 feet.

Corbin City limestone member. The main part of the Drum limestone near Independence, where locally it is 60 feet in thickness, consists of oölite called the Corbin City member (MOORE, 1932, p. 92). Lithologically and faunally this member is very sharply differentiated from the Dewey (Cement City) member, on which it rests disconformably in southern Kansas. Near Cherryvale, the irregularities in the upper surface of the Dewey (Cement City) are very abrupt, having a relief of nearly 5 feet. The oölitic limestone fills hollows and covers high parts of the underlying dense blue-gray rock. To the southwest, west, and northwest of Coffeyville, the Corbin City member is represented by limestone conglomerate, in which pebbles, cobbles, and locally rounded boulders of limestone 1 foot in diameter are embedded in a matrix of sandy, partly oölitic limestone. Despite the apparently unfavorable surroundings, there are well-preserved fossils in parts of the matrix. Some of the limestone pebbles are identical in lithologic features to the Dewey (Cement City) member and others correspond to dense dark-blue flaggy limestone beds which belong normally a few feet below the Dewey (Cement City) limestone in this region. The oölitic limestone, which is so prominent near Independence, is very light gray and weathers creamy white. Much of this rock is prominently cross-bedded. Its rich fauna contains a large variety of beautifully preserved brachiopods, bryozoans, and especially mollusks (SAYRE, 1931). Near Kansas City, a limestone 1 foot or less in thickness, separated from the Dewey (Cement City) by a few inches of shale which contains abundant *Teguliferina*, is thought to represent the Corbin City member. This limestone is suboölitic to coquinoid and contains algal structures called *Osagia.* All the observed characters indicate definitely that the Corbin City limestone is the algal-molluscan phase of the Drum cyclothem.

The thickness of the Corbin City member ranges from a feather-edge to approximately 60 feet, but the thickness is highly variable within short distances.

Chanute Formation

Definition of the Chanute formation (HAWORTH and KIRK, 1894, p. 109) is somewhat confused because of miscorrelations of the limestones below and above in the course of early stratigraphic studies of Upper Pennsylvanian rocks in Kansas. It is clear, however, that this name was intended to designate shale and sandstone beds which form the plain extending eastward from Chanute to the prominent escarpment made by the limestones of the lower part of the Kansas City group. The Iola limestone, which overlies this shale and sandstone unit, is well exposed in the vicinity of Chanute and it can be traced without difficulty to Iola, about 20 miles to the north. As seen at most places, the Chanute formation comprises the beds between the Drum limestone, below, and Iola limestone, above (Figs. 14, 16). A disconformity is recognized at the base of the Chanute beds in parts of southeastern Kansas and northern Oklahoma, including especially the region of the Chautauqua arch. The disconformity is observed also in the vicinity of Chanute, where the Drum limestone and underlying shale are cut out so extensively that basal Chanute sandstone is found resting directly on different beds of the upper Dennis limestone. Although the Chanute beds locally fill channel-like depressions cut in Drum, Cherryvale, or Dennis strata, in no area are deep troughs found corresponding to the diagram in the left part of Figure 16. Areas of eroded pre-Chanute rocks are many miles wide, so that stratigraphic relations are those of local overstep.

The Chanute formation is mainly composed in most areas of yellowish-brown to buff sandy shale and dark-gray to greenish clay shale, but especially toward the south, it contains much thin-bedded sandstone and at least one persistent coal bed (Thayer) (SCHOEWE, 1944). Except in the southern Kansas and northern Oklahoma region, where the disconformity at the base of the formation is clearly evident, cutting downward as much as 100 feet well below the horizon of the Drum limestone, sandstone occurs chiefly in the upper part of the Chanute, above the coal bed mentioned. Where this sandstone is absent the coal, which extends almost uninterruptedly from Kansas City into Oklahoma, lies near the top of the Chanute formation but in southern Kansas the coal, which has a maximum thickness of about 2.5 feet, occurs as much as 50 feet below the top of the Chanute. A widespread deposit of maroon shale, 1 to 5 feet thick, averaging about 2 feet, occurs in northeastern Kansas and northwestern Missouri near the base of the Chanute. In the region of the Chautauqua arch in southern Kansas, most of the Chanute deposits are coarse sandstone, presumably nonmarine, whereas the formation comprises thin marine sandstone and shale toward the northeast and southwest of the arch. Marine fossils are not common in this formation but they occur in places. A fairly well-preserved assemblage of land plants has been collected from Chanute beds near Thayer, in southwestern Neosho County.

The thickness of the Chanute shale ranges from about 10 feet at some places near Kansas City to 100 feet or more in southern Kansas. The average thickness in northeastern Kansas is about 25 feet and the thickness increases rather uniformly southward.

Noxie sandstone member. Lower Chanute sandstone, lying below the Thayer coal in the Chautauqua arch region, is designated as the Noxie sandstone member (Moore *et al.*, 1937, p. 43) of the Chanute formation. The sandy shale and sandstone of this part of the Chanute are especially prominent where the base of the formation lies unconformably on the Dennis limestone or part of the Cherryvale shale. The thickness of the Noxie member is approximately 40 to 75 feet.

Cottage Grove sandstone member. The Cottage Grove sandstone member (Newell, in Moore, 1932, p. 92) comprises sandstone and associated sandy shale lying above the Thayer coal (Figs. 16, 18). It constitutes approximately the upper half or more of the formation in much of southern Kansas. The sandstone is yellowish-brown or tan and includes both thin-bedded and massive sandstone. Some parts of the member are soft and friable. Others consist of tightly cemented rock that resists weathering. The Cottage Grove member is a prominent escarpment-forming sandstone in northeastern Oklahoma (Oakes, 1940, p. 63). The thickness of the Cottage Grove sandstone ranges from 2 feet in the north to about 50 feet in southern Kansas.

Iola Limestone

The Iola limestone (HAWORTH & KIRK, 1894, p. 109) is a prominent light-gray limestone about 30 feet thick at Iola, Allen County, where it is extensively quarried. Beneath this limestone is the Chanute formation and above it at Iola is the Lane-Bonner Springs shale, which is formed by the coalescence of the Lane and Bonner Springs shales of northeastern Kansas. The main part of the Iola formation is the Raytown (Avant) limestone, nomenclature of which is explained in description of this member. At the type locality, the Iola limestone is composed chiefly of light bluish-gray, irregularly thin-bedded fine-grained limestone which contains numerous thin (algal?) "veinlets" of calcite. In fresh exposures, the rock appears massive, but where weathered, somewhat uneven bedding is distinct. Between Iola and Kansas City the lowermost limestone of the Iola formation becomes increasingly distinct as a dense blue bed and is identifiable as a typical homologue of the Middle Creek, Canville, Merriam, Captain Creek, and other limestones occurring next below black platy shales (Fig. 18). It is a thin but very persistent member having importance as a cyclothem element and as a stratigraphic marker. The shale above this limestone, which is partly black and fissile, persistently carries small phosphatic nodules.

Miscorrelation of the Iola formation by HAWORTH & BENNETT (1908) in tracing limestone in this part of the section northeastward to Kansas City has been responsible for longstanding error in nomenclaure of Missourian units in northeastern Kansas and northwestern Missouri. The Drum limestone also was misidentified at Kansas City. The supposed Drum, of this area recorded in reports issued prior to 1932, is now known to be the Westerville limestone (BAIN, 1898), named from Iowa. Work mainly by N. D. NEWELL (MOORE, 1932) has shown that the Iola limestone is actually represented at Kansas City by beds called Paola, Muncie Creek, and Raytown. The "Iola limestone" of HAWORTH & BENNETT in the Kansas City area was renamed by NEWELL (in MOORE, 1932) (Frisbie limestone, Quindaro shale, Argentine limestone). Appropriate revision of classification which was adopted by Kansas and Nebraska was not accepted by Missouri (McQUEEN & GREENE, 1938; CLAIR, 1943) until the field conference of May 1947, when CLARK, GREENE, and SEARIGHT, after step-by-step review of outcrops between Kansas City and Iola, accepted the identity of the Paola-to-Raytown and the type Iola sections.

The Iola formation is well developed in northeastern Oklahoma (OAKES, 1940) where it is divided into the Paola, Muncie Creek, and Avant members. The Avant limestone (OHERN, 1910) occupies the stratigraphic position of the Raytown limestone (HINDS & GREENE, 1915) but lithologic dissimilarity, which indicates different cyclic relationships, suggests that these two units may not be exactly synonymous.

Settlement of the "Iola problem" has led automatically to a number of changes in the Missouri survey's classification of middle and upper Kansas City beds so as to bring inter-State agreement in nomenclature (Fig. 14). (1) The Union Station shale (CLAIR, 1943) member of the "Chanute formation" is suppressed because it is a synonym of Chanute as a whole. (2) The Cement City limestone, previously classed as a member of the Chanute shale, is recognized as representative in the Kansas City area of the Drum limestone, but the Missouri survey proposes to continue use of the name Cement City. (3) The Paola limestone, Muncie Creek shale, and Raytown limestone, which were treated as members of the Chanute shale, are recognized as belonging to the Iola formation. (4) The Liberty Memorial shale (CLAIR, 1943), overlying the Raytown limestone, is no longer considered as uppermost member of the Chanute shale. This name is suppressed as a junior synonym of Lane shale. (5) The Frisbie limestone, Quindaro shale, and Argentine limestone, which were indicated as members of the "Iola limestone" in western Missouri, are classified with the overlying Island Creek shale and Farley limestone as members of the Wyandotte formation. (6) The Island Creek shale and Farley limestone, which were associated with the overlying Bonner Springs shale as members of the "Lane shale," are included in the Wyandotte formation. (7) The Bonner Springs shale is recognized as a formational unit lying between the Wyandotte and Plattsburg formations.

The Iola limestone is known to extend northeastward to south-central Iowa and northward to the Platte Valley in Nebraska, in both of which regions the thin dense blue basal limestone and the overlying black fissile shale are found to be well defined and more persistent than the upper limestone member. In southern Kansas the Iola formation becomes very thin and locally is absent, but in northern Oklahoma it is represented in part by the Avant limestone. The thickness of the Iola ranges from a featheredge to a maximum of about 40 feet, near Chanute, Kansas. The average thickness of the formation in northeastern Kansas is about 7.5 feet.

Paola limestone member. The Paola limestone member (NEWELL, in MOORE, 1932, p. 92), named from the county seat of Miami County, Kansas, lies at the base of the Iola formation (Figs. 16, 18). It consists of fine-grained, dense, hard, brittle limestone, and breaks with a subconchoidal fracture. It occurs as a single massive bed, 1 to 2 feet thick, and is typically intersected by vertical joints. The color of the fresh rock ranges from dark blue to bluish-gray, and unlike some of the higher beds in the formation, which weather creamy or brown, the Paola limestone remains bluish-gray after weathering. The upper surface of the member is slightly hummocky, being marked by irregularly disposed depressions and protuberances. Worm borings, marked by iron-stained, unevenly cylindrical material which differs slightly from the matrix, extend downward a few inches from the top of the bed. The Paola member is identified beneath the Avant limestone in Oklahoma, near Independence in southern Kansas, and is persistent northward into Iowa and Nebraska as far as the Iola is known.

Muncie Creek shale member. Above the Paola limestone is the Muncie Creek shale member (NEWELL, in MOORE, 1932, p. 92) of the Iola. This shale occurs next beneath Raytown limestone in the Kansas City region and beneath the Avant limestone in Oklahoma. In the type region of the shale just west of Kansas City, Kansas, the lower part of the Muncie Creek member is composed of black fissile shale. The upper part is gray or buff clay shale containing numerous dark-gray or black phosphatic concretions, one-fourth to one-half inch in diameter. Northward, the black shale zone of the member is very persistent, but southward it becomes thinner and disappears in southern Johnson County. The light-colored shale and the zone of concretions can be traced to Iola. In exposures near Independence, Kansas, and in northern Oklahoma, the black fissile shale reappears. The thickness of the Muncie Creek shale ranges from less than 1 foot to a maximum of about 3 feet. If it were not for the geographic persistence and significance of this unit in terms of cyclic sedimentation, differentiation of such a thin shale as a member would hardly be justified. Some of the phosphatic nodules occurring in the Muncie Creek shale contain well-preserved ammonoids, arthropods, brachiopods, and fish remains.

Raytown (Avant) limestone member. The Raytown (Avant) limestone member represents the main part of the Iola limestone, overlying the Muncie Creek shale and occurring next below the Lane shale (Figs. 16, 18). The Raytown limestone (HINDS & GREENE, 1915, p. 27), named from outcrops in Jackson County, Missouri, a few miles southeast of Kansas City, and the Avant limestone (OHERN, 1910, p. 31), defined in Osage County, Oklahoma, are identified (also, for the Avant, OAKES, 1940, p. 71) as equivalent to the upper division of the type Iola limestone. Inasmuch as the Raytown is more firmly determined to have this relationship than the Avant, and is the most commonly used term in States north of Oklahoma, it is recognized in nomenclature here used; moreover, geologists unacquainted with the stratigraphy of middle Missourian rocks of the Kansas-Oklahoma boundary area are inclined to be skeptical of the upper Iola-Avant correlation, in view of the fact that this limestone is not continuous at the outcrop between Iola and Avant.

The Raytown (Avant) limestone near Kansas City, appears very massive in fresh exposures but on weathered crops, rather even beds a few inches thick are evident. Southwestward, the limestone becomes gradually thinner bedded, with uneven wavy partings between the layers. The color changes also to a light-gray and weathered outcrops are light-buff or creamy-white. This is the character of the member at Iola. The main part of the Raytown (Avant) limestone generally is overlain by thin algal and crinoidal limestone or by alternating beds of more or less flaggy limestone and shale. These rocks represent the more calcareous phase of the closing cyclothem of the Iola megacycle. The member contains abundant fossils at most places but the composition of the fauna differs somewhat in the south and north. At Iola, a large variety of brachiopods, bryozoans, and crinoids has been obtained near the top of the member. Near Kansas City, large productids (*Linoproductus, Echinoconchus*) and somewhat smaller ones (*Juresania*) are very abundant. *Neospirifer dunbari* is locally common and bryozoans occur in profusion.

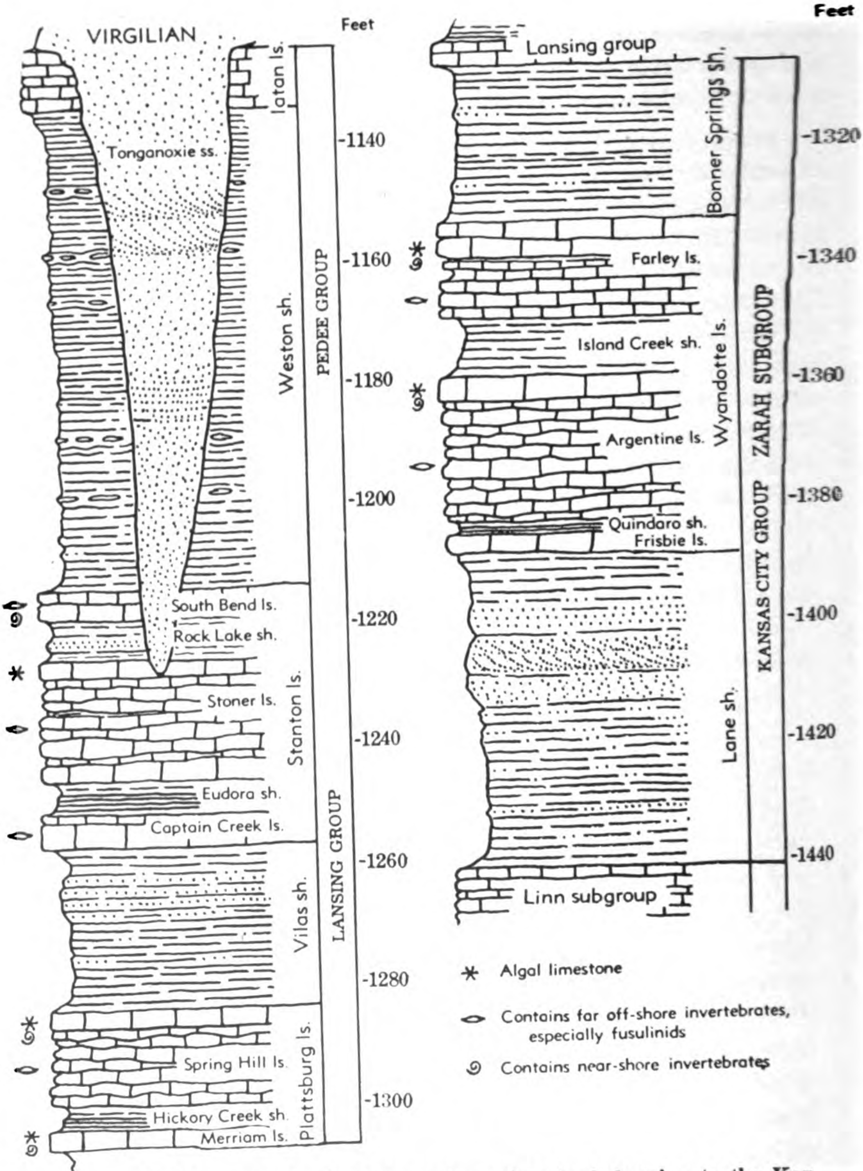

Figure 20. Generalized columnar section of rocks belonging to the Kansas City, Lansing, and Pedee groups in Kansas. These strata comprise the middle and upper parts of the Missourian Series in Kansas.

The thickness of the Raytown (Avant) limestone averages about 5 feet along the outcrop from northwestern Missouri to the vicinity of Tulsa, Oklahoma, where it disappears. South of Miami County, Kansas, however, the member gradually thickens to about 35 feet near Iola. In Oklahoma the Avant limestone, in part equivalent to the Raytown, ranges from a featheredge to 15 feet or more.

Zarah Subgroup

General Description

The upper part of the Kansas City group, comprising approximately one third of the section, is designated as the Zarah subgroup, named from the village of Zarah on Kansas Highway 10 at the Santa Fe Railway crossing in western Johnson County. The subgroup includes beds between the top of the Iola formation and base of the Plattsburg formation (Figs. 14, 20). Near Kansas City, this interval is mainly characterized by prominent limestone members of the Wyandotte formation, occurring between the relatively thin Lane shale and Bonner Springs shale, which comprise the lower and upper parts of the subgroup, respectively. The thickness of subdivisions varies greatly from place to place. Average thickness of the subgroup in Kansas is about 100 feet.

The Wyandotte extends northward into Iowa and Nebraska but southwestward from Kansas City it becomes thinner and the underlying Lane shale thicker. In eastern Anderson County, the Wyandotte is locally absent and in northern Allen County it is found to grade laterally into calcareous ripple-marked sandstone. Where the Wyandotte is missing, there is a virtually indivisible shale section between the Iola and Plattsburg formation and this shale is termed Lane-Bonner Springs shale. As a shale unit, the Zarah portion of the Kansas City group can be followed southward to Montgomery County, nearly but not quite to the Oklahoma line. In southernmost Kansas and northern Oklahoma it is equivalent to lower Ochelata beds.

Lane Shale

The Lane shale (HAWORTH, 1895, p. 277) includes beds between the top of the Iola limestone and base of the Wyandotte limestone (Figs. 14, 18, 20). It is developed as a distinct unit from the type locality in Franklin County, Kansas, northward, but disappearance of the Wyandotte limestone a short distance south of Lane makes it impossible to recognize the upper boundary of the Lane shale. Accordingly, as has been noted, in this region the Lane is combined with overlying shale as Lane-Bonner Springs shale.

The Lane beds are variable in lithologic character and in thickness. At some places the entire unit consists of dark bluish-gray clayey shale. This type of deposit is mostly found where the formation is thin, that is, about 15 to 35 feet in thickness. In parts of the Kansas City region, the clay shale contains fairly common marine invertebrates, including remarkably preserved complete crinoid crowns (especially *Aesiocrinus magnificus*) which are displayed in several museums. Where the Lane shale is thick, that is, 50 to 110 feet, most of the shale is sandy and micaceous. The color ranges from light-gray to yellowish-brown or buff. Thin plates and beds of friable sandstone a few inches thick appear, especially near the top. The thick sandy shale contains carbonaceous streaks but coal beds are not observed. Fossils are mostly lacking, but a few land plant remains are found at some outcrops.

The Lane shale is a thin but persistent unit from eastern Miami County, Kansas, northeastward. It has been recognized in northwestern Missouri, southwestern Iowa, and in the Platte Valley section of southeastern Nebraska. The thickness of the shale in Johnson and eastern Miami Counties, Kansas, ranges from 16 to 40 feet, the average being about 25 feet. In western Miami and eastern Franklin Counties, the thickness increases to about 100 feet. The Lane-Bonner Springs shale is sparsely fossiliferous, dark-bluish, clayey to fine silty shale, and is about 75 feet thick near Iola and about 60 feet thick farther south in Kansas.

Wyandotte Limestone

The Wyandotte limestone (Newell, in Moore, 1932, p. 92) comprises the beds between the Lane and Bonner Springs shales (Figs. 14, 18, 20). It consists predominantly of light-colored limestone but contains two shale members, of which the upper one locally attains a thickness of 20 feet or more. As a whole, the formation is readily traceable on the basis of its physical characters, stratigraphic position, and influence on topography.

The Wyandotte has a maximum thickness of about 60 feet in Johnson and Leavenworth Counties, Kansas, but is thinner to the south. The formation pinches out abruptly southwest of Lane, in Franklin County, and is recognized only locally southward as far as Allen County. It has been traced far northward, however, being identified in southwestern Iowa and along the Platte Valley in Nebraska. The members of the Wyandotte limestone (in upward order) are Frisbie limestone, Quindaro shale, Argentine limestone, Island Creek shale, and Farley limestone.

Frisbie limestone member. The basal Wyandotte member, called the Frisbie limestone (NEWELL, in MOORE, 1932, p. 92) consists of dark-blue or blue-gray dense limestone, which differs from succeeding beds in its massive character and (where typically developed) presence of vertical joints (Figs. 18, 20). The member is not very fossiliferous but commonly shows thin irregular calcite "veinlets" which seem to be of organic origin. Numerous brachiopods, bryozoans, and crinoids have been collected from this limestone in the Kansas City area, however. The thickness of the Frisbie limestone ranges from 1 to 3 feet.

Quindaro shale member. Shale and shaly limestone overlying the Frisbie limestone is defined as the Quindaro shale member (NEWELL, in MOORE, 1932, p. 92) of the Wyandotte limestone (Figs. 18, 20). Locally this shale is black, fissile, and carbonaceous, but more commonly it is yellowish and calcareous and beds of this type grade laterally into shaly limestone which is not sharply separated from limestones above and below. The thickness of the Quindaro shale is only 1 to 2 feet.

Argentine limestone member. Normally, the thickest subdivision of the Wyandotte formation is the Argentine limestone member (NEWELL, in MOORE, 1932, p. 92), which succeeds the Quindaro shale and is overlain by the Island Creek shale, or (where this shale is absent) by the Farley limestone (Figs. 18, 20). The Argentine limestone is light bluish-gray when fresh and weathers creamy-white, grayish-white, or light-buff. The bedding is thin and uneven, many of the layers being distinctly nodular. The rock is mostly very fine-grained but there is much crystalline calcite in the form of very thin irregular (algal?) "veinlets" and small cavity fillings. Sparse gray and brownish chert is somewhat characteristic. In the Kansas and Missouri River valleys the lower part of the rock is shaly and locally comprises alternating thin beds of limestone and shale. Fossils are numerous in most places, the fauna consisting chiefly of brachiopods and bryozoans.

The Argentine limestone is about 30 feet thick at Kansas City and has an average thickness of 20 feet in Johnson and Miami Counties, Kansas. This member disappears south of Lane but is persistent northeastward in Missouri. It is identified in Iowa and southeastern Nebraska.

Island Creek shale member. Bluish-greenish clay shale, which overlies the Argentine limestone in many places, belongs to the Island Creek shale member (NEWELL, in MOORE, 1932, p. 92) of the Wyandotte formation (Figs. 18, 20). At the type locality, northwestern Wyandotte County, Kansas, the Island Creek is 43 feet thick, which is nearly the observed maximum. In outcrops not far distant, the shale diminishes to a featheredge. In some exposures, most of the interval between the Argentine and Farley limestones is occupied by fine-grained massive sandstone. The member is nonfossiliferous.

Farley limestone member. A thin limestone lying between the Argentine limestone (formerly believed to be Iola) and the Plattsburg formation (Figs. 18, 20) in Platte County, Missouri, was named Farley by HINDS & GREENE (1915, p. 29). Later, it was found that two limestones, lithologically similar to the Farley, occur in this part of the section in the Kansas and Missouri River Valleys above Kansas City; collectively they were called Farley (MOORE, 1932, p. 92; NEWELL, 1935, p. 60). Still later studies have shown that in Kansas north of Miami County, an extremely variable assemblage of limestone and shale beds occurs next above the lithologically more persistent Argentine limestone. Many types of limestones are seen, suggesting that more than one cycle of marine deposition may be represented. With little doubt, the type Farley represents only one or two of the limestone elements of this variable unit, but the name may be applied to all. Among the Farley beds thus specified, the most characteristic are oölitic-appearing algal limestone, limestone breccia or conglomerate, and dense mottled pinkish limestone. Cross-bedding is common in both the algal limestone and breccias. Wavy- and thin-bedded mottled limestone, chiefly in the lower part, is somewhat similar to the main body of the underlying Argentine limestone. A thin bed of greenish-gray sandy shale containing a molluscan fauna occurs rather persistently in the approximate middle part of the Farley section. In general, the Farley limestones contain many fossils, especially shells of mollusks. Large nautiloid cephalopods are common at some places. The thickness of the Farley member ranges from a featheredge to about 40 feet.

Bonner Springs Shale

The Bonner Springs shale (NEWELL, in MOORE, 1932, p. 93) includes strata between the Wyandotte formation, below, and the Plattsburg limestone, above (Figs. 18, 20). The formation consists of 10 to 25 feet of gray or buff shale, the sandy lower part of which grades locally into soft sandstone filling channel-like depressions several feet deep carved in underlying strata. These sandy beds contain remains of land plants in some places. The upper part of the shale consists of olive-green clay shale and, near the top, 1.5 feet or less of maroon clay shale, which is persistent in Miami and Johnson Counties, Kansas. The maroon shale is commonly overlain by a thin layer of ocher-yellow to greenish, calcareous shale or soft nodular limestone. Locally, as at DeSoto, Johnson County, and one-half mile west of Bonner Springs, Wyandotte County, the Bonner Springs shale is absent, apparently due to nondeposition or perhaps to erosion preceding Plattsburg deposition, for a shell breccia at the base of the latter formation rests directly on the Farley member of the Wyandotte limestone.

The maximum observed thickness of the Bonner Springs shale is about 45 feet. South of the point in east-central Kansas where the Wyandotte beds disappear, the Bonner Springs shale is not separable from the Lane beds and the entire section between the Iola and Plattsburg limestone is designated as Lane-Bonner Springs shale. Thus, it comprises the undifferentiated Zarah subgroup of southern Kansas.

