SUBSURFACE GEOLOGIC CROSS SECTION FROM SCOTT COUNTY, KANSAS, TO OTERO COUNTY, COLORADO

By

JOHN C. MAHER

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INTRODUCTION

Regional stratigraphic investigations of the subsurface Paleozoic rocks in western Kansas, eastern Colorado, and parts of the adjacent states were begun in the fall of 1943 by the Geological Survey, U. S. Department of the Interior. The results of these investigations are being presented as a series of cross sections published by the State Geological Survey of Kansas. The location of this cross section and those published previously are shown on the index map. This cross section extends from the Atlantic Refining Company No. 1-A Mark well in the Cen. SE¼ SE¼ sec. 28, T. 20 S., R. 33 W., Scott County, Kansas, to the Carter Oil Company No. 1 Stratigraphic test in the SE cor. sec. 30, T. 26 S., R. 57 W., Otero County, Colorado. It includes eight wells, numbered from west to east, as shown on the index map.

This investigation has been aided by the cooperation of many geologists and oil companies. The well cuttings on which the work is based were generously loaned by the oil companies and the State Geological Survey of Kansas. L. G. Henbest identified the microfossils in the cuttings and gave valuable assistance in correlating the Pennsylvanian rocks. The writer is indebted to H. D. Miser and N. W. Bass for their careful review of the cross section and text, and to H. R. Castor for the drafting.

METHODS OF INVESTIGATION

The subsurface stratigraphy of the central Kansas oil fields has been well established through years of work by petroleum geologists who have examined samples from thousands of wells and outcrops. Many of the smaller units of the Permian and Pennsylvanian Systems described on the surface in central and eastern Kansas, and most of the major subdivisions of the Mississippian, Silurian, Devonian, Ordovician, and Cambrian Systems recognized in Missouri, Iowa, and Oklahoma have been identified in the wells, and their terminology is generally agreed upon by Kansas petroleum geologists. These subsurface units have been accepted in this investigation as a basis for extending correlations into western Kansas and eastern Colorado. The correlations were carried westward well by well through detailed microscopic examination of cuttings from selected wells located at intervals of 12 to 48 miles.

The microscopic examination of the cuttings consisted of describing the kind and character of the rocks by their color, hardness, texture (including crystallinity, or size, shape, and degree of sorting and abrasion), mineral composition, bond or cementing material, and the type and characteristics of chert, oölites, casts, microfossils, glauconite, pyrite, calcite, siderite, and sphalerite. The characteristics of some of the rocks are so distinctive that thin key beds may be traced over great distances. These key beds assisted in the recognition of large sequences of less-distinctive or less-persistent strata.

Most of the wells in western Kansas and eastern Colorado have been drilled by rotary methods

which do not permit accurate sampling of the formations penetrated except where cores are procured. Each sample of rotary cuttings contains fragments of many different kinds of rock, most of which have been cut at shallower depth than that at which the sample was collected. Usually only a small portion of the sample represents the rock actually drilled at the depth marked on the sample container. Therefore the logging of such samples consists of describing for a given interval only that type of rock that has not appeared in the samples at shallower depth and which the geologist believes belongs in that interval. Because this involves interpretation, the logs prepared from rotary cuttings are subject to the personal equation of the geologist, and complete agreement of different geologists regarding details cannot be expected.

In the preparation of this cross section the sample logs were drawn on a vertical scale of 1 inch equals 100 feet and were reduced to 1 inch equals 200 feet on the published chart. The logs are aligned on sea-level datum and the horizontal scale between wells is 1 inch equals 6 miles. The vertical exaggeration of the section is 158.4 times. This exaggeration permitted the representation of most stratigraphic units but not all the finer details serving to differentiate those units could be shown.

The well elevations used on this section are those reported by the operator at the time each well was drilled. Electric logs of wells 1, 2, 5, 6, and 7 were plotted on the section to illustrate the close correspondence between the electric logs and the sample logs and to show the relation of the distinctive markers on the electric logs to the geologic formations identified in the samples. Most of the sample logs were prepared before the electric logs were available and no adjustments were made. Comparison of the two types of logs reveals that generally the recorded depth of a given bed is a few feet less on the electric log than on the sample log. This difference is explained by the fact that the sampling at the surface lags behind the actual cutting of the given bed at depth. Depth corrections or adjustments can be made on the sample log if the electric log is at hand while the samples are being examined.

STRATIGRAPHY

The rocks that crop out in the region traversed by this cross section are Tertiary or Upper Cretaceous in age except in the steep-sided canyons along Purgatoire River in Colorado where rocks of Lower Cretaceous and Jurassic age are exposed. These rocks are underlain by Triassic (?), Permian, Pennsylvanian, Mississippian, Ordovician, and Cambrian sedimentary rocks resting on pre-Cambrian igneous and metamorphic rocks. The thickness of the sedimentary rocks ranges from 5,500 to 6,500 feet throughout the region, except in the westernmost part near well 1, where the thickness is 4,000 feet or less. Only the Paleozoic rocks, ranging from 3,049 to 5,659 feet in thickness, were studied in this investigation; they are described herein beginning with the youngest.

PERMIAN SYSTEM

The top of the Permian System, marked by a major unconformity, lies at depths ranging from 635 feet in well 4 to 1,115 feet in well 1. The thickness of Permian rocks ranges from 2,508 feet in well 5 to 1,267 feet in well 1. These rocks consist of marine beds of limestone, dolomite, and shale overlain by thick continental deposits of anhydrite, salt, red shale, and sandstone. The continental facies becomes progressively thicker westward, and constitutes most of the Permian in wells 1 and 2.

