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BULLETIN 33

SUBSURFACE MISSISSIPPIAN ROCKS OF KANSAS

By WALLACE LEE

With Report on Fossils of Mississippian Age from Well Cores in Western Kansas

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THE SUBSURFACE MISSISSIPPIAN ROCKS OF KANSAS

By Wallace Lee

ABSTRACT

This report embodies the results of a study of the Mississippian rocks that lie below the surface in Kansas. The study has been carried on as a coöperative project of the State Geological Survey of Kansas and the Federal Geological Survey. The object of the investigation has been to acquire and publish information that will be of value in the further development of the oil and gas resources of the state. A report dealing with the thickness of the Mississippian limestones and the relation of their thickness to the structure of the rocks and to oil and gas pools has already been published. The present paper deals chiefly with the stratigraphy of the Mississippian rocks, and will also be of interest to the oil industry.

Criteria for distinguishing the various units of the Mississippian have been determined by a microscopic study of the cuttings and cores of the Mississippian rocks and by the examination of insoluble residues. The significant results as to the character and relations of the formations are here briefly mentioned in the order of age, beginning with the oldest units.

The Chattanooga shale, of Kinderhook (?) age, is black and relatively thin in southern Kansas, but toward the north it is a dark or a gray-green shale, more than 250 feet thick. The Chattanooga sea was confined on the west by land in the region of the central Kansas uplift and in Clark county. The surface on which the Chattanooga was deposited was essentially a plain in eastern Kansas, but had some relief along the east side of the central Kansas uplift.

The Compton limestone and Northview shale, of Kinderhook age, are present only in southeastern Kansas. They are the correlatives of the Chouteau limestone of northeastern Kansas and northern Missouri. The Compton limestone is a noncherty grayish-green limestone and the Northview a silty calcareous shale. Both the Compton and the Northview are thin in southeastern Kansas, but they thicken toward the north and grade laterally into the Chouteau, an impure cherty limestone. The Chouteau and its correlatives are

confined to the area east of the subsequently formed Nemaha ridge fold; and the basin in which they were deposited seems to have been limited on the west by minor pre-Chouteau movements along the trend of this fold.

A relatively thin bed of slightly cherty dolomite, which may represent the Sedalia limestone of the outcrops in Missouri, overlies the Chouteau limestone. West of the Nemaha ridge, this dolmite overlaps beyond the Chouteau and rests upon the weathered surface of the Chattanooga shale. In north-central Iowa, brown dolomites and limestones of Hampton age, in places as much as 200 feet thick, were deposited above the Chouteau. A part of these rocks may be the equivalent of the Sedalia as tentatively identified in the subsurface of northeastern Kansas.

Rocks tentatively correlated with the Gilmore City limestone, which crops out in Iowa, overlie the Sedalia in northeastern Kansas and pre-Chattanooga rocks in western Kansas. The limestone beds of the Gilmore City are white and semigranular, and in some zones are oölitic. They are probably unconformable upon the underlying rocks in Kansas, for a disconformity was noted at their base in Iowa. Rocks of Gilmore City age in Kansas lie in the southwestern prolongation of the Gilmore City basin of Iowa and seem to have been deposited in an erosional basin that lay athwart the central Kansas uplift. Rocks correlated with the Gilmore City limestone are the oldest Mississippian rocks southwest of the Nemaha ridge.

The lower part of the rocks of Osage age is represented by the St. Joe limestone and Reeds Spring limestone, which are the correlatives of the Fern Glen limestone of southeastern Missouri. The St. Joe limestone is noncherty, in part argillaceous and in part semigranular white limestone. It has a somewhat restricted distribution in southeastern Kansas. The Reeds Springs is dolomitic and contains much dark chert, but toward the northwest grades into semigranular limestone with some semitranslucent bluish chert. It seems to be conformable above the St. Joe and overlaps upon Kinderhook rocks beyond the margin of the St. Joe. The distribution of these formations suggests that the configuration of the basin in which they were deposited was controlled by early movements along the trend of the Nemaha ridge anticline and slight elevation of the central Kansas uplift.

Gray limestones and dolomites, with opaque white even-textured chert, correlated tentatively with the Burlington limestone, conformably overlie limestone of Fern Glen age and spread far beyond its area of deposition. These rocks are unconformably overlain in some areas by a lithologic unit composed of limestone and dolomite with pitted chert and "cotton rock". This unit corresponds in lithologic character to the Keokuk in the Tri-State mining district and is therefore here regarded as of Keokuk age. The rocks tentatively assigned to the Keokuk are confined to a belt trending northwest toward the central Kansas uplift. In the mining district they overlie the Reeds Spring limestone, but toward the northwest they rest upon varying thicknesses of rocks believed to be of Burlington age.

Erosion, accompanied by slight southerly tilting of the region, followed the deposition of the Keokuk limestone; a basin in southern Kansas that extended westward along the Oklahoma line as far as Clark county, was eroded in the Osage rocks. The basin had a relief exceeding 350 feet in its deepest parts and in some places in Cowley and Chautauqua counties erosion cut through the Chattanooga shale. This basin was filled with somewhat diversified limestone and dolomite, in part dark and cherty and in part silty, with a concentration of glauconite at its base. These deposits are succeeded conformably by clean gray cherty limestone, which was deposited after the seas had spread over the partly dissected upland area that bordered the basin on the north and east. The dark and silty deposits filling the basin are herein called the Cowley formation. The gray cherty limestones of the upper part are believed by some geologists to be of Warsaw (Meramec) age. The Cowley, which underlies these beds of Warsaw age, is also placed in the Meramec, because it is apparently conformable below the Warsaw and unconformable above Osage rocks. No direct faunal evidence, however, is available for the age assignment of the Cowley rocks. The Warsaw seems not to have reached Logan county, Kansas, and is absent also in a well in Lane county on the flank of the central Kansas uplift.

The Warsaw limestone is overlain conformably by the Watchorn formation, consisting of white oölitic and semigranular essentially noncherty limestone and some dolomite. This formation has a maximum known thickness of 690 feet in Clark county. George H. Girty, who examined fossils collected from cores of wells from this formation in western Kansas, found them to be of probable Warsaw, Spergen, and St. Louis age and thus a part of the Meramec rocks. The Ste. Genevieve limestone may be represented in some areas. H. S. McQueen and Mary Hundhausen, of the Missouri

Geological Survey, by the use of insoluble residues, have also identified rocks of Spergen and St. Louis age in the Watchorn. The Watchorn is intended as a term for Meramec rocks younger than the Warsaw where it is not convenient to differentiate the subdivisions of the upper part of the Meramec. Lithologic units believed to represent the Spergen and St. Louis limestones have been identified in several areas east of the Nemaha ridge. It seems probable therefore that the rocks of the Watchorn formation were deposited across the central Kansas uplift, from which they were subsequently eroded during pre-Pennsylvanian base-leveling.

Rocks of Chester age are recognized in Kansas in Cherokee county in the southeastern corner of the state and in parts of southwestern Kansas. In Cherokee county the rocks are represented by a limestone of Batesville age, which rests unconformably upon Warsaw limestone. In Mayes county, Oklahoma, this limestone rests upon dark shaly deposits containing a († Spring Creek) lower Moorefield fauna. These two limestones together constitute the Mayes formation. The writer believes that the lower Moorefield part of the Mayes is the southeastern extension of the Cowley formation, which in Mayes county was partly eroded before the deposition of rocks of Chester age.

Not fewer than six unconformities have been recognized within the sequence of Mississippian rocks of Kansas. In addition, peneplanation preceded and followed Mississippian sedimentation. Other less conspicuous interruptions of sedimentation may also have occurred within the various formations, for the seas were in the main not deep and oscillations of the sea level were probably frequent. The structural relations of the upper part of the Mississippian are not clear, for the rocks of late Meramec age were much reduced in thickness and extent by folding and peneplanation in post-Mississippian time; also rocks of Chester age are so scantily represented that little is known of the history of Kansas during Chester time.

The following is a list of the recognized unconformities:

1. An unconformity in the Salina basin west of the Nemaha ridge between the Chattanooga shale and the dolomite provisionally referred to the Sedalia.

2. An unconformity reported by Laudon below the Gilmore City limestone in Iowa. Inasmuch as some formations present in Iowa between the Gilmore City and the Sedalia are absent, there is probably also an unconformity in Kansas, but the evidence in northeastern Kansas is slight.

3. An unconformity between the Northview shale and the St. Joe

limestone in some areas. The Reeds Spring and the Burlington overlap beyond the St. Joe and rest unconformably upon the Chouteau.

4. An unconformity between the Burlington and Keokuk limestones.

5. An unconformity between the Cowley formation and older rocks.

6. An unconformity at the base of the Chester rocks.

A southerly tilting of eastern Kansas is indicated by the progressive overlap of the lower Osage rocks toward the north. The thinning of the Warsaw toward the north and the overlap of the St. Louis limestone upon older rocks of Iowa suggests that southerly tilting of Kansas and the region toward the north was resumed immediately preceding or during Meramec time. Pre-Pennsylvanian tilting in the same general direction, although accompanied by local deformation, lowered southwestern Kansas relative to northeastern Kansas. In consequence greater thicknesses of rocks of late Meramec age were preserved from pre-Pennsylvanian erosion in southwestern Kansas than elsewhere.

INTRODUCTION

Purpose and nature of the work.—This report presents a part of the results of a coöperative investigation of the Mississippian rocks in Kansas conducted jointly by the State Geological Survey of Kansas and the Federal Geological Survey during a period of nearly four years, beginning September 1, 1935, and ending July 1, 1939. The investigation was undertaken in order to determine the relations of the features of the Mississippian rocks to the oil and gas deposits of the state.

The results of a part of this investigation that bear most directly on the oil and gas deposits have already been published (Lee, 1939).* The published report contains a map showing the oil and gas fields and also showing the thickness of the Mississippian limestones in central and eastern Kansas by 50-foot thickness lines. The map reveals the close relation existing between the anticlinal structure of oil and gas pools and areas of thin Mississippian rocks. It also shows several areas that are not productive in which the Mississippian rocks are thin. These are believed to indicate anticlinal areas that have not been adequately explored for oil and gas. Because of the importance of this information to those engaged in

* References to publications are indicated in this report by the name of the author and date, as given in the list at the end of the report.

the search for oil and gas, the map and a report on this phase of the investigation have been published in advance of the present report.

The material here presented deals chiefly with the stratigraphy and distribution of the Mississippian rocks and it, like that in the earlier report, will also be of interest and value to oil operators and oil geologists.

The Mississippian rocks of Kansas are exposed in the two southeastern townships of Cherokee county, in the southeast corner of the state, but elsewhere in the state they lie below the surface and can be studied only by means of cuttings and cores from wells. For the present investigation, samples were obtained from the warehouses of many oil companies, from individuals, and from the State Geological Survey. To facilitate the study of the samples the well-known representative outcrops of the Mississippian rocks in Missouri and Oklahoma were visited.

Much is known concerning the stratigraphic limits, distribution, relations, and classification of the subdivisions of the Mississippian in the Mississippi valley, but many matters are subjects of debate among geologists. The differences of opinion are due to the considerable similarities that exist in the exposed beds, to the lateral variation in their lithologic and faunal characteristics, and in parts of the section to the lack of significant changes in the faunas of adjacent units.

Many stratigraphic and other problems difficult of solution are also encountered in the subsurface units of the Mississippian and not all of them can be solved by a microscopic study of cuttings and cores. Although lithologic units can be traced by well cuttings from one district to another the cuttings do not provide enough faunal evidence to show the age of a particular unit if the rocks cannot be traced to identifiable outcrops. Although the study of well cuttings has certain obvious disadvantages, their use has some advantage over the study of outcrops. Where well samples are available, the entire section of Mississippian rocks is available for study for hundreds of miles from the outcrop. In the study of surface rocks, the work of the geologist is confined in most regions to a relatively narrow belt of outcropping rocks, the exposures are generally isolated and limited in vertical range, and complete sections representing the full thickness of more than one formation are relatively rare. A long columnar section of rocks is therefore the result of the patching together of a number of limited vertical exposures, generally many miles apart. The character of the Paleozoic rocks of the Mississippi valley is particularly well adapted to the study of the microscopic features of the rocks and of the insoluble residues. The basin during much of Paleozoic time was wide, the seas were in the main shallow and the adjoining land areas were low. Except near shore lines the conditions of sedimentation were unusually uniform, and characteristic lithological features were in the main widespread.

Use of microscopic criteria.—Cherty limestones constitute the greater part of the Mississippian rocks; and the similarity in their general appearance makes the lithologic discrimination between the various beds depend on the recognition of microscopic features. The degree to which such distinctions have proved useful seems remarkable. Virtually all areal mapping of beds at the surface, however, depends in the last analysis on some unique characteristic or combination of similar or contrasting lithological characteristics without which no separation of the beds can be made. The use of microscopic characteristics is only a change in technique that adds the microscope to the eye and substitutes a set of well cuttings for a series of outcrops.

The separation of superficially similar limestones in outcrops depends primarily on paleontologic criteria. Locally, lithologic differences are characteristic of certain limestones and are commonly used to identify them. The lithologic characters of the separate units differ, however, in different regions, to the confusion of stratigraphers, and in some regions paleontologists are uncertain of correlations where the faunal content varies but little between adjacent formations or where representative faunules are difficult to procure. The problem of correlation in subsurface work, as in surface work, is therefore to discover groups of beds having common and persistent characteristics and then to determine what changes take place laterally by tracing these units from area to area. H. S. McQueen (1931) of the Missouri Geological Survey, has shown the practical use of microscopic criteria for distinguishing units in well cuttings by the study of insoluble residues that are obtained by treating the cuttings of soluble rocks with hydrochloric acid. This work was first applied successfully by him to the Cambrian and Ordovician rocks of the Ozarks and has now been expanded and applied to the Mississippian beds of Missouri by Mary Hundhausen and J. G. Grohskopf under McQueen's direction.

Application of formation names to subsurface units.—The difficulty in correlating surface formations identified by one set of criteria with subsurface units recognized by another set has caused considerable hesitation on the part of the writer in the application of formational names for arbitrarily determined underground subdivisions. H. A. Buehler, Director of the Missouri Geological Survey, very generously made available that Survey's facilities for the study of insoluble residues. Miss Hundhausen, under the direction of Mr. McQueen, examined and analyzed 15 sets of Mississippian well cuttings taken from wells in critical areas in Kansas. Although the writer had recognized several lithologic units that are traceable from well to well, the Missouri Geological Survey provided the correlations between formations exposed in Missouri and the subsurface lithologic units in Kansas. The use of the terms Chouteau, Sedalia, Reeds Spring, Warsaw, and others in Kansas is based on a comparison by the writer of samples and residues analyzed and examined by the Missouri Geological Survey with samples and residues from other Kansas wells.

The well cuttings from Kansas examined for me by Miss Hundhausen are from a relatively small number of widely distributed wells. In parts of some of the wells where local conditions unlike those in Missouri prevail, the writer has made a different interpretation of the cuttings and residues. In southeastern Kansas the Cowley formation, which is absent in Missouri, has been differentiated; in northeastern Kansas the Gilmore City, parts of which in some wells are not unlike the St. Joe, has been identified tentatively; and the undivided Burlington and Keokuk limestone in Kansas, as reported by Miss Hundhausen, has been separated into two contrasting lithologic units. The wells from which samples were analyzed by the Missouri Geological Survey and made available for this report are listed below.

Wells in Kansas from which cuttings were analyzed by the Missouri Geological Survey

Operator.	Farm.	No. of well.	Location.	County.
Marland	Swenson	No. 1	Sec. 36, T. 18 S., R. 4 W.	McPherson
T. C. Johnson	Janssen	No. 1	Sec. 11, T. 28 S., R. 2 E.	Sedgwick
Aylward Prod. Co	Harrison	No. 1	Sec. 23, T. 25 S., R. 2 E.	Sedgwick
Hollow	Aschmann	No. 1	Sec. 8, T. 21 S., R. 4 W.	McPherson
Sheldon & Wixon	Houston	No. 1	Sec. 15, T. 28 S., R. 7 E.	Butler
National Ref. Co	Sutter	No. 4	Sec. 1, T 28 S., R. 6 E.	Butler
Empire	Hoffman	No. 1	Sec. 27, T. 34 S., R. 1 E.	Sumner
Empire	Bartel	No. 1	Sec. 31, T. 20 S., R. 2 E.	Marion
Mentor	Muir	No. 1	Sec. 17, T. 15 S., R. 2 W.	Saline
Empire	Beltz	No. 1	Sec. 36, T. 25 S., R. 4 W.	Reno
Watchorn & McNeeley	Spangler	No. 1	Sec. 23, T. 20 S., R. 32 W.	Scott
Prairie	Brown	No. 9	Sec. 26, T. 34 S., R. 11 E.	Chautauqua
St Louis Sm. & Ref. Co.	Ballard	No 1	Sec. 10, T. 35 S., R. 24 E.	Cherokee
Kesper	James	No. 1	Sec. 8, T. 13 S., R 25 E.	Johnson
Arnold	Stevenson	No. 1	Sec. 16, T. 26 S., R. 24 E.	Bourbon

Those Mississippian formations that are abundantly cherty have in the main such striking characteristics that they can be distinguished by microscopic examination without the aid of insoluble residues. The use of insoluble residues, however, is a great aid in bringing out the distinguishing peculiarities. The noncherty or sparsely cherty formations mentioned below can be satisfactorily determined only with the aid of insoluble residues. The peculiar siliceous assemblages that remain after the removal of limestone and dolomite are the distinguishing characteristics of the St. Louis and Spergen limestones. Residues are necessary also for the determination of the noncherty limestones of the Compton, the Gilmore City, and some phases of the St. Joe. The difference between the silty shales of the Northview and the more argillaceous shales of the St. Joe is also brought out by the use of residues.

Accuracy of samples.—Accuracy in the determination of boundaries between stratigraphic units is dependent on the care with which samples have been taken. Cavings and incomplete bailing during drilling operations necessarily contaminate the samples. If grains of chert peculiarly characteristic of higher beds get into a sample the apparent thickness of the higher formation is increased. Boundaries between units are usually indistinct in rotary-drilled wells because of the mingling of cuttings from a considerable thickness of rocks.

The amount of chert present in a sample is by no means a measure of the amount of chert in the rock before drilling. Abrasion by sharp-edged chert fragments may reduce limestone and dolomite to flour in the process of drilling, with the result that much or all of the limestone and dolomite is lost in washing and a disproportionate amount of chert remains. The speed of drilling also is a factor that affects the limestone and chert content, for a wet hole that slows drilling not only reduces the amount of limestone in the sample but also reduces the size of the chert grains in the cuttings. On account of these factors, the meticulous plotting of percentages of lime and chert in samples from standard-tool holes may not reveal the actual character of the rock any more closely than a rough estimate. Rotary cuttings are useful after the distinguishing characteristics of lithologic units have been determined, but are very unsatisfactory for determining these characteristics. Such cuttings have been used in this investigation only in western Kansas where wells drilled with cable tools are few.

Technique.—It was discovered in the early part of the work that among the many subtle and varied characteristics of the rocks it was difficult to determine which were the significant peculiarities on first examination. Consequently, wherever the size of the samples was sufficient a small pinch of each of the many samples was mounted on a paper log strip on a scale of 20 feet to the inch as a visible reference for studying the texture, color, fracture, and other features. The samples were mounted with glue on ordinary log strips, and there has been singularly little shedding except for shale grains, which do not become detached from the glue but break across the particles. This scheme is a modification of the practice followed by C. W. Studt of the Union Gas Company of Independence, George M. Fowler of Joplin, Mo., and others. More than 400 such log strips were prepared, and these have made it possible to turn to the original cuttings repeatedly in rechecking and comparing the material under the microscope when it would have been impracticable to go back to the original samples. The locations of wells whose cuttings have been examined and the wells whose insoluble residues were studied are shown in plate 1. The most prominent structural features in Kansas are indicated in figure 1.

The samples were examined with a binocular microscope using a 55mm. objective and a 6x eyepiece. The magnification thus obtained was 22 diameters. This is somewhat greater than that in general use by oil company geologists in the examination of cuttings, but, although it reduces the field, it reveals some of the subtle distinctions of chert and limestone that are easily overlooked with a lower magnification.

Terminology.—Terminology presents some problems in describing textures of limestone, dolomite, and chert because there is no standardized meaning for certain much-used words. The following words are used herein with the specialized meanings indicated.

Semigranular: Consisting of coarse crystalline grains, principally fossil fragments, in a microcrystalline matrix. In some zones the semigranular limestones are crinoidal.

Grainy: Consisting of microscopic crystals of limestone or dolomite or particles of silt sparsely distributed in a dull opaque usually calcareous matrix. The matrix, in some rocks, is cryptocrystalline; in others earthy. By decrease of the calcareous matrix this texture may become sucrose or silty.

Sucrose: Consisting of microscopic coarse or fine crystals—in most cases dolomite—packed closely (without matrix) like grains of granulated sugar.

Stippled: Having a character caused by the complete replacement by silica of rocks having grainy texture, resulting in a stippled pattern on the broken surface of the chert. The sharp outline of the replaced impurities is blurred in some zones, giving a cloudy margin to the spots.

Mottled: Composed of parti-colored chert in patches without sharp margins; microscopic but much coarser than is indicated by stippled.

Matted: Composed of closely packed fragments of silicified microfossils cemented together in a siliceous matrix.

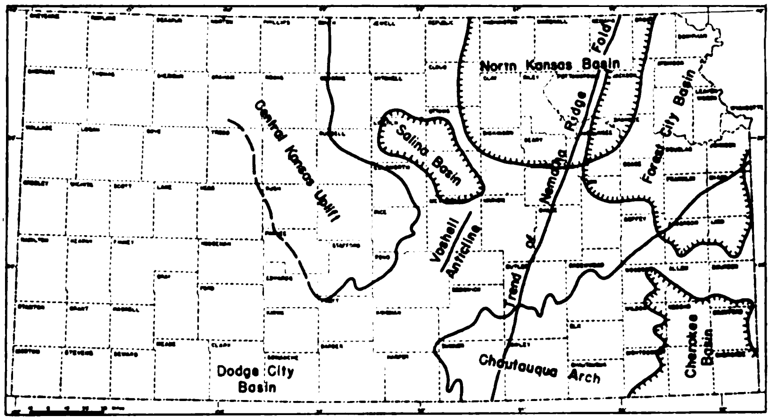


FIG. 1. Sketch showing principal structural features of Kansas. Chautauqua arch, indicated by pre-Chattanooga outcrops of base of Simpson sandstone (after Hugh W. McClellan); trends of Nemaha ridge fold and Voshell anticline as shown on thickness map of Mississippian limestones (Wallace Lee, Bulletin 26, Kansas Geological Survey); Salina basin, deepest part as indicated by Mississippian thickness map; central Kansas uplift as shown by area in which Mississippian limestone is absent; Forest City and Cherokee basins from thickness map of Cherokee shale by N. W. Bass (Bulletin 23, Kansas Geological Survey); North Kansas basin of John L. Rich from thickness map of Chattanooga shale of this report; and Dodge City basin (after Hugh W. McClellan).

Streaked: Having the microfossiliferous fragments of matted chert imperfectly replaced or subsequently modified; resulting in a blurring of the outlines of the inclusions.

Even-textured: Having a homogeneous character and, as applied to chert, a texture comparable to the term lithographic in referring to the texture of limestone.

Cotton rock: A soft, porous siliceous rock composed of white, opaque, incompletely cemented microscopic particles of silica.

Acknowledgments. — The author is particularly indebted to the Missouri Geological Survey, the Shell Petroleum Corporation, the Union Gas Company of Independence, and the Skelly Oil Company for the use of cuttings, and acknowledges with thanks the use of material from the geological departments of Atlantic Refining Company, Gulf Oil Corporation, Carter Oil Company, Magnolia Petroleum Company, Sinclair-Prairie Oil Company, Amerada Petroleum Company, Indian Territory Illuminating Oil Company, National Refining Company, Ohio Oil Company, Phillips Petroleum Company, Stanolind Oil Company, Continental Oil Company, Darby Oil Company, and Pure Oil Company. R. A. Wharton, Edward A. Koester, Howard S. Bryant, James I. Daniels, Anthony Folger, Geo. H. Norton, and many other individuals have been helpful.

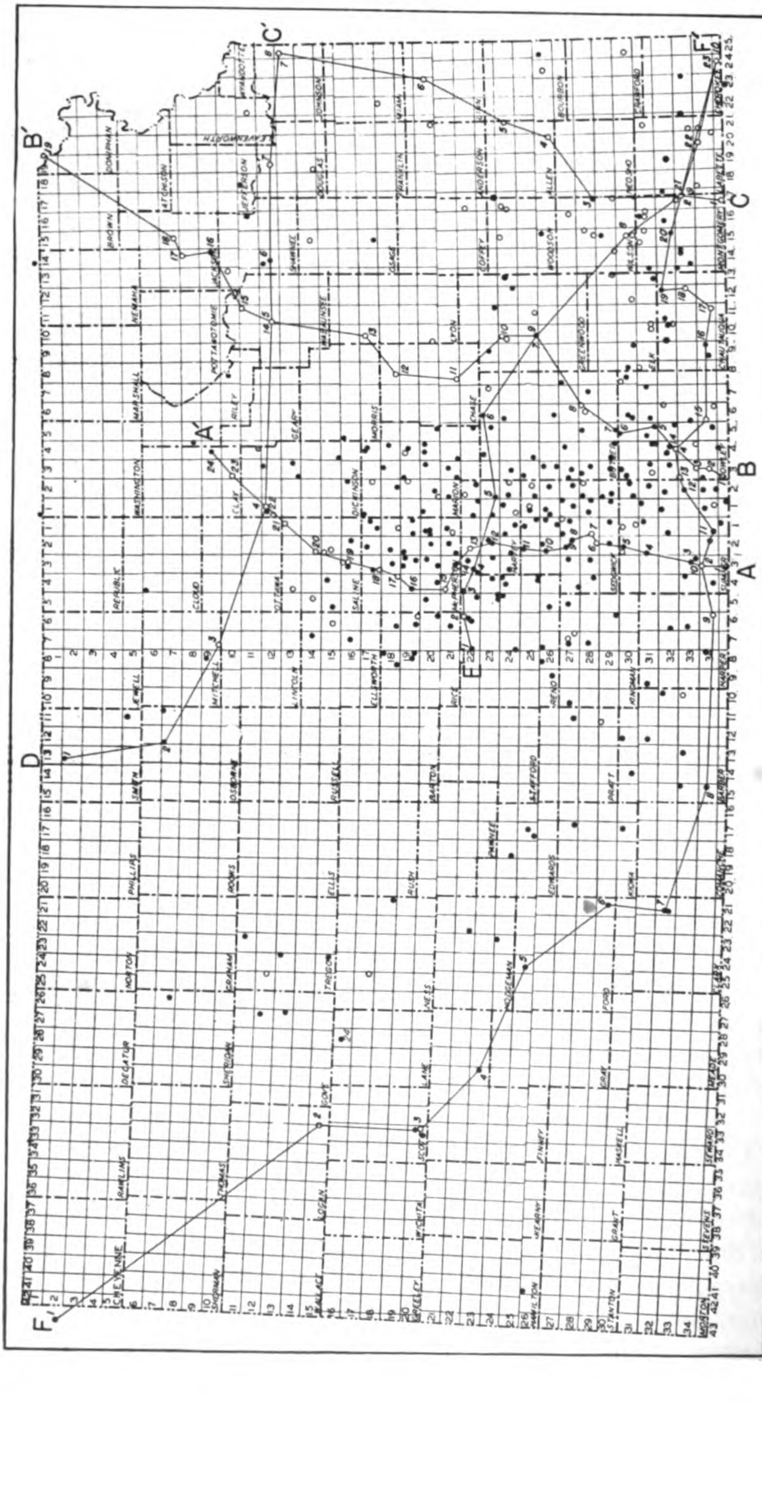


PLATE 1. Map showing (by dots) location of wells from which samples of Mississippian rocks were studied and position of cross sections. The circles indicate wells from which insoluble residues were also examined. The lines connecting wells indicate the position of cross sections of plates **5**, **6**, and **7**.

Age	
Chester	Limestn
Meramec	Watch
	Wars
	Cowle
Osage	Keok
	Burlir
	Rocks of Fern Glen age
Osage or Kinderhook	Gilm
	Seda
Kinderhook	Chouteau limestone
	Chat (l
Pre-Ch	

MISSISSIPPIAN SERIES

The Mississippian rocks are widely distributed in the Mississippi basin at the surface and in the subsurface. They were deposited from the Appalachian Mountains westward far beyond the Rocky Mountains. Outcrops of the Mississippian rocks occupy large areas in Iowa, Missouri, Oklahoma, and other states and underlie adjoining areas. In Kansas, outcrops are confined to a small part of Cherokee county in the extreme southeastern part of the state. Parts of the Mississippian series were probably deposited in every part of Kansas, but after the rocks had been deposited the region was elevated above sea level, and the Mississippian rocks were eroded from the central Kansas uplift and parts of the Nemaha ridge, before the region sank again below the level of the sea and was covered by younger sediments.

The depth of the Mississippian rocks below the surface in Kansas increases gradually toward the west from the outcrops in Missouri and in Cherokee county, Kansas, to more than 5,000 feet in southwestern Kansas.

The subsurface units of the Mississippian discussed in this report are shown in the columnar section, plate 2, and their relation to the subdivisions that have been made in the exposed rocks in Missouri, Oklahoma, and Iowa, are shown in table 1.

The rocks of Mississippian age in Kansas consist mostly of limestone and dolomite, which contain varying amounts of chert. Some stratigraphic units are noncherty and others contain chert in great abundance. Shale is represented at the base of the section by the Chattanooga shale, as much as 250 feet thick, and by the Northview shale, a thin calcareous silty unit slightly higher in the section. Some shale occurs also in the lower part of the St. Joe limestone in south-central Kansas. Some dark and very shaly limestones are also present in other formations. Sandstone is conspicuously absent except at the base of the Mississippian, where sandstone or sandy shale is present in many localities at the base of the Chattanooga.

The nomenclature and classification of the subsurface Mississippian rocks of Kansas, as used in this report, accord with usage of the Federal Geological Survey, except that the federal survey doubtfully places the Chattanooga shale in the Devonian system.

TABLE 1.—Showing stratigraphic units of the subsurface Mississippian rocks in Kansas and their relation to subdivisions made at the outcrops in neighboring states by other geologists.

