The Stratigraphic Succession in Kansas

Edited by Doris E. Zeller

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OF
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PREFACE

Bulletin 189 is the one-hundredth published by the State Geological Survey of Kansas since its distinguished predecessor, Bulletin 89, "The Kansas Rock Column," appeared in 1951. Bulletin 89 brought together under one cover the nomenclature and description of geologic units occurring in Kansas. It was widely acclaimed and proved to be useful to those concerned with the study of the strata in Kansas and surrounding states, but it has been out-of-print and out-of-date for a number of years. A distinct improvement over Bulletin 89 is the inclusion of a graphic presentation on one chart of the classification of rocks in Kansas as Plate 1, an integral part of Bulletin 189. This was not done with Bulletin 89, and proper bibliographic reference to the graphic column prepared later has been difficult, though the graphic column has been most useful.

Neighboring states that have published similar accounts of their stratigraphic succession are Nebraska ["The Geological Section of Nebraska" by G. E. Condra and E. C. Reed, 1959 (revised by Reed), Nebraska Geol. Survey Bull. 14-A] and Missouri ["The Stratigraphic Succession in Missouri," J. W. Koenig (Ed.), 1961, Missouri Geol. Survey & Water Resources, v. 40].

Changes in stratigraphic correlations and in nomenclature are not always accomplished without argument, but agreement seems to be reached more readily than in past years. The *Code of Stratigraphic Nomenclature* has helped, and perhaps most of the major areas of disagreement have been resolved. Erasmus Haworth, State Geologist of Kansas from 1895 to 1915, in "Special Report on Coal," The University Geological Survey of Kansas, Vol. III, p. 95-96, stated in 1898:

> Attempts have been made to change the nomenclature of the whole Carboniferous. The old and well established name Sub-Carboniferous would be replaced by the new name Mississippian, and the well known name Coal Measures likewise by the new term Pennsylvanian. To a great extent the detailed nomenclature of the subdivisions of the Sub-Carboniferous, or Mississippian, has been remodeled with a retention of but a few of the older terms, and the introduction of new ones. Likewise the widely employed division of the Coal Measures designated by the well known terms Lower, Middle, and Upper have been relegated to obscurity and new geographic terms, the Des Moines and the Missourian, substituted in their stead. Not only this, but one writer has even ventured to suggest that the name of worldwide recognition, Permian, be laid aside and an American geographic term, the Oklahoman, be used in its place. In this way the whole of the Carboniferous, recognized alike in the Old world and the New, would have its great divisions known entirely by American geographic names suggested by American geologists to replace older names for the same subdivisions.
>
> At this point in our nation's history it may seem a little less patriotic to adhere to the older terms and to refuse to accept the newer and strictly American geographic names. But if the former can be ignored, doing violence to all the rules of nomenclature known to science, or the latter accepted, merely on the suggestion of recent geologists, where can there be a stability to geologic nomenclature?
>
> O tempora! O mores!

Lawrence, Kansas
September 18, 1968

Frank C. Foley
State Geologist and Director
State Geological Survey of Kansas

EDITORIAL PREFACE

This bulletin is a revision based upon Bulletin 89, *The Kansas Rock Column,* by Raymond C. Moore, John C. Frye, J. M. Jewett, Wallace Lee, and Howard G. O'Connor (1951). Plate 1 of this bulletin, *Classification of Rocks in Kansas,* is a revision of the chart, *Graphic Column and Classification of Rocks in Kansas* by J. M. Jewett (1959). Information published since 1951 has been added to the descriptions of the units and, in the case of major changes, reference to the source of such information has been supplied. Changes in rank or description of nomenclatural units has been noted, *e.g.,* Fairport Chalk Member (formerly Fairport chalky shale member). In so far as possible, treatment of all stratigraphic units is in accordance with the 1961 *Code of Stratigraphic Nomenclature,* which has been adopted by the State Geological Survey as a guide. Nomenclature used is that officially accepted by the Survey for use in Kansas. Since 1958, the Survey has had a Committee on Stratigraphic Nomenclature whose purpose, among others, is to give advice and to recommend proposals for changes in geologic nomenclature within the State.

Quotation marks around a term such as "Nortonville clay" means that use of it is informal or local (or questionable). *Italics* are used to set off informal stratigraphic units below the rank of member. In the index, the major reference to a stratigraphic unit appears in **boldface.** Names of authors given in the text indicate those responsible for the revision of certain parts. For convenience in locating counties and rivers referred to in the text, an index map of Kansas (Fig. 1) has been included; in locating outcropping geologic formations, see *The Geologic Map of Kansas,* 1964 Edition. Nomenclature beyond stage divisions in the Pleistocene Series was not included on Plate 1 because names of units were not uniform statewide. The official nomenclature for these units is included in the text and on Table 3.

Lawrence, Kansas
April 5. 1968

Doris E. Zeller
Research Associate and Editor

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JOHN MARK JEWETT
CHARLES K. BAYNE
EDWIN D. GOEBEL
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ADA SWINEFORD
DORIS E. ZELLER

The Stratigraphic Succession in Kansas

ABSTRACT

Deposits of all the systems in the geologic column above the Precambrian, excepting the Triassic, are found in Kansas. Cambrian, Ordovician, Silurian, Devonian, and most of the Mississippian rocks are present only in the subsurface. The older outcropping rocks (Mississippian-Permian) occur principally in the eastern part of the State, the younger (Jurassic-Tertiary) in the western two-thirds of the State. Deposits of Pleistocene age are statewide in occurrence. The classification and nomenclature of the geologic units is that adopted by the State Geological Survey of Kansas for official use in accordance with the principles set forth in the *1961 Code of Stratigraphic Nomenclature* (American Comm. Strat. Nomenclature).

INTRODUCTION

The State Geological Survey of Kansas has issued summaries from time to time indicating current classification and nomenclature of rock units in the State. These summaries have proved of value in unifying and clarifying stratigraphic usage in the State and have served as an easily accessible reference for those unfamiliar with Kansas stratigraphy.

A chart entitled "Graphic Column of Kansas Rocks" (Moore, *et al.*, 1952) showed graphically the relationship of the stratigraphic sequence in Kansas. A revised chart, "Graphic Column and Classification of Rocks in Kansas," by J. M. Jewett was published in 1959.

The present report is similar to "The Kansas Rock Column," Bulletin 89, and "Tabular Description of Outcropping Rocks in Kansas," Bulletin 52, Part 4, inasmuch as it describes a generalized composite rock section in the State. The text is supplemented by a graphic representation (Pl. 1).

The classification used in this paper, like that in other tables of classification of rocks, is dual: (1) rocks are classified as to their origin within a commonly used and accepted geologic time scale, and (2) geographic names are applied to parts of the earth's crust that are regarded as rock-stratigraphic units.

TIME CLASSIFICATION

Geologic time is divisible as shown in Table 1. Judgement for the making of a geologic time classification is based on observation of the superposition and fossil content of the rocks.

TABLE 1.—Conceptual relationship between geologic time, time-stratigraphic units, and rock-stratigraphic units.

Geologic time	Time-stratigraphic unit	Rock-stratigraphic unit
Eon	———	———
Era	———	———
Period	System	———
Epoch	Series	———
Age	Stage	———
———	———	Group
———	———	Formation
———	———	Member
———	———	Bed

TIME-STRATIGRAPHIC CLASSIFICATION

Rocks that were formed during the *periods* of geologic time are called *systems* and bear the same names as those of the periods (Table 2). Hence, rocks of the Permian System were deposited during Permian time or in the Permian Period; rocks of the Cambrian System were formed during the Cambrian Period, etc. It is possible and useful to assign rocks to smaller divisions than those listed in Table 2. Rocks that are placed within a major division of a

system are said to constitute a *series,* which may be called lower, middle, upper, or which may be given a geographic name. In parts of the geologic section it seems advisable to assign strata to still smaller divisions, and hence *stages* are used as smaller and usually more local divisions within a series (Table 1).

ROCK-STRATIGRAPHIC CLASSIFICATION

A rock-stratigraphic unit is a subdivision of rocks that is delimited on the basis of lithologic characteristics (American Comm. Strat. Nomenclature, 1961). Rock-stratigraphic units are divided into groups, formations, members, and beds. A *formation* is the most fundamental and useful unit in this division. A *group* is the next higher ranking unit and may include two or more formations. A *member* is a subdivision of a formation. A *bed* is the smallest subdivision in rock-stratigraphic classification.

ACKNOWLEDGMENTS

Many persons have contributed to the revised description of the stratigraphy of Kansas. We are especially indebted to the authors of Bulletin 89, R. C. Moore, J. C. Frye, J. M. Jewett, Wallace Lee, and H. G. O'Connor, for the fund of information upon which this bulletin is based. Thanks are extended to P. H. Heckel, A. L. Hornbaker, P. L. Hilpman, of the State Geological Survey of Kansas, S. M. Ball and P. C. Franks, formerly of the State Geological Survey of Kansas, and M. E. Bickford, of the Department of Geology, The University of Kansas, for information and special assistance, and to Lila Watkins, JoAnne Crossfield, Diana Coleman, Karyl Higbie, and Anita Sloan for help in the preparation of final copy.

TABLE 2.—Classification and relationship of geologic time and time-stratigraphic units. (Time-scale in millions of years from Kulp, 1961.)

Time units		Beginning of period, in millions of years	Time-stratigraphic units
CENOZOIC ERA	Quaternary Period	1	Quaternary System
	Tertiary Period	63	Tertiary System
MESOZOIC ERA	Cretaceous Period	135	Cretaceous System
	Jurassic Period	181	Jurassic System
	Triassic Period	230	Triassic System
PALEOZOIC ERA	Permian Period	280	Permian System
	Pennsylvanian Period	320	Pennsylvanian System
	Mississippian Period	345	Mississippian System
	Devonian Period	405	Devonian System
	Silurian Period	425	Silurian System
	Ordovician Period	500	Ordovician System
	Cambrian Period	600 (approx.)	Cambrian System
Precambrian			

Many helpful suggestions were given by D. F. Merriam, of the State Geological Survey of Kansas, who reviewed the manuscript. Scribing of Plate 1 was done by Larry Hensiek. Preparation of copy for Plate 1 and the illustrations were by Sharon Hagen. Doris Zeller was responsible for the layout of Plate 1.

PRECAMBRIAN ROCKS

By EDWIN D. GOEBEL

Igneous, metamorphic, and metasedimentary rocks, which make up the Precambrian basement complex, underlie the entire state of Kansas (Fig. 1). Most boreholes that have penetrated Precambrian rocks are located along the crests of anticlines or structural highs; therefore, the overall distribution of rock types is known only vaguely. No test holes have penetrated through Precambrian rocks, but more than 2,500 feet of Precambrian rocks were penetrated in Nemaha County, where the Precambrian is approximately 580 feet below the surface (Merriam, 1963). In southwestern Kansas (Meade County), the top of the Precambrian is nearly 9,500 feet below the surface.

"Granite wash" is a term used to describe arkosic detrital material resting on older Precambrian rocks. The "granite wash" may range in age from Precambrian to Middle Pennsylvanian. Where overlain by the Lamotte Sandstone (Upper Cambrian) it is classified as Precambrian in age. On the crests of upwarped areas the "granite wash" is deeply weathered and locally is as thick as 150 feet.

In southwestern Kansas the Precambrian surface is largely unweathered. Quartzite outliers occur along the Central Kansas uplift in northeastern Barton County (Walters, 1946) and in southeastern Kansas (Ireland, 1955). The configuration of the Precambrian surface is reflected by the structural features depicted in Figure 6. Merriam (1963) reported that all major positive features on the Precambrian surface have a southerly plunge, and in general the Precambrian surface slopes southward.

Granite is the most common type of igneous rock reported, and quartzite and schist are the most common types of metamorphic rock (Merriam, Cole, and Hambleton, 1961). Several rock types have been observed within a 5-foot interval in cores in many locations. Scott and Hambleton (1965) identified six areas (terranes) in the west ranges of Kansas in which particular rock types are prevalent: (1) plutonic and volcanic rocks of granitic composition in the southern part; (2) a complex of gneiss, plutonic granite, and metamorphic rocks of greenschist facies in central Kansas; (3) a complex of granite gneiss and metamorphic rocks of almandine-amphibolite facies in the vicinity of Phillips County; (4) plutonic granite, granodiorite, and quartz monzonite in the vicinity of Norton County; (5) basaltic rocks in the vicinity of McPherson County; and (6) unmetamorphosed feldspathic sandstone and shale in the vicinity of Rice County.

In southwestern Kansas nonfoliated biotite granite and granodiorite (Muehlberger, Denison, and Lidiak, 1967) has an average isotopic age of 1,270 million years (m.y.). Rhyolite, which occurs in the Texas Panhandle, extends into Morton County. The Rb-Sr isotopic age of the rhyolite is between 1,180 and 1,100 m.y.

Merriam, *et al.* (1961) described an area of Precambrian sediments, including schist, quartzite, arkosic quartzite, arkose, and undifferentiated metamorphic clastics, gneiss, and "granite wash," along a band trending northwestward from the boundary between Missouri and Kansas and the central part of the boundary between Nebraska and Kansas. The continuity of the band is broken along the area of the Nemaha anticline in Pottawatomie, southeastern Riley, and eastern Geary counties, northwestern Wabaunsee County, and Morris County.

Metamorphic rocks are reported along the area of the Central Kansas uplift-Cambridge arch, and a granite batholith occurs at the Kansas-Nebraska border in northwestern Kansas (Muehlberger, *et al.*, 1967). A period of thermal activity of between 1,450 and 1,350 m.y. and a period of 1,250 to 1,100 m.y. are suggested by isotopic age determinations for the northwestern and north-central Kansas areas (Scott and Hambleton, 1965; Muehlberger, Hedge, Denison, and Marvin, 1966).

Muehlberger, Denison, and Lidiak (1967) reported basalt (Keweenawan—1,000 m.y.) and associated sedimentary rock units in northeastern Kansas. Rubidium-strontium ages of granites or their contained feldspars from basement rocks along the Nemaha anticline in northeastern Kansas range from 1,950 m.y. to 1,350 m.y. This indicates the existence of pre-Keeweenawan granitic rock. Areas of high gravity anomaly in northeastern Kansas are correlated with areas of basalt containing small amounts of gabbro. These high gravity anomalies are flanked by gravity lows associated with pre-late Cambrian arkosic sedimentary rocks (Lyons, 1950; Lidiak, 1964). Along the area of the Nemaha anticline, the dominant Precambrian rock types are granite and granite gneiss.

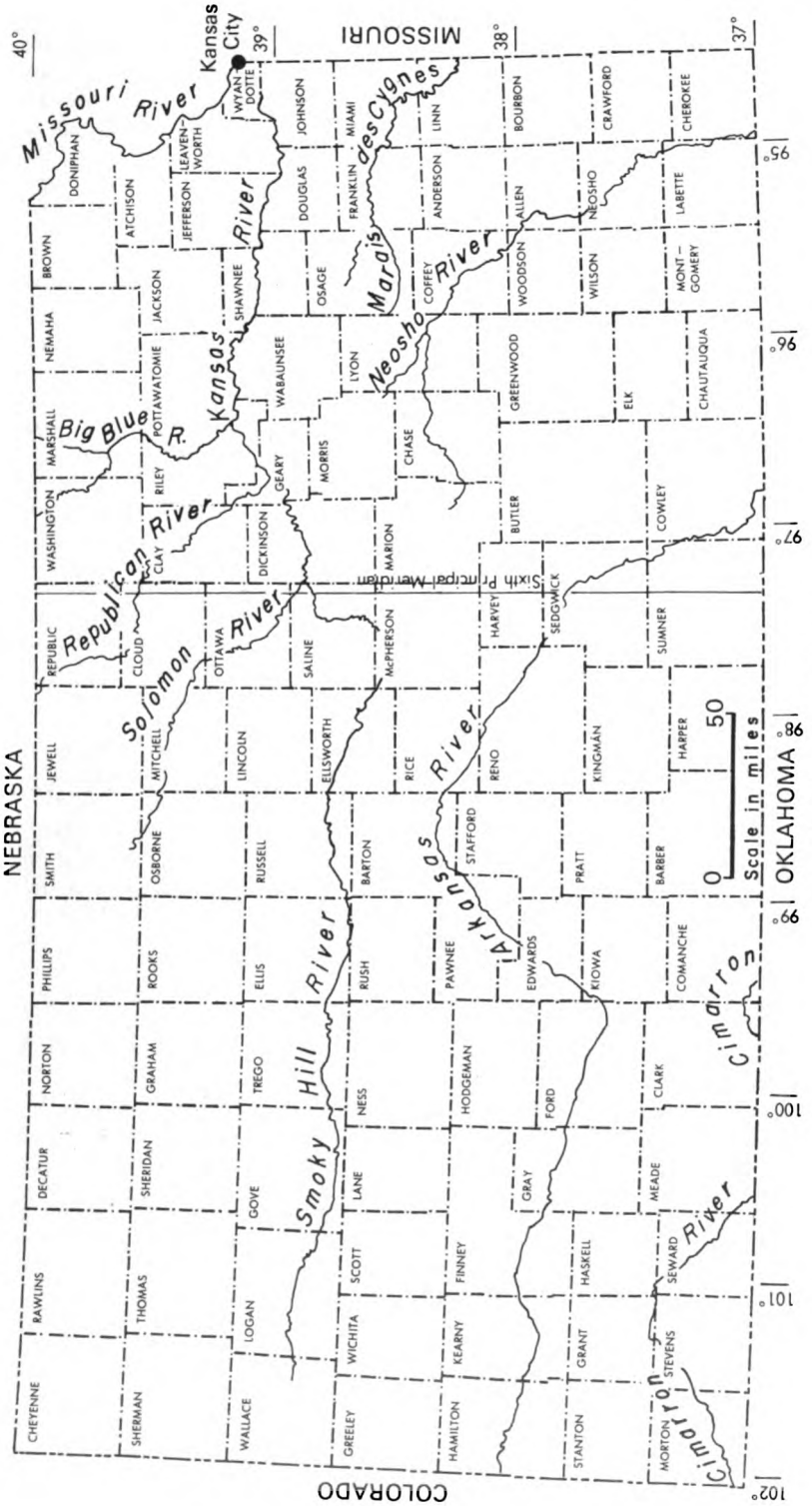

FIGURE 1. Index map of Kansas.

An area in southeastern Kansas from Bourbon County on the Missouri border westward to Butler and Sumner counties marks the northern boundary of a Precambrian igneous complex of coarse-grained granite and granite gneiss. Age of the granite ranges from 1,450 m.y. to 1,350 m.y. (Muehlberger, *et al.*, 1967). Andesite and basaltic andesite occupy a 500-square-mile area along the Kansas-Oklahoma boundary in southeastern Kansas. In Bourbon County there are questionable pre-late Cambrian sediments composed of incipient to low-grade metasedimentary rocks which contain clasts of highly strained quartz rhyolite, clay or shale detritus, authogenic chlorite, and metamorphic rock fragments. Metasediments (fine-grained muscovite-biotite schist, metagraywacke, and metabasalt) occur across the Nemaha anticline in northern Butler County and in northern Greenwood County. Muehlberger, Denison, and Lidiak (1967) suggested correlation of these rocks with the Rice Formation in north-central Kansas.

RICE FORMATION

Sedimentary rocks older than Late Cambrian age in Kansas are questionably assigned to the Precambrian. A thick sequence of these rocks in north-central Kansas has been distinguished by Scott (1966) from other material called "granite wash" and named "the Rice Formation" (Pl. 1). The formation occurs in a roughly triangular area between Marshall and Osborne counties on the north and Reno and Harvey counties on the south. The Rice Formation is composed of feldspathic sandstone, arkose, and red and green sandy micaceous shale and is unconformably overlain by the Lamotte Sandstone. The Rice is believed to rest upon Precambrian crystalline rocks. In Rice County, limestone and dolomite is interbedded with feldspathic sandstone and shale, but carbonate rocks are a minor constituent. Although the base of the formation has not been penetrated, the sequence locally exceeds 1,600 feet in thickness.

PALEOZOIC ERA

Marine and nonmarine sedimentary rocks of Paleozoic age underlie all of Kansas. All the systems of the Paleozoic Era are recognized (Pl. 1). In the eastern part of the State upper Paleozoic rocks that are chiefly Permian and Pennsylvanian in age crop out. Some Mississippian rocks are exposed in Cherokee County in extreme southeastern Kansas. Many of the series in the Paleozoic are absent or only partially developed in Kansas. Exposed Mississippian, Pennsylvanian, and Permian rocks have been intensively studied by many investigators, but work by Raymond C. Moore is noteworthy and has made the outcropping Pennsylvanian rocks in Kansas and surrounding areas internationally known. Sedimentary strata consisting of shale, limestone, dolomite, sandstone, conglomerate, breccia, and chert make up the bulk of the Paleozoic section. Coal, salt, gypsum, and other rock types occur in certain beds.

The total thickness of exposed Paleozoic rocks in Kansas, derived by compiling average measurements of subdivisions, is approximately 6,100 feet. The aggregate thickness of outcropping and subsurface Paleozoic rocks exceeds 11,500 feet. Paleozoic rocks are unconformable on the Precambrian and have an unconformable relationship with Mesozoic or Cenozoic rocks. Within the Paleozoic, major unconformities separate Pennsylvanian (Desmoinesian) from Mississippian rocks and Mississippian-Devonian rocks (Chattanooga Shale) from older Paleozoic rocks. Mississippian and older Paleozoic rocks are preserved for the most part in structural and stratigraphic basins. In Figure 2 pre-Chattanooga structural provinces are depicted, and in Figure 6 late Mississippian and early Pennsylvanian structural provinces are depicted.

All pre-Pennsylvanian formations were involved in the structural movements that deformed Pennsylvanian and younger rocks. The pre-Pennsylvanian, and especially the pre-Mississippian rocks, had already sustained structural deformations at variance with the later movements, and this resulted in some areas of marked discordance between the regional structure at the surface and that in the subsurface. Faults having small displacements are observed in a few places, but nowhere in Kansas is faulting in surface rocks a conspicuous feature.

The names of some rock units exposed in Iowa, Illinois, Missouri, Arkansas, and Oklahoma have been given to the Kansas subsurface rock units thought to be lateral equivalents. As with outcropping Paleozoic rocks, many Kansas subsurface units probably are time-transgressive. Some were deposited in this area earlier or later than their exposed counterparts.

CAMBRIAN SYSTEM

By EDWIN D. GOEBEL

No rocks of Early or Middle Cambrian age have been reported in boreholes in the Midcontinent area (Skillman, 1948). Upper Cambrian rocks are recognized in Kansas, and their distribution is similar to the distribution of rocks of

Early and Middle Ordovician age. The combined thickness of Upper Cambrian sediments is approximately 475 feet.

Cambrian rocks in Kansas comprise a marine sedimentary sequence of arkosic sandstone beds overlain by beds of dolomite. Upper Cambrian rocks unconformably overlie Precambrian rocks and conformably underlie rocks of Ordovician age.

Upper Cambrian Series

Three Upper Cambrian formations that crop out in Missouri have been correlated with subsurface units in Kansas. The oldest of these, the Lamotte Sandstone, is equivalent in position to the Reagan Sandstone of Oklahoma. The Bonneterre Dolomite is equivalent to the Honey Creek Limestone of Oklahoma. The youngest, the Eminence Dolomite, is included in the Arbuckle Group.

LAMOTTE SANDSTONE

The Lamotte is a basal Paleozoic sandstone. The sand grains composing the Lamotte are poorly sorted, rounded to angular, and coarse to fine. Quartzose sandstone, dolomitic sandstone, quartz-glauconite sandstone, arkose, and feldspathic sandstone are the dominant rock types. Arkosic material occurs in the lower part adjacent to Precambrian rocks. The Lamotte Sandstone was deposited unconformably on a complex of Precambrian rocks that formed an uneven surface of low relief. The formation is widespread in Kansas beneath the Bonneterre, but locally the Lamotte is absent and the Bonneterre lies on the Precambrian. Absence of the Lamotte locally in the area of the Central Kansas uplift and the Cambridge arch is attributed to post-depositional erosion. Thicknesses of 80 to 130 feet have been reported in southeastern Kansas, and as much as 175 feet in western Kansas, but the average thickness is about 40 feet.

BONNETERRE DOLOMITE

The Bonneterre is a conspicuously glauconitic, noncherty dolomite which is dark gray to brown and finely crystalline in eastern Kansas and buff to white and coarsely crystalline in western Kansas. It includes sandy and silty dolomite, and, locally near the top, dolomitic shale beds. The Bonneterre is distributed throughout Kansas except in places on the Central Kansas uplift and the Nemaha anticline. In western Kansas, most of the rocks reported to be Arbuckle are probably equivalent to the Bonneterre (Merriam, 1963). The Bonneterre is gradational downward into the Lamotte Sandstone. The thickness ranges from 0 at the margins of some uplifts to 150 feet in basin areas.

Undifferentiated Upper Cambrian and Lower Ordovician

Undifferentiated subsurface Cambrian and Ordovician rocks consist mostly of dolomite with lesser amounts of limestone, sandstone, and shale.

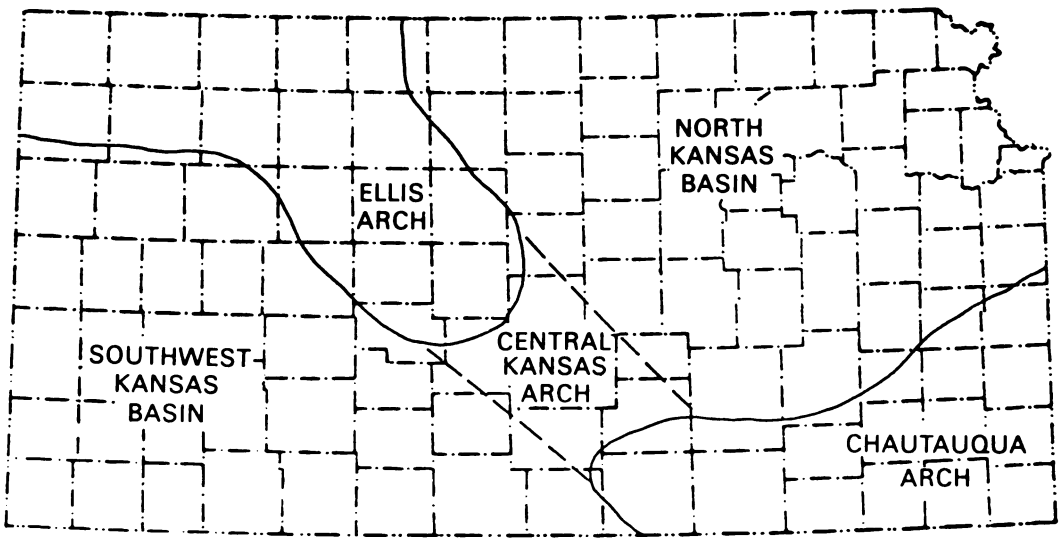

FIGURE 2. Generalized pre-Devonian-Mississippian (pre-Chattanooga Shale) structural features in Kansas. (Adapted from Moore and Jewett, 1942.)

They are absent from higher parts of the Nemaha anticline, Central Kansas uplift, and Cambridge arch (Fig. 6).

Arbuckle Group

The Arbuckle Group consists of Upper Cambrian and Lower Ordovician deposits, its subdivisions in Kansas being units that crop out in Missouri. The group includes the Eminence Dolomite, Gasconade Dolomite, Roubidoux Formation, Jefferson City Dolomite, and Cotter Dolomite. The Eminence is Late Cambrian in age; the other formations are Early Ordovician in age. "Arbuckle" sometimes is used for all rocks between the top of the Lamotte Sandstone and the base of the Simpson Group. Some authors restrict the term "Arbuckle" to rocks of Ordovician age.

The Arbuckle Group (Merriam, 1963) consists mainly of white, buff, light-gray, cream, and brown crystalline dolomite. Chert is common in the upper part. The aggregate thickness exceeds 1,200 feet. Where the Lamotte Sandstone is absent, the Bonneterre Dolomite and Arbuckle rocks commonly overlie the Precambrian. The Arbuckle Group thickens toward Oklahoma and Missouri.

Eminence Dolomite

Cherty, buff to white, very coarsely crystalline dolomite makes up the Eminence. Vitreous semitranslucent chert contains cavities encrusted by finely crystalline quartz. The chert commonly is mixed so intimately with the dolomite that insoluble residues consist dominantly of chert with lacelike, interconnecting molds of dolomite crystals. An angular unconformity separates the Eminence from the Bonneterre. Occurrence of Eminence deposits in eastern Kansas is confined mostly to a belt three counties wide bordering Missouri. It is recognized also in parts of western Kansas. The formation thickens eastward from 0 to more than 150 feet at the Missouri state line. Thicknesses of 40 to 90 feet are reported in west-central Kansas.

Gasconade Dolomite

Moore, Frye, Jewett, Lee, and O'Connor (1951) treated the Gasconade Dolomite and underlying Van Buren Formation as a unit (p. 119). Earlier, McQueen (1931, p. 18) differentiated the formations in Missouri by means of insoluble residues. Because the formations are difficult to separate in the subsurface far removed from outcrops, Keroher and Kirby (1948) designated the sequence in Kansas as Van Buren-Gasconade. The Missouri Geological Survey (Martin, Knight, and Hayes, 1961) no longer recognizes the Van Buren and includes the rock sequence from the top of the Eminence Dolomite to the base of the Roubidoux Formation as the Gasconade Dolomite. This practice is now followed in Kansas also.

The Gasconade consists mainly of cherty, coarsely granular dolomite. The chert in the upper part, which is dense and gray to dark bluish-gray, grades downward into white, dense, quartzose chert. The Gasconade is unconformable on Eminence beds and probably also on Bonneterre, Lamotte, and Precambrian beds. Gasconade rocks are reported in the subsurface in a belt along the Missouri state line. The thickness ranges from 0 to more than 200 feet in southeastern Kansas.

Gunter Sandstone Member

This member, present at the base of the Gasconade, is a sandy dolomite.

Roubidoux Formation

In Kansas, this formation consists mainly of sandy dolomite and fine-grained sandstone. Deposition of the Roubidoux seems to have been preceded by folding and erosion of older rocks. Thickness of the formation generally ranges from 150 to 200 feet.

Jefferson City Dolomite and Cotter Dolomite

Because the Cotter Dolomite and Jefferson City Dolomite recognized in outcrops are not distinctly separable in the subsurface on lithologic criteria, they are treated as a unit. They consist mainly of coarsely granular, cherty dolomite. The upper part of the sequence includes much oölitic chert which becomes white and decreases in volume toward the base where white, tripolitic chert becomes abundant. These rocks unconformably underlie different formations, such as the St. Peter Sandstone on the flank of the Southeast Nebraska arch, the Chattanooga Shale on the Chautauqua arch, and Pennsylvanian rocks on parts of the Central Kansas uplift and Nemaha anticline. The Jefferson City Dolomite probably is conformable on the Roubidoux Formation. The Cotter-Jefferson City sequence ranges in thickness from 0 feet in northern Kansas to more than 650 feet in Cowley County in southern Kansas.

ORDOVICIAN SYSTEM

By EDWIN D. GOEBEL

The Ordovician System in Kansas includes thick sequences of dolomite and dolomitic limestone overlain by sandy dolomite, sandstone, limestone, and shale. All are found in the subsurface. Their distribution (Fig. 3) is statewide, except in places on the Central Kansas uplift and the Nemaha anticline. (Lower Ordovician rocks were discussed under the section *Undifferentiated Upper Cambrian and Lower Ordovician.*)

Middle Ordovician Series

Middle Ordovician rocks above the Arbuckle Group comprise the Simpson Group, which includes unnamed beds of sandstone and shale, the St. Peter Sandstone, the Plattville Formation, and the Viola Limestone. Simpson rocks in Kansas represent only a part of the Simpson of Oklahoma, where the rocks exceed 1,500 feet in thickness (Lee, 1956).