Lansing Group

Definition

As originally defined (HINDS, 1912, p. 7), the name Lansing was applied to strata from the top of the so-called Iola limestone (Frisbie-Argentine of present classification) in the Kansas City area to the top of the Stanton limestone. The overlying shale (Weston) was thought to be a part of the Douglas "shale." The Lansing beds were designated as a formation and divided into members termed (in upward order) Lane shale (now recognized as Island Creek shale, Farley limestone, and Bonner Springs

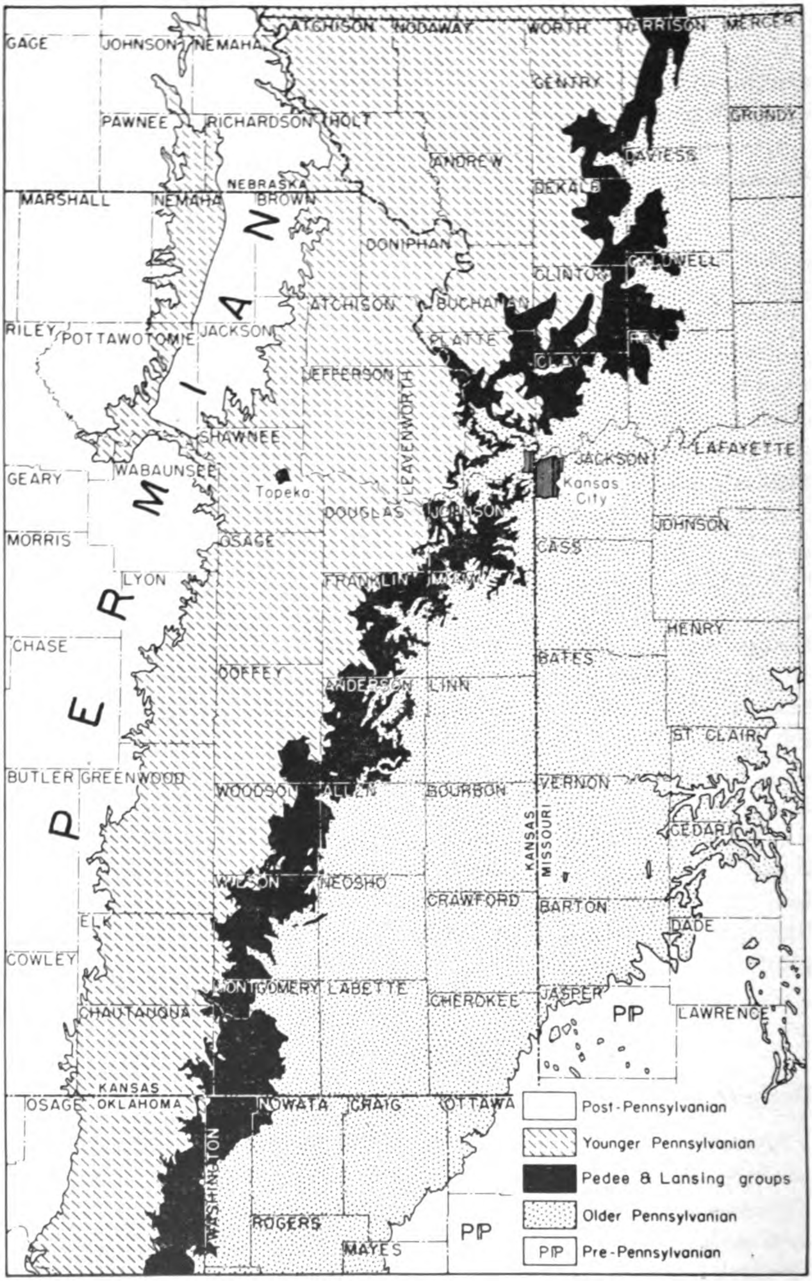

Figure 21. Distribution of outcrops of the Lansing and Pedee groups in Kansas and parts of adjoining States. These groups comprise the uppermost part of the Missourian Series. South of west-central Montgomery County, Kansas, strata equivalent to Lansing and Pedee are classed as belonging to the upper part of the Ochelata group.

shale), Plattsburg limestone, Vilas shale, and Stanton limestone. When work by Condra (1927), Newell (1935) and others led to subdivision of the Plattsburg and Stanton units into persistent limestone and shale components, which were classed as members, it became necessary to treat Plattsburg, Vilas, and Stanton as formations and to change Lansing formation to Lansing group. Moore (1932) revised the assigned span of the Lansing group by transferring beds below the Plattsburg to the Kansas City group. Usage of the Kansas Geological Survey in definition of the Lansing group consisting of the Plattsburg, Vilas, and Stanton formations, was accepted by the inter-State conference (Fig. 14).

Distribution and Thickness

The Lansing group is exposed in a belt which trends south-southwestward across Kansas from northern Leavenworth County to western Montgomery County (Fig. 21). The belt is much narrower than that of the Kansas City outcrops on the average, especially in areas where the shale which separates the lower and upper limestone formations is comparatively thin and escarpments made by the latter are close together. The eastern edge of the outcrops is topographically prominent and easily mapped, whereas the western margin is very obscurely marked and difficult to map precisely. The western boundary is drawn along the not-sharply-defined line where the gently inclined smooth plain developed on the uppermost Lansing limestone merges with hilly slopes formed by lower Pedee shales. The hard rocks of the Lansing group make rugged topography wherever the strata are crossed by major streams, for tributaries of these streams cut through the Lansing rocks in deep ravines. Excellent exposures of rocks belonging to the group are seen in Wyandotte, Leavenworth, Johnson, Franklin, Anderson, Woodson, and Wilson Counties, Kansas.

In northwestern Missouri, the Lansing formations are concealed in most places by glacial drift, but nevertheless the outcrop belt is generally expressed in the topography. Outcrops of Lansing strata are identified in Iowa and along the Platte River Valley in Nebraska, but because shales separating the Lansing from lower and higher limestones are thin, and because glacial drift is mostly very thick, there is no Lansing escarpment. Southward from Montgomery County, in southern Kansas, the Lansing is not clearly differentiated because the lower limestone formation disappears and the upper limestones become thin and somewhat discontinuous. The equivalent rocks in Oklahoma are classed as belonging in the upper part of the Ochelata group.

Rocks of the Lansing group seem to lie conformably on uppermost Kansas City beds in most places, but in southern Kansas and northeastern Oklahoma the lower Lansing rests disconformably on underlying rocks, with progressive overlap toward the area of the Chautauqua arch. Physical evidence of this hiatus is seen also near Bonner Springs, Lane, and Greeley, Kansas. It consists of the local absence of pre-Plattsburg beds, irregularities of contact, and local occurrence of conglomerate at the base of the Plattsburg. Slight regional warping of Kansas City and older rocks in the Chautauqua arch area, which does not affect Lansing beds, is associated with absence of lower Lansnig deposits.

The thickness of the Lansing group averages about 75 feet, but in parts of southern Kansas it is more than 150 feet.

Lithologic Character

The Plattsburg-to-Stanton division placed in the revised Lansing group is characterized by dominance of limestone and along most of the outcrop the Lansing limestones lie closely together, forming a prominent escarpment which is widely separated from escarpments made by lower and higher limestones. Shales belonging to this group are partly marine and partly nonmarine. The nonmarine shaly deposits, which are quantitatively most important, are silty to sandy and mostly unfossiliferous. Sandstone is a very inconspicuous constituent of the Lansing group.

Cyclic features of Lansing sedimentation are illustrated in Figure 18 and are described briefly in the introductory part of discussion of the Kansas City group.

Classification

Formations belonging to the Lansing group are named, in upward order, Plattsburg limestone, Vilas shale, and Stanton limestone. These units are readily differentiated along the outcrop and are identified at many places in the subsurface area of Lansing distribution. In well records, it is common practice, however, to mark the easily determined top of the Lansing strata and to unite Lansing with underlying Kansas City beds, dominantly limestone, under the designation of Kansas City-Lansing. These rocks are oil-bearing in many parts of central and western Kansas.

Plattsburg Limestone

The Plattsburg limestone (Broadhead, 1866, p. 317), named from outcrops in northwestern Missouri, overlies the Bonner Springs shale and occurs beneath the Vilas shale (Figs. 14, 18, 20). It shows little variation in lithologic and faunal characters and can be recognized without difficulty at most outcrops. The Plattsburg is identified in southeastern Nebraska, and has been traced from south-central Iowa across northwestern Missouri and eastern Kansas to a point near the Oklahoma boundary where it disappears. Marine fossils, especially the brachiopods *Enteletes, Marginifera*, and *Composita*, are common in certain zones, and a varied sponge fauna occurs in the Plattsburg throughout much of central and southern Kansas.

The thickness of the formation ranges from less than 5 feet to more than 100 feet, the average being about 20 feet. A noteworthy feature is the considerable variation of thickness in short distances along parts of the outcrop.

The Plattsburg limestone contains two limestone members, Merriam and Spring Hill, and an intervening shale member, Hickory Creek. With varying clearness in different places, these show characters that are typical of certain subdivisions of the typical megacyclothem.

Merriam limestone member. The lowermost member of the Plattsburg limestone, named Merriam limestone (Newell, in Moore, 1932, p. 93), commonly contains three distinct divisions: (1) a lower blocky, drab to light-gray, highly fossiliferous layer, which weathers gray or white; (2) a middle unit consisting of fine-grained dense, vertically jointed bluish limestone; and (3) an upper unit consisting of algal and granular limestone (Figs. 18, 20). The lower limestone contains numerous productids and a few other brachiopods, including locally a zone of *Composita* at the base. The large flat pelecypod, *Myalina ampla*, is characteristic of the lower Merriam, as is also the alga *Osagia*, which commonly occurs in such abundance as to form an appreciable part of the rock. In many places, this part of the Merriam member is oölitic.

The lower Merriam limestone ranges in thickness from a few inches to about 5 feet. The middle part of the Merriam is a typical homologue of the Paola, Middle Creek, and similar limestones. This bed is mostly poor in fossils, but the upper part contains numerous irregularly disposed cylindrical tubes which are filled with yellowish-brown ferruginous clay. These tubes are interpreted as worm borings. The middle division of the Merriam limestone member is about 1 foot thick. The upper unit ranges from a featheredge to about 8 feet in thickness and is less persistent than the lower two parts. It contains rather abundant nautiloid cephalopods.

Hickory Creek shale member. The middle Plattsburg member is named Hickory Creek shale (NEWELL, in MOORE, 1932, p. 93) from outcrops in Franklin County, Kansas. It ranges in thickness from less than an inch, in a few places, to a maximum of about 40 feet. Where thin, the shale contains a black carbonaceous zone, as is characteristic of the shales overlying limestones like the middle unit of the Merriam (Figs. 18, 20). Where the shale is thick, it is gray or yellowish in color and clayey. Fossils are rare or lacking.

Spring Hill limestone member. The uppermost division of the Plattsburg formation is named Spring Hill limestone (NEWELL, in MOORE, 1932, p. 93). The lower part consists of thin-bedded bluish-gray, fine-grained brittle limestone which bears numerous *Enteletes*, *Marginifera*, and, in Nebraska, abundant fusulinids. The upper part contains light-gray oölitic limestone, or granular drab-colored somewhat argillaceous coquinoid limestone. In addition to *Osagia* and possibly other algal remains, abundant echinoid spines and numerous specimens of a robust *Composita* are found in the upper part of the Spring Hill limestone (Figs. 18, 20).

The lower unit of the Spring Hill member has an average thickness of about 5 feet and the upper unit about 7 feet, making an average total of about 15 feet. Great variation in thickness, however, characterizes this limestone, for it is observed to range from a featheredge to 50 feet.

Vilas Shale

The Vilas shale (HAWORTH, 1898, p. 51) is the middle formation of the Lansing group, named from a town in northeastern Wilson County, west of Iola (Figs. 14, 18, 20). The shale is gray to buff, clayey and sandy, and is mostly barren of fossils. Near Kansas River a persistent zone of fine-grained gray, hard, ripple-marked sandstone occurs near the top or in the middle. Farther south, much reddish-brown soft sandstone and sandy shale occurs locally in the Vilas.

Average thickness of the formation in the north is about 15 feet but in southern Kansas thickness increases to 80 feet or more locally. Abrupt variation in thickness is characteristic of the Vilas.

Stanton Limestone

The Stanton limestone (SWALLOW & HAWN, 1865, p. 6; NEWELL, 1935, p. 76) overlies the Vilas shale conformably and, except where Virgilian strata directly overlie Stanton limestone, is succeeded conformably by the Weston shale of the Pedee group (Figs. 14, 20, 30). It forms a fairly prominent escarpment from northeastern Kansas to the southern part of the State. The thickness of the formation ranges from about 20 feet to at least 100 feet at a few places in southern Kansas. Along the Kansas and Missouri River Valleys, the Stanton is fairly uniform in character and averages 35 to 40 feet in thickness, but in east-central Kansas and farther south there are great local variations. For example, near Elk City in Montgomery County, the Stanton is approximately 100 feet thick, but 3 miles southward it is only 10 feet thick. Near the Oklahoma-Kansas line it is difficult to trace the Stanton, but in the vicinity of Ramona, south of Bartlesville, Oklahoma, limestone equivalent to the Stanton is thick and readily identified. These beds in Oklahoma are classed as part of the Wann formation (OAKES, 1940, p. 72) (Fig. 14).

The Stanton formation contains five members (in upward order): Captain Creek limestone, Eudora shale, Stoner limestone, Rock Lake shale, and South Bend limestone.

Captain Creek limestone member. The lowest member of the Stanton is called Captain Creek limestone (NEWELL, 1935, p. 76), from outcrops near Eudora, Douglas County, Kansas. It is readily identified in most sections by its distinctive lithologic character and by its position beneath black fissile shale of the Eudora member (Figs. 20, 30). The limestone is dark-gray or blue, dense, brittle, and hard. It is massive or even-bedded and in most places shows prominent vertical joints. Beautifully preserved specimens of the brachiopod, *Enteletes pugnoides*, are abundant in the Captain Creek limestone throughout most of northeastern Kansas, and a robust fusulinid, *Triticites neglectus*, occurs commonly on bedding planes of the member. This dense blue limestone is a typical representative of the cyclothem element previously noted in several limestone formations, occurring next below black platy shales. Such beds are a characteristic feature of Missourian and Virgilian megacyclothems, in which they belong to the second cyclothem of this sequence. At the top of the Captain Creek limestone, as seen at some exposures, a peculiarly brecciated siliceous bed, a few inches thick, bears mottled pink and blue color.

The Captain Creek limestone is identified throughout northern Kansas and northwestern Missouri, and has been recognized in Iowa and in the section of the Platte Valley, southeastern Nebraska.

The thickness of the member is 4.5 to 5.5 feet along Kansas River and most places farther north, but southward it increases to more than 10 feet in parts of Miami County and, according to Newell, 40 feet northwest of Independence, Kansas.

Eudora shale member. The shale overlying the Captain Creek limestone is named the Eudora shale member (CONDRA, 1930, p. 12) of the Stanton, from excellent exposures near Eudora, on Kansas River east of Lawrence. It is a very constant unit in northeastern Kansas and northwestern Missouri. The lower part consists of black fissile shale or in some places of dark clay shale containing a thin carbonaceous layer (Figs. 20, 30). The upper part is greenish- to bluish-gray in color, and is soft and clayey.

The thickness of the Eudora shale ranges from only 1 foot in some northern outcrops to 50 feet in part of Montgomery County, Kansas. The average thickness is about 5 feet. Megascopic fossils are rare in the Eudora shale of northeastern Kansas, but well-preserved molluscan shells are fairly common in southern Kansas, and in northeastern Oklahoma in equivalent beds.

Stoner limestone member. Light bluish-gray to nearly white limestone which commonly weathers very light-gray or creamy-white overlies the Eudora shale and comprises the Stoner limestone member (CONDRA, 1930, p. 11) of the Stanton (Figs. 20, 30). Normally, this is the thickest limestone subdivision of the formation. The member is named from outcrops in the Platte Valley of Nebraska. Beds of the Stoner limestone are mostly thin and wavy, with thin shaly partings between the layers; the rock is fine-grained, but in places much crystalline calcite is irregularly distributed.

This member is 11 to 15 feet thick along Kansas River and elsewhere in northeastern Kansas, but in parts of southern Kansas, where the Stanton attains a thickness of 100 feet, the member measures about 50 feet.

The fine-grained, light-colored character, thin wavy bedding, large relative thickness, and stratigraphic position next above black fissile shale, are all typical attributes of a megacyclothem element (representing the third cyclothem of type Shawnee examples). Seemingly, it marks the culminating part of the complexly oscillatory submergence which is inferred to be represented by a megacyclothem. The Stoner limestone is less fossiliferous on the average than most limestone units which are homologous to it. To the north, it contains abundant *Triticites* of the *T. irregularis* type.

Rock Lake shale member. Overlying the Stoner limestone is a persistent shale which is classed as the Rock Lake shale member (CONDRA, 1927, p. 59) of the Stanton limestone (Figs. 20, 30). Like the Stoner, it is named from outcrops in the Platte Valley. The contact at the base of the shale in many places is irregular, suggesting a slight disconformity. Commonly, a thin layer of greenish-gray clay shale is seen in the lower part of the member, but most of the unit consists of reddish-brown to dark-buff sandy shale or soft sandstone. The sandstone is shaly, even-bedded, or massive. A persistent red shale zone occurs in the middle part of the Rock Lake shale in southeastern Nebraska. The thickness of this member ranges from about 1 foot to 15 feet.

The Rock Lake shale contains locally a remarkable assemblage of well-preserved land plants of Permian aspect, including abundant *Walchia*, mingled with remains of amphibians, fishes, a scorpion, and marine invertebrates (MOORE, ELIAS, & NEWELL, 1936).

South Bend limestone member. The uppermost member of the Stanton formation is the South Bend limestone (CONDRA & BENGSTON, 1915, p. 23) which lies conformably on the Rock Lake shale and conformably beneath the Weston shale (Figs. 20, 30). It is named from a locality in the Platte Valley of Nebraska, where this limestone and associated beds clearly represent a cyclothem having several well-defined phases; this cyclothem is distinct from that to which the Stoner limestone belongs. The most persistent beds of the member consist of dark-gray, fine-grained limestone. The brachiopod *Meekella striatocostata* and a fusulinid similar to *Triticites moorei* are the most common fossils.

The thickness of the South Bend limestone in northeastern Kansas is rather constantly about 4 to 5 feet, and in southeastern

Nebraska, it is about 10 feet. The member is identified at numerous exposures in northwestern Missouri, but has not been identified definitely in southern Kansas.

Pedee Group

General Description

In the vicinity of the Kansas River, deposits of Virgilian age rest directly on upper beds of the Lansing group, but to the north and south there are post-Lansing strata of variable thickness that belong to the Missourian Series. These rocks are assigned to the Pedee group (Figs. 14, 20). They lie conformably on the Stanton formation and are bounded above by the disconformity that divides Missourian and Virgilian deposits. The lower part of the Pedee group is called Weston shale, and the upper part, which is definitely recognized only north of Kansas River, is named Iatan limestone.

It is probable that along the Missouri River in the vicinity of Iatan and Weston, between Leavenworth and Atchison on the Missouri side, and in some other places where the Iatan limestone is present, some shale of Missourian age may occur above the Iatan. Such shale is assignable to the Pedee group, but no beds in this position are identified definitely. Evidence of the exact position of the Missourian-Virgilian boundary near Iatan and Weston is lacking but inasmuch as the thickness of the zone within which the boundary belongs is only 5 to 20 feet, this uncertainty is not of great importance. Observation of somewhat variable lithologic characters in this zone, its irregular local changes in thickness, and at least in some places, unevenness of the top of the Iatan limestone, indicate that the disconformity here belongs at the top or a few feet above the Iatan. In other areas the Missourian-Virgilian disconformity plainly cuts downward far into the Weston or even well below the top of the Stanton formation, as in the Kansas River Valley.

The Pedee group is about 100 feet thick southeast of St. Joseph, but locally, as throughout much of Platte County, Missouri, and in the Kansas River Valley, Pedee beds are only a few feet thick or they are lacking. In southern Kansas Pedee deposits have a thickness of about 200 feet at some places, as just west of Caney.

Weston Shale

The Weston shale (KEYES, 1899, p. 300) includes the beds between the top of the Stanton limestone and the base of the Iatan limestone (Figs. 14, 20). Where the Iatan is absent, the top of the Weston is marked by the disconformity at the base of the Virgilian Series. Here, the next beds above the Weston may consist of coarse conglomerate, massive or irregularly bedded sandstone, red shale, or sandy brownish and bluish shale belonging to various horizons of the Douglas group.

The Weston shale is a fairly uniform dark bluish to bluish-gray marine clay shale, which in many places is characterized by the presence at several levels of many flattish, elliptical ironstone concretions. Fossils are not very numerous in the shale, but in places thin highly fossiliferous limestone beds in the Weston can be traced for several miles. No coal beds or sandstones have been observed in the Weston of northern Kansas and northwestern Missouri, but toward the south there are some layers of shaly to even-bedded sandstone and much of the shale is silty to fine sandy in texture.

The thickness of the Weston shale ranges from a featheredge to a maximum of about 140 feet. On account of post-Missourian erosion, the thickness of the Weston in near-by sections may be very dissimilar.

Iatan Limestone

The Iatan limestone (KEYES, 1899, p. 300) overlies the Weston shale conformably and is overlain disconformably by the Stranger formation, basal deposits of the Virgilian Series (Figs. 14, 20). The limestone is light bluish-gray or nearly white, both in fresh and weathered exposures, but parts of the Iatan are mottled with brown after prolonged weathering. The bedding is indistinct and somewhat uneven, so that the rock appears rough and shelly but very massive. Large blocks, separated by joint planes, tend to break from the outcrop and creep down steep slopes. The texture of the limestone is very fine and dense, but there are very numerous thin, irregular plates of clear calcite which are differentially etched by weathering. Numerous nodular fragments of dense limestone are thought to be algal deposits. Brachiopods, bryozoans, crinoid stem fragments, and locally, small corals, are the most common fossils, but fossil remains are not abundant in most places.

Fusulinids are numerous at the top of the formation between Weston and Iatan, Missouri, and in the lower half of the Iatan outcrops at St. Joseph. At the latter place the upper bed of the Iatan is a molluscan-algal phase limestone, containing *Derbyia*, mollusks, and crowded with large *Osagia*.

The thickness of the Iatan ranges from less than 5 feet to about 22 feet, the maximum being observed a short distance south of Iatan. The formation is extensive in northeastern Kansas and northwestern Missouri, north of Leavenworth and southward at least to the vicinity of Baldwin, in southern Douglas County, Kansas. The limestone which has been called Iatan in country farther south is mostly a lower Virgilian unit, the Haskell, but some limestone outcrops may represent true Iatan. A limestone belonging beneath the post-Missourian disconformity and above the Stanton limestone is observed near Caney in southern Kansas and northern Oklahoma.

Virgilian Series

General Description

The Virgilian rocks of Kansas include Upper Pennsylvanian formations lying between the unconformity that defines the upper limit of Missourian rocks and the similar unconformity, which is marked mainly by locally prominent channel sandstone (Indian Cave), at the Pennsylvanian-Permian boundary. In outcrops along the Kansas River Valley east of Lawrence, and in the vicinity of Leavenworth, the lowermost Virgilian sandstone (locally conglomerate), which is included in the Stranger formation, lies directly on eroded members of the Stanton limestone, from uppermost to lowermost; no rocks of Pedee age (latest Missourian) are present. Northward and southward from Kansas River, varying thicknesses of Pedee strata are found to have been left by the pre-Virgilian erosion, but locally, as southwest of Chanute, the unconformity cuts downward deeply into rocks of the Lansing group.

The formations belonging to the Virgilian Series in Kansas are characterized on the whole by regularity of arrangement and persistence of stratigraphic units, including members and subdivisions of members. Limestones alternate with shale in vertical succession, and marine deposits alternate with nonmarine. The general uniformity of sequence and approximately constant thickness of Virgilian rock divisions across Kansas are best developed in the middle and upper parts of the succession (Shawnee and Wabaunsee groups). They are not exhibited by lower Virgilian strata belonging to the Douglas group, even though some units are widely extended. No part of the Pennsylvanian section in the northern midcontinent region contains clearer evidence of cyclic sedimentation than that seen in characters of Shawnee and Wabaunsee cyclothems, especially. The Shawnee group contains the most complete—or at least the most complex—examples of cyclically arranged cyclothems which have been termed megacyclothems (MOORE, 1936, p. 29), whereas numerous Wabaunsee formations exhibit unusually well-differentiated, widely persistent phases of individual cyclothems, which are not grouped in the pattern of Shawnee megacyclothems.

The Virgilian limestones include several different kinds of calcareous rock. These occur in such relation to other strata and to one another and they are associated so constantly with certain paleontological characters that their differences must be interpreted inescapably as lithologic records of several combinations of environmental elements. The chief types of limestones are (1) light-gray, very fine-grained, thin-bedded rock having wavy partings of thin shale; (2) dark-bluish, dense, brittle, massive limestone, which weathers blue-gray; (3) bluish-gray, irregularly thick-bedded, ferruginous limestone, which weathers to rich-hued shades of brown; and (4) light-gray to nearly white, massive rock of nodular structure, which is seemingly of algal origin. These types represent phases of cyclothems. The limestones are expressed topographically by escarpments and benches on the fronts of escarpments and along valley walls. Also, the thicker limestone units underlie dip-slope plains of varying width, where covering weak strata have been stripped away. The Virgilian limestones influence the nature of residual soils and their outcrop areas are marked by types of vegetation adapted to these soils.

Shaly formations of the Virgilian section in Kansas are also of several types, which are differentiated by composition, color, bedding, organic content, mode of weathering, and average thickness. As shown by their fossil content and other features, some are nonmarine and others, which constitute a majority, are marine. The most important types are: (1) light-colored (gray, bluish, greenish, yellowish) clayey and sandy shales, which are noncalcareous, poorly to only moderately well laminated, and generally unfossiliferous; (2) red clayey to silty, poorly bedded, unfossiliferous shales; (3) bluish-gray to light brownish, calcareous shales, which are mostly well laminated and contain numerous marine fossils; and (4) black, highly carbonaceous, fissile, platy shales which commonly bear conodonts and some corneous brachiopods. Many of the Virgilian shale units are thick—that is, 50 to 100 feet from lower to upper limits—but these divisions are less regular than many shale units, especially the black platy shales, which have a maximum thickness of only 5 or 6 feet.

Sandstone is a prominent constituent of Virgilian deposits belonging to the Douglas group, and it is important in many of the thicker shale bodies of the Shawnee and Wabaunsee groups. Viewed from the standpoint of regional distribution, attention is drawn at once to the smaller sand content of the Virgilian deposits in northern Kansas and Nebraska and much larger proportion of sandstone throughout the section in southern Kansas and Oklahoma. Traveling northward along the strike of Upper Pennsylvanian formations, one moves basinward, whereas traveling southward he approaches territory which was the site of dominant subaerial sedimentation. Thick nonmarine sandstones and abundant redbeds characterize the latter region, which, however, does not include Virgilian deposits of Kansas; the described type of section is seen from northern Oklahoma southward. Some Virgilian sandstones are channel fills, as is demonstrated by their convexity of base and relations to underlying strata. A majority of the sandstones are widespread sheets.

Coal beds are observed in each of the Virgilian groups and are distributed from near the base to within a few feet of the top of the section representing this stage in Kansas. With minor exception, however, the Virgilian coal beds are too thin for commercial exploitation. Their most interesting features are constancy of occurrence in relation to cyclothems and surprising horizontal extent. Some coal beds of the Wabaunsee group are found at virtually every exposure of the part of the section in which they occur so that they can be traced as continuous layers from northern Oklahoma to Nebraska and Iowa; yet maximum thickness of the coal beds is commonly only a few inches.