State Geological Survey of Kansas	Missouri Bureau of Geology and Mines		Federal Geological Survey	
Subsurface Mississippian rocks of Kansas **This report; 1940.**	**Southeastern Missouri** **Stuart Weller and Stuart St. Clair; Geology of Ste. Genevieve Co., Mo; Bull. 22, 2nd series, 1928.**	**Southwestern Missouri** **R. C. Moore; Early Mississippian formations of Missouri; Bull. 21, 2nd series, 1928.**	**Northeastern Oklahoma, 1939**	**Iowa** **L. R. Laudon; Stratigraphy and paleontology of the Gilmore City formation; Univ. of Iowa, Studies in Natural History, Vol. 15, no. 2, 1933.**
Carboniferous system Pennsylvanian series Unconformity Mississippian series	Mississippian series	Mississippian series	Carboniferous system Pennsylvanian series Mississippian series	Mississippian
Rocks of Chester age Limestone of Batesville age in Cherokee Co., Kansas Rocks of Chester age are probably present in southwestern Kansas. Unconformity	Chester group		Fayetteville shale Limestone of Batesville age in Ottawa Co.; Mayes formation south of Ottawa Co. includes rocks of Batesville and Moorefield age	Chester Pella beds
Rocks of Meramec age Watchorn formation Includes undifferentiated rocks of Spergen, St. Louis and possibly Ste. Genevieve age. Spergen and St. Louis limestones have been identified in two wells by insoluble residues by Miss Hundhausen of the Missouri Geological Survey. Warsaw limestone Cowley formation Unconformity	Meramec group Ste. Genevieve limestone St. Louis limestone Spergen limestone Warsaw limestone	Osage group[3] Warsaw limestone	Boone formation	Meramec St. Louis limestone Spergen limestone Osage Warsaw limestone
Rocks of Osage age Keokuk limestone Burlington limestone Reeds Spring limestone } of Fern Glen age St. Joe limestone Unconformity	Osage group Keokuk limestone Burlington limestone Fern Glen limestone	Keokuk limestone Reeds Spring limestone St. Joe limestone	St. Joe limestone member	Keokuk limestone Burlington limestone
Rocks of Kinderhook or Osage age Gilmore City limestone Unconformity Sedalia limestone				Kinderhook Gilmore City limestone Hampton formation[5] Iowa Falls member Eagle City member Maynes Creek member (Wassonville ls. in part[6]) North Hill member[5] English River formation[2]
Rocks of Kinderhook age Chouteau limestone in northeastern Kansas } { Northview shale, Compton limestone in southeastern Kansas. Unconformity Chattanooga shale[1] (Kinderhook ?) Unconformity	Kinderhook group Sulphur Springs formation[2] (includes Bushberg ss., Glen Park ls. and unnamed shale)	Kinderhook group[4] Northview shale Compton limestone Chattanooga shale Sylamore sandstone	Devonian (?) system Chattanooga shale	Maple Mill shale
Devonian, Silurian or Ordovician system.				Devonian system

1. The nomenclature and classification of the subsurface Mississippian rocks of Kansas, as used in this report, accord with usage of the Federal Geological Survey except that the federal survey doubtfully places the Chattanooga shale in the Devonian system.
2. Not intended to show correlation with specific formations of other areas.
3. Section in Jasper and Lawrence counties, Missouri.
4. Section in Dade and Greene counties, Missouri.
5. In Stratigraphy of the Kinderhook series of Iowa: Iowa Geological Survey, vol. 35, p. 388, 1929, Laudon placed the Chapin limestone below the Maynes Creek limestone as the lowest member of the Hampton formation. In supplemental statement on the Mississippian of Iowa: Kansas Geological Society Guide Book, Ninth Annual Field Conference, p. 246, 1935, Laudon excluded from the Hampton formation the lower part of the Chapin limestone of north-central Iowa and the North Hill limestone of southeastern Iowa, which he correlated with the Chouteau limestone of Missouri.
6. In Stratigraphy of the Kinderhook series of Iowa: *op. cit.*, p. 372, Laudon refers to the Wassonville limestone of southeastern Iowa as a partial equivalent of the Maynes Creek limestone of north-central Iowa

The greatest known thickness of Mississippian rocks in Kansas is 1,145 feet in Clark county. The average thickness is about 350 feet, but the thickness varies materially from place to place and is much less than this in many places. Thin sections of Mississippian rocks have been produced as a result of anticlinal movements and base-leveling at the close of the Mississippian. Part of the deformation, however, may have taken place during Mississippian time. Convergence toward the north between certain formations as shown in the cross sections in general is the expression of tilting movements that were taking place during the deposition of the Mississippian.

ROCKS OF KINDERHOOK AGE

Deposits of Kinderhook age consisting of limestone, dolomite, and shale are widely distributed in the Mississippi Valley. In Kansas the following Kinderhook formations are recognized from the base upward—the Chattanooga shale (doubtfully assigned to Kinderhook), the Compton limestone, and the Northview shale, which together are local equivalents of the Chauteau. The Sedalia and the Gilmore City limestones and intervening formations of Iowa and Missouri are regarded by L. R. Laudon as of Kinderhook age. R. C. Moore, the Missouri Geological Survey, and the Federal Geological Survey place the Sedalia and directly overlying formations in the Osage.

Chattanooga Shale (Kinderhook?)

General Statement.—The Chattanooga shale is a black to gray shale, which is exposed in many places from Alabama and Georgia to Missouri and Oklahoma, and continues in the subsurface into Kansas. Throughout Tennessee, Kentucky, Missouri, and Arkansas, the Chattanooga is 15 to 50 feet thick in most places, but formations in adjoining states with which it has been correlated are much thicker. There is evidence to indicate its Devonian age in some areas and its Mississippian age in others. Some geologists have concluded that it is composed in part of Devonian and in part of Carboniferous rocks. The State Geological Survey of Kansas doubtfully classes the Chattanooga beds of Kansas as Kinderhook in age, assigning them to the Mississippian series of the Carboniferous system. This shale is conveniently studied with the Mississippian, in any case, for it is separated from the underlying beds by an angular unconformity whereas only an obscure disconformity separates it from the approximately parallel overlying deposits of definite Mississippian age. Its top is the only dependable datum plane below the Pennsylvanian to which beds of Mississippian age may be referred.

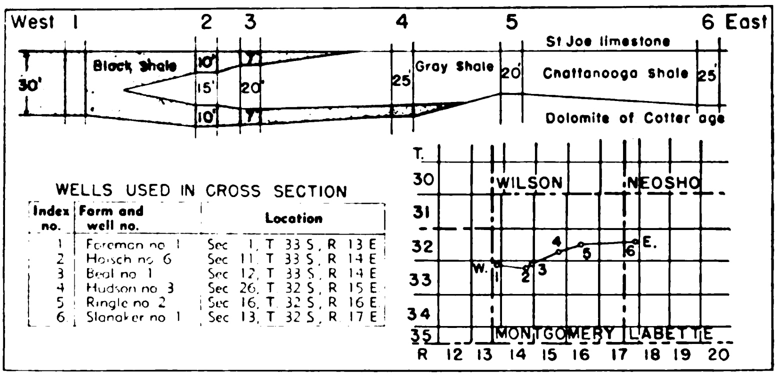
The Chattanooga shale was deposited widely in Kansas east of the central Kansas uplift (pl. 3), but it was subsequently removed by erosion in certain areas along the Nemaha ridge, in Cowley and Chautauqua counties east of the ridge, and in places on the flank of the central Kansas uplift. The shale is generally black in southeastern Kansas where it is in most areas less than 50 feet thick. Toward the north it thickens to more than 250 feet and becomes for the most part gray-green and in places includes some dolomitic and calcareous shale.

Character.—The Chattanooga shale in southeastern Kansas is normally a black fissile noncalcareous carbonaceous shale, which is argillaceous in some areas and silty and micaceous in others. It includes considerable fine pyrite, and varying numbers of *Sporangites huronensis.* These spores, abundant in some places, rare in others, occur throughout the Chattanooga in both black and gray shales. Toward the north, as shown in cross sections A-A′ and B-B′ of plate 5, the black shale interfingers with lighter gray and green shales and becomes more micaceous. The black color predominates in the southern part of the state, but in Montgomery county a wedge of gray shale starts in the middle of the black shale and gradually expands toward the east until the entire formation consists of gray shale (fig. 2).

Northward from Cowley county the relation of the black and gray shale is more irregular, the black shale in part grading out to dark shale before interfingering with the gray. The dark and black shales are most common at the base of the formation, but are generally absent in the northern and northeastern parts of the state. Black shale is present, however, in some northern areas. Among these are areas in T. 12 S., R. 19 E., in Douglas county where there is 40 feet of calcareous black and dark-green shale near the base of the Chattanooga and in T. 16 S., R. 3 W., in Saline county where 60 feet of black noncalcareous, somewhat micaceous shale occurs at the top of the formation.

The attention of the writer was drawn to beds of gray to dark-gray argillaceous shale present at the top of the Chattanooga in many wells in northeastern Kansas by Robert Carmody (oral communication, 1939). These shales differ from the usual type of Chattanooga shale in Kansas by their more argillaceous and less fissile character and by the absence of spores and mica. In some places this shale is slightly silty at its contact with the typical phase of the Chattanooga. It may represent only a lateral variant of the normal section, but in view of the uncertainty concerning the age of the Chattanooga its difference in character and its irregular thickness may have some significance.

In northeastern Kansas where the Chattanooga shale is thick, some parts of it contain impure silty dolomite or dolomitic shale as much as 10 feet thick. A bed of impure dolomite occurs also in Butler county in southern Kansas in the middle part of the black shale. The dolomitic shales are lenticular in character, having no persistence except within limited areas, and seem to be local variants of the Chattanooga.



WELLS USED IN CROSS SECTION

Index no.	Form and well no.	Location
1	Foreman no 1	Sec 1, T 33 S, R 13 E
2	Hoisch no 6	Sec 11, T 33 S, R 14 E
3	Beal no 1	Sec 12, T 33 S, R 14 E
4	Hudson no 3	Sec 26, T 32 S, R 15 E
5	Ringle no 2	Sec 16, T 32 S, R 16 E
6	Slanaker no 1	Sec 13, T 32 S, R 17 E

FIG. 2.—Cross section showing relation of black to gray shale in the Chattanooga shale in Montgomery county, Kansas.

In wells shown in cross section A-A′ of plate 5 and cross section D-C′ of plate 6 and in other wells in Wabaunsee, Dickinson, Cloud, and Clay counties, shown on the distribution map of the Chattanooga in figure 3, the upper 15 or 20 feet of the Chattanooga is red. In this area the Chattanooga shale seems to have been exposed to weathering during the deposition of the Chouteau before it was buried by younger rocks. The upper 10 feet of shale in a well (Derby No. 1 Neimuller, sec. 19, T. 10 S., R. 3 E., well No. 24 of cross section A-A′ of plate 5) in Clay county contains brown ironstone pellets not unlike oölite grains, but flattened and more irregular in shape.

In many places at the base of the Chattanooga, particularly in southeastern Kansas and in the counties east and south of the central Kansas uplift, there is a deposit of sandstone ranging in thickness from a thin streak of sandy shale to clean sandstone several feet thick. This sandstone is irregular in distribution and though widely deposited is only locally more than a few inches thick. In parts of Reno county and in other areas it is thick enough to be an important reservoir rock for oil. It has been well described by Leatherock and Bass (1936, pp. 96-97) and others. It is known as the Misener sand in the subsurface and occupies the position of the Sylamore sandstone of many reports.

Distribution.—A map showing the thickness and distribution of the Chattanooga shale is presented in plate 3. The map is based on the examination of well cuttings and of well logs on file July 15, 1938, at the State Geological Survey of Kansas. Most of the logs are from the Kansas Well Log Bureau.

Except for a small area in Ness county not shown in plate 3 or plate 8 the most westerly known occurrence of the Chattanooga shale in Kansas is in western Barber county (Skelly No. 1 Temple well, sec. 13, T. 34 S., R. 15 W.), where it is 52 feet thick. It is absent 40 miles beyond, in eastern Clark county (Watchorn and Olson No. 1 Morrison well, sec. 17, T. 32 S., R. 21 W.), where lower Osage rocks overlie pre-Chattanooga rocks (see cross section F-F′ of plate 7). The Chattanooga shale is generally absent north and west of Clark county.

On the southwestern flank of the central Kansas uplift in Barber county and also on its northeastern flank in Lincoln, Russell, and Osborne counties, the Chattanooga shale is overlapped by the Mississippian limestones, which in these areas rest upon pre-Chattanooga rocks. On the southeastern margin of the central Kansas uplift, however, the Chattanooga shale extends west of the present margin of the limestones as shown in plate 8, but here, as elsewhere adjacent to the central Kansas uplift, it is probable that the limestones originally extended beyond the shale. The absence of the Mississippian limestones above the shale in areas on the southeastern margin of the uplift was probably due to post-Mississippian deformation and erosion.

The shale may have been deposited in topographic depressions considerably farther west than is indicated by its present distribution and may still be preserved locally in synclinal areas that escaped the several periods of erosion that occurred during and at the close of Mississippian time. Such an outlier of Chattanooga shale may be represented by greenish-gray shale 16 feet thick containing spores reported by L. R. Fortier (oral communication) at the base of limestone of Burlington age in Ness county (Barnsdall No. 1 Lank well, sec. 35, T. 18 S., R. 21 W., 4,390 to 4,406 feet) on the western flank of the central Kansas uplift. Chattanooga shale is reported to be present also in a few wells in an isolated area shown in plate 3 in T. 17 S., R. 8 W., in Ellsworth county.

The Chattanooga shale is absent from several large and small areas along the trend of the Nemaha ridge fold. This is due to the fact that after Mississippian deposition was completed the Chattanooga and younger Mississippian rocks were folded and peneplaned. Where the Chattanooga shale was raised above the level of the peneplain the shale, together with the overlying rocks, was worn away, exposing pre-Chattanooga rocks on the crests of many anticlines and domes. The local thinning and absence of the Chattanooga in Sumner, Cowley, and Chautauqua counties are due to post-Keokuk erosion. The area in these counties from which the Chattanooga was removed is also shown roughly in plate 7 within the minus 50-foot thickness line representing the deeper part of the Cowley basin.

There was some erosion of the Chattanooga during Kinderhook time west of the Nemaha ridge in the area of weathered and reddened shales already mentioned, but the amount seems to have been small, for the thin dolomite overlying the weathered surface has a wide distribution. (See cross section D-C′ of plate 6.) Also, in southeastern Kansas the Chattanooga surface is so regularly overlain by the thin Compton and Northview formations that the surface in that area must have been essentially flat. In southern Kansas west of the Nemaha ridge the Chattanooga was exposed until the time of the deposition of the St. Joe limestone, but the evidence indicates that this area also was too low to have undergone much erosion.

Thickness.—The Chattanooga shale is relatively thin along the Oklahoma border and thickens toward the north. It reaches its maximum known thickness of 260 feet in Washington county in T. 3 S., R. 4 E. It is 245 feet thick in southeastern Nebraska just north of the Kansas-Nebraska border (Kerlyn No. 1 Robin Hood well, sec. 9, T. 1 N., R. 14 E.; see plate 3). The absence of the Chattanooga due to erosion has already been pointed out. In extreme southeastern Kansas the Chattanooga is absent seemingly because the surface lay above the level of deposition of the shale. On the flanks of the Ozark uplift in Crawford and Cherokee counties the St. Joe limestone rests directly on pre-Chattanooga rocks (St.

Louis Smelting and Refining Company, Ballard mine well, sec. 10, T. 35 S., R. 24 E.), probably for the same reason. The Chattanooga is also absent locally in parts of Labette county where the Compton limestone overlies pre-Chattanooga rocks. (Wert No. 1 well, sec. 16, T. 31 S., R. 21 E., and Romine No. 1 well, sec. 30, T. 33 S., R. 21 E.) From Labette county the shale thickens westward along the Oklahoma line and reaches a maximum of 130 feet in Barber county. (Sec. 19, T. 33 S., R. 12 W.) Farther west it becomes thinner, and, near western Comanche county, land formed the western margin of the broad Chattanooga basin. There are only slight variations in the thickness of the Chattanooga in the southern and eastern parts of the region, but in east-central Kansas there are areas of marked thinning. The most prominent of these areas is in Harvey county where the Chattanooga is exceptionally thin. In T. 23 S., R. 2 W., Harvey county, the Chattanooga is less than 15 feet thick and locally absent. The Chattanooga shale thickens in all directions from this township, and 18 miles to the north, in McPherson county, its thickness exceeds 200 feet. In southeastern Saline county the Chattanooga shale thins to less than 100 feet, but thickens again toward the north and east.

In many places in McPherson, Rice, and Reno counties, the Chattanooga shale is known to lie on remnants of Maquoketa shale, whose distribution adapted from McClellan's (1930, p. 1535) pre-Chattanooga areal map is shown in plate 4. In some wells fine sand or sandy shale was found between the two formations. In others, thin remnants of the Hunton separate the Chattanooga and the Maquoketa. The presence of spores, where they are found in the well cuttings, identifies the beds as Chattanooga, but in some wells in McPherson and adjoining counties where no spores have been found, the two formations are so similar that it is difficult to distinguish them even when cuttings are available. The thickness of the Chattanooga (pl. 3), where determined only from well logs, probably includes some unseparated Maquoketa shale in parts of these counties. In many wells in McPherson county, however, spores occur almost to the base of the thickest shale sections. The rapid increase in the thickness of the shale in these areas, therefore, does not seem to be caused so much by the two shales lying in contact with each other, though this also occurs, as by the Chattanooga filling depressions eroded in the Maquoketa shale. L. R. Fortier (oral communication, 1937), of Wichita, also has observed that in parts of McPherson county the Chattanooga shale thickens in

broad areas where it replaces the Hunton limestone and parts of the Maquoketa shale.

Stratigraphic relations.—The Chattanooga shale is definitely unconformable upon all the underlying formations with which it is in contact. The angular deformation of the older beds, however, is so slight as hardly to be detected in local areas, but regionally the beds underlying the Chattanooga range in age from Ordovician to Devonian.

The Chattanooga was deposited on a peneplaned surface throughout most of the Mississippi valley region. The low relief is indicated by the fact that the Chattanooga deposits, though present almost everywhere in the region, are in most places less than 100 feet thick. In parts of Kansas, however, there seems to have been more local variation in thickness than in most parts of the Mississippi valley region.

An attempt to show the original thickness of the Chattanooga is given on plate 4, which was prepared from plate 3 by omitting areas in which the shale is known to have been removed by post-Chattanooga erosion. As the upper surface of the Chattanooga was essentially flat, the map (pl. 4) showing the restoration of the thickness of the shale is believed to represent approximately the topography at the base of the Chattanooga. The thickening of the sediments toward the north may indicate northward tilting before or during the deposition of the Chattanooga shale. The fact that this thickening is accompanied by a gradual change in character and color of the shale suggests that the topography, as expressed in the thickness map (pl. 4), was to a large extent original and not caused by later erosion and removal of shale from the southern part of the area.

The pre-Chattanooga surface, as reconstructed on plate 4, shows the Chattanooga basin not yet divided by uplift along the trend of the subsequently formed Nemaha ridge fold as shown in plate 3. A drainage valley extending northward from Barber county, occupying in part the belt whose surface was underlain by the Maquoketa shale, emptied into a broad valley toward the north.

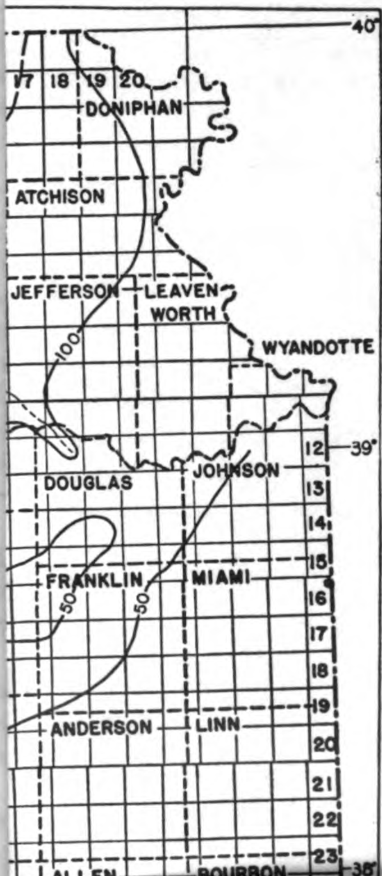
The relation of the topographic features of the pre-Chattanooga surface, as shown in plate 4, to the areal geology of the time is worthy of comment. The surface had low relief and except for the Maquoketa shale was underlain by hard cherty limestone and some sandstone. The principal valleys were broad and followed the belts of outcrop of the Maquoketa shale on the flanks of the central Kansas uplift and eastward across McPherson county. This shale in the region underlying Geary and Morris counties, where the valley is presumed to have drained into the open basin in northeastern Kansas, was removed by erosion in pre-Pennsylvanian time and the contours on plate 4 are therefore hypothetical where dotted across this area.

The development of parts of the valley, however, seems to have been independent of the areas of the outcropping shale. The area of Hunton limestone centering in Harvey county (pl. 4) was probably separated from the main outcrop of Hunton by an earlier eastward-flowing stream that entrenched the valley in the limestone and subsequently widened it in the underlying Maquoketa shale. Another abnormality is the narrow north-south valley, in Ts. 21 and 22 S., R. 6 W., that cuts across the western end of the Hunton outlier (see pl. 4). This part of the valley was trenched across hard limestone, whereas a belt of Maquoketa shale only a few miles farther west around the west end of the outlier would have provided a more easily eroded channel. The presence of this constricted channel is fully established by cuttings from several wells (pl. 3). Drainage failed to utilize the belt of Maquoketa shale (pl. 4) on the south and east sides of the outlier, probably in part because in Harvey county the Maquoketa shale is in places only 25 feet thick, whereas in Reno and McPherson counties the shale is more than 100 feet thick.

The next younger formation in Kansas, the Chouteau, which is the equivalent of the Compton and the Northview of Kinderhook age, seems to be conformable on the Chattanooga in some areas. The St. Joe and Reeds Spring limestones in some areas are unconformable above the Chattanooga, but, as has been pointed out, not much erosion seems to have occurred during the hiatus. On the southeastern margin of the central Kansas uplift and in places along the Nemaha ridge fold the Pennsylvanian rocks overlie the Chattanooga.

Chouteau Limestone, Northview Shale, and Compton Limestone

The Compton limestone and the Northview shale on the western flank of the Ozarks in west-central and southwestern Missouri were regarded by Moore (1928, pp. 118-127) on faunal grounds, as partial equivalents of the Chouteau limestone, which occupies a corresponding stratigraphic position on the northern flank of the Ozarks. Branson (1938) also regards the Compton and Northview as partial equivalents of the Chouteau. This conclusion, as expressed by Moore and Branson, is confirmed by work on insoluble residues by the


40°
17
18
19
20
DONIPHAN
ATCHISON
JEFFERSON
LEAVEN
WORTH
WYANDOTTE
100
12
39°
DOUGLAS
JOHNSON
13
14
15
FRANKLIN
MIAMI
50
50
16
17
18
19
ANDERSON
LINN
20
21
22
23
38°
ALLEN
BOURBON

Missouri Geological Survey, not yet published, and by the work of the writer on the subsurface rocks of Kansas. These formations are definite lithologic units in their respective areas; and transitional variations from Northview and Compton to Chouteau take place in the intervening area in Kansas.

COMPTON LIMESTONE AND NORTHVIEW SHALE

The Compton limestone was named by Moore (1928, pp. 118, 122) from outcrops in Webster county in southwestern Missouri. The Northview shale was named by Weller (1901, p. 140). Both these formations are well developed in southwestern Missouri, but they are thin and locally absent in the extreme southwestern corner of the state. Thin local deposits of these formations are reported by Moore (1939, pp. 5 and 6) in outcrops on Grand river in extreme northeastern Oklahoma. Moore (1928) reports a maximum thickness of 25 feet for the Compton at the outcrops in Missouri and 100 feet for the Northview shale.

Outcrops.—The Compton limestone at the outcrop is described by Moore as bluish-drab to grayish-blue, compact, very fine-grained limestone that breaks with conchoidal fracture. It contains a few crinoids and other fossils and is 5 to 25 feet thick.

The Northview shale is described as consisting of two members in the outcrops; the upper, a fine-grained yellow sandstone that may be as much as 25 feet thick, the lower, a blue or bluish-green silty shale that is 25 to 75 feet thick.

Branson (1938, pt. 2, pp. 3-5) presents a detailed description of the Northview shale by Jack W. Gardner, who found that the lower shaly part of the formation, as well as the upper part, is really a siltstone composed in many places entirely of fine quartz grains, but with the addition of calcareous and dolomitic cement. The upper sandy member was called by early Missouri geologists the "vermicular sandstone" from the tubular openings in the rock, which resemble worm borings.

Subsurface Character of the Compton Limestone.—The limestone from well cuttings in Kansas that is correlated with the Compton is typically a fine-textured, slightly greenish-gray limestone with a waxy luster. It varies in character and in some places is semi-granular and crinoidal and gray or pale buff gray. The cuttings ordinarily contain no chert.

The insoluble residues are very small and show only small amounts of white, shapeless, fragile, and spongy siliceous aggregates. As pointed out by Mary Hundhausen and J. G. Grohskopf of the Missouri Geological Survey (oral communication), the residues include occasional microscopic, white, loose-textured, twisted, siliceous aggregates that suggest casts of worm borings. In most residues, considerable pyrite is present. The residues from the Kansas well samples show similar characteristics.

Subsurface Character of the Northview Shale.—The shale that is correlated with the Northview in the Kansas well cuttings resembles, in most places, the lower member of the outcrops. It is gray to greenish-gray, but becomes a darker green in the thicker sections in Allen and Bourbon counties. It is slightly calcareous or dolomitic, the dolomitic character being more prominent toward the area in which the formations are transitional to the Chouteau. The Northview shale does not contain spores as does the underlying Chattanooga shale. The insoluble residues are typically green and porous, and show the silty character better than the original rock.

The upper, more coarsely silty member is generally absent in Kansas or not sufficiently distinctive to be separated. It is present, however, in Allen and Bourbon counties where it is 28 to 33 feet thick. West of Allen county in the Hogueland well in Woodson county (sec. 3, T. 24 S., R. 15 E.; the Compton is 29 feet thick, the Northview 40 feet thick), the Northview is thinner and the upper siltstone member is missing. Toward the north, the siltstone merges into the upper part of the Chouteau.

Thickness of Compton and Northview.—The Compton and Northview are both thin near the Oklahoma border but thicken gradually toward the north, where, as shown in cross section C-C′ of plate 6, they merge into the lithologically different Chouteau limestone. Eastward along the Oklahoma border from their margin in eastern Chautauqua county, the combined thickness of the Compton and Northview is less than 20 feet in most places. In some wells both formations are drilled through in 5 feet and may be represented in the same sample. The Compton is generally less than half the thickness of the Northview, but in the Marhenke well (sec. 34, T. 25 S., R. 11 E.) in central Greenwood county, the Compton is 10 feet thick and the Northview only 5 feet thick. In this area it is possible that a part of the Northview was eroded before the region was covered by younger rocks.

In southeastern Kansas, although both formations are thin, they maintain their lithological identity and in good sets of samples no difficulty is experienced in distinguishng them. The Compton limestone, because it is soft, yields small samples and there are "skips" in the samples of some wells at the horizon of the Compton, where the limestone is thin.

The maximum thickness of each formation occurs in the Dahl well (sec. 25, T. 26 S., R. 20 E., well No. 4 of cross section C-C′, pl. 6) in Allen county near the transition zone where the formations are still distinguishable. In this well the Compton is 28 feet thick and the Northview, including the upper siltstone member, is 61 feet thick.

Transition to Chouteau.—In the Dahl well the gray, fine-textured limestone, typical of the Compton farther south, is buff gray and has become brown and lithographic at the top. The Northview is dark-green limy siltstone containing some bands of shaly limestone. The coarse, almost sandy siltstone at the top, which is 6 feet thick, is very dolomitic. In the Briggs well (sec. 15, T. 24 S., R. 21 E., well No. 5 of cross section C-C′, pl. 6) in northern Allen county, the typical Northview at the top of the section is only 20 feet thick and overlies brown lithographic limestone and even-textured brown semiopaque chert. Below the lithographic limestone there is a zone of coarse-textured dark-gray limestone, which contains some brown chert. The basal part of the section is gray noncherty limestone, which rests on Chattanooga shale. This part of the section is typical of the Compton in most respects and the residues contain the characteristic spongy aggregates that resemble casts of worm borings. The middle part of the section containing the brown lithographic limestone and the brown chert resembles neither the Northview nor the Chouteau.

The basal part of the Kinderhook directly overlying the Chattanooga shale in the Leasure No. 5 well (sec. 24, T. 20 S., R. 23 E., well No. 3 of cross section C-C′, pl. 6) in Linn county is much like the Compton, but the upper part, though not typical, more closely resembles the Chouteau than the Northview. The upper part of the Chouteau in this well is gray impure dolomite with blocky dull dark-gray chert passing upward into buff and brown dolomite with dull dark-gray chert and brown chert. Some siltstone fragments were noted in the insoluble residues. Farther north, the middle part of the Chouteau contains much brown coarsely sucrose dolomite. The brown chert and lithographic limestone have disappeared and the silt content is smaller.

These wells show clearly the transition from the Compton and Northview to the Chouteau or rather from the Northview to the

Chouteau, for the Compton, although it becomes slightly cherty toward the north, maintains its lithologic identity in much of the Chouteau area.

CHOUTEAU LIMESTONE

The term Chouteau limestone, as used by Swallow (1855) in Cooper county, Missouri, was originally applied to rocks including the Sedalia limestone at Sedalia, Mo. Moore (1928, pp. 60, 128) restricted the term to the lower part of Swallow's Chouteau. Some geologists have continued to use the term Chouteau in the original sense. The Chouteau, as restricted by Moore, crops out around the northern flank of the Ozark uplift in Missouri extending from St. Clair county in west-central Missouri to Knox and adjoining counties in northeastern Missouri, and neighboring parts of Illinois and Iowa.