GUADALUPIAN SERIES

The Guadalupian Series, which ranges in thickness from 267 feet in well 1 to 453 feet in well 3, includes the Taloga formation, the Day Creek dolomite, and the Whitehorse sandstone. The Taloga formation ranges in thickness from 95 to 220 feet in wells 1 to 6 inclusive; it there consists of red sandy shale, fine red silty sandstone, and thin beds of anhydrite and dolomite. This formation is absent in wells 7 and 8, perhaps as a result of

post-Permian erosion. The Day Creek dolomite, 16 to 41 feet thick, is present in all wells on this section, but differs considerably in lithic character in the eight wells. In wells 7 and 8, it consists of two brown granular dolomite beds separated by red shale; in well 6, it probably is represented by thin-bedded anhydrite and red shale; in wells 1, 3, 4, and 5, it consists of a massive bed of cream-white finely crystalline to dense anhydrite; and in well 2, it consists of two beds of pink to red dense dolomite separated by a bed of red and white mottled finely granular anhydrite. The Whitehorse sandstone consists principally of thick beds of red shale, red sandy shale, and red sandstone, and a few thin beds of buff dolomite. The red shale and red sandy shale beds in the lower part of the Whitehorse cannot be readily distinguished from those of the underlying Dog Creek shale where the latter are not anhydrite. For this reason, the lower part of the sequence herein assigned to the Whitehorse in wells 1 and 2 may include the Dog Creek shale. The Whitehorse sandstone exhibits a gradual eastward increase in thickness from 130 feet in well 1 to 326 feet in well 7.

The upper part of the sequence of beds herein assigned to the Guadalupian Series is exposed in the canyons of Purgatoire River about 15 miles southeast of well 1. On the basis of the similar lithologic character and stratigraphic position of the exposed beds and the Lykins formation of the northern Front Range, many geologists have tentatively assigned the exposed beds to the Lykins formation. The Lykins formation is classed as being of Triassic (?) and probably Permian age. Nevertheless, the examination of cuttings from wells on this section suggests that the Guadalupian Series, the underlying Blaine formation, and possibly a few feet of red shale beneath the Blaine are probably equivalent to the Lykins formation of Purgatoire River Valley, and have been so correlated in well 1 on this section.

LEONARDIAN SERIES

Nippewalla group.—The Nippewalla group on the outcrop has been subdivided into the following six formations: Dog Creek shale, Blaine formation, Flowerpot shale, Cedar Hills sandstone, Salt Plain formation, and Harper sandstone. Not all of these formations can be readily identified in the subsurface, although their differentiation is suggested by the lithologic sequence in a few wells. The Nippewalla group ranges in thickness from 360 feet in well 1 in Otero County, Colorado, to 797 feet in well 5 in Hamilton County, Kansas. Conformable relations between the overlying rocks and this group are indicated on the section in accordance with the usage of the State Geological Survey of Kansas. Such a relationship is controversial and no decisive evidence either for or against conformable relations resulted from this investigation. The Dog Creek shale and Blaine formation consist of an upper bed of red shale and white finely granular anhydrite and a lower bed of white and pink finely granular to dense anhydrite and some salt. In well 2, this lower bed consists of white to cream-colored coarsely crystalline to dense dolomite containing some quartz crystals. The total thickness of the Dog Creek shale and Blaine formation ranges from 46 feet in well 1 to 208 feet in well 5. Norton regarded these two formations as "a single gypsiferous formation both at the surface and underground, in Kansas, either one thickening at the expense of the other depending on the presence or prior removal of anhydrite or gypsum."[1] I have been unable to differentiate satisfactorily the formations in all wells and therefore have followed Norton and classed them as a single unit, termed Dog Creek shale and Blaine formation. This unit is generally called the "Blaine gypsum" by oil geologists. The evaporite facies of the Dog Creek shale that is present in the eastern wells is absent, however, in wells 1 and 2, where the entire sequence of red shale, red sandy shale, and red sandstone between the Day Creek dolomite and the Blaine formation has been arbitrarily included in the Whitehorse sandstone. In general, the anhydrite beds of the Dog Creek shale and Blaine formation provide a subsurface unit that can be readily identified throughout the region.

The Flowerpot shale, a soft gypsiferous maroon

[1] Norton, G. H., Permian red beds of Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 23, no. 12. p. 1801, 1939.

shale, is distinguishable from the beds underlying it only in wells 7 and 8, where it is about 45 feet thick. The Cedar Hills sandstone, Salt Plain formation, and Harper sandstone which make up the lower part of the Nippewalla group are not differentiated. They are included in an irregular sequence, 330 to 640 feet thick, of red sandy shale and sandstone containing lenses of salt and anhydrite and thin beds of dolomite. A sandstone composed of orange coarse round quartz grains is present in the middle of this sequence in wells 3, 4, 5, and 6. Sandstones of this character commonly are referred to as the "Cedar Hills sandstone," but similar sandstones are present in other parts of the Permian System in eastern Colorado. The considerable thickness of salt in wells 7 and 8 may represent a part of the Salt Plain formation.

In well 1, the sandy sequence herein assigned to the Cedar Hills sandstone, Salt Plain formation, and Harper sandstone, undifferentiated, may be equivalent to at least a part of the Lyons sandstone of the Front Range. Beneath this sequence in well 1 is a 660-foot succession of alternating thin beds of shale, sandstone, and dolomite which are Permian in age in the writer's opinion. These beds are generally regarded as the upper part of the Fountain formation and therefore are shown as such on this section. If this correlation is correct, the age of the Fountain formation in this area must be in part Permian and in part Pennsylvanian.

Sumner group—The Sumner group, which may be separated from the Nippewalla group by a minor unconformity, includes the Stone Corral dolomite, the Ninnescah shale, and the Wellington formation. In the four easternmost wells, the group ranges from 537 to 636 feet in thickness; in the four westernmost wells, the group could not be differentiated from the underlying Chase group.