Simpson Group

Probably Simpson rocks formerly were present throughout eastern and central Kansas, but pre-Devonian (or pre-Chattanooga) erosion removed them from the Chautauqua arch, and early Mississippian and early Pennsylvanian erosion removed them from considerable areas on the Central Kansas uplift and northern part of the Nemaha anticline. In the Hugoton embayment, the Simpson is represented by about 90 feet of sandy dolomite, white dolomitic sandstone, and blue-green to gray shale, which thins to the north and west.

ST. PETER SANDSTONE AND LOWER SIMPSON BEDS

The St. Peter Sandstone and the underlying green shale and sandstone, which occur near the Oklahoma border, are part of the Simpson Group.

A shaly zone in the middle part of the St. Peter in northeastern Kansas becomes more prominent southward, and westward, near the Oklahoma border, upper St. Peter Sandstone is underlain by beds of light-green and dark-green clay shale, sandy clay, and sandstone. An angular unconformity separates gently dipping St. Peter and associated Simpson beds from underlying rocks. The St. Peter overlies Precambrian and Upper Cambrian rocks on the Nebraska arch in northeastern Kansas. Abnormal thicknesses of St. Peter Sandstone, especially in eastern Kansas, are thought to represent sink-hole fillings (Lee, *et al.*, 1946; Merriam and Atkinson, 1956). The thickness of the St. Peter Sandstone averages about 50 feet in northeastern Kansas. The St. Peter and associated Simpson rocks increase in thickness to 190 feet near the Oklahoma state line.

PLATTEVILLE FORMATION

The upper beds of the Platteville Formation in Kansas consist of dolomite, limestone, sandstone, and green shale, and in the basal part is a persistent dolomite 5 to 35 feet thick. Some sand generally occurs in the basal dolomite and dis-

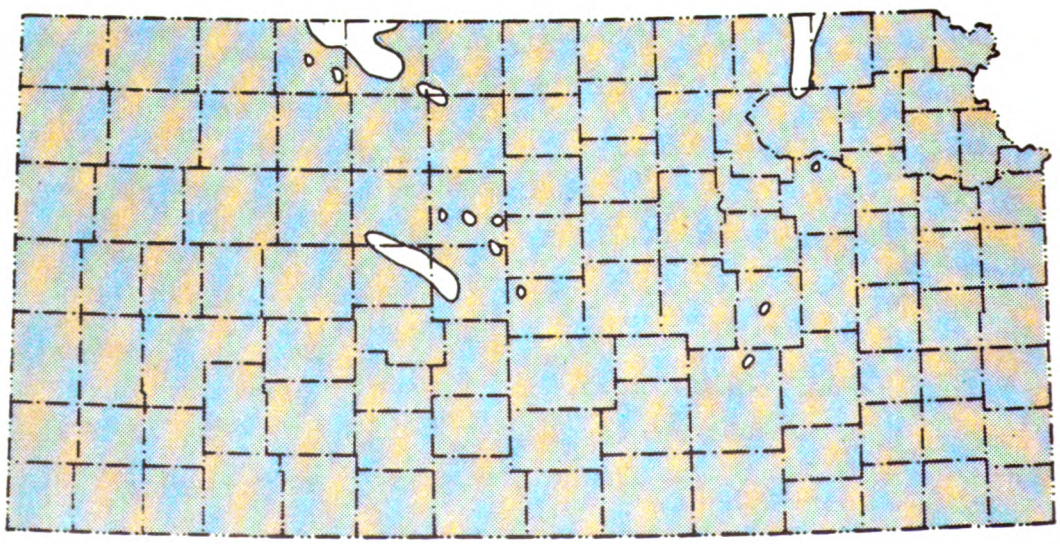

Figure 3. Distribution of Cambrian and Ordovician rocks in Kansas (shaded area). (Adapted from Merriam, 1963.)

seminated in the shales and dolomites of the upper part. The formation is restricted to the North Kansas basin. The Platteville is unconformable on the St. Peter Sandstone in northeastern Kansas (Lee, *et al.*, 1946). Maximum known thickness of the formation in Kansas is 100 feet in Brown County; it wedges out southward on the flanks of the Chautauqua arch and the Central Kansas uplift.

Twenhofel, *et al.* (1954) assigned a Middle Ordovician (Blackriveran) age to outcropping Platteville rocks in Missouri. Leatherock (1945) correlated the Platteville in Kansas with the Decorah of Missouri.

VIOLA LIMESTONE

The Viola Limestone of Kansas, which represents only part of the Viola of Oklahoma, consists of dolomite and limestone strata containing some cherty beds characterized by black flecks and spicular and tubelike fragments of microorganisms. In deep parts of the North Kansas basin, the carbonate rocks of the Viola are dominantly dolomite, but toward margins of the basin earthy and granular limestone beds are present, especially at the base. There is an unconformity between Viola and Platteville rocks in Kansas (Lee, 1956). The Viola occurs throughout the State except in places on the Central Kansas uplift, in northwestern Kansas, on the Chautauqua arch, and on the northern end of the Nemaha anticline. In the Hugoton embayment it is overlain unconformably by Mississippian rocks and oversteps underlying Simpson Group and older rocks eastward (Merriam and Atkinson, 1955) and westward (Maher and Collins, 1949). In eastern Kansas the Viola is 310 feet thick (Washington County), and it thins southward to 20 feet in Harvey County. In southwestern Kansas, where it is difficult to discern from Arbuckle rocks, the Viola thickens from 0 feet on the flanks of the Central Kansas uplift to more than 200 feet in the deepest part of the Hugoton embayment at the Oklahoma state line.

Upper Ordovician Series

Upper Ordovician rocks in Kansas are composed of beds of dolomite, dolomitic shale, and shale. They are restricted principally to the area of the North Kansas basin.

MAQUOKETA SHALE

The Maquoketa Shale of northeastern Kansas characteristically consists of greenish-gray, silty dolomitic shale or cherty, silty dolomite. Graptolites have been reported from Maquoketa cores from central Kansas. In southern Kansas, the Maquoketa becomes more argillaceous and less cherty and dolomitic. An angular unconformity between the Maquoketa Shale and the underlying Viola Limestone is revealed by the overlap, toward the southwest, of the Maquoketa upon progressively older beds of the Viola. Probably, the Maquoketa Shale is an equivalent of the Sylvan Shale in Oklahoma, but was removed from the Chautauqua arch by pre-Devonian or pre-Chattanooga erosion (Lee, 1956). The Maquoketa is not recognized in southwestern Kansas. In eastern Kansas, where it occurs beneath Silurian rocks, the Maquoketa ranges from 155 feet in the north to less than 40 feet in the south.

UNDIFFERENTIATED SILURIAN AND DEVONIAN

By EDWIN D. GOEBEL

Silurian and Devonian rocks (Fig. 4) consist mainly of dolomite and limestone and are restricted in distribution to northeastern and north-central Kansas (North Kansas basin, Fig. 2). Although the Silurian and Devonian rocks overlap some Ordovician rocks, they are more closely in accord with Ordovician than with Mississippian rocks (Merriam, 1963). Silurian rocks disconformably overlie Ordovician rocks (Maquoketa Shale). A disconformity separates Silurian and Devonian rocks (Lee, 1956). Devonian carbonate rocks are separated from undifferentiated Devonian-Mississippian rocks (the Chattanooga Shale) by an unconformity. These rocks are subsurface only.

"HUNTON GROUP"

Limestone and dolomite strata of Silurian and Devonian ages are called the "Hunton Group." In Oklahoma, where the term "Hunton" was first applied, the group consists of Silurian rocks as well as Lower Devonian rocks. Most of the Devonian portion of the "Hunton" in Kansas is no older than Mid-Devonian in age (Hilpman, 1967) and the Silurian portion is no younger than Mid-Silurian in age.

CHIMNEYHILL DOLOMITE

Silurian rocks (Chimneyhill Dolomite) consist mostly of light-gray to buff, fine- to medium-crystalline dolomite. On the margin of the North Kansas basin some limestone is interbedded with the dolomite. The lower part of the Silurian rocks includes beds of dolomitic oölites

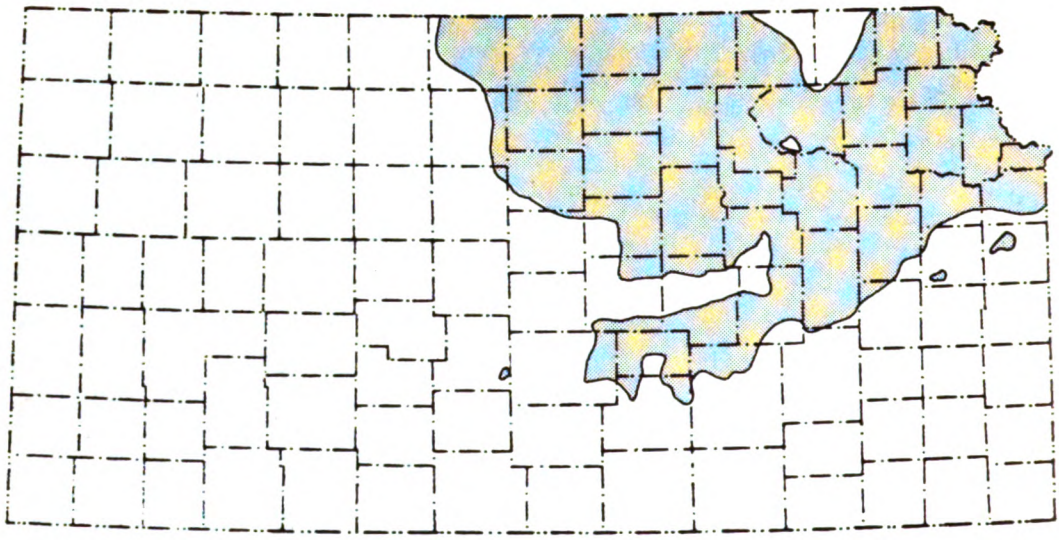

FIGURE 4. Distribution of Silurian and Devonian rocks in Kansas (shaded area). (Adapted from Lee, 1956; Hilpman, 1967.)

at the base, overlain by beds containing opaque white chert and slightly silty dolomite (Lee, 1956) with sparsely distributed siliceous foraminifers (Ireland, 1966). Higher strata are mostly coarsely crystalline white dolomite. The lower beds of the Kansas Chimneyhill may be equivalent to the Chimneyhill Limestone of Oklahoma (Lower Silurian). The Silurian rocks rest disconformably on Maquoketa Shale, but without marked relief. A disconformity separates Silurian from Devonian rocks (Lee, 1956). Lack of sand grains mainly distinguishes the Silurian rocks of Kansas from Devonian rocks. In Kansas, Silurian rocks are restricted to the ancient North Kansas basin and to an area north of the Chautauqua arch. Maximum thickness of Silurian rocks in Kansas is 435 feet in Nemaha County.

Devonian rocks in the North Kansas basin consist mostly of relatively pure lithographic and sublithographic limestones that grade westward and northwestward into dolomite. In some places, particularly just east of the Nemaha anticline, the Devonian rocks are coarsely crystalline and porous. A cherty zone commonly ocurs 30 to 100 feet above the base. Basal Devonian beds, consisting of sandy dolomite or limestone, are distinguished readily from nonsandy Silurian rocks (Chimneyhill). An unconformity which occurs at the base of the Devonian section is one of the most pronounced in the geologic sequence of Kansas, for it represents local pre-Devonian erosion of Silurian and older rocks that were hundreds of feet thick (Lee, 1956). In eastern Kansas, Devonian rocks successively overlap Silurian, Upper Ordovician (Maquoketa), and Middle Ordovician (Viola) rocks from north to south. Devonian carbonate rocks now are confined to central and eastern Kansas, where they occur flanking the Central Kansas uplift and the Chautauqua arch. They are not recognized in the Hugoton embayment, but reworked Devonian microfossils have been reported from the southwest flank of the Central Kansas uplift (Goebel, 1966). Middle Devonian rocks are reported by Hilpman (1967) in southern Stafford County on the Pratt anticline. The maximum known thickness of Devonian carbonate rocks (greater than 250 feet) occurs in Doniphan County in northeastern Kansas.

Undifferentiated Upper Devonian and Lower Mississippian

The shale sequence between Devonian and Mississippian carbonate rocks in northeastern Kansas is divided into two formations, the Chattanooga Shale below and the Boice Shale above. They are separated by a marked disconformity with as much as 110 feet of topographic relief locally (Lee, 1956). The Chattanooga Shale extends over most of the eastern two-thirds of Kansas (Fig. 5). It is probable that the Chattanooga Shale (often miscalled "Kinderhook shale" in Kansas) is Mississippian and Devonian in age and that the Boice Shale is Mississippian (Kinderhookian) in age only. All of this sequence occurs in the subsurface.

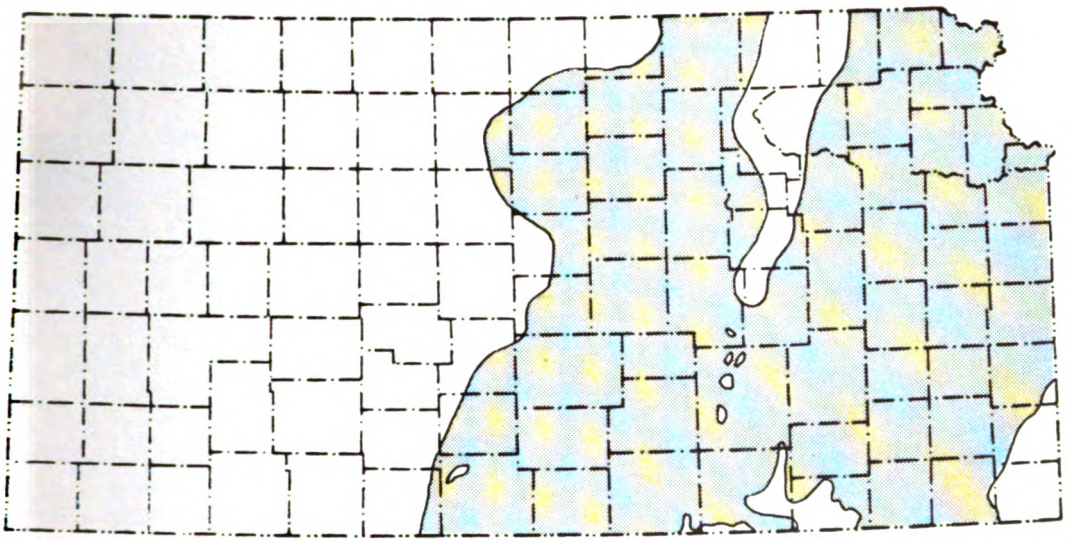

FIGURE 5. Distribution of undifferentiated Devonian and Mississippian rocks (Chattanooga Shale) in Kansas (shaded area). (Adapted from Lee, 1940.)

CHATTANOOGA SHALE

The Chattanooga Shale is silty, pyritiferous, and, in some places, partly dolomitic. Spores occur sparsely throughout the shale, but are most common in basal beds. The shale is black in southern Kansas, but it grades northward into gray shale. The Chattanooga Shale is separated from underlying rocks by an angular unconformity. From north to south, the Chattanooga overlaps rocks ranging in age from Middle Ordovician to Devonian (Lee, 1940). It is present in most of eastern and central Kansas, but it is absent at the northern end of the Nemaha anticline. The Chattanooga extends in an almost continuous sheet westward to a line from Clark County on the south to Osborne County on the north. Its thickness ranges from 0 feet in Osborne, Clark, and intermediate counties to more than 250 feet in northeastern Kansas near the Nebraska border. Abnormal thicknesses of Chattanooga Shale occur in McPherson County and areas to the east, where the formation was deposited in valleys eroded into the older rocks (Lee, 1956).

MISENER SANDSTONE MEMBER

The Misener, occurring at the base of the Chattanooga Shale, is a distinct unit in some places, but in most of eastern Kansas it is represented only by disseminated, rounded sand grains.

BOICE SHALE

Dark or light greenish-gray, spore-bearing silty or dolomitic shale and basal beds of red shale or ferruginous oölite comprise the Boice Shale. These strata conformably underlie the Chouteau Limestone or occur disconformably beneath the upper Sedalia Dolomite (both Kinderhookian). The Boice is disconformable upon the Chattanooga Shale. It is confined to northeastern Kansas, extending somewhat to the west of the Nemaha anticline. Its present known thickness is 110 feet near the Nebraska border in Brown County.

MISSISSIPPIAN SYSTEM

By EDWIN D. GOEBEL

Mississippian rocks are present in the subsurface throughout the State except on the crests of the Central Kansas uplift, the Cambridge arch, the northern and northwestern parts of the Nemaha anticline, and some isolated areas, where they have been removed by early Mississippian, late Mississippian, and early Pennsylvanian erosion (Fig. 6). The only outcropping Mississippian (Keokuk Limestone of Osagian age) is found in a small area in Cherokee County, in the extreme southeastern corner of the State (Fig. 7). Deposits of this age are mostly shallow-water carbonates. The older Mississippian rocks are marine; the younger Mississippian rocks are both marine and nonmarine. The maximum thickness of Mississippian rocks in the Hugoton embayment of southwestern Kansas is more than 1,700 feet.

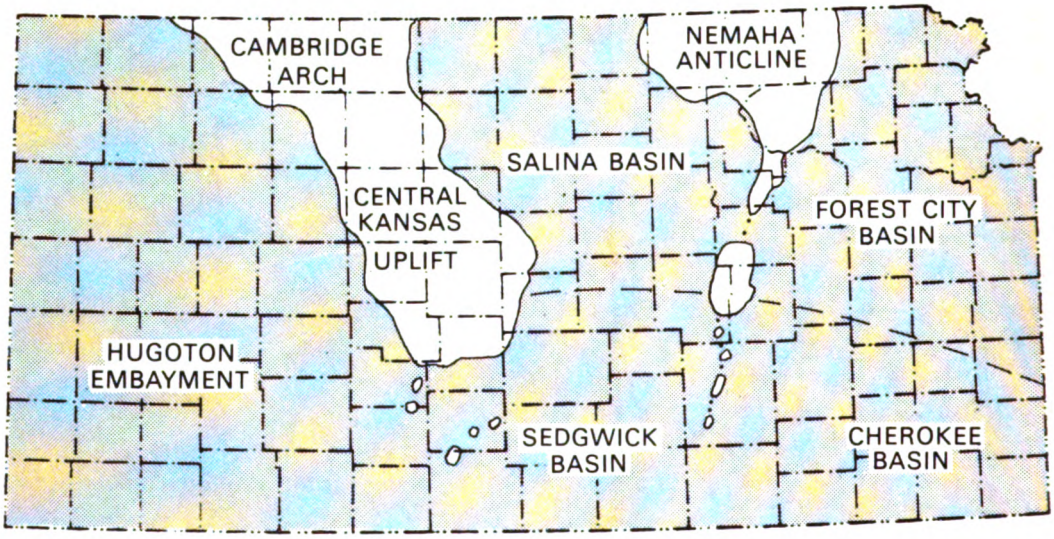

FIGURE 6. Late Mississippian and early Pennsylvanian structural provinces and distribution of Mississippian rocks in Kansas (shaded area). (From Goebel, 1966.)

Lower Mississippian Series

The Lower Mississippian Series in Kansas consists of beds of shale, limestone, dolomite, and chert. Cherty dolomite predominates.

KINDERHOOKIAN STAGE

An angular unconformity separates rocks of the Kinderhookian Stage from overlying Osagian rocks. The Kinderhookian thickens northward toward a basin in central Iowa, whereas the formations of the Osagian thicken southward (Lee, 1956; Goebel, 1966).

CHOUTEAU LIMESTONE

The Chouteau is the lowermost limestone formation of the Kinderhookian Stage in southeastern Kansas. It resembles the St. Joe Limestone (Osagian), but it is slightly greenish-gray and less granular than the St. Joe. The Chouteau is present only east of the Nemaha anticline. In southeastern Kansas the Chouteau is called the **"Compton Limestone."** The Chouteau (Compton) ranges in thickness from 0 feet east of the Nemaha anticline and at the Oklahoma border in southeastern Kansas to about 45 feet near Kansas City.

SEDALIA DOLOMITE

The lower Sedalia contains more chert than the upper part. The chert of the lower part is generally ash-gray and characterized by somewhat unique "stippled" markings. The lower part of the Sedalia Dolomite thins southward, and in southeastern Kansas it is equivalent to the **Northview Shale.**

The upper part of the Sedalia Dolomite consists of noncherty or sparsely cherty buff to gray dolomite, which extends from outcrops in Missouri westward in the Kansas subsurface to the northeastern flank of the Central Kansas uplift. It overlies conformably the lower part of the Sedalia east of the Nemaha anticline, but overlaps upon the Chattanooga Shale to the west. In northwestern Kansas, the upper part of the Sedalia occurs locally below the Gilmore City Limestone (Goebel, 1966). The upper part has a maximum thickness of 30 feet near Kansas City, but it is rarely more than 10 feet thick west of the Nemaha anticline in the Salina basin, where it occurs in local outliers beneath the Gilmore City Limestone or lower Osagian rocks, as in McPherson and adjoining counties.

GILMORE CITY LIMESTONE

Uppermost of the Kinderhookian deposits in Kansas, the Gilmore City Limestone consists of noncherty, soft, chalky limestone enclosing granules of broken calcareous fossils. Some zones are characterized by oölites, including some of irregular shape and black color. In western Kansas, the formation is oölitic limestone and locally contains traces of chert. The Gilmore City Limestone of Kansas occurs northeast and west of the Central Kansas uplift. In northeastern Kansas it lies disconformably upon Sedalia Dolomite. It thickens northwestward from 0 feet in Leavenworth County to 76 feet in Cloud County.

In western Kansas the Gilmore City thickens from 0 feet in Clark and Meade counties to more than 150 feet in northwestern Kansas.

OSAGIAN STAGE

Formations in the Osagian Stage consist of dolomite, limestone, chert, and cherty dolomite and limestone beds. The older Osagian formations are restricted to southern Kansas and are overlapped northward by younger formations. Basal Osagian rocks are separated from the underlying Kinderhookian rocks by an angular unconformity.

FERN GLEN LIMESTONE

The Fern Glen Limestone consists of the St. Joe Limestone Member conformably overlain by the Reeds Spring Limestone Member. The Fern Glen is restricted to south-central and southeastern Kansas and lies conformably below the Burlington Limestone in south-central Kansas. The upper member of the formation progressively overlaps northward the lower member as well as older Mississippian rocks. The pattern of distribution of the Fern Glen suggests that the southern part of the Central Kansas uplift and the Nemaha anticline were being gently deformed before or during the deposition of early Osagian rocks (Lee, 1956; Goebel, 1966).

ST. JOE LIMESTONE MEMBER

In southeastern Kansas, white, semigranular and coarsely granular noncherty crinoidal limestone is classed as St. Joe Limestone by Lee (1940, 1949, 1953). In the area south of the Central Kansas uplift, the St. Joe is made up of reddish- and greenish-colored calcareous shale and dark-gray argillaceous shale (Goebel, 1966). Erratically distributed reddish-colored crinoidal limestone beds are interspersed in the shale beds. Westward the lower portion of the member contains some lithographic limestone. The St. Joe has a maximum thickness in southeastern Kansas of about 45 feet, farther west it is mostly less than 20 feet, but in Barber County it exceeds 120 feet.

REEDS SPRING LIMESTONE MEMBER

Although slightly dolomitic in places, westward from the Kansas-Missouri border the Reeds Spring shows an increase of gray or buff semigranular and fine-textured limestone. In southeastern Kansas, abundant dark-gray to brown semitranslucent chalcedonic chert and varicolored semiopaque chert occurs. Silica and sponge spicules are common and microscopic crusts of chalcedony are present in insoluble residues. The chert content of the Reeds Spring is high in south-central Kansas, and the chert is pale bluish-gray and semitranslucent to translucent. In areas of Sedgwick, Butler, and Barber counties, the Reeds Spring is noncherty red and grayish-green crinoidal limestone interstratified with cherty limestone. The Reeds Spring has a maximum thickness of 150 feet.

BURLINGTON LIMESTONE AND KEOKUK LIMESTONE, UNDIFFERENTIATED

Although lithologically distinct in some subsurface areas and divided by an important disconformity (Lee, 1956), the Keokuk and Burlington formations are not clearly separable in others. In southeastern Kansas, where the Burlington is absent (Lee, 1940), Keokuk beds are characterized by white tripolitic chert, siliceous limestone, and dolomite. Chert content of the Keokuk throughout Kansas is generally greater than 50 percent by volume and weight (Goebel, 1966). Stratigraphic variations in chert and carbonate content are notable. Toward the north in eastern Kansas, limestone and dolomite beds that probably should be correlated with the Burlington, containing opaque white chert and varying amounts of quartz, underlie the Keokuk (Lee, 1940, 1956). Upper Keokuk rocks closely resemble some Burlington beds, and, where such deposits form a single sequence, they are not readily distinguishable. Near Wichita in Sedgwick County, where the Burlington consists of white semigranular limestone, it is differentiated from underlying limestone beds of early Osagian age only by traces of quartz that is apparent in insoluble residues. The Keokuk rocks are widely distributed in Kansas and formerly covered most, if not all, of the State. The Burlington is not recognized in much of western Kansas (Goebel, 1966). Pre-Pennsylvanian erosion removed Keokuk-Burlington rocks from the Central Kansas uplift, the Cambridge arch, and the northern part of the Nemaha anticline. In southern Kansas, the Burlington seemingly grades downward without a break into Fern Glen deposits, but at the margins of the basins, in western Kansas and especially toward the north in eastern Kansas (Lee, 1956), undifferentiated Burlington-Keokuk beds overlap onto pre-Osagian rocks. The combined thickness of the Keokuk and Burlington ranges from 170 feet or more in southern Kansas to about 100 feet in northern Kansas, and in western Kansas, it exceeds 350 feet in thickness.

Upper Mississippian Series

The Upper Mississippian Series in Kansas consists predominantly of beds of limestone and dolomite, with interspersed beds of sandstone and shale, and minor amounts of chert.

MERAMECIAN STAGE

Rocks of the Meramecian Stage lie disconformably on Osagian rocks, but in northeastern and southwestern Kansas the disconformity is obscure. The upper formations consist mostly of granular, sandy, oölitic and fossiliferous limestone, but lower formations contain interbedded dolomite or are mainly dolomite and silty, dolomitic limestone containing variable quantities of chert. Meramecian rocks, except for the Ste. Genevieve Limestone, probably extended originally throughout Kansas but were eroded from much of the State before Pennsylvanian deposits were formed.

"Cowley Facies".—The **"Cowley facies"** (formerly Cowley Formation) is restricted to an east-west belt 15 to 75 miles wide north of the Oklahoma border in south-central Kansas. Microfossil evidence indicates that the Cowley is a facies of the sequence from the St. Louis Limestone to the Chattanooga Shale (Thompson and Goebel, 1968). The "Cowley facies" is herein adopted for use in Kansas. Silty and siliceous dolomite, limestone, and dolomitic siltstone, and variable amounts of dark, opaque, microfossiliferous chert and chalcedonic chert characterize the "Cowley facies." The beds range locally from gray to black. In southeastern Kansas, grains of glauconite are thinly disseminated throughout and are especially conspicuous in the basal 20 to 30 feet. In southwestern Kansas, chert is less abundant and glauconite is inconspicuous or absent in the basal beds.

WARSAW LIMESTONE

Composed mainly of semigranular limestone interlaminated with saccharoidal dolomite, the Warsaw includes relatively large amounts of distinctive, gray, mottled, opaque, microfossiliferous chert. Glauconite occurs in the lower part. Insoluble residues of some dolomites contain masses of sponge spicules. The Warsaw is unconformable on Keokuk-Burlington beds in central and eastern Kansas (Lee, 1956) and seemingly conformable in western Kansas (Goebel, 1966). It is 30 to 40 feet thick in the Forest City and Salina basins and 250 feet thick in the central part of the Hugoton embayment.

SALEM LIMESTONE

The Salem Limestone conformably overlies the Warsaw Limestone. In northeastern Kansas it consists mainly of noncherty or sparsely cherty saccharoidal to silty dolomite interstratified with noncherty calcarenite, which in some places constitutes the greater part of the formation. The microfossiliferous chert resembles that in the Warsaw. The foraminifer *"Endothyra baileyi"* commonly is present. In southwestern Kansas, the Salem consists mainly of coarsely crystalline oölitic limestone and saccharoidal dolomite, dolomitic limestone, and chert. Thickness of the Salem is about 50 feet in the deepest part of the Salina basin, where it underlies Pennsylvanian rocks, and in the Forest City basin, where it underlies the St. Louis Limestone. In the Hugoton embayment, it is about 200 feet thick.

ST. LOUIS LIMESTONE

Probably conformable with other Meramecian rocks above and below, the St. Louis contains noncherty lithographic and sublithographic limestone, but also includes remarkably widespread beds of oölitic limestone and calcarenite. Traces of translucent chert contained in semigranular limestone occur locally. In the deeper part of the Hugoton embayment the St. Louis contains coarsely crystalline fossiliferous limestone and dolomitic limestone. Locally intraformational beds of limestone breccia, chert breccia, and anhydrite are preserved. Although restricted to basin areas, the St. Louis is more widely distributed than the Ste. Genevieve. It is not recognized in the Salina basin. Maximum thickness in the Forest City basin is about 50 feet and in the Hugoton embayment about 200 feet.

STE. GENEVIEVE LIMESTONE

The Ste. Genevieve Limestone, which lies disconformably beneath Chesteran rocks but seemingly conformable on the St. Louis Limestone, occurs in the deeper part of the Forest City basin and is widespread in the Hugoton embayment, but is not recognized in the Salina basin. It consists mainly of silty and sandy white fossiliferous limestone interbedded with fine-textured oölitic limestone and calcarenite. Beds in the Ste. Genevieve cannot be differentiated in areas in which they overlie finely oölitic limestone beds of the St. Louis Limestone. The thickness is about 30 feet in Doniphan and Atchison counties in northeastern Kansas. The thickness is more than 200 feet in the Hugoton embayment, where

the formation maintains a constant thickness except where it is beveled by pre-Chesteran or later erosion on the crests and flanks of uplifted areas.

CHESTERAN STAGE

Important unconformities separate the rocks of the Chesteran Stage from Pennsylvanian rocks above and Meramecian beds below. White, semi-granular limestone beds (Batesville) which crop out in northeastern Oklahoma above the Keokuk Limestone may extend into southeastern Kansas (Lee, 1940). Chesteran rocks are unknown in south-central and northern Kansas. In the subsurface of southwestern Kansas, Chesteran rocks are confined to deeper parts of the Hugoton embayment in Morton, Stevens, Seward, Meade, Grant, Haskell, and parts of adjacent counties. They consist of discontinuous beds of sandstone associated with variegated shale beds. Beds of fine-grained sandy limestone and crinoidal limestone are intercalated with pale-green shale. The lower Chesteran rocks locally are silty, grayish-red limestone. Thickness ranges from 0 feet to more than 300 feet near the Oklahoma state line. Locally Chesteran rocks are thin or absent on several structural highs.