In southeastern Iowa, the lithologically similar North Hill limestone of Laudon is correlated by both Moore (1935, p. 241) and Laudon (1935, p. 246) with the Chouteau limestone of Missouri. In north-central Iowa, Laudon correlates the lower gray limestone ledges of his Chapin limestone with the Chouteau. Moore regards the Chapin as equivalent to the Chouteau.

Outcrops.—At the outcrops in west-central Missouri, nearest to Kansas, the Chouteau limestone has been described by Moore and others as light bluish-gray to dark, drab, compact, dense, earthy to silty impure limestone. It contains layers of dull to gray chert nodules 1 to 4 inches thick.

In northeastern Missouri it has an irregular thickness of 20 to 50 feet. It is absent in some areas north of Missouri river, but reaches a thickness of 50 to 55 feet in Howard and Boone counties in central Missouri. At the outcrops in west central Missouri it is thinner, a maximum thickness of 25 feet having been observed in Benton county. Greater thicknesses for the Chouteau are given by Branson, who includes the Sedalia, Fern Glen, and Reeds Spring in the Chouteau.

Subsurface Character in Kansas.—Well cuttings of the Chouteau consist of impure earthy and silty gray and dark-gray limestone containing varying amounts of dolomite and chert. In some beds the dolomite occurs as microscopic crystals in a matrix of silty and siliceous limestone. Other beds consist of porous sucrose dark-gray or buff cherty dolomite not unlike the overlying Sedalia, except for the abundant chert. In the belt where the Chouteau is transitional to the Northview the dolomite is very coarsely sucrose in some beds.

Not much dolomite or chert occurs in the lower 30 feet that corresponds to the Compton.

The chert is of several types. The most characteristic is common throughout the formation. It is ash gray, dull, and opaque, and much of it breaks with a rough surface. Microscopically the chert shows a hard mealy texture with gray matrix between darker gray granules. Another less common type of chert is smooth in fracture, dull-gray opaque or brown semiopaque with stippled markings of lighter color on the fractured surface. The stippled dots seem to have consisted originally of fine silt particles or minute dolomite crystals around which siliceous cement was deposited. Some of the fragments seen in the residues show incomplete coalescence of these growths resulting in a texture microscopically botryoidal. The smoothly fractured stippled chert seems to have resulted from the silicification of the original rock, in which the impurities have become completely merged.

Thickness.—The thickest section of the Chouteau noted in wells in Kansas is in the Kasper-James well (sec. 8, T. 13 S., R. 25 E., well No. 7 of cross section C-C′ and well No. 8 of cross section D-C′, pl. 6) in Johnson county, near Kansas City, where the Chouteau is 111 feet thick. As shown in cross section D-C′ of plate 6, its thickness diminishes toward the west until in Wabaunsee county in the Empire-Schwalm well (sec. 19, T. 12 S., R. 11 E., well No. 5 of cross section D-C′, pl. 6), the thickness is only 30 feet. Toward the south, as shown in cross section C-C′, the combined Northview and Compton thins to 87 feet in the Dahl well (sec. 25, T. 26 S., R. 20 E., well No. 4 of cross section C-C′, pl. 6). In the Mary Watt No. 5 well (sec. 34, T. 28 S., R. 17 E., well No. 3 of cross section C-C′, pl. 6) in Wilson county, the combined Compton and Northview are only 35 feet thick. Further south on the line of cross section C-C′ they thin to less than 5 feet in places and probably disappear a short distance south of the Kansas-Oklahoma border.

Distribution.—The distribution of the Northview shale and Compton limestone and of the Chouteau limestone as revealed in well cuttings is shown in plate 8. These rocks are found only east of the Nemaha ridge. As the Mississippian was entirely removed from a broad area on the northern part of the Nemaha ridge, the exact position of the original margin of the Chouteau is uncertain, but the Chouteau is absent west of the denuded area. South of T. 19 S., the Northview and Compton phase of the Chouteau prevails. Some thin outliers of the Compton and Northview may be present in eastern Cowley county.

Stratigraphic Relations.—The Chouteau and its correlatives, the Compton and Northview, are underlain by the Chattanooga shale at all places in the subsurface of Kansas except in extreme southeastern Kansas, where the Compton and Northview locally overlap upon pre-Chattanooga rocks. In Webster and Wright counties in southwestern Missouri, Moore (1928, p. 119) noted that the Compton similarly overlaps directly upon the Ordovician. Branson (1938, pt. 1, fig. 8, p. 14) presents a photograph showing the Chouteau overlapping upon Devonian rocks in a quarry near Providence in Boone county, north-central Missouri, with only a thin basal sandstone, which he refers to the Bushberg, intervening. Moore reported other areas in which the Chouteau rests on pre-Chattanooga rocks in northern Missouri. No representative of the Bushberg sandstone or other sand was noted at the base of the Compton or Chouteau of Kansas.

In some areas such as those just noted the Chouteau overlapped beyond the margin of the Chattanooga and is in contact with pre-Chattanooga rocks. In southeastern Kansas, however, the Compton and Northview, correlatives of the Chouteau, are thin, and in Oklahoma they wedge out on the surface of the Chattanooga shale. In northeastern Kansas the Chouteau is not present above the Chattanooga shale west of the Nemaha ridge. It is possible that the sea did not entirely withdraw from the area of Chattanooga deposition and that the Chouteau is conformable upon the Chattanooga in the deeper parts of the Chouteau basin. It seems likely, however, that some slight deformation took place before the deposition of the Chouteau—notably along the Nemaha ridge—causing the Chouteau to overlap beyond the margin of the Chattanooga shale in some places and in others to fall short of covering it.

In southeastern Kansas the Northview is overlain in some places by St. Joe limestone and in others by Reeds Spring limestone or limestones of late Fern Glen age, and the thick series of lower Mississippian rocks in Iowa, known as the Hampton and Gilmore City formations, classified as Kinderhook by Laudon, are absent. There seems, therefore, to be a hiatus between the Northview and the Osage rocks in southeastern Kansas, although the regularity of the Northview and Campton does not seem to indicate much erosion during the interval of exposure, but rather a cessation of deposition.

Farther north in eastern Kansas in a few places the Chouteau is overlain by the Burlington limestone, although in most places a bed of dolomite of possible Sedalia age intervenes. In northern Missouri at the outcrops the rocks overlying the Chouteau and Sedalia are of Burlington age.

ROCKS OF KINDERHOOK OR OSAGE AGE

A sequence of strata in the subsurface of Kansas here tentatively designated the Gilmore City and the Sedalia limestones, is not now definitely referable to either the Kinderhook series or the Osage series. In north-central Iowa, where the Gilmore City is exposed, it is underlain by the Hampton formation of Laudon in which he includes as its basal member the Wassonville limestone, the correlative of the Sedalia limestone of northeastern Missouri. The areas in Iowa in which the Mississippian is exposed are continuous with the Mississippian exposures of Missouri only in a narrow belt along Mississippi river in southeastern Iowa and northeastern Missouri. In this connecting belt the Gilmore City limestone and all but the basal member of the Hampton are absent. In consequence the determination of the relations of the formations in Iowa to those in Missouri is dependent on paleontological criteria. L. R. Laudon, who has studied the Gilmore City and Hampton in greatest detail, believes that both these formations are of Kinderhook age but are younger than the Chouteau; on the other hand, R. C. Moore classifies the lowest member of the Hampton (the Wassonville) or the equivalent Sedalia as of Fern Glen age and the upper part as of Burlington age; and on the basis of Federal Geological Survey unpublished data, J. S. Williams also regards the Wassonville and Sedalia of northeast Missouri as of Osage age. Thus, according to the interpretation of Moore and Williams, the Hampton and Gilmore City cannot be of Kinderhook age. On account of these differences of opinion it seems desirable to discuss the Gilmore City and Sedalia, tentatively identified in the subsurface in Kansas, as rocks of Kinkerhook or Osage age.

Table 2, showing the sequence of geologic units for north-central Iowa and southeastern Iowa, is presented for the better understanding of the discussion to follow:

Moore and Laudon agree that the North Hill limestone of southeastern Iowa and the lower Chapin of north-central Iowa are correlatives of the Chouteau of Missouri. They also agree that the Sedalia or Upper Chouteau of some geologists is properly correlated with the Wassonville of southeastern Iowa and is at least in part equivalent to Laudon's Upper Chapin and Maynes Creek of north-central Iowa. Moore, however, from faunal evidence, concluded that the Sedalia limestone, equivalent to the Wassonville of Laudon, is of Fern Glen age. Laudon, on the contrary, also on faunal evidence, has concluded that not only the Wassonville and Maynes

TABLE 2.—Showing correlation of Kinderhook and associated formations in north-central and southeastern Iowa.

North-Central Iowa L. R. Laudon[a]	North-Central Iowa R. C. Moore[c]	Southeastern Iowa L. R. Laudon[b]	Southeastern Iowa R. C. Moore[c]
Mississippian	Mississippian	Mississippian	Mississippian
Meramec series	Meramec series		Meramec series
	Pella beds (Ste. Genevieve)	Pella beds	Pella beds
St. Louis ls.	St. Louis	St. Louis ls.	St. Louis ls.
Kinderhook series			
Gilmore City ls.[d]	Alden ls.	Spergen ls.	Salem ls.
	Osage series		Osage series
		Warsaw ls.	Warsaw ls.
		Keokuk ls.	Keokuk ls.
	Burlington ls.	Burlington ls.	Burlington ls.
		Kinderhook series	
Hampton fm.		Hampton fm.	
Iowa Falls ls.	Iowa Falls ls.		
Eagle City ls.	Eagle City ls.		
	Fern Glen ls.		Fern Glen ls.
Maynes Creek ls.	Maynes Creek ls. (Sedalia)		
Upper Chapin ls.		Wassonville ls.	Wassonville ls. (Sedalia)
	Kinderhook series		Kinderhook series
Lower Chapin ls. (Chouteau)	Chapin ls. (Chouteau)	North Hill ls. (Chouteau)	North Hill ls. (Chouteau)
	Sheffield sh.	English River ss.	English River ss.
		Maple Mill sh.	Maple Mill sh.
		Sweetland Crk. sh.	Sweetland Crk. sh.

a. Laudon, L. R., Stratigraphy and paleontology of the Gilmore City formation of Iowa: Iowa Univ. Studies in Natural History, vol. 15, No. 2, 1933, and Supplemental statement on the Mississippian system in Iowa: Guidebook, Ninth Annual Field Conference, Kansas Geol. Soc., p. 246, 1935.

b. Laudon, L. R., Stratigraphy of the Kinderhook series of Iowa: Iowa Geol. Survey, vol. 35, pp. 353 and 348, 1931, and *op. cit.*, Guidebook, p. 246.

c. Moore, R. C., The Mississippian system in the upper Mississippi valley region: Guidebook, Ninth Annual Field Conference, Kansas Geol. Soc., pp. 240-245, 1935.

d. Laudon correlates the Gilmore City limestone with the Alden limestone in north-central Iowa, but not with the Spergen (Salem) limestone of southeastern Iowa. Moore correlates the Alden with the Spergen (Salem).

Creek members of his Hampton formation are of Kinderhook age, but also places in the Kinderhook his overlying Eagle City and Iowa Falls limestone members of the Hampton as well as the still younger Gilmore City limestone. Whatever the age that may ultimately be assigned to these formations, distinct lithological units, corresponding to the outcropping rocks, occur in the subsurface above rocks of Chouteau age. These units will be discussed tentatively by the names of the surface formations that they are believed to represent.

Sedalia Limestone

General statement.—The term Sedalia limestone was introduced by Moore (1928, p. 149) for the slightly siliceous dolomite that was originally called Upper Chouteau by Swallow in 1855. This dolomite is still regarded as a member of the Chouteau by some geologists. It comes to the surface on the northern flank of the Ozarks where it extends from north-central Missouri to western Illinois. Moore (1928, p. 22; 1935, pp. 242, 245) correlated it with the Wassonville limestone in exposures at Burlington in southeastern Iowa.

Outcrops.—In its typical outcrops in north-central Missouri, the Sedalia is a massively bedded dolomite weathering to smooth, rounded surfaces. It is somewhat siliceous in some places. Dense, dark chert in discontinuous nodules and interrupted thin bands is mentioned by Moore as a local constituent. In most outcrops it is chiefly composed of sucrose buff or brown dolomite. Its maximum thickness in north-central Missouri is 40 feet.

Subsurface character in Kansas.—Down dip from the outcrops in Saline county, Missouri, the Missouri Geological Survey has identified the Sedalia limestone in the cuttings of some wells in northwestern Missouri. In the Kasper-James well (sec. 8, T. 13 S., R. 25 E.) in Johnson county, Kansas, samples of 30 feet of coarsely sucrose buff and gray dolomite overlying typical Chouteau rocks were identified as Sedalia by the Missouri Geological Survey at a depth of 1,060 to 1,090 feet below the surface. In other parts of northeastern Kansas, cuttings similar to those in the Kasper-James well are found in the samples overlying the Chouteau. These cuttings are generally buff and brown, moderately fine sucrose dolomite. They contain only small amounts of chert or other insoluble residue, but generally include some chert carried down from overlying limestones during drilling operations. That part of the residue that is characteristic of the Sedalia consists of microscopically botryoidal aggregations of roundish granules of chert, which seem to be the result of siliceous growth around impurities. Some of these aggregations are crumbly, but where the granules are more nearly completely merged, gray or buff rough grainy masses of chert similar to the chert in the underlying Chouteau are formed. Some of the Sedalia cherty residues show rhombohedral casts of dolomite crystals that were removed from the siliceous cement by acid treatment.

Distribution and thickness.—The rocks referred to as Sedalia have been recognized in Kansas only in the northeastern part of the state in the area shown in plate 8. In the Kasper-James well (cross sections C-C′ and D-C′, pl. 6) in Johnson county, the Sedalia is 30 feet thick, and in Douglas and Wabaunsee counties about 20 feet thick. It is thinner west of the Nemaha ridge, where it overlaps upon the Chattanooga shale (cross section D-C′, pl. 6). In Saline and Douglas counties its thickness is only about 10 feet and farther northwest it is thinner or absent.

In central Linn county (well No. 6, cross section C-C′, pl. 6) it is only 13 feet thick and in Allen county, wells No. 5 and No. 4 show, respectively, thicknesses of 10 and 6 feet. In northwestern Allen county (Oklahoma Natural Gasoline Company No. 1 Union Central Life Insurance Company well, sec. 28, T. 23 S., R. 18 E.), the Sedalia is 18 feet thick and overlies the coarsely silty phase of the Northview. Dolomite of similar character, though thin, occurs locally above the Northview even farther south in Crawford county (Kansas City Southern No. 1 Pittsburg well, sec. 20, T. 30 S., R. 25 E.), and in Wilson county (Union Gas Corporation No. 5 Mary Watt well, sec. 34, T. 28 S., R. 17 E., well No. 3 of cross section C-C′, pl. 6), where the writer believes the dolomite to represent the Sedalia. In the Wilson county well it underlies typical St. Joe limestone. An isolated area of thin dolomite (see pl. 8), which the writer believes to be an outlier of the Sedalia, occurs in southeastern McPherson county (Ts. 20 and 21 S., Rs. 2 and 3 W., well No. 15, cross section A-A′, pl. 5) between Chattanooga shale and beds assigned to the Gilmore City. Another possible outlier represented by 5 feet of dolomite below the St. Joe was observed in a single well in Harvey county (sec. 23, T. 23 S., R. 2 W., well No. 13, cross section A-A′, pl. 5).

Stratigraphic relations.—The buff and brown dolomite referred to the Sedalia occurs nearly everywhere above the Chouteau limestone in the outcrops, from northeastern Missouri to northeastern Kansas, except where younger rocks are unconformable above the Chouteau. As shown in cross section D-C′, plate 6, the Sedalia continues beyond the area of the Chouteau and overlaps upon the Chattanooga whose reddened upper surface seems to have been the result of weathering before the deposition of the dolomite. Laudon (1931, pp. 373-379), in his work on the Kinderhook in Iowa, reports that northward from Burlington, Iowa, the Wassonville (correlative of the Sedalia) similarly overlaps progressively beyond the North Hill (correlative of the Chouteau) upon English River, Maple Mill, and Sheffield formations in southeastern Iowa. Moore (1928, pp. 72-73, 150) noted that in northeastern Missouri the Sedalia rests in some places upon

Devonian and older rocks. This relation and the similar relation in Kansas also probably represents overlap.

In Allen and Wilson counties the brown dolomite, discussed as Sedalia, overlies Northview shale, which, as previously stated, is the approximate equivalent of the upper part of the Chouteau. Farther south and west in Kansas the Sedalia is absent. East of the Nemaha ridge where the Sedalia is absent, its position at the top of the Northview is occupied by rocks identified as St. Joe limestone.

In Wabaunsee county, in parts of Lyon and Jackson counties, and very generally west of the Nemaha ridge, the Sedalia is overlain by a group of limestones tentatively correlated with the Gilmore City of Iowa. In other localities of northeastern Kansas, as in the outcrops in Missouri, the Sedalia is unconformably overlain by Burlington limestone. In southeastern Kansas it is overlain in many places by rocks of late Fern Glen age.

The Sedalia of northern Kansas is a thin formation, but the Hampton formation of Laudon in Iowa, which he believes includes as its basal member the Wassonville (equivalent to the Sedalia) has been found by Laudon (1933, p. 19) to increase in the subsurface of Iowa to 180 feet near Webster City in Hamilton county. In the published composite columnar section for Iowa, Laudon gives the Hampton a thickness of 250 feet. These figures, however, include the North Hill or Lower Chapin limestones, which were subsequently correlated with the Chouteau and separated from the Hampton by Laudon (1935, p. 246).

The Sedalia seems to be conformable above the Chouteau, because the Sedalia is a thin formation throughout northern Missouri and Kansas and accompanies the Chouteau from Illinois to northwestern Kansas and overlaps upon other rocks beyond the Chouteau margin. Swartzlow (1933, p. 273), who treated the Sedalia as the upper member of the Chouteau, described the contact of the Chouteau and Sedalia as transitional in character and therefore one of conformity.

If the Sedalia is of Kinderhook age, a hiatus, represented by the absence of rocks of upper Hampton age, Gilmore City limestone, and Fern Glen limestones occurs where Burlington rocks are in contact with the Sedalia. The Gilmore City is reported by Laudon to be unconformable upon his Hampton formation in Iowa, but where the Gilmore City limestone overlies the Sedalia in Kansas the thickness of the Sedalia has such slight variations that there is little to suggest a hiatus. If an unconformity exists between these formations, the erosion of the surface of the Sedalia in Kansas must either have approached peneplanation locally before the Sedalia was covered by the Gilmore City or the surface remained so near sea level that only thin Hampton deposit sediments represented by the Sedalia were laid down in Kansas.

The Sedalia was identified in the cuttings of the Kasper-James well (sec. 8, T. 13 S., R. 25 E.) in Johnson county by the Missouri Geological Survey and was correlated by the writer with a similar lithologic unit in other wells in eastern Kansas. The fact that the Sedalia is thin, is consistently present above the Chouteau throughout a large area without irregular thinning, and is overlain in some places by rocks assigned to the Gilmore City formation suggests that the Sedalia is more closely allied to the Chouteau than to the overlying rocks of Osage age.

The age of this dolomite zone cannot be determined with confidence from the well cuttings because of the difference of opinion in regard to the age in outcrops. If the Gilmore City is of Kinderhook age the underlying dolomite must also be of Kinderhook age. If the formations overlying the Hampton in Iowa are of Osage age, the dolomite may be of Osage age.

Gilmore City Limestone

General statement.—The name Gilmore City was given by Laudon (1933) to a group of limestones in central Iowa. These limestones had previously been regarded in some localities as a part of the St. Louis limestone and in others assigned to the Kinderhook under the names Humboldt oölite and Alden limestone. The formation, as already mentioned, is placed in the upper Kinderhook on faunal grounds by Laudon (1933; 1935, p. 246), but some paleontologists place the formation in the Osage series.

Surface outcrops.—The outcrops of the Gilmore City in north-central Iowa are covered by glacial drift in most localities and the formation has only a small surface exposure. As described by Laudon, the Gilmore City at the outcrops is essentially a pure white or gray oölitic limestone. It is "usually bedded with green shale"; and minor amounts of blue dolomite occur at definite horizons. The formation is, however, not oölitic throughout and many beds are only sparsely oölitic. No single exposure shows both the top and bottom of the formation. The maximum exposed thickness is 57 feet at Gilmore City, Pocohantas county, Iowa, on Des Moines river where the formation is overlain by the St. Louis limestone. At Alden, in Hardin county, Iowa, on Iowa river it is 32 feet thick and rests unconformably upon the Iowa Falls, the youngest member of the Hampton formation, of which the Wassonville of southeastern Iowa, correlative of the Sedalia limestone of that area, is believed by Laudon to be the base.

Subsurface distribution in Iowa.—Laudon found it possible to trace the Gilmore City limestone in well logs in western and southwestern Iowa by its distinctive lithologic characteristics and prepared a thickness map of the formation for that state (Laudon, 1933, p. 18). The thickest areas of the Gilmore City in Iowa lie north and northeast of Omaha, Neb. If the basin, contoured by Laudon, were extended toward the southwest, its deepest part indicated by the thickness lines would extend across Nebraska and enter Kansas near the center of the northern border of Kansas. If projected across the region of the central Kansas uplift, the deep part of the basin would extend into the western part of Kansas. Northeastern Kansas and northwestern Missouri lie on the southeastern flank of the basin as thus projected. McQueen and Greene (1938, p. 33) have noted limestones in wells in northwestern Missouri similar to those described by Laudon and have tentatively correlated them with the Gilmore City limestone. These limestones are reported to be 74 feet thick in the well-known Forest City well (sec. 4, T. 59 N., R. 38 W., Holt county, Missouri) across Missouri river from the northeastern corner of Kansas.

Subsurface development in Kansas.—Rocks tentatively correlated with the Gilmore City limestone are found in the subsurface in Kansas in two areas. One of these is northeast of the central Kansas uplift and the other in western Kansas, southwest of that uplift.

In Smith, Osborne, Mitchell, western Dickinson, and northern Saline counties in Kansas, the brown dolomite correlated with the Sedalia limestone is overlain by clean noncherty or very slightly cherty limestone composed of fragments of broken shells and crinoids. The limestone is semigranular and, ordinarily, slightly buff gray or yellowish gray. Some beds contain fine-textured dark or black limestone pellets. The matrix that cements the crystallized fossiliferous granules is soft, opaque, and milky white. Owing to the softness of the limestone, the cuttings recovered in drilling are generally small. Fragments of green shale form a minor constituent of some samples.

The limestone in many places includes some oölitic beds, which, although irregular in horizontal and vertical distribution, are most commonly 25 to 35 feet above the base. The oölites, mostly gray, together with fragments of fossils, are cemented in a soft limy matrix. They are irregularly sized and many of them are slightly irregular in form. Where the black limestone pellets are present some of the oölites have black centers. Some of the broken oölites show alternating light and slightly darker gray bands.

The siliceous residues of samples from the Gilmore City limestone are very small and include cherty tailings from the overlying rocks and some translucent chert that may be indigenous. The characteristic residue includes fine quartz crystals in loose aggregates and thin finely drusy crusts. In Saline county and the counties to the north and northwest these crystalline assemblages and the associated semitranslucent chert are lemon yellow, both in beds that contain oölites and in the semigranular limestones that do not. In McPherson county and east of the Nemaha ridge, this fine drusy material is composed of clear quartz crystals, but otherwise the siliceous residues are similar. Pale-buff or gray, opaque, microscopically mamillary and columnar crusts of chalcedony are sparsely present with the drusy aggregates. Silicified shells of oölites though unusual are an occasional constituent in residues from the oölitic beds.

Where thin sections of Gilmore City overlap upon the Chattanooga shale in McPherson county and in areas east of the Nemaha ridge the oölites, which occur higher in the section, are generally not present, and the formation thus resembles the St. Joe limestone of earliest Fern Glen age. The Gilmore City is distinguishable, however, by its buff-gray color, and the soft opaque character of its matrix, and by the fine quartz aggregations and mamillary and columnar crusts of opaque chalcedony in the small insoluble residues.

In western Kansas in Logan, Scott, and Finney counties and in Yuma county, Colorado, similar gray, faintly yellow, and buff-gray limestones are widely present beneath the Burlington. The limestone is semigranular. The crystalline granules in many beds are composed largely of finely broken shell fragments cemented with a soft opaque gray limestone matrix. Many zones superficially seem to be oölitic, but perfectly rounded oölites are not common. The grains are subangular, elongated, and irregularly shaped particles with algal crusts, most of which are considerably thicker than the crusts common to oölites. The centers include fragments of shells, minute crinoid joints, and crystallized calcite. In some beds, near the base, the gray limestone crusts enclose irregular fragments of fine-textured dark-gray to black limestone, thus producing crusted granules, which, except for shape, are like the dark-centered oölites in northeastern Kansas. The siliceous residues of these rocks in the Watchorn and McNeeley No. 1 Spangler well (sec. 23, T. 20 S.,

R. 33 W., Scott county, well No. 3, cross section F-F′, pl. 7) are small and contain the same kind of yellowish loose drusy aggregates that characterize the rocks tentatively correlated with the Gilmore City east of the central Kansas uplift.

Thickness.—As may be seen from the cross sections and figure 3, the general thickness of the Gilmore City in northwestern Kansas is 20 to 35 feet. Its maximum known thickness is 52 feet in southeastern Mitchell county (Gurley No. 1 Abercrombie well, sec. 32, T. 9 S., R. 7 W.), but farther northwest (in well No. 2, cross section D-C′, pl. 6, where part of the samples are missing) in south-central Jewell county it may reach a thickness of 76 feet.

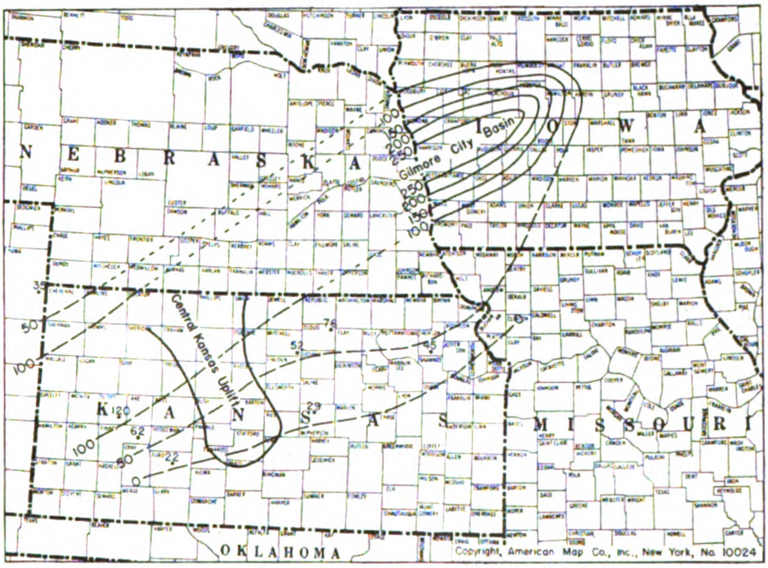


FIG. 3.—Sketch map showing distribution and thickness of Gilmore City limestone in Iowa, after Laudon, with additions for Kansas. Contour interval, 50 feet.

In western Kansas the greatest observed thickness of the Gilmore City beds is in Scott county (Watchorn and McNeeley-Spangler well), where it is 120 feet thick. In the Alma No. 1 McNeeley well (sec. 13, T. 15 S., R. 33 W., well No. 2, cross section F-F′, pl. 7) in Logan county it is 115 feet thick. From this well northwestward the thickness decreases to 35 feet in Yuma county, Colorado (I. T. I. O. No. 1 Strangways well, sec. 21, T. 2 S., R. 43 W., well No. 1, cross section F-F′, pl. 7). The thickness of the Gilmore City decreases southeastward from the Spangler well. In the National Refining Company No. 1 Wells well (sec. 13, T. 23 S., R. 30 W., well No. 4, cross section F-F′, pl. 7) of Finney county the thickness is 68 feet and it seems to be only 22 feet in the Swain No. 1 Taylor well (sec. 21, T. 25 S., R. 24 W., well No. 5, cross section F-F′, pl. 7), in northern Ford county.

Distribution.—In Kansas, east of the central Kansas uplift, the Gilmore City is present as far south as McPherson county (see pl. 8). Its southeastern margin trends approximately northeast through central Lyon county and north of Douglas county. The presence of 74 feet of limestone tentatively correlated with the Gilmore City in the Forest City well turns the 50-foot thickness line eastward from Jackson county, Kansas, where 45 feet is present (Haverbach et al. No. 1 Uhl well, sec. 26, T. 9 S., R. 14 E., well No. 16, cross section B-B′, pl. 5) farther south than was indicated by the Iowa data used by Laudon. Some thin outliers of the same limestone formation without oölites may be present even as far south as Harvey county.

The limits of the Gilmore City in southwestern Kansas are less sharply outlined because fewer wells have been drilled in that area. The formation seems to be absent in southeastern Ford county and to the southeast. It probably is thin from pre-Pennsylvanian erosion on the flank of the central Kansas uplift. If, as seems possible, it was deposited across the uplift it was removed during one of several periods of exposure that occurred during and at the close of Mississippian time.

Stratigraphic relations.—At the outcrops in north-central Iowa, the Gilmore City is reported by Laudon (1933) to rest unconformably on the Iowa Falls limestone, the uppermost member of his Hampton formation (see table 2). Near Webster City, Hamilton county, Iowa, the Hampton formation, which in Laudon's (1933, p. 19) report includes correlatives of the Chouteau of Missouri, is 180 feet thick. The Hampton decreases in thickness toward the south and west. At Bedford in Taylor county, in southwestern Iowa, near the Missouri line, the Gilmore City is reported to be in contact with the Chattanooga shale, and at Glenwood, Mills county, Iowa, south of Omaha, Neb., the pre-Gilmore City limestones are reported to be absent. The Hampton therefore is missing in considerable areas in southwestern Iowa and the area of its distribution is bounded by an irregular pattern, which excludes parts of southwestern Iowa and northwestern Missouri.

In northeastern Kansas the oölitic limestones correlated with the Gilmore City are chiefly in contact with the Sedalia, but in Mc-

Pherson county similar but nonoölitic limestone overlies the Chattanooga. In Cloud county, Kansas (Concordia Oil Company No. 1 Murdock well, sec. 6, T. 6 S., R. 4 W.), oölitic Gilmore City rocks extend beyond the Sedalia and overlie red shale at the top of the Chattanooga similar to that present beneath the Sedalia in many wells in this part of Kansas. In western Kansas the Gilmore City overlies pre-Chattanooga rocks.