The Stone Corral dolomite ranges in thickness from 33 feet in well 3 to 80 feet in well 8. On the outcrop, this formation consists principally of dolomite, but in the subsurface it consists mostly of white to buff granular anhydrite. Beds of pink finely crystalline limestone, buff granular dolomite, and salt are interbedded with the anhydrite in some wells. The Stone Corral dolomite is a good marker bed; it was identified in all wells on the section except 1 and 3 where it is apparently represented by thin-bedded, sandy, and argillaceous beds.

The Ninnescah shale was differentiated from the underlying Wellington formation in wells 4, 5, 6, 7, and 8 where it ranges from 157 to 202 feet in thickness. It consists primarily of thick beds of maroon shale and thin beds of red fine-grained standstone, dolomite, anhydrite, and salt. An unconformity may be present between the Ninnescah shale and the Wellington formation, although the evidence disclosed in this investigation is inconclusive.

The Wellington formation grades westward from a 288-foot sequence of thick anhydrite and salt beds in well 8 to a 340-foot succession of thin beds of maroon shale, fine-grained sandstone, dolomite, salt, and anhydrite in well 5. West of well 5, the Wellington seems to consist predominantly of maroon shale and fine-grained sandstone and there could not be accurately delimited.

WOLFCAMPIAN SERIES

Chase group.—The Chase group, which includes about 300 to 350 feet of beds between the top of the Herington limestone member of the Nolans limestone and the base of the Wreford limestone, can be traced westward as a unit as far as well 6. Individual formations of the group are recognizable somewhat farther west than well 6. The principal limestone units of the Chase group are the Nolans, Winfield, Barneston, and Wreford limestones.

The Nolans limestone, which includes the Herington limestone member, consists chiefly of buff finely porous and finely granular dolomite interbedded with maroon sandy shale. West of well 5, it grades into maroon shale and red fine-grained sandstone.

The Winfield limestone is composed of gray-buff fossiliferous finely granular dolomite, gray-buff mottled noncherty dolomitic limestone, and gray shale. It was identified in wells 5 to 8.

The Barneston limestone contains two thick limestone members—the Fort Riley and Florence limestones—separated by a bed of gray and red

shale. The Fort Riley limestone member ranges from about 35 to 80 feet in thickness and consists wholly of gray mottled finely granular dolomitic limestone in wells 5 to 8. In well 4, the upper part of the member consists of limestone and the lower part consists mainly of anhydrite, salt, and red shale. The Fort Riley cannot be traced with certainty west of well 4. The Florence limestone in wells 7 and 8 consists of gray to cream-colored finely crystalline to finely granular dolomitic limestone from 55 to 70 feet thick; in well 6, the dolomitic limestone is thinner than in wells 7 and 8 and beds of anhydrite, salt, and shale are present at the base of the member. Much cream-colored dense chert and some gray to black fossiliferous chert is present in the Florence limestone in well 8. The Florence limestone grades into red shale, anhydrite, and salt beds west of well 6.

The Wreford limestone is identifiable in wells 6, 7, and 8. In these wells, it is predominantly cream-colored finely crystalline limestone about 30 to 40 feet thick. Tan dense chert and gray dense spicular chert are present in the limestone in well 8.

Council Grove group.—The top of the Council Grove group, marked by an unconformity, is recognizable as far west as well 6 in Kearny County, Kansas; the base of the group can be traced to well 3 in Prowers County, Colorado. The thickness of the group ranges from 235 to 366 feet in wells 6 to 8 where it includes many thick beds of shale, two massive limestone units—the Grenola and Foraker limestones—and several thin limestone beds that could not be correlated from well to well. The Grenola limestone near the middle of the group includes the Neva limestone member, a cream-colored fossiliferous limestone that is finely oölicastic and slightly cherty in some wells, and the Burr limestone member, a gray algal limestone that contains cream-colored to gray-black chert. The Foraker limestone at the base of the Council Grove group is characterized by massive gray limestone beds containing gray to black dense chert, fusulinids, crinoids, and many spines except in well 3 where it consists chiefly of buff sandy dolomite containing pink-tinged chert. The thickness of the Foraker ranges from 78 to 97 feet in wells 3 to 8.

Admire group.—The Admire group conformably underlies the Council Grove group and rests uncomformably on rocks of the Pennsylvanian System. The group becomes progressively thicker and more clastic westward. In well 8 at the eastern end of the section, the Admire group is only 33 feet thick and consists of thin beds of gray marly limestone, gray shale, and gray fine-grained sandstone. In well 3, it is 252 feet thick and consists chiefly of thick beds of maroon shale and red fine-grained sandstone that contain thin layers of buff dolomite and cream-colored sandy limestone. A 22-foot bed of coarse-grained calcareous sandstone that contains weathered fragments of limestone and chert is present at the base of the group in well 3. West of well 3, the Admire group loses its identity in a thick sequence of continental red beds.

PENNSYLVANIAN SYSTEM

The Pennsylvanian rocks along the line of this section exhibit a marked change of facies from a dominantly marine limestone and shale sequence in the eastern wells to a continental arkosic sandstone and shale sequence in the western wells. The thickness of the system is 1,423 feet in well 8 in Scott County, Kansas, 2,554 feet in well 2 in Bent County, Colorado, and 1,604 feet in well 1 in Otero County, Colorado. Only rocks of the Virgilian, Missourian, Desmoinesian, and Morrowan Series are present in wells 6, 7, and 8. Rocks of the Atokan Series intervene between the Desmoinesian and Morrowan Series west of well 6; the Atokan Series is thickest in well 2 and accounts for the great thickness of the Pennsylvanian System there. In well 1 at the west end of the section, the seeming absence of fossils in the well cuttings, and the arkosic character of the Pennsylvanian rocks prevent even tentative identification of series and formations younger than the Atokan Series; it seems likely, however, that the Desmoinesian and Missourian Series may be present there.