The outcrops of formations belonging to the Virgilian Series occupy a south-southwestward-trending belt across Kansas from the boundary along the northeast, which is made by the Missouri River, to the south boundary of the State in Chautauqua County (Fig. 1). The outcrop belt is widest in the north and narrowest in the south. Holton, Lawrence, Topeka, Emporia, Yates Center, Eureka, and Sedan are cities located within the area of exposed Virgilian formations. An outlying outcrop strip, which belongs to upper rocks of the series, extends northward from the Kansas River Valley near Manhattan; it is located along the axis of the Nemaha granite ridge anticline, where erosion has removed the cover of Lower Permian rocks.

Rocks of the Virgilian Series are divided into three groups, in upward order: Douglas, Shawnee, and Wabaunsee (Fig. 2).

Douglas Group

Definition

The Douglas group (HAWORTH, 1898, p. 93), named from Douglas County, Kansas, comprises the lowermost part of the Virgilian Series, extending upward from the disconformity at the lower boundary to the base of the Oread limestone.

As originally defined, the term Douglas was used to embrace the predominantly shale and sandstone deposits occurring between the top of the Stanton formation and top of the Oread formation. The Oread is one of the best-marked escarpment makers in the Pennsylvanian succession of the northern midcontinent and naturally it was chosen as marking an important stratigraphic boundary. The line mapped by Haworth and his associates to show distribution of the Oread follows the escarpment front and coincides with the base of the lowermost limestone. Inasmuch as the Oread commonly makes a broad dip slope, the contact between the upper limestone and overlying shale (Kanwaka) is a topographically inconspicuous line which in most places is some miles west of the escarpment front. Partly on cartographic grounds but more on the basis of lithologic characters and megacyclothem relationships which call for associating the Oread beds with Lecompton, Deer Creek, and Topeka beds, MOORE (1932) redefined the stratigraphic span of the Douglas group to exclude both upper Missourian deposits (Weston, Iatan) and the Oread formation.

As previously defined by the Kansas Geological Survey and now recognized by the inter-State conference, the Douglas group comprises the strata, almost exclusively clastic, occurring between

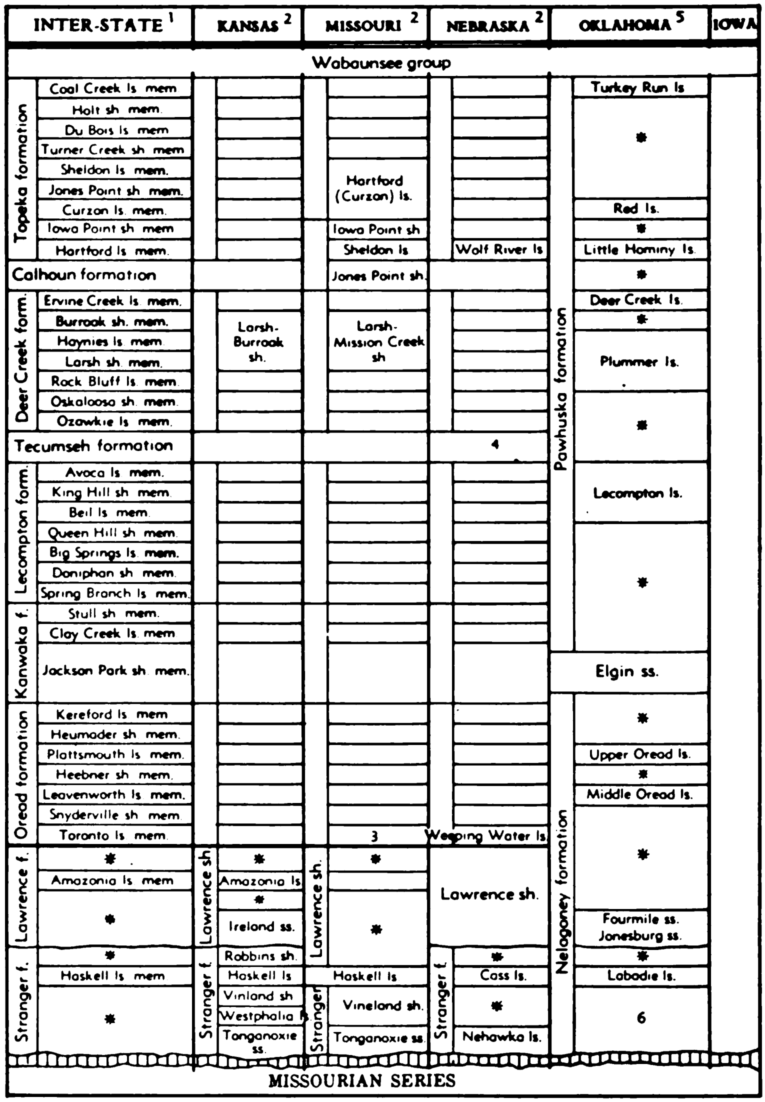

Figure 22. Classification of lower Virgilian rocks in the northern mid-continent area adopted by interstate conference of geological surveys. The agreed classification is compared with those previously used in the several States.

[1] In the interstate column, not all subdivisions, particularly in Douglas group, are recognized in Missouri, Nebraska, Oklahoma, and Iowa.

[2] Classification same as interstate excepting as shown.

[3] Called Toronto or Weeping Water limestone by McQueen and Greene (1938).

[4] Tecumseh shale in Nebraska is divided into members, in upward order: Kenosha shale, Ost limestone, Rakes Creek shale.

[5] Classification not yet adequately investigated or reported in publications of State Geological Survey. Many Shawnee units have been identified, but correlation of some with stratigraphic units in Kansas and other states is not definitely known.

[6] Shale and sandstone, including Chesewalla sandstone, and possibly Revard and Bigheart sandstone.

*Subdivision unnamed.

the disconformity at the base of Virgilian rocks and the base of the Oread formation (Figs. 2, 22, 24, 25). Lateral variations in the nature of the Douglas deposits naturally impose differences in local classification and it is not intended to exclude such differences as may be judged needful in the several States.

Where the disconformity that marks the boundary between Missourian and Virgilian beds is not identifiable in wells, the clastic deposits between the Stanton and Oread limestones may be termed Pedee-Douglas.

Distribution and Thickness

The outcrop belt of Douglas rocks is generally a rolling plain, bounded on the west by the east-facing Oread limestone escarpment and on the east by the contact of basal Douglas sandstone on weak Pedee strata or upper Stanton limestones which form a dip slope. This eastern boundary is very poorly expressed by topographic features. The width of the exposed Douglas strata is only 3 or 4 miles on the average, but locally it is as much as 30 miles (Fig. 23). The outcrop belt is mapped across Kansas from northeastern Doniphan County to eastern Chautauqua County. The trend of the belt is comparatively straight in a south-southwest direction. Best outcrops of Douglas beds are seen in Leavenworth and Douglas Counties adjacent to the Kansas River Valley, and farther south in Franklin, Coffey, Woodson, Wilson, Elk, and Chautauqua Counties. In southern Kansas, the Douglas outcrop area is an upland formed by hard sandstone layers and it is not topographically differentiated sharply from belts belonging to older and younger rocks. This area is continuous with rough scrub-oak country of eastern Osage County, Oklahoma, which is underlain by stratigraphic equivalents (lower Nelagoney formation) of the Douglas group.

The thickness of the group ranges from about 50 feet in southeastern Nebraska to nearly 700 feet in southern Kansas. In northeastern Kansas and northwestern Missouri the Douglas beds are 150 to 250 feet thick.

Lithologic Character and Classification

The Douglas group consists primarily of clastic deposits, in which fairly thick bodies of massive or cross-bedded sandstone, shaly sandstone, and sandy shale are prominent. It contains two

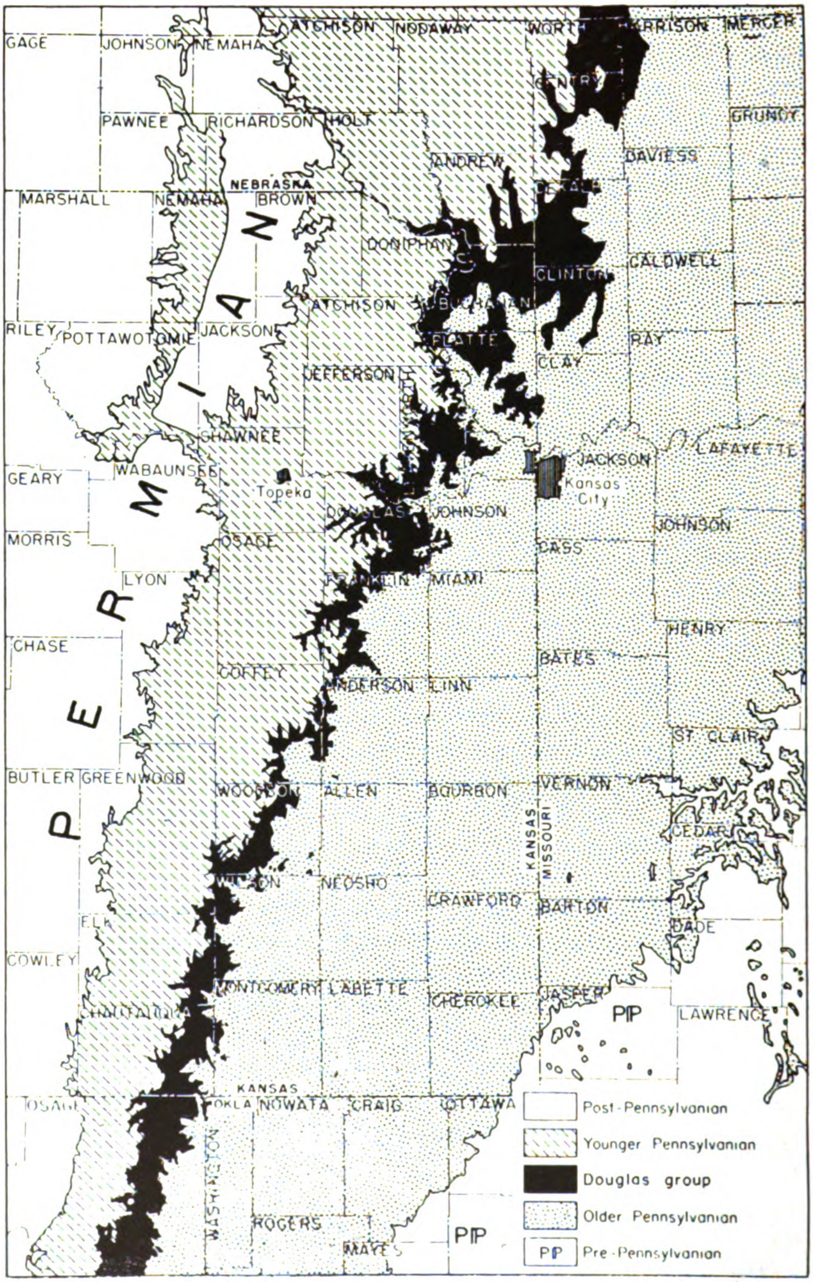

Figure 23. Distribution of outcrops of the Douglas group in Kansas and parts of adjoining States. This group is not recognized in classification of rocks of Oklahoma; outcrops south of Kansas shown as equivalent to Douglas deposits are included in the Nelagoney formation.

persistent, though rather thin, limestone beds (Haskell, Westphalia) in the middle or lower part, and some coal beds. Locally, conglomerate occurs at the base of the group.

As now classified, the rocks of the Douglas group are divided in two formations, called Stranger and Lawrence, respectively. These formations are separated in many places by a disconformity (Figs. 24, 25).

Stranger Formation

The Stranger formation (Newell, in Moore, 1932, p. 93) is defined (Moore, 1936, p. 147) to embrace nonmarine and marine beds of the lower part of the Douglas group extending upward from the base of the Virgilian rocks to a disconformity at the base of the Lawrence formation (Figs. 22, 24, 25). The type section of the formation is in southern Leavenworth County, Kansas. In northern Kansas, the upper boundary of the Stranger formation is at or near the Haskell limestone, but in southern Kansas a considerable body of marine shale belonging to the Stranger formation occurs above the Haskell limestone.

The thickness of the Stranger formation ranges from about 30 feet in northernmost exposures to about 300 feet in southern Kansas.

Tonganoxie sandstone member. The Tonganoxie (Moore, Elias, & Newell, 1934) sandstone member includes cross-bedded channel sandstones, sandy shales, and several thin coal beds, comprising all strata from the base of the Stranger formation to the top of the upper Sibley coal or base of the Westphalia limestone (Figs. 24, 25, 26). Nearly all the sediments of the Tonganoxie in Kansas are nonmarine. Seemingly, they are fluviatile deposits laid down on a broad coastal plain.

In much of Douglas, Leavenworth, and Wyandotte Counties, massive sandstones at the base of the member rest unconformably on various parts of the Stanton, Weston, and Iatan formations. Conglomerate composed of cemented pebbles of limestone occurs at the base of the member. The sand of the thick Tonganoxie beds is composed chiefly of angular quartz grains, having an average diameter of 0.2 mm. Somewhat larger grains of muscovite are common and characteristic. The sandstones are characteristically cross-bedded, and in northeastern Kansas the foreset beds dip generally in a westerly direction. Probably much of the Tonga-

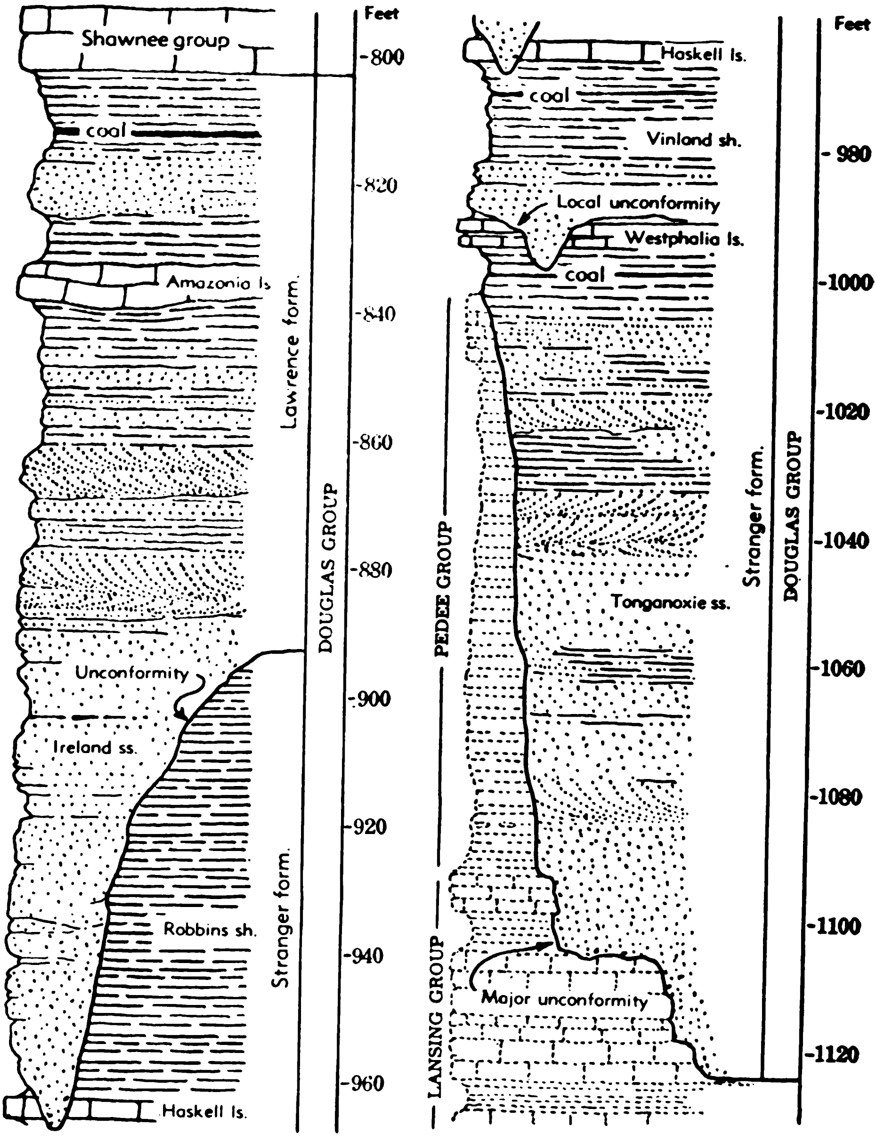

Figure 24. Generalized columnar section of rocks belonging to the Douglas group in Kansas. These rocks comprise the lowermost part of the Virgilian Series in this region.

noxie sand in southern Kansas was derived from a southern source. The sandy shales interbedded with the sandstone beds locally contain plant fragments, but do not have marine fossils. Coal beds occur in the north but disappear southward. One of these beds is about 30 feet and another 55 feet below the top of the member.

The Tonganoxie sandstone consists mostly of discontinuous lenses and channel-fillings (Fig. 25). The lower contacts are obviously unconformable on underlying strata, as evidenced by overlap relations, irregular sharp contact, and local masses of conglomerate at the base. At least five separate channel deposits are recognized at outcrops in Kansas. Toward the margins the channel fillings wedge out into homogeneous shale, as near Baldwin, west of Garnett, near Yates Center, and near Elk City.

The Tonganoxie member is exceedingly variable in thickness, ranging from 3 feet near Elk City, Kansas, to nearly 100 feet in eastern Leavenworth County.

Westphalia limestone member. Throughout most of its outcrop area the Westphalia limestone (Moore & Newell, in Moore, 1936, p. 150) is characterized by abundant fusulinids (*Triticites secalicus oryziformis*). The member is not definitely recognized at the outcrop north of T. 19 S. (Fig. 25). At its northernmost unquestioned outcrops in northwestern Anderson County, the member is overlapped by a channel filling (Ireland sandstone) belonging to the Lawrence formation. The Westphalia and its equivalents are cut out by the Ireland throughout southern Franklin County. The Westphalia limestone may be represented by a thin limestone above the Sibley coal near Baldwin, Kansas, and Iatan, Missouri. This limestone, 0.2 to 1 foot thick, is finely laminated and commonly contains thin layers of reworked coaly material; well-preserved plant fossils are found on the bedding planes. It also contains the marine ostracode *Jonesina howardensis* and minute gastropods. The interval between this limestone and the Haskell limestone corresponds to that of the Westphalia and Haskell.

The Westphalia limestone was well known in the subsurface before it was recognized at the outcrop. Together with the Haskell, it can be recognized as far west as R. 6 W. (Kellett, 1932), where both beds are overlapped by younger rocks on the flanks of the Central Kansas uplift.

Vinland shale member. The next higher member of the Stranger formation includes shale and sandstone, probably all

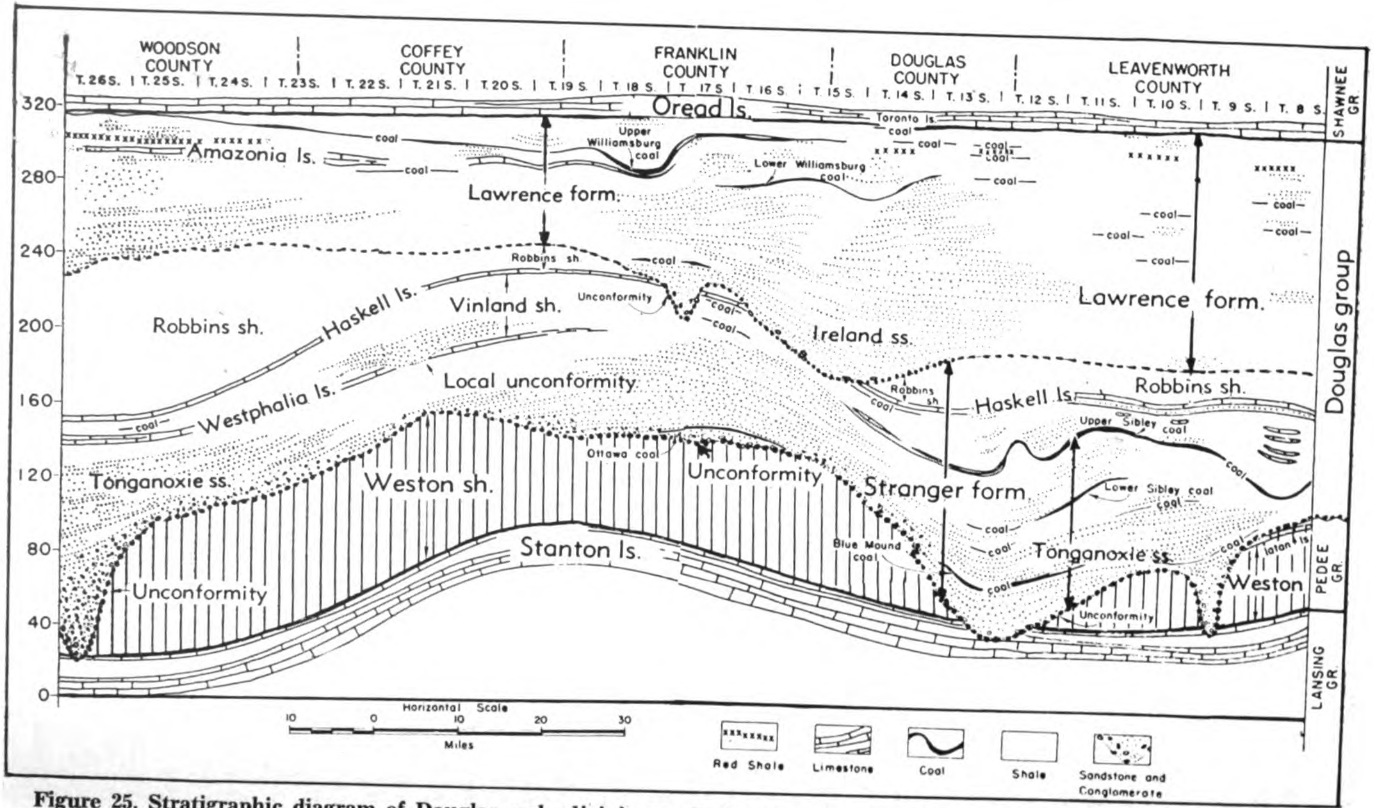

Figure 25. Stratigraphic diagram of Douglas and adjoining rocks in part of eastern Kansas. The diagram shows subdivisions of the Douglas group and varying stratigraphic relations as seen along the outcrop from the vicinity of Leavenworth to Yates Center, in Woodson County (*Redrawn from Bowsher & Jewett.*)

marine, between the Westphalia and Haskell limestones (Figs. 24, 25, 26). It is called the Vinland shale (PATTERSON & ADDISON, in MOORE, 1936, p. 151). The member consists of 9 to 50 feet of gray argillaceous, calcareous or sandy shale, and locally some sandstone. In Woodson County a dark-green layer near the middle of the member may be equivalent to a persistent variegated layer known at this horizon in the subsurface (KELLETT, 1932) of central Kansas.

The Vinland shale is ordinarily highly fossiliferous at many places along the outcrop. A well-preserved molluscan fauna in the shale near Iatan and Weston includes the clam *Nuculana arata*, described from this area more than 80 years ago. Near Lawrence the member is sandy and rather unfossiliferous, but from Vinland southward into Oklahoma a zone of prolific *Myalina* occurs near the top.

Haskell limestone member. A remarkably persistent and uniform limestone, which occurs next above the Vinland member, is called the Haskell limestone (MOORE, 1932) (Figs. 24, 25, 26). Undoubtedly it is the best key bed between the Lansing and Shawnee groups. Throughout much of the outcrop the Haskell is a bluish-gray, blocky, fine-grained limestone, occurring as a single ledge without shale partings. The Haskell contains the alga *Ottonosia* ("*Cryptozoon*") and some fusulinids and brachiopods. Locally, oölitic layers occur at the base and top of the member. The upper oölite layer at Lawrence furnished the types for several pelecypods described by BEEDE & ROGERS (1900). Northeastward, in Missouri, the member becomes shaly. The shale just below the Haskell limestone in Chautauqua County contains a prolific molluscan fauna, which resembles that associated with the Labadie ("Wildhorse") limestone of Osage County, Oklahoma. Probably the two limestones are the same.

Commonly, the Haskell is only 2 to 4 feet thick.

Robbins shale member. Above the Haskell limestone lies a marine, argillaceous shale of a variable thickness, which is called Robbins shale (MOORE & NEWELL in MOORE, 1936, p. 153) and classed as topmost member of the Stranger formation (Figs. 24, 25, 26). It is overlain unconformably by the Ireland sandstone. The shale above the Haskell and below the Oread limestone for a long time was classed as a single formation, the Lawrence shale. Inasmuch as the hiatus at the base of the Ireland sandstone seems to extend across Kansas, it calls for recognition in stratigraphic classification, and is now recognized as the boundary between the Stranger and Lawrence formations. In northeastern Kansas, the Ireland sandstone rests on the Haskell limestone or beds just above the Haskell. Southward, the base of the Ireland sandstone rises, so that in southern Kansas a thick wedge of clayey shale separates it from the Haskell. In this area, the base of the Lawrence, as defined by the Ireland, occurs scores of feet above the Haskell.

South of Lawrence, the Robbins shale is first definitely recognized near Baldwin, where it is 1 to 5 feet thick. At several outcrops in this area the Robbins and Haskell are cut out and overlapped by the Ireland. A persistent zone of ellipsoidal phosphatic concretions occurs at the base of the Robbins shale from Baldwin to Leavenworth. These concretions contain brain casts of fish, and ammonoid cephalopods. Southward from Yates Center, in Woodson County, the Robbins shale, consisting chiefly of gray argillaceous and silty shale, thickens to about 100 feet. Some massive sandstone beds appear abruptly in the Robbins in Chautauqua County and probably continue into Oklahoma.

Lawrence Formation

The Lawrence formation was originally defined (Haworth, 1894a, p. 122) to include strata belonging between the limestone now called Haskell and the base of the lower limestone of the Oread formation. Later the definition was amended by Moore & Newell (in Moore, 1936, p. 154) to exclude beds assigned to the Robbins shale member of the Stranger formation. The Lawrence formation is thus defined to embrace rocks between the base of the Ireland sandstone, or equivalent horizon, and the base of the Oread formation (Figs. 22, 24, 25). The Ireland is unrecognizable in the vicinity of Lawrence and in this area the lower limit of the Lawrence is placed at the top of the fossiliferous, phosphatic concretions known to occur in the Robbins elsewhere.

The upper limit of the Ireland sandstone is indefinite and probably does not constitute a single stratigraphic horizon (Fig. 25). Although the lower part of the Ireland is almost invariably massive cross-bedded sandstone, devoid of marine fossils, the higher part grades upward into sandy shale. Where the Ireland is well developed, it makes up the lower half to two-thirds of the

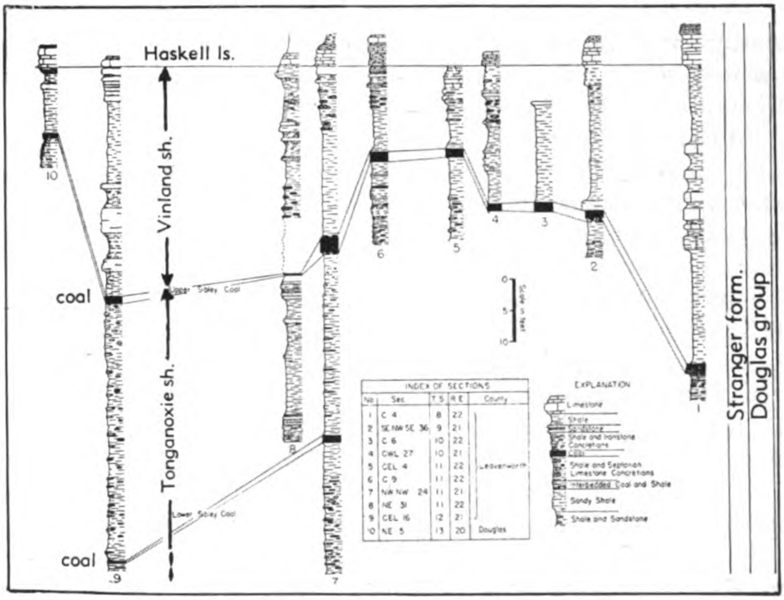

Figure 26. Sections of upper Stranger beds in Leavenworth and Douglas Counties, Kansas. (*Modified from Bowsher & Jewett*).

formation, not uncommonly attaining a thickness of 100 feet. Where the Ireland rests on Tonganoxie sandstone, as in the Leavenworth area, the lower boundary of the Lawrence formation cannot be recognized exactly. Identification of the presence of Ireland in this area rests on observation that the upper part of the sandstone mass rises 30 or 40 feet above position of the Haskell limestone, which is missing in the sandstone area, although clearly recognizable at Weston and Iatan, Missouri, not far distant.