The relation of the Gilmore City to the Sedalia presents an appearance of conformity in the Kansas cross sections A-A′, plate 5, and D-C′, plate 6, but in view of the widespread unconformity at the base of the Gilmore City in Iowa and the absence of rocks of Hampton age younger than the Sedalia in northeastern Kansas, it is probable that there is also an unconformity between the Gilmore City and the Sedalia in Kansas.

The Hampton formation of Laudon may have had originally a much wider distribution and the even surface that the Sedalia (correlative of the basal Hampton) presents to the Gilmore City in northeastern Kansas may be the result of erosion that in this area left only the basal part of the formation.

The St. Louis limestone of Meramec age unconformably overlies the Gilmore City limestone at the type locality and in the subsurface in west-central Iowa. In southwestern Iowa, however, the Gilmore City is reported by Laudon (1933, p. 18) to be overlain by Osage cherty limestones, reported to be 200 feet thick at Council Bluffs and as much as 300 feet thick in Taylor county near the Missouri state line.

In Kansas the Gilmore City strata are in most areas overlain by rocks of Burlington age. In McPherson county they are overlain by rocks of Fern Glen age. (See cross section A-A′ of pl. 5.) The upper surface of the Gilmore City is not so smooth and regular in northeastern Kansas as its lower contact with the underlying Sedalia for small local fluctuations in the thickness of the Gilmore City are noticeable. The most striking of these occurs in Jackson county. The Gilmore City limestone in the Haverbach et al. No. 1 Uhl well (sec. 26, T. 9 S., R. 14 E., well No. 16, cross section B-B′, pl. 5) has a thickness of 40 feet, the lower 20 feet of which is oölitic. Eleven miles to the north, in Goens No. 1 Wabaunsee well (sec. 3, T. 8 S., R. 14 E., well No. 17, cross section B-B′, pl. 5) the Gilmore City and Sedalia are both absent and the Burlington rocks are in contact with the Chouteau. Six miles northeast of this well the Chouteau in Garvin No. 1 Lutz well (sec. 27, T. 7 S., R. 15 E., well No. 18, cross section B-B′, pl. 5) is overlain by 15 feet of Gilmore City, the Sedalia possibly being represented in 15 feet of missing samples. It seems probable, therefore, that, although Gilmore City deposition may have centered in the Kinderhook basin of Iowa, the limestone may once have had a greater thickness and a more widespread distribution than at present and that it was reduced in thickness by erosion before being covered by the overlapping Osage and Meramec rocks. The Gilmore City basin, as outlined, has a trend that does not conform to any of the structural trends of this part of the Mississippi basin. As reported by Laudon the Gilmore City limestones are thick where they overlie the Chattanooga shale and thin where they overlie the Chouteau or Hampton rocks. These relations suggest that the Gilmore City limestone was deposited in an erosional basin.

ROCKS OF OSAGE AGE

Rocks of Osage age extend from the Appalachian Mountains to the Rockies. They are widely distributed in the Mississippi valley, both at and below the surface. They probably extended at one time across the region of the Ozark Mountains (Bridge, 1917, p. 558). West of Mississippi river, the Osage consists almost entirely of cherty limestones and dolomitic limestones, though some of the limestones included in it are free from chert or contain chert in very minor amounts. The name Osage was first applied to rocks in southeastern Iowa, where it consists only of Burlington and Keokuk limestones, together about 150 feet thick. The term was later expanded to include beds of Fern Glen age and some geologists include

Summary of Formations from Residue Analyses of Cuttings from the Ballard Mine Well of St. Louis Smelting and Refining Company, Cherokee County, Kansas, sec. 10, T. 35 S., R. 24 E.

	Thickness, feet	Total depth, feet
Carboniferous system:		
No samples	60	60
Mississippian series:		
Rocks of Chester age (20′)—		
Limestone	20	80
Rocks of Meramec age (90′)—		
Warsaw limestone	70	150
(J bed)	20	170
Rocks of Osage age (285′)—		
Burlington and Keokuk limestones, undivided	130	300
Grand Falls chert of Missouri Geological Survey	45	345
Reeds Spring limestone of Fern Glen age (includes St. Joe limestone)	110	455
Ordovician system		
Dolomite		

in it the Warsaw limestone, which is above the Keokuk limestone. The Osage rocks become thicker in the Joplin area, where, exclusive of the Warsaw limestone, they have a thickness of 285 feet, as shown in the preceding summary of formations in the Ballard Mine well, Cherokee county, Kansas, near the Mississippian outcrops. The cuttings of this well were analyzed by the insoluble-residue method by Mary Hundhausen in the laboratory of the Missouri Geological Survey.

Underground in Kansas, the Osage has a variable thickness, owing to overlap at the base and to unconformities at the top.

The Osage strata are composed almost entirely of limestone, cherty limestone, and cherty dolomitic limestone. Some geologists regard the Warsaw limestone as Osage in age and others regard it as Meramec in age. The rocks of Osage age, as defined in this report, include the greater part of the Boone formation of Missouri, Arkansas, and Oklahoma reports, but the Warsaw limestone, which is a part of the Boone formation, is excluded from the Osage on account of a pronounced disconformity at the base of the Warsaw, which will be discussed later. The lower formations of the Osage in southwestern Missouri consist of the St. Joe limestone and the overlying Reeds Spring limestone, which were correlated by Moore (1933, pp. 203-204) with the Fern Glen limestone of southeastern Missouri. The upper formations are the Burlington and Keokuk limestones.

St. Joe Limestone

Outcrops.—The St. Joe is the lowest formation regarded as of Osage age. It was first described by T. C. Hopkins (1893, pp. 253-349) in northern Arkansas where it is regarded as a member of the Boone formation. It is present in southwestern Missouri and is a partial equivalent of the Fern Glen limestone of southeastern Missouri, which it resembles lithologically. In the outcrops of Arkansas and Missouri, it has a thickness of 10 to 40 feet. In the outcrops it is a semigranular, crinoidal limestone, which in some places includes interstratified beds of greenish and reddish limy shale and pink and reddish limestone of no great thickness. It is generally noncherty though some outcrops show a little chert. In southwest Missouri and adjoining states this limestone is overlain by the cherty limestone and dolomite of the Reeds Spring. Laudon (1939, pp. 325-327) has described the St. Joe limestone in outcrops in Oklahoma where two phases of the formation are pointed out. One consists of thin-bedded gray to bluish-gray slabby limestone beds that are not markedly fossiliferous. The other consists of bioherms of exceptionally crinoidal limestone interbedded with greenish-gray and red very fossiliferous marls. These bioherms are reported to be a few feet to 2 miles long and as much as 80 feet thick. Laudon noted the presence of bioherms in correlatives of the St. Joe from Kentucky to New Mexico where they have a thickness exceeding 400 feet in one place.

Area of deposition in Kansas.—The St. Joe limestone was deposited in southern Kansas along the Oklahoma border as far west as Barber county. In Clark county (Watchorn No. 2 Morrison well, sec. 20, T. 32 S., R. 21 W., well No. 7a, cross section F-F′, pl. 7) it overlapped upon a surface underlain by pre-Chattanooga rocks and seems not to have been deposited much farther west in Kansas. On the Missouri border it has not been identified north of Cherokee county. Toward the north it overlapped upon the very flat post-Kinderhook surface. As shown in plate 8 it has not been observed north of central Greenwood county east of the Nemaha ridge. It extends into northern Sedgwick county west of the Nemaha ridge.

Subsurface character in Kansas.—The limestone correlated with the St. Joe in the subsurface of Kansas has the same stratigraphic relations and lithologic character as at the surface outcrops. It is for the most part semigranular in texture and is composed of crystalline fragments imbedded in a firm limestone matrix. In some places, and especially near the base, the limestone is partly fine-textured and does not contain the crystalline fragments that are probably composed chiefly of broken fossils. Where the formation is thick the upper part is more or less crinoidal. The formation is distinguished in the cuttings by the small amount or complete absence of chert in contrast to the usually very cherty overlying rocks of the Reeds Spring or rocks of late Fern Glen age. Much of the chert in the insoluble residues seems to have been abraded from the higher rocks during drilling operations. Neither glauconite nor oölitic limestone was observed in any of the St. Joe samples from Kansas wells, although both are reported in some outcrops in northeastern Oklahoma.

Shale of the St. Joe formation.—East of Cowley county the St. Joe formation is only 5 to 20 feet thick, although somewhat thicker sections occur locally. West and north of Cowley county where the St. Joe borders the central Kansas uplift, the formation thickens greatly and the lower part includes considerable dark greenish argillaceous shale. The upper part of the formation is not very shaly, although a few flakes of shale appear in some of the cuttings. Some of the limestone is semiopaque and greenish and the residues in most places show paper-thin flakes of greenish or gray shale.

No red shale or red limestone, such as distinguishes the St. Joe in Missouri and Arkansas, was noted in the cuttings of wells east of Cowley county, except in one well in Montgomery county (Lynn No. 1 well, sec. 10, T. 33 S., R. 17 E.) where some pink limestone was present 20 feet above the base of the formation, which in this well is thicker than usual for the area. In many wells in Cowley and Sedgwick counties considerable red shale and pink and reddish limestone are interstratified with crinoidal limestone. These red rocks occur in a zone 30 to 50 feet thick that lies above the lower shaly part of the section. In some wells, the red shale is 5 feet or more thick, but in most wells it seems to be present as partings between limestone beds, some of which are faintly colored by ferruginous impurities. The red shales are lenticular and in some places seem to grade laterally into green shales. The reddish limestones are erratic in distribution and have a greater vertical range than the red shale.

The wells in which red rocks were found in the St. Joe are indicated on the map (pl. 8). Red rocks seem not to be present in all wells in the localized area of occurrence. The absence of red shale in the samples may be due in part to excessive washing of the cuttings, but is probably due mainly to the erratic distribution of the ferruginous material. The red shales are probably somewhat more widely distributed, however, than is indicated on the map.

The grayish-green and dark-green shale near the base of the formation is much more widely distributed than the red shale. It is a common constituent of the St. Joe from Cowley county westward to Barber county. The shale is argillaceous and is unlike the shale of the Northview, which is predominantly silty over wide areas. In parts of Barber county (Sinclair-Prairie No. 1 Gentry well, sec. 1, T. 33 S., R. 15 W., and Skelly No. 1 Temple well, sec. 13, T. 34 S., R. 15 W.) the calcareous green shale member, which is not a sharply defined unit, is 50 feet thick and occurs 40 to 60 feet above the base of the formation. As shown in cores of the Sinclair Prairie-Gentry well the shale contains thin sheets and streaks of crinoidal limestone. The underlying limestone, which includes some shale, contains semitranslucent chert, which, although scarce, is more abundant than in the St. Joe farther east. In Cowley and adjoining counties the prominent shale member near the base is only 10 to 20 feet thick and occurs 10 to 35 feet above the base of the formation.

Limestone of the St. Joe formation.—In some localities, limestones that have the lithologic characteristics of the St. Joe attain considerable thickness, especially in a belt extending along the southern margins of Sedgwick and Butler counties. In south-central Sedgwick county (Alco Royalty et al. No. 1 Schulte well, NE¼ SE¼ NW¼ sec. 18, T. 28 S., R. 1 W.), a total thickness of 210 feet of noncherty limestone rests on Chattanooga shale. The lower 45 feet consists of dark limy shales and fine-textured limestone typical of the lower St. Joe in the area, but the upper 160 feet is an unbroken sequence of noncherty crinoidal gray and greenish-gray limestone. Pink limestone and some greenish shaly dolomite occur in some of the samples from this interval. One mile to the south in the nearest well (Murphy and Western Kansas No. 1 Thone well, SW¼ NW¼ sec. 19, T. 28 S., R. 1 W.) from which samples are available, limestone of Fern Glen age with typical chert is present from 75 to 120 feet above the Chattanooga. The overlying rocks consist of chert characteristic of the Burlington and Keokuk limestones, but inasmuch as they contain no limestone and show considerable weathering they are not in place.

In southeastern Sedgwick county (Shell and Tatlock No. 1 Gouldner well, sec. 6, T. 29 S., R. 2 E.) an uninterrupted section of noncherty limestone, 278 feet thick, overlies the Chattanooga. At the base is 66 feet of fine-textured limestone and limy dark-green shale overlain by 50 feet of red and gray shale and fine-textured limestone. No chert occurs in this part of the section nor in the overlying 162 feet of gray crinoidal limestone. The nearest well in which adequate samples are available is 6 miles to the north. In this well (T. C. Johnson No. 1 Janssen well, sec. 11, T. 28 S., R. 2 E.) a similar but sparsely cherty limestone section was drilled. The basal shaly section is present to 44 feet above the Chattanooga. Pink limestone was noted to 98 feet above the Chattanooga. Granular gray limestone with some semitranslucent bluish chert typical of the upper Fern Glen is present to 153 feet above the Chattanooga. The remainder of the Osage section, 75 feet thick, extending to 233 feet above the Chattanooga, is chiefly crinoidal limestone, but the insoluble residues contain small amounts of opaque white chert and drusy quartz characteristic of the Burlington.

Another area of similar variations occurs in T. 28 S., Rs. 6 and 7 E. In Sheldon and Wixon No. 1 Houston well (SE¼ NW¼ sec. 15, T. 28 S., R. 7 E.), gray crinoidal noncherty limestone, broken only by slight variations in texture, extends to 252 feet above the Chattanooga. The lower shaly member of the St. Joe is 47 feet thick. No division of the rest of the limestone can be made from the samples. The lower part to 100 feet above the Chattanooga, however, yielded microscopic crusts of mammillary chalcedony of probable Fern Glen age. The remaining 175 feet of the noncherty limestone to 252 feet above the Chattanooga is characterized by insoluble residues consisting chiefly of drusy quartz, and probably represents both Burlington and Keokuk. A well (National Refining No. 4 Sutter well, NE¼ SE¼ NW¼ sec. 1, T. 28 S., R. 6 E.), 4 miles distant, contains enough chert to distinguish the formation without the aid of insoluble residues, although the residues also were examined. The St. Joe and the equivalent of the upper part of the Fern Glen extend to 105 feet above the Chattanooga; the remainder of the Osage section, 55 feet thick, is cherty limestone and dolomite of undivided Burlington and Keokuk age.

In view of the propensity of the St. Joe limestone and its correlatives to develop bioherms over a very broad region, as pointed out by Laudon (1939) and as most of the thick masses of crinoidal limestone correspond to the descriptions of the bioherm phase of the St. Joe, it seems possible that these abnormally thick bodies of noncherty limestone are bioherms. Whatever the cause, there was a striking absence of chert in certain areas in limestones deposited during a period that included Fern Glen and at least a part of Burlington time.

Thickness.—The St. Joe limestone averages about 15 feet in thickness in southeastern Kansas, but it is no more than 5 feet thick in some areas. In Montgomery county its thickness is irregular, but locally reaches 45 feet.

In Cowley county the cuttings, including the red shales, show thicknesses as great as 65 feet and in Sedgwick county thicknesses of 80 to 90 feet. In Barber county the thickness including the shale is at least 120 feet (McPherson No. 1 Rule well, sec. 10, T. 33 S., R. 13 W.). Rocks that are lithologically similar to the St. Joe but are probably in part correlatives of the upper part of the Fern Glen and the Burlington, as already noted, reach a thickness of 278 feet in Sedgwick county.

Distribution.—The approximate northern limit of the St. Joe limestone is shown in plate 8. The southern limit is irregular on account of the unconformity below the Cowley to be discussed later, whereby in local areas the St. Joe as well as the overlying younger Osage rocks are absent. Evidence of slight, early movement along the trend of the Nemaha ridge fold in pre-Chouteau time was noted. The distribution of the St. Joe, as shown in plate 8, suggests that slight movements along the trend of the Nemaha ridge were revived prior to the deposition of the St. Joe and were responsible for the bifurcation of the St. Joe basin. The wells showing red and green shale in the St. Joe are located in the reëntrant between the Nemaha ridge and the central Kansas uplift, suggesting that the near-by unsubmerged areas were a factor in localizing these deposits. The green shale continues westward in increasing amount around the southern side of the central Kansas uplift. In Harvey county and adjoining areas in southeastern McPherson county rocks of late Fern Glen age are underlain by brown limestone, which is in part slightly silty and argillaceous. In some localities these brown limestones are dolomitic or are underlain by a thin bed of dolomite. These dark and brown slightly earthy limestones have been included in the St. Joe. They probably represent a phase of the St. Joe deposited at the head of the reëntrant west of the Nemaha ridge fold. No green or red shales, however, are present in these deposits.

In the area south of the central Kansas uplift on the northern margin of the Dodge City basin in Barber county much red and dark shale and red crinoidal limestones are interstratified with cherty limestones. The nearness of the shore line to the rising central Kansas uplift seems to have caused irregular deposition in this area and the introduction of much shale and silt throughout Osage time. In consequence, the lithologic criteria for distinguishing the St. Joe, the rocks of late Fern Glen age, and the Burlington in this area are inadequate to distinguish these units with confidence.

Stratigraphic relations.—The absence of Chouteau and of rocks of possible younger Kinderhook age in much of the area of the St. Joe limestone in Kansas indicates its unconformable relation to the Chattanooga shale. It is similarly unconformable upon the Northview and in one well in Wilson county (Union Gas Company No. 5 Mary Watts well, sec. 34, T. 28 S., R. 17 E.) it rests unconformably upon 5 feet of gray sucrose dolomite above the Northview, which, the writer believes, represents an outlier of the Sedalia. The relation of the St. Joe limestone to the overlying Reeds Spring or to equivalent rocks representing the upper part of the Fern Glen is more obscure because the presence or absence of chert does not provide a very sharp or dependable boundary. Bioherms also, if present, tend to make an irregular contact. The St. Joe limestone is everywhere overlain by rocks of later Fern Glen age of which the Reeds Spring of the outcrops in southwestern Missouri seems to be a local variant. As no local variations in the thickness of the St. Joe abrupt enough to offset the indefiniteness of its contact with the overlying rocks have been noted, there seems to be no reason to conclude that the St. Joe is not conformable below rocks of late Fern Glen age.

Reeds Spring Limestone

Surface character and distribution.—In the outcrops of southwestern Missouri and northeastern Oklahoma the St. Joe limestone is overlain by the Reeds Spring limestone, first described by Moore (1928, p. 169) as a member of the Boone formation. Cline (1934, p. 1143) describes the Reeds Spring as consisting of "thin alternating, regularly bedded, fine-grained, dense, and sparsely fossiliferous limestone and dark, blue-gray, or black chert." The proportion of limestone and dolomite, the color and amount of chert, and the distribution of the chert in the limestone vary greatly in different localities. Moore reports a maximum thickness on the outcrops of 225 feet near Wentworth in Newton county in southwestern Missouri and an average of 150 feet for the Joplin district. In northeastern Oklahoma, Laudon (1939, p. 328) reports its thickness as 186 feet on Grand river in northern Delaware county. Moore (1933, p. 203) correlated the Reeds Spring and the St. Joe limestones with the Fern Glen formation of southeastern Missouri, which consists largely of greenish-gray or blue-gray semigranular crinoidal limestone with reddish limestone and red and green shale beds. The upper part is similar lithologically to the dense cherty limestones of the Reeds Spring of southwestern Missouri.

Subsurface character in Kansas.—There are no outcrops of the Reeds Spring in Kansas. In Cherokee county, Kansas, the well cuttings from the Reeds Spring resemble the exposures in adjacent parts of Missouri and Oklahoma. The limestone is gray or buff and mostly dolomitic and finely sucrose in texture. Some semigranular and fine-textured and slightly dolomitic, grainy limestone is, however, present. In Cherokee county the chert is predominantly bright, translucent and semitranslucent, although some semiopaque chert and opaque chert are also present. The semitranslucent chert breaks with a smooth conchoidal fracture, and is mostly dark gray, dark blue, or bluish, although some is gray and some dark brown. The black chert of the outcrop shows in the thin fragments of the well cuttings as brown chert. In most samples, the chert is of two or more shades, which some of the larger fragments show to be due to banding or mottling. Most of the chert is smooth and even-textured, but cross sections of spicules and spines occur on the surface of some fragments. The semiopaque and opaque chert breaks in blocky chips and is mostly dull, dark gray or buff gray. Like the more flaky semitranslucent chert, the semiopaque chert is particolored. In some zones where the limestone is grainy with minute dolomite crystals, the chert also shows a grainy texture with dark-gray or buff semitranslucent stippling. In some beds the dots are blurred and cloudy and run together. The insoluble residues of the lower part of the formation show bands and patches of fossiliferous spongy silica in the dense chert.

The Grand Falls chert of the Joplin district was recognized in the subsurface in Cherokee county (see p. 46) by Miss Hundhausen of the Missouri Geological Survey. It contains no limestone and consists of lighter-colored, slightly yellowish and gray semiopaque, even-textured chert and some similar gray opaque chert. It is not mottled or banded and is more even in texture and color than the underlying chert. Moore, Laudon, and Cline are reported by Cline (1934, p. 1142) to be in agreement that the Grand Falls chert is a local variant of the Reeds Spring, but Moore in 1928 and at present (Moore, Fowler, and Lyden, 1939, p. 7) regards it as Keokuk in age. Somewhat similar chert, associated with dolomite and limestone, was noted in the upper part of the Reeds Spring in parts of Butler, Chase, and Lyons counties, but definite correlation with the Grand Falls chert does not seem to be warranted. Typical Grand Falls chert has not been recognized with confidence outside the lead and zinc areas and its development may be due in part to the mineralization of that area. It is shown in this area on the cross sections as indeterminate between the Reeds Spring and the Keokuk.

Toward the west there is a lithologic change in the character of the Reeds Spring. The cuttings become less cherty and less dolomitic, and though slightly sucrose and dolomitic in places, consist increasingly of semigranular and fine-textured limestone. In Labette county there is a considerable increase in the amount of dull blocky particolored dark-gray chert and there is an increase of chert with grainy texture. The semitranslucent flaky chert, which is paler blue and more closely resembles chalcedony, is less abundant in most zones but continues prominent in the lower part. The spongy silica in the insoluble residues of the lower part of the formation persists. Farther west and northwest there is a progressive increase in the

amount of granular gray limestone and a decrease in the amount of chert. In many areas as far west as Sedgwick county and as far north as Chase county the dark bluish and brownish or buff semi-translucent chert occurs only in certain zones in the Reeds Spring. The greater part of the chert is pale bluish or gray and semitranslucent or translucent; and much of it resembles chalcedony. In the insoluble residues microscopic crusts of chalcedony seemingly representing the lining of minute pockets occur. In this respect the residues contrast with those of the overlying Burlington limestone in which drusy quartz crusts are commonly present.

The presence of areas of noncherty crinoidal limestones at the horizon of rocks of late Fern Glen age in Sedgwick and Butler counties has already been discussed. If these rocks represent bioherms they seem to have continued their growth during the later part of Fern Glen time, for the insoluble residues show the microscopic mammillary crusts of gray chalcedony characteristic of this part of the Fern Glen. In areas where the St. Joe is thick and shaly the insoluble residues of the cherty limestones, referred to as limestone of Fern Glen age, contain some paper-thin flakes of shale suggesting continuity of deposition with the St. Joe.

North and northwest of the sparsely cherty crinoidal limestone area in Sedgwick and Butler counties, abundant translucent chert again appears in amounts adequate to identify these rocks as a lithologic unit without resorting to insoluble residues. The limestones are semigranular and gray in color. The usage in this report is to refer to the limestone containing dark chert as the Reeds Spring and to the semigranular limestone containing the light-colored semi-translucent bluish chert as limestone of late Fern Glen age. One seems to be a local variant of the other.

Thickness.—The thickness of the Reeds Spring or the equivalent rocks of late Fern Glen age in the subsurface is fairly regular where they are overlain by the Burlington but more variable where overlain by the Keokuk. The Reeds Spring, combined with the Grand Falls chert in the Ballard mine well (see p. 46) in Cherokee county, has a thickness of 142 feet, exclusive of 13 feet of sparsely cherty St. Joe limestone at the base. Exclusive of the Grand Falls chert, which is 45 feet thick, the Reeds Spring in this well is 97 feet thick. In Labette county (Union Gas Corporation No. 3 Hudson well, sec. 26, T. 32 S., R. 15 E.), the Reeds Spring is 130 feet thick. Farther west it is 80 to 110 feet thick along the lines of the cross sections F-F′ (pl. 7) and A-A′ (pl. 5). Where it is overlain by unconformable beds its thickness is reduced. The combined thickness of the St. Joe and rocks of late Fern Glen age shows less variation than that of the separate members. Toward the west where the shaly section of the St. Joe thickens, the rocks of Fern Glen age as a whole also become thicker.

Distribution.—Limestone of late Fern Glen age extends beyond the area of the St. Joe and overlaps upon the Kinderhook surface. Plate 8 shows the northern limit of limestone of Fern Glen age; and its relation to the underlying rocks is shown in the several cross sections. The relation of the distribution of rocks of Fern Glen age to the known structural features of the region is so striking that there seems little reason to doubt that structure was the controlling factor in determining the configuration of the basin of deposition. The removal of the Mississippian rocks from the northern part of the Nemaha ridge before the deposition of the Pennsylvanian prevents the examination of the section in that area. Rocks of late Fern Glen age, however, wedge out beneath the Burlington on the west flank of the ridge and were therefore not deposited on the subsequently eroded crest of the ridge. Rocks of the same age similarly wedge out beneath the Burlington on the east side of the central Kansas uplift, the Burlington encroaching farther upon the area of the uplift than do the underlying rocks. The distribution suggests very strongly that the central Kansas uplift and the Nemaha ridge were both gently deformed before or during the deposition of lower Osage rocks. The thinning and overlap toward the north, as shown in the cross sections, indicate a southerly tilting of the whole region, which is also shown by the similar overlap of younger Mississippian rocks.

Stratigraphic relations.—The probable conformity of rocks of late Fern Glen age on the St. Joe has already been discussed. The fluctuations in the contact as shown in the cross sections seemingly are due mainly to the irregular presence of chert and possibly in part to the presence of bioherms. The Reeds Spring or upper part of the rocks of Fern Glen age is unconformable on all the older Mississippian rocks except the St. Joe. The relations to the Burlington and Keokuk will be discussed more fully in a later chapter, but the Reeds Spring seems to be conformable below one lithologic unit regarded as the Burlington and unconformable beneath another tentatively identified as the Keokuk. Moore, Cline, and Laudon have pointed out in different publications that in northeastern Oklahome and in parts of southwestern Missouri the Burlington is absent and the Keokuk is disconformable upon the underlying Reeds Spring. This relation seems to exist in some places in the subsurface in Kansas.

Burlington and Keokuk Limestones

Surface character and distribution.—The rocks of the upper part of the Osage have been identified from the Appalachians to regions beyond the Rocky Mountains. The type localities of the Burlington and Keokuk limestones are in southeastern Iowa where these rocks are composed of cherty limestone, though some of the limestone is dolomitic. The Keokuk in northern Iowa and Indiana becomes shaly (Laudon, 1937, p. 1158). At the type locality these formations are distinguishable lithologically as well as faunally, but the lithologic characteristics are not persistent enough to be a safe guide at distant points.

The Burlington limestone of the outcrops nearest to Kansas is described by Moore (1928, p. 167) as a coarse-grained crystalline crinoidal limestone. Parts of the formation contain considerable amounts of dolomite, which is interbedded with limestone or is present as irregular masses within the limestone beds. The formation contains considerable white opaque chert in thin uneven beds, irregular nodules, and scattered lenticular masses. In some outcrops chert comprises half the section. In others very little chert is present. The lower part of the Burlington is reported to be less cherty than the upper part, but the lower beds and probably the higher beds also show varying amounts of chert along the outcrop. The Burlington is reported to have an average thickness in Missouri of about 150 feet.

The Keokuk limestone of the outcrops is described by Moore (1928, 1939) as mainly bluish and gray or buff medium- to coarse-grained more or less crystalline limestone. The color in general is more bluish than that of the Burlington. Shale seams separate the limestones in southeastern Iowa, but little or no shaly material is present in central and southwestern Missouri. Chert is abundant especially in the southwestern part of Missouri. The amount and distribution of the chert and the texture and purity of the limestones vary greatly in different localities not far apart.

Moore (1928, pp. 143, 207; Moore, Fowler, and Lyden, 1939, p. 9) observed a hiatus between the Burlington and the Keokuk in southwestern Missouri; and in the Joplin district the Keokuk rests disconformably on the Reeds Spring. Laudon (1939, p. 329) reports that the Keokuk is disconformable on the Reeds Spring throughout northeastern Oklahoma.

The thickness of the Keokuk in Iowa averages about 70 feet, but in southwestern Missouri, where the Keokuk rests on the Reeds Spring, the thickness, as noted by Moore, is 100 to 150 feet. Laudon (1939, pp. 330-332) noted a maximum of 80 feet in outcrops in northeastern Oklahoma, where the Keokuk is in contact with the Reeds Spring.

Occurrence in Kansas.—In the examination of the well cuttings from Kansas the Missouri Geological Survey found it impracticable to separate the Burlington from the Keokuk limestone. Two readily distinguishable types of chert, however, were noted in the examination of the Kansas well cuttings, but whether these actually represent the Burlington and the Keokuk has not been determined by direct comparison of insoluble residues of surface and subsurface rocks. One type is well represented in the Ballard mine well (sec. 10, T. 35 S., R. 24 E.) reported by Mary Hundhausen on page 46. This well is near the margin of the small area of outcrop of Mississippian rocks in southeastern Kansas and is only 15 miles from a locality in Oklahoma (sec. 31, T. 27 N., R. 24 E.), where the Keokuk is reported by Laudon to overlie the Reeds Spring. As Moore reports the Burlington to be absent in the Joplin area, in the Kansas part of which the Ballard mine well was drilled, it seems probable that the undivided Burlington and Keokuk reported by Miss Hundhausen in the Ballard well is of Keokuk age.

Laudon (1937, p. 1160) reports an upper Burlington index fossil (*Pentremites elongatus* Shumard) in a core from a well (Sinclair Prairie-Gentry, sec. 1, T. 33 S., R. 15 W.) in Barber county, Kansas. This fossil, which came from a bed a short distance below the contact with the Pennsylvanian rocks, is not directly associated with chert, but it occurs in an area in which the first type of chert is absent and the second type of chert is present directly above rocks of Fern Glen age. These limestones having contrasting types of chert are therefore tentatively regarded as representative of the Burlington and the Keokuk in the subsurface.