VIRGILIAN SERIES

Wabaunsee group.—The Wabaunsee group is bounded by unconformities at the top and base.

The group was traced westward from well 8 to well 2. In well 8, it consists of a 107-foot sequence of gray algal limestone, buff finely crystalline slightly oölicastic limestone, and gray calcareous shale; in well 2, it consists chiefly of red calcareous shale containing thin layers of red fine-grained sandstone and pink sandy limestone, 248 feet thick.

Shawnee group.—The Shawnee group lies unconformably below the Wabaunsee group; it ranges from 260 to 430 feet in thickness in wells 2 to 8. In the eastern wells, it consists chiefly of beds of buff finely crystalline cherty limestone and gray fossiliferous marly limestone separated by thin beds of black, gray, and maroon shale. Fusulinids are common in the limestones and are found embedded in the chert of the lower beds. The content of shale, mostly maroon in color, is larger in the western wells than in the eastern wells; it exceeds 50 percent of the total sequence in well 2. The thin, oölitic, and sandy limestones in well 2 are suggestive of a shoreward facies of the thick dense limestones that are present farther east. The correlation of beds in well 2 with beds in well 1 is not apparent and no fusulinids of Virgilian age were found in well 1. These facts suggest the possibility that neither Wabaunsee nor Shawnee beds are present in well 1.

Douglas group (Virgilian) and Pedee group (Missourian), undifferentiated.—Either one or both the Douglas and Pedee groups may be represented by the irregular sequence of gray and maroon shale, thin-bedded limestone, and calcareous sandstone that intervenes between the Shawnee and Lansing groups in wells 2 to 8. This sequence, ranging in thickness from 22 to 68 feet, rests unconformably on the Lansing group and is a valuable aid in determining the top of that group.

MISSOURIAN SERIES

Lansing, Kansas City, and Bronson groups, undifferentiated.—The Lansing, Kansas City, and Bronson groups are commonly considered as a unit by subsurface geologists in Kansas because of the impracticability of distinguishing individual groups or formations. This unit consists chiefly of beds of cream-colored to gray-buff cherty fossiliferous finely crystalline and oölitic limestones separated by thin beds of gray, black, and maroon shale westward from well 8 to well 3. Beyond well 3, the sequence grades into thick beds of red calcareous shale, and thin beds of porous sandy limestone and calcareous sandstone. It seems likely that this unit is equivalent to a part of the Fountain formation in well 1 but no fossil evidence was obtained and the lithologic similarities of beds in wells 1 and 2 are not sufficient for correlation. The unit exhibits a general thinning westward; its thickness is 477 feet in well 8 and only 328 feet in well 2.

DESMOINESIAN SERIES

The Desmoinesian Series consists principally of dark-gray limestone and shale in the eastern wells. This marine facies grades westward into red limy shale and sandstone that cannot be differentiated from younger beds of the Fountain formation in well 1. The thickness of the series in wells 2 to 8 ranges from 315 to 438 feet, being thickest near the middle of the area traversed by the cross section. In most wells the top of the series is marked by red shale and sandstone containing fragments of limestone and chert. The basal bed of the series is the oil-bearing "Patterson sand" in well 6, and an arkosic sandstone in wells 1 and 2. The lower boundary of the series is not distinct in wells 3 and 5, but it has been tentatively drawn at the base of a bed of calcareous sandstone. In wells 4, 7, and 8, this boundary has been tentatively drawn at the top of a green and black shale bed.

The Desmoinesian Series is divided into the Marmaton and the Cherokee groups; these groups were differentiated in wells 4 to 8 where the Fort Scott limestone, the basal formation of the Marmaton group, was identified. The Marmaton group, whose thickness is 145 to 200 feet in wells 4 to 8, consists of gray to gray-buff finely crystalline to dense limestone, and gray, green, red, and black shale. Many of the limestones contain brachiopods, fusulinids, oölites, and gray to black chert. The coral *Chaetetes* is abundant in the lower half of the group. The Fort Scott limestone con-

tains many brachiopods, fusulinids, and corals; it consists of gray to buff dense oölitic and cherty limestone and hard black fissile shale. The beds of dark limestone and shale of the Marmaton group grade westward from well 4 into red limy shale and red sandstone.

The Cherokee shale in wells 4 to 8 is characterized by beds of gray to black shale and dark-gray to dark-buff dense limestone. Some of the limestones are oölicastic and fossiliferous and contain gray to black chert. The Cherokee shale is progressively thicker westward, ranging in thickness from 135 feet in well 8 to 293 feet in well 4. Like the Marmaton beds, the dark shale and limestone beds of the Cherokee grade westward from well 4 into red limy shale and red sandstone.

ATOKAN SERIES

Rocks equivalent to the Atoka formation of Oklahoma are present in wells 1 to 5 where they range in thickness from 406 to 860 feet. These rocks are treated as a series in this report, following the suggestion of Spivey and Roberts[2] that the name "Atoka" be elevated to series rank. In the eastern wells, the Atokan rocks are characterized by alternating beds of brown to black dense cherty limestone and black shale in the upper part, and by thick beds of hard black shale and thin beds of gray to black limestone in the lower part. Some of the upper limestones are fossiliferous and glauconitic. A thin bed of anhydrite in the lower part of the series is a valuable key bed for correlating the Atokan beds in wells 2, 3, and 5. A bed of anhydrite in a similar stratigraphic position was noted in wells in Kiowa and Cheyenne Counties, Colorado, north of the line of this cross section. In well 2, the Atokan rocks are very thick and show the transition of the dark limestone and shale facies of the eastern wells into the arkosic facies of a part of the Fountain formation of well 1. The boundaries of the Atokan Series shown in wells 1 and 2 were drawn tentatively where unconformities are indicated by the samples; the few fusulinids found in the well samples were not sufficient to mark the top and bottom of the series.