A prominent Ireland channel-filling in southwestern Douglas and western Franklin Counties marks the base of the Lawrence formation in that area, where Rich (1933, p. 865) has described angular coal fragments in the basal part of the Ireland. The coal fragments, derived from the Sibley coal bed, were altered to hard coal before the pre-Lawrence erosion. According to Rich, the long time which probably was involved in making the coal suggests an important break at the base of the Ireland. The evolutionary change in invertebrates between the Stanton and Oread formations certainly is not pronounced, however, for scarcely any faunal break is seen in this part of the column. Seemingly, the time involved in the pre-Virgilian disconformity, plus that represented by the pre-Lawrence hiatus, is not measurable in terms of evolution of Pennsylvanian faunas.

At least two fairly persistent coal beds occur in the upper part of the Lawrence in northeastern Kansas. The more important bed is the Upper Williamsburg coal, which occurs 15 to 40 feet below the Oread limestone (BOWSHER & JEWETT, 1943). This coal extends from the vicinity of St. Joseph, Missouri, to northeastern Greenwood County, Kansas. It is more than 1 foot thick near Williamsburg, in Franklin County, where it is mined. The other coal, which occurs 5 to 30 feet below the Williamsburg bed, extends from St. Joseph to Baldwin, in southern Douglas County, Kansas, and occurs sporadically as far south as Woodson County (Fig. 25).

A massive nodular limestone, ranging up to 15 feet thick, occurs some 25 to 60 feet below the top of the Lawrence formation in northwestern Missouri. North of Iatan, Missouri, this limestone (Amazonia) occurs about 65 feet below the Oread and 70 feet above the Haskell (Fig. 24). In central and southern Kansas it appears to lie between the Lower and Upper Williamsburg coal beds (BOWSHER & JEWETT, 1943, p. 98) (Fig. 25).

A clayey and calcareous maroon shale is widely distributed between the Williamsburg coal beds and just above the Amazonia limestone (Fig. 25). This shale commonly occurs as one irregular bed, 1 to 5 feet thick, but in places there are three or more layers of maroon shale separated by greenish or buff shale. The zone extends from St. Joseph to southern Douglas County, Kansas, but is unrecognized farther south until it reappears in Woodson County. Maroon shales are common in and above the Ireland sandstone in Chautauqua County, Kansas, and northern Osage County, Oklahoma.

The only named members of the Lawrence formation are the Ireland sandstone and Amazonia limestone.

Ireland sandstone member. Massive or irregularly cross-bedded buff to brownish sandstone, some tens of feet thick, is prominent in the lower part of the formation at many places. This sandstone is designated as the Ireland member (MOORE, 1932, p. 93) (Figs. 24, 25). Its main characters and stratigraphic relations have been described. In the type region of the Ireland sandstone in Woodson County, Kansas, the top of the member is only a few feet below the top of the Lawrence. North of Kansas River and in subsurface sections extending to west-central Kansas, sandstone bodies in the middle and lower part of the formation have been classed as Ireland.

The thickness of the Ireland sandstone ranges from a featheredge to about 125 feet.

Amazonia limestone member. A prominent limestone which occurs about 24 feet below the top of the Lawrence shale at Amazonia, Missouri, and near Wathena, Kansas, is defined as the Amazonia limestone member (HINDS & GREENE, 1915, p. 31) (Fig. 24). Southward the shale above the Amazonia gradually thickens to more than 60 feet southeast of Atchison. HINDS & GREENE report as much as 100 feet of Lawrence beds above the Amazonia, between Rushville and St. Joseph, Missouri. At the type locality in Andrew County, Missouri, the Amazonia member is 9 feet thick. Near St. Joseph and Wathena it is 13 to 15 feet thick but southward it gradually diminishes and disappears. It is believed to be represented by a rather thin mottled nearly unfossiliferous limestone in central and southern Kansas (BOWSHER & JEWETT, 1943).

The physical characters of the Amazonia limestone in northeastern Kansas and northwestern Missouri are very similar to those of the Iatan limestone. It is a light-gray rock when fresh and weathers nearly white with irregular brownish mottling. Most of the beds are very fine-grained and dense but in places the upper part is coquinoid or appears fragmental, containing rounded or angular pieces of dense gray rock in a brownish matrix. Bedding is poorly developed and the member tends to weather, therefore, as a very massive ledge, which breaks along joint planes allowing large blocks to slump downward on steep slopes. Weathering of the faces of these blocks or of the bed reveals a faint but distinct uneven, wavy stratification. Fossils are not abundant generally, but in some outcrops and in certain parts of the member numerous brachiopods, bryozoans, crinoid fragments, and some other invertebrate remains may be found. Sponges are abundant in exposures of the Amazonia southeast of Atchison.

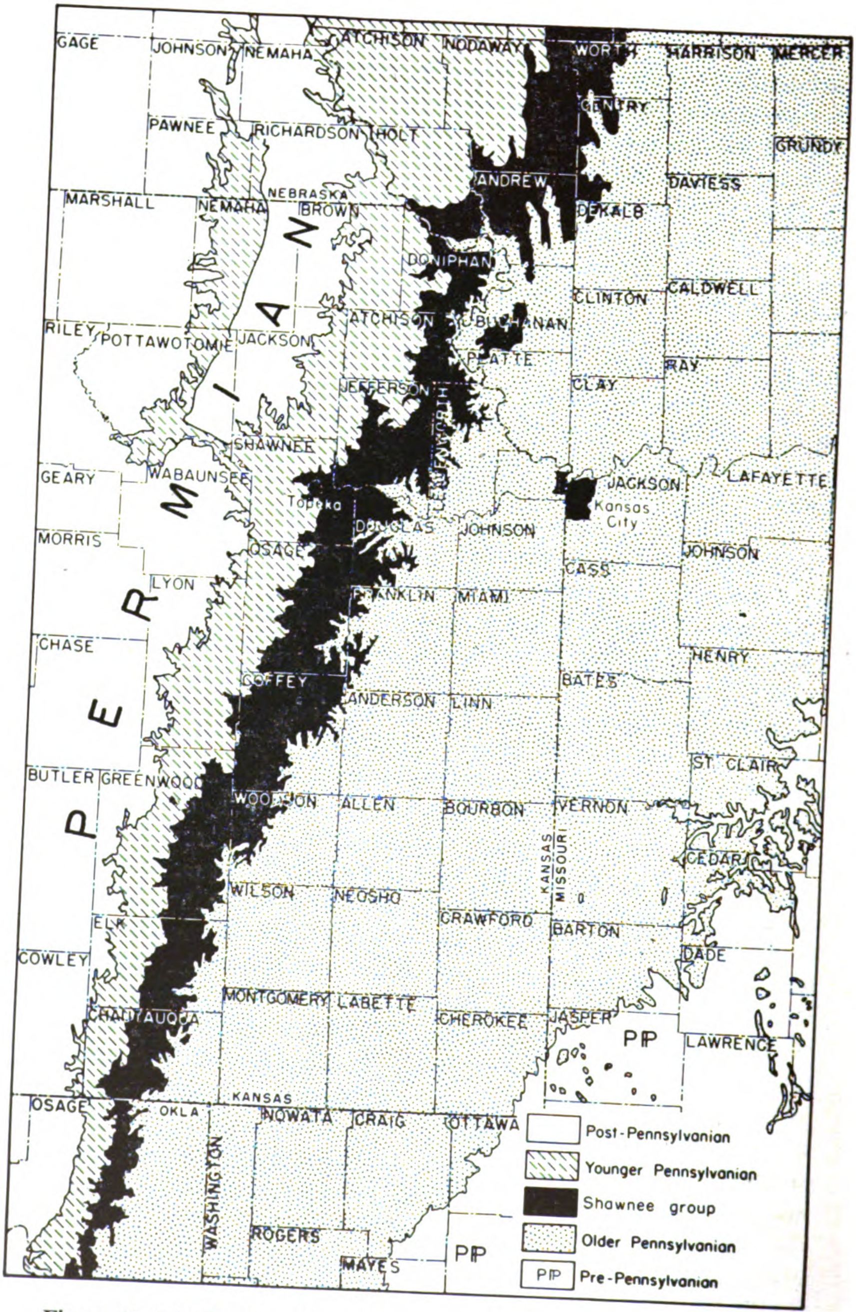

Figure 27. Distribution of outcrops of the Shawnee group in Kansas and parts of adjoining States. South of the Kansas-Oklahoma boundary, rocks equivalent to the Shawnee group are classed as belonging to the upper part of the Nelagoney formation, Elgin sandstone, and Pawhuska formation.

Shawnee Group

Definition

As originally defined and subsequently used in Kansas and adjacent States for many years, the Shawnee group or "formation" (HAWORTH, 1898, p. 93) includes the beds from the base of the Kanwaka shale to the top of the Scranton shale (base of Burlingame limestone). There is no evident reason for this segregation of strata except inclusion together of beds between two readily mappable escarpments. Consistency, even on this basis, would require the inclusion of the Oread limestone in the Shawnee group, because the line that is followed in mapping an escarpment is the base, rather than the top, of the resistant bed, which may have a dip slope of several miles.

The Shawnee group as redefined by MOORE (1936, p. 159) includes beds from the base of the Oread limestone to the top of the Topeka limestone. Thus limited, the group is a very well differentiated assemblage of strata, in which thick limestones and a distinctive type of cyclic sedimentation are prominent features. This stratigraphic span has been recognized uniformly in reports of the Kansas and Nebraska geological surveys and in many other papers during the last 15 years but until recently it has not been accepted by the Missouri and Iowa geological surveys. The inter-State conference recognizes classification of the Shawnee group as shown in Figure 22. The persistence of most stratigraphic units and the surprising uniformity displayed throughout their known area of distribution in Iowa, Missouri, Kansas, and Nebraska permit unusual uniformity in classification and nomenclature. Problems are introduced, however, near the Kansas-Oklahoma boundary owing to southward change of facies.

Distribution and Thickness

The Shawnee outcrop belt occupies the middle part of the area underlain at the surface by Virgilian formations. The Shawnee rocks are mapped across Kansas from Doniphan County, on the north, to Chautauqua County, on the south (Fig. 27). The width of the outcrop belt averages about 20 miles. Excellent exposures of Shawnee limestones, and less commonly, shale deposits, are found in virtually every county crossed by the belt. It is distinguished from the Douglas and Wabaunsee belts by the

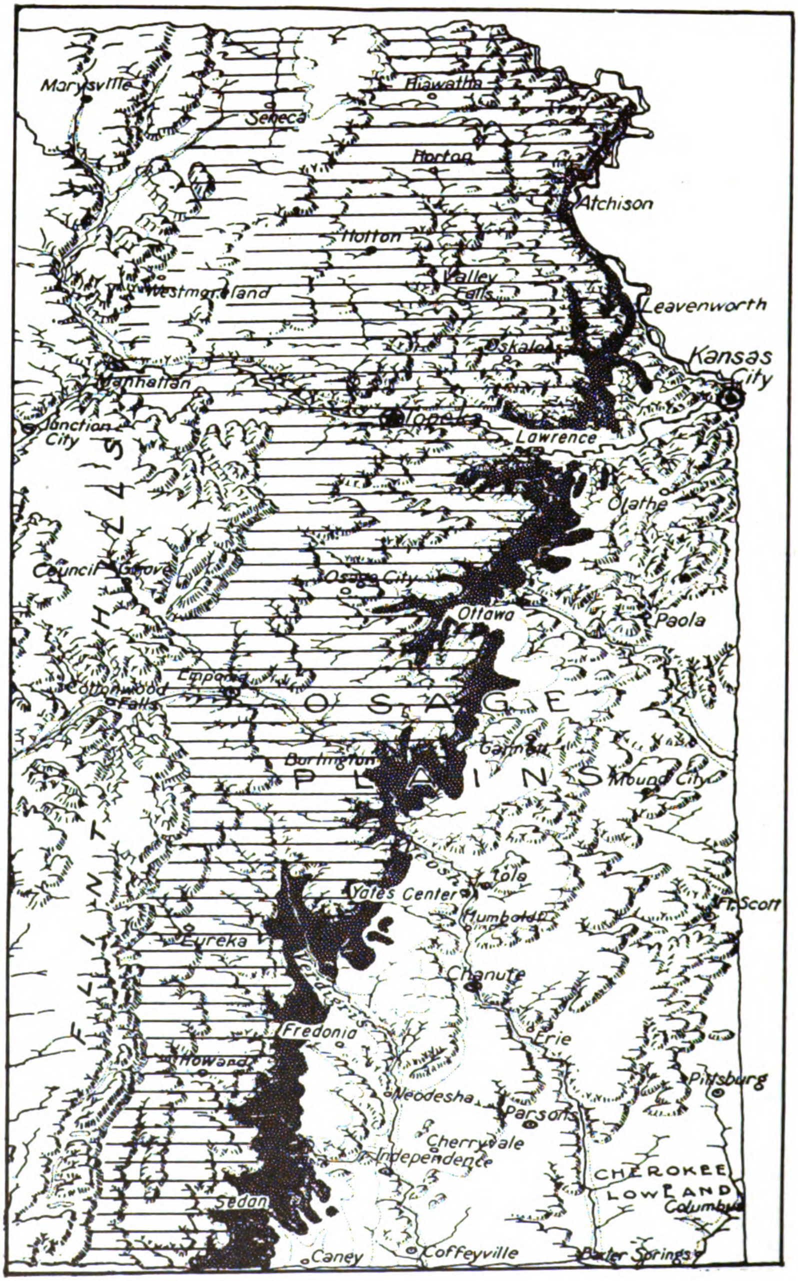

Figure 28. Escarpments formed by Pennsylvanian and Lower Permian limestones in eastern Kansas. The outcrop belt of Virgilian rocks is shaded, the dark band along the eastern margin representing Douglas strata and higher groups ruled horizontally. The prominent limestones of the Shawnee group form escarpments just west of the Douglas belt.

greater prominence of escarpments and generally more rugged topography, except as compared with outcrops of Douglas strata in southern Kansas (Fig. 28). In the vicinity of the Kansas River Valley, each of the Shawnee limestone formations makes a well-defined escarpment, but in southern Kansas, diminution of the shale between the upper two limestones (Deer Creek, Topeka) brings these together in a single escarpment. North of Kansas River, the cover of glacial drift partly masks bedrock topography and in this part of the State the Shawnee escarpments are indistinct. Best exposures are found in many quarries and in the bluffs of stream valleys.

The Shawnee group underlies all of Kansas west of its belt of outcrop excepting small areas along the northern part of the Nemaha ridge where Wabaunsee strata lie directly on Pre-Cambrian rocks. In tracing these beds underground, it is found that the limestones converge to form a thick body of nearly solid limestone, which is readily separated from the clastic Douglas beds below and from the shaly strata and thin limestones of the Wabaunsee group above. Paleontologic characters of the Shawnee beds are in harmony with the present grouping.

Beyond the borders of Kansas, outcrops of Shawnee rocks are traced across northwestern Missouri into southwestern Iowa. All formations belonging to the group are exposed also in southeastern Nebraska. Although rocks of Shawnee age in Oklahoma are differently named than in Kansas, outcrops are traced readily across the central part of Osage County southward. Equivalents of the Shawnee group in northern Oklahoma include the topmost beds of the Nelagoney formation (Oread), Elgin sandstone, Pawhuska formation, and approximately the lower 50 feet of the Buck Creek formation.

Thickness of the Shawnee group along the outcrop belt in Kansas is fairly uniform, amounting to about 350 feet. This lack of variation in total thickness is somewhat surprising in view of considerable change in thickness of individual Shawnee formations. Evidently, thickening of some formations along parts of the outcrop belt is compensated by thinning of others.

Lithologic Character and Classification

The Shawnee group is especially distinguished by prominence of limestones (Fig. 29). In this respect, the Shawnee part of the

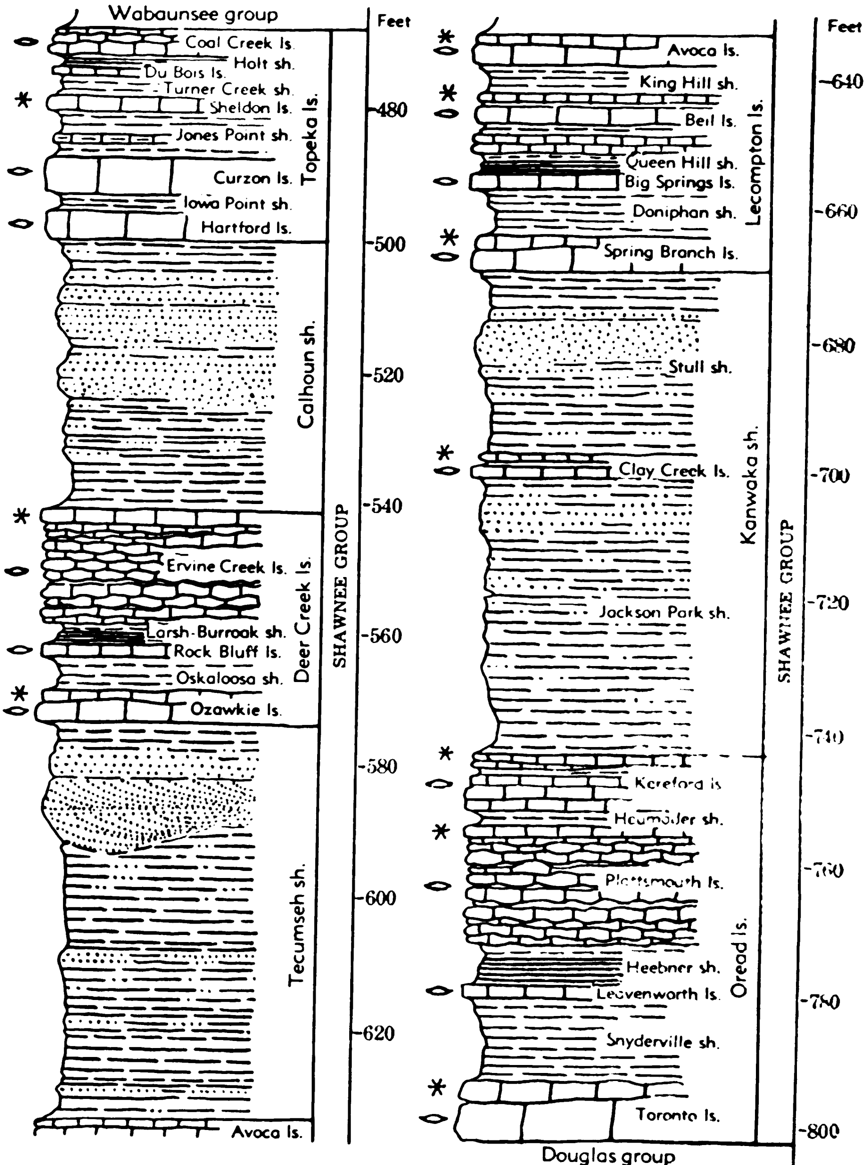

Figure 29. Generalized columnar section of rocks belonging to the Shawnee group in Kansas. These rocks comprise the middle part of the Virgilian Series in the northern midcontinent region.

Virgilian Series is comparable with the Kansas City and Lansing groups of the Missourian Series. The mid-portion of Virgilian time was characterized in the Kansas region by maximum accumulation of clear-water calcareous sediments which seem to be mainly organic in origin. Clastic deposits are not lacking, for in total thickness they exceed the aggregate of all limestone beds, but they are much less prominent than the limestones.

Four formations assigned to the Shawnee group are largely, if not predominantly, made up of limestone. The three intervening formations consist mainly of shale and sandstone. These alternating calcareous and clastic deposits reflect major cyclic oscillations of sedimentation, which furnish evidence of important back and forth shifting of the strand lines of Virgilian seas. Sedimentation associated with retreat of the shallow seas consists of coal beds and nonmarine sandstone and shale, some of which contain well-preserved land plants. Marine sedimentation is represented by the limestones and by several types of shaly deposits; most of these strata contain marine invertebrates of various sorts. The arrangement of terrestrial and marine deposits indicates both a simple progression in cyclic sedimentation, in which as many as a dozen distinct environments are represented, and a repetition of sets of cycles in constant order. The compound cyclic arrangement of Shawnee deposits is expressed in units named megacyclothems (MOORE, 1936, p. 29). Each Shawnee megacyclothem includes four or five simple cyclothems having individual peculiarities (Figs. 30, 31). The various kinds of limestone and shale are described in discussing formations of the Shawnee group. The presence of cyclothems (designated by the letter "A" in Figures 30 and 31) characterized by prominent brown-weathering massive limestone, which contains abundant fusulinids in many places, distinguishes the Shawnee megacyclothems from those recognized in Missourian and Desmoinesian deposits of Kansas and Missouri.

The Shawnee group contains the following formations, named in upward order: Oread limestone, Kanwaka shale, Lecompton limestone, Tecumseh shale, Deer Creek limestone, Calhoun shale, and Topeka limestone.

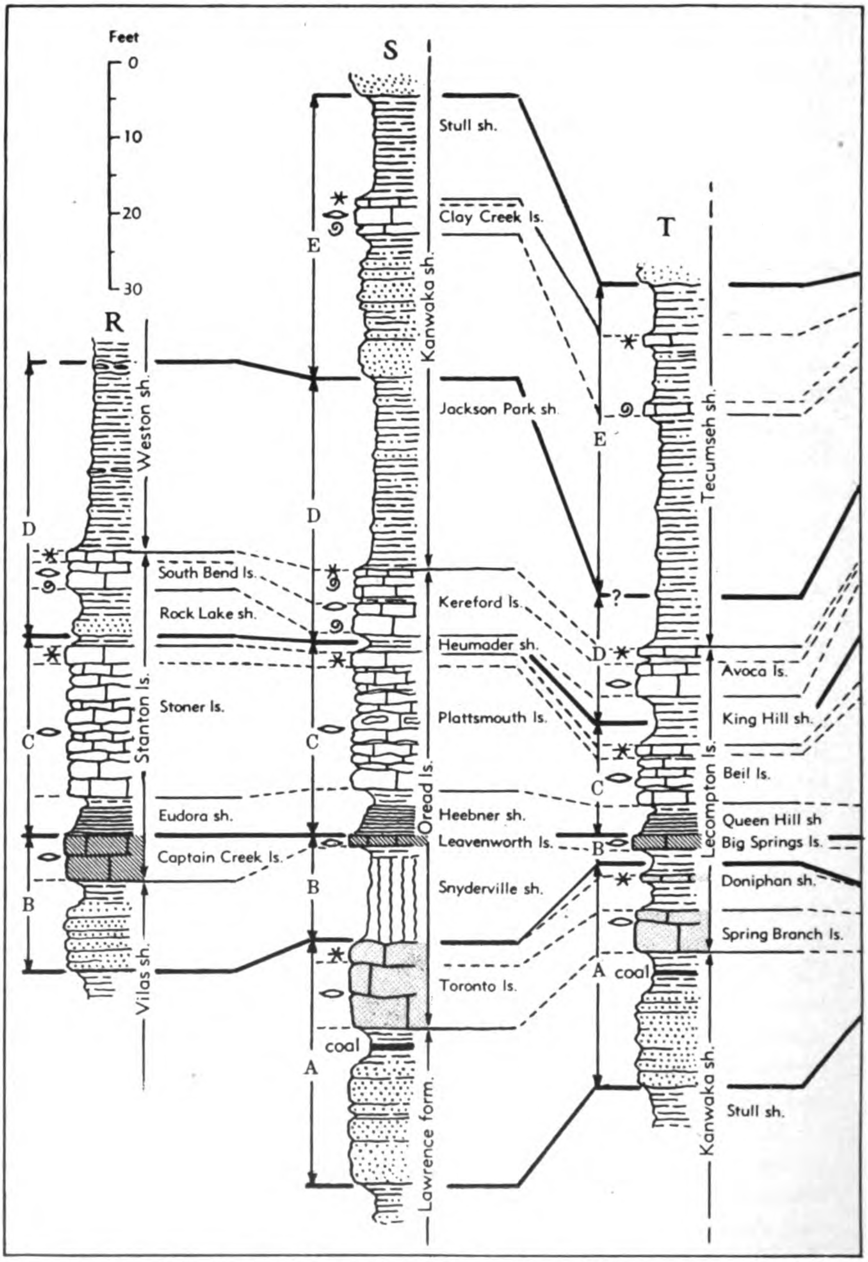

Figure 30. Sections of upper Lansing and lower Shawnee beds showing cyclothems and megacyclothems. The cyclothems are indicated by the letters A-E. Megacyclothems include the entire sequence of beds in any one of the three plotted sections, R, S, T. Stratigraphic position of the sequences is indicated on the general section at right in Figure 31.

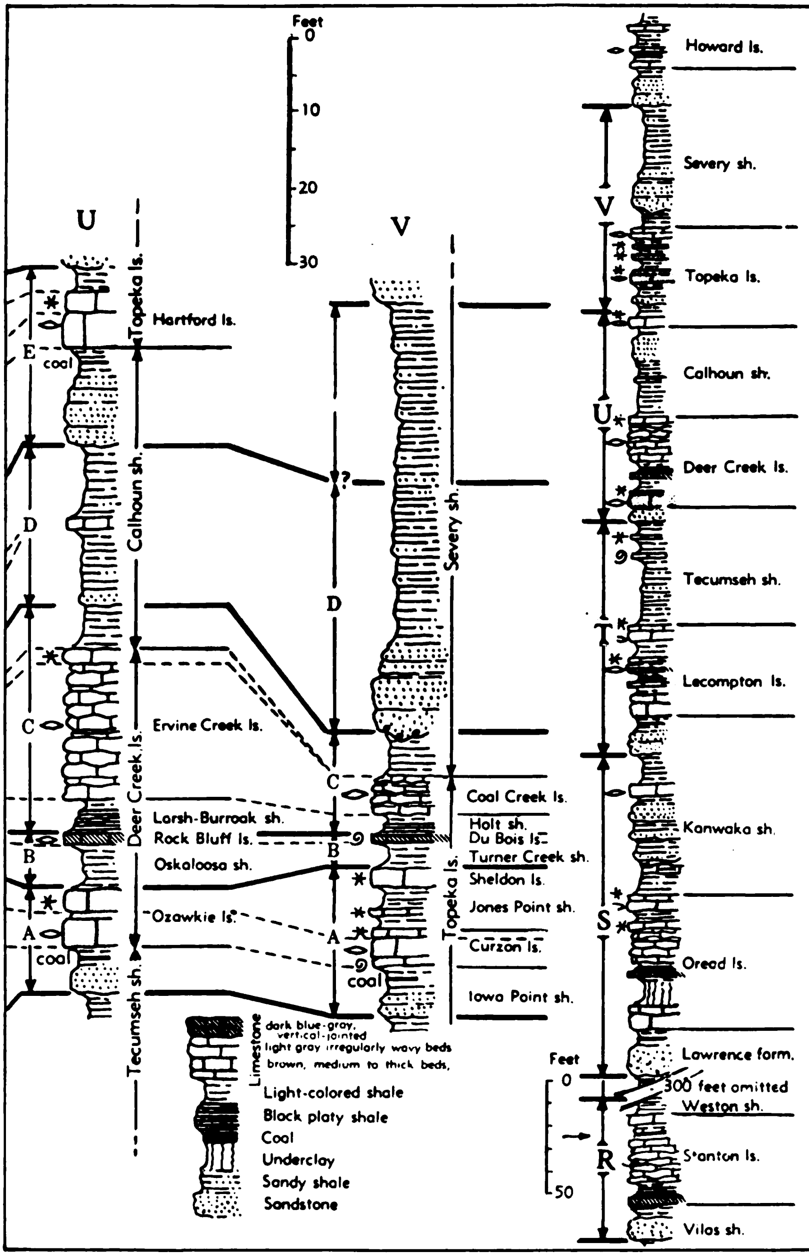

Figure 31. Sections of upper Shawnee beds showing cyclothems and megacyclothems. These units are differentiated as explained in description of Figure 30.