BURLINGTON LIMESTONE IN SUBSURFACE IN KANSAS

The limestone, tentatively referred to the Burlington, consists chiefly of white and gray semigranular crinoidal limestone interstratified with relatively thin beds of gray dolomite and limestone grained with minute dolomite crystals. Large quantities of chert are present in most places, but the amount of chert is variable. In southern Sedgwick and Butler counties, beds believed to represent the Burlington are entirely devoid of chert in some places and in other parts of the same area contain very small amounts. Normally the Burlington contains 20 to 75 percent chert and in places where the Burlington was folded and eroded in pre-Pennsylvanian time, as along the Voshell anticline, leaching to considerable depths below the surface has removed most of the limestone in its upper part, so that the cuttings are principally chert.

Burlington chert is characteristically even-textured, opaque, and gray, gray white, or bluish white. The surface of the bluish-white chert in some places shows lines and tracings of individual spines and tubes and cells of microörganisms. Chert in dolomitic limestones usually shows a grainy or stippled texture. In the insoluble residues of dolomitic rocks, where silicification has been incomplete, the acid removes the unreplaced very minute dolomitic crystals, leaving their angular molds. Most of the chert breaks with a smooth fracture in blocky fragments, but some rough-surfaced chert is present in most samples. Some of the smooth chert is semiopaque; but semitranslucent chert, though present in minor amount in some localities, is confined to thin horizontal zones and is unusual. Drusy quartz and minute pockets lined with fine quartz crystals are common constituents of the insoluble residues, and coarse fragments of quartz, like broken glass, are not uncommon even in the samples. In the upper part of the formation in the Kasper-James well (sec. 8, T. 13 S., R. 25 E.) in Johnson county and neighboring wells broken fragments of minute fossils have been preserved in a glassy matrix. This zone is unique and occurs 197 feet above the Chattanooga shale in the Kasper-James well. It was also noted at about the same stratigraphic position in some other wells in northeastern Kansas. This chert and some of the more opaque spicular chert are not unlike some of the chert in the Warsaw.

Thickness.—As the Burlington is everywhere unconformable below the overlying rocks its thickness varies widely. Its thickness is 147 feet in the Kasper-James well. In Sedgwick county (Fitzwilliams No. 1 Struthers well, sec. 34, T. 28 S., R. 2 W.), its thickness is 143 feet and in Butler county (Prairie No. 1 Linier well, sec. 34, T. 29 S., R. 5 E.) its thickness is 165 feet. Thicknesses of 50 to 100 feet are usual, but in some places, as in Cherokee and parts of Labette counties, where it is replaced by Keokuk limestone, the Burlington is entirely absent. In western Kansas it has an apparent thickness of 180 feet in Logan county (Alma and McNeeley No. 1 Watchorn well, sec. 13, T. 15 S., R. 33 W., well No. 2, cross section F-F′, pl. 7) and

101 feet in Scott county (Watchorn and McNeeley No. 1 Spangler well, sec. 23, T. 20 S., R. 33 W., well No. 3, cross section F-F′, pl. 7).

Distribution.—The Burlington is the most widespread of the Mississippian limestones of Kansas. It is present throughout the state except in southeastern counties, in the central Kansas uplift, on deeply peneplaned anticlines along the Nemaha ridge, and locally on the peneplaned crest of the Voshell anticline. It was removed from parts of southeastern Kansas before the deposition of the Keokuk and in parts of the most southern tier of counties from Montgomery county to Clark county by the erosion that preceded the deposition of the Cowley formation. It overlaps beyond the margin of rocks of Fern Glen age on the Central Kansas uplift (see cross section E-F′, pl. 6). As thicknesses exceeding 150 feet are known in some areas it may well have buried that area, though no Burlington rocks are now present on the uplift and the marginal thickness, where covered by the Keokuk, is now less than 100 feet in most places.

Stratigraphic relations.—There is no evidence in the subsurface of unconformity between rocks of Fern Glen age and the Burlington. Where the full thickness of the Fern Glen equivalents is present, rocks of Fern Glen age maintain a fairly even thickness of 90 to 120 feet below the Burlington, the thickness increasing toward the west. In some places there seems to be a transition from the rocks of Fern Glen age to the Burlington, for the semitranslucent chert that characterizes the upper part of the Fern Glen extends upward in some places into beds containing gray even-textured opaque chert characteristic of the Burlington. Cline (1934, p. 1154) observed that "in northern Arkansas the lower Burlington rests with apparent conformity upon the Reeds Spring formation and it is followed by upper Burlington limestone and chert. . . ."

Rocks tentatively correlated with the Keokuk overlie the Burlington unconformably and in some places, as in the subsurface of extreme southeastern Kansas, rest on rocks older than the Burlington.

The Cowley formation and the Warsaw limestone, which conformably succeeds the Cowley, both overlie the Burlington unconformably in parts of eastern Kansas where the Keokuk is absent.

KEOKUK LIMESTONE IN SUBSURFACE IN KANSAS

Rocks tentatively correlated with the Keokuk limestone in the subsurface include much more dolomite and dolomitic limestone than the Burlington, although where the Keokuk is thick much limestone is present in the lower part. The thickest section of

Keokuk rocks is in the Ballard mine well (sec. 10, T. 35 S., R. 24 E., see p. 46) in the Tri-State mining district. The lower rocks, exclusive of the much-discussed Grand Falls chert, consist of calcareous gray dolomite alternating with buff-gray semigranular crinoidal limestone. The limestone is less siliceous than the dolomite. In general the Keokuk dolomites are extremely siliceous and contain large quantities of opaque white cotton rock and calcareous white pitted and porous opaque chert. Most zones contain no even-textured chert, though this type of chert is present sparingly in some samples. Occasional grains of disseminated glauconite occur in the pitted limy cherts in the northwestern part of the area of deposition, but they were not noted elsewhere. The distinguishing feature of the rocks, tentatively referred to the Keokuk, is the pitted and porous calcareous chert and abundance of siliceous cotton rock in some zones. These characteristics are in strong contrast to the even-textured opaque chert of the Burlington.

The insoluble residues of some zones in the upper part of the Keokuk consist almost entirely of soft friable cotton rock. Much cotton rock occurs also in the lower part; but in this part, as exemplified in the Ballard mine well, the cotton rock residues are denser and firmer. The residues of the calcareous pitted chert consist of hard white, porous, and spongy aggregates, which in some zones are unaccompanied by cotton rock. In the more siliceous beds the porous and pitted insoluble residue constitutes 50 to 90 percent of the samples by volume. The insoluble residues from the interbedded limestones of the lower part of the formation are usually less than 10 percent of the sample.

Oölitic limestone.—A bed of oölite 5 to 10 feet thick, tentatively correlated with the Short Creek oölite of the outcrops in southwestern Missouri, occurs in occasional wells from Cherokee county to Rice county. This oölite is gray, and the ovules are moderately well sorted as to size. The bed is erratic in occurrence, being absent in many of the wells examined. Its position is from 160 to 240 feet above the Chattanooga shale; the thinner interval occurs west of the axis of the Nemaha ridge. As shown in cross section E-F' of plate 6, the interval increases southeast of the ridge and remains fairly constant.

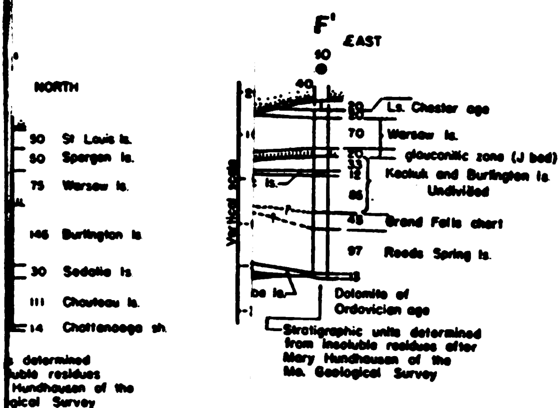
A dark glauconitic silty limestone, known in the Joplin area as the "J bed", occurs at the irregular lower boundary of the Warsaw in some areas. The interval from the glauconitic zone down to the top of the oölite in the Keokuk varies widely; in the Ballard mine well the interval is 30 feet. In several wells in southeastern Kansas the glauconitic zone is in contact with or only a few feet above the oölite. As shown in cross section E-F' of plate 6, a considerable thickness of Keokuk rocks occurs above the oölitic limestone in places east of the central Kansas uplift. In well No. 5 of cross section E-F' 80 feet of typical Keokuk rocks occurs above the oölitic limestone. They are overlain by 47 feet of cherty Warsaw limestone, which has at the base a well-developed glauconitic zone. In well No. 6 of cross section E-F', the Keokuk limestones above the oölitic limestone are 92 feet thick and there is 37 feet of residual chert above, none of which is of the Warsaw type. It seems probable, therefore, that the Keokuk limestones were originally much thicker over the whole region but were greatly reduced in thickness by pre-Warsaw erosion.

The chert in some zones above the oölitic limestone includes even-textured white or gray opaque chert, some of which is vaguely grainy in texture and not strikingly different from that in the Burlington. In such zones, however, this chert is accompanied by cotton rock or by pitted siliceous limestone characteristic of the Keokuk but in less than the usual volume. The chert from this interval is distinctly unlike the chert in the Cowley or in the Warsaw. Near the top of some of the thicker post-oölite limestones, some bluish semitranslucent chert has been noted.

Moore (1928, p. 232) originally regarded the Short Creek oölite, with which this oölitic limestone is tentatively correlated, as the basal member of the Warsaw, but now includes it in the Keokuk. Laudon (1939, p. 331) refers to the Short Creek oölite rather vaguely as lying "on top of the Keokuk." In view of the varying interval of this bed beneath the unconformity and the similarity of the chert in the interval above to that below the oölite, it seems plausible from purely lithologic evidence to regard this oölite and the rocks up to the unconformity as Keokuk in age. This interpretation has been advanced by Fowler and Lyden (1934, addendum, p. 62) and is accepted by Moore, Fowler, and Lyden (1939, p. 9).

The oölite is not present at any place in rocks herein tentatively correlated with the Burlington. Within the belt in which the Keokuk occurs the oölite is a fairly constant bed. It is, however, not present in all Keokuk areas, partly because the oölitic zone was eroded either before the deposition of the Warsaw or by pre-Pennsylvanian peneplanation.

Pre-oölite folding.—Cross section E-F' of plate 6 runs lengthwise across the area in which the pitted beds, tentatively correlated with



KEY

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and no.	Location
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a. 1	Sec. 33, T. 25 S., R. 10 E.
no. 1	Sec. 22, T. 30 S., R. 15 E.
1	Sec. 10, T. 33 S., R. 17 E.
. 1	Sec. 10, T. 35 S., R. 24 E.

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lar ls. with Chester (Batesville) fauna
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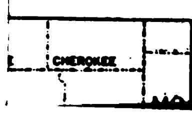

the Keokuk, have been recognized. It shows these rocks in contact with the Reeds Spring toward the southeast and with the Burlington toward the northwest. The cross section has been plotted using the top of the oölite as a datum plane. The interval from the oölite to the top of the Chattanooga shale is fairly constant west of the position of the subsequently deformed Nemaha ridge fold, but is 80 to 100 feet thicker east of it. These relations seem to indicate that east of the Nemaha ridge a gentle monoclinal displacement downward toward the east occurred during the interval between the end of Chattanooga time and the deposition of the oölite zone.

This displacement seems to have been a forerunner of the major movement that later, at the close of the Mississippian, produced the Nemaha ridge fold, and supports the evidence shown by the distribution of the Chouteau and of the lower Osage rocks that deformation on the trend of the Nemaha ridge began in early Mississippian time.

Thickness.—In the Ballard mine well, where the Burlington is absent and the Keokuk overlies the Grand Falls chert and Reeds Spring limestone, the Keokuk is 130 feet thick exclusive of the Grand Falls. This unusual thickness is due partly to the fact that in this well 33 feet of the portion of the Keokuk limestone above the oölite has been preserved from erosion and partly to the depth of the basin at this point, the whole of the Burlington having been eroded. Farther northwest the Keokuk is thinner; in some places very little limestone of post-oölite age has survived subsequent erosion and the basin in which the Keokuk was deposited was not eroded so deeply into the Burlington. On the south side of the area of deposition pre-Warsaw erosion has partly or completely removed the Keokuk. In some areas thinning of the section below the oölitic limestone is compensated by the preservation of thicker rocks above. In well No. 6 of cross section E-F′, plate 6, the Keokuk rocks below the top of the oölitic limestone are 60 feet thick. This, with 92 feet of Keokuk rocks above the oölite, makes a total thickness of 152 feet. Thicknesses exceeding 100 feet of Keokuk are not unusual. The Keokuk becomes thinner toward the northwest on the line of the cross section and the pre-oölite portion wedges out before reaching the central Kansas uplift.

Distribution.—The distribution of the Keokuk is shown in plate 8. It has not been recognized in western Kansas. It occupies a broad belt, 80 to 150 miles wide, trending northwest from the Tri-State mining district toward the central Kansas uplift. Cross sections A-A′, B-B′ of plate 5 and cross section C-C′ of plate 6 show its lenticular character in cross section and its relation to the Burlington and Warsaw limestones. The width of the belt of Keokuk rocks in southeastern Kansas was originally considerably greater, but the erosion preceding the deposition of the Cowley formation cut off the southwestern margin of the Keokuk in parts of Montgomery, Chautauqua, and probably Cowley counties.

Stratigraphic relations.—The subsurface relations of the lithologic units, tentatively identified as Burlington limestone and Keokuk limestone, are in conformity with the relations at the surface described by Moore, Laudon, and Cline, who have most recently studied the unconformity between the Burlington and Keokuk in Missouri and Oklahoma. The writer finds that the Keokuk is unconformable below the Cowley and the Warsaw formations.

The trend of the Keokuk basin, as mapped, does not correspond to any known synclinal movements, but follows roughly the trend of the Chautauqua arch, which, however, does not seem to have been conspicuously active during the Mississippian or at its close. The basin in which the Keokuk was deposited in southeastern Kansas seems to have been an erosional basin. Greater depth of erosion toward the southeast implies drainage in this direction. The maximum relief of the pre-Keokuk surface, indicated by the removal of all the Burlington and part of the Reeds Spring, could hardly have been less than 150 feet in extreme southeastern Kansas.

ROCKS OF MERAMEC AGE

Rocks of Meramec age overlie the Osage rocks at the surface in parts of Kentucky, Illinois, eastern Missouri, and adjoining states, where they have been subdivided into Warsaw, Spergen, St. Louis, and Ste. Genevieve limestones. Some geologists regard the Warsaw as Osage in age, however. Ste. Genevieve county in southeastern Missouri is the area nearest to Kansas in which the complete Meramec section has been described in detail. The total thickness of the Meramec beds in that area is about 500 feet.

Rocks of Early Meramec Age

In the report on Ste. Genevieve county, Missouri, by Weller and St. Clair (1928, pp. 193-226) the Warsaw is placed in the Meramec series. Its average thickness in that area is 100 feet. The lower half is composed principally of bluish shale, but includes some ash-colored to grayish-black calcareous shale and streaks and lentils of bluish-gray or grayish-black fine-grained argillaceous limestone.

The upper part is composed of limestone, which is for the most part fine-grained, gritty, argillaceous, somewhat magnesian, and siliceous. It is nearly free of chert in some places and moderately cherty in others.

In southwestern Missouri, at Carthage, 50 miles east of the Kansas line, the Warsaw consists of sparsely cherty crinoidal and fossiliferous gray limestone. Microscopic examination of chert collected from the Carthage quarries shows it to be so packed with the silicified remains of microfossils as to have a matted texture. In the Tri-State mining district the Warsaw is more dolomitic and the chert is more abundant and more varied in character than in the outcrops in the Carthage area. Moore (1928, p. 232) reports a probable thickness of about 100 feet in southwestern Missouri. He states that there is "apparently an erosion interval between the time of deposition of the Keokuk and Warsaw beds . . . indicated by basal conglomerates consisting mainly of angular chert at the base of the Warsaw and of solution cavities in the Keokuk filled by limestone and chert fragments cemented in a Warsaw matrix." He concluded on paleontologic grounds, however, that the Warsaw is a part of the Osage series. On account of the very well developed unconformity at the base of rocks assigned to the Warsaw in Kansas, to be discussed, and because of the absence of any evidence of unconformity with the overlying rocks in the subsurface, the writer has included the Warsaw in the Meramec, although faunally the Keokuk and Warsaw are very closely related. Laudon (1939, p. 325) states that, as far as can be determined, there are no rocks in northeastern Oklahoma that are to be correlated with the Warsaw as exposed in the upper Mississippi valley.

Fowler and Lyden (1934, addendum p. 62) report a shaly bed with glauconite at the base of the rocks regarded by them as of Warsaw age in the Tri-State mining district. This shaly bed is generally referred to in the mining district as the J bed; other locally recognized Mississippian units have been designated by them from the top down by letters of the alphabet. The J bed rests on an irregular surface at the top of the Keokuk. Fowler and Lyden state that within the mining field and several detached areas to the west—

"Erosion cut into the horizontal Keokuk surface before the Warsaw was deposited on it and removed part or all of K and L beds and the upper part of M bed to a total depth of 45 feet below the top of K bed, the top of the Keokuk. J bed is essentially uniform in thickness and character throughout the field and nearly everywhere is an excellent marker horizon. In the areas where the underlying beds have been eroded, the section below the normal 4 to 5 feet of J bed down to the old erosion surface is filled with material similar in character to that in the J bed but generally more shaly near the base, especially in the deeper places."

The study of well cuttings by the writer indicates that the relief below this unconformity is much greater farther west.

Doubt as to the presence of the Warsaw in the Tri-State mining district has been expressed by some paleontologists. The rocks here assigned to the Warsaw in the subsurface in that district consist of the J bed and the limestones directly above the J bed. Farther west a thick series of silty limestones intervenes between the J bed or glauconitic zone, which is a transgressive basal deposit, and the overlying Warsaw. The Warsaw limestone has distinctive characteristics and can be distinguished from the Keokuk and the Burlington and, aside from the question of its Warsaw age, constitutes a distinct lithologic unit. It was identified as Warsaw by Mary Hundhausen of the Missouri Geological Survey in the Ballard mine well (p. 46), where it is 70 feet thick exclusive of 20 feet of gray glauconitic limestone at the base reported as the J bed. The lithologic unit reported as Warsaw was also recognized in several other wells examined by Miss Hundhausen, and the usage of Missouri geologists in referring it to the Warsaw will be followed in this report.

COWLEY FORMATION

In southeastern Kansas, the rocks of Osage age are overlain unconformably by thick beds of dark, more or less silty, limestone. As pointed out by Fowler and Lyden, the top of the J bed furnishes a good datum in a considerable part of the Tri-State mining district, but the lower part replaces the uppermost beds of the Keokuk. Toward the west in the southern tier of counties in Kansas, the glauconitic zone cuts progressively deeper into the older Mississippian rocks and is overlain by thick deposits of gray and dark-colored silty, cherty, and dolomitic limestones stratigraphically below the base of the Warsaw. These rocks, together with the glauconitic zone at the base, are here designated the Cowley formation. They constitute the greater part of the Mississippian in parts of Cowley, Chautauqua, and Sumner counties.

The importance of the unconformity at the base of the Cowley formation is shown by the contact of the Cowley in different areas with the Keokuk, Burlington, Reeds Spring, and St. Joe limestones of Osage age. Also, in some places the Cowley rests on the Northview shale, Compton limestone, Chattanooga shale, and even on underlying pre-Chattanooga rocks. At most places in southeastern Kansas it is unconformably overlain by Pennsylvanian rocks, but in some places it is overlain conformably by the Warsaw. In western Kansas no break is recognized between the Cowley and the Warsaw.

North of the southernmost tier of counties in Kansas, the Cowley formation is absent or thin and erratic in distribution. In some places it is represented only by the transgressive silty glauconitic zone, which is regarded under such circumstances as the basal deposit of the Warsaw. The Cowley thickens southward along the Oklahoma line where it is 290 feet thick at one point in southwestern Chautauqua county, 464 feet in southeastern Harper county, 410 feet in central Clark county, and 405 feet in Woods county, Oklahoma. The greater thicknesses may include equivalents of part of the Warsaw.

Definition.—The Cowley formation is here named for Cowley county, Kansas, where in most wells, except those in the north-central part of the county, there is a good development of the Cowley formation. In some areas, beds lithologically similar to the Warsaw limestone of the outcrops in Missouri overlie the Cowley. Sets of cuttings from the following wells among many on file at the State Geological Survey show good sections of the Cowley formation: Roxana No. 1 Seacat well, sec. 36, T. 33 S., R. 4 E., 3,215 to 3,465 feet; Roxana No. 1 Vickery well, sec. 7, T. 35 S., R. 3 E., 3,505 to 3,628 feet; Barnsdall No. 1 Black well, sec. 26, T. 34 S., R. 6 E., 2,991 to 3,244 feet.

Oil company warehouses contain many sets of well samples showing the Cowley formation. The Johnson and Shell No. 1 Jarvis well, sec. 19, T. 33 S., R. 6 E., shows cherty white semigranular limestone, probably of Warsaw age, above the Cowley formation, which extends from a depth of 3,117 to 3,396 feet. Other wells showing the Cowley formation are included in the lists of wells accompanying the cross sections.

The Cowley consists of dark or gray limestone containing dark chert, of black to gray silty dolomitic limestone, or of brown dolomite containing large amounts of dark and gray microfossiliferous chert. Its top is placed at the contact of such beds with white or gray partly semigranular limestones containing gray microfossiliferous chert. In some areas in southwestern Kansas as in well No. 7 of cross section F-F′ (pl. 7) rocks with Cowley characteristics extend upward to the base of white semigranular noncherty limestone and may include rocks of Warsaw age. The base of the formation is marked in southeastern Kansas by an accumulation of glauconite at its unconformable contact with older beds.

The dark parts of the Cowley formation have been known vaguely for many years in subsurface work as the "black lime". This term is misleading because the beds are only in part black and only in part limestone. The Cowley is not represented in Missouri, but the J bed of the Warsaw in the Tri-State mining district represents an eastward continuation of the transgressing basal deposit of the Cowley. The Cowley seems to be partly exposed in northeastern Oklahoma where it may be represented by the lower or Moorefield part of the Mayes formation to be discussed later.

Surface at the base of the Cowley formation.—A thickness map (pl. 7) with lines drawn at 50-foot intervals has been prepared showing the interval between the base of the Cowley formation and the top of the Chattanooga shale. Only those wells whose cuttings have been examined have been used, except in the area in which the Chattanooga is absent. Drillers' logs, in which no Chattanooga was reported, have been used to outline this area more sharply. Where the base of the Cowley lies below the top of the Chattanooga, the thickness lines are marked by minus signs. In those areas where the Chattanooga has been completely removed, the original position of its top has been determined by using as a datum the base of a semi-granular gray limestone that lies near the top of the Cowley formation in parts of Cowley and Chautauqua counties.

As the top of the Chattanooga shale was originally essentially flat, the thickness map (pl. 7) shows the configuration of the surface upon which the Cowley was deposited, referred to the top of the Chattanooga shale as a datum plane. Some deformation of the datum plane had taken place prior to Cowley time, but the relief of the pre-Cowley surface is so great and the pre-Cowley warping of the Chattanooga relatively so slight that the surface shown on the map represents the major features of the pre-Cowley erosion surface. The absence of any relation between the regional structure of southern Kansas and the thickness of the Cowley formation shows that folding and baseleveling, such as preceded the Chattanooga, did not take place immediately prior to Cowley time.

The pre-Cowley surface in Kansas seems to be the northern part of a large erosion basin lying chiefly in Oklahoma. The region north of Cowley county was a moderately dissected upland without sharp relief, breaking off along a marginal rim to a basin toward the south.

The regularity of the contact of the J bed upon the Keokuk in large parts of the Tri-State mining district, pointed out by Fowler and Lyden, is the expression of the relatively small amount of dissection that occurred in parts of the upland area. The topographic relations between the upland area and the basin area to the south were broadly not unlike that of the upland region west of the "flint hills" in Kansas and the topographically lower region lying east of it. In both cases the exposure of cherty limestone helped to preserve the upland area from dissection.

The cross sections A-A′, B-B′, and C-C′ (pls. 5 and 6) show a well-defined slope with a maximum grade of 40 feet per mile between the basin and the upland areas. In some places thin Cowley rocks or the transgressing glauconitic zone at the base of the Warsaw are present north of the area contoured where they overlap upon the irregularly but not deeply dissected upland surface. The contours show several valleys cutting back into the upland area. The deepest and longest of these valleys lies in Cowley and Butler counties; it must have drained a considerable region of upland to the north. Another well-defined valley is indicated in Sumner and Sedgwick counties west of the position of the Nemaha ridge.

The slope from the basin to the upland area although not steep is nevertheless well marked in Cowley county and adjacent counties and also in Barber county, as shown in the cross sections (pls. 5 and 7). The exaggerated vertical scale used in the cross sections makes this slope seem much steeper than it actually is. In the 9 miles between the Skelly-Temple well (sec. 13, T. 34 S., R. 15 W.) and the Sinclair Prairie-Gentry well (sec. 1, T. 33 S., R. 15 W., well No. 8, cross section F-F′, pl. 7) the rise toward the north is 150 feet. The slope between the Watchorn and Olson No. 1 Morrison well in Clark county (sec. 17, T. 32 S., R. 21 W., well No. 7, cross section F-F′, pl. 7) and the Carter-Everett well in southeast Ford county (sec. 22, T. 29 S., R. 21 W., well No. 6, cross section F-F′, pl. 7) is about 250 feet in 18 miles.

The pre-Cowley surface, shown by the contours, deviates from the actual topography by the amount of earlier deformation of the Chattanooga whose top has been used as a datum plane in contouring. Gentle deformation along the axis of the Nemaha ridge has already been noted as taking place during Osage time. The ridge shown in western Cowley county (pl. 7) lies near the Nemaha axis and its position may have been determined by gentle warping along this axis. There had probably been some downward warping also, on the flanks of the central Kansas uplift. The regional tilting toward the south, which was already taking place during Osage time, may have determined the southerly trend of the drainage.

Lithology.—A detailed description of the Cowley deposits has been deferred until after a description of the pre-Cowley topography because the local character of the deposits seems to be closely related to the configuration of the Cowley basin. The beds present a considerable variety of lithologic types, the character of each being determined by its relation to the topography and shore line. Deposits of these various types, however, seem to be contemporaneous, for they grade laterally and interfinger from one to another.

Silty limestone.—The most striking and most widely distributed deposits in Kansas are black to gray shaly and very silty limestones. They contain minor but varying amounts of mica, and scattered grains of glauconite in most localities. The deposits have very little chert in some wells and much chert in others. In some localities these deposits are very black and have very little lime. The greater part is dark and calcareous and contains microscopic crystals of dolomite set in a matrix of fine-textured calcareous silty shale. This microscopic texture is distinctive and will be referred to as grainy. Gray dolomitic limestones of grainy texture have been noted sparingly in the Burlington and Keokuk limestones and locally in the Reeds Spring, but these rocks are not shaly or silty. The dark shaly deposits of the Cowley grade upward in some areas into gray or white silty beds, of similar character. In some places the transition from black to light gray is abrupt, in others the change is so gradual that no point of division can be made. This type of the Cowley is distinctly clastic, and much of it is more nearly shale than limestone. In most samples the silty and shaly constituents form so large a part of the rock that cuttings remain coherent and do not crumble when digested in acid. Near the northern margin of the basin chert is rare and mica is a common constituent. In some places the beds are so black and shaly that they have been mistaken for Pennsylvanian or Chattanooga shale, but the microscopic texture and other characteristics are unmistakable. The base of the formation usually consists of black or very dark brown silty beds containing striking amounts of glauconite. On the flank of the basin these beds contain, as an occasional constituent, minute cylindrical particles of pale bluish chert or chalcedony, apparently filling microscopic tubelike voids in the rock.

Except in the area of the open valley in southern Cowley county, the greater part of the formation along the sloping shore of the basin

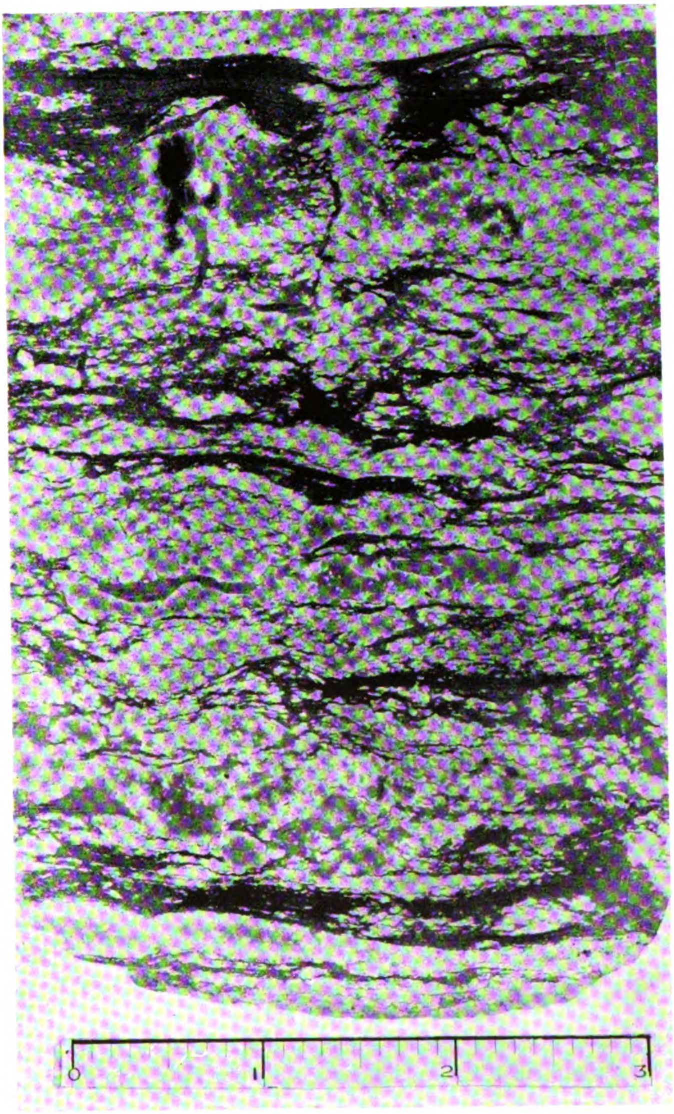

PLATE 9.—Photograph of polished section of core from upper part of Cowley formation in Patton Drilling Company No. 1 Rogers well, in sec. 35, T. 31 S., R. 2 W., Sumner county, Kansas. The photograph shows the laminated character of the silty limestone. In this core the Cowley contains a much larger proportion of chert (shown by the lighter areas) than is usual. The laminae are shown to be interrupted by the chert. Both the chert and siltstone are crowded with spicules and the remains of calcareous microörganisms. Photograph is natural size.

in Kansas as far west as Clark county is of the silty type though there is considerable variation in the amount of clastic material and chert contained in it and a range in color from gray to almost coal black. South of the sloping margin of the basin the shaly and silty deposits have an unbroken thickness exceeding 280 feet in several places (Prairie No. 1 Graham well, sec. 23, T. 32 S., R. 4 E).