PENNSYLVANIAN SYSTEM

By JOHN MARK JEWETT, HOWARD G. O'CONNOR, and DORIS E. ZELLER

This division of rocks of late Paleozoic age is widely represented throughout the world, being distinguished by coal deposits and by abundant marine invertebrates and land plants. Pennsylvanian outcrops are widespread in eastern Kansas (Fig. 7), and these serve as a standard of reference in the study of deposits of equivalent age in other parts of the Continent. The system in Kansas is divided into a Lower, Middle and Upper Pennsylvanian Series (Pl. 1). Pennsylvanian rocks comprise five stages, in ascending order: Morrowan, Atokan, Desmoinesian, Missourian, and Virgilian. Rocks of Morrowan age (Lower Pennsylvanian) are thought to be restricted to the Hugoton embayment. Possibly some Atokan rocks are present in northeastern Kansas. The cyclic nature of the Desmoinesian (Middle Pennsylvanian) and younger Pennsylvanian deposits is striking. The cycles consist of marine shales and limestones alternating with nonmarine beds. The aggregate thickness of exposed stratigraphic units belonging to the Pennsylvanian System in Kansas is about 3,100 feet. Outcrops occur throughout the eastern one-third of the State (State Geol. Survey Kansas, 1964).

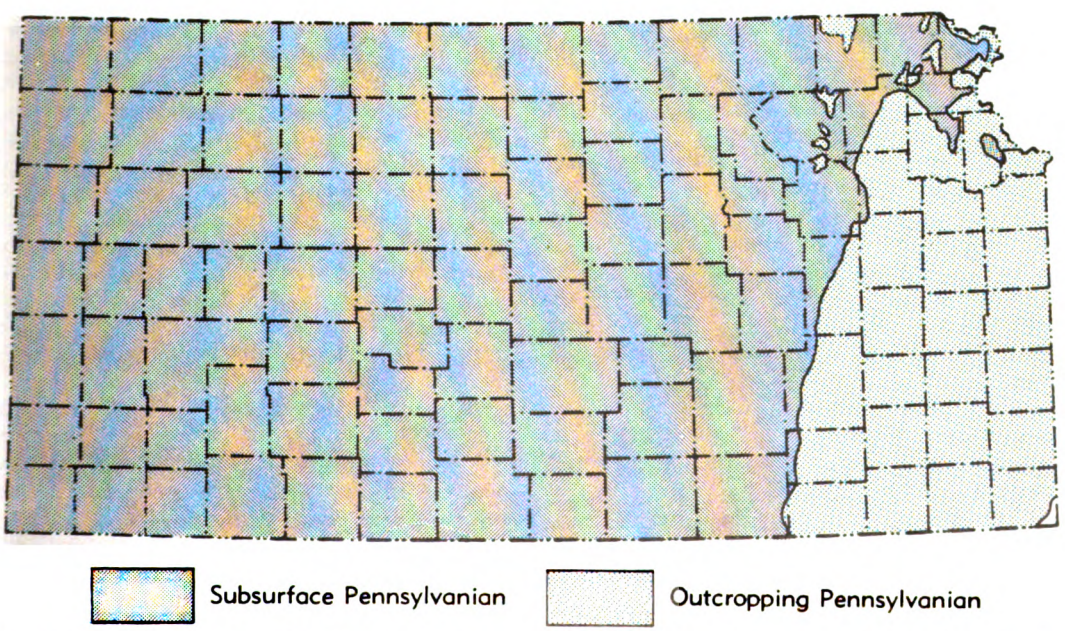

FIGURE 7. Distribution of Pennsylvanian rocks in Kansas. Area in white in southeast corner of State is outcropping Mississippian. (Adapted from Moore, *et al.*, 1951; State Geol. Survey Kansas, 1964.)

At the outcrop, the Pennsylvanian strata have a gentle west or west-northwestward dip of from 15 to 35 feet per mile. Locally, there are dips in other directions, or the beds may be horizontal; nowhere are the strata steeply inclined. A belt of distinct, though gentle, eastward dips may be traced across the State from the vicinity of Arkansas City (Cowley County) in the south to the neighborhood of Seneca (Nemaha County) in the north; this defines the east limb of the buried Nemaha anticline.

All stage and group divisions of the outcropping Pennsylvanian succession have been traced westward in the subsurface to the Colorado state line, although some minor units thin or become indistinguishable locally (Merriam, 1963). Northward thinning of shale formations and members, as seen in outcrops, has its counterpart in westward thinning of shales in the subsurface. Some limestones also become thinner and wedge out westward, but they are more persistent than the shales. In western Kansas, Pennsylvanian rocks above the Atokan Stage consist mainly of limestones separated by shale beds. As along outcrops, most shales in the subsurface thicken southward toward the Oklahoma border, and many limestones disappear or grade into shale or sandstone in this direction.

Pennsylvanian rocks in Kansas are conformable with overlying Permian rocks but unconformable on Mississippian and older Paleozoic rocks. The "Pennsylvanian basal conglomerate" is a good subsurface marker bed outside the Hugoton embayment (Fig. 6). It is best developed where underlying Mississippian and older rocks are cherty limestones and dolomites. The conglomerate is composed of cobbles and pebbles of cherty limestone in a matrix of finer-grained detrital material. The genesis of the conglomerate is discussed by Lee (1939, p. 10).

Although the thickness of the Pennsylvanian rocks increases southwestward, the regularity is modified by local structural features developed by differential movements during Pennsylvanian time. Before earliest Pennsylvanian sedimentation in Kansas, the eroded surface of Mississippian and older rocks was deformed by renewed uplift of the Nemaha anticline, the Central Kansas uplift, and some minor structures (Fig. 2). Parts of the Central Kansas uplift were not covered by Pennsylvanian sediments until late Pennsylvanian time. The differential structural movements that took place in this region are revealed by gradual thinning of all Pennsylvanian units above the Desmoinesian over the crests of anticlines. Most major Pennsylvanian units are thicker in the Hugoton embayment than elsewhere in Kansas.

Lower Pennsylvanian Series

Lower Pennsylvanian rocks are present only in the subsurface of western Kansas in the Hugoton embayment. They are overlain unconformably and overlapped in western Kansas by rocks of Middle Pennsylvanian age.

MORROWAN STAGE

Rocks of the Morrowan Stage seemingly are unconformable upon Chesteran and older rocks. They comprise 600 feet of shale, limestone, and sandstone.

KEARNY FORMATION

Rocks of Morrowan age were first reported by M. L. Thompson (1944, p. 414) who named the Kearny Formation ". . . for the 127 feet of rocks encountered between . . . 4,752 feet and the top of the highly oölitic limestone believed to be of Mississippian age at a depth of 4,879 feet in the Stanolind Oil and Gas Company No. 1 Patterson well." He assigned a Morrowan age on the basis of the fusulinid *Millerella*. The lithology of a thick section of marine sandstone, shale, and limestone was described by McManus (1959). Additional data on the lithology and distribution are known from work by Moore (1949), Maher and Collins (1952, 1953), Beebe (1957), and Rascoe (1962). McManus (1959) expanded the definition of the Kearny to include beds up to the base of the Atokan. He described a lower shale unit including many sandstone and limestone beds and an upper shale unit containing fewer beds of limestone and sandstone. The thickness of the two units ranges from 0 to 600 feet. The lower unit ranges from 0 to 250 feet, thickens to the southwest, and is overlapped northward and eastward in western Kansas by the upper shale unit. The upper unit (from 0 to 350 feet thick) also demonstrates a southward thickening in western Kansas. There the Kearny overlaps progressively older Mississippian rocks to the north, and thins northward and eastward. The unconformity at the base of the Kearny is obscure where this unit lies on upper Chesteran rocks. The upper boundary arbitrarily is placed just below a persistent coal bed (Atokan).

Middle Pennsylvanian Series

Rocks of the Atokan Stage are gradational with rocks of the Desmoinesian Stage in western Kansas. The Atokan is absent in central Kansas,

but it may be present in northeastern Kansas. Rocks of the Desmoinesian Stage are widespread.

ATOKAN STAGE

Rocks of this sequence are mainly interbedded dark-gray, black, and dark-brown, cherty limestones and dark-gray to black shales. Near the base a few fine-grained sandstones occur locally. Fusulinids of Atokan age have been reported by M. L. Thompson (1944) and McManus (1959). McManus reported a gradational contact between Atokan and Desmoinesian rocks in the deeper parts of the Hugoton embayment. Atokan rocks overlap Morrowan rocks locally in southwestern Kansas. The Atokan rocks are from 0 to 500 feet in thickness. At the base of the Atokan there is commonly a well-developed coal bed.

In northeastern Kansas, on the basis of identification of Atokan rocks in adjacent northwestern Missouri (Searight and Howe, 1961), it seems probable that pre-Desmoinesian (Atokan) rocks are preserved.

DESMOINESIAN STAGE

The lowermost major division of Pennsylvanian rocks that crop out in Kansas is the Desmoinesian Stage. Desmoinesian rocks occupy the stratigraphic interval between important regional unconformities. These deposits are set off from rocks of the overlying Missourian Stage by pronounced paleontologic and lithologic differences. Rocks of the Cherokee and Marmaton groups are 600 to 750 feet in outcrop thickness.

Cherokee Group

The Cherokee Group includes both marine and nonmarine rocks lying between the base of the Fort Scott (Marmaton Group) and the Mississippian. Much sandstone and sandy shale and the most important coal beds in the State are in this group. Little limestone is present. The group is not divisible readily into mappable units comparable in thickness to those found in the Upper Pennsylvanian Series. The thickness on the outcrop ranges from 350 to 500 feet. In outcrops in southeastern Kansas the group contains two formations.

Rocks in the Cherokee Group, in an earlier stratigraphic summary (Moore, *et al.*, 1951), were classified on the basis of cyclothems. In later detailed stratigraphic studies, Howe (1956) subdivided the Cherokee Group into the Krebs Subgroup and Cabaniss Subgroup, which together contained eighteen formations. Rocks from the top of one coal bed to the top of the next overlying coal bed were classed as a formation, and the formation was given the same geographic name as one of the included coal, limestone, or sandstone beds. Practical mapping considerations led Jewett (1959) to change the Krebs and Cabaniss subgroups to units of formational rank. Jewett retained only the previously named coal beds, limestones, and sandstones as subdivisions of the two formations.

The named members and beds in the Krebs and Cabaniss formations (Pl. 1) are restricted herein to those units that conform with the rules of the Code of Stratigraphic Nomenclature (American Comm. Strat. Nomenclature, 1961) and application of identical geographic names to more than one lithologic unit is avoided. Although light- and dark-colored shales predominate in the Krebs and Cabaniss formations, none of the shales have been named. In the subsurface the Cherokee Group generally is not divisible into formations.

KREBS FORMATION

The Krebs Formation comprises strata, principally shale, but including sandstone, limestone, underclay, and coal, lying above rocks of Atokan age and below the top of the Seville(?) Limestone Member. For practical purposes, because the Seville(?) Member is absent in most places, the top of the Bluejacket Sandstone Member may be regarded as the upper boundary of the formation (Howe, 1956, p. 27). The thickness of the Krebs is 200-250 feet.

The *Riverton coal bed* is the lowermost named unit in the Krebs Formation. It overlies about 10 feet of shale and underclay and underlies the Warner Sandstone Member. The thickness is generally less than 1 foot.

WARNER SANDSTONE MEMBER

This member is a fine- to medium-grained gray to brown quartzose sandstone, 10 to 25 feet thick, which overlies the Riverton coal bed. The member is overlain by about 50 feet of dark shales and several thin beds of argillaceous limestone. It is commonly asphaltic in outcrops. This unit was formerly called the "Little Cabin sandstone" (Howe, 1956, p. 33).

The *Neutral coal bed* (Howe, 1956, p. 34), which is about 0.5-foot thick, lies about 10 feet below the Rowe coal bed. It has a fossiliferous limestone "cap rock."

The *Rowe coal bed* (formerly Columbus) occurs several feet below the Dry Wood coal and is commercially the most important coal in the Krebs Formation. Locally a fossiliferous limestone occurs next above the coal. Thickness of

the coal bed ranges from about 0.8-foot to 1.7 feet (Howe, 1956, p. 37).

Irregular in thickness, the *Dry Wood coal bed* commonly is found a few feet below the Bluejacket Sandstone Member. Its thickness is from 0 to about 1.7 feet.

BLUEJACKET SANDSTONE MEMBER

This sandstone lies near the top of the Krebs Formation. A thin underclay and coal, and locally the Seville(?) Limestone Member, overlie it. The Bluejacket consists of fine- to medium-grained, micaceous, angular to subangular quartzose sandstone, with minor amounts of silt, and it is conglomeratic in the basal part. Its thickness on the outcrop is 10 to 40 feet.

SEVILLE(?) LIMESTONE MEMBER

A limestone tentatively correlated with the Seville Limestone of Illinois (Howe, 1956, p. 44) occurs locally in eastern Crawford County. It is a fossiliferous, argillaceous, slabby-weathering rock. The thickness is about 0.5 foot.

CABANISS FORMATION

The Cabaniss Formation, principally shale, but containing some sandstone, limestone, and coal, lies below the Fort Scott Limestone and above the Seville(?) Limestone Member. The thickness is about 220 feet.

The *Weir-Pittsburg coal bed* is commercially the most important coal bed in Kansas. Characteristically there is a thin parting of clay a few inches above the base. A few feet of shale and underclay generally occur below the Weir-Pittsburg coal and above the Seville(?) Limestone Member. The average thickness of the Weir-Pittsburg is about 3.6 feet.

The *Tebo coal bed* (Howe, 1956, p. 51), which is about 0.5-foot thick, generally occurs 15-20 feet above the Weir-Pittsburg coal bed. The Tebo was formerly called the "Pilot" coal.

The *Tiawah limestone bed* is a thin, discontinuous limestone above the Tebo coal bed and several feet below the Scammon coal bed (Howe, 1956, p. 54). It is abundantly fossiliferous, containing gastropods and brachiopods. The Tiawah averages 0.3-foot in thickness.

CHELSEA SANDSTONE MEMBER

This member is a gray to brown, fine-grained, micaceous sandstone, which is locally conglomeratic (Howe, 1956). The maximum thickness is about 30 feet.

The *Scammon coal bed* is separated from the Mineral, above, by about 16 feet of underclay, sandy and silty shale, and a thin, discontinuous limestone. The thickness of the Scammon is about 0.7 foot.

The *Mineral coal bed* is about 1.5 to 2.0 feet in thickness. Strata, chiefly shale and underclay about 15 to 20 feet thick, are present between the Mineral coal bed and the overlying Fleming coal bed. The "Robinson Branch coal bed," in one place in Cherokee County, occurs between the Mineral and the Fleming coals.

The *Fleming coal bed* is separated from the Croweburg by about 20-25 feet of underclay, sandstone, and shale. The thickness is a fraction of an inch to about 2 feet.

The *Croweburg coal bed* is one of the most persistent beds in the Cherokee Group, occurring a few feet below the Verdigris Limestone Member. It is reported to be the equivalent of the Whitebreast coal in Iowa and the Broken Arrow coal in Oklahoma (Howe, 1956). The thickness is commonly 0.8 foot to 1.3 feet. About 5 feet of light-gray and dark-gray shale lies between the Croweburg and the Verdigris Limestone Member.

VERDIGRIS LIMESTONE MEMBER

This is the most easily identified "marker bed" in the Cherokee Group, occurring just below the underclay of the Bevier coal bed in most of its outcrop area. In Labette County it is separated from the Bevier by several feet of underclay, sandstone, and shale. The Verdigris is chiefly dark-gray, foraminiferal limestone. This unit has also been called the "Ardmore limestone" (Scaright, *et al.*, 1953). The thickness is about 2 feet.

The *Bevier* is a bright, hard, blocky coal, containing pyrite and calcite. The thickness along most of its outcrop belt is about 1.3 to 2 feet.

The Bevier is separated from the overlying Breezy Hill Limestone Member by 60 to 70 feet of rocks, chiefly light-gray shale, but including dark-gray shale, sandstone, and underclay. This interval contains the "Squirrel sandstone" of the subsurface.

BREEZY HILL LIMESTONE MEMBER

The Breezy Hill Limestone Member is commonly nodular, irregularly bedded, sandy, and conglomeratic. Near the Kansas-Oklahoma boundary, the member becomes thin-bedded to massive, dense, gray to brown limestone. The thickness ranges from about 2 to 16 feet.

The *Mulky coal bed*, about 1-foot thick, overlies the Breezy Hill and is separated from it by 2 to 4 feet of underclay. The Mulky is separated

from the overlying Fort Scott Limestone by 2 to 5 feet of black, platy, concretion-bearing shale.

Marmaton Group

The upper part of Desmoinesian beds in Kansas, approximately 250 feet thick, is assigned to the Marmaton Group. These strata are more calcareous than those of the underlying Cherokee Group. Eight formations are recognized.

Fort Scott Limestone

This formation comprises two limestones and an intervening shale member. Characteristic thickness is about 33 feet.

Blackjack Creek Limestone Member

The Blackjack Creek Member is 4 to 17 feet thick. The lower part of the member is about 2 feet of sparsely fossiliferous brownish-gray limestone that weathers brown. The upper part of the member is a light-gray, coarsely crystalline, irregularly bedded *Chaetetes*-bearing limestone.

Little Osage Shale Member

Black platy shale containing small phosphatic concretions and gray clayey calcareous shale, coal, and limestone makes up the Little Osage Member. The lower part commonly is black and platy and the upper part is generally light gray and calcareous. A persistent, thin bed of granular limestone that occurs a few inches to 2 or more feet below the Higginsville Limestone Member may be equivalent to the Houx Member of Missouri. The *Summit coal bed*, which is persistent from northern Crawford County northeastward into Missouri, occurs in the upper middle part of the Little Osage Shale. Thickness of the member ranges from 4 to 12 feet.

Higginsville Limestone Member

The Higginsville Limestone Member is chiefly light-gray, thin-bedded to massive limestone characterized by scattered unusually large crinoid stems, irregular distribution of small to large fusulinids, and isolated colonies of *Chaetetes*. Locally the upper part is composed entirely of *Chaetetes*. Average thickness is 15 feet.

Labette Shale

The Labette Shale consists of gray and yellow clay shale, sandy shale, and sandstone, coal, and limestone beds. Near the top is a persistent limestone believed to be the Wymer City Limestone of Oklahoma. A black shale and a coal bed are present in the basal part. Black shale occurs locally in the upper part. Some sections contain several thin limestone and coal beds. A limestone bed 1- to 2-feet thick occurs in the middle lower part. Thickness ranges from about 30 to 100 feet.

Englevale Sandstone Member

This is one of several bodies of sandstone lying in the middle and lower parts of the Labette Shale. The Englevale locally fills channels eroded into the Fort Scott Limestone. It is the "Peru sand" of the subsurface. The average thickness is about 30 feet.

Pawnee Limestone

The lower part of the Pawnee Limestone consists of shale and a thin, nonpersistent basal limestone. The upper, main part of the Pawnee formation comprises two persistent limestone members separated by a shale member. The thickness ranges from about 15 to 60 feet.

Anna Shale Member

This member is a black, platy, locally fissile, shale, with lenses of dark, slabby, crystalline, locally crinoidal limestone in the basal part. A few inches of gray shale occur near the top in some places; small phosphatic concretions are common. Thickness ranges from 2 to 5 feet.

Myrick Station Limestone Member

The Myrick Station Limestone Member is a dark-gray, brown, and light-gray limestone. The lower part, comprising about 2 feet of massive dark-gray, brown-weathering limestone, is most persistent, and this is overlain locally by a lighter-colored *Chaetetes*-bearing limestone. The thickness ranges from 2 to about 8.5 feet.

Mine Creek Shale Member

The Mine Creek Shale Member is a light-gray to black shale, flaky, platy and fissile, locally containing one or more thin limestone beds in the middle part. It contains abundant brachiopods and a few corals. This member is thin or absent in Labette County. The thickness ranges from 0 to 15 feet.

Laberdie Limestone Member

The Laberdie is a light-gray, crystalline, *Chaetetes*-bearing limestone that occurs in thin wavy beds or beds of irregular thickness. The lower part is somewhat more massive. The member forms extensive dip slopes and caps prominent escarpments. Fusulinids and other marine fossils are plentiful locally. The Laberdie Limestone is the Coal City Member of Missouri and Iowa (Searight and Howe, 1961, p. 93). The thickness is about 10 to 20 feet.

BANDERA SHALE

The Bandera Shale is mainly nonmarine gray and yellow, mostly blocky claystone, well-bedded shale, and massive to thin-bedded sandstone. Maroon bands are present in the upper part. The formation contains limonitic concretions and veins and septarian limestone concretions locally. Plant fossils are found in the lower part of the sandy facies. The *Mulberry coal* is a persistent bed in the lower part of the Bandera north of Crawford County. Shale below the coal is light to dark gray and carbonaceous. Locally, a thin, dark-gray limestone lies just above the Mulberry coal. The thickness of the formation ranges from 20 to 50 feet.

BANDERA QUARRY SANDSTONE MEMBER

This member is a gray and brown, thin-bedded sandstone. The thickness ranges from 0 to 30 feet. Where present, the Bandera Quarry sandstone occupies the middle or lower part of the Bandera Shale.

ALTAMONT LIMESTONE

The Altamont Limestone consists of two limestone members separated by a shale member. The lower limestone is most prominent in the southern part of the outcrop area in southeastern Kansas, and the upper limestone is most prominent in northern outcrops. The formation is absent locally in the subsurface of Miami County owing to pre-Missourian erosion. The average thickness is 19 feet.

AMORET LIMESTONE MEMBER

The Amoret Limestone, about 10 feet in thickness, is a light-gray, massive, *Chaetetes*-bearing, dense limestone, associated with two shale beds in the southern part of the outcrop area. In the northern part of the outcrop area the limestone, which is about 1 to 2 feet in thickness, is darker gray, more granular, and locally cross-bedded.

LAKE NEOSHO SHALE MEMBER

This member is a light- and dark-gray to nearly black shale with abundant phosphatic concretions containing fish teeth and bone fragments. The thickness is about 2 to 8 feet.

WORLAND LIMESTONE MEMBER

The Worland Member is a light-gray limestone, semilithographic in the upper part, the remainder mostly crystalline, brecciated, and wavy-bedded. The Worland contains a few brachiopods and fusulinids, the latter locally abundant. Thickness commonly is about 8 feet.

NOWATA SHALE

The Nowata Shale contains gray to yellow clay shale, sandy shale, and sandstone; it is both marine and nonmarine. The formation is locally absent in the subsurface of Miami County, owing to pre-Missourian erosion. The thickness is 3 to 30 feet.

WALTER JOHNSON SANDSTONE MEMBER

The Walter Johnson is a thin-bedded to massive sandstone in the Nowata Shale occurring locally in southeastern Kansas. It is the "Wayside sand" of the subsurface. Outcrop thickness is commonly 4 to 10 feet.

LENAPAH LIMESTONE

This formation is made up of two limestone members separated by a shale member and is locally thin or absent as a result of pre-Missourian erosion. The lower two members are absent in some places. Thickness ranges from 1 to 18 feet.

NORFLEET LIMESTONE MEMBER

The Norfleet Limestone Member is a dark brownish-gray, massive to bluish-gray, slabby limestone. The Norfleet resembles local facies of the Idenbro Limestone Member in some northern outcrops. South of the Kansas-Oklahoma line, the Norfleet grades into massive, dense limestone that is continuous with the overlying nodular limestone facies of the Perry Farm Shale Member. The thickness ranges from a few inches to about 3 feet.

PERRY FARM SHALE MEMBER

The Perry Farm Member is a light- to dark-gray clay shale containing nodules of limestone. It grades laterally into nodular limestone south of the Kansas-Oklahoma line. Locally the shale is abundantly fossiliferous, brachiopods occurring in the upper part and a molluscan fauna in the middle and lower parts. The member is locally absent in the northern part of the outcrop area. The thickness ranges from 0 to about 20 feet.

IDENBRO LIMESTONE MEMBER

The Idenbro Limestone Member is chiefly light-gray crystalline and pseudo-brecciated limestone. In Linn and Bourbon counties it is represented by brownish-gray to dark-gray limestone, mostly crystalline, but dense and earthy locally. This member forms low escarpments and broad dip slopes in the southern part of the outcrop area. The thickness in the northern part of the outcrop area is 1 to 2 feet; in the southern part it is 6 to 9 feet.

HOLDENVILLE SHALE

The Holdenville Shale (formerly Memorial shale) is a gray and yellowish-gray clay shale, generally unfossiliferous. In Labette County it comprises dark-gray shale that contains marine fossils including abundant *Acaciapora austini* and *Mesolobus* and contains two coal beds. The unit locally is absent owing to pre-Missourian erosion. The maximum known thickness is 30 feet.

Upper Pennsylvanian Series

Outcropping Upper Pennsylvanian rocks of Kansas aggregate nearly 1,800 feet of limestone, shale, and sandstone. These strata are cyclical in nature. The Upper Pennsylvanian Series is divided into two stages, the Missourian below, accounting for one-third of the section, and the Virgilian above, encompassing two-thirds of the section.

MISSOURIAN STAGE

Upper Pennsylvanian rocks in Kansas belonging to the Missourian Stage lie with seeming conformity below the base of sedimentary rocks assigned to the Virgilian Stage and above a regional disconformity that separates them from deposits of the Desmoinesian Stage. Missourian rocks are distinguished essentially by paleontologic characteristics and by some pecularities of cyclic sedimentation. The outcrop area of these rocks in Kansas is a 20- to 40-mile-wide belt, marked by fairly prominent east-facing escarpments, extending from Doniphan County in the north to Montgomery County in the south (Fig. 1). The thickness averages about 650 feet.

Pleasanton Group

Rocks lying between the base of the Hertha Limestone and the disconformity that separates Missourian from Desmoinesian beds are mainly clastic sediments derived from land and deposited in shallow seas which advanced over Kansas after a time of more or less prolonged emergence. Gray, yellow, and dark-gray to black clay shale predominates, but there is much sandstone and some limestone and coal. The thickness ranges from about 30 feet to 135 feet (Jewett, Emery, and Hatcher, 1965). Three formations are recognized.

SEMINOLE FORMATION

In southeastern Kansas where the Checkerboard Limestone is identified, beds between the base of the Checkerboard and the disconformity at the base of the Pleasanton Group are assigned to the Seminole Formation. The thickness ranges from about 1 to 25 feet. Two members are recognized.

HEPLER SANDSTONE MEMBER

A persistent sheetlike deposit of brown and gray sandstone overlies the regional disconformity at the base of the Missourian Stage. A calcareous facies of the Hepler Sandstone is seen locally in southeastern Kansas. The thickness ranges from 2 to 25 feet, the thicker sections occurring toward the north.

SOUTH MOUND SHALE MEMBER

This is a unit composed mostly of shale, which in southeastern Kansas contains coal and underclay (Jewett, *et al.*, 1965). Some marine fossils occur above the coal. The member is not recognized in Linn County and northward, where the upper boundary of the member cannot be identified. The thickness ranges from a few inches to about 8 feet.

CHECKERBOARD LIMESTONE

This formation is a gray limestone, locally containing a coquina of gastropods or crinoid fragments. Where thickest this formation comprises two thin limestones separated by gray shale. The Checkerboard Limestone is an important marker in the Pennsylvanian strata of northeastern Oklahoma and is recognized in southern Kansas as far north as southern Neosho County. Possibly the Checkerboard equivalent (Exline Member) occurs in western Missouri and in nearby parts of central eastern Kansas. The thickness ranges from 0 to about 14 feet in Kansas (Jewett, *et al.*, 1965).

TACKET FORMATION

The Tacket Formation (Jewett, *et al.*, 1965) is a gray to yellowish-gray shale, locally containing much dark-gray to black shale, some flaggy, bluish-gray limestone, and massive sandstone. The base of the formation is at the top of the Checkerboard Limestone, where present, but in the northern part of the outcrop area the Tacket is in contact with the Hepler Sandstone, the basal member of the Seminole Formation. In Miami and Linn counties the interval is occupied chiefly by massive sandstone (Knobtown), which locally is as much as 25 feet thick. In southern Linn and northern Bourbon counties thin beds of dense, bluish-gray limestone known informally as the "Bourbon flags" and alternating beds of dark-gray to black shale occupy the same interval and attain a thickness of 50 feet locally. Gray shale

occurs in this position in southern Bourbon and northern Labette counties, but farther south there is much black, platy shale in this part of the section. The thickness ranges from about 15 to more than 60 feet.

Kansas City Group

The Kansas City Group includes strata from the base of the Hertha Limestone to the base of the Plattsburg Limestone. Three subgroups are recognized on the outcrop. The Kansas City Group is about 350 feet thick in the vicinity of Iola and about 325 feet thick in the Kansas City area.

In southern Montgomery County where the Swope Limestone and Hertha Limestone are absent equivalent strata between the base of the Dennis Limestone (Kansas City Group) and the top of the Checkerboard Limestone (Pleasanton Group) are called the **"Coffeyville Formation"** (Pl. 1) and equated with the lower part of the Skiatook Group of Oklahoma.

Bronson Subgroup

The lower division of the Kansas City Group, the Bronson Subgroup, comprises strata from the base of the Hertha Limestone to the top of the Dennis Limestone. The subgroup is characterized by thick limestones that form a prominent escarpment, except in southern Kansas, where the Galesburg and Ladore shales are thicker and limestones are thin or absent. Total thickness of the Bronson ranges from about 85 feet in the Kansas City area to about 175 feet in southeastern Kansas.

Hertha Limestone

Two limestone members and a shale member make up the Hertha Limestone. The two limestones are persistent and distinct throughout much of the outcrop area, especially in Miami, Linn, and northern Bourbon counties. In Labette and Montgomery counties, the shale member is thin or absent. The formation is easily recognized northward from central Labette County, and can be identified locally as far south as Coffeyville in Montgomery County. The thickness ranges from 0 to about 30 feet.

Critzer Limestone Member

The Critzer consists of a massive, brownish-gray, granular, partly algal limestone and a thin, wavy-bedded, gray limestone. In a part of the outcrop area this member is the most conspicuous part of the Hertha Limestone, commonly forming a rimrock along the Hertha escarpment. Much of the rock weathers deep brown. Bellerophontid gastropods are characteristic of the massive facies; brachiopods and corals are plentiful locally in the thin-bedded facies. The thickness ranges from 0 to about 11 feet.

Mound City Shale Member

The Mound City Shale Member is gray and yellow clayey to calcareous shale, containing a persistent 2-inch bed of crinoidal limestone in Linn and Bourbon counties. Marine fossils are locally plentiful. The thickness ranges from 0 to about 14 feet.

Sniabar Limestone Member

The Sniabar is a gray and brown massive to thin-bedded limestone. Marine fossils are moderately common and locally auloporid corals are abundant. The thickness ranges from 0 to about 10 feet.

Ladore Shale

The Ladore Shale contains gray and brownish-yellow shale, sandstone, and some coal. Like the Galesburg Shale, the formation thickens southward. The Ladore is a thin marine shale in the Kansas City area and east-central Kansas, but it changes into a thick, sandy, deltaic deposit in southeastern Kansas. In Montgomery and southern Labette counties, it is not easily separated from the overlying Galesburg Shale and the two form the upper, more sandy part of the Coffeyville Formation there. Thin coal beds are present in Labette County, and plant fossils are plentiful. The thickness ranges from 2 to 50 feet.

Swope Limestone

Two limestone members and a shale member make up the Swope Limestone. South of eastern Montgomery County the Swope is not generally recognized. The thickness ranges from 0 to about 35 feet.

Middle Creek Limestone Member

The Middle Creek Limestone Member is dark bluish-gray limestone, commonly dense and brittle, with closely spaced vertical joints. The maximum observed thickness of 8 feet is in southern Linn County; the common thickness is about 2 feet.