MORROWAN SERIES

A sequence of interbedded black shale, green shale, cream-colored glauconitic and crinoidal limestone, and white calcareous sandstone which underlies the Atokan Series and overlies unconformably the Mississippian System in well 6 has been referred by Thompson[3] to the Morrowan Series on the basis of its fusulinid fauna. This sequence of Morrowan beds has been traced eastward to well 8, where it is only 120 feet thick, and westward to well 1, where it is about 550 feet thick. The rocks seem to be wholly marine in character as far west as well 3. In well 2, beds of arkosic sandstone and red shale that are probably of terrestrial origin are interbedded with the marine beds, and in well 1, such beds predominate. The Morrowan Series in well 1 consists of an upper unit of coarse-grained arkose and red limy shale, about 290 feet thick, a middle unit of green shale, black shale, and gray-buff finely crystalline limestone, about 90 feet thick, and a lower unit of interbedded red shale and arkose grading downward into coarse-grained basal arkose, about 170 feet thick. Several thin red sandy limestones in the upper unit contain foraminifera that were identified by Henbest as *Millerella sp.*, *Tetrataxis sp.*, and *Tolypammina* (?) *sp.* The limestones in the middle unit contain many specimens of *Millerella sp.* and a few specimens of *Tetrataxis millsapensis* (?). The lower unit is seemingly nonfossiliferous. The middle and lower units are generally considered to be equivalent to the Glen Eyrie shale of the Front Range, which Henbest[4] classified as being of Morrowan age on the basis of its fusulinid fauna. Accordingly, if only the middle and lower units in well 1 represent the Glen Eyrie shale, the upper unit must be part of the Fountain formation in this well. It is noteworthy,

[2] Spivey, R. C., and Roberts, T. G., Lower Pennsylvanian terminology in central Texas: Am. Assoc. Petroleum Geologists Bull., vol. 30, no. 2, pp. 185-186, 1946.

[3] Thompson, M. L., Pennsylvanian Morrowan rocks and fusulinids of Kansas: Kansas Geol. Survey, Bull. 52, pt. 7, 1944.

[4] Henbest, L. G., Stratigraphy of the Pennsylvanian, in the west half of Colorado and in adjacent parts of New Mexico and Utah: (Abstract) Program, 31st Ann. Meeting, Am. Assoc. Petroleum Geologists, p. 23, April 1946.

however, that the upper unit is included tentatively in the Morrowan Series primarily on the basis of a few specimens of *Millerella sp.* that were found in thin sandy limestones.

MISSISSIPPIAN SYSTEM

The Mississippian rocks along the line of this section consist chiefly of beds of light-gray to buff limestone and dolomite, some of which are cherty and others oölitic. The classification of these beds into five lithologic units follows that used by Lee[5] for the most part. A major angular unconformity is present at the top of the Mississippian sequence, and several minor unconformities separate some of the formations. Rocks of Mississippian age are present in all wells except well 1 in Otero County, Colorado. Their thickness is less than 380 feet west of well 2 in Bent County, Colorado; about 730 feet in well 5 in Hamilton County, Kansas; and about 600 feet in well 8 in Scott County, Kansas.

MERAMECIAN SERIES

Ste. Genevieve limestone.—The Ste. Genevieve limestone, the uppermost Meramecian formation, is present in wells 2 to 7 and a thin remnant of it may be present in well 8 although the fragments found in the samples seem to be erosional debris on top of the St. Louis limestone. The Ste. Genevieve limestone ranges in thickness from 18 feet in well 2 to 175 feet in well 4. It consists of cream-white to buff finely crystalline, finely oölitic, and noncherty sandy limestone containing some glauconite.

St. Louis limestone.—The St. Louis limestone is present in all wells of this section except well 1. It ranges in thickness from 120 feet in well 3 to 240 feet in well 5; well 7 penetrated only the upper 57 feet of the formation. The St. Louis consists of gray-buff coarsely crystalline to dense limestone in most places; it contains a 10-foot bed of dolomitic limestone near the middle in well 6 and a 20-foot bed of dolomite about 30 feet above its base in well 2. Dolomite beds are present in the lower part of the St. Louis in well 3 but the powdered condition of the samples from this well, which was drilled with cable tools, precludes a determination of their true distribution within the sequence. Beds of oölitic and slightly cherty limestone and dolomite are common near the top and bottom of the St. Louis; the base is generally marked by gray to almost black slightly mottled chert. In contrast to the Ste. Genevieve limestone, the St. Louis contains large oölites and very few sandy limestone beds. Some glauconite and a few brachiopods and crinoids commonly are present near the top of the St. Louis.

Spergen and Warsaw limestones, undifferentiated.—The Spergen and Warsaw limestones were not differentiated because facies changes are present within this sequence in relatively short distances and fossils are rare. The sequence ranges in thickness from 105 feet in well 4 to 150 feet in well 6. It and other Mississippian units are absent in well 1; it was not reached in well 7. The lithologic character of the Spergen and Warsaw beds differs considerably from well to well, ranging from gray-buff slightly cherty and oölitic limestone to brown resinous finely granular dolomite. In the easternment wells, they consist mostly of limestone, but a few dolomitic limestone beds are present near the base. Nearly the entire Spergen-Warsaw sequence consists of dolomite in well 3; in well 2, the upper part is made up of dolomite and the lower part consists of gray silty limestone and gray shale. Gray dense mottled or fossiliferous chert is common in the middle and near the base of the sequence. The foraminifer *Endothyra,* which is found in the Spergen limestone on the outcrop, is present near the middle of the sequence in some wells.