A cherty core 25 feet long that shows this phase of the Cowley was taken from the top of the formation in the Patton Drilling Company No. 1 Rogers well (sec. 35, T. 31 S., R. 2 W.) in Sumner county. A reproduction of a polished section of a part of this core from a depth of 3,852 feet is presented in plate 9 to illustrate the silty beds of the Cowley. The core consists primarily of finely laminated dark-gray limy, silty shale with much gray chert interrupting the lamination. The core contained no fossils except remains of microörganisms. In some wells in Cowley county the silty limestones are present only in the lower part of the formation, the upper part being of another type yet to be described.

In a few Kansas wells, lenses of white semigranular noncherty limestone, rarely more than 10 feet thick, occur in the midst of the dark grainy limestone. These deposits occurring in dark silty limestone seem to have an origin similar to that of clean limestone lenses that are occasionally found in the midst of thick shale deposits. The formation of such lenses may be due to the temporary configuration of the bottom or the direction of currents that provide conditions unfavorable for shale deposition. Only a few wells in the Kansas area show these lenses, but they are more common in the scattered wells examined farther south in Osage county, Oklahoma. These thin white limestone beds generally cannot be correlated from well to well, but one bed, 25 to 55 feet thick, 260 feet above the Chattanooga is somewhat persistent in Cowley county and its base provides a local datum plane within the Cowley formation.

Glauconitic zone.—The strongly glauconitic zone generally present at the base of the Cowley is represented in the base of the Warsaw in the Tri-State mining district by the J bed. It is a transgressing basal deposit of the Cowley and Warsaw formations and follows the contact of the Cowley with all the older formations. It is shown on the cross sections as a separate unit although its upper limit is not sharply defined in all wells. It is thickest on the flank of the basin and thins toward the upland area, where in many places it is absent. It also thins toward the south away from the apparent source of the glauconite and silt. In Osage county, Oklahoma, the glauconitic zone is generally not developed although disseminated glauconite is found near the base of the Cowley in some wells. In the National Refining Company No. 4 Sutter well (sec. 1, T. 28 S., R. 6 E.), on the flank of the basin, 55 feet of black silty glauconitic rock at the base of the Warsaw-Cowley sequence was referred to the J bed by Miss Hundhausen, who examined the insoluble residues of this well. In the Prairie No. 9 Brown well (sec. 26, T. 34 S., R. 11 E., well No. 17, cross section F-F′, pl. 7) in southern Chautauqua county near the Oklahoma border where the Cowley is in contact with pre-Chattanooga rocks, the glauconitic zone, though very thin, is recognizable in the residues. In the Prairie No. 1 Foster well (sec. 13, T. 34 S., R. 9 E., well No. 16, cross section F-F′, pl. 7), also in southern Chautauqua county, the glauconitic zone is in contact with pre-Chattanooga dolomite. It is 7 feet thick in this well and contains at least 25 percent glauconite.

Dark limestone and semitranslucent dark chert.—South of the margin of the basin, toward the Oklahoma line in Sumner county, the silty and grainy beds are increasingly interstratified with black, dark-brown, or buff fine-textured limestone. The insoluble residues of the dark limestones are chiefly porous, coherent, earthy aggregates, but are not silty. Opaque black chert and semitranslucent brown chert, not unlike that found in some places in the Reeds Spring, occur in increasing abundance and become darker toward the south, although some streaked and matted gray chert is present in some wells. In the samples examined from wells in Osage county, Oklahoma, the grainy texture is infrequent and the earthy brown and black limestone with much dull semiopaque black chert predominates. Mica and glauconite are much less common constituents than they are farther north.

In the Amerada-Misak well (sec. 25, T. 34 S., R. 6 W., well No. 9, cross section F-F′, pl. 7) in Harper county, Kansas, many of the Cowley cuttings closely resemble those in Osage county, Oklahoma. The Cowley, which may include some Warsaw at the top, is 469 feet thick in this well. The cuttings consist chiefly of almost black fine-textured dull limestone. The insoluble residues of the limestone are coherent, very porous, dark gray, and earthy, and contain extremely fine casts of dolomite crystals. Grainy silty limestone, however, occurs 230 feet from the top and also in the lower 80 feet, where there is much brown and almost black splintery semiopaque chert, gray matted chert, and dark glauconitic limestone.

Dolomite and matted chert.—A third lithologic type of the Cowley formation consists of fine sucrose buff and brown dolomite, with which is associated much gray to dark-gray chert, which gives the cuttings a dark-gray color. The chert is distinguished by the silicification of broken microfossils that are present in such quantities as to give much of the chert a matted texture under the microscope (see pl. 10). Much of the chert breaks smoothly, showing outlines of broken minute organisms in contrasting shades of dark gray or black, but some of the chert breaks with a rough fracture and shows the matted microfossils in relief. In some chert the outlines of the microörganisms are blurred, giving the chert a streaked texture of gray and dark gray or brown.

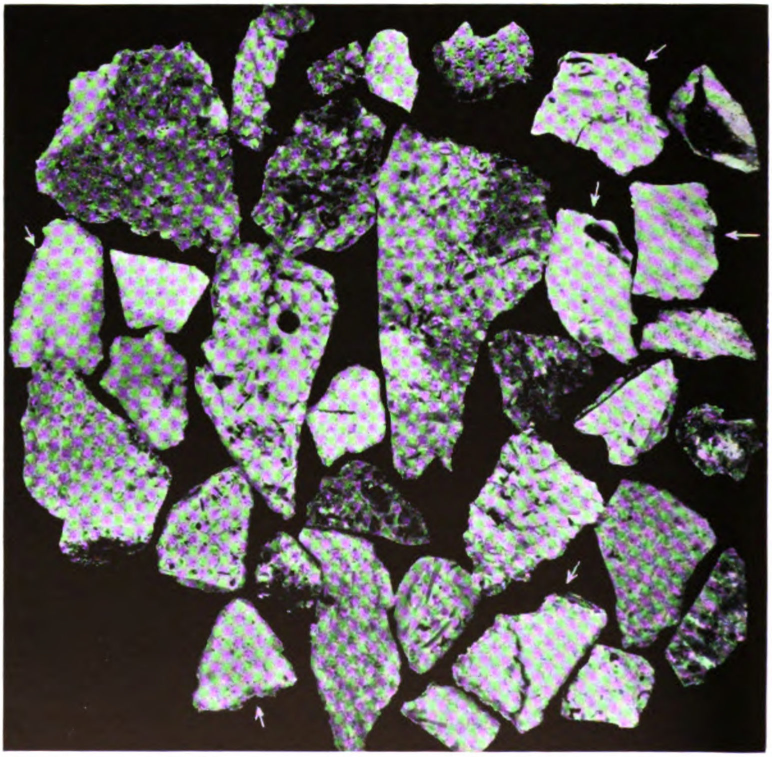

PLATE 10.—Photomicrograph of polished surface of well cuttings of matted chert from the Warsaw and Cowley formations. The light-colored fragments, indicated by arrows, in which the microfossils are faintly shown by different shades of gray are characteristic of the Warsaw. The fragments showing the microfossils sharply marked by contrasting light and dark chert are from the Cowley formation. Magnification 5.2×.

This type of deposit is best developed in the deepest part of the open valley in Cowley county where almost the entire Cowley formation is composed of it (Prairie No. 9 Brown well, sec. 26, T. 34 S., R. 11 E., well No. 17, cross section F-F′, pl. 7). In several places, east and west of this valley, this type overlies the dark shaly or grainy type at varying intervals above the Chattanooga. Inasmuch as the contact in some places is sharp it seemed at first that the cherty dolomites might be unconformable on the shaly limestone, but it was later noted that the concentration of glauconite occurs at the contact of either of these types with the pre-Cowley formations but does not occur between them. Near the Oklahoma line there is interfingering of the dolomite and matted chert type with the cherty dark lime type characteristic of the deposits in Osage county, Oklahoma. This interfingering is similar to that observed in Sumner county between the shaly lime and the cherty dark lime. In several wells on the marginal slope of the basin in southwestern Sedgwick county and southeastern Butler county, 5 to 30 feet of the characteristic matted chert occurs in the base of and below the black earthy phase of the Cowley.

These occurrences all lead to the conclusion that the dolomite containing the matted chert deposit is a local variation of the Cowley formation. The occurrence of such thick deposits of this type in the deep valley in Chautauqua county suggests that the accumulation of the microfossils, so abundantly preserved in the chert, is due in some way to the drainage that entered at the head of the embayment while the basin was being filled. The occurrence of this type of chert at the base of the black shaly limestone in some wells along the slope south of the upland and similar chert in the white limestones of Warsaw age above the Cowley, which overlap upon the upland, suggests that the organisms represented in the matted chert found a favorable habitat in the shallow marginal areas of the basin and in the shallow sea that ultimately advanced across the enclosing land area.

White chert.—In Ts. 34 and 35 S., Rs. 1 and 2 E., in Sumner county, the samples of five wells show white chert deep in the Mississippian section. The chert consists of opaque gray-white chert and semitranslucent gray chert and some cotton rock. The near-by wells all show thick sections of typical Cowley rocks, which in this locality consist of interbedded rocks of the silty limestone and cherty dark limestone types of the Cowley. The white chert resembles closely the cherts of the Burlington and Keokuk formations.

but similar chert occurs also in the Warsaw and overlying rocks in some places. In four of the five wells the white chert lies in the pre-Pennsylvanian zone of weathering, which is very thick, and is unaccompanied by limestone. In one well (Tidal No. 1 McCutcheon well, sec. 33, T. 34 S., R. 2 E.) the weathered zone is 163 feet thick and extends downward to within 70 feet of the top of the Chattanooga. In another well (Mathews No. 1 Berry well, sec. 14, T. 35 S., R. 1 E.) the weathered zone containing the white chert is 150 feet thick and extends to within 35 feet of the top of the Chattanooga. Considerable caving is indicated by the presence of dark shale with the chert. In the Empire No. 1 Hoffman well (sec. 27, T. 34 S., R. 1 E.) the weathered zone at the surface is 95 feet thick. It consists of white opaque chert 50 feet thick overlying 45 feet of dark semiopaque chert and streaked chert commonly found in the Cowley. The calcareous Cowley rocks, below this point, are 193 feet thick. They are exceptionally cherty, consisting almost exclusively of chert, but the lithological characteristics of the chert are normal for the Cowley of this locality except for 45 feet of white opaque chert that contains almost no limestone and lies between 103 and 58 feet above the base. A thin but well-developed glauconitic zone is present at the base of the Cowley section. This is the only well in which white chert occurs within the Cowley formation.

All the wells in which there is an important development of the white chert are on or near the axis of the Nemaha ridge fold, the most sharply defined structural feature in eastern Kansas outside the Tri-State mining district. The close relation between chert deposition and structural deformation in the Tri-State mining district has been pointed out by Fowler and Lyden (1934, p. 28). H. E. Redmon (oral communication) also has noted the increase in the amount of chert toward the crest of anticlinal folds. The writer believes that the development of the white chert in and associated with the Cowley along the Nemaha ridge in this area is related to the deformation of the Nemaha ridge, for the following reasons: (1) The white chert has not been noted in other areas in the Cowley; (2) the area in which it is found has been structurally deformed; (3) it does not appear at the same horizon in near-by wells; and (4) the Cowley rocks also are exceptionally cherty in this locality.

White chert above the Cowley deposits is much thicker in areas bordering the Nemaha ridge fold than elsewhere. Prior to Pennsylvanian sedimentation the area of the Nemaha ridge fold in most areas was raised above the region to the east. If, as seems probable, the ground-water level was simultaneously depressed below the surface of the upraised area conditions were favorable for deep weathering. The great thickness of the weathered zone in this locality may be in part the result of weathering under these conditions and in part the accumulation of residual chert washed into sink holes.

Relation of lithologic types to pre-Cowley topography.—The Cowley formation filled the inequalities of the basin eroded in the older rocks. Its upper part and the succeeding conformable Warsaw strata overlapped upon the upland. Silt and earthy material, mica, and glauconite are common near the shore south of the upland area and around the head of the open basin in Cowley county. Chert and earthy limestones occur farther south where the basin was deeper and farther from shore. The cherty dolomitic phase is best developed in the Cowley county embayment. Where the upper part of the Cowley overlaps upon the upland surface, the deposits are thin and in some places consist only of the glauconitic zone, which is included in the lower part of the Warsaw. The deposits of the Cowley formation are overlain by the Warsaw, which consists in most areas of dolomite and semigranular white limestone containing gray matted chert and little or no clastic material.

In Kansas all phases of the Cowley from top to bottom contain scattered grains of glauconite, in which respect it contrasts sharply with the lower Osage deposits in which glauconite is rare. The Keokuk limestones contain some disseminated glauconite in some areas. In southeastern Kansas disseminated glauconite occurs throughout the Cowley but it is infrequent in the Cowley formation in Osage county, Oklahoma, which is farther from the northern shore line of the Cowley basin. In southeastern Kansas there is almost invariably a high concentration of glauconite in the basal beds. Glauconite occurs in the Cowley in western Kansas but is not an important constituent.

Unconformable relation to underlying rocks.—A controversy has existed for many years over the relation of the "black lime" to the Osage. One group of geologists has asserted that the "black lime" is merely a lateral variation of the Reeds Spring, Burlington, Keokuk, and Warsaw. Another group contends that the "black lime" rests unconformably on these beds. A paper well presenting the arguments of both sides as to the relation of the "black lime" and the Mayes formation to the Boone formation has been published by Cram (1930, pp. 559-565). There is, of course, much lateral variation in the subdivisions of the Osage, but it is not abrupt and areas of transition are found. Where the dark-colored Cowley formation appears the change is abrupt and the contact with the older rocks, especially in southeastern Kansas, is marked by a concentration of glauconite. There is much variation in the Cowley formation also, but strata of the several lithologic types of the Cowley interfinger with each other in passing from one area to another. No such transition occurs between the white and gray Osage limestones and the dark rocks of the Cowley, though the latter does contain thin lentils of white semigranular noncherty limestone in some places. These white limestones are distinctly local and cannot be traced to the Osage rocks.

In Harvey county, where the Chattanooga is thin or absent over the pre-Chattanooga land (pl. 4) the succeeding Mississippian deposits are typical beds of the Osage series. In Sumner, Cowley, and Chautauqua counties, on the other hand, where the Chattanooga is thin or absent the succeeding beds are very different and consist of beds of one of the types described as Cowley. Where the Chattanooga is absent in these counties these beds are exceptionally thick instead of being thin as would be the case if they overlapped upon land.

The fact that the area of erosion in Cowley and Chautauqua counties, Kansas, is continuous with the so-called "Osage island" of Osage county, Oklahoma, leads to the belief that the absence of the Chattanooga there is due to erosion and not to the presence of land too high to be covered by the Chattanooga sea.

Sphalerite.—Cores taken in the Cowley formation in the Kessler and Thier No. 1 Wolfje well (sec. 17, T. 33 S., R. 6 W.) in Harper county at depths of 4,427 and 4,437 feet show a few small crystals of yellow sphalerite. This mineral is in dark shaly dolomite and is associated with dark-blue chert and white calcite crystals. The cores were taken near the top of the Cowley formation at 323 and 333 feet above the Chattanooga. Pennsylvanian shales cap the Cowley unconformably 15 feet above the highest mineralization noted.

Sphalerite was also noted in the rotary cuttings of the Bates-Nimocks well in sec. 16, T. 16 S., R. 28 W., in Lane county at a depth of 4,645 to 4,650 feet in the upper part of the rocks of probable Burlington age, 35 feet below their contact with the upper part of the Meramec, the Cowley being absent. Inasmuch as the well was drilled by rotary tools, the sphalerite may have fallen in from younger rocks higher in the hole.

WARSAW LIMESTONE IN THE SUBSURFACE

The rocks referred to the Warsaw in the Ballard mine well (sec. 10, T. 35 S., R. 24 E., Cherokee county) by Miss Hundhausen of the Missouri Geological Survey (see p. 46) are 70 feet thick exclusive of the J bed. They consist of gray and gray-white limestone, part of which is fine textured and part semigranular, containing an average of about 50 percent insoluble residues by volume. A few grains of glauconite are present. Much of the insoluble residue is very light and porous and resembles cotton rock. All the chert is gray. Some is dense and opaque and some is semitranslucent. A large proportion of the chert is characterized by matted microfossils like the matted chert of the Cowley formation, except that both the silicified microörganisms and the matrix are gray (see pl. 10).

In some zones the microfossils are not silicified and the insoluble residues consist of soft cotton rock, rough opaque chert or semi-opaque glazed chert, with molds from which the calcareous microorganisms have been removed by the acid. The molds left in the glazed chert are partly lined with minutely drusy quartz crystals. All combinations of these characteristics occur. Some of the residues that resemble cotton rock are white and firm. The crowded fossil fragments in some zones farther north are crinoidal and coarser than is typical of the matted chert. The semigranular crinoidal and only slightly cherty character of the outcrops at Carthage, Mo., has been noted. Similar slightly cherty or non-cherty limestones occur in some places above the Cowley west and north of the Tri-State mining district. The Warsaw rocks in the Kasper-James well (sec. 8, T. 13 S., R. 25 E., residues examined by the Missouri Geological Survey; see p. 83) in Johnson county are 75 feet thick. The limestone is more crinoidal than in the Ballard mine well. The chert is denser and in some zones the matted chert is coarse and includes small silicified crinoid stems. Some detached crinoid stems in the residues are covered with a crust of white chalcedony. In some of the more coarsely matted chert, the fossil fragments are brown and buff with some semitranslucent buff chert. In the upper part, some of the cavities, revealed in the insoluble residues, are lined with columnar and mammillary crusts of buff chalcedony. In northern McPherson county (Archer No. 1 Templin well, sec. 32, T. 17 S., R. 3 W., well No. 19, cross section A-A′, pl. 5) and southern Saline county (Brouk et al. No. 1 Thelander well, sec. 10, T. 16 S., R. 3 W., well No. 20, cross section A-A′, pl. 5) the insoluble residues of the uppermost part of the rocks referred to Warsaw consist of spongy aggregations of loose spicules, which may belong to the overlying less cherty limestones characteristic of the Spergen. Where the rocks are crinoidal and not very siliceous, drusy crusts similar to those in the Spergen constitute a part of the small residue.

In Scott county the Warsaw is 75 feet thick in the Watchorn and McNeeley-Spangler well (sec. 23, T. 20 S., R. 33 W., residues examined by the Missouri Geological Survey, p. 83). The limestone is chiefly cherty semigranular gray limestone, but contains 20 feet of silty dolomitic limestone, like the Cowley, 15 feet below the top. Most of the chert is matted. In the insoluble residues, the micro-organisms are in part represented by molds in the chert, but some of the chert is dense. Most of the chert is light colored, but there are some fragments showing dark markings. The residues of the zone of silty dolomitic limestone near the top are similar to the residues obtained from the silty phase of the Cowley, but because these rocks immediately underlie beds tentatively referred to the Spergen and have Cowley characteristics only in part, they are assigned to the Warsaw.

Thickness.—No locality is known where well-defined Warsaw is in contact with both the Cowley below and the Spergen or upper Warsaw above. In the Kasper-James well in Johnson county the thickness of the Warsaw is 75 feet, but there the Cowley formation is absent. In most places the thickness of the Warsaw has been reduced by post-Mississippian erosion. In western Kansas, wells Nos. 6, 7, and 9 probably lay too near the margin of the confining basin for the seas to become clear as in eastern Kansas so that in these places the Warsaw continued to receive silt and shale. An uninterrupted thickness of Warsaw probably is present in this area beneath the Spergen, but as no definable break separates the Warsaw from the Cowley the thickness of the Warsaw is uncertain.

Distribution.—The Warsaw is widely distributed in eastern Kansas, but on account of the unconformity at its base north of the Cowley basin and on account of the pre-Pennsylvanian peneplanation, which completely removed it in many areas, its distribution is extremely erratic and unpredictable. It seems not to have been deposited in southeastern Logan county (Alma and McNeeley No. 1 Watchorn well, sec. 13, T. 15 S., R. 33 W., well No. 2, cross section F-F', pl. 7) nor north and northwest of this county. It is probably present in southwestern Kansas, but not in areas bordering the central Kansas uplift, for it is absent in northern Lane county (Bates

No. 1 Nimock well, sec. 16, T. 16 S., R. 28 W., well No. 24 inset in cross section F-F′, pl. 7) where upper Meramec rocks overlap upon representatives of the Osage.

Stratigraphic relations.—The Warsaw seems to be conformable above the Cowley and conformable below younger Meramec rocks. In southeastern Kansas the Cowley formation is chiefly a dark-colored finely clastic deposit, confined more or less closely by the margin of the basin contoured in plate 7. When the slightly dissected upland surface north of the basin was submerged the shore line must have receded rapidly, allowing the deposition of limestone relatively free of silt and mud. The transition from Cowley to Warsaw seems to be the expression of the clearing of the seas. On account of the more rapid advance of the sea across the relatively flat upland surface, the glauconitic zone at the base of the Warsaw was generally not developed in east-central and northeastern Kansas. When limestones free of silt and mud were being deposited in southeastern Kansas, the areas nearer the shore line were probably still receiving silt. Cross section F-F′ (pl. 7) shows that the Spangler well (sec. 23, T. 20 S., R. 33 W.) in Scott county (well No. 3) was not far from the margin of Warsaw sedimentation. Its nearness to the shore may explain the presence of silty deposits in the Warsaw. The transition from silty to relatively clean limestones probably took place earlier in some areas than others so that the boundary between the Warsaw and the Cowley is probably transgressive. Although the contact between the Warsaw and the Cowley seems to be conformable, the Warsaw is unconformable upon the relatively level surface underlain by Burlington and Keokuk limestones.

Rocks of Late Meramec Age

Outcrops.—The nearest extensive outcrops of the rocks of late Meramec age are in Ste. Genevieve county in southeastern Missouri, where the Spergen, St. Louis, and Ste. Genevieve limestones were described by Weller and St. Clair (1928, pp. 193-226). The Spergen limestone in that area is 160 feet thick. Its character varies from light-gray or white oölite to white crystalline limestone, nearly or quite free of chert. It is very fossiliferous. The overlying St. Louis limestone is approximately 160 feet thick in Ste. Genevieve county. It is composed of light-gray to bluish compact dense limestone; some beds are lithographic in texture. Locally some of the beds contain buff dolomite. In some parts there is considerable gray and black chert in definite but discontinuous horizontal bands. The

Ste. Genevieve is separated from the St. Louis by a not very pronounced unconformity and ranges in thickness from 60 to 100 feet. It is composed of sparsely oölitic and arenaceous cross-bedded, commonly white limestones. The beds exhibit considerable diversity and locally are shaly. Toward the top horizontally bedded crystalline limestone includes red chert, and locally some fine-grained brown sandstone lenses are present.

An outcrop of St. Louis limestone extending over an area of about 200 square miles was discovered by Clark (1937) in Dade county in southwestern Missouri where it has been preserved by faulting. The limestone varies in color from light gray to dark and in texture from dense lithographic to coarse-grained crinoidal limestone. Some layers are oölitic and some are conglomeratic with limestone pebbles in a limestone matrix. Massive, spongy and tripolitic chert and seams and bands of dense light blue-gray chert are present. Its stratigraphic relation to the underlying beds is not determinable. The maximum thickness exposed is 40 feet.

Subsurface formations in Kansas.—The Meramec rocks above the cherty limestones of Warsaw age in Kansas consist mainly of crinoidal semigranular limestones with very little chert. They contain some oölitic and fossiliferous beds and a well-defined dolomitic zone is generally present in the lower part. In southwestern Kansas these rocks probably have a very general distribution, but in eastern Kansas they are present only locally beneath the pre-Pennsylvanian unconformity.

The Missouri Geological Survey, by means of insoluble residues, has subdivided these rocks into the Spergen (Salem of some classifications) limestone and St. Louis limestone in two widely separated wells, one in Johnson county in northeastern Kansas and the other in Scott county in western Kansas. The criteria used were worked out in Missouri where the rocks have a more general distribution in the subsurface and are nearer the outcrops than in Kansas. The Mississippian formations in these wells identified by Mary Hundhausen are summarized below according to the classification used in this report.

McQueen and Greene (1938, p. 31) have expressed hesitancy in identifying the Spergen in the cuttings of wells in northwestern Missouri and have provisionally referred the rocks immediately above the cherty Warsaw in northwestern Missouri to the upper Warsaw. Girty found fossils in cores from wells in western Kansas that led him to refer to certain cores as of probable Spergen age (see

Summary of Mississippian Formations from Residue Analyses of Cuttings from the Kasper No. 1 James Well, Johnson County, Kansas, sec. 8, T. 13 S., R. 25 E.

	Thickness, feet	Total depth, feet
Carboniferous system:		
No samples	740	740
Mississippian series:		
Rocks of Meramec age—		
St. Louis limestone	50	790
Spergen limestone	50	840
Warsaw limestone	75	915
Rocks of Osage age—		
* Burlington and Keokuk, undivided	145	1,060
† Rocks of Kinderhook or Osage age—		
Sedalia limestone	30	1,090
Rocks of Kinderhook age—		
Chouteau limestone	115	1,205
Chattanooga shale (Kinderhook?)	14	1,219
Devonian system		

* The cherts of this interval are tentatively referred to the Burlington by the writer.
† Classification by Wallace Lee.

Summary of Mississippian Formations from Residue Analyses of Cuttings from the Watchorn and McNeeley No. 1 Spangler Well, Scott County, Kansas, sec. 23, T. 20 S., R. 33 W.

	Thickness, feet	Total depth, feet
Carboniferous system:		
No samples	4,810	4,810
Mississippian series:		
Rocks of Meramec age—		
St. Louis limestone	50	4,860
* Spergen limestone	140	5,000
Warsaw limestone	69	5,069
Rocks of Osage age—		
Burlington and Keokuk, undivided	101	5,170
† Rocks of Kinderhook or Osage age—		
Oölitic limestone, possible equivalent of the Gilmore City of Iowa	110	5,280
No samples	15	5,295
Silurian (?) system		

* The dolomitic limestone member of the Watchorn formation lies between 4,933 and 4,998 feet below the surface and is a part of the Spergen as here determined.
† Classification by Wallace Lee.

Girty's accompanying report on Watchorn No. 2 Morrison well). Approximately the same zones were originally correlated as Spergen by Miss Hundhausen of the Missouri Geological Survey. They will therefore be discussed herein as of tentative Spergen age.

In the Kasper-James well in Johnson county, the Spergen or upper Warsaw, as it is referred to by the Missouri Geological Survey (McQueen and Greene, 1938, p. 31) in northwestern Missouri, is represented by 50 feet of semigranular buff and gray limestone. It contains very little chert, but some semiopaque red chert is present in the upper and lower parts. Some oölites seem to be present and some reddish and greenish calcareous shale occurs near the base. The insoluble residues are small and consist chiefly of brownish drusy sugary crusts that originally must have lined microscopic pockets in the limestone.

In the Spangler well 140 feet of rock was identified as Spergen. The upper part consists of buff fossiliferous limestone and oölitic limestone with a fine-textured limestone matrix. The lower 75 feet is similar, but the matrix consists of buff dolomite. Some specimens of the foraminifer *Endothyra* occur in the middle part of the section. The residues of some zones contain some bluish hackly semi-opaque chert showing silicification of coarse aggregates of crowded broken fossils. No red chert is present. Most of the residues are small, but show abundant brown drusy crusts originally lining voids in the limestone, but some of the crusts cover crinoid joints and other fossil fragments. Some of the drusy crusts are gray or chalcedonic.

The limestone identified as St. Louis in the Kasper-James well in Johnson county is 50 feet thick and consists of fine-textured and lithographic limestone and some crystalline limestone. Some sand seems to be occluded in the limestone. In some zones there are virtually no insoluble residues, but some samples from the uppermost and middle parts yield chert with blurred gray silicified fossil fragments in a gray almost glassy translucent matrix. Some opaque white chert similar to the matted chert of the Warsaw is present, but the microscopic organisms are in part bordered by thin gray glassy silica. In the Spangler well in Scott county the limestone similar to that referred to the St. Louis in the Kasper-James well contains fossils definitely identified by Girty as St. Louis although no limits were set. The grayish-buff limestone is not very fine-textured, however, and contains little if any lithographic limestone. The limestone consists mainly of finely broken fragments of fossils and some oölites in a fine-textured matrix. The residues are very small and consist mainly of the gray translucent silica enclosing gray opaque fossil fragments such as characterize the St. Louis in Johnson county.

WATCHORN FORMATION

Definition.—In western Kansas very few residues have been available for examination and the separation of the thick sequence of limestones above the Warsaw is dependent on residues. The term Watchorn formation is here applied as a convenient subsurface lithologic term where the subdivision of this sequence of strata into the Spergen, St. Louis, and possibly Ste. Genevieve limestones is impracticable. The formation consists essentially of these limestones. The Watchorn formation is well developed in southwestern Kansas, but, except for a few localities where the lower beds may be present, it has been eroded from the region east of the central Kansas uplift.