Hushpuckney Shale Member

The Hushpuckney Shale Member contains bluish-gray clay shale in the upper part and black fissile shale in the lower part. This unit and the underlying Middle Creek Limestone Member are persistent northward from Neosho County. The thickness ranges from 0 to about 6 feet.

BETHANY FALLS LIMESTONE MEMBER

The Bethany Falls Limestone is a light-gray, dense, thin-bedded limestone, commonly containing fossils, overlain by mottled gray, massive limestone or by nearly white, commonly cross-bedded, oölitic limestone. The lower, thin-bedded part ranges from 1 to 20 feet in thickness, and that of the upper part from 7 to 15 feet. The thickness of the member ranges from about 12 to 30 feet.

GALESBURG SHALE

The Galesburg Shale contains gray and yellow marine shale, sandy nonmarine shale, sandstone, and coal. Probably some of the sandy shale and sandstone is marine also. In the Kansas River valley, the unit is about 3 feet thick and comprises light-colored, calcareous, nodular shale that is distinguishable from the overlying black Stark Shale Member of the Dennis Limestone. The thickness increases abruptly southward from Bourbon County and much sandstone is present in Neosho, Labette, and Montgomery counties. Plant fossils are common in the sandy facies. Southward from the point where the underlying Swope Limestone disappears a few miles north of the Oklahoma state line, the Galesburg is not separable as a unit, and it forms the upper part of the Coffeyville Formation. The thickness of the Galesburg Shale ranges from 3 to 75 feet.

DODDS CREEK SANDSTONE MEMBER

The Dodds Creek Sandstone Member is a massive to thin-bedded sandstone, possibly of deltaic origin, which occurs in the Galesburg Shale in southeastern Kansas. The thickness of this member is as much as 40 feet. A seemingly persistent coal bed in sandy shale in this part of the section is called the *"Cedar Bluff coal."*

DENNIS LIMESTONE

The Dennis Limestone contains two limestone members and a shale member. The upper member forms the long dip slope of the prominent Bronson escarpment in southeastern Kansas. In Oklahoma, this formation, or more specifically the Winterset Limestone Member, is known as the "Hogshooter Limestone." The thickness of the Dennis ranges from 2 feet in parts of Neosho County to about 60 feet in northeastern Labette County.

CANVILLE LIMESTONE MEMBER

The Canville Limestone Member is a medium dark-gray, dense to granular limestone, which is commonly massive-bedded but that is locally platy or slabby. This limestone is persistent from northwestern Labette County to northern Linn County. It is represented in parts of Montgomery County by about 1 foot of dark bluish-gray, vertically jointed limestone, and it reappears locally in Oklahoma. The thickness ranges from 0 to as much as 8 feet; it is commonly 1.5 feet thick.

STARK SHALE MEMBER

The Stark Shale Member is chiefly black fissile shale with some gray and yellow shale in the upper part. The member is persistent northward from northwestern Labette County, but it is present only locally in Montgomery County and neighboring parts of Oklahoma. The common thickness is about 3 feet.

WINTERSET LIMESTONE MEMBER

The Winterset Limestone Member is a light bluish-gray and light-gray limestone characterized by abundant chert in the middle and upper part. In the Kansas River area, the chert is almost black, but elsewhere it is light gray. Along much of the outcrop belt, cross-bedded oölite occurs in the upper part of the Winterset, and there is much light-gray, thin-bedded limestone having a brecciated appearance. Black platy shale containing land-plant remains occurs in the middle part of the member in northern outcrops, and calcareous gray shale occupies the same position in southern outcrops. Marine invertebrates are abundant in various zones; in places there are well-preserved molluscan faunas. In southeastern Kansas algal material forms mounds in the upper part of the member. Locally in the same region, the Winterset and possibly lower beds have been cut out by pre-Chanute erosion. The thickness ranges from 0 to about 60 feet.

Linn Subgroup

Named from prominent outcrops in western Linn County, this middle division of the Kansas City Group consists of two limestone and two shale formations. It includes strata from the top of the Dennis Limestone to the base of the Lane Shale. These deposits are easily recognized in the outcrop area, except in parts of southeastern Kansas, where a disconformity at or near the base of the Chanute Shale brings upper Linn deposits in contact with beds as low as the basal part of the Dennis Limestone. The subgroup is characterized by a relative abundance of shale, but there are persistent limestones, and locally much sandstone. The average thickness is about 110 feet.

CHERRYVALE SHALE

The Cherryvale Shale comprises beds between the top of the Dennis Limestone and the base of the Drum Limestone. At its type locality near Cherryvale, Montgomery County, this unit consists almost entirely of bluish-gray clayey to silty shale. In nearby exposures there are numerous thin beds of dense blue-gray limestone in the upper part; farther south, in the vicinity of Coffeyville, similar limestone beds occur in the lower part. In the northern part of the outcrop belt the formation is differentiated into three shale and two limestone members. In the southern part of the outcrop belt the members cannot be differentiated. The thickness of the formation is about 60 feet. The Nellie Bly Formation of Oklahoma is believed to be the exact equivalent of the Cherryvale Shale.

FONTANA SHALE MEMBER

Greenish-gray to buff shale containing scattered calcareous nodules is differentiated as Fontana in Linn County and northward. South of Linn County the Fontana can be identified only where the Block Limestone Member is present. The Fontana Member ranges in thickness from about 5 to 25 feet.

BLOCK LIMESTONE MEMBER

The Block Limestone Member is a bluish-gray, fine-grained limestone. It is commonly massive and displays vertical jointing, but locally it is thin bedded. In the Kansas City area, the unit is represented by thin blue limestone beds separated by shale. Fusulinids are generally common, and in places *Marginifera wabashensis* is abundant. South of Linn County, a bed a few feet above the Winterset Limestone Member has been tentatively identified as Block Limestone. Thickness ranges from about 0.5 foot to 8 feet.

WEA SHALE MEMBER

The Wea Shale Member is an olive-green clay shale containing a persistent, thin, silty maroon shale in the upper part. The thickness of the Wea, where it can be differentiated, ranges from 15 to 35 feet.

WESTERVILLE LIMESTONE MEMBER

A persistent unit northward from Miami County, the Westerville Limestone Member is variable in lithology. Cross-bedded oölite in the Kansas City area frequently has been called the "Kansas City oölite." Chert, which is light pink, and hence differs from other Pennsylvanian cherts, comprises 50 percent or more of the rock in some outcrops. The thickness ranges from less than a foot to 19 feet.

QUIVIRA SHALE MEMBER

This unit consists chiefly of olive-green clay shale having generally about 1 foot of black or maroon shale in the basal or middle part. Small brachiopods occur in the black shale facies. The thickness ranges from 2 to 11 feet. The Quivira is differentiated only in Miami County and northward.

DRUM LIMESTONE

Two limestone units locally separated by a thin shale make up the Drum Limestone. The thickness ranges from 0 to about 60 feet. Throughout most of the outcrop area, however, the formation is less than 10 feet thick, and only the lower member is present. The Drum Limestone of Kansas is equivalent to the Dewey Limestone of Oklahoma.

DEWEY LIMESTONE MEMBER

Bluish-gray limestone, mottled with brown upon weathering, commonly fine-grained or dense, and more or less massive, comprises the Dewey Limestone. Marine fossils are generally abundant. The horn coral *Caninia* is characteristic of the upper part of this limestone in northeastern Kansas. The thickness ranges from about 2 to 15 feet. For many years this part of the Drum Limestone, locally the only part present in the Kansas City area, has been known as the "Cement City limestone" (Moore, 1948, p. 2030-31).

CORBIN CITY LIMESTONE MEMBER

The Corbin City Limestone Member is chiefly light-gray oölitic, cross-bedded limestone that is abundantly fossiliferous. This member is best developed in the vicinity of Independence (Montgomery County), where it is 50 feet or more thick. It is represented by a few feet of limestone conglomerate near Coffeyville, Montgomery County, and by 1 foot or less of chiefly oölitic limestone in the Kansas City area. Fossils are abundant in the thick oölitic facies. A few inches of shale that lies between the two limestone members of the Drum at some exposures is included with the Corbin City Member. In southeastern Kansas, the Corbin City Limestone seemingly rests disconformably on the Dewey Limestone. In the vicinity of Cherryvale in Montgomery County the oölitic limestone of the upper member fills depressions nearly 5 feet deep in the lower limestone.

CHANUTE SHALE

This formation contains yellowish-brown sandy shale and dark-gray to greenish-gray shale, sandstone, and one coal bed. The sandy shale and sandstone occur chiefly in the upper part, above the coal bed. Members have been differentiated in southeastern Kansas. In Allen County and northward, the Chanute is chiefly shale with minor amounts of sandstone, argillaceous limestone, and a thin coal bed. The thickness of the Chanute Shale ranges from 12 feet near Kansas City to 200 feet in southeastern Kansas.

NOXIE SANDSTONE MEMBER

Sandstone at the base of the Chanute Shale, commonly filling channels that extend as low as the Stark Shale Member of the Dennis Limestone, or perhaps lower, is known as the "Noxie Sandstone Member." Locally a limestone conglomerate occurs at the base of the sandstone. This member of the Chanute is recognized in southeastern Kansas and also in the subsurface of south-central Kansas. The thickness locally may reach 100 feet. The disconformity at the base of the Noxie Sandstone is recognized at many places in southern Kansas, especially south of Allen County.

An unnamed shale, locally calcareous or sandy, with nodular claystone, occurs in the middle part of the Chanute Shale and, where the Cottage Grove Sandstone Member is absent, in the upper part as well. The persistent *Thayer coal bed,* or a thin underclay, is commonly found near the top of this shale and below the Cottage Grove Sandstone. This coal ranges in thickness from less than an inch to 2.5 feet. The unnamed shale is 10 to 75 feet thick, the maximum being observed in places where the Noxie Sandstone is absent.

COTTAGE GROVE SANDSTONE MEMBER

Yellowish-brown or tan, thin-bedded to massive sandstone makes up the upper one-third to one-half of the Chanute Shale in southeastern Kansas, but this sandstone occurs only locally in northeastern Kansas. A red shale facies is common in the upper part of the Chanute in northeastern Kansas. The thickness ranges from 0 to 60 feet.

IOLA LIMESTONE

The Iola Limestone contains two limestone members and a shale member. The upper limestone is the most conspicuous part of the formation. The thickness of the Iola ranges from 0 to 30 feet and has its greatest thickness in Allen County. In northeastern Kansas the thickness commonly is about 7 feet.

PAOLA LIMESTONE MEMBER

The Paola Limestone Member is a dense, dark bluish-gray, massive-bedded limestone that has closely spaced vertical joints and that weathers bluish-gray. Irregular subcylindrical "worm borings" that differ slightly in color and texture from the surrounding rock matrix are more or less characteristic. The thickness ranges from 0 to about 3 feet.

MUNCIE CREEK SHALE MEMBER

The Muncie Creek Shale Member consists of black fissile shale overlain by gray or buff shale and contains abundant phosphatic nodules. The thickness commonly ranges from about 1 to 3 feet.

RAYTOWN LIMESTONE MEMBER

The Raytown Limestone Member consists chiefly of very light-gray to medium-gray, fossiliferous limestone having slightly uneven to wavy beds 3 to 12 inches thick. In most outcrops it contains little or no shale. Locally, however, the main ledge includes a thin shale near its base, and elsewhere the main ledge is separated from an upper limestone by as much as 12 feet of shale. The Raytown averages about 5 feet in the Kansas City area, thickens to 35 feet in Allen and Neosho counties, and is 0 to 4 feet thick in Montgomery County. The Raytown is the Avant Limestone of Oklahoma.

Zarah Subgroup

The upper part of the Kansas City Group, comprising approximately one-third of the section, is designated as the Zarah Subgroup. It includes beds between the top of the Iola Limestone and the base of the Plattsburg Limestone. The thickness of the subdivisions differs greatly from place to place. Average thickness of the subgroup in Kansas is about 100 feet.

LANE SHALE

The Lane Shale consists of dark bluish-gray shale, locally containing rather abundant marine fossils, gray and yellowish-brown unfossiliferous sandy shale, and thin-bedded sandstone. The thickness ranges from about 7 to 108 feet, averaging about 50 feet. Southward from the point where the Wyandotte Limestone pinches out in Anderson County, the Lane and Bonner Springs shales cannot be differentiated.

WYANDOTTE LIMESTONE

The Wyandotte Limestone contains three limestone and two shale members. The lower two limestones and the intervening shale are more constant in lithologic character and thickness, but the entire formation, which is prominent in northeastern Kansas and especially along the Kansas River, disappears in or near northwestern Anderson County. Thickness ranges from 0 to about 100 feet.

FRISBIE LIMESTONE MEMBER

The Frisbie Limestone Member is a bluish-gray to dark-blue, massive limestone, locally containing numerous marine fossils. Thickness commonly ranges from 1 to 3 feet.

QUINDARO SHALE MEMBER

The Quindaro Shale Member is chiefly a yellowish-gray to greenish-gray calcareous shale, locally interbedded with gray, nodular limestone. Both the shale and the limestone are fossiliferous. In some localities, the Quindaro contains a thin dark-gray to black fissile shale at the base. In parts of Johnson and Miami counties the member is absent or cannot be distinguished. The thickness ranges from 0 to 8 feet, but it is commonly 2 to 5 feet thick.

ARGENTINE LIMESTONE MEMBER

This is a prominent escarpment-forming light bluish-gray, wavy-bedded limestone, much of which weathers very light gray or yellowish-gray. Clay partings are numerous in some outcrops. Marine fossils are plentiful. Thickness ranges from 0 to 37 feet.

ISLAND CREEK SHALE MEMBER

The Island Creek Shale Member is a gray, yellow, and bluish-gray clayey shale of highly variable thickness. Locally in Wyandotte County, several feet of sandstone, which seems to be a channel filling, occupies this position. Thickness ranges from 0 to perhaps as much as 40 feet.

FARLEY LIMESTONE MEMBER

This member comprises an extremely variable assemblage of limestone and shale beds that is recognized definitely only north of southern Johnson County. Many types of limestone are represented, but oölitic or pelletal limestone, limestone breccia or conglomerate, and dense, mottled, pinkish-gray limestone are characteristic. Cross-bedding is common. The algal or oölitic facies commonly are in massive beds; the breccias and conglomerates are slabby. Detrital beds are mostly in the upper part. Wavy and thin-bedded, mottled, dense limestone, chiefly in the lower part, is somewhat similar to the underlying Argentine Limestone. The Farley Limestone is abundantly fossiliferous. Thickness ranges from 0 to about 35 feet.

BONNER SPRINGS SHALE

The Bonner Springs Shale consists chiefly of gray and green shale, but locally it may contain an appreciable thickness of sandstone or siltstone and minor amounts of limestone, conglomerate, and coal. A thin bed of maroon shale or claystone is present near the top. The formation ranges from 1 foot to 65 feet or more and can be identified northward from southeastern Franklin County. South of Franklin County the intervening Wyandotte Limestone is absent and the Bonner Springs Shale and Lane Shale are not differentiated.

Lansing Group

The uppermost group in the Missourian Stage consists of two limestone formations and a shale formation. The group forms an escarpment that is traced readily across eastern Kansas. In the southern part of the Lansing outcrop area, the limestone units thicken abruptly locally into mounds or banks of limestone, which thin or disappear southward. Generally the overlying shale units thin over the limestone mounds and thicken where the limestone units become thinner (Harbaugh, 1959). Many of the limestone units in the Kansas City and Marmaton groups in eastern Kansas outcrops are believed to have marine-bank facies, also, but they have not been studied or described. The Lansing Group is recognized in the subsurface, but usually it is not separated from the Kansas City Group. Thickness averages about 85 feet.

PLATTSBURG LIMESTONE

The Plattsburg Limestone consists of two limestone members separated by a shale member. The upper is the thicker of the two limestone members, except locally, as in eastern Franklin County. In Wilson County the Plattsburg forms marine limestone banks (Harbaugh, 1959) and attains its maximum thickness of 115 feet. The formation disappears near the Oklahoma state line. Thickness of the Plattsburg Limestone in Kansas averages about 25 feet.

MERRIAM LIMESTONE MEMBER

In central and northern outcrops in eastern Kansas the Merriam consists of a light-gray to

yellowish-gray limestone bed characterized by mollusks, *Composita,* and abundant *Osagia* and oölites in the upper part. This bed is overlain by a fine-grained gray limestone containing fusulinids, brachiopods, and crinoids. The Merriam commonly is 1 to 3 feet thick except locally where the oölitic or *Osagia*-bearing limestone expands the thickness to as much as 11 feet. In southern outcrops the Merriam is a single thin fossiliferous limestone generally having a thickness of 1 foot or less.

HICKORY CREEK SHALE MEMBER

The Hickory Creek Shale Member in central and northern outcrops comprises 0.1 foot to 6 feet of calcareous light olive-gray shale. Locally the member includes a thin bed of greenish-black or very dark-gray shale. Outcrops of the Hickory Creek in southern Kansas range from 0 to 40 feet in thickness. Where thickest it comprises gray calcareous shale interbedded with thin fragmental limestones and contains abundant crinoids, sponges, and bryozoans.

SPRING HILL LIMESTONE MEMBER

The Spring Hill Limestone Member is chiefly gray, fine-grained, even to slightly wavy-bedded limestone that weathers yellowish-orange. Along most of its outcrop in eastern Kansas it has a fine- to medium-grained texture and contains abundant fossils. Oölitic limestone comprises part of the middle or upper beds. In Wilson County the middle part of the member is coarsely crystalline limestone containing *Archaeolithophyllum* (Wray, 1964). The lower part is a fragmental, pelletal limestone, and the upper part is a calcarenite (Harbaugh, 1959). The member has a thickness of 7 to 23 feet in northern outcrops and ranges from 0 to 88 feet in southern outcrops.

VILAS SHALE

From Anderson County northward the Vilas ranges from about 1 to 35 feet in thickness and comprises sandy, silty, and carbonaceous gray shale which weathers yellowish-gray. Locally the formation contains beds of sandstone and a fossiliferous sandy limestone. In Wilson and Montgomery counties the Vilas ranges from 5 to 120 feet in thickness, is fossiliferous in the uppermost part, and contains beds of ironstone concretions.

STANTON LIMESTONE

The Stanton Limestone contains three limestone and two shale members. Northward from Anderson County the Stanton is rather uniform in thickness and character. In Anderson County and southward the formation has many facies variations. Northern exposures are commonly 30 to 50 feet thick, whereas southern outcrops of the formation range from 15 to 130 feet in thickness.

CAPTAIN CREEK LIMESTONE MEMBER

The lower member of the Stanton Limestone comprises 4 to 11 feet of limestone having even to slightly uneven, thin to medium bedding. It is chiefly light-gray to medium-gray, fine- to medium-grained, fossiliferous limestone that weathers light gray. The upper 2 feet may be brecciated and mottled. Southern outcrops of the Captain Creek may be as much as 64 feet thick and contain beds of coarsely crystalline algal limestone and oölitic limestone.

EUDORA SHALE MEMBER

The Eudora Shale Member ranges from 2 to 11 feet in thickness in eastern Kansas, except in Montgomery County, where it ranges from 0 to 70 feet in thickness. In most exposures the middle part of the Eudora comprises 1 to 5 feet of grayish-black fissile shale that contains small phosphatic nodules. The grayish-black shale overlies a thin bed of greenish-gray calcareous shale and is overlain by 1 to 6 feet of light- to dark-gray shale. In Montgomery County the member is chiefly gray calcareous and fossiliferous shale locally containing a few inches to a few feet of grayish-black fissile shale near its base.

STONER LIMESTONE MEMBER

The Stoner Limestone Member comprises thin to medium beds of medium-gray to very light-gray wavy-bedded limestone. It is 10 to 20 feet thick throughout most of eastern Kansas. The uppermost beds locally may be brecciated or nodular-appearing or calcarenitic. The member includes much fine- to medium-grained light-gray mottled limestone containing abundant coarsely crystalline calcite and some oölitic limestone in southern outcrops. It has a maximum thickness of about 50 feet in northern Montgomery County.

ROCK LAKE SHALE MEMBER

Gray and olive-gray argillaceous to sandy shale and sandstone that weathers yellowish-gray to yellowish-orange comprise most of this member. The sandstone contains *Myalina* and *Aviculopecten*. Locally the Rock Lake includes a conglomerate; elsewhere a thin black shale or thin coal overlain by a thin, laminated gray limestone is present. The thickness ranges from about 1 to 15 feet in most of eastern Kansas but is as much as 30 feet locally in Montgomery County.

SOUTH BEND LIMESTONE MEMBER

The upper member of the Stanton is a medium- to thick-bedded, dense, fine-grained, medium- to dark-gray or bluish-gray, fossiliferous limestone that weathers yellowish-gray to yellowish-brown. The lower part commonly is sandy or conglomeratic. The South Bend ranges from about 1 to 6 feet in thickness along its outcrop except in Montgomery County, where it is as much as 27 feet thick.

VIRGILIAN STAGE

The Virgilian Stage comprises the youngest Pennsylvanian rocks of the Midcontinent Region. In Kansas the stage is represented by three groups, which are separated on the basis of general differences in lithology and the nature of cyclic deposits. The total thickness is commonly 1,200 feet.

Douglas Group

The Douglas Group consists primarily of clastic rocks and underlies the Shawnee Group conformably everywhere except possibly in southern Douglas County. Its thickness ranges from 240 feet in northern outcrops to 400 feet in southern outcrops. The Douglas Group is divided into two formations and, as now defined (O'Connor, 1963), includes rocks that were formerly assigned to the Pedee Group.

STRANGER FORMATION

The Stranger Formation contains sandstone, shale, and a minor amount of limestone, coal, and conglomerate. The thickness ranges from 100 to 180 feet, generally increasing southward. The Stranger is divided into five members (O'Connor, 1963, p. 1877). The Weston Shale Member and the Iatan Limestone Member were formerly included in the Pedee Group.

WESTON SHALE MEMBER

The Weston Shale Member is a grayish-blue to medium-gray, clay shale that weathers yellowish-gray to light olive-gray. It is generally unfossiliferous, but locally it may contain thin fossiliferous zones. In many places ironstone concretions are abundant. Plant remains are present locally in the middle or upper beds. In southeastern Kansas, where the Iatan Limestone Member is absent, and where there are no massive sandstones to mark the base of the Tonganoxie Sandstone Member, the upper boundary of the Weston is difficult to define. The thickness ranges from 0 to 140 feet.

IATAN LIMESTONE MEMBER

The Iatan Limestone Member outcrops in Kansas only in Leavenworth County, where it ranges in thickness from 0 to 14 feet. It is a dense, light-gray limestone, which locally contains *Archaeolithophyllum* and *Osagia,* as well as fusulinids, brachiopods, bryozoans, crinoids, and corals.

TONGANOXIE SANDSTONE MEMBER

Generally lenticular, massive, cross-bedded sandstone and more continuous sandy shale, containing several discontinuous coal beds, occupy the middle part of the Stranger formation in most places. The *upper* and *lower Sibley coal beds,* in the northern part of the outcrop area, are distinctive units. Locally, there is a disconformity at the base of the Tonganoxie where it cuts through the lower members of the Stranger and into the top of the underlying Stanton Limestone. In other places, where the intervening Iatan Limestone Member is absent, the lower contact is gradational into the Weston Shale Member. The thickness ranges from 0 to 120 feet.

Formerly the base of the Tonganoxie Sandstone was regarded as marking the base of the Douglas Group and of the Virgilian Stage. The Douglas Group has been expanded to include beds downward to the top of the Stanton Limestone (O'Connor, 1963). Ball (1964) has shown that there is no persistent disconformity on which the Tonganoxie Sandstone was deposited.

WESTPHALIA LIMESTONE MEMBER

The Westphalia Limestone Member comprises brown, flaggy-bedded, argillaceous limestone about 1 to 5 feet thick from northern Anderson County southward to northeastern Chautauqua County. The upper part of the member contains fusulinids, *Osagia,* and mollusks. In Anderson County and northward, the member is a discontinuous, gray, laminated, carbonaceous limestone 0 to 1.5 feet thick that directly overlies the upper Sibley coal bed.

VINLAND SHALE MEMBER

This unit consists of gray to greenish-gray, clayey, calcareous shale, sandy shale, and sandstone. North of Anderson and Coffey counties, where the Westphalia Limestone Member is absent, the top of the upper Sibley coal is regarded as marking the base of the Vinland Shale. A persistent zone of septarian concretions occurs in the upper middle part of the member in northeastern Kansas. A faunal zone containing

abundant mollusks, particularly myalinid clams, characterizes the upper part of the Vinland Shale. The thickness of the Vinland ranges from about 2 to 50 feet.

LAWRENCE FORMATION

The Lawrence Formation consists chiefly of gray shale and sandstone, which weathers yellowish-gray, and minor amounts of red shale, coal, gray limestone, and conglomerate. The Lawrence is subdivided into five members, of which the Haskell and Robbins members were formerly included in the underlying Stranger Formation. As redefined, the Lawrence Formation now extends from the base of the Haskell Limestone Member to the base of the overlying Toronto Limestone (O'Connor, 1963). Thickness ranges from 140 feet in northern Kansas to 250 feet in southern Kansas.

HASKELL LIMESTONE MEMBER

The Haskell Limestone Member is a bluish-gray, fine-grained limestone, with a locally developed oölitic facies at the top and base in which pelecypods and gastropods occur. The main part contains algal remains, fusulinids, and brachiopods. This is the most continuous marker bed within the Douglas Group. Thickness ranges from 0 to 12 feet.

ROBBINS SHALE MEMBER

This member consists of gray and yellowish-gray marine shale, which is locally eroded and overlapped by the Ireland Sandstone Member in Franklin County and southern Douglas County. Phosphatic concretions and black fissile shale occur in a zone at the base of the member in the northern part of the outcrop area. Locally a molluscan fauna occurs in the lower beds. The thickness is 0 to 120 feet.

IRELAND SANDSTONE MEMBER

This member consists of shales and siltstones with some coal in the upper part and is typified by lenticular light-buff to brown, thin-bedded, in part cross-bedded, and massive sandstones in the lower part (O'Connor, 1963, fig. 3; Ball, 1964). The sandstone is thickest where it lies disconformably upon the Robbins Shale Member or older beds. In some places, especially where the Ireland cuts through the Haskell Limestone Member and into the Stranger Formation, a limestone conglomerate is found at the base of the sandstone. The thickness of the Ireland Member ranges from 30 to 120 feet.

AMAZONIA LIMESTONE MEMBER

This member is typically a light-gray, dense, lenticular limestone. Locally it is coquinoidal or brecciated in appearance. Outcrops are found in Doniphan, Atchison, Franklin, Coffey, and Woodson counties and possibly farther south. Fossils are not abundant generally, but sponges are common locally in the member (Atchison County) and fusulinids occur in southern Kansas. Thickness ranges from 0 to about 14 feet.

An unnamed shale unit comprises the upper part of the Lawrence above the discontinuous Amazonia Limestone Member. It consists primarily of gray, green, and red shale and earthy limestone with minor amounts of siltstone and sandstone, and from Douglas County to Elk County contains the *Williamsburg coal bed*. Fossils are common at the top of this unit in southern Kansas. Thickness ranges from 10 to 60 feet.

SHAWNEE GROUP

The Shawnee Group comprises four limestone and three shale formations. Comparatively thick limestones and a distinctive type of cyclic sequence (Moore, 1935) are characteristic of these rocks. The average thickness is about 325 feet.

OREAD LIMESTONE

The basal formation of the Shawnee Group comprises four limestone members and three shale members, which form a prominent escarpment across the State from Doniphan County, in the north, to Chautauqua County, in the south (Fig. 1). The average thickness in northern and central Kansas outcrops is 52 feet. In southern outcrops the thickness increases to about 100 feet owing mainly to expansion of the interval between the lower two limestone members.

TORONTO LIMESTONE MEMBER

The Toronto Limestone Member is brownish-gray, massive limestone that weathers deep brown. The Toronto is typically developed from Woodson County northward, but it is thinner, sandy, or locally absent in southeastern Kansas. The member is absent also in parts of southern Douglas and western Franklin counties, where a limestone conglomerate occupies its approximate stratigraphic position. Fusulinids, corals, and small brachiopods are the most common fossils. The thickness of the Toronto in northern outcrops ranges from 5 to 12 feet. In southern outcrops it is generally less than 4 feet thick.

SNYDERVILLE SHALE MEMBER

This member contains gray to bluish-gray, red, and green claystone and shale. In northern outcrops, the lower and middle parts are a structureless underclay-like deposit; in southern outcrops, the member becomes more sandy and locally contains sandstone and nodular, argillaceous limestone. Marine fossils, especially *Chonetes,* occur in the uppermost part. The thickness in the northeastern part of the State averages about 12 feet, but in southeastern Kansas it increases to about 75 feet.

LEAVENWORTH LIMESTONE MEMBER

The Leavenworth Limestone Member is a dark bluish-gray, dense, massive limestone occurring in a single bed, which has closely spaced joints. Fusulinids, brachiopods, and gastropods are the most common fossils. The member is absent locally in Franklin County. Almost everywhere along the outcrop its thickness is more than 1 foot and less than 2 feet.

HEEBNER SHALE MEMBER

In many outcrops this member consists of four distinct shale units which are, in ascending order: a thin bed of gray or yellow clay shale, black platy shale, dark bluish-gray shale, and calcareous clay shale. The black platy shale is almost everywhere the thickest part and is commonly less than 3 feet thick. Small brachiopods occur in the calcareous clay shale, conodonts are found in the black shale, and locally there are numerous gastropods and chonetid brachiopods in the thin clay shale at the base of the member. The thickness of the Heebner Shale in outcrops is commonly 5 to 8 feet. It is also a widely distributed subsurface marker identified in radioactivity logs by its intense gamma ray emission.

PLATTSMOUTH LIMESTONE MEMBER

The Plattsmouth is the thickest of the limestone members of the Oread Limestone. Commonly it is light bluish-gray, light-weathering, wavy-bedded, dense limestone. Chert is locally abundant in the northern part of the outcrop. Fossils include fusulinids, corals, bryozoans, brachiopods, and mollusks. The thickness is commonly 15 to 30 feet.

HEUMADER SHALE MEMBER

The Heumader Shale Member is chiefly gray to greenish-gray, clayey to silty shale, which becomes more sandy in southeastern Kansas. Well-preserved mollusks and other fossils are common. The thickness in northeastern Kansas ranges from 2 to 5 feet and increases to as much as 33 feet in Osage County. It is relatively thick in the southern part of the outcrop area.

KEREFORD LIMESTONE MEMBER

This member is extremely variable in thickness and lithology. Locally it is predominantly light-gray oölitic limestone, even-bedded, dense, blue-gray flaggy limestone, or thick, fine-grained, gray to blue-gray limestone. In northeastern Kansas, upper slabby cross-bedded layers, containing algal and locally land-plant remains, overlie more massive rock that contains fusulinids and other marine invertebrates. In southeastern Kansas, it is locally sandy and contains invertebrate fossils, also. The thickness ranges from 0 to more than 40 feet.

KANWAKA SHALE

In northeastern Kansas, the Kanwaka Shale is divisible into two shale members and a limestone member. In southeastern Kansas, much of the interval between the Oread and Lecompton limestones is occupied by sandstone, sandy shale, and red shale, collectively called the *"Elgin sandstone."* The outcrop thickness ranges from about 40 to 145 feet.

JACKSON PARK SHALE MEMBER

The Jackson Park Shale Member is a bluish-gray to yellowish-brown and red sandy shale and sandstone. Land-plant fossils are more or less abundant. Locally in Douglas County, a thin coal bed and pelecypod-bearing sandy layers occur in the upper part. The thickness ranges from 16 to 52 feet.