Oread Limestone

The Oread formation (HAWORTH, 1894a, p. 123; 1895, p. 461) is a prominent scarp-forming limestone named from the hill on which the University of Kansas at Lawrence is situated. HAWORTH first applied this name only to the lowermost limestone of the formation, but later extended it to include the overlying thick light-gray limestone now commonly known as the upper Oread or Plattsmouth limestone. An intermediate thin blue limestone (Leavenworth member) was not differentiated in early reports. As later recognized (MOORE, 1936, p. 161), the Oread includes not only these three limestones and the intervening shales, but a still higher limestone that is oölitic or composed of dense dark-blue flagstone (Figs. 22, 29, 30). This upper bed, called "Waverly flagging" in older literature, comprises a distinct element in the Oread megacyclothem, and was included with the Oread beds by BENNETT (1896) and HINDS & GREENE (1915). It was named the Kereford limestone by CONDRA (1927).

The total thickness of the Oread formation in the type area at Lawrence is 45 feet. The Lawrence shale lies conformably beneath the Oread and the Kanwaka shale is conformable above.

Because of the resistance to erosion afforded by the Oread limestone its outcrop is marked by a prominent escarpment that may be traced entirely across Kansas from Doniphan County in the northeast to Chautauqua County on the Oklahoma border. In the northern half of the State shale members of the Oread are thin, and the limestone members accordingly are close together, forming subordinate benches of a single escarpment. In southern Kansas, however, the lower shale member increases in thickness to 75 feet or more, so that separate escarpments which are locally a mile or more apart are made by the Toronto (lower Oread) limestone and the Leavenworth-Plattsmouth (middle and upper Oread) members. Coincident with the increase in thickness of the lower shale (Snyderville) member is prominence of red shale and appearance of nodular limestone and calcareous sandstone beds in this part of the formation. Disappearance of the limestone members of the Oread in northern Oklahoma makes it impracticable to differentiate the formation as a stratigraphic unit in this region. The equivalent strata are included in the upper part of the Nelagoney formation.

The Oread limestone contains the following members, named in upward order: Toronto limestone, Snyderville shale, Leavenworth limestone, Heebner shale, Plattsmouth limestone, Heumader shale, and Kereford limestone.

Toronto limestone member. The lowermost member of the Oread formation, named Toronto limestone (HAWORTH & PIATT, 1894, p. 117) from a town in southwestern Woodson County, Kansas, is distinguished by its strongly brown color in weathered outcrops and its massive character (Figs. 29, 30). Locally it is distinctly sandy. This limestone is traced from Toronto southward to Oklahoma and northward to Nebraska, where it has been called the Weeping Water limestone (CONDRA, 1927). It is absent locally in parts of Douglas County, Kansas, where a limestone conglomerate occupies its approximate stratigraphic position. The Toronto breaks in uneven slabby fragments which are variously inclined to the poorly defined bedding. Fossils are numerous locally but in many places they are scanty. Fusulinids are common, and associated with them are brachiopods, bryozoans, crinoid remains, and mollusks. The upper few inches to 2 or more feet of the Toronto limestone in many exposures is clearly differentiated from the underlying part of the member, both on lithologic and paleontologic grounds. This upper part is distinctly algal in some places and lacks fusulinids. It represents the algal-molluscan phase of the Toronto cyclothem (Fig. 30).

The thickness of the Toronto limestone exceeds 6 feet in most outcrops, but in a few places it is more than 10 feet thick.

Snyderville shale member. The lower shale member of the Oread limestone, called Snyderville shale (CONDRA, 1927, p. 38) from exposures in southeastern Nebraska, is a bluish to grayish, in part red shale, which occurs next above the Toronto limestone (Figs. 29, 30).

In northern Kansas and Nebraska, it is clayey and its maximum thickness is mostly less than 18 feet, its average being about 12 feet. To the south, this member becomes more sandy and includes subordinate earthy limestone and sandstone beds. Red shale becomes increasingly evident in this region and the thickness of the shale increases to 75 feet or more.

Most outcrops of the Snyderville shale in northern Kansas and Nebraska show that all of the member except the topmost 1 or 2 feet consists of structureless gray clay which weathers in irregularly shaped blocky fragments. It has the character of an underclay such as occurs typically below a coal bed, but underclays 10 to 12 feet thick are decidedly unusual in the Pennsylvanian section of Kansas. That this part of the Snyderville is, in fact, an underclay is indicated by its position above the algal bed of the Toronto limestone, by the local occurrence of a carbonaceous streak (where a coal bed should occur in the normal cyclic sequence) at the top of the blocky shale, and by the character of the upper 1 to 2 feet of the Snyderville, which is a well-laminated shale bearing a marine fauna of brachiopods, bryozoans and some pelecypods. The overlying Leavenworth limestone contains fusulinids and is the culminating marine phase of the cyclothem to which the Snyderville shale belongs.

Leavenworth limestone member. The middle member of the Oread formation is the Leavenworth limestone (CONDRA, 1927, p. 38), named from outcrops a short distance west of Leavenworth, Kansas. It is very distinctive in physical characters and for hundreds of miles along the outcrop is rarely found to have a thickness less than 1 foot or more than 2 feet (Figs. 29, 30). Such a thin bed might well be presumed by one who did not know to be an inconsequential unit of probably very local distribution. Instead, the member is found to extend without break or essential change of characters from central Iowa and northeastern Nebraska to Oklahoma. The chief lithologic peculiarities of the Leavenworth limestone are the uniform fine-grained, dense, hard character of the rock, its dark-blue color, and the prevalence of vertical joints. The member consists of a single massive layer. On weathering a thin surface film is altered to a light-gray or slightly creamy color and the substance of the rock is slowly removed by solution. This tends to round the edges of joint blocks, giving rise eventually to bouldery remnants of the bed along some long weathered outcrops. Fossils are fairly numerous but cannot be broken readily from the limestone. Fusulinids and molluscoids are most common but in many places there are abundant mollusks in the lower and upper part of the bed.

Heebner shale member. The shale next above the Leavenworth limestone is named the Heebner shale member (CONDRA, 1927, p. 37) of the Oread formation (Figs. 29, 30). It was named from a locality in southeastern Nebraska. The lower portion of the Heebner shale is characteristically black, carbonaceous, hard and very fissile. It contains conodonts but mostly lacks megascopic fossils. The upper part is a bluish to yellowish gray clayey shale, which in places contains numerous fossils, chiefly brachiopods. The fact that black "slaty" shale is seen in no other part of the Oread formation and the occurrence of this shale between the very distinctive middle and upper limestone members make recognition of the Heebner member easy and certain.

The thickness of the member varies little from 5 feet, and this is true in southern Kansas as in Nebraska.

Plattsmouth limestone member. The so-called upper Oread limestone (but not uppermost, which is called Kereford) is named the Plattsmouth limestone member (KEYES, 1899, p. 306; CONDRA, 1927, p. 37) of the Oread formation (Figs. 29, 30). It is the thickest limestone unit of the formation, averaging about 15 feet and locally attaining nearly twice that thickness. It is very light bluish-gray in color, and weathers light creamy yellow to nearly white; the beds are thin, irregular, and separated by wavy thin shale partings. The texture is very fine to almost lithographic, but there are commonly thin to coarse streaks and patches of clear crystalline calcite. Chert occurs in parts of the member, being more prominent in some localities than in others. Fossils are fairly common. Fusulinids, brachiopods, and bryozoans predominate. This is the topmost limestone along the Oread escarpment in most places, for the overlying Kereford limestone, where present, is mostly found at some distance back from the front of the escarpment.

Heumader shale member. The few feet of shale which lies between the base of the Kereford limestone and top of the Plattsmouth limestone is termed Heumader shale (MOORE, 1932, p. 96) and classed as a member of the Oread formation (Figs. 29, 30). The shale is clayey to sandy and appears dark gray. Some exposures show the presence of fairly numerous mollusks and a few other fossils, but in some places the shale is unfossiliferous. Where the Kereford limestone is absent, the Heumader and beds which may be shaly equivalents of the Kereford, are not differentiated. Although stratigraphic continuity with units classified as parts of the Oread formation is recognized, the shale next above the Plattsmouth is not Heumader alone, but Heumader combined with Kanwaka, and it may be designated as Heumader-Kanwaka shale or (using the lower Kanwaka member name) as Heumader-Jackson Park shale.

Thickness of the Heumader shale ranges from almost nothing to 10 feet.

Kereford limestone member. The uppermost division of the Oread limestone has been named the Kereford limestone (CONDRA, 1927, p. 45) from the Kereford quarry at Atchison, Kansas (Figs. 29, 30). The member is a very interesting stratigraphic unit which is perhaps chiefly characterized by its local variation in development, and by the richness of its fossil content. Unlike the other limestones, which generally are remarkably constant in thickness and physical nature, the Kereford ranges in thickness in a few miles from a featheredge to 10 or 12 feet. The member consists locally almost wholly of oölite and in these places the rock is somewhat slabby and cross-bedded. In other places, the Kereford is a single, dense, dark bluish, massive, hard, somewhat siliceous limestone. In still other outcrops, it is a blue flagstone, consisting of 50 feet or more of alternating even-bedded dense blue limestone layers and approximately equal thicknesses of shale. Almost all these types of deposits contain numerous very well preserved fossils in which mollusks are strongly predominant. Fusulinids are abundant in some parts of the member as seen at several places in northern Kansas.

Kanwaka Shale

The name Kanwaka (ADAMS, in ADAMS, GIRTY, & WHITE, 1903, p. 163) is applied to beds between the top of the Oread formation and the base of the Lecompton formation (Figs. 22, 29, 30). From the standpoint of general lithologic character and topographic expression, the Kanwaka shale is a well-defined formational unit. It includes both marine and nonmarine deposits, however, and comprises the terminal part of the Oread megacyclothem and the initial part of the Lecompton megacyclothem. Limestone in the upper middle part is found in central and northern Kansas, and probably equivalent sandstone and shale bearing marine fossils occur in southern Kansas and northern Oklahoma. The limestone (Clay Creek) contains a varied fauna of brachiopods, bryozoans, and some mollusks, and in places abundant fusulinids. The upper part of the shale is sandy and contains remains of land plants. A few feet below the Lecompton limestone is a persistent sandstone, which thickens southward to form the main part of the Elgin sandstone of Oklahoma. Above this sandstone locally is a coal bed. The sandstone is the initial deposit of the Lecompton megacyclothem.

The Kanwaka shale is divisible into three members which are recognized from central Kansas northward. These are named (in upward order): Jackson Park shale, Clay Creek limestone, and Stull shale.

Jackson Park shale member. The lower part of the Kanwaka shale comprises the Jackson Park shale member (MOORE, 1932, p. 96), named from outcrops in the south part of Atchison, Kansas (Figs. 29, 30). The member is bounded below by the Kereford limestone and the upper limit is marked at the base of the Clay Creek limestone, which at its type locality near Atchison occurs about 24 feet above the top of the Kereford limestone. Along Kansas River, the Jackson Park shale is more than 50 feet thick. Bluish-gray and yellowish-brown sandy shale, in part containing remains of land plants, compose most of the Jackson Park shale section. This member is clearly defined only in the northern half of the State, because the Clay Creek limestone has not been traced definitely beyond south-central Kansas.

Clay Creek limestone member. A thin but persistent limestone, dark-blue to bluish-gray in color, medium fine-grained to granular, and moderately hard comprises the Clay Creek limestone member (MOORE, 1932, p. 96) of the Kanwaka shale (Figs. 29, 30). In fresh exposure the rock is massive and dense, the top and bottom of the bed fairly even, and vertical joints distinct. The Clay Creek typically weathers in shelly chips, and in this respect differs from any previously described Shawnee limestone. The fossils consist of fusulinids and molluscoids, a few mollusks, crinoid stems, and other forms. In some places the fusulinids are extremely abundant. On Clay Creek, just west of Atchison, this rock forms a low falls. Its thickness is about 2 feet. Numerous good exposures of the bed have been seen from Doniphan County southward at least to Osage County, and it has been identified in Greenwood and Elk Counties.

Stull shale member. The part of the Kanwaka shale above the Clay Creek member is called the Stull shale (MOORE, 1932, p. 96) named from a village in western Douglas County, between Lawrence and Topeka (Figs. 29, 30). This member consists mainly of yellowish-brown sandy shale, containing fossil land plant remains, and in most places where well exposed is seen to contain a soft friable sandstone which is interpreted as the initial deposit of the Lecompton megacyclothem. Just above the sandstone is a thin coal bed.

The thickness of the Stull shale member near Stull is about 30 feet, but in the vicinity of Atchison it is 45 feet thick.

Lecompton Limestone

The Lecompton limestone (Bennett, 1896, p. 116), according to present definition (Condra, 1927, p. 44), includes four closely associated limestones, which with the included shales have a total thickness in the vicinity of the type locality at Lecompton, on Kansas River west of Lawrence, of 35 to 40 feet (Figs. 22, 29, 30). The formation is underlain by the Kanwaka shale and overlain by the Tecumseh shale. Because of the thickness and resistance of the Lecompton limestone beds and because the shale formations below and above are 60 feet or more in thickness, the Lecompton makes a distinct escarpment in the Kansas River region and throughout most of northern Kansas. Thinning of the limestones and thickening of the shale members of the Lecompton, accompanied by thinning of the Tecumseh shale in central and southern Kansas, reduce the prominence and distinctness of the Lecompton escarpment, so that it becomes a subordinate bench on the prominent escarpment capped by the Deer Creek and Topeka limestones. Persistence of lithologic and paleontologic characteristics of the Lecompton permit definite identification of this formation and of various members at many exposures from Nebraska to Oklahoma. In southernmost Kansas and northern Oklahoma, however, some of the limestones disappear, and going southward, all the limestone members eventually disappear. Stratigraphic equivalents of the Lecompton limestone in northern Oklahoma are included in the lower part of the Pawhuska formation.

The Lecompton contains seven members (in upward order): Spring Branch limestone, Doniphan shale, Big Springs limestone, Queen Hill shale, Beil limestone, King Hill shale, and Avoca limestone.

Spring Branch limestone member. The lowermost subdivision of the Lecompton formation is the Spring Branch limestone (Condra, 1927, p. 47). The type locality of the member is near

Lecompton, Kansas. The limestone is characterized by its strong brown color on weathered outcrops, by its thick, slightly uneven bedding, and in most places by extreme abundance of fusulinids (Figs. 29, 30). Besides disseminated iron oxide, which is responsible for the brown color, earthy or sandy impurities are appreciable.

The average thickness of the Spring Branch limestone throughout northern Kansas is 5 feet. In most of the southern outcrops it is a very impure sandy limestone, 2 to 3 feet thick. This member is not recognized in Nebraska. In all respects the Spring Branch limestone is strikingly similar to the lower limestone member of the Oread formation.

An interesting bed that occurs at the top of the Spring Branch member at places both in northern and southern Kansas is a very dense light drab gray, somewhat nodular algal limestone about 1 foot in thickness. Some exposures also show the presence of 1 to 2 feet of coquinoid, somewhat conglomeratic limestone containing abundant discoid algal growths, classed as *Osagia*.

Doniphan shale member. The shale which overlies the Spring Branch member of the Lecompton is mostly bluish and yellowish-brown and clayey (Figs. 29, 30). It is named the Doniphan shale member, from outcrops in the northeasternmost county of Kansas (CONDRA, 1927, p. 47). Southward some red shale appears in this member. Thickness of the Doniphan member throughout observed exposures ranges from about 5 to 10 feet. Like the cyclically homologous Snyderville member of the Oread, it thickens southward but not so greatly. Fossils are rare or lacking.

Some sections of the Doniphan shale in southeastern Shawnee County show the blocky clay character described in the Snyderville shale of northern Kansas. This zone seems to represent an underclay and together with underlying sandy shale and an overlying thin coaly streak represents the nonmarine part of a typical cyclothem. The top portion of the Doniphan shale may contain marine invertebrates.

Big Springs limestone member. The second limestone of the Lecompton, counting upward, is known as the Big Springs limestone (CONDRA, 1927, p. 47). It is named from outcrops near Lecompton, Kansas. Like the Leavenworth member of the Oread limestone, it is a dark-bluish, dense, fine-grained limestone, 1 to 3 feet thick, and occurs commonly in a single massive bed intersected by prominent vertical joints (Figs. 29, 30). In some places, however, there are two or three beds separated by shaly partings. On weathering a thin surface film of the rock is altered in color to light yellowish-brown or bluish-gray, and the fusulinids, which abound in it everywhere, stand weathered slightly in relief. The rock does not break down into small fragments, but is slowly removed by solution so as to produce bouldery blocks by rounding the originally rectangular masses defined by joint planes. The member overlies the Doniphan shale and occurs beneath the distinctive black fissile shale in the lower part of the Queen Hill shale member. The Big Springs limestone is very persistent, having been recognized from Iowa and Nebraska southward to Oklahoma.

Queen Hill shale member. The shale above the Big Springs limestone is named Queen Hill (CONDRA, 1927, p. 46) from a locality in southeastern Nebraska (Figs. 29, 30). This member is commonly divisible into two parts, a lower hard, black, fissile shale and an upper soft, bluish to yellowish, argillaceous shale. The black shale contains conodonts. The Queen Hill shale is recognizable along the outcrop entirely across Kansas, but in southern exposures the black shale is not commonly found.

The thickness of the member commonly ranges from 3 to 6 feet.

Beil limestone member. The third Lecompton limestone (which corresponds to the Plattsmouth limestone of the Oread megacyclothem) is named the Beil limestone member (CONDRA, 1930, p. 20) from outcrops in southeastern Nebraska (Figs. 29, 30). It consists of alternating layers of somewhat flaggy, hard limestone and very calcareous fossiliferous shale. Fossils, especially the corals *Caninia torquia* and *Syringopora multattenuata,* and numerous fusulinids, are especially abundant in this member, and are characteristic of it in most exposures from Nebraska to Oklahoma. Outcrops in southernmost Kansas and northern Oklahoma show several feet of solid limestone which exhibit the somewhat wavy bedding and other peculiarities characteristic of the Plattsmouth member of the Oread. The characteristic assemblage of fossils and the stratigraphic association of this member permit positive recognition, and it is an important horizon marker in the Shawnee group.

The top bed of the Beil limestone, as well shown at the type locality and in other Nebraska, Iowa, and northern Kansas exposures, is a massive *Osagia*-bearing bed, 1 to 1.5 feet thick, which appears coarsely granular or oölitic.

The thickness of the Beil limestone is 5 to 10 feet in most places.

King Hill shale member. The uppermost shale division of the Lecompton, lying between the Beil and Avoca limestones, is called King Hill shale (CONDRA, 1927, p. 45) from a Nebraska type locality (Figs. 29, 30). The King Hill member is a bluish-green to reddish, blocky, clayey or sandy shale about 7 feet thick in southeastern Nebraska. Its thickness is about 5 feet in sections near Lecompton, but in southern Kansas it increases to 16 feet or more. Fossils are mostly rare except near the top of the shale where numerous brachiopods may be found. Exposures of the King Hill shale in northern Kansas commonly show the presence of one or two very irregular nodular impure limestones, which weather yellowish brown.

Avoca limestone member. The uppermost Lecompton limestone is a persistent member named Avoca (CONDRA, 1927, p. 45), from a town in southeastern Nebraska. The Avoca limestone is a dense, dark bluish, somewhat earthy rock which occurs in one or two beds having a total thickness in most outcrops of 1 to 2 feet (Figs. 29, 30). Near Lecompton this member is 4.5 feet thick and is very hard and massive. It lies conformably on the King Hill shale and is overlain by shale classed as part of the Tecumseh shale. The Avoca is identified at very many outcrops from Nebraska and Missouri southwestward to southern Kansas. Fairly robust fusulinids are the most common fossils in the limestone and these occur in almost all places where the rock is exposed.

The Avoca limestone is classed as a member of the Lecompton formation because, throughout the outcrop area, the bed is separated from the underlying Beil limestone by only a few feet of shale. The member is homologous to the fusulinid-bearing Kereford limestone of the Oread megacyclothem.

Tecumseh Shale

The Tecumseh shale (BEEDE, 1898, p. 28) includes strata from the top of the Avoca limestone member of the Lecompton limestone to the basal member of the Deer Creek limestone (Figs. 22, 29, 30, 31). The type locality is a few miles east of Topeka in the Kansas River Valley. The shale is sandy to clayey, and mostly unfossiliferous. In places it contains a thin limestone, named the

Ost limestone. In the upper part of the Tecumseh shale is a widely distributed sandstone, locally conglomeratic at the base, which marks the initial deposit of the Deer Creek megacyclothem.

The thickness of the Tecumseh shale along Kansas River is about 70 feet. In southern Kansas the thickness is about 50 feet.

Three members are recognized in the Tecumseh in Nebraska, named (in upward order) Kenosha shale, Ost limestone, and Rakes Creek shale, but these units are not distinct enough in Kansas to be treated as subdivisions.

Deer Creek Limestone

The Deer Creek limestone (BENNETT, 1896, p. 117) is one of the most important, widely persistent formations of the Shawnee group (Figs 22, 29, 31). It is named from outcrops in eastern Shawnee County, between Lawrence and Topeka. The upper limestone member alone attains a thickness of 35 feet in Elk County, Kansas, and the formation has a thickness in most places of more than 40 feet. With very little change in lithologic characters or variation in members, the Deer Creek limestone is known to extend from west-central Iowa to northern Oklahoma, and limestone at this horizon is traced to southern Oklahoma. Most of the Deer Creek outcrop across Kansas is marked by a very prominent escarpment, and accordingly the formation can be mapped readily. The formation is underlain by the Tecumseh and overlain by the Calhoun shale. The Deer Creek is readily differentiated on the basis of appearance and on fossil content from the adjacent Lecompton limestone below and the Topeka limestone above, but the Deer Creek members duplicate so strikingly those of the Oread limestone that it is easily possible for a geologist who is familiar with the lithology and sequence of the members to mistake one formation for the other if information as to stratigraphic position is neglected. The Deer Creek is a prominent part of the Pawhuska formation as defined in northern Oklahoma.

The Deer Creek formation in Kansas contains the following members (in upward order): Ozawkie limestone, Oskaloosa shale, Rock Bluff limestone, Larsh-Burroak shale, and Ervine Creek limestone.

Ozawkie limestone member. The lower Deer Creek limestone is known as the Ozawkie member (MOORE, 1936, p. 182), from a town in Jefferson County, Kansas, northwest of Lawrence (Figs. 29, 31). It is a brown massive or thick-bedded limestone which resembles closely the lowermost limestone members of the Oread, Lecompton, and Topeka formations. In contrast to the higher limestone members of the Deer Creek, the Ozawkie appears somewhat sandy and impure, and, as indicated by the strongly brown color of weathered outcrops, it is quite ferruginous. The massive rock commonly weathers in irregular shelly slabs. Fossils are not very common in most places. Locally, however, there are numerous fusulinids, crinoid stem fragments, and fairly common brachiopods, bryozoans, and corals. The elements of a nearly complete cyclothem are recognizable in the Ozawkie member in some places. Some outcrops show that the member consists locally almost wholly of fusulinid-bearing limestone, but elsewhere the upper half or more of the member is an oölitic, granular, algal rock which contains gastropods and other mollusks. Unusually well-preserved shells of *Bellerophon, Euphemites, Warthia,* and a new genus called *Knightites* have been described from the Ozawkie limestone exposed on U.S. Highway 40, 9 miles west of Lawrence (Moore, 1940).

The average thickness of the member is about 5 feet, but near Lyndon, Osage County, it is about 15 feet.

Oskaloosa shale member. The shale member that lies between the Ozawkie limestone below and the dense blue middle Deer Creek bed (Rock Bluff limestone) is named the Oskaloosa shale (Moore, 1936, p. 96), from the county seat of Jefferson County, Kansas (Figs. 29, 31). It is normally 5 to 10 feet thick in the northern part of Kansas, but it increases southward to 25 feet or more. The shale is bluish-gray or yellowish and consists of blocky clay containing one or two calcareous, somewhat ferruginous siltstones in northern Kansas. South of Coffey County parts of the member are distinctly sandy and micaceous; in this area a prominent red zone and one or two thin beds of nodular light bluish-gray impure limestone appear. The Oskaloosa shale member is mostly unfossiliferous, but, excepting possibly the red shale, appears to be marine in origin.

Rock Bluff limestone member. The Rock Bluff limestone (Condra, 1927, p. 50) is one of the most persistent, uniform and distinctive members of the Deer Creek formation in the northern midcontinent region (Figs. 29, 31). It is a dense blue bed which as seen in most exposures is a single massive stratum 1 to 2 feet thick. The top of the bed is very even but the base may be slightly uneven on account of the presence of "fucoid" markings. Vertical joints are well developed in two systems which intersect approximately at right angles and cause the bed to separate in rectangular blocks along the outcrop. The rock is not broken into small fragments by weathering, but the sharp edges of the blocks are gradually rounded by solution so as to produce bouldery shapes. A very thin surface film of the limestone is altered by weathering to a light bluish-gray or creamy color, and a zone a few inches thick inside this coating may be altered to a purplish or brownish-blue, but because of the dense texture of the rock the deeper interior of blocks remains dark-blue. Fusulinids are the most common fossils in most outcrops of this member but they are not, in general, very abundant. A few brachiopods, bryozoans, and small mollusks are present.

The thickness of the middle Deer Creek limestone nowhere is known to exceed 2 feet and in few places it is less than 1 foot. In this approximate uniformity of thickness and persistence of distinctive physical characters from the type locality in southeastern Nebraska eastward into Iowa and Missouri, and southward across Kansas into north-central Oklahoma, this member is a most striking sedimentary unit and stratigraphic marker. Almost all good exposures show the presence of black slaty shale next above the blue limestone. It corresponds in all respects to the Leavenworth limestone member of the Oread formation, which it strikingly resembles and is homologous to the Big Springs limestone member of the Lecompton formation.