The Watchorn formation was first penetrated in western Kansas in Clark county in 1931 in the Watchorn Oil and Gas Company No. 2 Morrison well, in the NE¼ NW¼ sec. 20, T. 32 S., R. 21 W. Many cores were taken during the drilling of the well, but only a few samples, saved by James I. Daniels for the Continental Oil Company, could be located. In 1936 the Watchorn Oil and Gas Company and Olson Drilling Company drilled No. 1 Morrison, a producing well, in the SE¼ SW¼ sec. 17, of the same township, offsetting the original deep well. The limestones in this well that overlie with apparent conformity the undivided Cowley and Warsaw formations and that unconformably underlie the Pennsylvanian rocks are herein termed the Watchorn formation, named for the company that drilled the first well that penetrated these rocks in Kansas. The Watchorn and Olson No. 1 Morrison well, in the SE¼ SW¼ sec. 17, T. 32 S., R. 21 W., is the type locality. The formation extends from a depth of 5,330 feet to 6,020 feet and is 690 feet thick in this well. Samples from this well are on file at the State Geological Survey of Kansas at Lawrence, and at the geological department of the Municipal University of Wichita. Fossils obtained from the cores of Watchorn Oil and Gas Company No. 2 Morrison well, in sec. 20, T. 32 S., R. 21 W., were examined by G. H. Girty, and his discussion of them is given in another section of this report. They indicate the Meramec age (probably Spergen and Warsaw) of the lower 268 feet from which fossiliferous core samples are available. No fossils or cores from the upper 359 feet of the Mississippian of this well were available.

It is probable that the St. Louis and the Ste. Genevieve limestones are represented above the cores examined by Girty. Fossils of Warsaw and Spergen age have been identified from cores collected from several other wells in western Kansas. Limestone of definite St. Louis age is present in the Atlantic No. 1-A Mark well in Scott county.

Roth (McClellan, 1930, p. 1548; confirmed by Roth, letter to the writer, June 8, 1938), who examined the cores and cuttings from the No. 2 Morrison well at the time it was drilled, reported that fossils of Chester age are present in the upper part of this well, but made no record of the fossils nor the depths from which they were obtained.

If Chester rocks are present and can be differentiated it is not intended to include them in the Watchorn formation. Where Chester rocks are absent the Watchorn is unconformably overlain by Pennsylvanian strata.

Description.—In Watchorn and Olson No. 1 Morrison, the Watchorn has three lithologically separable units; at the base, a member 120 feet thick, consisting of noncherty or only sparsely cherty semigranular gray limestone; in the middle, a member 25 feet thick, consisting of buff sucrose dolomite containing some dull and semitranslucent gray chert; and at the top, a member 545 feet thick, consisting of semigranular gray and white limestone. The dolomitic zone in the Watchorn and McNeeley-Spangler well, reported on p. 83, is there included in the Spergen. The matrix of some of the semigranular limestone beds of the uppermost member is finely sucrose gray dolomite. The whole member shows bands of oölitic limestone 5 to 15 feet thick at intervals of 20 to 80 feet. Some of the beds, as shown by the cuttings, are extremely fossiliferous. In some wells, notably in Scott county, thin beds of lithographic limestone are present in the upper part, probably indicating the St. Louis. In some wells also rounded grains of sand occur with oölites and rounded shell fragments enclosed in the same matrix. In the Watchorn and Olson No. 2 well, these sandy oölitic limestones occur between 420 and 480 feet above the top of the Warsaw.

The Watchorn as a whole is noncherty, but minor amounts of dull and semitranslucent gray chert are present in some beds. As nearly all the samples examined from western Kansas are from a few rotary wells, it was not determined whether the chert is confined to certain zones that might be useful datum planes. Glauconite is sparsely and erratically disseminated throughout the Watchorn.

Watchorn formation in eastern Kansas.—The dolomite member of the Watchorn and the underlying basal semigranular limestone are present in several scattered wells east of the central Kansas uplift, but the dolomite becomes less prominent northeastward and is absent in Johnson county. In the Hammond et al. No. 1 Roeder well (sec. 23, T. 27 S., R. 2 W., well No. 9, cross section A-A′, pl. 5) in Sedgwick county, 20 feet of noncherty semigranular limestone rests on cherty Warsaw limestone. Farther north in Sedgwick county in the Kayser No. 1 Stroot well (sec. 8, T. 26 S., R. 2 W., well No. 11, cross section A-A′, pl. 5), 50 feet of similar limestone overlies the Warsaw. In the Hawkins No. 1 Marshall well (sec. 4, T. 25 S., R. 2 W., well No. 12, cross section A-A′, pl. 5) the cherty limestones assigned to the Warsaw are only 15 feet thick. They are overlain by 40 feet of noncherty semigranular limestone and 55 feet of gray almost noncherty dolomite. In McPherson county in the Curley No. 1 Johnson well (sec. 17, T. 18 S., R. 2 W.) the cherty Warsaw limestones are absent and 10 feet of noncherty limestone overlies the Keokuk. The noncherty limestone is overlain by 35 feet of gray dolomite with which some pink semitranslucent chert is associated. The dolomite is overlain by 40 feet of gray semigranular limestone. In the Brouk et al. No. 1 Thelander well (sec. 10, T. 16 S., R. 3 W., well No. 20, cross section A-A′, pl. 5) in Saline county, gray dolomite, 40 feet thick, at the top of the section overlies 40 feet of siliceous dolomite and limestone with residues of gray chert containing casts of dolomite crystals. This limestone does not have Warsaw characteristics but may represent a cherty marginal phase of the noncherty limestone of the Warsaw usually present directly below the dolomite, for it rests directly on the Keokuk. In Lyon county (well on Runyan farm, sec. 9, T. 17 S., R. 10 E., well No. 13, cross section B-B′, pl. 5) scattered samples in the upper 100 feet of the Mississippian section show the presence of noncherty limestone above noncherty dolomite. They probably represent parts of the Watchorn formation, for clear drusy crusts occur in the residues. In Wabaunsee county (Empire No. 1 Schwalm well, sec. 19, T. 12 S., R. 11 E., well No. 14, cross section B-B′, pl. 5) a noncherty dolomitic zone, 66 feet thick, directly overlies cherty dolomite like that in the Brouk-Thelander well with very feeble development of Warsaw characteristics. No typical Warsaw is present below these rocks, which overlie the Burlington.

Watchorn formation in western Kansas.—The Morrison field in Clark county at present provides the only tie between the Mississippian beds in western Kansas and the better known sections east of the central Kansas uplift. In this field no Chattanooga shale is present though it is 45 feet thick in the Sinclair No. 1 Stewart well in sec. 33, T. 27 S., R. 16 W., in Woods county, Oklahoma, 20 miles south, and 52 feet thick in the Skelly No. 1 Temple well (No. 8 of cross section F-F′, pl. 7) in Harper county, Kansas, 40 miles east. In the Watchorn and Olson No. 1 Morrison well (No. 7 of cross section F-F′), 45 feet of St. Joe limestone, consisting of 30 feet of gray shale at the top and 15 feet of limestone at the base, unconformably overlies pre-Chattanooga rocks. It unconformably underlies the Cowley formation, which, possibly including undivided Warsaw, is 410 feet thick. The overlying basal noncherty semigranular limestone member of the Watchorn, here almost free of chert, is 120 feet thick. This limestone is overlain by approximately 25 feet of moderately cherty sucrose buff dolomite similar to that observed above semigranular limestone in Sedgwick county. The section up to this point is similar to that observed in a few wells east of the central Kansas uplift. The highest member of the Watchorn consists of 545 feet of white granular limestone, characterized by numerous beds of oölite and rolled grains of fossil fragment and beds of fossiliferous limestone. Some of the oölite beds contain scattered well-rounded frosted sand grains imbedded in the limestone. The Watchorn includes some beds of lithographic limestone and contains very little chert. The entire thickness of this sequence of rocks is rarely represented in Kansas east of the central Kansas uplift, though as already mentioned the basal rocks of this formation have survived the pre-Pennsylvanian erosion in some places.

Most of the wells drilled through the Watchorn in western Kansas were drilled with rotary tools and consequently do not yield very satisfactory material for subdividing the formations, though units already determined from cuttings of standard tools elsewhere in the region can usually be recognized. On this account, and because relatively few wells have been drilled through the Watchorn, no subdivisions of the upper member of the Watchorn have been made. Eventually the lithographic limestone and some of the fossiliferous zones, particularly those containing ***Endothyra*** reported by Girty as prominent in the Spergen, may prove to be important markers.

Age of the Watchorn formation.—Through the coöperation of the Atlantic Refining Company, the Continental Oil Company, the Carter Oil Company, the Skelly Oil Company, and the Magnolia Petroleum Company, and the Geological Department of the Municipal University of Wichita, several sets of fossiliferous cores were assembled and submitted to George H. Girty of the United States Geological Survey, whose report is attached. From this report it seems that the uppermost zone of the Cowley and the lower zones of the Watchorn up to the top of the dolomitic zone are "of probable Warsaw age". This is followed by beds conservatively reported as "probably Spergen in age" up to about 160 feet above the top of this dolomite member. Some fossils of definite St. Louis age were noted in the Atlantic No. 1-A Mark well (No. 2, cross section F-F', pl. 7), but the limits of the formation are not determinable by faunal content. The wells from which most of the cores were taken are shown on cross section F-F′, plate 7. In the Watchorn No. 2 Morrison well (No. 7a, cross section F-F′), 359 feet of limestone occurs above the highest beds whose age has been determined. The basal part of this zone corresponds in stratigraphic position to the zone determined as at least in part of St. Louis age in the Atlantic No. 1-A Mark well in Scott county (No. 3a, in cross section F-F′). Girty noted some evidence that beds of Ste. Genevieve age are present above the St. Louis in the Atlantic No. 1-A Mark well in Scott county, sec. 28, T. 20 S., R. 33 W. (well No. 3a, cross section F-F′). No rocks of Chester age were definitely identified in the cores. The results of the paleontologic examination indicate that those parts of the Watchorn formation from which fossiliferous cores are available are above the Warsaw, although the lower part of the noncherty limestone of the Spangler well is reported as of probable Warsaw age. Since the examination of the cores by Girty, specimens of *Endothyra* have been found in some of the samples from this zone that would suggest a probable or possible Spergen age for at least a part of these rocks.

The residues examined by Miss Hundhausen, of the Missouri Geological Survey, indicate that the dolomite and the noncherty limestones to 67 feet above the top of the dolomite are of Spergen age, and the rest, as far as samples were available (50 feet), is of St. Louis age. Both fossils and residues are in agreement that the upper part of the Watchorn in this area includes beds of St. Louis age. The oölitic limestone at the top of the Atlantic No. 1-A Mark well cores, regarded by Girty as of possible Ste. Genevieve age, was not represented in the cuttings of the Spangler well.

Some discrepancies occur between the identifications by means of fossils from the well cores and those made by siliceous residues. The reports are, however, not necessarily in disagreement, for the scanty faunal evidence does not indicate the divisions so sharply as the residue criteria, and in view of the small number of fossils that were recovered from the cores the results are essentially harmonious.

ROCKS OF CHESTER AGE

Strata of Chester age of considerable thickness and diversity occur in Kentucky, Illinois, Missouri, and adjoining states. Limestone of Batesville age probably referable to the Hindsville limestone member of the Batesville sandstone of Arkansas forms the upper part of the Mayes formation in Mayes county, northeastern Oklahoma (unpublished manuscript by G. H. Girty). In the zinc-lead district in Oklahoma, this limestone in some places rests unconformably upon limestone referred to the Warsaw. These rocks extend northward into the extreme southeastern part of Kansas, where they were identified above the Warsaw in cuttings from the Ballard mine well, by Mary Hundhausen of the Missouri Geological Survey (see page 46, St. Louis Smelting and Refining Company, Ballard mine well, well No. 23 of cross section F-F′, pl. 7).

Robert Roth (see page 85), who examined the paleontologic evidence, has stated that Chester fossils were found in the upper 400 feet of Mississippian rocks in the Watchorn No. 2 Morrison well (sec. 20, T. 32 S., R. 21 W., well No. 7a, cross section F-F′, pl. 7) of Clark county. This interval is that from which the writer was unable to procure cores or fossils. Cuttings from this part of the well obtained from the Indian Territory Illuminating Oil Company in Bartlesville yielded no diagnostic fossils. Dille (1932) reported the presence of Chester fossils from the cuttings of several wells in southwestern Kansas. The rocks from which the fossils were obtained in Oklahoma were reported to be soft fossiliferous gray shales and light-colored limestones that are not found in other parts of that state. The wells in which Chester rocks were identified and the depths below the surface in the various wells were given. The wells listed from Kansas are the Watchorn No. 1 Morrison well (probably No. 2), sec. 20, T. 32 S., R. 21 W., at 5,395 feet, and Wood Oil Company (McCrary) No. 1 Ranson well, sec. 5, T. 25 S., R. 41 W. (no depth reported). The area in which rocks of Chester age were identified by Dille includes parts of northwestern Oklahoma, southeastern Colorado, and southwestern Kansas. It is therefore probable that Chester rocks will be found in other wells in southwestern Kansas in the deep structural basin southwest of the central Kansas uplift.

CROSS SECTION IN WESTERN KANSAS

In the preceding chapters discussion is devoted chiefly to the Mississippian rocks in central and eastern Kansas, where they have been penetrated by thousands of wells; and frequent reference has been made to the several detailed cross sections for those portions of the state. Inasmuch as little has been said thus far in regard to the stratigraphic relations of the rocks in western Kansas, where they have been penetrated by only a few wells, a brief discussion of their relations, as revealed in that part of the state by cross section F-F′, plate 7, is here given. The column of Mississippian rocks in western Kansas differs from that in eastern Kansas by including at the top a greater thickness of the Watchorn formation, which is incompletely and only locally represented in eastern Kansas. The Chattanooga shale, which provides a convenient datum in other parts of the state, is generally absent in western Kansas.

The wells in cross section F-F′ are correlated on the top of the Chattanooga shale east of Clark county in wells 8 to 22. From Clark county northwestward the contact of the Watchorn formation with the cherty Warsaw limestone has been used as a datum in wells 3 to 7. In wells 1 and 2, where the Warsaw is absent, the wells have been correlated on the top of the Burlington. The correlation of the Watchorn and Olson No. 1 Morrison well in Clark county (No. 7 of the cross section) with the Skelly No. 1 Temple well in Barber county (well No. 8 of the cross section) is the link that connects the Mississippian rocks of eastern Kansas with those of the western part of the state. In both these wells the green limy shale member of the St. Joe limestone is present. In the Skelly No. 1 Temple well (well No. 8) the St. Joe limestone is underlain by the Chattanooga shale, but in the Watchorn and Olson No. 1 Morrison well (well No. 7) the shale member of the St. Joe overlaps upon the pre-Chattanooga rocks.

In the Watchorn and Olson No. 1 Morrison well (well No. 7), the base of the Cowley formation lies 45 feet above the base of the Mississippian section, but 18 miles north, in the Carter No. 1 Everett well (well No. 6), the surface of the Osage rocks was not eroded so deeply in pre-Cowley time, for 110 feet of limestone identified as Burlington and 126 feet of rocks of Fern Glen age are present below the Cowley. In the Carter No. 1 Everett well (well No. 6) the rocks of lower Osage age include 2 feet of shale of the St. Joe and 12 feet of St. Joe limestone at the base and 40 feet of dense noncherty green and red lithographic limestone at the top. The only other well in which lithographic limestone of similar character was observed is well No. 8, in which lithographic limestone 8 feet thick is present in rocks of Fern Glen age directly below the Cowley. Undivided Warsaw and Cowley rocks 180 feet thick occur above the Burlington in the Carter No. 1 Everett well (well No. 6). The Watchorn and Olson No. 1 Morrison well (well No. 7) to the south has 410 feet of similar rocks but the Swain-Taylor well (well No. 5) 24 miles north has no Cowley and only 44 feet of Warsaw overlying the Burlington. The Carter No. 1 Everett well (well No. 6) therefore seems to be near the margin of the pre-Cowley upland, for Osage strata, which farther south were almost completely eroded, were only partly removed by pre-Cowley erosion.

The area in which the Swain-Taylor well (well No. 5) was drilled did not receive deposits of Fern Glen age. It seems to have been covered by the Gilmore City rocks and was overlapped by the Burlington in the same way as the area northeast of the central Kansas uplift. Pre-Cowley erosion did not greatly affect the surface of the upland and did not remove the Burlington. Twenty-two feet of noncherty limestone that seems to represent a marginal wedge of the Gilmore City underlies the Burlington and rests on pre-Mississippian rocks. Wells Nos. 3 and 4 of the cross section are not essentially different from the Swain-Taylor well (well No. 5), except that in these wells rocks assigned to the Gilmore City limestone are thicker. The Warsaw limestone of well No. 3 contains some silty deposits similar to the Cowley. This is believed to be due to the nearness of the shore line, for no rocks of Warsaw age were recognized in the Alma and McNeeley No. 1 Watchorn well (well No. 2) in Logan county 36 miles north, nor in the Bates No. 1 Nimock well (well No. 24) in Lane county. In this well the Watchorn formation is believed to overlie the Burlington, which includes a zone of cherty dolomite not recognized in wells farther southeast. The upper part of the Burlington in well No. 2 contains some glauconite, but the chert is unlike the chert of the Warsaw.

An attempt has been made to correlate the Indian Territory Illuminating Oil Company No. 1 Strangways well (well No. 1) in Yuma county, Colorado, with the other wells, although it is necessary to make a jump of 107 miles beyond the Logan county well (well No. 2). As shown in the cross section, the limestone at the top of the Mississippian section of this well is referred to the Burlington, the Watchorn formation is absent, and Pennsylvanian rocks overlie the Burlington. The Burlington in this well consists of semigranular limestone containing glauconite and chert, and closely resembles the beds referred to the same zone in Logan county (well No. 2). At the base of the Burlington in the Strangways well (well No. 1) there is 30 feet of brown, noncherty coarsely sucrose dolomite corresponding in position and character to the buff, coarsely sucrose, but cherty dolomite of Logan county, which is there referred to the lower part of the Burlington. These beds in the Strangways well (well No. 1) rest on 35 feet of semigranular pseudo-oölitic limestone of probable Gilmore City age at the base of the Mississippian.

The Watchorn is present in all the wells shown on the cross section northwest of Comanche county except No. 1. In these wells it seems to be overlain everywhere by Pennsylvanian rocks, although there is a possibility that in some wells rocks of Chester age may be present. The thickness of the Watchorn is dependent on the amount of erosion that took place before the deposition of the Pennsylvanian rocks; the three lithologic units of the formation are present though the dolomite zone toward the west is represented by dolomitic limestone, in which the dolomite occurs as the matrix for limestone granules. The interval between the dolomite and the top of the Warsaw thins slightly northwestward.

The western part of cross section F-F′ is based on only a few widely separated wells and, although their interpretation makes a consistent whole, details will no doubt be modified as further information accumulates. A few other wells, not on the line of the cross section, are consistent with the interpretation here given. Typical Warsaw cherts are present in beds that overlap upon the pre-Mississippian in the Gulf No. 1 Risser well in Kiowa county, Colorado. In the Bates No. 1 Nimock well in Lane county (not on the line of the cross section but inserted on the cross section as well No. 24), the dolomitic zone of the Watchorn overlaps upon rocks referred to the Burlington limestone.

RELATION OF THE COWLEY FORMATION TO THE MAYES FORMATION

In Mayes county, Oklahoma, the Mayes formation consists of two parts. The upper part is white semigranular limestone of Batesville (Chester) age. The lower part of the Mayes is dark to black limestone containing a lower Moorefield († Spring Creek*) fauna. The lower Moorefield fauna has been interpreted as a facies fauna. Its exact position in the Mississippian time scale has been a matter of discussion for many years, but the fauna of higher beds of the typical Moorefield shale of Arkansas is recognized by all workers as of Chester age. It is the writer's belief that the lower Moorefield part of the Mayes formation of eastern Oklahoma is the outcropping marginal part of the dark limestones of the Cowley formation.

Limestone of Batesville age overlies rocks of lower Moorefield age in Mayes county, Oklahoma, but elsewhere in that part of Oklahoma the same limestone can be seen at the surface resting in places upon the Warsaw. It is the writer's interpretation that in Mayes county, as elsewhere, the dark basinward deposits of early Moore-

* A dagger (†) preceding a geologic name indicates that the name has been abandoned or rejected for use in classification in publications of the Federal Geological Survey.

field age were originally overlain by the white cherty limestones correlated with the Warsaw by the Missouri Geological Survey by the use of insoluble residues. These rocks of early Moorefield age overlapped toward the northeast upon the upland of the pre-Cowley surface. If this interpretation is correct, the Warsaw rocks and the zone of contact between the Warsaw and the lower Moorefield were removed by erosion during the exposure that preceded the Chester. Limestone of Batesville (Chester) age was subsequently deposited on the eroded surface so that this limestone rests on Warsaw toward the north and on the lower Moorefield toward the south. The present cycle of erosion has exposed these beds in such a way that the outcropping areas of rocks of Warsaw and of early Moorefield age are now separated by a belt of limestone of Chester age outcropping between them (see fig. 4 and cross section G-G′, pl. 6).

The contrasting lithologic and faunal characteristics and the separation of the areas of outcrop have prevented the recognition in surface studies of the close relation that the writer believes originally existed between the Warsaw of southwestern Missouri and the dark limestones in Mayes county, Oklahoma, containing the lower Moorefield († Spring Creek) fauna of doubtful stratigraphic position. The dark limestones that crop out in Mayes county, Oklahoma, which the writer believes are marginal deposits of Cowley age, have been linked with the overlying limestone of Batesville age and the two together have been termed the Mayes formation, although it has long been recognized that the two faunas are very different. It is interesting to note that in some places in the outcrops the upper and lower parts of the Mayes are separated by sandy limestone.

Cline (1934, pp. 1156-1158) has shown that the Mayes overlaps upon all the units of the Osage series from the St. Joe to the Keokuk. The Cowley formation in southeastern Kansas has similar relations to the same units of the Osage and in the subsurface is unconformable also on the Kinderhook, Chattanooga, and older rocks.

The relation of outcrops containing the lower Moorefield († Spring Creek) fauna to the subsurface rocks down dip, as revealed in well cuttings (cross section G-G′, pl. 6), provides additional evidence that the lower Moorefield is equivalent to a part of the Cowley formation. At a locality (No. 5 of cross section G-G′, pl. 6) described by Snider (1915, p. 29) in sec. 8, T. 19 N., R. 19 E., Oklahoma, that part of the Mayes representing the lower Moorefield consists of black limestone 19 feet thick resting on 169 feet of Reeds Spring

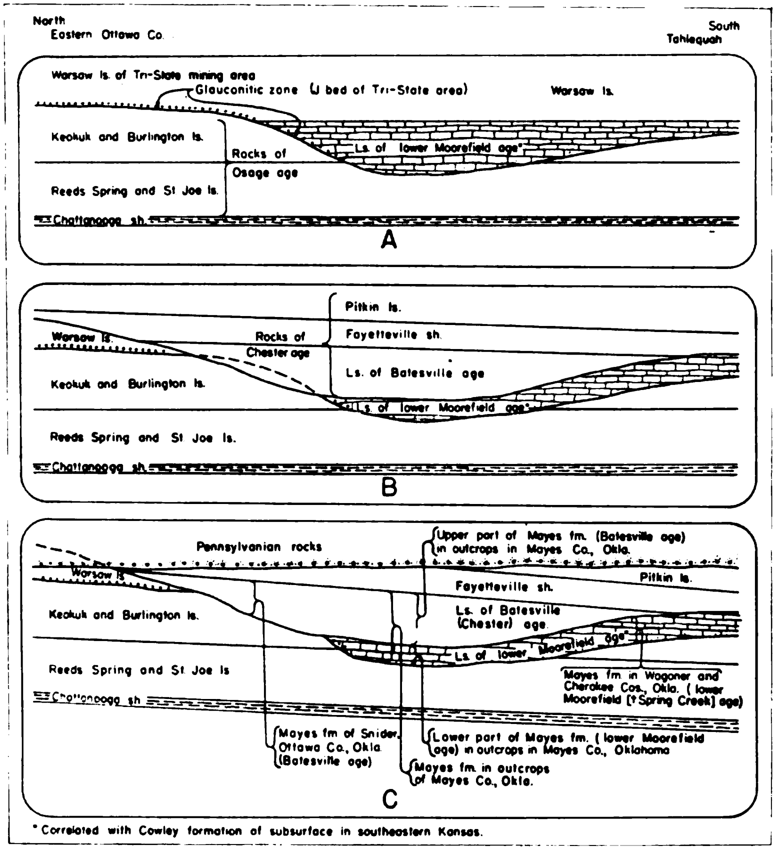

FIG. 4.—Diagrammatic cross sections showing probable relation of Mayes formation of Oklahoma to limestones of lower Moorefield († Spring Creek) and Batesville (Chester) age, to Warsaw limestone of Kansas and Missouri, and to Cowley formation of the subsurface in Kansas and Oklahoma.

Cross section A shows original relations of Cowley formation and Warsaw limestone to older Mississippian rocks.

Cross section B shows erosion of the Cowley and Warsaw and their replacement by Chester rocks, including at the base limestone of Batesville age.

Cross section C shows erosion of Mississippian rocks and deposition of Pennsylvanian rocks on eroded surface. Limestone of Batesville (Chester) age overlies the Warsaw and Keokuk toward the north and constitutes the Mayes formation in Ottawa county. Farther south in Mayes county, Oklahoma, the Mayes formation consists partly of limestone of Batesville age and partly of the Cowley formation (lower Moorefield phase of the Mayes). Still farther south in Wagoner and Cherokee counties the Mayes consists of part of the Cowley formation (lower Moorefield alone) without the limestone of Batesville age.

and St. Joe limestone measured by the writer. The dark beds of Moorefield age at the outcrop seem to be represented in well cuttings by dark limestones which toward the northwest rest upon progressively lower rocks of Osage age. The dark limestones increase in thickness down dip in this direction from well to well so that in well No. 1 of the cross section G-G′, plate 6, they are identical with the Cowley formation of well No. 16 of cross section F-F′ (pl. 7) where the Chattanooga and Osage limestones are replaced by the Cowley formation. In the same direction the overlying white limestone of Chester age at the outcrop thins and wedges out beneath the overlying unconformable Pennsylvanian beds.

REPORT ON FOSSILS OF MISSISSIPPIAN AGE FROM WELL CORES IN WESTERN KANSAS

By George H. Girty

In the paleontologic field, the study of well cores is likely to be attended by the maximum of labor and the minimum of result. Whatever may be said of the microfossils, the story is quite different with regard to shells of ordinary size. Most of the specimens recovered consist of fragments of large shells, with now and then a small shell that is whole and belongs to some small species or is an immature representative of some large one.

In some of the well cores examined and reported upon below, fossils are remarkably abundant in certain zones, but their evidence is qualified by the facts just stated. It has been possible to make many generic identifications upon fragmentary specimens and even some specific identifications if the fragments are large. Even where it has been possible to assemble a respectable faunal list by genera, however, the list may have slight value as evidence for age determination, because most Carboniferous genera have long ranges. Indeed, many species are so closely related to others of a different geologic age that reliable identifications are hardly possible on one or two specimens, for the variation in each is such that one species, so to speak, overlaps with some other species. Indeed, in my experience, there are few guide fossils in our Carboniferous faunas, and it is necessary to rely upon faunal associations for age determination and not upon single species. It is rarely possible to recover enough determinable fossils from well cores to constitute an adequate faunal association.

In these well cores the faunas consist of bryozoa and brachiopods but hardly any other zoölogic types. Among the bryozoa fronds of *Fenestrellina* and *Polypora* are at some horizons very abundant. I have not attempted to identify them specifically, because to do so would be laborious and the results of uncertain value. Some of the other bryozoan types could not be identified without thin sections, and for similar reason these too have not been specifically identified. As mere genera, on the other hand, most of these types have no stratigraphic significance. There are two bryozoa, however, that are more or less abundant in the well cores, that can be identified generically with reasonable assurance, and that have value as evidence in age determination. The genus *Hemitrypa* has a known range from Keokuk to St. Louis. It has been recognized in several samples and probably occurs in many others, for it can be recognized only when one side of the frond is exposed. If the other side is exposed it is indistinguishable from *Fenestrellina*. *Worthenopora spinosa* also occurs abundantly in many samples and has a range from Keokuk to Spergen. *Archimedes* was recognized in a fragment in one collection and it ranges from Keokuk upward.

Among the brachiopods the genus *Spirifer* is preëminently abundant, but most of the specimens belong to a type that is represented at many horizons and goes by different names. The species are probably valid, but then cannot be identified satisfactorily on a few specimens or on fragmentary ones. I mean the line of descent represented by *S. keokuk, S. bifurcatus, S. pellensis,* and *S. increbescens,* not to mention other species related to them. Not all the Spirifers in these cores, however, are of this type. There is a finely ribbed form that seems to be *S. tenuicosta* (Keokuk to Spergen), another that seems to be *S. lateralis* (Warsaw and Spergen), a third that seems to be *S. subaequalis* (Warsaw and Spergen), and a fourth that seems to be *S. bifurcatus* (St. Louis and, according to Butts, basal Warsaw). There are other forms that have stratigraphic significance but occur more rarely in the samples. They are commented upon in connection with the samples in which they were found.

In weighing the significance of the species recognized in the well cores I have had to depend chiefly upon their recorded ranges, without a critical examination or verification of the records as of the present day. Some of the identifications recorded may be incorrect and the supposed range too great. On the other hand, as facts accumulate, some of the ranges may be increased.

Taken as a whole, the well cores record faunas of Warsaw, Spergen, St. Louis, and possibly Ste. Genevieve ages, but it rarely happens that two of them can be definitely recognized in any one core. They are probably represented, but Mr. Lee will have to determine their positions by comparisons of depth with relation to the height of the well head above sea level. Furthermore, I have been unable to indicate the boundaries of any formation or period, and consequently, the thickness of rock that represents it. Most of the conclusive evidence occurs in a sample or samples taken from but a few feet, with only nondescript faunas above and below. None of the diagnostic forms indicates an age older than Keokuk but many of them appear first in the Keokuk and range upward from there. The Burlington would seemingly be unrepresented in the cores and it is doubtful if the Keokuk is represented in them. Some of the forms that have definite stratigraphic significance begin in the Keokuk, but I have seen nothing that is distinctive of that period. As most of the Keokuk faunas of the Boone occur in or are associated with cherty beds, as the well cores consist chiefly of limestone or at most contain little chert, and as Lee tells me that cherty beds are numerous below the core samples sent me for examination, it seems probable that the lowest samples considered in my report are Warsaw, although by reason of the ambiguous faunal evidence they might be either Keokuk or Warsaw.