OSAGIAN SERIES

Keokuk and Burlington limestones, undifferentiated.—The Keokuk and Burlington limestones are similar lithologically and are thus treated as a single unit in this report. To this unit, the term "Boone" or "Osage" is generally applied by oil geologists. The unit ranges in thickness from 150

[5] Lee, Wallace, Subsurface Mississippian rocks of Kansas: Kansas Geol. Survey, Bull. 33, pl. 7, 1940.
———, The stratigraphy and structural development of the Forest City Basin in Kansas: Kansas Geol. Survey, Bull. 51, p. 66; 1943.

feet in well 8 to 54 feet in well 2. It is absent in well 1 and was not penetrated by well 7. It consists principally of beds of gray-buff to buff finely granular dolomite containing much white devitrified chert. A more calcareous facies of the unit is present in wells 6 and 8 where dolomitic limestone is common. White to grayish-white dense chert, glauconite, calcite, drusy quartz, and crinoid stems are present in most beds. Gray spicular chert is common in the lower beds. Glauconitic chert generally marks the basal beds in eastern Colorado and is an aid in distinguishing them from similar beds of the Viola limestone in that area.

KINDERHOOKIAN SERIES

Gilmore City limestone.—Large oölites or pisolites embedded in cream to buff finely crystalline noncherty limestone are characteristic of the Gilmore City limestone. Some of the limestones have a distinctive "mealy" texture. A few beds of dense limestone are interbedded with the "mealy" limestones in some wells. In well 8, the Gilmore City limestone sequence, as shown by Lee[6] and used in this report, includes a thin buff finely granular dolomite bed about 30 feet above the base which is underlain by pisolitic dolomitic limestone and a thin gray shale. A somewhat thicker tan finely granular slightly cherty dolomite underlain by pisolitic limestone is present at about the same horizon in well 4. These dolomite beds can be interpreted as facies changes within the Gilmore City as indicated herein or they may be classed as being of older Kinderhookian age. The thickness of the Gilmore City, including the aforementioned lower beds of dolomite, ranges from 18 feet in well 2 to 166 feet in well 6. It was not possible to determine accurately the lithologic character of the Gilmore City or to separate the Gilmore City and the "Misener" beds in well 3, owing to the powdered condition of the samples.

"Misener sand."—The basal Mississippian sandstone in this area is termed "Misener sand," in accordance with general usage, although it is not overlain by the Chattanooga shale. The "Misener sand" is best developed in well 2 where it is about 35 feet thick and is composed of coarse subrounded quartz grains, green glauconitic sandy shale, weathered white chert fragments, and some beds of gray finely granular dolomite. In well 3, it seems to be mostly dolomitic sandstone, but the samples from this well are so finely powdered that doubt exists as to the true character of the beds. In wells 4, 5, and 6, the "Misener sand" consists of white calcareous and glauconitic fine-grained sandstone less than 5 feet thick, and in well 8, it is either absent or is represented by the thin bed of gray shale shown at the base of the Gilmore City limestone.

[6] Lee, Wallace, *op. cit.*, pl. 7-A, 1940.

ORDOVICIAN AND CAMBRIAN SYSTEMS

All wells on this section except well 6, which stopped in Mississippian rocks, penetrated rocks of Ordovician and Cambrian age. However, only well 1 passed through the Ordovician and Cambrian into pre-Cambrian rocks. Therefore the total thickness of the Ordovician and Cambrian beds is not known except in well 1 where it is 178 feet. A penetration of 460 feet was recorded in well 3 which suggests the great eastward thickening of the Ordovician and Cambrian Systems. Eastward, progressively younger beds are at the top of the sequence. Widespread unconformities are present at the top of the Viola limestone, the Simpson rocks, the Arbuckle limestone, and the pre-Cambrian rocks.

BEDS OF TRENTON AGE

Viola limestone.—The term Viola limestone is applied herein to a sequence of buff to gray-buff finely crystalline to granular very cherty beds of dolomite that overlie rocks of Simpson or Arbucke age in central and western Kansas. Gray banded to white dense porcelainlike chert, some of which is fossiliferous and pyritic, is abundant in this unit. Glauconite is present in dolomite at the top and base of the unit. The relationship of this unit to the Viola limestone of southern Oklahoma or to the Galena limestone of the upper Mississippi Valley has not been determined.

The Viola limestone thins westward along the course of this section, ranging in thickness from 117 feet in well 8 to 50 feet in well 3. It is absent in wells 1 and 2, and was not penetrated in well 7.

BEDS OF BLACK RIVER AND CHAZYAN AGE

Simpson rocks.—Rocks of Simpson age are present only in the structurally low area that includes wells 4 and 5. The Simpson consists of an upper bed of gray calcareous slightly glauconitic fine-grained sandstone and gray-green pyritic shale about 5 to 10 feet thick, a middle bed of gray-white sandy dolomite about 10 to 20 feet thick, and a lower bed of pale-green pyritic shale and white fine-grained sandstone about 5 feet thick. The relationship of these beds to the Simpson group of southern Oklahoma is unknown. Traces of sand and detrital chert were found on top of the Arbuckle limestone in wells other than 4 and 5 but this material is not considered to be a part of the Simpson of the cross section.

BEDS OF BEEKMANTON AND ST. CROIXIAN AGE

Arbuckle limestone. Seven wells on this section reached the Arbuckle limestone and penetrated it to depths of 35 to 412 feet. The total thickness of the Arbuckle is not known except in well 1, which penetrated 178 feet of cream, buff, and pink finely to coarsely crystalline dolomite beds, tentatively correlated with the Arbuckle limestone of Kansas and with the Manitou limestone of the Front Range. Eastward from well 1, the Arbuckle limestone is considerably thicker as well 3 was drilled 412 feet into the unit and did not reach its base. Unfortunately the samples from well 3 are so finely powdered that a detailed description of the lithologic sequence of beds in the Arbuckle is not possible, and the short penetrations of other wells are not adequate. In general, however, the Arbuckle limestone in well 3 consists of an upper unit 100 feet thick of cream to buff finely crystalline to granular dolomite containing some milky chert and sand grains, a middle unit 150 feet thick of gray-buff finely to coarsely crystalline cherty dolomite containing oölitic chert; and a lower unit 170 feet thick of gray-white coarsely crystalline sandy dolomite containing small amounts of white chert.