CLAY CREEK LIMESTONE MEMBER

This member is dark-blue to bluish-gray, commonly massive and dense limestone. Fusulinids are locally abundant and other fossils are fairly plentiful. Locally, oölitic, algal, and crinoidal deposits occur in the upper part. The Clay Creek Limestone is persistent in northeastern Kansas at least as far southward as Osage County and is identified in Coffey, Greenwood, and Elk counties as a zone of limestone and fossiliferous, calcareous, sandy shale. The thickness may be as much as 5 feet.

STULL SHALE MEMBER

The Stull Shale Member is a yellowish-brown to red, sandy shale, locally containing one or more coal beds. Sandstone, with somewhat plentiful land plants, occurs in the upper part of the member in northeastern Kansas. The Stull Shale

is identified northward from Elk County and tentatively in parts of southeastern Kansas. The thickness ranges from about 25 to at least 45 feet.

LECOMPTON LIMESTONE

Four limestone members and three shale members, all of which can be traced along the outcrop in eastern Kansas, make up this formation. The thickness ranges from about 30 to 66 feet.

SPRING BRANCH LIMESTONE MEMBER

The Spring Branch Limestone Member is a gray, somewhat sandy limestone that weathers deep brown and occurs in massive, slightly uneven beds. Fusulinids are abundant in most outcrops. In northeastern Kansas the thickness is commonly 5 feet, but locally as much as 14 feet, with shale and earthy limestone in the upper part. In southeastern Kansas this member locally is very sandy, impure limestone about 4 feet thick.

DONIPHAN SHALE MEMBER

The Doniphan Shale Member consists of shale, sandstone, and thin, earthy limestone beds. It is thicker and contains some red shale and prominent sandstone beds in southeastern Kansas. Fusulinids are plentiful in the basal part at some exposures. Thickness ranges from about 2 to 34 feet.

BIG SPRINGS LIMESTONE MEMBER

This member is a dark bluish-gray, dense limestone, commonly occuring as a single bed with closely spaced vertical jointing. It weathers yellowish-brown. Locally two or three limestone beds are separated by thin shale beds. Fusulinids are abundant in the member. The thickness ranges from 1 to 5 feet.

QUEEN HILL SHALE MEMBER

The upper part of the Queen Hill Member is a bluish-gray or yellowish-gray shale, and the lower part is a hard, black, fissile shale, containing conodonts. The thickness ranges from about 2 to 6 feet.

BEIL LIMESTONE MEMBER

The Beil Limestone Member consists of thin- to medium-bedded, abundantly fossiliferous, bluish-gray limestone averaging 8 to 10 feet, but ranging from 4 to 15 feet in thickness. In northern outcrops the upper part includes interbedded calcareous shale and thin limestones, whereas in southern outcrops the member is more massive and contains fewer shaly beds. Fossils are very abundant, especially horn corals, bryozoans, and fusulinids.

KING HILL SHALE MEMBER

The King Hill Shale Member is greenish-gray to reddish-gray shale that is calcareous in northeastern Kansas. Brachiopods occur sparsely in the upper part of the member. The thickness ranges from about 4 to 20 feet.

AVOCA LIMESTONE MEMBER

The Avoca Limestone Member is a dark bluish-gray, somewhat earthy limestone occurring in one or more beds. Large fusulinids are the most common fossils. In southeastern Kansas "cryptozoon"-bearing limestone is characteristic of the member. Algal-molluscan limestone beds occur at the top of the Avoca in some outcrops. The thickness ranges from about 1 to 20 feet.

TECUMSEH SHALE

The Tecumseh Shale is chiefly gray to bluish-gray, clayey and sandy shale. In southern Nebraska the Ost Limestone is reported to occupy a position near the top of the Tecumseh. This limestone may be present locally in northeastern Kansas. Gray sandstone is locally present in the upper part. The thickness of the Tecumseh ranges from an observed minimum of 12 feet in southeastern Kansas to a maximum of about 65 feet near the Kansas River.

DEER CREEK LIMESTONE

This is a persistent, escarpment-making formation comprising three limestone members and two shale members. The thickness ranges from about 20 to a local maximum of 80 feet in Osage County.

OZAWKIE LIMESTONE MEMBER

The Ozawkie Limestone Member is a brownish-gray, brown-weathering, massive limestone. Fossils are somewhat sparse, but fusulinids and other marine fossils are abundant in some outcrops. Commonly the thickness is about 5 feet but ranges from 1 to 20 feet.

OSKALOOSA SHALE MEMBER

This member is a bluish-gray or yellowish-gray shale in northeastern Kansas and a sandy, micaceous shale containing some red shale and nodular limestone in the southeastern part of the State. The thickness ranges from a minimum of 3 feet to a maximum of about 50 feet locally in Osage County.

ROCK BLUFF LIMESTONE MEMBER

The Rock Bluff Limestone Member is a massive bed of dark-blue limestone that weathers a bluish-gray or yellowish-gray. It has abundant, closely spaced joints. Fusulinids are common; a few brachiopods and other marine invertebrates are present. The thickness ranges from about 1 to 3 feet.

LARSH AND BURROAK SHALE MEMBERS

Because the intervening Haynies Limestone Member, which is present in Nebraska, is missing in outcrops in Kansas, these two members, formerly called "Larsh-Burroak," are indistinguishable and are treated as a unit. It consists of gray or yellow clayey shale in the upper part and black, fissile shale in the lower part. Fossils are rare in the upper part, but conodonts occur in the black portion. Thickness ranges from about 2.5 to 7 feet.

ERVINE CREEK LIMESTONE MEMBER

The Ervine Creek Limestone Member is composed mainly of light-gray to nearly white or bluish-gray, fine-grained limestone characterized by thin, wavy bedding. Locally chert nodules are present. It contains a large assemblage of fossils, including fusulinids, corals, echinoid and crinoid fragments, bryozoans, brachiopods, and mollusks. Shale partings contain ostracodes and small foraminifers. Above the basal wavy-bedded limestone is a less persistent limestone, generally massive, that is variable in lithology. Locally it is oölitic; elsewhere it is coquinoidal, nodular, very fine-grained, or sandy, and contains *Osagia*. This upper limestone bed, which ranges from 0 to about 6 feet, is generally separated from the underlying limestone by 1 to 2 feet of yellowish-gray, clayey to sandy shale. The thickness of the member ranges from about 5 to 32 feet.

CALHOUN SHALE

The Calhoun Shale contains clayey and sandy shale, a minor amount of limestone and one or more coal beds. In northeastern Kansas, there is a thin coal bed near the top. Much sandstone occurs in the middle part of the formation. Locally sandstone lies on an erosional surface cut into the Ervine Creek Limestone. Dark-gray, silty, fossiliferous shale and locally flaggy limestone beds are present in the lower part. Plant remains occur in the sandy part. In southeastern Kansas, the shale thins progressively, and near the Oklahoma boundary it is very thin or absent. In northeastern Kansas, near the Nebraska line, the Calhoun is only about 7 feet thick. The maximum thickness of this formation is about 50 feet in Shawnee County.

TOPEKA LIMESTONE

This formation contains limestones and shales having a wide range of lithology. Between northern Shawnee County and Greenwood County, the upper Topeka beds commonly are absent as a result of post-Topeka erosion. In southeastern Kansas all of the members in this formation cannot be positively identified. The thickness of the Topeka ranges from a nearly constant measurement of 33 feet in northeastern Kansas to 55 feet near the Oklahoma boundary.

HARTFORD LIMESTONE MEMBER

The Hartford is a massive, light bluish-gray limestone that weathers yellow-brown. This member commonly contains numerous fusulinids. In the upper part, *Osagia* is abundant. The lower beds are characterized by the sponge *Amblysiphonella*. The upper limestone ranges in thickness from 0 to 12 feet. The thickness of the member ranges from about 3 to 13 feet.

IOWA POINT SHALE MEMBER

The Iowa Point Shale Member is a yellowish-gray to bluish-gray, clayey to calcareous shale that locally contains sandstone layers and a thin coal bed. This shale is thickest in northeastern Kansas near the Nebraska boundary. Near Topeka it is only 2 feet thick, and farther south it disappears, as indicated by fusulinid-bearing lower layers of the Curzon resting directly on the upper part of the Hartford Limestone Member. The thickness ranges from 0 to 14 feet.

CURZON LIMESTONE MEMBER

This member of the Topeka Limestone is readily identifiable throughout northeastern Kansas but is not differentiated or is doubtfully identified in southeastern Kansas. It consists of two or more beds of massive bluish-gray, brown-weathering limestone that is mostly hard and resistant, forming a prominent escarpment. Nodules of chert are common. Fusulinids are sparse to abundant in the lower and middle parts of the member, together with some brachiopods and other invertebrates; bryozoans and echinoid remains are common in the upper layers. The thickness ranges from 5 to 12 feet.

JONES POINT SHALE MEMBER

Clayey, calcareous, and silty gray shale, locally containing nodular or platy limestone beds comprise the Jones Point Shale Member. The mem-

ber contains fairly numerous brachiopods and mollusks at some outcrops but is sparsely fossiliferous at many exposures. The thickness in northeastern Kansas ranges from 1 to 10 feet.

SHELDON LIMESTONE MEMBER

The Sheldon Limestone Member is a massive light-gray to nearly white, very fine-grained, dense limestone that weathers light yellowish-gray. It commonly contains *Osagia*. The member is a persistent layer that is identified northward from the Kansas River. Thickness ranges from 0.7 foot to 2 feet.

TURNER CREEK SHALE MEMBER

The Turner Creek Shale Member is a bluish-gray or greenish-gray clayey and calcareous shale that contains few fossils. The thickness ranges from 1 to 5 feet in northeastern Kansas.

DU BOIS LIMESTONE MEMBER

One or more dark-blue or greenish-blue, fine-grained, somewhat earthy limestone beds with closely spaced vertical joints make up the Du Bois Limestone Member. Mollusks and brachiopods are common in the member. The thickness in northeastern Kansas commonly ranges from about 0.5 foot to 2 feet.

HOLT SHALE MEMBER

The Holt Shale Member is made up of a grayish-black shale in the lower part and a bluish-gray shale in the upper part. This member is not recognized with certainty south of the Kansas River. Inarticulate brachiopods and conodonts occur in the black shale. The thickness ranges from 1.5 to 3 feet.

COAL CREEK LIMESTONE MEMBER

The Coal Creek Limestone consists of light bluish-gray limestone and nodular shale or dark-blue, more massive limestone that weathers light bluish-gray or brown. The Coal Creek is recognized in northeastern Kansas, but it is only locally identified in southeastern Kansas. Fusulinids are abundant, and at many places numerous other well-preserved invertebrate fossils are found. The thickness of the Coal Creek ranges from 2 to 8.5 feet.

Wabaunsee Group

The uppermost major division of Virgilian strata includes beds above the Topeka Limestone and below the Permian Admire Group. Shale is the chief rock type in this group, but sandstone is locally plentiful. Limestones in this group are uniformly thin, but persistent. The thickness of the Wabaunsee Group commonly is about 500 feet.

Sacfox Subgroup

Strata from the top of the Topeka Limestone to the base of the Burlingame Limestone are included in the Sacfox Subgroup. The thickness commonly is about 200 feet.

SEVERY SHALE

This formation is a yellowish-brown and bluish-gray clay shale with a minor amount of platy to massive sandstone. Marine fossils occur sparsely in the uppermost part. A disconformity in the lower part of the Severy can be seen in various outcrops in northeastern Kansas. Locally, as in southern Shawnee County, sandstone fills channels cut well into the Topeka Limestone. Where the Bachelor Creek Limestone Member of the Howard Limestone is absent, the base of the Nodaway coal bed is regarded as the top of the Severy Shale. The thickness is commonly 70 to 80 feet.

HOWARD LIMESTONE

This formation comprises three limestone members and two shale members, of which the middle limestone is the most persistent. The thickness of the Howard ranges from about 8 to 40 feet.

BACHELOR CREEK LIMESTONE MEMBER

The Bachelor Creek Limestone Member is commonly sparsely fossiliferous, bluish-gray, argillaceous, sandy limestone, which is present from Osage County southward. Locally the unit contains two limestone beds separated by a shale. Thickness is as much as 8 feet.

AARDE SHALE MEMBER

The Aarde Shale Member is a bluish-gray to yellowish-gray clayey and sandy shale containing the persistent *Nodaway coal bed*, ranging from about 0.1 foot to 2 feet in thickness. A black fissile shale is present in the upper part of the Aarde. A hard, dense limestone, 0.2- to 1-foot thick, occurs above the Nodaway coal and below the black fissile shale in many outcrops. Thickness of the member ranges from about 2 to 15 feet. Where the Bachelor Creek Limestone Member is absent, the part of the Aarde beneath the Nodaway coal is not differentiated from the Severy Shale.

CHURCH LIMESTONE MEMBER

This member is commonly one massive bed of bluish-gray limestone that weathers yellowish-brown. Crinoid remains, productid brachiopods, and stromatoliths are common. A thin zone at the top contains abundant bryozoans, and fusulinids occur sparingly in the upper part in southeastern Kansas. The thickness ranges from about 1.5 to 6 feet.

WINZELER SHALE MEMBER

The Winzeler Shale Member is a bluish-gray to yellowish-gray clay shale. Marine fossils occur in the lower part. The thickness is about 1 to 12 feet.

UTOPIA LIMESTONE MEMBER

The Utopia Limestone Member is a gray to brown, sandy, coquinoidal limestone in many outcrops. Fossils include algae, fusulinids, bryozoans, brachiopods, and mollusks. The thickness ranges from less than 1 foot to a maximum of about 16 feet. In some parts of the State the Utopia Member consists of two or more limestones separated by an ostracode-bearing shale.

SCRANTON SHALE

This formation, consisting predominantly of shale, constitutes approximately the upper half of the Sacfox Subgroup, and comprises strata between the Howard Limestone and the Bern Limestone. It is subdivided into five members. The average thickness is about 125 feet.

WHITE CLOUD SHALE MEMBER

The White Cloud Shale Member is a bluish-gray to yellowish-brown clayey and sandy shale. Locally sandstone and conglomerate fills channels cut into the Howard Limestone or lower beds. Sparse marine invertebrates and land-plant fossils are present. The thickness ranges from about 30 to 80 feet.

HAPPY HOLLOW LIMESTONE MEMBER

The Happy Hollow Limestone Member is generally a single, persistent, massive bed of pinkish-brown limestone characterized by large fusulinids. In places an oölitic or algal bed is present in the upper part, and it may be separated from the massive limestone by a thin shale bed. A dark bluish-gray limestone containing mollusks, brachiopods, and bryozoans occurs locally below the fusulinid-bearing bed. In some areas the fusulinid bed is absent, and the member is represented only by algal and molluscan beds. Thickness ranges from about 1 to 10 feet.

CEDAR VALE SHALE MEMBER

The Cedar Vale Shale Member consists of bluish-gray to yellowish-brown clayey and sandy shale and sandstone containing the persistent *Elmo coal bed* near the top. The topmost beds, between the Elmo coal and the base of the Rulo Limestone Member, contain a fauna of mollusks, brachiopods, and bryozoans. The thickness ranges from about 16 to 60 feet.

RULO LIMESTONE MEMBER

This member is a bluish-gray limestone that locally is mottled with light brown when weathered. Brachiopods and bryozoans are common. In places a molluscan limestone occurs in the lower part and a thin algal zone in the upper part. The thickness ranges from 0 to about 4 feet.

SILVER LAKE SHALE MEMBER

Gray and yellow clay shale, in places associated with platy, argillaceous limestone, sandy shale, or sandstone, comprises the Silver Lake Shale Member. Sandstone fills channels cut into beds as low as the Cedar Vale Shale Member. One or more coal beds occur in the upper part. Marine invertebrates and land-plant fossils are present locally. The thickness ranges from about 4 to 45 feet.

Nemaha Subgroup

Strata from the base of the Bern Limestone to the base of the Tarkio Limestone constitute the Nemaha Subgroup (Moore and Mudge, 1956). Because the Tarkio Limestone Member is not identified south of Lyon County the subgroup is not recognized in southeastern Kansas. The thickness is about 150 feet.

BERN LIMESTONE

This formation comprises three members, the Burlingame Limestone, the Soldier Creek Shale, and the Wakarusa Limestone (Moore and Mudge, 1956). The thickness of the Bern, which is a persistent escarpment-forming unit, ranges from about 7 to 35 feet.

BURLINGAME LIMESTONE MEMBER

The Burlingame Member is a fine-grained, hard, thick-bedded light-gray to brown limestone that appears mottled and brecciated in some exposures. Shale partings occur in the limestone beds. Fusulinids are common in the more persistent part, and algal remains are conspicuous near the top. Biscuit-like algal deposits, composed of *Somphospongia,* are numerous in a few

exposures in northeastern Kansas. The thickness ranges from about 2 to 16 feet.

SOLDIER CREEK SHALE MEMBER

The Soldier Creek Shale Member is a bluish-gray, clayey to sandy shale, which locally contains a thin coal bed in the upper part. Marine invertebrates occur in the upper part of the member in places. Thickness ranges from less than 1 foot to about 25 feet.

WAKARUSA LIMESTONE MEMBER

The Wakarusa Limestone Member is a dark bluish-gray, hard limestone that weathers brown. The most persistent bed in the member contains large fusulinids, algae, brachiopods, and bryozoans. Locally, an algal-molluscan limestone occurs above, and is separated from, the main bed by a thin shale. The thickness of the member ranges from 2 to 18 feet.

AUBURN SHALE

The Auburn Shale is a complex and variable formation composed chiefly of shale, minor amounts of sandstone, and limestone, some of which is chalky. Near the Kansas River the middle part of the Auburn is a cross-bedded, conglomeratic limestone about 5 feet thick containing molluscan and algal remains. In places there are dark-gray shale beds containing numerous ostracodes and pelecypods. Two or more coal beds occur locally in the Auburn. The thickness of the formation in Kansas ranges from about 20 to 70 feet.

EMPORIA LIMESTONE

This formation includes three members, which are in ascending order: the Reading Limestone Member, the Harveyville Shale Member, and the Elmont Limestone Member. The thickness ranges from about 7 to 40 feet.

READING LIMESTONE MEMBER

The Reading comprises one to four beds of limestone interbedded with blue-gray shale, and locally in southeastern Kansas it contains a coal bed. The most persistent part of this member consists of dense, hard, dark bluish-gray limestone showing closely spaced vertical joints and weathering light bluish-gray mottled with light brown or yellowish-brown. Fusulinids are characteristic of the persistent, bluish-gray limestone. Locally an algal limestone is present above the more persistent part, and a brachiopod- and pelecypod-bearing limestone may be present below this bed. Thickness of the member is 1.5 to 15 feet.

HARVEYVILLE SHALE MEMBER

The Harveyville Shale Member is a bluish- and greenish-brown clayey shale, which locally contains sandy shale and a thin bed of sandstone. In places a coal bed occurs above the sandstone, and marine invertebrate fossils are found above the coal horizon. The thickness ranges from less than 1 foot to 25 feet.

ELMONT LIMESTONE MEMBER

A thin bluish-gray, conglomeratic limestone marks the base of the Elmont Limestone Member. It is overlain by 0.3 foot to 4 feet of clayey, calcareous gray shale containing *Derbyia* and *Chonetes*. The next higher bed is a persistent, dense, bluish-gray limestone, which contains small fusulinids, algae, brachiopods, and crinoid remains. This bed is characterized by its closely spaced vertical joints. The upper part of the Elmont consists of a few inches to 1 foot of gray calcareous shale overlain by a thin algal-molluscan limestone. The upper and lower limestones may be absent in some places. The thickness of the member ranges from 1 to 15 feet.

WILLARD SHALE

This formation consists of dark bluish-gray and brown shale and sandstone. The sandstone is prominent in many places in northeastern Kansas but is thin or absent in southeastern Kansas. The Willard Shale is not differentiated from overlying shale beds south of the point where the Tarkio Limestone Member of the Zeandale Limestone disappears. The thickness of the Willard in northeastern Kansas ranges from 30 to 65 feet, the maximum being near the Kansas River.

Richardson Subgroup

Strata from the base of the Zeandale Limestone to the top of the Wood Siding Formation are included in the Richardson Subgroup. This division can be distinguished in northeastern Kansas only. The thickness commonly is about 150 feet.

ZEANDALE LIMESTONE

This formation consists of three members, two limestones and an intervening shale (Moore and Mudge, 1956). The thickness ranges from 19 to 53 feet.

TARKIO LIMESTONE MEMBER

This unit consists of gray limestone that weathers deep yellowish-brown and is one of the most easily recognized units in the Wabaunsee

Group. It is characterized by the brown color of weathered outcrops and the abundance of large fusulinids *(Triticites)*. Locally algae occur in the upper part. Seemingly discontinuous in southeastern Kansas, it is persistent from southern Lyon County northward. The thickness ranges from 0 to about 10 feet.

WAMEGO SHALE MEMBER

The Wamego Shale Member is a bluish-gray clay shale and yellowish-brown micaceous shale, which is locally fossiliferous and contains dark-gray shale in the upper part. The *Stormont limestone bed* occurs in the lower part of the member in an area between the Kansas and Neosho rivers (O'Connor, 1953). A thin coal bed occurs in the upper-middle part. The Wamego has been called the "Pierson Point Shale" in some older reports. The thickness ranges from 4 to 25 feet.

MAPLE HILL LIMESTONE MEMBER

The Maple Hill is a gray limestone weathering reddish-brown, containing crinoid fragments, bryozoans, brachiopods, and a few mollusks. Fusulinids are common at some localities. This limestone is not definitely recognized south of Lyon County. The thickness ranges from 1 to 5 feet.

PILLSBURY SHALE

The Pillsbury is bluish-gray clayey to sandy shale, containing a persistent thin coal bed. Platy to massive sandstone occurs in the upper part; locally sandstone fills channels cut 30 or more feet into older beds. This formation formerly was called "Langdon" (Moore and Mudge, 1956). The thickness ranges from 1 to 50 feet.

STOTLER LIMESTONE

This formation comprises two limestone members separated by a shale member (Moore and Mudge, 1956). Locally the shale is very thin or absent. The thickness ranges from about 5 to 35 feet.

DOVER LIMESTONE MEMBER

In northeastern Kansas this member commonly is a single bed of limestone or sandy limestone containing algae and fusulinids. Southward from Greenwood County a fine-grained, blue-gray limestone with a fauna of mollusks and brachiopods occurs below the more persistent upper part, which in this area contains a shale that separates the fusulinid-bearing limestone from the upper algal-bearing part. The thickness in northeastern Kansas ranges from about 1 to 5 feet; in southeastern counties, where shale comprises most of the member, the thickness is as much as 24 feet.

DRY SHALE MEMBER

The Dry Shale Member is a gray, locally red and green, clayey and occasionally sandy shale containing a thin coal bed in southeastern Kansas. Marine fossils are abundant in the upper part in some localities. In places a cross-bedded algal-molluscan limestone occurs in the middle part of the member. The thickness ranges from 0 to 26 feet.

GRANDHAVEN LIMESTONE MEMBER

This member commonly contains two limestones separated by a few feet of shale, but in places it is one limestone bed. The lower limestone is gray to yellowish-brown and fossiliferous. It ranges from 1 to 3 feet in thickness. The upper limestone is light-gray, weathering almost white, and contains much oölitic or algal material. In exposures along the Cottonwood River, the upper limestone is cross-bedded and contains abundant brachiopods and bryozoans and some mollusks. Large fusulinids are present in the Grandhaven at some outcrops. The member can be traced from Shawnee County southward into Oklahoma and may be present north of the Kansas River. The thickness ranges from about 2 to 10 feet.

ROOT SHALE

This formation comprises, in ascending order, the Friedrich Shale Member, the Jim Creek Limestone Member, and the French Creek Shale Member (Moore and Mudge, 1956). The thickness ranges from 30 to 90 feet.

FRIEDRICH SHALE MEMBER

The Friedrich Shale Member is a bluish-gray shale that weathers yellowish-brown. Sandstone is common in the member, and in southeastern Kansas thin coal and limestone beds are present. Locally channels cut 30 feet or more into lower beds are filled with sandstone. The member contains pelecypods, sparse bryozoans, and brachiopods. The thickness ranges from 5 to 40 feet.

JIM CREEK LIMESTONE MEMBER

This member is a persistent bluish-gray, fine-grained limestone, containing small fusulinids in many places and more locally a large variety of other marine fossils. The thickness ranges from 0.3 foot to about 2 feet.

FRENCH CREEK SHALE MEMBER

Bluish-gray, clayey, and sandy or silty shale that weathers yellowish-brown to brown comprises the French Creek Shale Member. It commonly contains one or more sandstone beds and one or more coal beds in the upper part. The thickness ranges from 20 to 45 feet.

WOOD SIDING FORMATION

The Wood Siding Formation is made up of the Nebraska City Limestone Member, the Plumb Shale Member, the Grayhorse Limestone Member, the Pony Creek Shale Member, and the Brownville Limestone Member (Moore and Mudge, 1956). It averages 36 feet in thickness.

NEBRASKA CITY LIMESTONE MEMBER

This member is a gray, argillaceous, soft limestone, containing brachiopods, bryozoans, algae, and locally plentiful pelecypods. The thickness is about 1 to 5 feet.

PLUMB SHALE MEMBER

This member is mostly gray, clayey shale. In southeastern Kansas it contains some sandstone and limestone beds. *Myalina,* small snails, bryozoans, and fusulinids are present in the Plumb in southeastern Kansas. The thickness ranges from 10 to 30 feet.

GRAYHORSE LIMESTONE MEMBER

The Grayhorse Limestone Member is gray, medium- to coarse-grained limestone, fragmental or coquinoidal, and ferruginous. Large specimens of *Myalina* are common. Thickness ranges from 0.5 foot to 6 feet.

PONY CREEK SHALE MEMBER

The Pony Creek Shale Member is chiefly bluish-gray shale, with some red clayey or sandy shale locally. A thin coal bed is present in the upper-middle part in southeastern Kansas. Commonly siltstone or sandstone occurs near the middle part, and in places fills channels cut into the Friedrich Shale Member or lower. Brachiopods and bryozoans are abundant in the upper part in some exposures. The thickness ranges from about 5 to 50 feet.

BROWNVILLE LIMESTONE MEMBER

This member is a bluish-gray limestone that weathers yellowish-brown or brown, occurring in a single bed or in two beds separated by a thin bed of shale. Characteristic fossils include large fusulinids, *Marginifera* and *Chonetes,* crinoid fragments, bryozoans, and, rarely, trilobites. The thickness ranges from about 1 to 5 feet.

PERMIAN SYSTEM

By HOWARD G. O'CONNOR, DORIS E. ZELLER, CHARLES K. BAYNE, JOHN MARK JEWETT, and ADA SWINEFORD

Rocks of Permian age that occur in Kansas include predominantly marine deposits in the lower part of the section and marine and nonmarine deposits in the upper part. The prevailing dip of outcropping Permian strata is westward or northwestward.

Lowermost Permian beds consisting of light-gray to cream-colored limestones, many of which are distinguished by an abundance of chert, form persistent eastward-facing escarpments in the Flint Hills, which extend across Kansas from Nemaha County on the Nebraska border to western Chautauqua County on the Oklahoma border. Limestones and calcareous shales in the Flint Hills are characterized by abundant marine fossils.

West of the Flint Hills, and roughly paralleling them, is a lowland that is formed on shales of the Wellington Formation. Above the Wellington, beds of red siltstone and shale, containing some gypsum, form the Red Hills in south-central Kansas from eastern Meade County to Harper County. Occurring in the red beds are a few thin, persistent dolomites. Thick deposits of salt that are present in the Wellington and at other horizons in the subsurface are not found on the surface.

A two-fold classification for the Permian (O'Connor, 1963) has been adopted by the Kansas Geological Survey:

Upper Permian	Custerian Stage
Lower Permian	Cimarronian Stage
	Gearyan Stage

Permian rocks occur in the subsurface of Kansas west of the outcrop belt (Fig. 8). They are covered unconformably by Jurassic rocks locally near the southwest corner of the State and in the subsurface of some northwestern counties, and elsewhere, by Cretaceous, Tertiary, and Quaternary rocks. A thickness of 3,000 feet is attained in the Hugoton embayment (Fig. 2).

The structure of buried Permian rocks in Kansas is broadly synclinal, except where they overlie the Nemaha anticline. The axis of the syncline trends north-northwest across the western one-third of the State, and it plunges gently

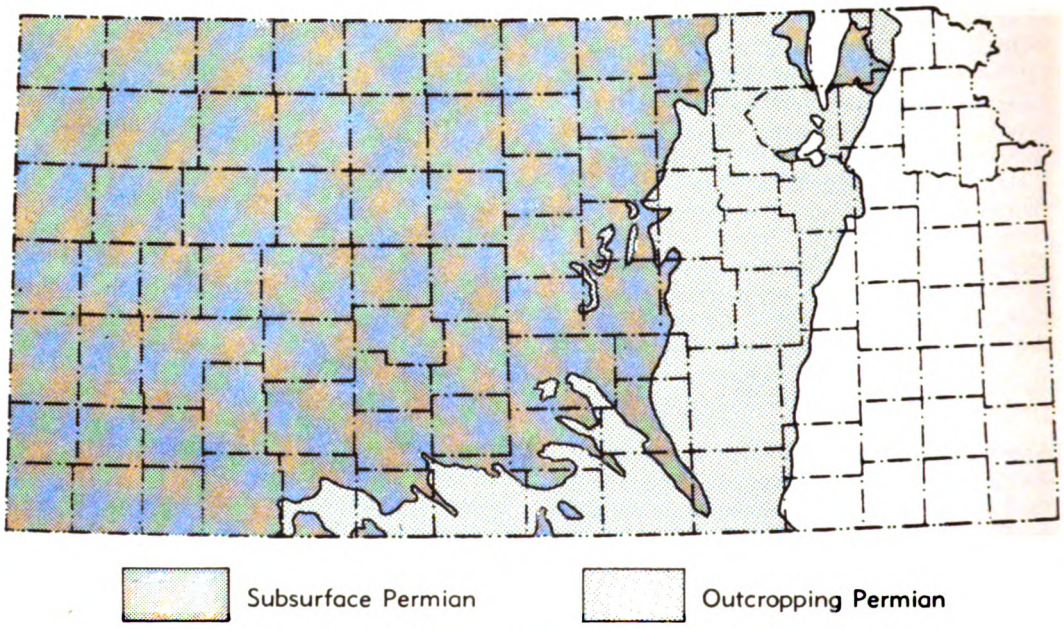

FIGURE 8. Distribution of Permian rocks in Kansas. (Adapted from State Geol. Survey Kansas, 1964.)

northward. Eastward dips are found in subsurface Permian strata in westernmost Kansas.

Lower Permian Series

In a recent revision of Kansas stratigraphic nomenclature the great bulk of Kansas Permian rocks has been assigned to the Lower Permian Series (O'Connor, 1963). The Series comprises more than 1,900 feet of evaporite-bearing siltstones, sandstones, and shales in the upper part and a little less than 800 feet of alternating limestone, shale, and minor amounts of gypsum in the lower part, aggregating a total thickness of roughly 2,700 feet. Lower Permian rocks in Kansas have been subdivided into two stages, Gearyan (below) and Cimarronian (above).

GEARYAN STAGE

The Gearyan Stage (O'Connor, 1963) comprises three groups, the Admire, the Council Grove, and the Chase. It contains about 790 feet of rocks, which are predominantly limestone and shale, and contains units that are remarkably continuous laterally. The Gearyan Stage is named from Geary County in northeastern Kansas. Rocks of this stage are exposed throughout east-central Kansas in a north-northeast-trending belt from Cowley County on the Oklahoma border to Marshall and Brown counties on the Nebraska border.