I should also mention that in searching for paleontological evidence in the cores I have relied greatly upon Mr. W. H. Hass, who broke up and selected the fossiliferous specimens. I began by looking over all the fragments in a sample myself and continued to look over a piece or two in many lots, but I found that Mr. Hass had made a very accurate selection. I concluded that in general any fossil that was so obscure that he overlooked it would also be too poorly preserved to add much to the paleontological evidence.

Well of the Carter Oil Company

No. 1 Everett, sec. 22, T. 29 S., R. 21 W., Ford county (well No. 6, cross section F-F', pl. 7)

Core 5428-5432.* Many fragments, but few that can be recognized or are significant. A *Spirifer,* probably *S. tenuicosta* (Keokuk, Warsaw, and Spergen), a large *Reticularia,* type of *R. pseudolineata,* fragments of a large *Productus* and a small undeterminable *Pustula?*. Geologic age not older than Keokuk and possibly as young as Spergen. It cannot well be Spergen as it occurs below probable Warsaw and is, tentatively, itself Warsaw.

Core 5425-5428. Fauna much like the foregoing, but not so good. The only additional form with significance is *Worthenopora spinosa* (Keokuk, Warsaw, and Spergen).

Core 5422-5425. Fossils numerous, but limited in variety. *Spirifer lateralis, Spirifer* of the *keokuk-washingtonensis-pellensis* group and *Cliothyridina?* sp. If *Spirifer lateralis* is correctly identified, the zone is probably Warsaw. The species is recorded as Warsaw and Salem but is commonly regarded as a distinctive Warsaw form.

Core 5419-5422. *Spirifer subaequalis* (Warsaw and Spergen),

* Core numbers indicate depth below the surface.

S. lateralis, *Spirifer* aff. *S. washingtonensis*, and a few other forms by fragments. Warsaw is indicated.

Core 5419-5404 (samples 5417-5419, 5416-5419, 5413-5416, 5410-5413, 5407-5410, 5404-5407). Little except fragments and nothing of significance.

Core 5401-5404. A rather varied fauna, though many of the forms have no stratigraphic significance. The most notable are *Spirifer* aff. *S. pellensis* (abundant), *Spirifer tenuicosta*, *Pustula ozora?*, *Echinoconchus biseriatus*, *Worthenopora spinosa*; Warsaw age indicated.

Core 5398-5401. Fossils abundant; fauna much like the foregoing, but not so varied. *Worthenopora spinosa*, *Pustula ozora*, *Spirifer lateralis*, *Spirifer* aff. *S. bifurcatus* (abundant); Warsaw age indicated.

Core 5395-5398. Fossils abundant, fauna much like the foregoing. *Worthenopora spinosa*, *Spirifer* aff. *S. bifurcatus* (a Spergen species, but I have it in the Joplin Warsaw), *Echinoconchus biseriatus*. Other forms fragmentary and without significance. Warsaw again indicated.

Core 5392-5395. Very fossiliferous. Fossils mainly bryozoa. Fauna like the preceding. *Worthenopora spinosa*, *Echinoconchus biseriatus*, *Pustula ozora*, *Avonia williamsiana?*, *Spirifer tenuicosta*, *Girtyella turgida?* (a Spergen species), together with several other forms, either fragmentary or lacking in interest. Geologic age seemingly Warsaw.

Core 5375-5392 (four samples, designated first 2 feet recovered, last 2 feet recovered, third 2 feet recovered, and second 2 feet recovered). Fossils not abundant. The fauna is small, but like the foregoing. *Worthenopora spinosa*, *Echinoconchus biseriatus*, *Spirifer* aff. *S. bifurcatus*, *Spirifer tenuicosta?*, and a few other forms, none of them worth recording. There is no reason to differentiate this fauna from the preceding.

Core 5361-5375 (two samples, designated first 2 feet recovered, and last 2 feet recovered). Fossils scanty and fauna small. Identifications mostly indefinite. Note should be made of *Worthenopora spinosa* and a large spiriferoid having a punctate shell and seemingly belonging to the genus *Spiriferella*, as Weller used that name. The only species referred to *Spiriferella* in this country occur in the Burlington and Keokuk, but I have seemingly the same species in the Warsaw fauna of the Joplin area. The same form occurs in the well of the Atlantic Oil Production Company at a depth of 5,088 to

5,097 feet. There seems to be no reason to differentiate this bed from the preceding.

Core 5360-5341 (two samples, designated first 2 feet of 5 feet recovered, and last 2 feet of 5 feet recovered). Fauna much restricted. *Fenestrellina, Polypora, Worthenopora spinosa,* and a few fragments.

Core 5341-5306 (12 samples, 5339-5341, 5336-5339, 5333-5336, 5330-5333, 5327-5330, 5324-5327, 5321-5324, 5317-5321, 5314-5317, 5311-5314, 5308-5311, and 5306-5308). Fossils generally scanty and fragmentary. The faunas are sparse and many of them without distinctive characters. *Worthenopora spinosa,* which occurs chiefly in the Keokuk and Warsaw, but is known also in the Spergen, was recognized in several of these samples, including the last (5306-5308). Sample 5330-5333 contains a better fauna than the rest, but the only significant things are *Worthenopora spinosa, Hemitrypa* sp., and another bryozoan, which seems to belong to the genus *Diplopora,* a genus that at present is not known below the Chester. There is also a small *Spirifer* related to *pellensis,* and a small *Productus.* The association of *Worthenopora spinosa* and *Hemitrypa* sp. is found also in sample 5308-5311, which contains in addition a species of *Sulcoretepora,* a genus that, though not mentioned before, has been recognized in numerous samples.

The next sample, 5278-5283, contains *Fenestrellina* (fragments), a rhynchonellid, which I would not undertake to identify, and *Cliothyridina?* sp.

In summary: The lowest fossiliferous bed, 5428-5432, can hardly be older than Keokuk, but may be younger. As a Warsaw fauna makes its appearance slightly higher, this lot would probably be best so referred. Warsaw faunas seemingly continue up to and include sample 5306-5308, a thickness of about 125 feet. So far as the evidence goes, the Warsaw very likely ranges up to include samples 5278-5283. At least there is nothing out of keeping with Warsaw and nothing definitely suggestive of Spergen.

The significant forms in the part of the core here referred to the Warsaw (5422-5425 to 5306-5328) are as follows:

Worthenopora spinosa	Keokuk, Warsaw, Spergen
Pustula ozora	Warsaw
Echinoconchus biseriatus	Keokuk?, Warsaw, Spergen
Avonia williamsiana	Keokuk, Warsaw
Spirifer lateralis	Warsaw, Spergen
Spirifer subaequalis	Warsaw, Spergen
Spirifer tenuicostus	Keokuk, Warsaw, Spergen
Spirifer bifurcatus	basal Warsaw, Spergen
Spiriferella sp.	Warsaw

It will be observed that the recorded ranges of these forms overlap, some going down into the Keokuk, some going up into the Spergen, but the only zone in which all occur together is Warsaw. There is no definite evidence of Keokuk nor any definite evidence of Spergen. Furthermore, the parts of the core above and below the section here regarded as Warsaw, which are poorly characterized faunally, are nevertheless tied faunally to the Warsaw part and I find no reason in paleontology for believing the one to be Keokuk or the other Spergen. Such possibilities, however, are not to be dismissed.

Well of the Atlantic Oil Production Company

No. 1-A Mark, sec. 28, T. 20 S., R. 33 W., Scott County, (well No. 3a, cross section F-F', pl. 7)

Beginning at the bottom of the section there are four samples from about the same zone. One has a given depth of 5088 to 5091 feet, the three others are alike, 5088-5097. This zone is abundantly fossiliferous, but most of the fossils are fragmentary and otherwise poorly preserved. Bryozoa are numerous, but it would not be profitable to identify them specifically. The following are significant: *Hemitrypa* (Keokuk to St. Louis), *Archimedes* (Keokuk and later), *Worthenopora spinosa* (Keokuk, Warsaw, and Spergen). Few of the brachiopods are identifiable specifically and the generic identifications mean little. Especially notable is a large punctate *Spirifer* seemingly belonging in the genus *Spiriferella*, as interpreted by Weller. The same striking species occurs in the Carter-Everett well in a fauna that I interpret as Warsaw. The same or a closely related species is found in the Joplin Warsaw. Mention may also be made of *Spirifer tenuicostus* (Keokuk, Warsaw, Spergen), a species of *Reticularia* (abundant) and a rhynchonellid (abundant). I believe that these samples represent the Warsaw zone of the Carter-Everett well, but the rock here is darker and very cherty.

Sample 5065-5068 contains no fossils.

Five samples (5060-5065, 5060-5065, 5055-5060, 5050-5065, 5050-5055) contain fossils, but nothing distinctive. General suggestion of Keokuk or Warsaw. Sample 5060-5065 marked "Cowley chert".

Three samples (all marked 5035-5050) contain little that is instructive. One marked "third foot" contains a specimen of *Avonia williamsiana*, a species that I recognize in the Keokuk and Warsaw faunas of the Joplin region.

Four samples (5033-5035, 5030-5035, 5026-5030, and 5019-5026) are also more or less noncommittal, but not differentiated faunally from the Warsaw below. One of them contains *Worthenopora* *spinosa* (Keokuk to Spergen) and another (5019-5026) contains one of those elliptical crinoid stems with dentate projections that have sometimes been identified as *Platycrinites penicillus* (Ste. Genevieve). It is doubtful if this fossil is reliable as a zone marker or that it has such significance here.

The four samples (5012-5019, top of 5012, 5000-5012, 4993-5000) present problems. Sample 5012-5019 contains no fossils. Sample top of 5012 contains a *Productus* like *P. cora* or *P. ovatus,* but more like the latter (Mississippian). Several crushed specimens that might represent a *Productus* of the *nebraskensis* group (Pennsylvanian) or a species related to *Buxtonia arkansana* (a Moorefield and Chester type) and, lastly, a small spiriferoid shell, which seems to be *Squamularia perplexa* (Pennsylvanian), but is conceivably a very young *Reticularia* (Mississippian). Sample 5000-5012 contains nothing significant, and sample 4993-5000 contains a Pennsylvanian fauna with *Chonetes* (*Mesolobus*) *mesolobus* and *Squamularia perplexa.* The age of this fauna is certainly Pennsylvanian, for the range of *C. mesolobus* is well known and it has always been found in Pennsylvanian rocks. I do not see how a Pennsylvanian bed could occur at this horizon, and if the lot is misplaced I would be inclined to regard lot 5012 top as also misplaced and also Pennsylvanian.

Four samples ranging from 5000 to 4989 contain nothing significant.

Three samples (4980.5 to 4987.5, 4979-4980½, 4981-4983) represent a somewhat fossiliferous zone, but one whose fauna is not easy to interpret. Bryozoa are numerous, among them *Worthenopora spinosa* (Keokuk, Warsaw, and Spergen). The brachiopods do not help much, for they cannot be definitely identified specifically, and generically they have long ranges. Spirifers predominate and belong to a type that ranges almost throughout the Mississippian, but goes under different names at different horizons. The evidence of such forms cannot be interpreted safely if the material is poor and small in quantity. Little also can be made of the other brachiopod genera such as *Cliothyridina* or even of *Reticularia.* I see no reason to regard this zone as younger than Warsaw and it cannot be older if some of the underlying beds are Warsaw, as they probably are.

Thirteen samples, ranging from 4895 to 4978, with no fossils at all, or with fragments of *Fenestrellina.* As an exception, sample 4962-4963 contains a somewhat doubtful fragment of *Worthenopora spinosa.*

Three samples (4891-4895, 4889-4891, and 4885-4887) represent another fossiliferous zone. The two samples (4891-4895 and 4889-4891) are much alike faunally, though the faunas are small. I recognized only three species, a rhynchonellid (probably *Camarotoechia*), which is without significance, another rhynchonellid, which closely resembles *Moorefieldella eurekensis* (almost diagnostic of the Moorefield fauna), and a *Spirifer,* which closely resembles *S. bifurcatus* (described from the Spergen limestone, but recorded also from the basal Warsaw and related to other species of the same genus.) No species of this type is known in the Moorefield fauna. The sample 4885-4887 contains a different fauna. *Productus ovatus* is very abundant and a small *Spirifer,* similar to Weller's *Brachythyris altonensis,* described from the St. Louis limestone. There are also a few other forms, long ranging or doubtfully identifiable.

Eight samples (4880-4823) that show little or nothing. I may note the occurrence of the same *Brachythyris altonensis?* in sample 4855-4861, and seemingly a conglomerate bed at 4861-4863.

Sample 4812-4814 contains a coral commonly identified as *Lithostrotion proliferum,* which is generally regarded as diagnostic of the St. Louis limestone. This remarkable sample contains parts of numerous corallites, and Mr. Ralph A. Brant of the Atlantic Refining Company of Tulsa has provided me with a photograph showing a cross section of one of them.

The rest of the samples, 16 in number, contain nothing that is diagnostic, or else nothing at all. In thickness this part of the section extends from a depth of 4,810 feet to a depth of 4,087 feet. Noticeable, but not significant, is a sample from 4789-4790, which cuts through a colony of *Syringopora*. It also contains a terebratuloid, which may well be a small specimen of *Girtyella indianensis*. That species was described from the Ste. Genevieve limestone and if the identification is correct it carries a suggestion that the sample is of that age. Mention may also be made of a poorly preserved *Euomphalus* in light-colored limestone at a depth of 4,192 to 4,194 feet.

In summary: The lowest zone contains a fauna that with reasonable probability is Warsaw in age. Some distance above this zone (4812-4814) occurs a fauna that on generally accepted evidence would be St. Louis. There is some evidence that some of the beds below 4,814 feet are also St. Louis. It is a fair assumption that beds of Spergen age are present in the core between the Warsaw and the St. Louis, but there is no specific evidence of the fact. The presence of samples of Pennsylvanian age referred to this part of the core is a disturbing factor in the evidence, even granting that the reference was due to carelessness. There is some evidence also that beds of Ste. Genevieve age are present above the St. Louis, but there is nothing in the paleontologic evidence to establish boundaries between the Warsaw and the Spergen, between the Spergen and the St. Louis, or between the St. Louis and Ste. Genevieve.

WELL OF THE ATLANTIC OIL PRODUCTION COMPANY

No. 1-B Mark, sec. 14, T 20 S., R. 33 W., Scott county

Only two samples were received from this well. One of them marked at depth 4633-4649 is an oil-soaked oölite. The sample of oölite was very small and the fauna obtained from it was also small. The forms recovered are fragmentary or come under the head of microfossils. A complete list is as follows: *Triplophyllum?* sp., *Fenestrellina* sp., *Rhombopora* sp., *Sulcoretepora lineata*, *Aclisina?* sp., small indeterminable gastropods. In addition to the foregoing this collection yielded the following ostracodes identified by P. V. Roundy: *Paraparchites carbonarius?*, *Bairdia permagna*, *Amphissites* sp.

The general facies of this fauna recalls that of the Spergen limestone, although the Ste. Genevieve in places contains a fauna reminiscent of the Spergen. Mr. Roundy, as I recall, was inclined to interpret the ostracodes as indicating Spergen, but I think that the faunal evidence is indecisive. If the horizon of this fauna is above the St. Louis as determined by "*Lithostrotion proliferum*" in Atlantic No. 1-A Mark, the age is necessarily Ste. Genevieve or at least not Spergen. A conclusion on this head would rest with the stratigraphic evidence.

Wallace Lee has made an annotation on a preliminary draft submitted to him that the field geologists thought they had Ste. Genevieve in an oölitic oil zone at the top of the Mississippian in Mark 1-B, 3 miles north of Mark 1-A. The identification was based on a fossil tentatively referred to *Platycrinites huntsvillae*. The correct name is *Platycrinites penicillus*, which I mentioned as possibly occurring in samples 5019-5026 of Atlantic No. 1-A Mark. I do not doubt that the evidence in both instances consists of those elliptical stems surrounded by a serrated flange. Both horizons cannot be Ste. Genevieve in age if a St. Louis zone comes between them and there is some support (*Girtyella indianensis*) for the Ste. Genevieve age of the upper zone in Mark 1-B if above the *Lithostro-*

tion bed of Mark 1-A, though my well core did not contain *P. penicillus.*

The second sample (depth 4590-4606) contained no fossils. It was a very fine sandstone, olive or brown in color with black patches.

Well of Alma Oil Company and Robert B. McNeeley

No. 1 Watchorn, sec. 13, T. 15 S., R. 33 W., Logan county (well No. 2, cross section F-F', pl. 7)

Core 4631½-4632. *Fenestrellina, Orthotetes, Paraparchites* and indeterminata. Age not indicated.

Well of Watchorn Oil and Gas Company

No. 2 Morrison, sec. 20, T. 32 S., R. 21 W., Clark county (well No. 7a, cross section F-F', pl. 7)

The five samples 6480-6464 (6473-6480 bottom of core, 6473-6480 middle of core, 6473-6480 top of core, 6464-6470 bottom of core, 6464-6470 middle of core, 6464-6470 top of core) contain nothing that is significant and very little at all. A few crinoid stems, fragments of *Fenestrellina,* and a *Sulcoretepora.*

The sample 6462-6464 contains *Fusulina* and is of Pennsylvanian age. In the conversation between Mr. Lee and me concerning this sample, Mr. Lee said that it was almost certainly misplaced. I would think the same, as there are no other Pennsylvanian samples in the entire core.

The next 13 samples, ranging from 6293 to 6114 (6291-6293 with intermediate samples to 6114-6119), contain no fossils so far as ascertained.

Core 6051-6065 (samples 1-5) contain fossils in sample 1, which is the top, and in samples 2 and 5, as follows: *Worthenopora spinosa,* fragments of a *Spirifer* related to *S. keokuk* and *S. washingtonensis,* a finely costate *Spirifer* (fragment) possibly *S. lateralis,* and *Rhipidomella* aff. *R. dubia.* The fossils in these samples are fragmentary and poorly preserved. From the very small fauna the geologic age might be as old as Keokuk, but it is more probably Warsaw, and later ages are not precluded.

Core 6004-6051 (samples 1-4) contains nothing worth mentioning except sample 4 (the bottom one), which agrees with the foregoing.

Core 5976-6004 (samples 1-7) all except sample 1 (top) are fossiliferous. Fossils are fairly abundant in 4, 5, and 6. *Worthenopora spinosa* (Keokuk, Warsaw, Spergen) is somewhat abundant as are pieces of fenestrellinid fronds. Among the brachiopods, fragments of *Spirifer*, of the *keokuk-washingtonensis-pellensis* group. Fragments of other brachiopods (*Productus, Dielasma?, Reticularia,* and *Eumetria verneuiliana?*). Nothing significant except the *Worthenopora,* and nothing can safely be said about the geologic age except that the fauna is not older than Keokuk and not younger than Spergen.

Core 5947-5976 (samples 1-4). Fossils few and fragmentary. *Worthenopora spinosa* (Keokuk to Spergen) occurs in all except sample 4. In addition fragments of *Fenestrellina* and fragments of brachiopods, which cannot be safely identified generically, and even generically would have little weight as evidence. A small rhynchonellid is abundant in sample 3.

Core 5932-5947 (samples 1-4). Very much like core 5976-6004, but not so good. *Worthenopora spinosa* is found in sample 2. *Eumetria verneuiliana* in sample 3, which makes the best showing. Fragments of *Spirifer* and other brachiopods in other lots. The geologic age might be Keokuk, Warsaw, or Spergen; there is no definite evidence for one rather than another.

Core 5917-5932 (samples 1-3). The fauna is essentially the same as in the foregoing. *Worthenopora spinosa* occurs in samples 1 and 2.

Core 5885-5917 (samples 1-5). No fossils in any but sample 5, which contains *Composita* aff. *C. trinuclea* and a few fragments. No evidence that can be estimated.

Core 5871-5885 (samples 1-4). Fossils scanty and fragmentary, no evidence except *Hemitrypa* (Keokuk to St. Louis), in sample 1, and *Worthenopora spinosa* in sample 2.

Core 5850-5871 (samples 1-4). Scantily fossiliferous. Fragments of *Fenestrellina, Spirifer,* and a few other forms. No evidence except what would comport with Keokuk or later.

Core 5833-5850 (samples 1-5). Fossils few and fragmentary, some identifiable generically, some not even that. Nothing distinctive, though *Camarotoechia mutata?* in sample 1, if it is that species, suggests a Spergen age.

Core 5813-5833 (5 samples). All fossils poor and fragmentary. Some forms not determinable between 2 or more genera. Other forms that can be determined generically cannot be determined specifically. No evidence except that the age seems to be Keokuk or younger.

Core 5793-5802 (5 samples). Fossils scanty and poor. *Spirifer* (not determinable). *Eumetria verneuiliana* (long range).

Core 5788-5793 (4 samples). Two samples lack fossils, the others contain but few and those fragmentary and mostly indeterminable. No appreciable evidence.

Core 5758-5776. We come here to a fauna that is quite different from anything yet seen. The rock is a whitish oölite and obviously very fossiliferous, though the material recovered comprises mostly small or fragmentary specimens. The fauna and lithology somewhat pointedly suggest Spergen though very few of the specimens can be definitely identified. The following will show the general character of the fauna present: Fragments of a small, finely plicated rhynchonellid like *Camarotoechia mutata,* fragments of a small *Spirifer,* which might be *S. bifurcatus, Composita* sp., *Athyris densa?, Eumetria verneuiliana* (fragments), *Nucula* sp. (fragment), *Sphenotus* sp. (fragment) and *Myalina* sp.

Core 5745-5758 (3 samples). Only one sample (at 5748 ±) contains any fossils and these are very few and lack significance.

Core 5736-5745 (4 samples). Three of these are wholly negligible. The one at 5745 contains a variety of forms. Besides the ever-present *Fenestrellina* and *Polypora* I find fragments of *Productus* representing one or possibly two species; fragments of two species of *Spirifer,* one finely and the other coarsely plicate (*S. tenuicostus*? and *S. bifurcatus*?); a *Reticularia* (fragment); a *Cliothyridina* (*C. hirsuta*?); and *Girtyella.* In addition to these more or less definite fossils, there are two objects that I interpret as sections across a species of *Pentremites.* None of these forms can be satisfactorily identified, but the general make-up of the fauna suggests an age at least as young as Spergen. As this fauna occurs only about 30 feet above the other fauna that seemed to have Spergen affinities, it seems safe to assign both to that age, the evidence of one reinforcing that of the other. As a precaution, however, it will be well to remember that the faunas contain some types that are alien to the typical Spergen fauna (e. g. *Myalina* sp. and *Sphenotus* sp.).

In summary: Except for one outstanding zone, there is little in any of the samples from this well core that is distinctive paleontologically. The outstanding zone, of course, is the one represented by core 5758-5776. If this is Spergen some of the beds above and below are probably also of that age. The higher sample (core 5736-5745) has already been mentioned. Some of the lower samples, though indefinite, are suggestive of the Spergen fauna showing sporadically a small rhynchonellid resembling *Camarotoechia mutata* or a *Spirifer* probably belonging to *S. bifurcatus* (Spergen and basal Warsaw) as in core 5813-5833. It may be fairly inferred that some of the samples from lower zones are older than Spergen and, unless the Warsaw is absent, that they are of Warsaw age. The fauna of core 6051-6055 is especially suggestive of Warsaw. The evidence furnished by the samples below this level would permit them to be either Warsaw or Keokuk and whether any are of Keokuk age is a question that cannot be decided by the paleontologic evidence present. The evidence is noncommittal except that if some of the lower faunas are of Warsaw age, even the lowest are not differentiated from them in any way, though this may be due to the fact that the evidence obtained from the lowest samples is so scanty and indecisive.

Well of Kessler and Thier, Inc.

No. 1 Wolfje, sec. 17, T. 33 S., R. 6 W., Harper county

Core 4425-4437.* (First foot of recovery) sponge spicules; (second foot) crinoid stems; (third foot) crinoid stems, abundant, fragments of unidentified bryozoa, fragments of shells (*Rhynchopora?* and *Platyceras?*); (fourth foot) crinoid stems and fragment of a brachiopod; (fifth foot) abundant crinoid stems; (sixth foot) nothing recognizable; (seventh foot) sponge spicules?; (eighth foot) several fragments of brachiopods (*Dielasma?*) and a small crushed brachiopod, not determinable; (ninth foot) fragment of a punctate brachiopod and a small crushed brachiopod of uncertain affinities; (tenth foot) nothing recognizable; (eleventh foot) nothing determinable.

Core 4465-4468. (Upper foot of recovery) abundant crinoid stems and fragments of some brachiopod shell; (second foot) numerous crinoid stems, numerous fragments of *Fenestrellina, Polypora* sp., *Rhombopora?* sp., *Streblotrypa?* sp.; (third foot) numerous crinoid stems, small fragment of *Fenestrellina,* and *Chonetes* aff. *C. illinoisensis.*

These samples offer no evidence whatever as to geologic age. The dearth of any fossils at all, compared with their abundance in the other well cores is, however, striking and probably significant.

* These cores are lithologically and stratigraphically from the Cowley formation. Wallace Lee.

Wells of Magnolia Petroleum Company

Robbins lease, T. 28 S., R. 1 E., Sedgwick county

Robbins No. 4

Core 3082-3086. *Worthenopora spinosa* and other bryozoa, none of which have been determined, *Productus ovatus, Echinoconchus biseriatus* (abundant), and *Productus* indet.

Core 3079-3082. *Worthenopora spinosa, Fenestrellina,* and undetermined bryozoa, an undetermined rhynchonellid, and fragments of *Productus* and *Spirifer*. Geologic age probably Warsaw, nothing very definite and nothing distinctly Keokuk. It might, on the other hand, be post-Warsaw.

Robbins No. 5

Core 3095-3102. Fragments of *Fenestrellina* and *Rhombopora.* No suggestions as to geologic age.

Robbins No. 6

Depth not given. Fossils abundant. *Worthenopora spinosa* and other bryozoa (*Sulcoretepora, Rhombopora,* etc.), *Productus ovatus, Productus setiger, Echinoconchus biseriatus* (abundant), fragments of other brachiopods (*Productus, Spirifer, Reticularia,* etc.). Apparently same zone as Robbins No. 4 (depth, 3082-3086).

Robbins No. 7

Core 3080-3087. Depth, 3087 (pieces 1, 2, and 3). Fragments of brachiopods; (piece 4) *Productus setiger?*; (piece 5) *Worthenopora spinosa, Sulcoretepora* sp., *Fenestrellina* sp., *Productus setiger?, Echinoconchus biseriatus, Reticularia* sp.; (piece 6) *Worthenopora spinosa, Orthotetes?* sp., *Productus setiger, Pustula ozora?, Productus* sp., *Reticularia* sp.

Core 3087-3092 (probably 3087 to 3088). Fossils abundant. Many fragments of bryozoa including *Worthenopora spinosa,* unidentified species of *Fenestrellina, Rhombopora, Sulcoretepora,* and other genera. Among the brachiopods are *Productus setiger?, Echinoconchus biseriatus,* fragments of other Producti, *Pustula* sp., and *Brachythyris altonensis?*.

These faunas seem to be mutually related, and although they come from different wells, I judge that the cores do not represent any considerable thickness of rock. Fossils are abundant, but the fauna is small and singularly lacking in forms that would determine its geologic age. An age determination is also handicapped by lack of information about the faunas that come in below and above this one. On the whole I am inclined to regard this fauna as post-Warsaw. One item worth considering is the small *Spirifer* resembling *Brachythyris altonensis,* a species that Weller described from the St. Louis limestone. The same species seemingly occurs in the Atlantic No. 1-A Mark in beds not far below a fauna that seems definitely referable to the St. Louis. On this very slender evidence the present fauna might be Spergen if not St. Louis and at least there is nothing in the paleontologic evidence that would refute such an interpretation of its age. The cores from wells No. 4 to No. 7 are from white noncherty limestone directly above porous oil-bearing dolomite believed to be of Cowley age. According to this evidence the Cowley therefore might be Warsaw or even Spergen.

Well of J. E. Trigg et al (Bates)

No. 1 Nimock, sec. 16, T. 16 S., R. 28 W., Lane county (well No. 24, cross section F-F', pl. 7)

Core 4517-4527. Bryozoan fragments.

Core 4516. *Sulcoretepora* sp., *Hemitrypa* sp., *Pustula* aff. *P. indianensis*; geologic age, Keokuk or younger.

Core 4515. *Endothyra* and other foraminifera, also *Fenestrellina*; age uncertain, suggestive of Spergen.

Core 4513. No fossils.

Core 4512. *Polypora, Platycrinites* (stem), *Pustula* n. sp.; evidence as to geologic age indeterminate.

Core 4505. Fragments of *Spirifer.*

Core 4504. *Fenestrellina,* obscure.

Core 4500. *Fenestrellina, Dichotrypa?, Pustula* sp., *Spirifer tenuicostus?, Spirifer* sp. (fragment), *Brachythyris subcardiiformis, Cliothyridina* sp.; probable age, Spergen.

Core 4499. Nothing determinable.

Core 4498. *Fenestrellina, Worthenopora spinosa?, Spirifer* (fragments). If the age of this lot is Spergen, *Worthenopora spinosa* is not out of place, although it is rare except in the Keokuk and Warsaw.

Core 4496. *Worthenopora spinosa.*

Core 4495. *Fenestrellina* and *Sulcoretepora.*

Core 4493. *Fenestrellina* and *Echinoconchus biseriatus?*

Core 4491. Crinoidal limestone.

Core 4489. *Fenestrellina, Sulcoretepora, Productus ovatus, P. ovatus* var. *minor?, Spirifer* sp., *Reticularia?* sp.; geologic age probably Spergen, at least there is no evidence of St. Louis.

Core 4488. *Productus* (fragments), rhynchonellid (indet.), *Spirifer* sp., *Reticularia* sp., *Cliothyridina?* sp. None of these forms is specifically determinable, and in combination they afford no evidence as to geologic age.

In summary: Beginning with 4416, we have only 28 feet included in this core, the median part of which seems with some probability to be Spergen in age, and at least there is no reason to believe that the entire 28 feet is not of the same age, whatever that age may be. There is nothing to indicate that the lowest bed is older (Warsaw) or that the highest beds are younger (St. Louis), although these possibilities are not excluded.

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