Lamotte sandstone (?).—A 3-foot bed of glauconitic sandy dolomite and dolomitic sandstone is present at the base of the Arbuckle in well 1. This bed represents the basal Paleozoic sandstone that is commonly called the Lamotte sandstone and is generally correlated with the Sawatch sandstone of the Front Range.

PRE-CAMBRIAN ROCKS

Well 1, the only well on this section that reached pre-Cambrian rocks, penetrated 72 feet of igneous and metamorphic rocks. As indicated by the cuttings, the well passed through 37 feet of green talc (?) schist and then penetrated 35 feet of basic igneous rock containing veins of pink granite.

STRUCTURAL FEATURES

The wide spacing of the wells in southeastern Colorado and the irregular course of the cross section give an inadequate representation of the structural features of the region traversed. The Las Animas arch, also termed the Sierra Grande arch[7], is one of the largest structural features crossed by the section. The arch is well defined in the exposed Cretaceous formations and has been mapped by Darton[8], and Dane and Pierce[9] as a broad arch trending northeastward across eastern Colorado, intersecting the line of this section between wells 1 and 2. The expression of the arch in the Paleozoic rocks is only vaguely known because of the paucity of subsurface data, and therefore no attempt has been made to depict it on the section.

[7] Rich, J. L., A probable buried mountain range of early Permian age east of the present Rocky Mountains in New Mexico and Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 5, no. 5, pp. 605-08, 1921.

[8] Darton, N. H., Geology and underground waters of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey, Prof. Paper 52, pl. 26, 1906.

[9] Dane, C. H., and Pierce, W. H., Geology and oil and gas prospects in part of eastern Colorado: U. S. Dept. Interior press release (June 8, 1933).

An anticline of considerable significance, if not magnitude, is evident at well 6 in the Patterson oil pool. The anticline is present in the Morrowan and older rocks on the eastern rim of a regional basin or trough that is filled with early Pennsylvanian black organic shales and limestones that grade westward into arkose.

OIL AND GAS

In western Kansas, the oil and gas reservoirs include the Lamotte sandstone, Arbuckle limestone, Simpson rocks, Viola limestone, Mississippian limestone, the "Patterson sand" of the Cherokee shale, the Sooy conglomerate, limestone beds of the Lansing and Kansas City groups, limestone beds at the top of the Shawnee group, and several limestone and dolomite beds in the Chase and Sumner groups. Unconformities seem to be associated with each of these reservoirs except perhaps the limestone and dolomite beds in the Chase and Sumner groups. Oil pools on or adjacent to the line of this cross section are (1) the Shallow Water pool in T. 20 S., R. 33 W., Scott County, Kansas, which yields oil from limestone beds lying near the top of the St. Louis limestone; (2) the Nunn pool in T. 21 S., R. 34 W., Finney County, Kansas, which yields oil from a bed of sandstone of Pennsylvanian age and a bed of limestone of Mississippian age; (3) the Patterson pool in T. 22 S., R. 38 W., Kearny County, Kansas, which yields oil from the "Patterson sand" that lies at the base of the Cherokee shale. In all of these pools, the trap that caused the accumulation of oil in the pool seems to be a combination of anticlinal and stratigraphic types. In the first two, the trap seems to have been formed by the truncation of an anticline and by the subsequent sealing of the permeable beds by the deposition of younger relatively impermeable strata. In the third, it seems that the "Patterson sand" may represent a shoreline deposit of the Cherokee sea laid down upon the beveled edge of Morrowan beds and then sealed with impermeable Cherokee sediments. The black organic shale and limestone deposited in the basin to the westward in Atokan and Morrowan time deserve consideration as possible sources of the oil in the "Patterson sand." Similar geological conditions may exist north and south of well 6 in Kearny County, Kansas, but they cannot be predicted from the present data. In the area adjacent to the line of section between wells 7 and 8, conditions similar to those in the Shallow Water pool, where the St. Louis limestone yields oil, might be expected but present subsurface data are insufficient to localize structures.

Most of the limestone and dolomite reservoir beds of the central Kansas oil fields persist westward into the first two counties of eastern Colorado, and therefore are potential oil and gas reservoirs in that area also. Pre-Cherokee Pennsylvanian sands, the "Misener sand," and sands of Simpson age are present in several wells indicating the possibility of oil accumulations in them where favorable structural conditions exist.

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PART 1. COAL RESERVES IN KANSAS, by G. E. Abernathy, J. M. Jewett, and W. H. Schoewe, pp. 1-20, figs. 1, 2, April 30, 1947.

PART 2. MAGNETIC SURVEY OF THE BALA INTRUSIVE, RILEY COUNTY, KANSAS, by Robert M. Dreyer, pp. 21-28, figs. 1-4, June 15, 1947.

University of Kansas
State Geological Survey of Kansas

Prepared by Geological Survey, United States Department of the Interior, with cooperation of State Geological Survey of Kansas
1947

Oil and Gas Investigations
Preliminary Cross Section No. 4

SUBSURFACE GEOLOGIC CROSS SECTION FROM SCOTT COUNTY, KANSAS, TO OTERO COUNTY, COLORADO

BY JOHN C. MAHER

Drafting of cross section by H. Russell Castor.