ADMIRE GROUP

This division consists chiefly of clastic deposits but contains some thin limestones and coal beds. Shale predominates. The thickness is about 130 feet. In places where sandstone in the basal part seemingly fills channels the thickness may be appreciably more.

ONAGA SHALE

This formation includes the Towle Shale Member, the Aspinwall Limestone Member, and the Hawxby Shale Member. The thickness is about 30 feet.

TOWLE SHALE MEMBER

The Towle Shale Member is a gray, red, and green clayey and silty shale with some thin limestone beds (Moore and Mudge, 1956). In most exposures, the Towle Shale lies with apparent conformity on the Brownville Limestone Member of Pennsylvanian age. The *Indian Cave sandstone* fills channels cut into underlying beds. These channels may be as much as 85 feet in depth (Mudge and Yochelson, 1962). The common thickness of the Towle ranges from about 2 to 15 feet.

ASPINWALL LIMESTONE MEMBER

The Aspinwall Limestone Member is made up of one limestone bed or several limestone beds

separated by calcareous shales. The member thickens southward, with calcareous shale predominating in the lower and middle parts. It is sparsely fossiliferous, the most abundant fossils being mollusks and productid brachiopods. The thickness ranges from about 1 to 15 feet.

HAWXBY SHALE MEMBER

The Hawxby Shale Member is a gray to yellowish-gray shale, which contains some green and red shale in the lower part. The upper part is calcareous and locally sandy. The thickness ranges from about 4 to 19 feet.

FALLS CITY LIMESTONE

In northeastern Kansas the Falls City Limestone consists of an upper and lower fossiliferous limestone bed separated by gray shale containing fossiliferous limestone lenses. The Falls City in southeastern Kansas is thinner and probably contains beds which are correlative with the lower part of the formation in northeastern Kansas. The limestone beds are argillaceous and contain mollusks, bryozoans, and brachiopods. Cone-in-cone structures are characteristic of the upper beds in the central part of the outcrop area. The thickness ranges from about 6 to 17 feet.

JANESVILLE SHALE

The Janesville Shale contains the West Branch Shale Member, the Five Point Limestone Member, and the Hamlin Shale Member (Moore and Mudge, 1956). The maximum thickness is about 90 feet.

WEST BRANCH SHALE MEMBER

The West Branch Shale Member is a gray, green, and red shale. In central and southeastern Kansas it is sandy in the upper part and may contain up to 5 feet of sandstone locally. One or more persistent coal beds occur in the upper and middle parts of the member. Limestone lenses are present in the West Branch Shale in northeastern Kansas. The thickness ranges from about 20 feet to about 43 feet.

FIVE POINT LIMESTONE MEMBER

The Five Point Limestone Member consists of one or more limestone beds, which are massive to slabby and fossiliferous. Locally the upper part is a thin coquina. The thickness of the member is about 1 to 13 feet, commonly about 3 feet.

HAMLIN SHALE MEMBER

The Hamlin Shale Member comprises maroon to grayish-green shale, thin tannish- to grayish-brown limestones, and tan siltstones and sandstones. Celestite is present in the upper beds in Brown County. In northeastern Kansas the *Houchen Creek limestone bed,* which occurs in the upper part of this member, consists largely of laminated algal structures. The thickness of the Hamlin ranges from about 34 feet to 52 feet.

Council Grove Group

This division of Permian rocks comprises about 310 to 330 feet of limestones and shales. In general, these rocks include less massive and thinner limestone units than occur in the overlying Chase Group.

FORAKER LIMESTONE

The Foraker Limestone consists of two limestone members and a shale member. The thickness is about 50 feet.

AMERICUS LIMESTONE MEMBER

This member commonly consists of two gray to bluish-gray limestone beds separated by a medium-gray to very dark-gray shale bed. The limestones are fossiliferous, containing crinoids, brachiopods, bryozoans, pelecypods, fusulinids, and algae, and in southeastern outcrops the upper beds are cherty. The thickness ranges from 1.5 to 20 feet (Mudge and Yochelson, 1962).

HUGHES CREEK SHALE MEMBER

In northeastern Kansas this part of the Foraker comprises light-gray to nearly black shale and thin limestone beds containing a profusion of fusulinids and abundant brachiopods. In southeastern Kansas the member is predominantly limestone, massive in the lower part and containing much chert. The thickness ranges from about 20 to 56 feet.

LONG CREEK LIMESTONE MEMBER

This member consists of alternating beds of grayish-orange limestone and dolomitic limestone containing secondary calcite, celestite, and colorless to pink or red quartz and thin-bedded, olive-gray shale. In southeastern Kansas the limestone is light gray and sparsely fossiliferous and is divided into an upper and a lower unit by a brown to gray shale. The thickness ranges from 2.5 to 12 feet.

JOHNSON SHALE

This formation is a tan, gray, green, and red shale which contains thin beds of argillaceous limestone. Carbonaceous material occurs in the

upper part. The lower part locally contains thin beds of gypsum. The thickness ranges from 13 to 26 feet.

RED EAGLE LIMESTONE

This formation contains two limestone members and one shale member. In southeastern Kansas the Red Eagle contains very little shale, but the members still can be identified. The thickness ranges from 6 to 33 feet.

GLENROCK LIMESTONE MEMBER

The Glenrock Member is a gray to brownish-gray limestone containing brachiopods, algae, gastropods, abundant fusulinids, and other smaller foraminifers. The member can be traced in outcrops from southern Nebraska to southern Cowley County, except for a small area in Wabaunsee County where it is absent. The thickness ranges from 0 to about 3 feet.

BENNETT SHALE MEMBER

North of Wabaunsee County the Bennett is chiefly gray to very dark-gray, calcareous shale containing *Orbiculoidea*. From southern Wabaunsee County to southern Greenwood County the member contains an increasing amount of limestone. South of Greenwood County the Bennett is chiefly light-gray limestone in which brachiopods, echinoderms, corals, and algae are common (O'Connor and Jewett, 1952). The thickness ranges from 4 to 27 feet.

HOWE LIMESTONE MEMBER

The Howe Limestone Member is a persistent and uniform gray to grayish-brown, fine-grained algal limestone. Its fauna includes tiny pelecypods and gastropods, ostracodes, and foraminifers. The thickness is from 1 to 6 feet.

ROCA SHALE

The Roca Shale consists of gray, gray-green, and red shales and thin, gray, argillaceous limestones. The thickness ranges from 7 to 34 feet.

GRENOLA LIMESTONE

This formation includes three limestone members and two shale members. The thickness ranges from 32 to 54 feet.

SALLYARDS LIMESTONE MEMBER

The Sallyards Limestone Member is a gray to tannish-gray fossiliferous limestone with thin shale breaks. It contains a molluscan fauna and locally other fossils. The thickness ranges from about 0.3 foot to 5 feet.

LEGION SHALE MEMBER

This member is gray shale containing some black fissile shale. Locally it contains thin pelecypod- and brachiopod-bearing limestones. The thickness ranges from about 1.4 to 13 feet.

BURR LIMESTONE MEMBER

The Burr Limestone Member is fossiliferous gray limestone and gray to olive-gray shale. In Chase County the middle limestone beds are very fine-grained and platy. Ostracodes are abundant in some of the limestones. Mollusks and other fossils are abundant locally in the lower beds. The thickness ranges from 1 to 15 feet.

SALEM POINT SHALE MEMBER

This member is a silty, calcareous gray shale without fossils or very sparingly fossiliferous. The thickness ranges from 4 to 15 feet.

NEVA LIMESTONE MEMBER

The Neva Limestone Member comprises gray limestone beds interbedded with gray and grayish-green shale beds. The basal bed is a gray algal limestone 0.4 foot to 3.7 feet thick, which is overlain by medium-gray to very dark-gray, silty, calcareous shale about 3 feet thick. Fusulinids, *Orbiculoidea,* and *Crurithyrus* are abundant in the shale. In the central part of its outcrop a lens of gray limestone divides the shale. Next above is the main limestone ledge of the Neva, a gray, massive limestone 1.8 to 14.4 feet thick. This bed has a brecciated and porous appearance on outcrops and contains a diverse fauna of fusulinids, brachiopods, echinoids, and algae. About 3 feet of gray to grayish-green fossiliferous shale separates the main ledge from the upper limestone. The upper limestone is gray and fossiliferous and ranges from 0.6 foot to 6 feet in thickness. Overall thickness of the member ranges from 9 feet in Lyon County to 28 feet in Cowley County.

ESKRIDGE SHALE

The Eskridge Shale is composed of varicolored shales with gray and tannish-gray being the predominant color. Two persistent molluscan limestones are found in the middle or lower part of the Eskridge, and a thin coal occurs in the formation in Lyon, Wabaunsee, and Brown counties. The thickness ranges from 20 to 41 feet.

BEATTIE LIMESTONE

This formation contains two limestone mem-

bers and a shale member. The thickness ranges from about 10 to 25 feet.

COTTONWOOD LIMESTONE MEMBER

This limestone is massive, light buff, weathering nearly white, cherty, and contains abundant fusulinids in the upper part. In southern Kansas and locally elsewhere it is thin-bedded and shaly. It contains five distinct facies (Laporte, 1962). Along much of its outcrop it is marked by a fringe of shrubs on the grass-covered slopes of the Flint Hills. Except for thinning toward the south, the thickness of the Cottonwood is remarkably constant, amounting to about 6 feet.

FLORENA SHALE MEMBER

The Florena Shale Member is a highly fossiliferous calcareous, gray to tannish-gray shale containing thin nodular limestone beds in southeastern Kansas. Dolomitic shale occurs in the Florena from southern Wabaunsee County to northern Greenwood County. *Chonetes granulifer* is abundant in the Florena. In southern outcrops the variety of fossils is greater than in the north. The fauna contains numerous species of pelecypods and brachiopods, and well-preserved specimens of a small trilobite are common locally. The thickness ranges from about 3 to 18 feet.

MORRILL LIMESTONE MEMBER

This unit consists of brown to grayish-brown, argillaceous, cellular-weathering limestone that generally contains one or more thin shale partings. In southern outcrops the Morrill contains much algal (*Osagia*) limestone. The thickness ranges from about 2 to 9 feet.

STEARNS SHALE

This formation is mostly gray to olive-gray shale, but red shale occurs in the middle and lower parts. It contains a minor amount of argillaceous limestone and locally, in Lyon and Morris counties, a thin coal bed. The thickness ranges from about 5 feet to 20 feet.

BADER LIMESTONE

This formation is made up of two limestone members and a shale member. The thickness ranges from 15 to 33 feet.

EISS LIMESTONE MEMBER

The Eiss Member contains two limestone beds separated by shale and is remarkably persistent across Kansas. The lower limestone, 1.5 to 6 feet in thickness, is shaly, thin-bedded, and fossiliferous. It contains abundant, small, high-spired gastropods. The middle part, 2 to 11 feet locally, consists of gray fossiliferous shale. The upper limestone bed, 2 to 3 feet thick, is siliceous and locally contains some chert. The thickness of the member ranges from about 7 to 18 feet.

HOOSER SHALE MEMBER

This member is a gray to grayish-green and red shale. Its thickness ranges from 3 to 11 feet.

MIDDLEBURG LIMESTONE MEMBER

The Middleburg Limestone Member consists of a slabby to massive limestone, a middle olive- to dark-gray shale, the lower part of which is fossiliferous, and an upper platy limestone. Thickness ranges from about 1.5 to 8 feet.

EASLY CREEK SHALE

This formation consists of red, green, and gray shale, locally containing thin limestone beds. The lower part of the formation is largely red shale; the upper part is light-colored, calcareous shale. In Marshall County a bed of gypsum, approximately 8 feet thick, occurs in the basal part. The thickness is about 10 to 20 feet.

CROUSE LIMESTONE

The Crouse Limestone comprises an upper and a lower limestone separated by a few feet of fossiliferous shale. The upper part displays platy structure and weathers tan to brown. The limestone beds locally are cherty. The thickness ranges from about 6 to 18 feet.

BLUE RAPIDS SHALE

This formation is a gray, green, and red shale, locally containing some limestone. A thin coal bed occurs in the upper part in Geary County. The thickness ranges from about 15 to 30 feet.

FUNSTON LIMESTONE

The Funston is a light-gray to bluish-gray limestone separated by gray to yellowish-gray shale that commonly is abundantly fossiliferous. In southern and central Kansas outcrops bluish-gray to grayish-black shale occurs in the lower part, and locally the limestone beds contain chert. The thickness of the Funston ranges from about 5 to 28 feet.

SPEISER SHALE

The upper part of this formation consists of gray fossiliferous shale underlain by a fairly per-

sistent limestone bed, which is commonly less than 1 foot thick and occurs about 3 feet below the Wreford Limestone. The remainder consists of beds of varicolored shale, red shale being predominant. The thickness of the Speiser is about 18 feet in northern and central Kansas outcrops and about 35 feet in the southeastern part of the State, where a lenticular bed of sandstone occurs in the middle part.

Chase Group

This group is made up of about 335 feet of escarpment-making limestones alternating with shales. The shale formations are characterized by shades of red and green. The thick chert-bearing limestones are a prominent topographic feature in the Flint Hills.

WREFORD LIMESTONE

The Wreford Limestone contains two limestone members and a shale member. The limetones are characterized by an abundance of chert. The thickness ranges from about 30 to 40 feet.

THREEMILE LIMESTONE MEMBER

The Threemile Limestone Member is a light-gray to nearly white limestone, cherty in part, but containing massive and more resistant noncherty beds in the middle and lower parts. The thickness ranges from about 6 to 33 feet.

HAVENSVILLE SHALE MEMBER

This member is a gray, calcareous shale containing thin limestone beds. The shale thins considerably in southeastern Kansas and becomes more calcareous. Locally, as in southern Riley County, algal and coquinoidal limestone occurs in this interval. The thickness ranges from about 1.5 to 27 feet.

SCHROYER LIMESTONE MEMBER

The Schroyer Member is a light-gray to nearly white limestone, mostly chert-bearing, but commonly containing a noncherty bed about 3 feet thick in the upper part. The thickness ranges from about 6 to 13 feet (Hattin, 1957).

Matfield Shale

The Matfield Shale contains two varicolored shale members separated by a limestone member. The thickness ranges from about 50 to 80 feet.

WYMORE SHALE MEMBER

This member is gray and yellowish-gray shale with beds of vivid red, green, and purple shale. Limestone beds and fossiliferous shale beds are included in the lower part in the southeastern part of the State. The thickness ranges from about 9 to 25 feet.

KINNEY LIMESTONE MEMBER

This member generally includes two gray fossiliferous limestone beds separated by a gray fossiliferous shale bed. The thickness ranges from about 1 to 24 feet.

BLUE SPRINGS SHALE MEMBER

The Blue Springs Member consists chiefly of red and gray shale, and a relatively minor amount of limestone. In southeastern Kansas the gray calcareous shales and several of the thin limestone beds, which occur in the upper part of the member, are fossiliferous. In northeastern Kansas the member is less calcareous and limestone is absent. The thickness ranges from about 15 to 35 feet.

BARNESTON LIMESTONE

This formation comprises two thick limestone members separated by a thin shale member. The upper limestone makes an extensive dip slope and crops out as a steep escarpment that extends from north to south across eastern Kansas. The Barneston Limestone caps much of the western part of the Flint Hills. The thickness of the formation ranges from about 80 to 90 feet.

FLORENCE LIMESTONE MEMBER

The Florence Limestone Member is chiefly limestone with an abundance of chert and a minor amount of shale. The limestone is light-gray to yellowish-gray in color with nodules and layers of bluish-gray chert. Fossils include brachiopods, pelecypods, bryozoans, and fusulinids. The thickness ranges from 12 to 45 feet.

OKETO SHALE MEMBER

The Oketo is a calcareous, gray shale. It is generally absent in southeastern Kansas and locally absent elsewhere. The thickness ranges from 0 to 8 feet, but is generally less than 5 feet.

FORT RILEY LIMESTONE MEMBER

The Fort Riley is a light-gray to tan, massive to thin-bedded limestone with a minor amount of gray shale. In the basal part there are thin, shaly beds that are overlain by a massive "rim rock," which is a conspicuous outcrop maker. Thin shaly beds and locally clayey shale occurs in the middle part. The upper strata are

massive, but less so than the "rim rock." Algae are somewhat conspicuous in the "rim rock." The thickness ranges from about 30 to 45 feet.

DOYLE SHALE

Two shale members and a separating limestone member comprise the Doyle Shale. The thickness is about 70 feet.

HOLMESVILLE SHALE MEMBER

The Holmesville Shale Member is green, gray, yellow, and red, unfossiliferous shale containing argillaceous limestone. The thickness ranges from about 7 to 33 feet.

TOWANDA LIMESTONE MEMBER

This member consists of light bluish-gray to yellow, slabby and platy limestone that is commonly brecciated in the upper part. Fossils are generally rare. The common thickness ranges from about 5 to 15 feet.

GAGE SHALE MEMBER

The Gage Shale Member is mostly clayey shale, but calcareous fossiliferous shale and a minor amount of limestone occur in the upper part. The lower and middle parts are chiefly noncalcareous red, green, purple, and chocolate-colored shale interbedded with gray and yellow shale. The characteristic thickness is approximately 45 feet.

WINFIELD LIMESTONE

This formation consists of a thin limestone member that is locally cherty overlain by a member that comprises about 10 feet of fossiliferous gray shale, and a thick upper limestone member that is locally cherty. The two lower members are not definitely identified in southeastern Kansas. The combined thickness is about 25 feet.

STOVALL LIMESTONE MEMBER

The Stovall Member is a dense, gray limestone with an abundance of gray chert in northeastern Kansas. It becomes thicker and less cherty in Chase County, but it thins southward and is absent in Cowley County. Fossils are rare. The thickness is commonly about 1 foot.

GRANT SHALE MEMBER

This member is a gray, calcareous and fossiliferous shale. It is a distinct unit except in southern Kansas. The Grant is abundantly fossiliferous at some exposures. Thickness in northern outcrops is about 10 to 12 feet; in central outcrops it is about 6 feet.

CRESSWELL LIMESTONE MEMBER

This member consists of a massive fossiliferous limestone in the lower part and locally shale in the middle and upper parts. Echinoid spines and other fossils are plentiful in the lower massive limestone. The shaly middle part commonly contains calcareous concretions, geodes, and some chert. Cavernous weathering is characteristic. Throughout a considerable distance the lower massive ledge is about 3 feet thick. South of Butler County the lower part of the Cresswell consists of two massive beds of hard gray limestone separated by a thin limy shale; these have an aggregate thickness of 8 to 10 feet. Near the State line this part of the Cresswell is a single massive bed about 12 feet thick. Above the massive part of the Cresswell, rocks consisting of a thin-bedded limy shale and shaly limestone have been called the "Luta limestone," but these are now considered to be a part of the Cresswell. The boundary between the Cresswell and the Odell Shale is not distinct. The maximum thickness of the member is 25 feet.

ODELL SHALE

The Odell Shale is chiefly red and green shale with some gray and yellow shale. The thickness ranges from 20 to 40 feet.

NOLANS LIMESTONE

This formation consists of an upper and a lower limestone member separated by a shale member in northern and central Kansas outcrops. In southern Kansas outcrops, the member boundaries are not clearly defined. Thickness ranges from about 22 to 40 feet.

KRIDER LIMESTONE MEMBER

This member commonly comprises two beds of limestone separated by a bed of shale, each generally slightly more than 1 foot thick. In southern Kansas outcrops the separating shale is somewhat thicker. The color is yellowish-brown. The characteristic thickness is about 4 feet.

PADDOCK SHALE MEMBER

The Paddock is a gray shale, which in northern Kansas outcrops contains stringers and vein fillings of calcite. In southern Kansas outcrops it is buff colored and contains dolomite in the lower part. Pelecypods are locally abundant in north-

ern and central Kansas outcrops. The thickness ranges from about 7 to 13 feet.

HERINGTON LIMESTONE MEMBER

The Herington is composed of yellowish-tan, dolomitic limestone and dolomite. It is more dolomitic in southern and central Kansas outcrops than in the northern outcrops. The Herington is characterized by siliceous and calcareous geodes and concretions, and cauliflower-like masses of chert and quartz. Fossil mollusks are locally abundant. The thickness ranges from 6 to 10 feet in the northern part of the outcrop area and is about 30 feet in the southern part of Kansas.

CIMARRONIAN STAGE

The Cimarronian Stage (O'Connor, 1963) includes the evaporite-bearing clastic rocks that form the upper two-thirds of the Lower Permian section in Kansas. This 1,900-foot sequence of rocks is divided into two groups of roughly equal thickness: the red and gray Sumner Group below, and the predominantly red Nippewalla Group above. Cimarronian rocks are exposed from Comanche to Cowley counties in southern Kansas and northward to Washington County (Fig. 1). The Cimarronian Stage is probably equivalent to the Leonardian Stage and the lower part of the Guadalupian Stage of the West Texas section.

Sumner Group

This division comprises about 1,000 feet of strata at the outcrop, chiefly shale and silty shale. Thick beds of salt occur in the subsurface. Gray shale predominates, but there are also beds of red, maroon, purple, and green shale, as well as dolomite, limestone, gypsum, and anhydrite.

WELLINGTON FORMATION

In its outcrop area the Wellington is predominantly shale with minor amounts of limestone and dolomite, siltstone, and gypsum and anhydrite (Swineford, 1955). The shales are chiefly gray and greenish-gray, with some red, maroon, and purple shale. The limestones and dolomites are generally light colored and argillaceous. Thick beds of salt are present in the subsurface. The Wellington includes marine and brackish- and fresh-water deposits. *Lingula, Derbyia,* mollusks, ostracodes, and cup corals are found in the lower part. Conchostracans (clam shrimp) and carbonized plant remains are found in much of the Wellington with the exception of the uppermost part (Tasch, 1964 [1966]). Well-preserved fossil insects occur at several horizons. The thickness of the formation is about 700 feet.

HOLLENBERG LIMESTONE MEMBER

A bed of argillaceous, dolomitic limestone, not definitely known to be of widespread occurrence, has been named the "Hollenberg Limestone Member" in Washington County and tentatively identified in Cowley and Clay counties. The thickness is 1 to 5 feet.

CARLTON LIMESTONE MEMBER

The lenticular Carlton Limestone Member (in some places dolomitic) occurs below the Hutchinson Salt Member. Freshwater deposits in this member contain fossil insects.

HUTCHINSON SALT MEMBER

The Hutchinson Salt Member occurs in the subsurface in Central Kansas. Because it is highly soluble, it is not found in outcrops of the Wellington. The thickness of the member in the subsurface exceeds 700 feet in Clark County (Kulstad, 1959).

MILAN LIMESTONE MEMBER

The Milan Limestone Member consists of one to three thin beds of greenish-gray shaly limestone or fine-grained dolomitic limestone containing barite, which on the outcrop are characterized by bright-green copper carbonate. A thin bed of maroon and gray shale commonly underlies the topmost limestone bed. Where the member is absent the change in color from gray to purplish-red shale or reddish-brown shale may be regarded as the upper boundary. The member may be as much as 8 feet in thickness.

NINNESCAH SHALE

The Ninnescah is a predominantly silty shale, mostly red, but containing some gray shale, argillaceous limestone and dolomite, and calcareous siltstone. Some weathered surfaces show bright-green copper carbonate. Several distinctive beds of calcareous or dolomitic siltstone and calcareous shale have been traced for long distances. Clam shrimp [*Cyzicus (Lioestheria)*] are common, particularly in nonred layers. Some of the beds show ripple marks. Rosette-shaped calcareous concretions occur in the middle part. Weathering and erosion of these beds have produced the "Red Jaw" country in Reno County. This unit contains much salt in the subsurface in southwestern Kansas. The formation thins northward and is only about 50 feet thick in the subsurface

near the Nebraska state line. The maximum outcrop thickness, however, is about 450 feet; the average thickness is about 300 feet.

RUNNYMEDE SANDSTONE MEMBER

This member, which marks the top of the Ninnescah Shale, is a very fine-grained, gray to grayish-green siltstone and sandstone. The thickness is about 7 to 8 feet.

STONE CORRAL FORMATION

The Stone Corral Formation is composed of dolomite, anhydrite, gypsum, and salt. The anhydrite, gypsum, and salt portions are lost through solution in exposed sections and the remaining dolomite ledge is cellular or contains numerous calcite-filled or gypsum-filled vugs. The dolomite ledge is not well developed south of Rice County. Parts of the formation are oölitic in Rice County. The color is chiefly gray but locally there are red and pink streaks. Ripple marks are common. At some exposures the formation is chiefly red shale, bounded above and below by thin dolomite beds. The outcrop belt is interrupted in eastern Rice, western McPherson, and other counties to the south by eastward overlap of Cenozoic deposits. The Stone Corral is one of the most readily recognized "key beds" in the Kansas subsurface red-beds section, as it produces well-marked reflections in seismograph surveys. Maximum measured thickness at the outcrop is about 6 feet.

Nippewalla Group

This group includes the generally unfossiliferous strata below the Whitehorse Formation and above the Stone Corral Formation and is widely exposed in south-central Kansas south of the Arkansas River. The rocks are mostly red beds that form a nearly featureless plain. In Barber County and adjacent areas, where gypsum beds make prominent escarpments, the Nippewalla forms highly dissected badland topography. It contains thick salt beds in the subsurface. The total thickness on the surface is about 930 feet.

HARPER SANDSTONE

This formation is chiefly red argillaceous siltstone and very fine silty sandstone divided into two members. It crops out in Harper, Kingman, Reno, and Rice counties. The thickness is about 220 feet.

CHIKASKIA SANDSTONE MEMBER

The Chikaskia is composed of siltstone, silty sandstone, and shale, which are predominantely red but may be gray or other colors. It contains fine-grained, ripple-marked, and locally cross-bedded sandstone in the lower part. Some white sandy siltstone and dolomite lenses and concretions occur in the upper part. This member thins northward along the outcrop. The thickness ranges from about 100 to 160 feet.

KINGMAN SANDSTONE MEMBER

The Kingman Sandstone Member is a red argillaceous siltstone and silty sandstone with a few beds of red shale and white sandstone. A prominent bed of white sandy siltstone, 3 feet thick, occurs at the base. The thickness is about 80 feet.

SALT PLAIN FORMATION

This formation is composed chiefly of red, flaky, silty shale and some siltstone. There are two prominent coarse silty sandstone beds, the lower one, the *Crisfield sandstone bed*, about 29 feet thick, occurring about 115 feet below the top of the formation, and the upper, about 25 feet thick, occurring about 42 feet below the top of the formation. The coarse silty sandstones are in part cross-bedded. Outcrops in eastern Barber, Harper, and southern Kingman counties form a surface of low relief. The thickness is about 265 feet.

CEDAR HILLS SANDSTONE

The Cedar Hills Sandstone comprises feldspathic sandstone, siltstone, and silty shale, chiefly red, and beds of white sandstone in the upper and lower parts. The upper sandstone bed contains "snowballs" of white gypsum. Shaly siltstones are interbedded with the more resistant and more massive coarse siltstones and very fine sandstones. The Cedar Hills crops out in Barber County. The thickness is about 180 feet.

FLOWER-POT SHALE

The Flower-pot Shale (formerly Flowerpot) consists of about 180 feet of reddish-brown gypsiferous shale and silty shale with a few thin beds of sandstone and siltstone. A thin lenticular bed of dolomitic sandstone has been observed in the middle part, and the formation is cut by intersecting veins of satin spar (gypsum). Thin fine-grained sandstones occur near the top. The formation is exposed in Barber, southeastern

Kiowa, southeastern Clark, and Comanche counties. Outcrops are strewn with white, pink, and red satin spar and clear crystals of selenite.

BLAINE FORMATION

This formation consists mainly of gypsum beds separated by dolomite and red shale. It is divided into four members. In many places the upper three members are absent (Swineford, 1955). Outcrops are found in Clark, Comanche, Kiowa, and Barber counties. The thickness is about 50 feet.

MEDICINE LODGE GYPSUM MEMBER

This is the thickest bed of gypsum in Kansas, and it forms a conspicuous rim rock at the top of steep slopes of the Flower-pot Shale. Ordinarily there is a bed of oölitic dolomite and anhydrite at the base, which ranges from 0.5 to 1 foot in thickness. The maximum thickness of the member is 30 feet or more; the average is 20 feet.

NESCATUNGA GYPSUM MEMBER

This member includes 8 feet or less of red shale underlying 2 to 8 feet of gypsum, which is overlain by 8 feet or less of red shale. The gypsum bed pinches out in Comanche County and is absent in Barber County.

SHIMER GYPSUM MEMBER

The Shimer Gypsum Member consists of 13 to 23 feet of gypsum overlying 0.5 foot to 1.5 feet of oölitic dolomite.

HASKEW GYPSUM MEMBER

This member consists of 1 foot or less of gypsum underlain by about 5 feet of red shale. The gypsum in most places has been removed by solution.

DOG CREEK FORMATION

Maroon silty shale, siltstone, very fine-grained feldspathic sandstone, thin layers of dolomite, dolomitic sandstone, and gypsum comprise the Dog Creek Formation (formerly Dog Creek shale). The top generally is marked by about 3 feet of maroon shale, but locally a gypsum bed about 1 foot thick and having red and white laminae occurs at the top. The most persistent part is a 6-foot bed of white and red very fine-grained sandstone, that locally is capped by dolomitic sandstone, which occurs next below the upper maroon shale. The outcrops are in southeastern Kiowa, eastern Comanche, and western Barber counties. The thickness ranges from 14 to 53 feet. Where the upper three gypsum members of the Blaine Formation are missing the Dog Creek includes the shales overlying the Medicine Lodge Member.

Upper Permian Series

The revised Upper Permian Series includes beds from the base of the Whitehorse Formation through the Big Basin Formation (O'Connor, 1963). These comprise red sandstones, shales, and siltstones, and a minor amount of dolomite. They are seemingly unfossiliferous. Upper Permian rocks are exposed along the Kansas-Oklahoma border from Barber County to Meade County. The thickness of the series is about 315 feet. It contains only one stage (Custerian).

CUSTERIAN STAGE

Fay (1965) named the Custerian Series and included in it the Whitehorse Group, the Cloud Chief Formation, the Doxey Shale, and the Elk City Sandstone of Oklahoma. The Custerian Stage is adapted herein for those rocks from the base of the Whitehorse Formation to the top of the Big Basin Formation. The Custerian Stage includes 315 feet of red sandstone, siltstone, gypsum, and dolomite.

WHITEHORSE FORMATION

Red beds of feldspathic sandstone, siltstone, and shale with a minor amount of dolomite comprise the Whitehorse Formation. Cross bedding is common and the formation is characterized by small calcite-cemented "sand balls." It crops out in Clark, Comanche, Barber, and southeastern Kiowa counties. The thickness is about 270 feet.

MARLOW SANDSTONE MEMBER

The Marlow Sandstone Member consists of about 100 feet of massive, fine-grained, locally argillaceous or silty, cross-bedded red sandstone. "Sand balls" are locally prominent.

RELAY CREEK(?) DOLOMITE MEMBER

This member consists of two beds of dolomite separated by about 21 feet of red and white fine-grained sandstone. The dolomite beds are found only in southern Comanche County. They range in thickness from 0.3 to about 1 foot, and in places one or both may be absent. Locally anhydrite or gypsum occupies this interval. The sandstone is cross-bedded at some localities. The member is about 22 feet thick.

Overlying the Relay Creek(?) Member is a very fine-grained sandstone and shaly siltstone "member" that is mostly even-bedded but locally is cross-bedded in the upper part. It contains "sand balls" and "sand crystals." The color is brick-red and maroon, and the thickness is about 100 feet.