Larsh-Burroak shale member. The shale called Larsh-Burroak (Condra, 1927, p. 40; Condra & Reed, 1943, p. 48) contains two persistent subdivisions, the lower half, approximately, consisting of hard black fissile shale and the upper half of gray to yellowish soft clay shale (Figs. 29, 31). Because this shale seems to be exactly equivalent to the Larsh shale, Haynies limestone, and Burroak shale, as described in Nebraska, the shale between the Rock Bluff and Ervine Creek limestones of Kansas is called Larsh-Burroak. Excepting conodonts, fossils are rare or lacking in the black shale and they are not generally found in the upper part. In places, however, the latter contains calcareous brachiopods, bryozoans, and other invertebrates. There is very little observed change in this member from Doniphan County in the northeastern corner of the State to the point where the Deer Creek formation passes out of Kansas in southern Chautauqua County.

The thickness of the Larsh-Burroak shale member ranges from about 2.5 to 7 feet, the average being about 4 feet.

Ervine Creek limestone member. The upper limestone member of the Deer Creek formation, which is the thickest subdivision in most places, is named the Ervine Creek limestone (CONDRA, 1927, p. 50) from outcrops in southeastern Nebraska (Figs. 29, 31). As redefined by MOORE (1936, p. 188), it is divisible into two parts. Of these the lower is the most persistent and prominent, comprising the bulk of the member in most places. It is typical of other upper limestone of Shawnee formations, such as the Plattsmouth and Beil limestones, and possesses all the lithologic and faunal characters that distinguish these. The rock is light-gray to nearly white in most places but locally appears bluish and weathers mottled gray and yellowish-brown or exceptionally all brown. The texture of the limestone is fine crystalline to dense, and it is fairly uniform, except for (algal?) "veinlets" and irregularly distributed small masses of clear calcite. The bedding is thin and wavy, with partings of clay shale between the layers. Chert nodules occur locally. Fossils include fusulinids, calcareous brachiopods, corals, crinoid and echinoid fragments, bryozoans, and less commonly mollusks, sponges, and trilobites. A variety of ostracodes and small foraminifers may be washed from the shaly partings between the limestone layers.

The thickness of the Ervine Creek limestone ranges from about 3 to 30 feet.

The upper part of the Ervine Creek member, not present in some localities, consists mainly of limestone of algal-molluscan character. This part may rest directly on the underlying limestone or it may be separated from it by a few inches or a foot or two of shale that commonly is somewhat sandy. The lithologic characters and faunal content of the upper limestone are clearly distinguishable from those of the lower but there is much variation in lithology and fauna of the upper limestone from place to place. A single very massive bed of uniform texture, moderately to finely granular, containing numerous small *Osagia* but few other organic remains may represent this unit. This limestone appears more or less oölitic. Fusulinids are lacking and the invertebrates found consist of scattered mollusks and calcareous brachiopods. In other places the limestone is strongly coquinoid. It consists of a mass of shells and shell fragments pressed together, so that the rock has an irregularly platy or "oatmeal" texture. Pelecypods mingled with certain types of brachiopods, such as *Derbyia*, *Juresania*, and *Linoproductus*, and bryozoans, are the chief fossils. Still other outcrops show the presence of fine-grained earthy to sandy limestone, even-bedded or nodular, mostly lacking in fossils. The thickness of this part of the Ervine Creek member ranges from a featheredge to 5 or 6 feet.

The Ervine Creek limestone is equivalent to the Pawhuska limestone as originally defined in northern Oklahoma and is one of the most prominent and persistent limestones in the Pawhuska formation as now defined in Oklahoma.

Calhoun Shale

The Calhoun shale, named by Beede (1898, p. 29) from the so-called Calhoun Bluffs of Kansas River, northeast of Topeka, includes strata consisting chiefly of shale between the top of the Deer Creek limestone and the base of the Topeka limestone (Figs. 22, 29, 31). Sandstone lenses occur a few feet below the Topeka limestone, and represent the initial deposits of the Topeka megacyclothem. A thin bed of coal lies between the sandstone and the basal Topeka limestone. Sandstone and sandy shale occur also in the lower middle part and are underlain by dark gray silty shale, which contains abundant bryozoans and brachiopods in its lower part. Land plant remains occur in the sandy shale and sandstone.

In the type region, where the Calhoun attains approximately its maximum thickness of about 50 feet, the formation consists largely of clayey to sandy shale.

In southern Kansas the Calhoun progressively diminishes in thickness until near the Oklahoma boundary it is locally absent. In northern Kansas the formation is only about 10 feet thick.

Topeka Limestone

The Topeka limestone, named (Bennett, 1896a, p. 116) from outcrops in the vicinity of Topeka, Kansas, comprises the topmost formation of the Shawnee group (Figs. 22, 29, 31). Although somewhat variable in its development from place to place, the Topeka limestone is readily differentiated from the Deer Creek and other limestone formations of the Shawnee group below. It is very fossiliferous, and where completely developed, there are 9 distinctive members, of which the lowermost is generally much the thickest and most prominent at the outcrop. In many places this unit consists of two or three limestone beds separated by shale.

The Topeka limestone makes a distinct escarpment, which rises some 60 feet above the Deer Creek dip slope in parts of north-central Kansas, but to the south, the Topeka outcrop is not sharply differentiated from that of the Deer Creek limestone, which is the main scarp-maker in this part of the section. The long dip slope on the Topeka is a characteristic topographic feature, however, from northern to southern Kansas, although this is masked somewhat in the extreme northern part of the State and in Nebraska by glacial drift.

The thickness of the Topeka limestone ranges from a nearly constant measurement of 33 feet in northern Kansas to about 55 feet in parts of southern Kansas. The formation is recognized from southern to northern Kansas, in Nebraska, and in Missouri. It is equivalent to the uppermost part of the Pawhuska formation of Oklahoma and forms the top of what was formerly called the Braddyville formation in Iowa.

The members of the Topeka limestone named in upward order are: Hartford limestone, Iowa Point shale, Curzon limestone, Jones Point shale, Sheldon limestone, Turner Creek shale, DuBois limestone, Holt shale, and Coal Creek limestone. The Coal Creek member is clearly the equivalent of the so-called upper limestone members of other Shawnee limestone formations.

Hartford limestone member. Massive, light bluish-gray limestone which weathers brownish composes the Hartford limestone member (KIRK, 1896, p. 80) at the base of the Topeka formation (Figs. 29, 31). It is named from outcrops on the Neosho River in central Kansas. This member commonly bears numerous fusulinids except in the upper part, which contains *Osagia* and is of algal origin. The lower beds are characterized by presence of the chambered sponge, *Amblysiphonella*, specimens of which can be found at almost every outcrop from Nebraska to Oklahoma. The upper algal limestone is highly variable in thickness, ranging from almost nothing to 12 feet. This member is the same as rocks recently called Wolf River limestone in Nebraska reports (CONDRA & REED, 1937).

The thickness of the Hartford limestone ranges from 3 to 13 feet; the average is about 5 feet.

Somewhat tentatively, the Hartford limestone and associated shaly deposits at the top of the Calhoun and belonging to the base of the Iowa Point shale, are interpreted here as constituting the terminal part (cyclothem E) of the Deer Creek megacyclothem (Fig. 31). As seen in the vicinity of Topeka, for example, the Hartford and adjacent strata clearly represent an individual cyclothem in which sandstone and sandy shale overlain by a thin coal bed are followed by brownish limestone containing common (and persistent) sponges (*Amblysiphonella*) at the base and numerous fusulinids in the middle part; the algal structures called *Osagia* appear at the top of the Hartford, indicating a retreatal phase of the sea in which lower Topeka deposits were being formed. The Iowa Point shale contains land plant remains and a thin coal smut, which denote emergence of the surface of sedimentation. The Curzon limestone, which occurs next above the Iowa Point shale member of the Topeka formation, is a brown massive fusulinid-bearing limestone. It is followed also by algal and molluscan beds and has attributes of a normal "A" cyclothem. Still higher is the undoubted "B" cyclothem which contains the Du Bois limestone, followed by the "C" cyclothem initiated by the Holt black platy shale and having the richly fossiliferous, fusulinid-bearing Coal Creek limestone in its upper part. Because of the close association of the Hartford limestone with succeeding units of the Topeka formation in the type region and along most of the outcrop across Kansas, it is natural and proper to class this limestone as a member of the Topeka. Southward from Kansas River the Calhoun shale becomes gradually thinner and shales of the Topeka formation expand. Need for detailed stratigraphic studies in this part of the section is evident, in order to determine with assurance relations of beds seen in northern and southern Kansas in the upper part of the Shawnee group.

Iowa Point shale member. Above the Hartford limestone is the Iowa Point shale (Condra, 1927, p. 51) defined from outcrops along Missouri River in northeasternmost Kansas (Figs. 29, 31). This member consists of yellowish-gray to bluish-gray, clayey to calcareous shale which locally contains sandstone layers and a thin coal bed.

This shale is typically developed and thickest in northern Kansas near the Nebraska boundary; in sections near Topeka it is only 2 feet thick, and farther south it disappears, as indicated by fusulinid-bearing lower layers of the Curzon which rest directly on the algal upper part of the Hartford limestone. The thickness is a featheredge to 14 feet.

Curzon limestone member. The second limestone of the Topeka formation is called the Curzon limestone (GALLAHER, 1898, p. 57; CONDRA, 1927, p. 52) from outcrops in the Missouri River Valley near Forest City, Missouri (Figs. 29, 31). This member is a persistent and prominent subdivision of the Topeka formation which is readily and positively identifiable throughout northern Kansas. It consists of two or more beds of massive bluish-gray, brown-weathering limestone, mostly hard and resistant. It forms a well-marked escarpment. Nodules of chert are common. Fusulinids occur sparingly to very abundantly in the lower and middle parts of the member, together with some brachiopods and other invertebrates; bryozoans and echinoid remains are common in upper layers. This limestone, which erroneously has been called Hartford in some earlier Kansas reports, is undoubtedly the same as that termed the Curzon limestone in publications of the Nebraska Geological Survey and, in spite of some objections to the origin of this term, it is employed for rocks in Kansas.

The thickness of the Curzon ranges from 5 to 12 feet.

Jones Point shale member. Shale above the Curzon limestone comprises the Jones Point member (CONDRA, 1927, p. 51), the type locality being located on the Missouri River in Nebraska below Plattsmouth (Figs. 29, 31). It consists of clayey, calcareous, and silty gray shale which locally contains nodular or platy limestone beds. The member yields fairly numerous brachiopods and mollusks at some outcrops but is poor in fossils elsewhere.

The thickness in northern Kansas ranges from 1 to 10 feet, but beds in Elk and Chautauqua Counties correlated with the Jones Point shale are 10 to 15 feet thick. The average thickness in Kansas is about 6 feet.

Sheldon limestone member. A massive light-gray to nearly white, very fine-grained, dense limestone which commonly contains numerous small algal growths of the type known as *Osagia* overlies the Jones Point shale and is defined as the Sheldon limestone member (CONDRA, 1930, p. 22) of the Topeka formation

(Figs. 29, 31). The name is derived from a locality near Nehawka in southeastern Nebraska. The rock weathers light yellowish-gray and makes smooth rounded surfaces at the outcrop. The member is a persistent layer which is identified northward from Kansas River but is absent to the south as far as Greenwood County; in southern Kansas there is an algal limestone at the Sheldon horizon.

Thickness of the Sheldon limestone in Kansas ranges from about 0.7 to 2 feet.

Turner Creek shale member. The next higher Topeka member is the Turner Creek shale (Condra, 1927, p. 52), named from Pawnee County, Nebraska (Figs. 29, 31). It is bluish or greenish-gray clayey and calcareous shale, bearing few invertebrate fossils.

The thickness ranges from 1 to 5 feet in northern Kansas; shale in southern Kansas that is correlated with the Turner Creek measures 12 to 15 feet.

Du Bois limestone member. Dark-blue or greenish-blue fine-grained, somewhat earthy limestone with prominent vertical jointing is named the Du Bois member (Condra, 1927, p. 52), also named from outcrops in Pawnee County, Nebraska (Figs. 29, 31). Mollusks and brachiopods are common.

The thickness commonly ranges from 0.5 to 2 feet, but the member is not definitely recognized south of Topeka.

Holt shale member. The highest shale subdivision of the Topeka formation is the Holt shale (Condra, 1927, p. 52), named from Pawnee County, Nebraska (Figs. 29, 31). This member consists of bluish-gray shale in the upper part and black shale in the lower part. It is not recognized with certainty south of Topeka because the limestone beds above and below it disappear, at least for many miles, and because the distinctive black slaty beds do not persist southward. Shale beneath the uppermost Topeka limestone in southern Kansas probably represents the Holt member, however. Corneous brachiopods and conodonts occur in the black shale.

The thickness of the Holt shale in Kansas ranges from 1.5 to 3 feet.

Coal Creek limestone member. A highly fossiliferous limestone, named Coal Creek (Condra, 1927, p. 52) from the neighborhood of Union, Nebraska, east of Lincoln, forms the top of the Topeka formation in Nebraska and northern Kansas (Figs. 29, 31).

It consists of light bluish-gray limestone and nodular shale or dark-blue more massive limestone which weathers light bluish-gray or brown. The member is not positively identified south of Kansas River, but the "red limestone" in southern Kansas is probably its equivalent. Fusulinids are locally abundant, and at many places numerous brachiopods, bryozoans, and other well-preserved invertebrate fossils are found.

The thickness of the Coal Creek limestone ranges from about 2 to 5 feet.

Wabaunsee Group

Definition

The Wabaunsee group was originally defined (PROSSER, 1895) as a formation extending from the Nodaway coal in the Howard formation to the base of the Cottonwood limestone. It has been revised by addition of lower strata down to the top of the Topeka formation (MOORE, 1932) and by elimination of the upper part of beds classed as belonging in the Permian System (MOORE & MOSS, 1934; CONDRA, 1935; MOORE, 1936). Virtually all usage of Wabaunsee published during the last 15 years recognizes the upper boundary as drawn at the prominent disconformity just above the Brownville limestone. The Wabaunsee group consists of numerous thin but very persistent stratigraphic units, most of which maintain remarkably uniform lithologic and faunal characteristics along outcrops extending from northern Oklahoma to Nebraska and Iowa. Recognized by the inter-State conference as standard is the classification which has been developed mainly in Kansas and Nebraska, but nomenclature in the several States may deviate from this by combination or omission of terms where certain named rock units are not recognizable (Fig. 32).

Distribution and Thickness

Outcrops of the Wabaunsee group occur in a belt along the western margin of the Pennsylvanian area in Kansas (Fig. 33). This belt extends from eastern Brown and western Doniphan Counties, at the northeastern corner of the State, south-southwestward to western Chautauqua County. Wabaunsee strata also are exposed in an area nearly surrounded by Permian outcrops in the northern part of Kansas; this area extends northward from the vicinity of Manhattan, on the Kansas River, passing through Pot-

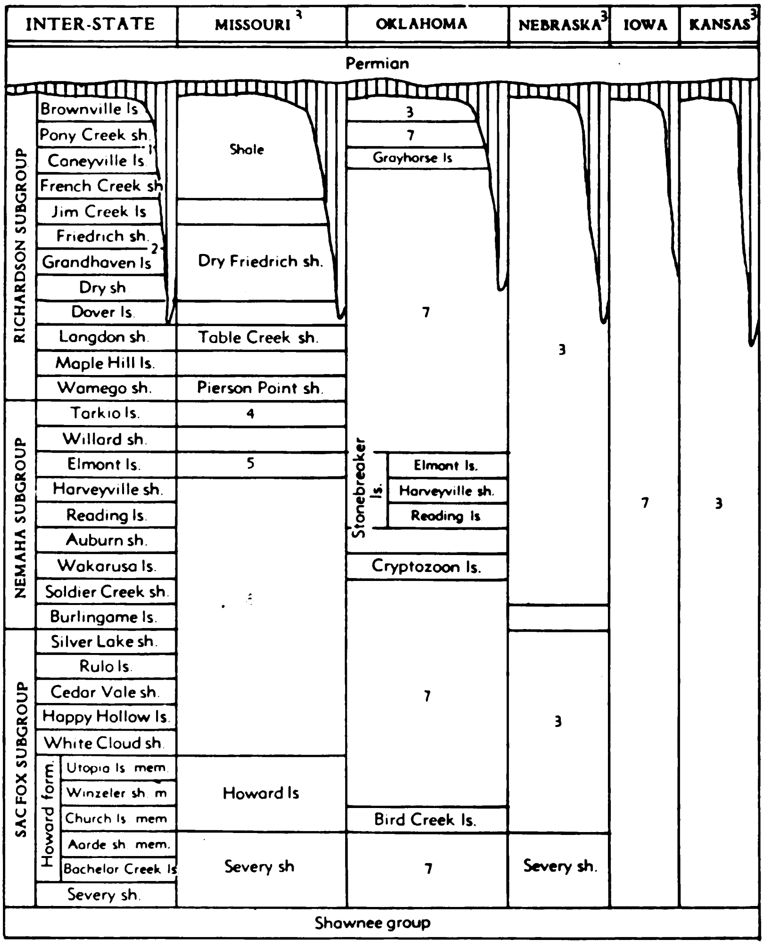

Figure 32. Classification of upper Virgilian rocks in the northern mid-contient area adopted by interstate conference of geological surveys. The agreed classification is compared with those previously used in the several States.

[1] Or Wood Siding formation, including in upward order, Nebraska City limestone, unnamed shale, Pony Creek shale.

[2] Or, in upward order, Morton limestone, Minesville shale, Palmyra limestone, Otoe shale.

[3] Classification same as interstate, excepting as shown.

[4] Tarkio limestone has been indicated as basal division of the Wabaunsee group in Missouri (Hinds and Greene, 1915; McQueen and Greene, 1938).

[5] Called Elmont or Preston limestone by McQueen and Greene (1938).

[6] Beds between Howard and Elmont limestone called Scranton by Hinds and Greene (1915).

[7] Units incompletely differentiated and identified.

[8] Nebraska recognized members of Burlingame limestone, in upward order, Taylor Branch limestone, Winnebago shale, South Fork limestone.

tawatomie and Nemaha Counties into Nebraska. The upper Pennsylvanian rocks are brought to the surface here by erosion along the crest of the Table Rock anticline, which overlies the Nemaha granite ridge. Average width of the main Wabaunsee outcrop belt is about 20 miles in northern Kansas but only half as much near the Oklahoma-Kansas boundary.

Exposures of Wabaunsee strata generally are more numerous and better suited for stratigraphic study of these rocks in the area south of the Kansas River. This is because country north of the Kansas River is extensively covered by glacial drift. Excellent sections of Wabaunsee strata are found in Shawnee, Osage, Lyon, Greenwood, Elk and Chautauqua Counties, Kansas.

Outcrops of Wabaunsee rocks can be followed southward across west-central Osage County, Oklahoma. They are found also north of Kansas along the Missouri River in southeastern Nebraska and northwestern Missouri (Fig. 33), as well as in the area of the Table Rock anticline, farther west. Wabaunsee formations appear at the surface locally in southwestern Iowa, but glacial drift mostly covers these rocks in the Iowa, Nebraska, and Missouri region.

The thickness of the Wabaunsee group in Kansas shows little variation although the thickness of several of its contained formations shows a considerable range. Excepting places where the Indian Cave sandstone, at the base of the Permian System, cuts out the upper beds, the thickness of the Wabaunsee group is about 500 feet. Where the channel sandstone just mentioned occurs, the thickness of the group is reduced 80 to 125 feet.

Lithologic Character and Classification

The Wabaunsee group is distinguished chiefly by its general lithologic features and by the character of its cyclothems from the underlying Shawnee and the succeeding Lower Permian beds, but there are also some faunal peculiarities. Shale is relatively much more prominent in the Wabaunsee group than in adjoining parts of the geologic section (Figs. 34, 35). Much of the shale is sandy and at several horizons there are extensive sandstones. The Wabaunsee limestones are very persistent but are uniformly thin, the average thickness of individual members being only 2 to 3 feet. A distinctive feature of the Wabaunsee group is the character of the cyclic sedimentary succession, which shows regularly alternating nonmarine and marine units, in which (excepting beds at

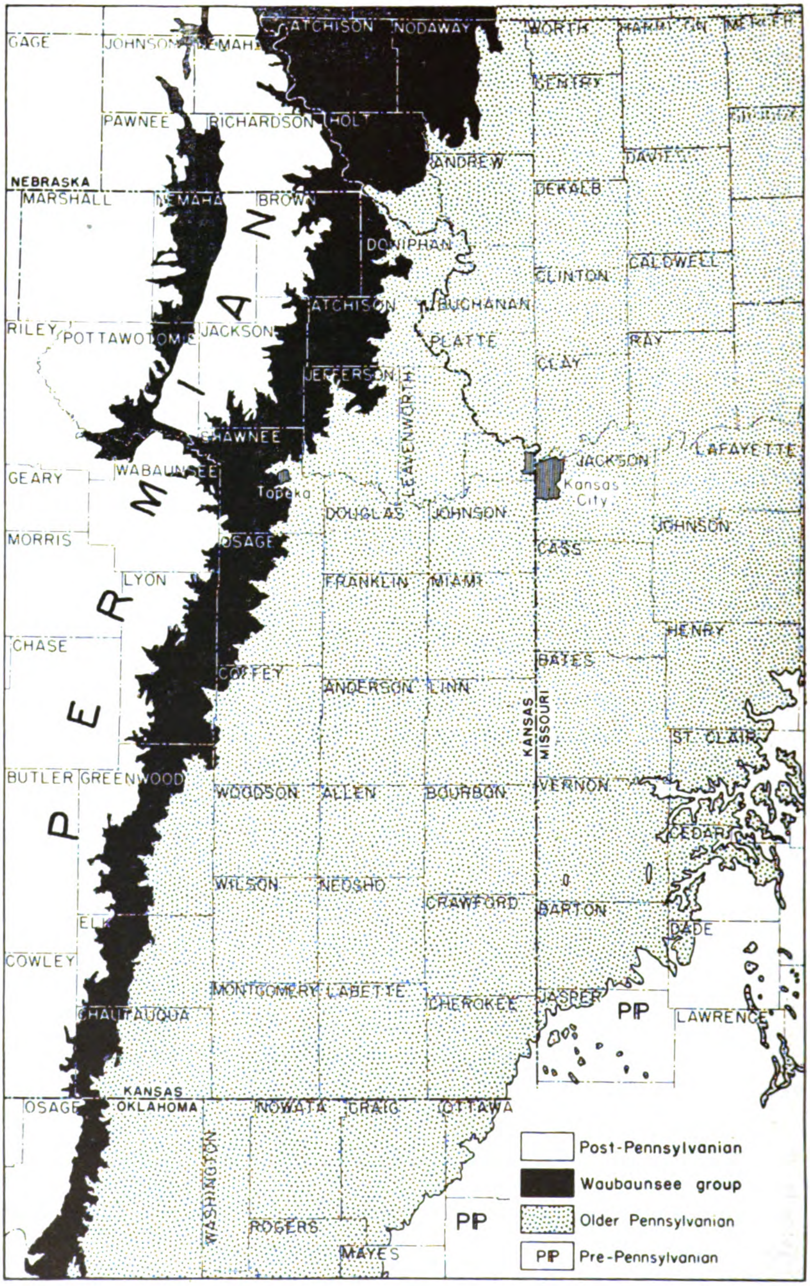

Figure 33. Distribution of outcrops of the Wabaunsee group in Kansas and parts of adjoining States. The belt forms the westernmost subdivision of the Pennsylvanian outcrop area.

the base) a grouping of cyclothems in megacyclothems is not evident (Figs. 36, 37). This serves especially to set the Wabaunsee beds apart from those of the Shawnee group.

The Wabaunsee group is divided into alternating shale and limestone formations. The shales include shale, sandstone, coal, and some minor limestone beds which all together comprise the initial and terminal parts of adjoining cyclothems. The limestones contain limestones and intervening shales which represent the medial part of each cyclothem. This classification is applicable to all of the Wabaunsee beds except one or two seemingly rudimentary cyclothems, which are not separately indicated by the present defined formations. These formations also may be assigned to subgroups called Sacfox, Nemaha, and Richardson, which have been defined in Nebraska (CONDRA & BENGSTON, 1915; CONDRA, 1935). These are included in agreed inter-State classification but use of them is not mandatory. This follows partly from the fact that units like the Tarkio limestone and Burlingame formation, which mark boundaries between the subgroups, are extremely inconspicuous or unrecognizable in parts of the midcontinent area. Thus, the Tarkio limestone cannot be identified south of Emporia, Kansas, although it is followed very readily in areas farther north.

Sacfox Subgroup

General Description

The lower one third of the Wabaunsee strata, including formations upward to the base of the Burlingame limestone, is classed as belonging to the Sacfox subgroup (Fig. 32). This division can be followed readily across Kansas, inasmuch as the Burlingame makes a well-defined escarpment and extends from Nebraska into Oklahoma.

Average thickness of rocks assigned to this subgroup in Kansas is about 200 feet.

The Sacfox part of the Wabaunsee group includes the moderately thick Severy shale at the base, overlain by persistent escarpment making rocks of the Howard limestone. The overlying White Cloud shale, Happy Hollow limestone, Cedar Vale shale, Rulo limestone, and Silver Lake shale are weak rocks, generally, for

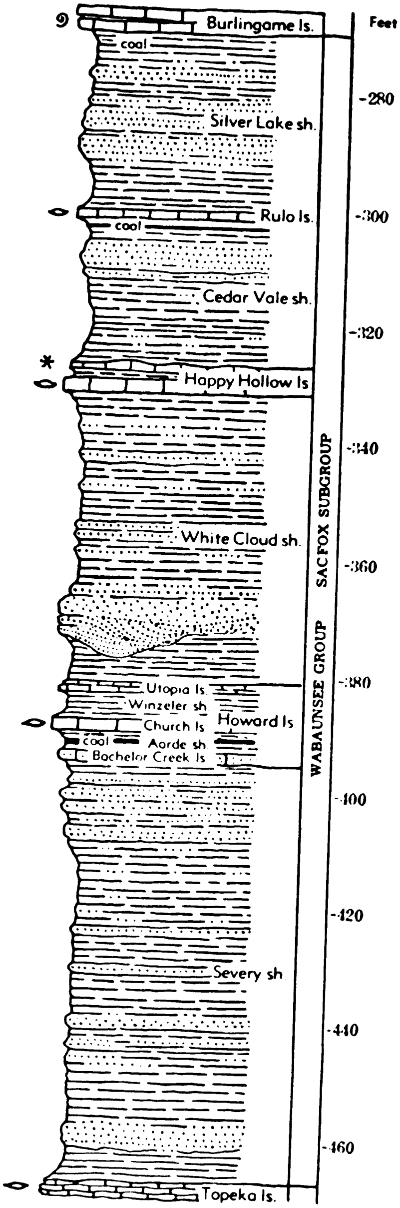

Figure 34. Generalized columnar section of rocks belonging to the Sac-fox subgroup, lower Wabaunsee, in Kansas. These rocks are late Virgilian in age.

the limestones are too thin to be expressed topographically in most places.

Severy Shale

The Severy shale (HAWORTH, 1898, p. 67), named from Severy in southern Greenwood County, Kansas, conformably overlies the Topeka limestone of the Shawnee group and includes the beds up to the base of the Howard limestone (Figs. 32, 34). Depending on variations in the development of the limestone members of these contiguous formations, the lower and upper boundaries of the Severy shale are drawn in different places at slightly different stratigraphic horizons. For example, where the Coal Creek member of the Topeka limestone is recognized, the base of the Severy is at the top of the Coal Creek limestone, but where the Hartford is the only identified member of the Topeka, the lower boundary of the Severy is considered to extend to the top of this limestone. Similar relationships are found in tracing the contact of the Severy and the Howard, but it is deemed proper to designate the section in some places, the Severy-Aarde indicating that the stratigraphic equivalent of the lower Howard shale member is believed to be present although the lower limestone is not and the Aarde has changed facies.