EXPLANATION

- Limestone
- Sandy limestone
- Dolomitic limestone
- Dolomite
- Sandy dolomite
- Anhydrite or gypsum
- Sandstone
- Limy sandstone
- Dolomitic sandstone
- Red shaly sandstone
- Conglomerate
- Salt
- Variegated shale
- Red or maroon shale
- Green shale
- Gray shale
- Black shale Coal or lignite
- Red sandy shale Green sandy shale
- Red limy shale Green limy shale
- Gray limy shale
- Red dolomitic shale
- Granite
- Basic igneous rock
- Schist
- Glauconite Feldspar
- Chert
- Oolites
- Oolitic chert
- Unconformity
- NS — No samples

SYSTEM	SERIES	GROUP	FORMATION	FORMATION NAMES USED IN COLORADO
PERMIAN	GUADALUPIAN	WOLFCAMPIAN AND LEONARDIAN	Taloga formation	Lykins formation
			Day Creek dolomite	
			Whitehorse sandstone	
			Blaine formation	
				Lyons sandstone
			Stone Corral dolomite	
PENNSYLVANIAN	?	DESMOINESIAN AND MISSOURIAN		Fountain formation
	ATOKAN			
	?			
	MORROWAN			Glen Eyrie shale
CAMBRIAN AND ORDOVICIAN	ARBUCKLE LIMESTONE			Manitou limestone
			Lamotte sandstone	Sawatch sandstone
PRE-CAMBRIAN ROCKS				

1 CARTER OIL CO. NO.1 STRATIGRAPHIC TEST SE cor. sec. 30, T26S, R57W. OTERO COUNTY, COLORADO Elevation 4685 feet. T.D. 4235

2 PACIFIC WESTERN CORP.–FRONTIER REFINING CO. NO.1 SMITH–GOVT. SW NW SE sec. 12, T26S, R50W. BENT COUNTY, COLORADO Elevation 4227 feet. T.D. 5989

3 TROJAN OIL & GAS CO. NO.1 LOTUS NW NE NE sec. 15, T23S, R46W. PROWERS COUNTY, COLORADO Elevation 3650 feet. T.D. 5913

4 STANOLIND OIL & GAS CO. NO.1 HOUSE Gen. SW NE sec. 32, T24S, R41W. PROWERS COUNTY, COLORADO Elevation 3501 feet. T.D. 6200

5 DENVER PRODUCING & REFINING CO. NO.1 PORTER SW cor. NE sec. 30, T25S, R41W. HAMILTON COUNTY, KANSAS Elevation 3390 feet. T.D. 6453

6 STANOLIND OIL & GAS CO. NO.1 PATTERSON Gen. E. line SE SE sec. 03, T22S, R38W. KEARNY COUNTY, KANSAS Elevation 3322 feet. T.D. 5690

7 ATLANTIC REFINING CO. NO.1 THORNBROUGH NW SE NW sec. 16, T21S, R35W. KEARNY COUNTY, KANSAS Elevation 3130 feet. T.D. 4925

8 ATLANTIC REFINING CO. NO. 1–A MARK Gen. SE SE sec. 29, T20S, R33W. SCOTT COUNTY, KANSAS Elevation 2943 feet. T.D. 5645

FORMATION	GROUP	SERIES	SYSTEM
Day Creek dolomite		GUADALUPIAN	PERMIAN
Whitehorse sandstone			
Dog Creek shale and Blaine formation	NIPPEWALLA		
Flowerpot shale			
Stone Corral dolomite		LEONARDIAN	
Ninnescah shale			
Wellington formation	SUMNER		
Nolans limestone			
Winfield limestone			
Barneston limestone	CHASE	WOLFCAMPIAN	
Wreford limestone			
Grenola limestone	COUNCIL GROVE		
?			
Foraker limestone			
ADMIRE			
WABAUNSEE	SHAWNEE	VIRGILIAN	PENNSYLVANIAN
DOUGLAS AND PEDEE			
LANSING, KANSAS CITY AND BRONSON (UNDIFFERENTIATED)		MISSOURIAN	
CHEROKEE	MARMATON	DESMOINESIAN	
	MORROWAN		
St. Louis limestone	MERAMECIAN	MISSISSIPPIAN	
Spergen and Warsaw limestones			
Keokuk and Burlington limestones	OSAGIAN		
Gilmore City limestone	KINDERHOOKIAN		
VIOLA LIMESTONE		CAMBRIAN AND ORDOVICIAN	
ARBUCKLE LIMESTONE			

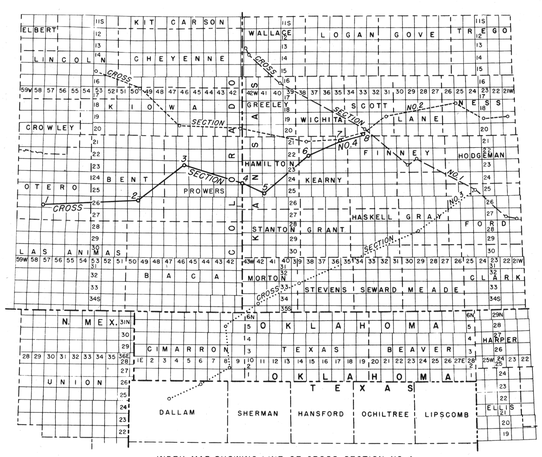
Sea Level

Gilmore City limestone
"Miesner sand"
VIOLA LIMESTONE
ARBUCKLE LIMESTONE
SIMPSON ROCKS
Ste. Genevieve limestone
St. Louis limestone
Spergen and Warsaw limestones
Keokuk and Burlington limestones
Gilmore City limestone
Samples powdered

Cottonwood is member
Fort Riley ls. member
Florence ls. member

5 0 25 Miles
Horizontal scale

INDEX MAP SHOWING LINE OF CROSS SECTION NO. 4 AND PREVIOUSLY PUBLISHED SECTIONS



0 10 20 30 40 50 Miles
Scale