KIGER SHALE MEMBER

The Kiger Shale Member (O'Connor, 1963) comprises beds of silty shale, siltstone, and a minor amount of very fine-grained sandstone, mostly brick-red or maroon. Locally it contains a bed of dolomite in the basal part and a bed of gray-green sandy shale or argillaceous sandstone in the upper part. The thickness is about 38 feet.

DAY CREEK DOLOMITE

This formation is a light-gray to pink, dense, fine-grained dolomite cropping out in Clark County and locally in southern Comanche County. At some localities the formation contains chert nodules and disseminated chert. The thickness is about 2 to 3 feet.

BIG BASIN FORMATION

Beds of red silty shale, siltstone, dolomitic siltstone, and very fine-grained feldspathic sandstone, the "Taloga" of earlier reports, belong to the Big Basin Formation (O'Connor, 1963). It crops out in western Clark and eastern Meade counties. These strata are seemingly equivalent, all or in part, to the Quartermaster Formation in Oklahoma. The maximum exposed thickness is about 45 feet.

MESOZOIC ERA

Most of the deposits of Mesozoic age in Kansas belong to the Cretaceous System. Older Mesozoic rocks, representing the Jurassic System, are identified in well borings and locally in two small exposures in Morton County.

The outcrops of Mesozoic strata in Kansas are confined to the western two-thirds of the State. They extend much farther eastward along the northern border (eastern Washington County) than along the southern border (Barber County); in central Kansas exposures are found eastward as far as Dickinson and Marion counties. Mesozoic rocks are unconformably separated from Paleozoic and Cenozoic rocks. The aggregate thickness of Mesozoic rocks is about 3,350 feet (Merriam, 1963).

JURASSIC SYSTEM

By HOWARD G. O'CONNOR

Deposits judged to be Jurassic in age (Fig. 9) occur in the subsurface in northwestern Kansas and crop out in a small area in southern Morton

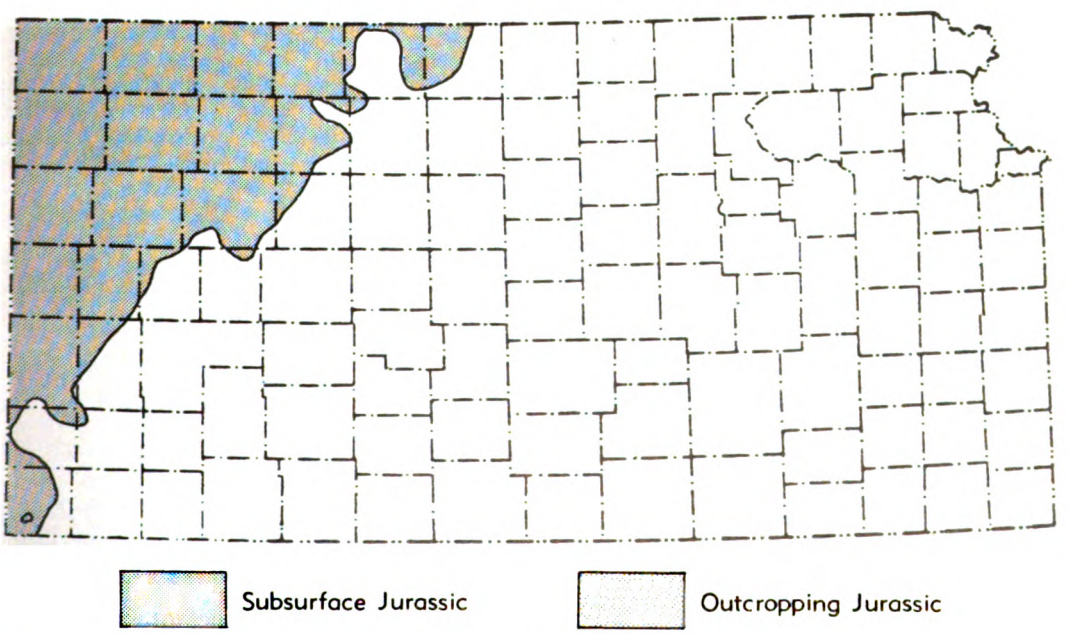

FIGURE 9. Distribution of Jurassic rocks in Kansas. (Modified from Moore, *et al.*, 1951.)

County. They consist primarily of varicolored shales and red sandstones and attain a maximum thickness of about 350 feet. In the subsurface they pinch out eastward along an irregular line extending from Morton County to Smith County and, in general, thicken toward the west. The Jurassic beds in southwestern Kansas, formerly classified as Triassic, Dockum (?) Group, have been restudied and are now designated as undifferentiated Jurassic (E. D. Gutentag, personal communication with H. G. O'Connor, 1966, 1967; see also Voegeli and Hershey, 1965).

Upper Jurassic Series

In Morton County undifferentiated beds of red siltstone and buff, green, and white sandstone that are believed to be equivalent in part to the Entrada Sandstone of Colorado underlie the Morrison Formation and overlie the Permian Big Basin Formation. The maximum exposed thickness is about 40 feet, but in the subsurface of Stanton and Hamilton counties, the thickness is about 250 feet (Gutentag, *ibid.*).

MORRISON FORMATION

The upper Morrison beds are chiefly green sandy shale containing limestone lenses. The lower shale beds contain pink chert, anhydrite, and gypsum. Where noted in wells, the Morrison Formation ranges in thickness from 100 to 350 feet (Merriam, 1963).

CRETACEOUS SYSTEM

By HOWARD G. O'CONNOR

Rocks of Cretaceous age crop out at the surface or underlie much of central and western Kansas (Fig. 10). These rocks are mostly marine, but parts of the Cheyenne Sandstone and Dakota Formation are of nonmarine origin. The predominant lithology of rocks of the system is shale. Chalk, limestone, and chalky shale comprise most of the middle beds. Sandstone is conspicuous in the lower beds. The thickness of the Cretaceous System in Kansas is about 3,000 feet.

A major unconformity occurs at the base of the Cretaceous rocks. The contact is marked locally by a zone of pebbles and cobbles. The Cretaceous rocks overlap northward on the pre-Cretaceous erosion surface, with successively younger beds lying above the contact northward across the State, ranging from the Cheyenne Sandstone in Comanche and Kiowa counties to the Dakota Formation in Washington County. Rocks underlying the unconformable contact range from the Permian Herington Limestone Member in Washington County to beds believed to be of Jurassic age in northwestern Kansas.

In the subsurface, rocks assigned to the Lower Cretaceous Series display lateral variability and progressive overlap on pre-Cretaceous rocks. Rocks of the Upper Cretaceous Series display a remarkable degree of uniformity throughout their area of occurrence in the State; although some progressive changes in thickness occur, their essential characteristics remain the same.

Lower Cretaceous Series

The Lower Cretaceous Series in Kansas (formerly Comanchean Series) is correlated with the Comanchean Series of Texas on evidence of abundant fossils found in the Kiowa Formation.

The oldest Cretaceous deposits in Kansas represent nonmarine and littoral deposits laid down as the sea advanced northeastward. The nonmarine deposits rapidly gave way to sediments laid down in a brackish-marine environment, and marine shales and sandstones overlie and overlap the older nonmarine deposits. Lower Cretaceous rocks crop out in a belt extending diagonally across Kansas from Washington County to Comanche County, and in scattered areas in southwestern Kansas. The maximum thickness is about 400 feet.

CHEYENNE SANDSTONE

The Cheyenne Sandstone comprises massive, white to buff to light-gray, mostly fine-grained, and partly cross-bedded sandstone, lenses of gray sandy shale and conglomerate, and locally minor amounts of clay, selenite crystals, ironstone nodules, and pyrite. A zone of pebbles and cobbles occurs locally at the base. Plant fossils are found in the dark shales in the upper part. The thickness in outcrops in Barber, Kiowa, and Comanche counties ranges from 0 to 94 feet. The Cheyenne thickens westward in the subsurface. The maximum subsurface thickness is 300 feet.

KIOWA FORMATION

The Kiowa Formation[1] (formerly Kiowa Shale) consists chiefly of light-gray to black, illitic shale (Franks, 1966). Locally it contains

[1] The State Geological Survey of Kansas has adopted the proposal by Paul C. Franks (1966) to change the name "Kiowa Shale" to "Kiowa Formation."

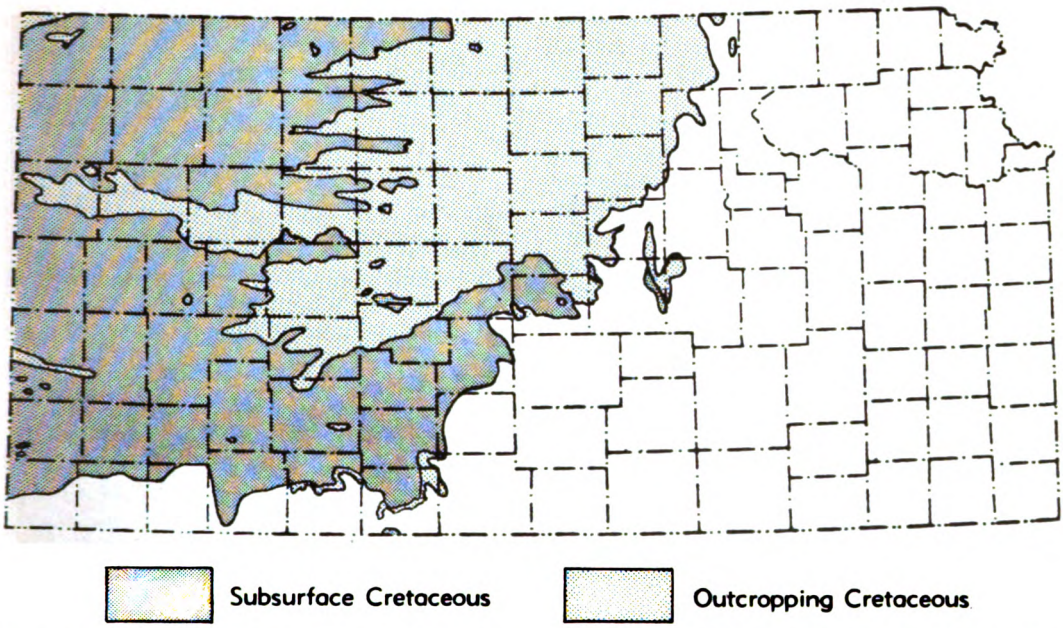

FIGURE 10. Distribution of Cretaceous rocks in Kansas. (Adapted from Moore, *et al.*, 1951; State Geol. Survey Kansas, 1964.)

thin coquinoidal limestone beds, with the *"Champion shell bed"* (Cragin, 1895) at the base in much of the type area. Fossil plants are found in several beds in the Kiowa. Sandstone lenses occur within the shale sequence, but are most abundant in the upper parts of the formation in central and southwestern Kansas. Locally, in north-central Kansas, sandstone may approximate as much as 80 percent of the Kiowa Formation. Lenses and concretions of calcareous cone-in-cone are common in the shale. Sandstone with calcite cement is locally abundant. Selenite crystals are common on weathered slopes. The Kiowa pinches out or becomes unidentifiable in north-central Kansas at about the Clay-Washington county line; it thickens southwestward to achieve a maximum thickness in the type area in Kiowa County. The top commonly is marked by bench-forming sandstone showing cross-stratification, transverse ripple marks, small U-shaped burrows, and concretionary masses of calcite cement. Along the eastern fringes of much of the Kiowa outcrop belt in north-central Kansas, the lower parts of the Kiowa Formation are marked by a bed or zone of siltstone that is underlain by gray mudstone and claystone with red mottles, carbonaceous dark-gray claystone and mudstone, and lignitic material. The thickness ranges from 60 to 150 feet.

DAKOTA FORMATION

The Dakota Formation comprises white, gray, red, brown, and tan kaolinitic claystone, mudstone, shale, and siltstone, as well as interbedded and lenticular sandstone. It contains carbonaceous material, lignite, and locally sandstone cemented with calcite or iron oxide. Granular aggregates of iron oxide are seen on weathered surfaces. Grains or pellets of siderite are common in much of the claystone and mudstone. The Dakota Formation occurs in north-central and western Kansas. It contains fossil plants and land vertebrates. The thickness ranges from 200 to 300 feet (Franks, 1966).

[Note: In Kansas, the Dakota Formation is underlain by the Kiowa Formation, which is Lower Cretaceous and is correlated with the Kiamichi and Duck Creek formations of the Comanchean Series of Texas. Although the Dakota Formation is largely devoid of diagnostic marine fossils, fossils of supposed Early Cretaceous age have been found near the top of the Dakota Formation in its type area in northeastern Nebraska (Tester, 1952) and also in southeastern Colorado (McLaughlin, 1954). More recently, a faunal assemblage found at the top of the Dakota Formation in central Kansas has been assigned a Late Cretaceous age (Hattin, 1967). Thus, the boundary between the Lower and Upper Cretaceous cannot be located accur-

ately and, in most places, properly should be placed within the Dakota Formation.]

TERRA COTTA CLAY MEMBER

This member consists of interbedded claystone, shale, and siltstone, which are mainly gray or greenish-gray with abundant red mottles. Grains and pellets of siderite are common in the claystone and siltstone. The Terra Cotta contains abundant interbedded and lenticular, fine- to coarse-grained sandstone, cemented with iron oxide, and locally it is cemented with calcite. The sandstone generally weathers brown. Carbonaceous matter and lignitic beds are common near the base. The thickness ranges from 70 to 200 feet.

JANSSEN CLAY MEMBER

Gray to dark claystone, siltstone, and fissile shale, with lenticular sandstone, lignite, and lignitic clay make up the Janssen Clay Member. Locally it contains lenses or beds of red mottled greenish-gray claystone and siltstone with abundant grains and pellets of siderite. Concretionary iron oxide is common near the base of the member. The Janssen occurs in central and north-central Kansas. The thickness ranges from 30 to 80 feet.

Upper Cretaceous Series

In Kansas, the Upper Cretaceous Series (formerly Gulfian Series) is represented by marine shales and limestones constituting the Colorado and Montana groups. Its thickness is about 2,500 feet.

Colorado Group

Calcareous and noncalcareous shales and chalk of this group underlie the surface of and crop out in north-central, northwestern, and west-central Kansas. Limestone is interbedded with the calcareous shales. These rocks are all of marine origin. Their thickness is about 900 feet.

GRANEROS SHALE

The predominant lithology of this formation is fissile, noncalcareous, medium-gray to dark-gray shale that weathers to shades of gray and yellowish-brown. Beds of calcareous and noncalcareous sandstone and siltstone lie in the middle part of the Graneros Shale at many localities. Clay-ironstone and calcareous septarian concretions occur locally in the shale beds. Selenite crystals are abundant on the weathered shale slopes. Several layers of bentonite and beds of skeletal limestone lie in the middle and upper part of the formation. *Ostrea, Inoceramus* prisms, and fish scales are found locally. The thickness ranges from 24 to 44 feet in central Kansas (Hattin, 1965) to 65 feet near the Colorado state line.

GREENHORN LIMESTONE

This formation comprises thin-bedded, light-gray to dark-gray, chalky limestone and calcareous shale that weathers yellowish-gray to light gray. The thickness is 64 feet in Ellsworth County, 95 feet in Ellis County, and 132 feet in Hamilton County.

LINCOLN LIMESTONE MEMBER

The Lincoln Limestone Member is made up of interbedded, light-gray chalky shale and chalky limestone that weathers to yellowish-gray or yellowish-tan. Beds of dark-gray, petroliferous, hard, crystalline limestone occur at the base and the top of the member. The shales contain thin beds of bentonite. Fossils include *Inoceramus* and sharks' teeth. The thickness ranges from about 2 to 35 feet.

HARTLAND SHALE MEMBER

This member comprises gray, chalky shale with a few thin beds of chalky limestone and bentonite. The upper part becomes more chalky southwestward. Fossils include *Inoceramus* and ammonites. The thickness ranges from 23 feet in Kearny County to 35 feet in Ellis County.

JETMORE CHALK MEMBER

The Jetmore Chalk Member contains interbedded gray chalky shale and chalky limestone that weathers light gray. A small species of *Inoceramus* is common in the "shell rock limestone" at the top of the member. Ammonites occur in some beds. The thickness averages 22 feet.

PFEIFER SHALE MEMBER

The Pfeifer Shale Member consists of interbedded chalky shale and chalky limestone. The *Fence-post limestone bed*, at the top of the member, is bluish-gray, weathering light tan. In Hamilton County the Pfeifer Shale Member and the underlying Jetmore Chalk Member are thicker than they are farther to the east. In this county where the two members cannot be distinguished, they have been called the "Bridge Creek limestone member," and have a total thickness of 74 feet (Bass, 1926). The limestone beds contain *Inoceramus labiatus*. The thickness of the Pfeifer averages 20 feet.

CARLILE SHALE

This formation consists of chalky shale with bentonites and thick chalk beds, dark-gray fissile shale containing large septarian concretions, and fine-grained sandstone. The thickness is about 300 feet.

FAIRPORT CHALK MEMBER

This member (formerly Fairport chalky shale member) comprises bluish-gray to gray, chalky shale, chalky limestone, and calcareous shale that weathers to yellowish-gray and grayish-orange. Thin bentonite beds occur throughout the member. Chalky limestone is more abundant near the base. Fossils include *Inoceramus* and *Ostrea*, and ammonites, fish scales, and sharks' teeth. Worm tubes, bryozoans, and barnacles are common in the middle part of the member (Hattin, 1962). The thickness is 85 feet in Russell County and 147 feet in Hamilton County.

BLUE HILL SHALE MEMBER

The Blue Hill Shale Member is a dark-gray, clayey, blocky to fissile, shale. It becomes more sandy toward the top. Calcareous septarian concretions and clay-ironstone concretions occur in several zones. Pyrite nodules and selenite crystals are common locally. The most common fossils are pelecypods and ammonites. The thickness ranges from about 70 feet in Hamilton County to 200 feet in Jewell County.

CODELL SANDSTONE MEMBER

This member (formerly called "the Codell sandstone zone") is fine-grained, silty sandstone that locally becomes shaly. The lower contact is usually gradational. Fossils are sparse. The maximum thickness is 25 feet in northern Ellis County, thinning to about 1 foot to the northeast and south.

NIOBRARA CHALK

This formation (formerly Niobrara formation) consists of interbedded, soft, light-gray calcareous shale and chalk. It crops out in a belt trending generally northeast-southwest and extending from north-central to western Kansas. The thickness is 500 to 750 feet in Logan and Wallace counties and averages 600 feet.

FORT HAYS LIMESTONE MEMBER

The Fort Hays Limestone Member is a massively bedded, gray to cream-colored chalk or chalky limestone. Thin beds of light- to dark-gray, chalky shale separate the massive chalk beds. The Fort Hays is characterized by a large species of *Inoceramus*. The thickness ranges from 30 feet in Jewell County to 65 feet near the Colorado state line.

SMOKEY HILL CHALK MEMBER

The Smoky Hill Member comprises gray, shaly chalk and interbedded shale and chalk that weathers white, yellow, and orange. The Smoky Hill contains limonitic concretions and locally, massive chalk beds. A notable fossil is a species of *Inoceramus* which may attain 3 feet in length. Other invertebrates include *Ostrea* and occasional ammonites. The member contains well-preserved vertebrates, both fish and reptile. The thickness ranges from 450 to 700 feet.

MONTANA GROUP

The Montana Group comprises dark-colored marine shales that occur in northwestern Kansas. Only one formation in this group is present in Kansas.

PIERRE SHALE

This formation consists of thin-bedded, black to dark- gray and light-gray shale that weathers to gray and coffee-brown. It contains concretions, selenite crystals, thin beds of bentonite, and, locally, chalky beds. The thickness ranges from 1,000 to 1,600 feet.

SHARON SPRINGS SHALE MEMBER

The Sharon Springs is a flaky, black, somewhat bituminous shale. Large clay-ironstone septarian concretions and calcareous concretions are abundant in the upper part. A few beds of light-gray shale and, locally, thin chalk beds are found in the lower part. The thickness is 155 feet.

WESKAN SHALE MEMBER

The Weskan is a gray, clayey shale. It contains large calcareous concretions and some limonite. Bentonite beds are most abundant in the lower part. The thickness is 170 feet.

LAKE CREEK SHALE MEMBER

This member is a dark-gray to black, thin-bedded, flaky shale. It contains limestone concretions, zones of concretionary limonite, and, locally, gypsum. The thickness is 200 feet.

SALT GRASS SHALE MEMBER

The Salt Grass is a gray, clayey, shale containing numerous thin bentonite beds, calcareous concretions, and concretionary limonite zones distributed throughout. Its thickness is 60 feet.

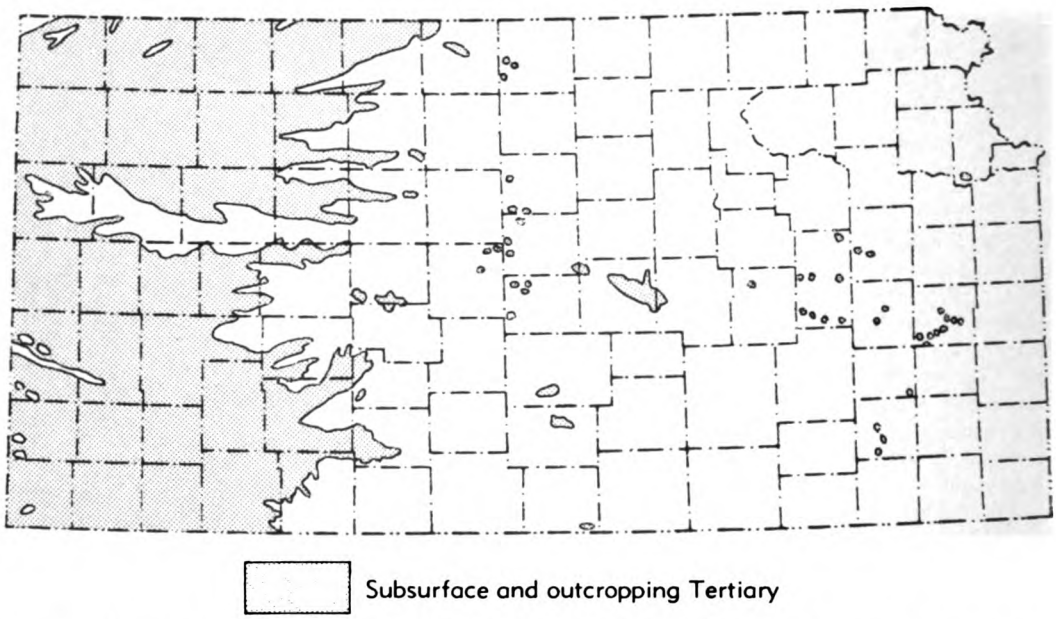

FIGURE 11. Distribution of Tertiary rocks in Kansas. (Adapted from Moore, *et al.*, 1951; State Geol. Survey Kansas, 1964.)

Lying between the Salt Grass Shale Member and the Beecher Island Shale Member is from 500 to 600 feet of undifferentiated gray to black shale.

BEECHER ISLAND SHALE MEMBER

The Beecher Island is a gray shale containing calcareous concretions in the lower part, thin beds of bentonite, limonitic concretions throughout, and irregular concretionary limestone near the top. The thickness is about 100 feet.

CENOZOIC ERA

Deposits of Cenozoic age are widespread in Kansas. They constitute a discontinuous veneer upon the eastward-sloping pre-Cenozoic erosion surface and comprise Tertiary deposits that cover much of western Kansas but are of only local occurrence elsewhere, and Quaternary sediments that include glacial deposits in northeastern Kansas and nonglacial deposits of Pleistocene age in all parts of the State.

TERTIARY SYSTEM

By CHARLES K. BAYNE
and HOWARD G. O'CONNOR

Deposits of Tertiary age occur widely in western Kansas and locally in central and eastern Kansas (Fig. 11). The Tertiary rocks are nonmarine and are predominantly stream-laid deposits. The source of most of these deposits was to the west, principally the area of igneous rocks in the Rocky Mountain Region and the area of sedimentary rocks in eastern Colorado and extreme western Kansas. The thickness of the Tertiary deposits ranges from a few feet to more than 350 feet, but the maximum thickness has nowhere been observed at the surface. At one time the Tertiary alluvium constituted a surface of low relief that merged westward with the erosion surface in the Rocky Mountains and eastward with the Flint Hills, which formed a divide in east-central Kansas. The Flint Hills was a local source of sediment (mostly chert gravels). A short distance west of the Flint Hills, chert gravels are interfingered with arkosic material derived from the Rocky Mountains. Tertiary deposits east of the Flint Hills are largely accumulations of chert gravel in a brownish-red clay and are less than 20 feet thick. These occur as dissected terrace deposits at elevations 100 to 200 feet higher than the present major streams. Some of these chert gravels are believed to be of Pliocene age or older. No formal stratigraphic name has been applied to these gravels derived from the Flint Hills Region.

Tertiary rocks unconformably overlie beds of Cretaceous, Jurassic, Permian, and Pennsylvanian ages.

Pliocene Series

Rocks of Tertiary age in Kansas are all included in the Pliocene Series. One formation is recognized.

OGALLALA FORMATION

The Ogallala is massive to cross-bedded, generally arkosic gravel, sand, and silt, locally cemented with calcium carbonate. It is greenish-gray, pink, red, tan, and ash-gray in color. It contains limestone, volcanic ash, diatomaceous marl, opaline sandstone, and bentonitic clay. It contains diagnostic vertebrate and plant fossils. The Ogallala is distributed widely over the western one-third of Kansas and in a few places in the central part of the State. The maximum thickness of the Ogallala is about 350 feet.

The Delmore Formation, consisting of sands and gravels in McPherson and nearby counties, is equivalent in part to the Ogallala (Frye, Leonard, and Swineford, 1956, p. 57). The Rexroad Formation, which is late Pliocene in age, is probably equivalent to the upper part of the Ogallala. Similarly, some of the chert gravels in upland positions east of the Flint Hills may be of Pliocene age.

VALENTINE MEMBER

The Valentine Member consists of greenish-gray, pink, and gray silt, sand, and gravel that is loosely cemented locally forming "mortar beds." It also contains opaline sandstone, bentonitic clay, and diatomaceous marl. The *Stipidium* fossil seed zone occurs in this member. The maximum thickness is more than 100 feet. The Valentine occurs only in topographically low positions on the Mesozoic and Paleozoic erosional surface where it is overlain by the Ash Hollow Member.

ASH HOLLOW MEMBER

Sand, gravel, and silt of the Ash Hollow Member is loosely cemented in many zones forming "mortar beds." The member contains soft, diatomaceous marl and volcanic ash. It is predominantly pink and gray in color. This member is the most widely occuring unit of the Ogallala in Kansas. It appears that "basin-fill" deposits in Kansas that have been called "Laverne" are probably equivalent in age to upper Ash Hollow deposits (Claude W. Hibbard, personal communication with Charles K. Bayne, 1964). The basal Ash Hollow is characterized by the *Krynitzkia coroniformis* fossil seed zone. The maximum thickness of the Ash Hollow is more than 130 feet.

KIMBALL MEMBER

Gray sand, gravel, and silt, secondary opal and chert, and caliche make up the Kimball Member. Locally a hard pisolitic limestone (mature caliche, formerly called an "algal limestone") occurs at the top, and coarse channel gravels, probably comparable to the Sidney gravels of Nebraska, at the base. It is exposed at scattered localities, principally in northwestern and north-central Kansas. The occurrence of the fossil seeds *Prolithospermum johnsoni, Berrichloa minuta,* and *B. maxima* together is an accurate guide to the Kimball Member. The thickness commonly is 35 feet.

QUATERNARY SYSTEM

By CHARLES K. BAYNE
and HOWARD G. O'CONNOR

Quaternary deposits, chiefly unconsolidated, are widely distributed but discontinuous across the State. The rocks of this system are all included in a single series, the Pleistocene (Table 3). At most localities where noneolian deposits have been observed in contact with older rocks, there is evidence of significant erosion or weathering prior to Pleistocene deposition. Rocks of Pleistocene age lie uncomformably upon all older outcropping formations. The deposits are of nonmarine origin and include glacial, lacustrine, fluvial, and eolian sediments. Glacial sediments occur only in northeastern Kansas, whereas stream-laid deposits occur generally throughout the State in the stream valleys (Fig. 12). Windlaid deposits occur throughout the State, also, but are most extensive in northern and western areas (Fig. 13). Loess is the most widespread Quaternary deposit and forms the immediate surface material over approximately one-half the area of the State. Much of the fertile topsoil of Kansas has been developed from Quaternary alluvium and loess. Lacustrine deposits are most commonly associated with the glacial deposits in northeastern Kansas.

Subsurface investigations have revealed abandoned filled valleys in areas where the present surface topography is of relatively low relief. McPherson valley and Wilson valley of central Kansas, an extensive network of filled valleys in Rice County and in the area of the Great Bend sand dune tract, and the valleys in Marshall, Nemaha, Jackson, Atchison, Brown, and Doniphan counties are examples of these abandoned filled valleys (Frye and Leonard, 1952, p. 194). More than 450 feet of Quaternary deposits have been penetrated in drilling in Grant and Stanton

counties. The maximum composite thickness is nearly 1,000 feet.

Pleistocene Series

Worldwide periodic climatic fluctuation was the most characteristic phenomenon of the Pleistocene Epoch. Four periods of continental glaciation and four interglacial intervals are recognized. The glaciations resulted in worldwide lowering of sea levels and cycles of erosion and deposition on the continents. At the beginning of each glaciation or glacial stage there was a sharp reduction in both chemical weathering and soil formation and a pronounced acceleration of stream erosion. From approximately the mid-glacial to the early part of the next interglacial stage a cycle of deposition occurred, marked by a sequence of coarse- to fine-grained sediments in the stream valleys. Deposition of glacial till and outwash material characterized the glaciated area of Kansas, and in the latter part of each glaciation, widespread deposits of eolian silts were laid down, especially adjacent to the stream valleys carrying glacial outwash

The four interglacial stages, the Aftonian, Yarmouthian, Sangamonian, and Recent, are characterized by warmer climates and stable land surfaces in which neither erosional nor depositional processes were dominant. As a result, the interglacial periods are marked by the formation of distinct *geosols* (weathering pro-

TABLE 3.—Classification of deposits in the Pleistocene Series of Kansas.