The Severy shale is chiefly a yellowish-brown and blue-gray sandy shale. Near the top, the shale grades into very evenly bedded thin layers of tan or buff sandstone separated by partings of sandy shale. This sandy zone is distinctive and widespread. The upper Severy sandstone is thicker, harder, and much more irregularly stratified in northern Oklahoma than in Kansas. Where the sandstone is soft and thin-bedded, the Severy forms a smooth slope along the Howard escarpment, extending down to the dip-slope plain on the top of the Topeka limestone. Calcareous beds are mostly lacking in the Severy shale. Fossils are not found in most of the Severy shale, but small brachiopods and some other invertebrates are abundant locally just below the Howard limestone.

The thickness of the Severy shale is rather constantly about 70 to 80 feet.

Howard Limestone

The Howard limestone (HAWORTH, 1898, p. 21) is a thin but extremely persistent formation overlying the Severy shale conformably (Fig. 32). It is named from the county seat of Elk County, Kansas. Except in northern Kansas where topographic expression of the stratified rocks is blurred by effects of glaciation, the outcrop of the Howard beds is marked by a distinct escarpment which is less prominent than that of the Burlingame-Wakarusa limestones or those of limestones in the Shawnee group, but is clearly differentiated in most places.

The most complete development of the Howard limestone shows the presence of three limestone members and two shale members (Fig. 34). These have been named (in upward order) Bachelor Creek limestone, Aarde shale, Church limestone, Winzeler shale, and Utopia limestone. The lithologic and faunal characteristics of the Howard will be described according to these members. The Howard sedimentary cycle seems to be intermediate between the typical megacyclothems of the Shawnee group and the simple cyclothems of the Wabaunsee group, in which no grouping into megacycles is evident.

The thickness of the Howard limestone ranges from about 8 to 30 feet.

Bachelor Creek limestone member. The lowermost member of the Howard limestone, the Bachelor Creek limestone (MOORE, 1932, p. 94) is developed in southern Kansas southward from the type area of the member in Greenwood County (Fig. 34). It is also well developed, perhaps locally, in Lyon and Osage Counties. It is a hard, somewhat sandy, impure, bluish-gray limestone, which ranges in thickness up to about 3 feet. The rock is massive, but on weathering breaks into irregular shelly fragments of yellowish-brown color. Fossils consist of crinoid stem fragments and a few brachiopods and bryozoans. The member is distinguished by lithologic characters and by its position below the Nodaway coal in the Aarde shale. The thickness of the Bachelor Creek limestone ranges up to about 4 feet.

Aarde shale member. Above the Bachelor Creek limestone and also defined from outcrops in Greenwood County, Kansas, is the Aarde shale member (MOORE, 1932, p. 94) (Fig. 34). It is chiefly a bluish-gray to yellowish clayey and sandy shale about 3 to 10 feet thick. The very persistent Nodaway coal occurs in this member, locally near the base, elsewhere near the middle, and in a few places near the top. The coal has been identified at numerous exposures from Nebraska, Iowa, and northwestern Missouri across Kansas and extending 50 miles or more into Oklahoma. It ranges in thickness from an inch or two to about 2 feet. The bed is mined at various places in Missouri and in Osage County, south of Topeka.

Parts of the Aarde shale can be differentiated in upward order: (1) sandstone, (2) sandy shale, (3) gray clay shale, (4) underclay, (5) coal (Nodaway), (6) gray clay shale, (7) dark hard limestone, (8) black fissile shale, (9) gray marine clay shale. The cyclic sequence is somewhat like that in the Cherokee rocks and the limestone (7), which seems out of place in a "Cherokee" cyclothem, is lithologically similar to limestones occurring next below black shales in Marmaton cycles or to "middle limestones" in Shawnee megacycles. Fossil plants are collected from the shale beds immediately below or above the coal at a number of places, and a marine fauna consisting of pelecypods and a few kinds of calcareous brachiopods occurs rather commonly in the uppermost gray shale.

Church limestone member. The most persistent and important limestone member of the Howard formation is named the Church limestone (CONDRA, 1927, p. 54) from outcrops in Pawnee County, Nebraska (Fig. 34). This limestone overlies the Aarde shale or, where the Bachelor Creek limestone is absent and Aarde shale cannot be differentiated, it is considered as forming the basal unit of the Howard, resting on Severy-Aarde shale.

The lithologic and faunal characters of the Church limestone are remarkably constant throughout its outcrop from Nebraska and Iowa to north-central Oklahoma. The color of the unweathered limestone is rather dark-blue to blue-gray. On weathering, a zone a few inches thick adjacent to exposed surfaces is altered to drab or brownish-blue and a thin coating of rich chestnut brown color is developed over the surface. The rock is very hard, dense, and brittle, breaking with a subconchoidal fracture when struck by a hammer. Commonly, the Church is a single massive bed. Along the outcrop in most places rectangular joint blocks, somewhat rounded at the edges by solution, are separated from the rock in place.

The most common fossils are crinoid stem fragments and large productids belonging to the genus *Dictyoclostus*. Specimens of *Enteletes* are common in the Bird Creek (Church) limestone in northern Oklahoma. The fossils are scattered at random through the fine-grained matrix. Large specimens of *"Cryptozoon"* are noteworthy in some exposures. At the top of the limestone is a thin crust containing very abundant bryozoans, especially *Rhombopora* and *Streblotrypa*. Fusulinids occur sparsely in the upper part of the Church limestone in southern Kansas and northern Oklahoma, but near Topeka fusulinids are abundant.

The thickness of the Church limestone ranges from about 1.5 to 6 feet, the average being a little more than 2 feet.

Winzeler shale member. Conformably above the Church limestone is the Winzeler shale (MOORE, 1932, p. 94), named from Greenwood County, Kansas (Fig. 34). It is about 3 to 8 feet thick, bluish-gray or yellowish and clayey to calcareous. The lower part contains a marine fauna in which a variety of bryozoans and a few brachiopods are most common. This member is recognizable from Nebraska and Iowa southward to Oklahoma, but locally where the overlying limestone disappears, the Winzeler cannot be differentiated from the White Cloud shale; the combined unit is termed Winzeler-White Cloud shale.

Utopia limestone member. The uppermost member of the Howard limestone, occurring between the Winzeler shale and White Cloud shale, is called the Utopia limestone (MOORE, 1932, p. 94) from a town in Greenwood County (Fig. 34). It is a rather thin, but persistent unit which differs lithologically and in faunal content from other limestone beds of the Howard formation. In central and southern Kansas the Utopia member is a single hard bed of dense rather dark bluish limestone which breaks along vertical joint planes into rectangular blocks. The color of the weathered rock is light brownish-gray. Exposed surfaces are slightly rough because of etching by solution that leaves fine horizontally disposed platy fragments of shells and algal growths standing in relief. This textural feature and the abundance of algal material called *Osagia* are distinguishing characters of this phase of the Utopia limestone. From Osage County northward the Utopia limestone is divisible into several limestone beds that are lithologically different and are separated by shale beds, one of which, at least, is black and fissile and bears abundant ostracodes.

Two or more cyclothems seem to be represented. A variety of brachiopods, bryozoans, and some mollusks is observed at northern outcrops.

The thickness of the Utopia limestone ranges from less than 1 foot to a known maximum of about 15 feet in Osage County.

White Cloud Shale

The White Cloud shale (CONDRA, 1927, p. 58; 1930, p. 53) includes beds occurring between the top of the Howard limestone and the base of the Happy Hollow limestone (Figs. 32, 34). It is named from a place in Doniphan County, northeastern Kansas. The formation consists of bluish or yellow-brown clayey and sandy shale 30 to 80 feet in thickness. Locally, beds of shaly to massive sandstone occur in the upper part, and north of Topeka, channel sandstone associated with a foot or two of moderately coarse conglomerate at the base, occurs below the middle of the White Cloud shale. These sandy and conglomeratic deposits are interpreted as the initial phase of the Happy Hollow cyclothem. Fossils are rare or absent at most outcrops of the White Cloud shale. Both marine invertebrates, chiefly mollusks, and land plant remains have been observed. The White Cloud shale is traceable from Iowa and Nebraska entirely across Kansas into Oklahoma.

Happy Hollow Limestone

The Happy Hollow limestone (CONDRA, 1927, p. 58) occurs conformably above the White Cloud shale and lies next below the Cedar Vale shale (Figs. 32, 34). It is the so-called "salmon bed," distinguished by a peculiar salmon-yellow or pinkish-brown color, noted by various geologists along the Missouri River in northwestern Missouri, northeastern Kansas, and southeastern Nebraska. Its type locality is in Doniphan County, Kansas.

The Happy Hollow limestone consists typically of a single massive bed of pinkish-brown, somewhat impure limestone which weathers in rounded or irregularly porous surfaces. At some places it is very sandy, soft, and somewhat shaly, so that its outcrop is difficult to trace. The presence of abundant robust *Triticites* is a common feature. Some sections show clearly an upper part of the limestone which lacks fusulinids and most other invertebrates but contains *Osagia* and other algal material. This part of the formation, which clearly represents the regressive algal-molluscan limestone phase of the cyclothem, appears to rest disconformably on the fusulinid-bearing limestone, the contact being sharp and irregular. Locally there is a little shale between these two limestone phases. A dark bluish limestone containing mollusks, brachiopods, and bryozoans has been observed a foot or two below the fusulinid limestone at some places.

The thickness of the Happy Hollow limestone ranges from about 1 foot to 7 or 8 feet. It extends from Cass County, Nebraska, at least to southern Osage County, Oklahoma. Its distinctive lihologic and faunal characters make it a useful horizon marker.

Cedar Vale Shale

The Cedar Vale shale (Condra, 1930, p. 53), named from western Chautauqua County, Kansas, comprises the middle part of the interval formerly termed Scranton shale (Figs. 32, 34). The top of the Happy Hollow limestone forms its lower boundary and the base of the Rulo limestone its upper boundary. The Cedar Vale shale is bluish to yellowish brown, includes clayey and sandy beds and near the top contains the very persistent Elmo coal. At many places the few feet of beds underlying this coal consists of soft shaly sandstone or of hard fairly massive sandstone. The sandstone, sandy shale, and coal in the upper part of the Cedar Vale represent the initial, terrestrial deposits of the Rulo cyclothem. Fossils are uncommon in most parts of the Cedar Vale shale. The topmost beds, between the Elmo coal and the base of the Rulo limestone, contain a fauna of marine mollusks, brachiopods, and bryozoans.

The thickness of the Cedar Vale shale averages about 25 feet. The formation is traceable from southern Nebraska to northern Oklahoma.

Rulo Limestone

The Rulo limestone (Condra & Bengston, 1915, p. 14) overlies the Cedar Vale shale and underlies the Silver Lake shale (Figs. 32, 34). The limestone can be recognized by its lithologic characters and position just above the Elmo coal and between the Happy Hollow and Burlingame limestones.

The Rulo limestone is a bluish-gray rock in fresh exposures and appears in some cases faintly mottled with irregular light-brownish areas. The limestone weathers brown or dark-gray. In general, it appears as a single massive bed that breaks along joints into fairly large rectangular blocks. A tendency to disintegrate in small chips is observed in some exposures, and locally the bed is distinctly shaly. Argillaceous, silty or sandy impurities are commonly present. Fossils are abundant in some outcrops but are few in others. Brachiopods and bryozoans are most common. Small fusulinids have been observed in a few places. The presence of a transgressive molluscan phase is indicated by occurrence of numerous pelecypods at the base in some exposures and a thin zone of algal limestone at the top locally marks the regressive algal-molluscan phase of the typical cycle. In general, however, the different calcareous elements of the cyclothem are not well differentiated in the Rulo limestone.

The thickness of the Rulo averages about 2 feet. The bed is identified at many places from its type locality in southeastern Nebraska to northern Oklahoma.

Silver Lake Shale

The Silver Lake shale (Beede, 1898, p. 30; Condra, 1927, p. 58), named from outcrops west of Topeka, Kansas, includes strata between the Rulo limestone, below, and the Burlingame limestone, above (Figs. 32, 34). It is somewhat variable in lithologic character, in some places consisting chiefly of bluish-gray and yellowish clay shale, with or without platy impure beds of limestone, and in other places being composed largely of light yellowish-brown sandy shale and shaly sandstone. Locally a coal bed occurs in the upper part of the shale. Some outcrops of the Silver Lake shale yield remains of land plants and some show fairly abundant marine mollusks, brachiopods, bryozoans, and other invertebrates. These kinds of fossils reflect different phases in the sedimentary cycle. Two or more dissimilar fossil zones may be seen in a single exposure of the shale.

The thickness of the Silver Lake shale averages about 25 feet. The formation is traced from Nebraska across Kansas into northern Oklahoma.

Nemaha Subgroup

General Description

The middle part of the Wabaunsee group, which is designated as the Nemaha subgroup in Nebraska, contains formations from

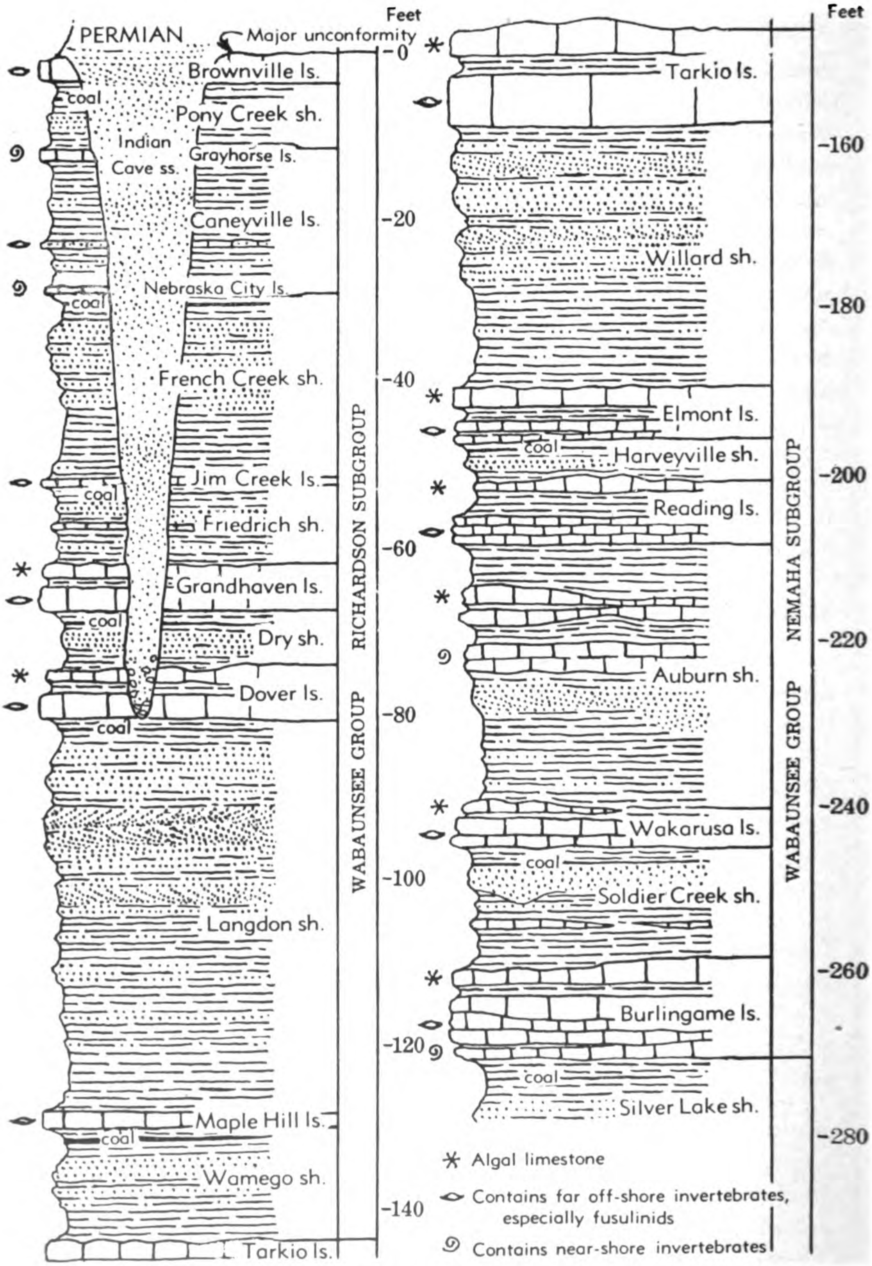

Figure 35. Generalized columnar section of rocks belonging to the Nemaha and Richardson subgroups, Wabaunsee group, in Kansas. These rocks comprise the uppermost part of the Virgilian Series in the northern midcontinent region. The unconformity which marks the boundary between Pennsylvanian and Permian rocks is indicated.

the base of the Burlingame limestone to the top of the Tarkio limestone (Fig. 32). This division can be traced southward in Kansas as far as central Lyon County, in the vicinity of Emporia, but because the Tarkio limestone is not identified farther south, the subgroup is not recognized in southern Kansas.

Limestones of the Nemaha subgroup are generally good escarpment-makers, and in this respect the middle Wabaunsee is rather well differentiated from the lower and upper divisions. Only the Howard limestone in the lower Wabaunsee and only the Dover limestone in the upper Wabaunsee are persistently well expressed topographically. On the other hand, each of the Nemaha limestones commonly makes a well-defined bench.

Average thickness of the Nemaha subgroup in Kansas is about 160 feet.

Formations assigned to this subgroup include (in upward order): Burlingame limestone, Soldier Creek shale, Wakarusa limestone, Auburn shale, Reading limestone, Harveyville shale, Elmont limestone, Willard shale, and Tarkio limestone.

Burlingame Limestone

The Burlingame limestone (HALL, 1896, p. 105), which occurs next above the Silver Lake shale, is one of the most prominent scarp-makers in the Wabaunsee group (Figs. 32, 35, 36). It was one of the first units to be named in the course of work by the Haworth Survey, the type locality being located in central Kansas.

The Burlingame limestone is chiefly distinguished by its strongly brown color and thick bedding. The rock is hard, medium- to fine-grained, and is commonly rather unfossiliferous. Many exposures show a peculiar mottled color and apparently brecciated structure, with irregularly shaped fragments of dense gray or light brownish limestone in a matrix that becomes very dark-brown on weathering. This type of rock is generally somewhat porous, and it may contain numerous fine calcite veins and other markings. Some beds of the Burlingame are light-gray and rich in fossils, but the color of the weathered rock is brown.

Different kinds of limestone and assemblages of fossils, which represent certain parts of the sedimentary cycle, are seen in the Burlingame formation, but the development of these phases is very unequal from place to place. At the base of the formation locally is limestone containing abundant pelecypods and a few

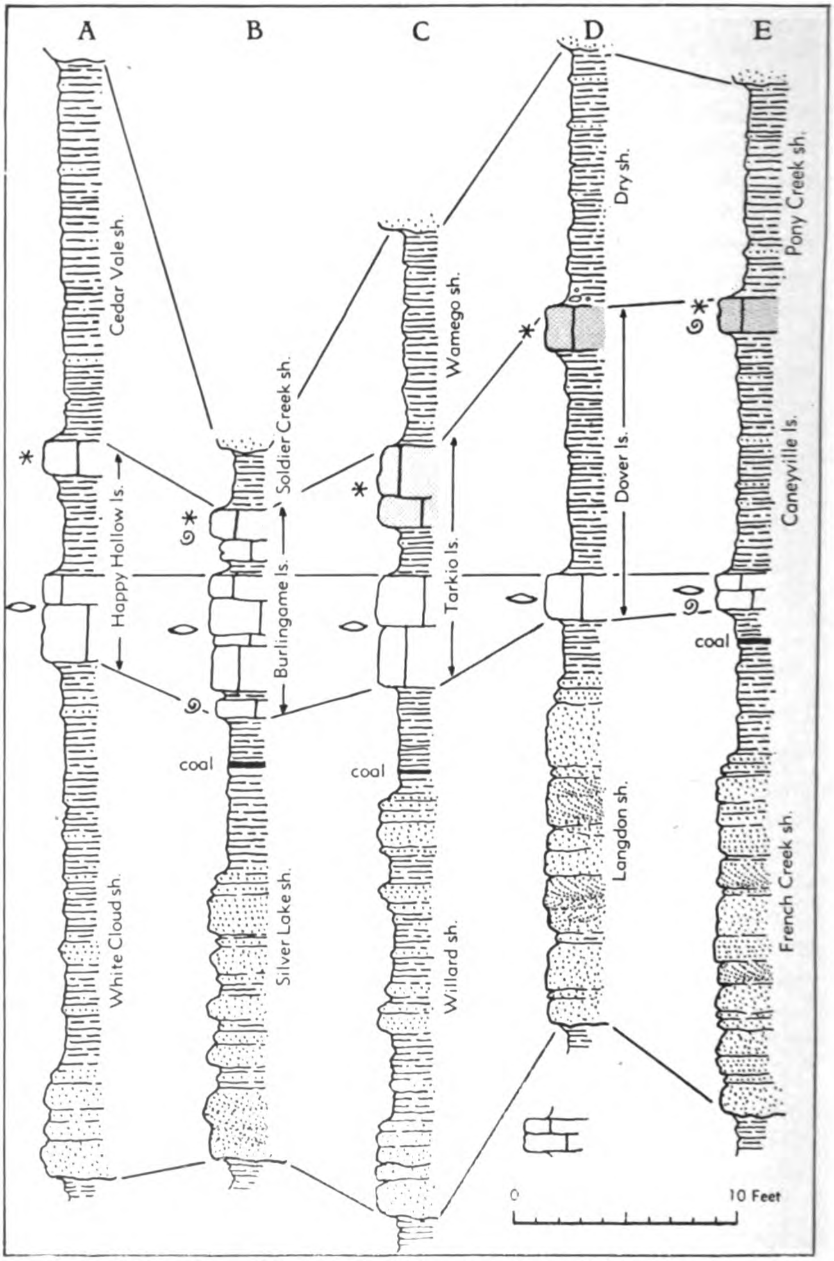

Figure 36. Sections of Wabaunsee beds showing cyclothems. Corresponding phases of the cyclothems are correlated. The stratigraphic position of the cyclothems is indicated in the general section at right in Figure 37. Algal-molluscan limestone beds are shaded.

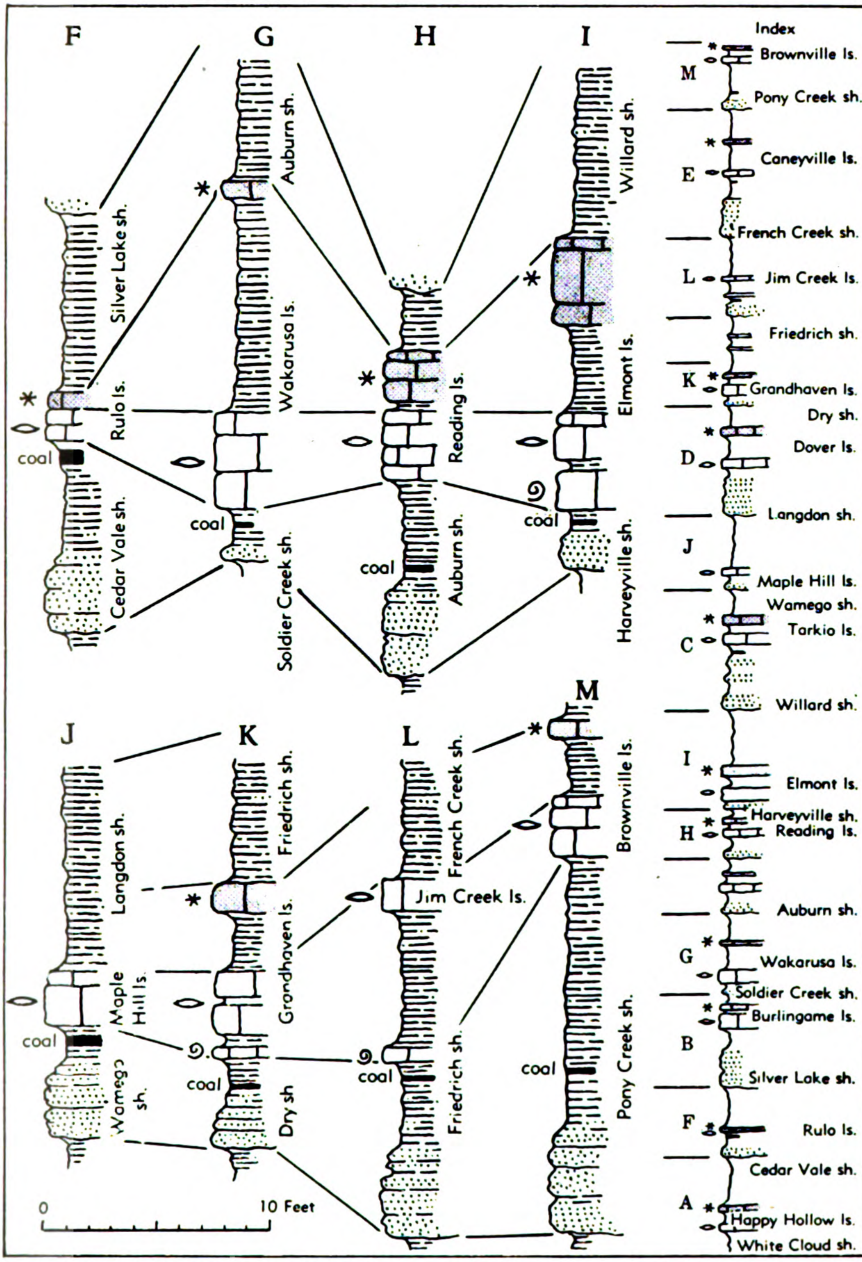

Figure 37. **Sections of Wabaunsee beds showing cyclothems.** Algal-molluscan beds are shaded.

brachiopods such as *Derbyia* and *Juresania* but no fusulinids. This clearly represents the transgressive molluscan phase of the cyclothem. A few inches of shale overlies the molluscan limestone, or limestone with fusulinids occurs next without a shale parting. The fusulinids of the Burlingame are mostly small and may easily be overlooked. There are many outcrops of Burlingame, however, which lack fusulinid-bearing beds. A very important element of the formation as observed in most places is the limestone classed as the regressive, algal-molluscan phase of the cyclothem. This includes the massive apparently brecciated rock at many outcrops; beds that contain abundant *Osagia* and other algal material; thin-bedded platy, very dense limestone which is unfossiliferous; molluscan limestone containing well-preserved fossils; and locally, conglomeratic limestone (Fig. 36). Many gastropods are found in this part of the Burlingame. In northern Kansas, a remarkable development of algal limestone of two or three sorts occurs at this horizon. One of these consists of beds and local "reefs" of subspherical, sponge-like bodies, an inch to 4 or 5 inches in diameter. Interpreted by Beede as sponges, he named them *Somphospongia*, but they are believed to be algal.

The thickness of the Burlingame limestone ranges from about 4 to 16 feet, the average being about 8 feet. The formation has been mapped from southern Nebraska across Kansas and has been identified 40 miles or more south of the Kansas-Oklahoma line.

Soldier Creek Shale

The Soldier Creek shale (Beede, 1898, p. 30; Condra, 1927, p. 77) overlies the Burlingame limestone and underlies the Wakarusa limestone (Figs. 32, 35, 36, 37).

It is a bluish-gray to bluish, clayey to sandy or silty micaceous stratigraphic unit that locally contains a little sandstone. Locally, also, a thin coal bed occurs in the upper part of the shale, but in most places this is absent. Fossils are not common. In a few places there are marine invertebrates at the top of the shale just below the Wakarusa limestone. The Soldier Creek is 15 to 25 feet thick in southern Nebraska and part of northern Kansas, but near Kansas River and southward for many miles it is less than 6 feet thick. In southern Kansas this shale is 12 to 18 feet in thickness.

Wakarusa Limestone

The Wakarusa limestone (BEEDE, 1898, p. 30; CONDRA, 1927, p. 66), named from outcrops southwest of Topeka, comprises the first resistant unit above the Burlingame limestone (Figs. 32, 35, 37). The most persistent and distinctive element in the Wakarusa formation is a thick-bedded or massive dark bluish hard limestone which contains large fusulinids, algae of the type called *Ottonosia*, a robust *Dictyoclostus*, crinoid stem fragments, *Fistulipora*, and a varied assemblage of other brachiopods, bryozoans, and some additional groups of invertebrates. On weathering the Wakarusa becomes mottled gray and light-brown or the rock is changed entirely to brown. Both lithologic and faunal characters serve readily to distinguish the Wakarusa limestone from the underlying Burlingame and it can be differentiated from somewhat similar lithologic phases of the Reading and Elmont limestones by observation of stratigraphic position and faunal characters. The thickness of the Wakarusa limestone ranges from about 2 feet to about 18 feet, the latter thickness including somewhat more shale than limestone. The formation is traceable from Nebraska into northern Oklahoma.

The so-called "Cryptozoon limestone" of Osage County, Oklahoma, which is a widely recognized datum in this part of the Pennsylvanian column in northern Oklahoma, is the fusulinid-bearing phase of the Wakarusa limestone.

Auburn Shale

The Auburn shale (BEEDE, 1898, p. 30; CONDRA, 1927, p. 78), named from southern Shawnee County, Kansas, includes the strata between the top of the Wakarusa limestone and the Reading limestone (Figs. 32, 35, 37). It is a more complex unit than most of the shale formations of the Wabaunsee group, for it includes not only the terminal clastic portion of the Wakarusa cyclothem and the initial clastic part of the Reading cyclothem, but several identifiable phases of what seems to be a partially developed intermediate cyclothem.

The lowermost part of the Auburn consists of yellowish-brown or gray sandy shale, mostly lacking in fossils. The lower part of a cyclothem belonging above the Wakarusa is clearly marked by sandstone or red shale and locally by coal and underclay in the lower part of the Auburn shale. These nonmarine deposits are overlain by shale and thin even-textured fine-grained blue limestone beds that contain marine pelecypods and commonly the brachiopod *Linoproductus*. Other brachiopods, bryozoans, and crinoid remains are fairly abundant in the shale at some exposures. A blocky, somewhat impure limestone about 0.4 to 0.5 feet thick with very even top and bottom, is identified in this zone entirely across Kansas and in northern Oklahoma. It is underlain by a thin platy limestone which carries plant fragments and some pelecypods. The persistence and uniformity of characters of these thin layers for scores of miles along the outcrop is very striking and the horizon is a very useful stratigraphic marker.

No fusulinid-bearing limestone beds have been observed in the middle part of the Auburn shale but in Shawnee County there is a locally prominent limestone containing abundant molluscan and algal remains. Near Kansas River this limestone is a resistant scarp-making limestone, 5 feet thick. It is coquinoid and in part conglomeratic and cross-bedded. Very dark, nearly black clay shale just beneath this limestone in some outcrops contains a fauna of well-preserved pectinoid and other pelecypods and a profusion of large ostracodes.

The upper part of the Auburn shale contains persistent platy sandstone 1 to 3 feet thick. The overlying shale contains remains of mollusks, chiefly pelecypods, and some brachiopods. A thin coal horizon belongs at the base of this zone.

The thickness of the Auburn shale ranges from about 20 to 70 feet. The formation is identified in Nebraska and is continuous southward across Kansas into Oklahoma.

Reading Limestone

The Reading limestone (Smith, 1905, p. 150), named from eastern Lyon County, Kansas, includes one to three beds of limestone and the shale between these beds (Figs. 32, 35, 37). The formation rests on the Auburn shale and is followed by the Harveyville shale. The Reading comprises the lower part of the beds which previously have been called Emporia limestone, or in northern Oklahoma, the Stonebreaker limestone.

The most persistent subdivision of the Reading limestone is a fusulinid-bearing unit consisting of one to three or four layers of dark-blue, fine-grained, dense, hard limestone which shows prominent vertical joints. The weathered rock is light bluish-gray mottled or blotched with light brownish or lemon-yellow areas. In places the entire thickness of the fusulinid-bearing member is yellowish brown. Fossil fragments weather in relief. Fusulinids are abundant in this part of the Reading limestone occurring with or without other types of invertebrates. A limestone bed containing numerous pelecypods and some brachiopods occurs in some outcrops below the fusulinid-bearing limestone. The distinguishing feature of the uppermost member is the presence of *Osagia* or other algal remains accompanied by some mollusks. Fusulinids are absent. The shale beds between limestones of the Reading formation commonly are blue-gray and clayey to calcareous, but in southern Kansas coal underlain by black shale and overlain by gray shale occurs next below the fusulinid-bearing limestone. In places marine fossils are found in the shale.

The thickness of the Reading limestone ranges from about 1.5 feet to 15 feet. The formation is continuous from southern Nebraska to northern Oklahoma, being represented in the latter region by the lower part of beds classed as the Stonebreaker limestone.

Harveyville Shale

The Harveyville shale (Moore, 1936, p. 226) is named from southern Wabaunsee County, Kansas. It includes the beds between the Reading and Elmont limestones (Figs. 32, 35, 37). The shale is mostly bluish or yellowish-brown and clayey, but locally there is sandy shale and thin, platy sandstone. A coal bed occurs locally above the sandstone. Pelecypods and some other invertebrates are found between the coal horizon and the base of the Elmont limestone.

The thickness of the Harveyville shale ranges from less than a foot in a few places to an observed maximum of about 25 feet. The shale is identified from Nebraska to Oklahoma.

Elmont Limestone

The Elmont limestone (Beede, 1898, p. 30) comprises the upper part of the Emporia limestone of some early reports. It lies between the Harveyville shale and the Willard shale (Figs. 32, 35, 37). Exposures in the vicinity of Elmont, Kansas, show a strong development of the algal-molluscan phase but the fusulinid-bearing phase is poorly developed. Elsewhere, especially in southern

Kansas, the fusulinid limestone is prominent. It is a dense, hard, dark-blue rock, very much like the Reading limestone, but it commonly bears much more closely spaced vertical joints and it is typically a single massive bed which weathers light bluish. In southern Shawnee County the lowest Elmont member is a dense, very fine-grained unfossiliferous blue limestone containing round pebbles of limestone slightly different in color and texture from the matrix.

The thickness of the Elmont limestone ranges from about 1 to 15 feet. The formation is traced from Nebraska across Kansas to northern Oklahoma where it has previously been included as the upper part of the Stonebreaker limestone.

Willard Shale

The Willard shale (Beede, 1898, p. 31) is defined to include the beds lying between the Elmont and Tarkio limestones (Figs. 32, 35, 37). South of the point in Lyon County where the Tarkio limestone disappears, the Willard is overlain by the Wamego shale and the combined shale unit is designated as the Willard-Wamego shale. South of Emporia the Maple Hill limestone likewise disappears, so that there is a continuous shale and sandstone section from the base of the Willard to the top of the Langdon shale. This combination of shales which are distinct in the north is called Willard-Langdon shale in southern Kansas.

The Willard shale includes the upper part of the Elmont cycle and the lower part of the Tarkio cyclothem. The boundary between these cycles is marked in some sections by the contact between clayey or sandy shale in the lower part of the Willard and massive light-tan sandstone in the upper part. The sandstone is prominent at many places in northern Kansas and southern Nebraska but it thins and disappears toward the south. This is a departure from the general rule that sandy deposits become more prominent southward and that clastic units are thicker in the south than in the north. Near the Kansas-Oklahoma line the section from the top of the Elmont limestone to the base of the Dover limestone is about 40 feet thick and is largely sandstone with a coal bed near the base. The color of the Willard shale is mostly dark bluish and brown. Fossils are not common.

The thickness of the Willard shale ranges from about 30 to 60 feet in northern Kansas and southern Nebraska, maximum thickness being observed near Kansas River.

Tarkio Limestone

The Tarkio limestone (CALVIN, 1901, p. 420, CONDRA & BENGSTON, 1915, p. 9) is a distinctive formation that occurs next above the Willard shale and beneath the Wamego shale (Figs. 32, 35, 36). As indicated by the name used by SWALLOW in 1867, "Chocolate limestone," the rock typically weathers to a very strong brown color, which, however, is somewhat more yellow in hue than chocolate. The name Tarkio is derived from northwestern Missouri and was applied originally to a bed below the limestone which is now known as Tarkio. Usage has fixed application of the name firmly to the unit here described.

The Tarkio limestone is moderately hard and in most outcrops appears as a single massive bed. It breaks down in irregularly shaped shelly slabs. Except locally the thickness and resistance of the formation are sufficient to produce a well-defined escarpment. Aside from lithologic features, the most prominent character of the Tarkio limestone is the presence almost everywhere of extremely abundant large ventricose fusulinids (*Triticites* sp.) which weather in relief, and because of their nearly white color, appear in strong contrast to the brown matrix. This feature is so striking and so unlike most other limestones in this part of the section that it is possible to identify exposures of Tarkio very easily. Some outcrops of this limestone show a gray color and these resemble in appearance certain exposures of the Dover limestone which also contains abundant large fusulinids. Above the fusulinid-bearing limestone there is present in some outcrops a few inches to 4 or 5 feet of algal limestone that lacks fusulinids but contains mollusks and some brachiopods. This represents the algal-molluscan phase of the cyclothem. It is not a persistent unit.

The Tarkio limestone ranges in thickness from less than a foot in a few places to a maximum of about 10 feet, as seen in the vicinity of Maple Hill in eastern Wabaunsee County, Kansas. The formation is traced from Nebraska southward to northern Lyon County, Kansas, but no outcrops identifiable as Tarkio have been found farther south.

Richardson Subgroup

General Description

The Richardson subgroup, defined in Nebraska, comprises the upper part of the Wabaunsee group, from the top of the Pennsylvanian section down to the Tarkio limestone (Figs. 22, 32, 35). This division can be distinguished in northern Kansas but not south of the Cottonwood River Valley in Lyon County. The Tarkio limestone disappears, or if present, has not been identified in the country south of Emporia. Generally, the upper Wabaunsee section lacks hard rocks having sufficient thickness to be expressed topographically.

Average thickness of the Richardson subgroup is about 140 feet.

Formations assigned to the upper part of the Wabaunsee section, called Richardson, include six limestone units and six consisting predominantly of shale: Wamego shale, Maple Hill limestone, Langdon shale, Dover limestone, Dry shale, Grandhaven limestone, Friedrich shale, Jim Creek limestone, French Creek shale, Caneyville limestone, Pony Creek shale, and Brownville limestone. Each of these formations, as well as some of its subdivisions, is traceable across Kansas.

Wamego Shale

The Wamego shale (Condra & Reed, 1943, p. 42), named from a town on Kansas River east of Manhattan, comprises beds lying between the Tarkio and Maple Hill limestones (Figs. 32, 35, 36). It consists of bluish clay shale and yellowish-brown sandy, micaceous shale, the total thickness ranging from about 6 to 25 feet. Locally in the north the upper portion is nearly black. A persistent zone of shaly to thin-bedded tan or buff sandstone, 1 to 4 feet thick, appears in the upper middle part of the shale in Kansas. The sandstone marks the initial phase of the Maple Hill cyclothem. Above the sandstone, near the top of the shale, is a coal bed that in places attains a thickness of nearly a foot. It is observed at most outcrops between the Kansas and Cottonwood Rivers in Kansas. Marine fossils, consisting of pelecypods, brachiopods, and bryozoans chiefly, occur above the coal but other parts of the Wamego shale are mostly unfossiliferous. Some of the historically famous Nebraska City fossils, described in early writings by GEINITZ (1866) and by MEEK (1872), come from the Wamego shale.

South of the point where the Tarkio limestone disappears, the Wamego rests directly on the Willard shale and because it is not practicable to separate these contiguous, lithologically similar units, the shale between the Elmont and Maple Hill limestones, about 90 feet thick near Emporia, is termed Willard-Wamego shale. South of Emporia where the Maple Hill limestone also disappears there is a continuous shale section from the Elmont limestone to the Dover limestone. This shale may be called Willard-Langdon shale. It contains some sandstone beds, one of which is probably a continuation of the sandy zone in the Wamego shale, but it is not possible to differentiate the Wamego shale. The coal bed of the upper Wamego has not been observed south of northern Lyon County.

Maple Hill Limestone

The Maple Hill limestone (CONDRA, 1927, p. 80) consists in most places of a single bed of bluish-gray, somewhat sandy limestone, 1 to 4 feet thick (Figs. 32, 35, 37). It is defined on the basis of excellent exposures near the town of Maple Hill, west of Topeka. The limestone is fairly hard and commonly forms a bench a little above the escarpment of the Tarkio limestone. The rock is intersected by two or more systems of rather widely spaced vertical joints and in some places there are large rectangular or rhomb-shaped blocks along the outcrop. The joints are locally much enlarged by solution. On weathering the Maple Hill limestone commonly appears reddish-brown but in some places it is rather a brownish-gray. Fossils are rare in some outcrops of the Maple Hill, but in others they are abundant. Small slender fusulinids are very common in the southern part of the outcrop area but not in the north. Crinoid stem fragments, several kinds of brachiopods and bryozoans, and a few pelecypods and gastropods may be found at most exposures of this limestone.

The Maple Hill limestone extends from Emporia northward into Nebraska. Because the Wamego shale is much thinner, on the average, than the Langdon shale, the outcrop of the Maple Hill is closer to that of the Tarkio than to the Dover escarpment. At Emporia, however, the Maple Hill limestone is less than 5 feet below the Dover limestone, and in Lyon County these limestones form a single escarpment. The Maple Hill bed is readily distinguished by lithologic and faunal characters from the Tarkio and Dover limestones.

Langdon Shale

The Langdon shale (CONDRA & REED, 1943, p. 42) includes the strata that occur between the Maple Hill and Dover limestones (Figs. 32, 35, 37). The shale is largely bluish-gray in color, and clayey to sandy in character. In many places the upper part of the formation consists of tan or buff sandstone which is shaly, platy, or fairly massive. This sandstone is the basal phase of the Dover cyclothem. The underlying shale contains marine fossils in many places and represents the terminal part of the Maple Hill cyclothem. This horizon furnished part of the famous Nebraska City fossil collections described by GEINITZ in 1866 and by MEEK in 1872. The fauna is by no means so varied or the specimens so abundant as in many other Pennsylvanian formations of Nebraska and Kansas. Near the top of the Langdon shale is a widely persistent thin coal bed that is locally worked in Missouri and Iowa. It is known as the Nyman coal. The coal extends almost uninterruptedly across southeastern Nebraska and northern Kansas and is recognized locally in southern Kansas.

The Langdon shale ranges in thickness from about 25 feet in southern Nebraska to 50 feet or more in Wabaunsee County, Kansas. Southward from this region the thickness gradually diminishes until at Emporia less than 5 feet of shale separates the Maple Hill and Dover limestones. South of Emporia, Langdon is not separable from underlying shale that represents the Wamego and Willard shales of areas to the north. This combined shale section which is about 100 feet thick near Emporia thins southward to about 15 feet in parts of Chautauqua County, Kansas.

Dover Limestone

The Dover limestone (BEEDE, 1898, p. 31) is an important although thin formation that is traced from Oklahoma across Kansas and southern Nebraska into Iowa (Figs. 32, 35, 36). As observed at the type locality, a few miles southwest of Topeka, and at many other places in northern Kansas and Nebraska, the Dover most closely resembles the Tarkio limestone, perhaps mainly because both of these units contain an abundance of very large fusulinids. Very unlike the rich-brown color of the weathered Tarkio, however, the weathered Dover limestone is light-gray, and it is generally much softer than the Tarkio. Numerous large "*Cryptozoon*" growths, which are rare or absent in the Tarkio, are seen in most outcrops of the Dover. In much of northern Kansas only the fusulinid-bearing limestone is present, but south of Kansas River an algal bed with abundant *Osagia* and in places what seems to be other types of algal growths occurs above the fusulinid bed. Extending southward from Greenwood County there is a dense, fine-grained blue limestone carrying a mixed fauna of mollusks, brachiopods, and bryozoans, that appears a few feet below the fusulinid-bearing bed. The algal bed at the top of the Dover is very persistent and prominent in the southern area. The changes in the composition of the Dover limestone along the outcrop have been determined by detailed field work which includes mapping and the careful study of many sections.

The Dover limestone is about 2 to 4 feet thick in northern Kansas and Nebraska, but where the three limestone members are present in southern Kansas the formation is about 15 to 20 feet thick.

Dry Shale

The Dry shale (MOORE, 1936, p. 236) comprises shaly beds, 5 to 20 feet or more thick, that separate the Dover limestone from the next higher limestone, the Grandhaven (Figs. 32, 35, 36, 37). The shale is bluish-gray and clayey for the most part, but sandy beds appear in places. A thin coal bed occurs near the top of the Dry shale in southern Kansas, the coal and sandy beds belonging to the Grandhaven cyclothem. The shale between the top of the coal and the base of the Grandhaven limestone is locally rich in marine fossils, calcareous brachiopods, and bryozoans being dominant.

The Dry shale is a well-defined stratigraphic unit from Shawnee County, Kansas, southward to the Oklahoma line, but northward it coalesces with the Friedrich shale above the Grandhaven limestone, for the Grandhaven disappears. It is possible—indeed, there is some explicit indication—that the Grandhaven beds grade laterally northward into shale, but it is not practicable to subdivide the shale section between the Dover and Jim Creek limestones. This may be designated, accordingly, as the Dry-Friedrich shale.

Grandhaven Limestone

The Grandhaven limestone (MOORE, 1936) overlies the Dry shale and underlies the Friedrich shale (Figs. 32, 35, 37). It comprises the only persistent limestone beds that occur between the rather easily recognized Dover limestone, below, and the Jim Creek limestone, above. There are commonly two limestone members which are separated by a few feet of shale. The lower limestone is gray to bluish in color, and unlike the Dover, commonly weathers brown,—in some cases a strong reddish-brown. It contains numerous fusulinids and some other invertebrates in some exposures, but elsewhere fusulinids are sparse or absent. Toward the south this limestone is thinner and finer grained, weathers shelly, and in many ways resembles outcrops of the Maple Hill limestone. There are numerous brachiopods, but few or no fusulinids. The changes in faunal character along the strike of this member are similar to those observed in corresponding phases of the Dover limestone, in which northern outcrops show abundant fusulinids and "*Cryptozoon*," but southern outcrops lack the fusulinids and retain numerous "*Cryptozoon*" remains. The upper limestone member of the Grandhaven formation is characterized by an abundance of algal deposits, mostly of the *Osagia* type. This bed so closely resembles some outcrops of the upper member of the Dover that it is easy to mistake one for the other unless attention is given to stratigraphic sequence. The algal bed of the Grandhaven limestone is very light-gray, weathering almost white, and in some exposures the prominent rounded algal growths give the rock a resemblance to conglomerate. The shale between the two limestones is mostly bluish-gray, and clayey to calcareous. Locally, the upper Grandhaven is strongly cross-bedded and it contains an abundant brachiopod and bryozoan fauna, in which are included also some mollusks.

The thickness of the Grandhaven limestone averages about 10 feet. The lower limestone is 2 to 5 feet in the north, but only 0.5 foot in the south. The upper limestone is 1 to 2 feet thick in most places, but locally attains a thickness of 8 feet or more. The intermediate shale is 4 to 10 feet thick. The Grandhaven limestone is recognized from Shawnee County southward to Oklahoma, but is not seen north of Kansas River. The formation clearly belongs to a cycle of sedimentation distinct from that of the Dover limestone.

Friedrich Shale

The Friedrich shale (MOORE, 1936) includes clayey and sandy beds that lie between the Grandhaven and Jim Creek limestones (Figs. 32, 35, 37). The unweathered shale is chiefly bluish-gray, but outcrops of weathered shale commonly appear yellowish or brownish. Locally there is sandstone in the upper part of this zone and at least in southern Greenwood County a thin coal bed appears a little below the Jim Creek limestone. *Myalina* and other pelecypods and some brachiopods, bryozoans, and other marine fossils appear near the top of the Friedrich shale, but in some outcrops fossils are rare or absent.

The thickness of the Friedrich shale averages about 15 feet. The unit is clearly identifiable throughout the region in which the Grandhaven limestone is developed — that is from Shawnee County, Kansas, southward—but farther north where the Grandhaven is not seen, the shale lying between the Dover and Jim Creek limestones may be called Dry-Friedrich shale.

Jim Creek Limestone

The Jim Creek limestone (MOORE, 1936, p. 239) is a thin but surprisingly persistent fusulinid-bearing rock extending entirely across Kansas; a thickness of more than 2 feet has not been observed (Figs. 32, 35, 37). The Jim Creek is a useful horizon marker and it belongs to a sedimentation cycle that is distinct from those containing the adjacent Grandhaven and Caneyville limestones. Hence it is desirable, in spite of the thinness of the unit, to differentiate it as an independent formation. The Jim Creek limestone is fine-grained, hard, and bluish-gray or bluish in fresh exposure. The weathered rock is commonly brown and gray and in most cases there are reddish or purplish tones. The bed appears as a single massive layer that is vertically jointed, but on prolonged weathering there is a tendency for the rock to break down in small shelly chips. A large variety of marine fossils, including especially brachiopods, bryozoans, and pelecypods, is found in the Jim Creek limestone in some places.

French Creek Shale

The French Creek shale (MOORE, ELIAS & NEWELL, 1934) comprises clayey and sandy beds between the Jim Creek and Caneyville limestones (Figs. 32, 35, 36, 37). The color is bluish-gray to yellowish-brown. The upper part commonly contains light brown or tan sandstone which locally is fairly hard, thick, and massive. This shale is variable in lithology but its lower part clearly represents the terminal part of the Jim Creek cycle, and its upper part, including sandstone beds, belongs to the Caneyville cycle. The Lorton coal occupies a position near the top of the French Creek shale. Although this coal bed is thin, it is one of the most widespread of the Late Paleozoic coal deposits of the northern midcontinent region. Above the coal and below the Nebraska City limestone member of the Caneyville formation there is a dark-colored shale with an abundant marine fauna characterized especially by large *Myalina* and *Derbyia* shells.

The thickness of the French Creek shale averages about 30 feet. The formation is recognized across all Kansas.

Caneyville Limestone

The Caneyville limestone (Moore, 1936) includes beds from the base of the limestone designated in some reports as Nebraska City to the top of the limestone called Grayhorse (Figs. 32, 35, 36). The Nebraska City limestone is a molluscan bed belonging to the transgressive part of a cyclothem for which no fusulinid-bearing phase was known until outcrops in Chautauqua County, Kansas, of this expected phase were discovered. Above the fusulinid-bearing limestone in Chautauqua County, is a fragmental, algal, and molluscan limestone, that clearly belongs to the regressive part of this cyclothem. It is traced southward into the Grayhorse limestone of Osage County, Oklahoma, and it was thus determined that the Nebraska City and Grayhorse limestones are parts of a single cyclothem which includes the unnamed fusulinid-bearing limestone between them in southern Kansas.

Nebraska City limestone member. The Nebraska City member (Condra, 1927, p. 116) of the Caneyville limestone is a bluish or greenish-gray sandy limestone that weathers light-yellowish brown (Figs. 35, 36). It is rather soft and does not make a prominent outcrop in most places. Brachiopods, bryozoans, and some mollusks are common in this bed. The stratigraphic position of the member with reference to the Jim Creek, Brownville, and other distinctive limestones in this part of the section, and the occurrence of a coal bed a few inches below the member, are the chief means of recognizing the Nebraska City limestone. This limestone ranges in thickness from less than 1 foot to about 5 feet, the average being about 1.5 feet.

The **fusulinid-bearing limestone** of the Caneyville cyclothem, is a bluish-gray, massive, slightly arenaceous bed with vertical joints. Few fossils other than long slender specimens of *Triticites* occur. The thickness of this limestone averages about 1 foot, and the maximum observed thickness is about 1.5 feet. It occurs 5 to 10 feet above the Nebraska City limestone.

Grayhorse limestone member. The Grayhorse member (Bowen, 1918, p. 138) of the Caneyville limestone is very different in appearance from the other two limestone members (Figs. 35, 36). It is medium- to coarse-grained, appears fragmental or coquinoid, and is rather strongly ferruginous. Broken surfaces of the unweathered rock commonly show curved cleavage surfaces of iron or magnesium-bearing carbonate crystals. In some exposures the bed appears massive but commonly there is distinctly evident cross-bedding. Large specimens of *Myalina* of the *M. subquadrata* type are the most common type of fossil. The Grayhorse limestone ranges in thickness from about 0.5 to 5 or 6 feet, the average being about 1 foot. This member occurs 5 to 15 feet above the fusulinid-bearing limestone.

The average total thickness of the Caneyville limestone is 15 to 20 feet. The formation extends from northern Oklahoma across Kansas to southern Nebraska.

Pony Creek Shale

The Pony Creek shale (Condra, 1927, p. 81; Moore, 1936, p. 243) comprises 5 to 20 feet of bluish and bluish-gray shale and locally some red clayey or sandy shale (Figs. 32, 35, 36, 37). The middle part locally contains some sandstone. The lower Pony Creek shale is mostly unfossiliferous, but the upper part commonly contains a variety of brachiopods and bryozoans, with *Marginifera wabashensis* and *Chonetes granulifer* among the most common species. A thin coal bed which belongs to the Brownville cyclothem appears in the upper middle part of the Pony Creek, just beneath the fossiliferous marine zone, in southern Kansas and northern Oklahoma. The Pony Creek shale extends entirely across Kansas and is well developed both in Nebraska and northern Oklahoma.

Brownville Limestone

The Brownville limestone (**Condra & Bengston**, 1915, p. 17) is a very widespread and distinctive formation that is here regarded as the uppermost stratigraphic division of the Wabaunsee group and of the Pennsylvanian System in Kansas (Figs. 32, 35, 37). At most places the Brownville consists of one or two beds of bluish-gray, hard limestone that weathers yellowish or somewhat reddish brown. Some outcrops show rock that appears impure and sandy, but in most places the limestone is fairly pure, dense, massive, and fine-grained. Commonly the Brownville limestone weathers in angular or rounded blocks or it disintegrates in irregularly shaped shelly fragments. The occurrence of abundant shells of *Marginifera wabashensis* characterizes most outcrops and in addition, exposures in Kansas commonly show the presence of fairly numerous large fusulinids, the bryozoan *Meekopora*, the brachiopod *Chonetes granulifer*, and crinoid stem fragments. Not infrequently these fossils occur in clusters or "nests" between which the rock contains only scattered fossils. A bed with algal and molluscan remains occurs above the fusulinid-bearing bed in parts of Chautauqua County, Kansas.

The Brownville limestone was named from outcrops in southeastern Nebraska. It has been traced entirely across Kansas and is known to extend at least 50 miles southward into Oklahoma. The thickness of the formation ranges from about 2 to 8 feet.

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