<table>
<tr><th>Time-stratigraphic units</th><th colspan="6">Rock-stratigraphic units</th></tr>
<tr><td></td><td colspan="2">Northeastern area</td><td colspan="2">Southeastern area</td><td colspan="2">Central and Western area</td></tr>
<tr><td>Recent Stage</td><td colspan="6">Eolian and fluvial deposits</td></tr>
<tr><td rowspan="4">Wisconsinan Stage</td><td>Bignell Formation</td><td>Fluvial deposits</td><td>Bignell Formation</td><td>Fluvial deposits</td><td>Bignell Formation</td><td>Fluvial deposits</td></tr>
<tr><td colspan="6">Brady Soil</td></tr>
<tr><td>Peoria Formation
Gilman Canyon Formation</td><td rowspan="2">Fluvial deposits</td><td>Peoria Formation</td><td rowspan="2">Fluvial deposits</td><td>Peoria Formation</td><td rowspan="2">Fluvial deposits</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>Sangamonian Stage</td><td colspan="6">Sangamon Soil</td></tr>
<tr><td rowspan="2">Illinoisan Stage</td><td rowspan="2">Loveland Formation</td><td rowspan="2">Fluvial deposits</td><td rowspan="2">Loveland Formation</td><td rowspan="2">Fluvial deposits</td><td>Loveland Formation</td><td rowspan="2"></td></tr>
<tr><td>Crete Formation</td></tr>
<tr><td>Yarmouthian Stage</td><td colspan="6">Yarmouth Soil</td></tr>
<tr><td rowspan="5">Kansan Stage</td><td>Loess</td><td>Fluvial deposits*</td><td rowspan="5">Fluvial deposits*</td><td rowspan="3">Sappa Formation*</td><td rowspan="5"></td></tr>
<tr><td colspan="2">Cedar Bluffs Till</td></tr>
<tr><td colspan="2">Fluvial deposits</td></tr>
<tr><td colspan="2">Nickerson Till</td><td rowspan="2">Grand Island Formation</td></tr>
<tr><td colspan="2">Atchison Formation†</td></tr>
<tr><td>Aftonian Stage</td><td colspan="6">Afton Soil</td></tr>
<tr><td rowspan="3">Nebraskan Stage</td><td>Loess</td><td>Fluvial deposits</td><td rowspan="3">Fluvial deposits</td><td>Fullerton Formation</td><td rowspan="3"></td></tr>
<tr><td colspan="2">Iowa Point Till</td><td rowspan="2">Holdrege Formation</td></tr>
<tr><td colspan="2">David City Formation</td></tr>
</table>

* Locally contains the Pearlette ash bed.
† Atchison Formation has been defined as proglacial outwash of early Kansan age. Similar deposits of sand are found between the Nickerson Till and the Cedar Bluffs Till.

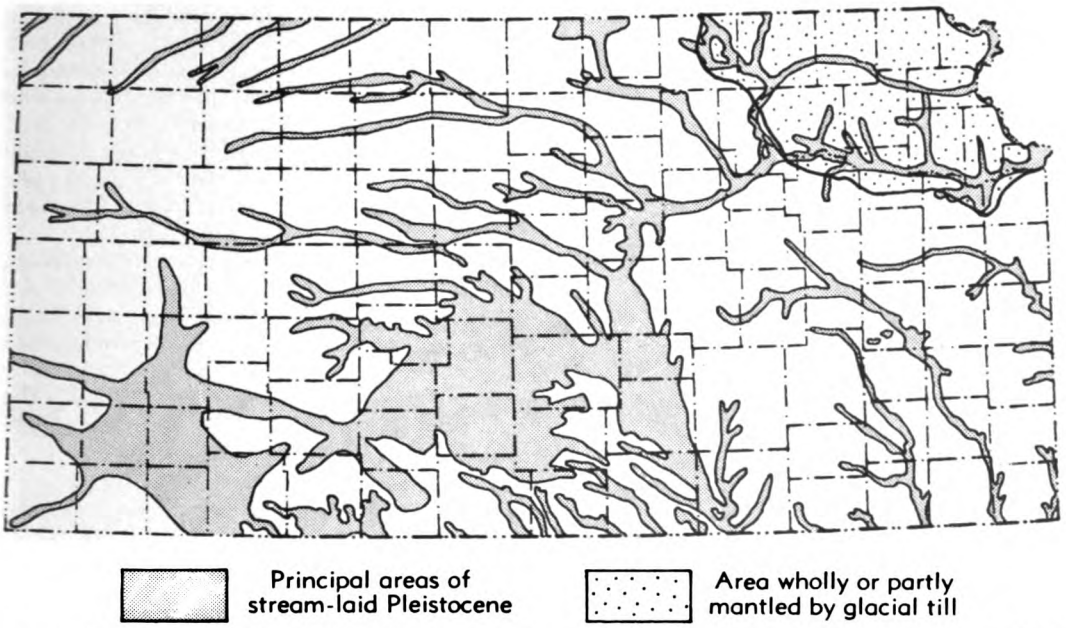

FIGURE 12. Distribution of noneolian Pleistocene deposits in Kansas. (Adapted from Frye and Leonard, 1952; State Geol. Survey Kansas, 1964.)

files) that are recognizable across Kansas and parts of adjacent states. Because the geosols are time-stratigraphic markers and the climatic factors that produced them are essentially worldwide and synchronous, they serve as a basis for interregional correlation in the middle latitudes.

The Pleistocene Series is divided into eight stages in the time-stratigraphic classification now used by the State Geological Survey of Kansas (Pl. 1). Some rock-stratigraphic names previously used throughout Kansas for units of the same age but of differing mineralogical composition and source are herein restricted in usage to geographical areas. Three general sedimentary areas are proposed (Table 3) in which the rock-stratigraphic units are genetically related. Interstadial intervals (unnamed) are recognized locally within the glacial stages and permit a further division of the deposits of each glacial stage.

Till of early Nebraskan age is not recognized in Kansas; however, fluvial deposits of this age are recognized in numerous exposures in the bluffs adjacent to the Missouri River. Till of Nebraskan age has been described (Frye and Leonard, 1949, p. 887-888) in Doniphan County. At this locality an interglacial soil (Afton Soil) is developed on the uneroded surface of the till, indicating a probable late Nebraskan age for this till, since erosion or truncation had not occurred before soil development began. The name *Iowa Point Till* (Reed and Dreeszen, 1965) is herein adopted for this till and the exposure in NE SE sec. 6, T 2 S, R 20 E in Doniphan County, Kansas, is the type locality.

Two tills of Kansan age with associated fluvial deposits and locally an interstadial soil, are present in northeastern Kansas. The older of these tills locally rests on the truncated surface of the Afton Soil and underlies the younger till and glaciofluvial deposits. The name *Nickerson Till* has been used for a till of similar age in Nebraska, and this term has been adopted herein for use in Kansas. The type locality is designated as a road cut in Washington County, Nebraska (Reed and Dreeszen, 1965, p. 27). The Nickerson Till is typically exposed in a gravel pit in the Missouri River bluffs adjacent to the river road 0.8 mile south of Wathena, Doniphan County, Kansas, near the center of sec. 33, T 3 S, R 22 E.

Till of Kansan age has been named *Cedar Bluffs Till* in the Platte River valley in Saunders County, Nebraska (Reed and Dreeszen, 1965, p. 32), and the name is herein adopted for use in Kansas. The Cedar Bluffs Till is typically exposed above the Nickerson Till near the center of sec. 33, T 3 S, R 22 E, and in a quarry in SE NW NE sec. 9, T 5 S, R 21 E, Doniphan County, Kansas, where a poorly developed interstadial soil underlies the Cedar Bluffs.

At some localities the Sangamon Soil formerly was considered to include an abnormally thick

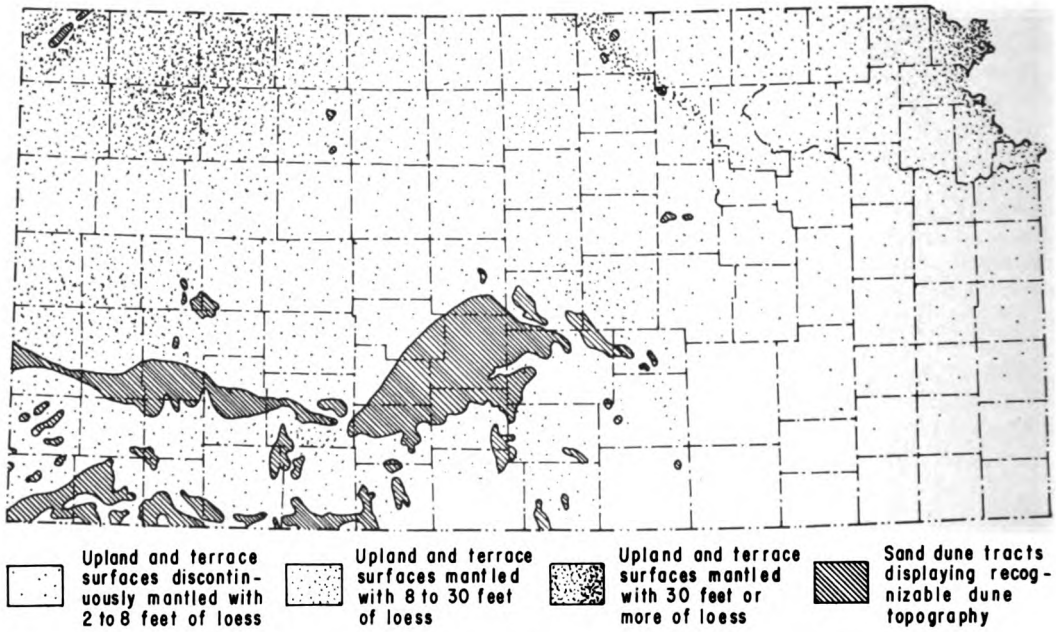

FIGURE 13. Distribution of eolian Pleistocene deposits in Kansas. (Adapted from Frye and Leonard, 1952; State Geol. Survey Kansas, 1964.)

A-horizon and a double A-horizon at some other localities. The upper part of the thick Sangamon A-horizon or the upper Sangamon A-horizon, where a double A-horizon occurs, is now recognized as a distinct depositional unit that is younger than Sangamonian and older than the Wisconsinan Peoria Formation. This unit, which is separated from the Peoria by a weakly developed soil horizon, is named the *Gilman Canyon Formation* in Nebraska (Reed and Dreeszen, 1965, p. 42). It has been recognized in northeastern Kansas (Table 3) and the name is adopted herein. The Gilman Canyon Formation is typically exposed in the south bank of a draw which parallels a private road near the center of sec. 12, T 3 S, R 21 E, Doniphan County, Kansas.

Because Pleistocene deposits are diverse and scattered in occurrence, these geologic units are described by areas (Table 3). The sequence in which they are described in each area is from the oldest to the youngest unit. In northeastern Kansas the area glaciated by Nebraskan and Kansan glaciers is roughly bounded by the Big and Little Blue rivers on the west and by the Kansas River on the south. The southeastern area includes the remainder of eastern Kansas south of the Kansas River and east of the Flint Hills. Central and western Kansas is the largest of the three areas and includes the remainder of Kansas.

Early stratigraphic studies of Pleistocene rocks in Kansas include deposits of unconsolidated light-gray and tan silts, sands, and gravels in McPherson, Harvey, and Sedgwick counties known as the *"Equus beds."* These were reported as Illinoisan or younger in age by Haworth (1897). Lohman and Frye (1940) reported that although part of these deposits were Pleistocene in age, a large part of them appeared to be Pliocene in age. The "*Equus* beds," which occur in the central and western area (Table 3), contain bones and teeth of Quaternary horses and are an important source of ground water.

During the **Nebraskan Stage** a continental glacier invaded extreme northeastern Kansas. Nebraskan till and outwash deposits are less extensive than are those of the Kansan glaciation. Fluvial deposits of Nebraskan age occur locally throughout the State, but quantitatively are much less than those of the Kansan Stage.

During **Aftonian** time soil-forming processes were predominant and the *Afton Soil* probably is present over much of Kansas but is not well exposed.

Sediments of the **Kansan Stage** are the most widespead of the Pleistocene deposits in Kansas. During the Kansan Stage continental glaciers advanced into Kansas to a position far beyond the limits of Nebraskan ice. Fluvial deposits of Kansan age exceed in volume those of any other

Pleistocene stage in Kansas. Eolian deposits of Kansan age are recognized only locally. The *Pearlette ash bed,* of widespread occurrence, is an important marker bed.

During the **Yarmouthian Stage,** like the other Pleistocene interglacial stages, climatic conditions were relatively stable and the principal geologic processes were chemical weathering and soil formation. The *Yarmouth Soil* is similar to the Afton Soil and Sangamon Soil, where developed under similar conditions.

During the **Illinoisan Stage** the continental glaciers were more remote from Kansas than in any of the other glacial stages. Fluvial deposits of Illinoisan age are quantitatively less than those in the preceding or succeeding stages.

The **Sangamonian Stage** (interglacial) was a time of relative climatic stability during which the principal geologic processes were weathering and soil formation. The *Sangamon Soil* is well developed, is exceptionally well preserved, and is found in all parts of the State.

The **Wisconsinan,** youngest of the four major glacial stages, constitutes the surface material over much of Kansas. These deposits are better preserved and more extensively exposed at the surface than older Pleistocene deposits. Multiple advances and retreats (stades) during the Wisconsinan resulted in the deposition of alluvium in the valley areas and loess in the upland areas.

Sedimentary deposits formed since the disappearance of the last continental ice sheet from North America, approximately 5,000 years ago, are classed as belonging to the **Recent Stage.** These deposits are chiefly fluvial, but they include some loess and dune sand. The U. S. Geological Survey recently adopted the term "Holocene" in preference to the term "Recent." They conclude that Holocene should have series rank equal to that of the Pleistocene. The State Geological Survey of Kansas considers Recent to be a stage of the Pleistocene.

NORTHEASTERN AREA—NEBRASKAN STAGE

DAVID CITY FORMATION

The David City Formation consists of proglacial deposits. Locally derived gray and brown chert and limestone gravel containing some arkosic material make up the lower part of the formation. Gray and brown clay, silt, and sand, compose the upper part. It is recognized only in Atchison, Brown, and Doniphan counties. The thickness ranges from 0 to 15 feet.

IOWA POINT TILL

The Iowa Point Till comprises unsorted clay, silt, sand, gravel, cobbles, and boulders. It is calcareous except in the upper weathered zone. The thickness is 30 feet or less.

Fluvial deposits.—These are water-laid silt and clay, with some sand and gravel. Where the Iowa Point Till is absent, these deposits cannot be differentiated from the David City Formation. The maximum observed thickness is about 10 feet.

Loess.—These deposits consist of eolian silt exposed in very restricted areas adjacent to the Missouri River valley. Locally the loess contains gastropods. The maximum thickness is about 10 feet.

NORTHEASTERN AREA—AFTONIAN STAGE

AFTON SOIL

The Afton Soil has a well-developed profile. It is dark gray on till or fluvial deposits in poorly drained conditions and red under well-drained conditions in loess. The thickness may be as much as 15 feet.

NORTHEASTERN AREA—KANSAN STAGE

ATCHISON FORMATION

The Atchison Formation is a proglacial deposit which is not recognizable beyond the limits of Kansan glaciation. It is composed of fine-grained sand and silt and locally gravel at the base. The upper part is thinly laminated. Similar deposits occur between the Cedar Bluffs and Nickerson tills. The maximum known thickness is nearly 100 feet, but it is commonly less than 40 feet thick.

NICKERSON TILL

This till is composed of clay, silt, sand, gravel, and boulders. Erratics are less common than in the Cedar Bluffs Till. The Nickerson is dark-gray to very dark-gray except in the upper few inches to few feet where it is weathered to a brown or reddish-brown color. It is the most extensive till sheet in Kansas. One and possibly two weakly developed interstadial soils of Kansan age are recognized locally. The maximum thickness of the Nickerson Till is 40 feet, but it is commonly less than 20 feet thick.

Fluvial deposits.—These are outwash materials consisting of silt, sand, gravel, and boulders occurring between the Cedar Bluffs and the Nickerson tills. The maximum thickness is 40 feet, but it is commonly less than 20 feet thick.

CEDAR BLUFFS TILL

The Cedar Bluffs is till, which locally contains some lenses of sorted sand and gravel. Erratics are more common in the Cedar Bluffs than in the Nickerson Till, and it is generally more deeply weathered. It is commonly brown or reddish-brown clay, but locally it contains gray or light-gray clay. The maximum thickness probably exceeds 100 feet, but it is generally less than 40 feet in thickness.

"Nortonville clay."—The "Nortonville clay" (Frye and Leonard, 1952, p. 81) is present at the top of the Cedar Bluffs Till. This clay occurs at the upland level and is believed to be an accretion gley deposited in shallow depressions on the surface of the newly formed till plain. The thickness is as much as 40 feet.

Fluvial deposits.—These are clay, silt, sand, and gravel adjacent to major stream valleys. Locally the *Pearlette ash bed* occurs in these deposits. The thickness is commonly 20 to 60 feet.

Loess.—Discontinuous eolian silt deposits occur in the bluffs adjacent to the Missouri River valley. Deposits of loess of this age are not recognized elsewhere. They are generally less than 10 feet thick.

NORTHEASTERN AREA—YARMOUTHIAN STAGE

YARMOUTH SOIL

This unit consists of eroded remnants of a fossil soil commonly developed in till of Kansan age. The till has been deeply oxidized, with a caliche accumulation at the base. The dark A-horizon is generally missing. The Yarmouth Soil may be 10 or more feet thick.

NORTHEASTERN AREA—ILLINOISAN STAGE

Fluvial deposits.—These deposits consist of silt, sand, and gravel underlying an intermediate terrace level. They are discontinuous in smaller drainage basins. Locally, silts in the upper part resemble loess and probably are the valley equivalent of the Loveland loess found in the uplands. The maximum thickness is about 90 feet.

LOVELAND FORMATION

This formation comprises eolian silt (loess), having a reddish-brown or yellowish-brown color. Where unleached it is calcareous and contains gastropods. The maximum thickness is rarely more than 20 feet along the Missouri River valley; elsewhere it is generally thin and discontinuous.

NORTHEASTERN AREA—SANGAMONIAN STAGE

SANGAMON SOIL

The Sangamon Soil includes a dark-gray to grayish-brown A-horizon and a thick reddish-brown B-horizon containing some caliche in the lower part. The Sangamon Soil profile is thick and well developed adjacent to the Missouri River valley, where it may be as much as 24 feet thick. It is thinner to the west. It may be developed in Loveland loess or in older material.

NORTHEASTERN AREA—WISCONSINAN STAGE

Early Wisconsinan fluvial deposits.—These deposits consist of silt, sand, and gravel. They are generally not exposed in northeastern Kansas because they are below stream levels and are overlain by deposits of late Wisconsinan and Recent ages. They may be as much as 50 feet thick.

GILMAN CANYON FORMATION

This formation occurs locally in northeastern Kansas above the Sangamon Soil and below the Peoria Formation. The lower part is light-gray to nearly white, displaying faint bedding. Deposition occurred in local depressions under moist or swampy conditions. The upper part is dark-gray, silty clay generally representing the A_1-horizon of an accretion gley. It is 2 to 4 feet in thickness.

PEORIA FORMATION

Buff eolian silt (loess) comprises the Peoria Formation. It mantles the upland areas in much of northeastern Kansas and locally contains gastropods. It is as much as 100 feet thick adjacent to the Missouri River valley, but thins rapidly away from the river.

BRADY SOIL

This is an interstadial soil (geosol) locally present below the Bignell Formation in the

Missouri River bluffs where it consists of a few feet of leached gray silt, grading downward into a more compact faint reddish-buff silt containing large caliche nodules.

Late Wisconsinan fluvial deposits.—These deposits are composed of clay, silt, sand, and gravel derived in part from local glacial materials. They are generally not separable from similar early Wisconsinan deposits. They underlie a low terrace position in the principal valleys. They may be as much as 50 feet thick.

BIGNELL FORMATION

The Bignell Formation, which is made up of eolian silt (loess), occurs as discontinuous deposits along the Missouri River valley. The maximum thickness is 35 feet, and it thins rapidly away from the valley.

SOUTHEASTERN AREA—NEBRASKAN STAGE

Fluvial deposits.—These deposits consist of sand and chert gravel in a noncalcareous, brownish-red clay that occurs in dissected high terrace positions along some of the present streams and across divides locally. The thickness is commonly less than 20 feet.

SOUTHEASTERN AREA—AFTONIAN STAGE

AFTON SOIL

The Afton Soil is not definitely identified in this area, but it may be part of a complex soil developed throughout several stages of the Pleistocene in local upland areas.

SOUTHEASTERN AREA—KANSAN STAGE

Fluvial deposits.—These deposits consist of sand and gravel underlying a high terrace in the major stream valleys. They are principally chert gravels derived locally from Paleozoic rocks. The distinctive *Pearlette ash bed* occurs locally. The maximum thickness is 50 feet, but it is generally less than 30 feet thick.

SOUTHEASTERN AREA—YARMOUTHIAN STAGE

YARMOUTH SOIL

This unit is not definitely identified in this area. Locally a soil in high terrace positions may include soil developed during the Yarmouthian Stage.

SOUTHEASTERN AREA—ILLINOISAN STAGE

Fluvial deposits.—These deposits consist of silt, sand, and gravel, underlying an intermediate terrace level in the major valleys. The gravel is principally chert and limestone derived from Paleozoic rocks. The maximum thickness is 40 feet, but it is commonly about 20 feet thick.

LOVELAND FORMATION

This formation is not definitely recognized in this area. It may mantle some of the upland area, where it may be included in a modern soil.

SOUTHEASTERN AREA—SANGAMONIAN STAGE

SANGAMON SOIL

The Sangamon Soil includes a dark-gray to grayish-brown A-horizon and a reddish-brown B-horizon. It may be represented in part by a complex soil developed during Yarmouthian and Sangamonian time.

SOUTHEASTERN AREA—WISCONSINAN STAGE

Early Wisconsinan fluvial deposits.—These deposits consist of clay, silt, sand, and gravel. They are locally separable from late Wisconsinan deposits, which are physiographically lower. The gravel is composed principally of chert and limestone derived from Paleozoic rocks. These deposits can be differentiated from late Wisconsinan deposits by means of the fossils they contain. They may be as thick as 30 feet.

PEORIA FORMATION

The Peoria Formation, which consists of eolian silt (loess), has a maximum thickness of about 10 feet. It mantles much of the upland area where locally all of it may be included in the modern soil.

BRADY SOIL

This soil is not definitely identified in this area, but it is probably included within the modern soil in the uplands and may be represented in the principal valleys by a buried soil developed in deposits in a low terrace position.

Late Wisconsinan fluvial deposits.—These deposits are clay, silt, sand, and gravel derived principally from Paleozoic rocks. The gravel is chiefly composed of chert and limestone fragments. These deposits are generally not separable from similar early Wisconsinan deposits. They may be as much as 30 feet in thickness.

BIGNELL FORMATION

The Bignell is a discontinuous eolian silt (loess), which has been incorporated into the modern soil.

CENTRAL AND WESTERN AREA—NEBRASKAN STAGE

HOLDREGE FORMATION

This formation is composed of sand and gravel occurring as fill in abandoned valleys or locally as dissected high terrace deposits adjacent to the major stream valleys. The maximum thickness is in excess of 125 feet, but it is commonly about 35 feet thick.

FULLERTON FORMATION

The Fullerton comprises clay, silt, and sand, in part derived from Pliocene deposits, but locally containing much material from Paleozoic and Mesozoic bedrock. The thickness is commonly less than 25 feet.

[Hibbard (1958) has used the term "Ballard Formation" for deposits of Nebraskan and Aftonian ages in Meade County. The Ballard includes the Angell Member below and the Missler Member above.]

CENTRAL AND WESTERN AREA—AFTONIAN STAGE

AFTON SOIL

Eroded remnants of the Afton Soil occur in the central and south-central part of the State. In far western Kansas a complex soil developed on Ogallala deposits (Pliocene) probably includes the Afton Soil.

CENTRAL AND WESTERN AREA—KANSAN STAGE

GRAND ISLAND FORMATION

The Grand Island Formation consists of silt, sand, and gravel. In south-central Kansas these occur as sheetlike deposits laid down by coalescing streams. In the central and north-central part of Kansas the Grand Island underlies a prominent terrace adjacent to the major streams. In the western and northwestern part of the State these deposits underlie a dissected terrace adjacent to major streams. These deposits range in age from early Kansan to late Kansan. The "McPherson Formation" in McPherson, Harvey, and Sedgwick counties and the "Belleville Formation" in Republic County are in part equivalent to the Grand Island, and the "Abilene conglomerate" in Dickinson and Clay counties may be of this age. The maximum thickness is 80 feet, but it is more commonly 20 feet in thickness.

SAPPA FORMATION

This unit consists of alluvial silt and some sand. In south-central Kansas sheetlike deposits laid down by coalescing streams are present. In northern and central Kansas these deposits underlie a prominent terrace adjacent to the principal stream valleys. In northwestern Kansas these deposits underlie a dissected terrace adjacent to the major streams. Locally the Sappa contains the distinctive *Pearlette ash bed*. The thickness is commonly 20 feet.

[Hibbard (1949) used the term "Crooked Creek Formation" for deposits of Kansan and Yarmouthian ages in Meade County. The formation comprises the Stump Arroyo Member overlain by the Atwater Member, which includes the Pearlette ash bed (Hibbard, 1958).]

CENTRAL AND WESTERN AREA—YARMOUTHIAN STAGE

YARMOUTH SOIL

Poorly exposed soil identified as Yarmouth is present locally. In this area a buried soil on eroded Ogallala below a cover of Wisconsinan loess shows evidence of multiple cycles of soil development that probably include the Yarmouth Soil.

CENTRAL AND WESTERN AREA—ILLINOISAN STAGE

CRETE FORMATION

This formation is composed of silt, sand, and gravel. In larger valleys the gravel is primarily arkosic, reflecting derivation from Pliocene and older Pleistocene rocks, but in some tributary valleys the deposits may be derived almost entirely from the Paleozoic and Mesozoic bedrock. Silts in the upper part of the formation that resemble loess are probably the valley equivalent

of the Loveland Formation that occurs in the uplands. The thickness may be as much as 60 feet, but it is commonly about 40 feet thick.

LOVELAND FORMATION

The Loveland Formation comprises yellowish-brown or reddish-brown silt (loess). The thickest deposits are in north-central Kansas where they may exceed 40 feet in thickness. Southward and westward the deposits thin and become discontinuous.

[Hibbard (1958) applied the term "Kingsdown Formation (restricted)" to deposits of Illinoisan and Sangamonian ages in Clark County.]

CENTRAL AND WESTERN AREA—SANGAMONIAN STAGE

SANGAMON SOIL

The Sangamon Soil is best developed in north-central and northwestern Kansas. It is characterized by its reddish-brown color in north-central and southwestern Kansas; in northwestern Kansas it is pale reddish-brown in color.

CENTRAL AND WESTERN AREA—WISCONSINAN STAGE

Early Wisconsinan fluvial deposits.—These deposits are composed of silt, sand, and gravel. In northwestern Kansas they are not generally exposed. In south-central Kansas these deposits underlie the higher of two low terraces. The gravel in northwestern Kansas is derived from Pliocene and older Pleistocene arkosic deposits; in south-central Kansas it is derived from Paleozoic and Mesozoic deposits. The thickness may be as much as 30 feet.

PEORIA FORMATION

The Peoria Formation (formerly Peoria silt member) comprises pale yellowish-buff to light-gray eolian silt (loess) that mantles most of the upland areas in the central and western part of the State. The formation is as much as 90 feet thick in northwestern Kansas, but it is commonly 20 to 30 feet thick. In central Kansas it is 10 feet or less in thickness.

BRADY SOIL

The Brady Soil is generally more maturely developed than the modern soil and is dark gray in the upper part, grading into a grayish-brown zone containing small caliche nodules. It is widespread, but it is discontinuous in the uplands of northwestern Kansas below the Bignell Formation. In south-central Kansas the Brady is identified only in alluvial deposits.

Late Wisconsinan fluvial and eolian deposits.—Silt, sand, and gravel of late Wisconsinan age underlies a low terrace in most valleys. Gravel in major stream valleys is derived principally from Pliocene and older Pleistocene arkosic deposits, but in some tributary valleys it is derived from Paleozoic and Mesozoic deposits.

Deposits of wind-laid sand (dunes) are widespread in south-central Kansas and in western Kansas south of the Arkansas River. The dunes may attain a thickness of 50 feet, or more commonly, 20 feet.

BIGNELL FORMATION

Loess deposits of the Bignell Formation are widely distributed in northwestern Kansas but are thin and discontinuous in central Kansas. They are generally less than 10 feet thick.

[Hibbard (1949) proposed the name "Vanhem Formation" for deposits of Wisconsinan and Recent ages in Clark County.]

RECENT STAGE

Fluvial deposits.—These deposits consist of clay, silt, sand, and gravel and are the sediments in and along the active channels of streams. Recent sediments comprise deposits on the floodplain and on the upper part of some low terraces. The lithology and mineralogy of Recent fluvial deposits in each stream valley reflects the source materials provided to the drainage basin. The thickness of Recent fluvial deposits is not well documented, but probably ranges from 0 to about 40 feet in the various stream valleys.

Loess.—Thin, discontinuous deposits of loess of Recent age are present over parts of Kansas. Generally these deposits are incorporated into the modern soil.

Dune sand.—These deposits are composed of fine-grained eolian sand and are most extensive adjacent to the Cimarron River, the Arkansas River, and locally in the Republican River valley. The dunes are largely stabilized; however, in those areas where they are most extensive, some active dunes are present.

IGNEOUS AND METAMORPHIC ROCKS

By HOWARD G. O'CONNOR

Outcrops of igneous and metamorphic rocks occur in Riley, Woodson, and Wilson counties

(State Geol. Survey Kansas, 1964). The igneous rocks are chiefly peridotite and granite; the metamorphic rocks are quartzite and hornfels. Merriam (1963) and Franks (1966) have summarized information about the origin and age of these igneous and metamorphic rocks.

IGNEOUS ROCKS

Hills Pond Peridotite.—Outcrops of sill-like intrusive bodies of olive-gray, medium-grained peridotite are found in parts of sec. 29, 32, and 33, T 26 S, R 15 E, Woodson County. The peridotite is of late Cretaceous age (Zartman, *et al.*, 1966) and is in contact with rocks of late Pennsylvanian age (Lansing Group and Douglas Group) at the surface.

Wagner (1954) has described the Hills Pond Peridotite as a dike-like intrusion, along a fault, which spread laterally at several horizons in the Pennsylvanian strata as sill-like bodies. The igneous rock intruded into the Pennsylvanian strata has caused a doming effect in the surface rocks. The name "Silver City dome" is applied to the surface structure.

Granite.—Medium- to coarse-grained granite or granitoid igneous rock is found at the surface on Rose Dome in the SE ¼ sec. 13, T 26 S, R 15 E, Woodson County, and in parts of adjacent sections in association with peridotite and other ultramafic rock (Franks, 1965, 1966).

The upper Pennsylvanian shales into which the granite is intruded are mildly metamorphosed. K-feldspar from a sample of the granite has been dated (Muehlberger, Denison, and Lidiak, 1964) by the Rb-Sr method as 1,220 m. y. and is therefore Precambrian in age. Emplacement of the granite as xenoliths in an intrusive peridotite plug of possible Cretaceous age has been suggested (Merriam, 1963; Franks, 1965, 1966).

Alkaline ultramafic rocks.—Five plug-like intrusives (sec 27 and 35, T 6 S, R 6 E; sec. 22, T 8 S, R 5 E; sec. 23, T 8 S, R 6 E and sec. 6, T 9 S, R 5 E) of basic igneous rock crop out in association with lower Permian rocks in Riley County. One of these intrusives, at Bala, has been described as a dark-green carbonatized, porphyritic, peridotite breccia (Moore and Haynes, 1920). Another intrusive near Stockdale, having a mineralogy similar to that of the Bala intrusive, (Rosa and Brookins, 1966 [1967]) has been described as a kimberlite pipe.

The age of the intrusives is uncertain, but they are post-early Permian and probably late Cretaceous or early Tertiary.

METAMORPHIC ROCKS

Metamorphic rocks exposed at the surface in Kansas are associated with the Riley and Woodson county intrusives. Lower Permian limestones and shales have been slightly altered by contact metamorphism in Riley County. In the area of Rose Dome in Woodson County and Silver City Dome in Woodson and Wilson counties Pennsylvanian shales and limestones have been altered to dense hornfels composed largely of feldspar and mica. Pennsylvanian sandstones have been converted to a greenish-gray quartzite. The quartzite in Woodson and Wilson counties is known informally as the "Silver City quartzite."

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