STATE GEOLOGICAL SURVEY *of* KANSAS
RAYMOND C. MOORE, State Geologist

BULLETIN 10

PART I

THE GEOLOGY OF RUSSELL COUNTY, KANSAS

With Special Reference to Oil and Gas Resources

By W. W. RUBEY and N. W. BASS

PART II

A Subsurface Correlation of the Stratigraphic Units from Russell County to Marion County, Kansas

By M. N. BRAMLETTE

PART III

Fossils from Wells in Central Kansas

By RAYMOND C. MOORE

Prepared in coöperation with
The United States Geological Survey

Printed by authority of the State of Kansas.

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STATE BOARD OF ADMINISTRATION.

STATE GEOLOGICAL SURVEY OF KANSAS.

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* In scientific usage, as a geological term, the accepted spelling of this word is "Ogalalla." The spelling used in this bulletin, however, is in conformity to Webster's New International Dictionary.

ILLUSTRATIONS.

* The large plates included in this bulletin will be found in a pocket on the inside of the back cover.

PART I.

The Geology of Russell County, Kansas, With Special Reference to Oil and Gas Resources.

By W. W. Rubey and N. W. Bass.

INTRODUCTION.

Significance of the Investigation in Russell County.[1]

AFTER the richly productive oil and gas fields in eastern Kansas and Oklahoma had been discovered and developed, the oil-producing territory in this region was gradually and rather slowly extended westward to areas where the formations that contain oil in the region to the east are more deeply buried. This westward movement of the border of Mid-Continent production has not been simply progressive, for much country that had been partly explored without success was passed over in going from the fields of Wilson and Allen counties to the test wells in Butler county, the success of which marked the beginning of the chief "oil age" in Kansas. The discovery wells in the highly productive fields of Butler and Marion counties were located by means of good geologic evidence, and the development of these fields has been guided mainly by geologic studies.[2]

The development of oil and gas in central and western Kansas west of Butler county has met many obstacles. The beds of limestone in the oil fields of Butler and Marion counties, which furnished a ready and satisfactory means of determining the geologic structure, are practically the uppermost hard rocks in the Paleozoic system in Kansas. In central Kansas the soft, variously colored shales, the easily soluble beds of salt, and the irregular, mainly rather weak "Red Beds," which here constitute the uppermost Paleozoic strata, are very poorly exposed, or in wide areas are not exposed at all. Most of central Kansas lacks beds that can be traced over territory large enough to make them valuable as key horizons in mapping the geologic structure. Consequently there is very little to guide

1. By Raymond C. Moore.
2. The El Dorado oil field, by A. E. Fath: Kansas Geol. Survey Bull. 7, 1920.

exploration for oil and gas. Though a considerable number of wells have been drilled in this region, mostly on a "hit or miss" plan, only one or two have been productive. Some of the larger oil companies have recently been determining the geologic structure of parts of this region by drilling shallow diamond-drill test wells down to one of the beds of limestone that lies near the surface and that may be used as a datum plane.

Next to the belt that lacks surface key beds lie the basal deposits, mainly sandstone, of the Cretaceous system. These rocks, which crop out in a belt thirty to forty miles wide, are millions of years younger than the next underlying series of rocks, and between the time of the deposition of the two series there intervened a long period in which the underlying rocks were exposed and more or less eroded. The sandstones of the Cretaceous system, therefore, rest at some places on higher and at others on lower beds in the underlying series. The erosion at the close of Paleozoic sedimentation in this region has produced a lack of parallelism of the beds, and at some places, doubtless, has made the relations between the younger and older rock series very irregular. Further, the belt of sandstone at the base of the Cretaceous is extremely irregular. It shows abundant cross-bedding, and affords, so far as known, no horizon that can be followed with confidence in structural mapping. The exposures in parts of the belt where this zone is nearest the surface are very poor. Thus there is a fairly wide belt west of the oil fields in Butler and Marion counties in which, though it may contain beds that will yield oil or gas, the surface affords no evidence that is of use to the geologist in guiding exploration.

Above the Dakota sandstone, and therefore appearing at the surface in a belt that extends across the state next west of and parallel to the outcrops of the sandstone, there is a series of alternating beds of dark shale and thin, more or less resistent chalky limestone. In previous publications this division of the Cretaceous system has been called the Benton, but in this report it is divided into three formations—the Graneros shale below, the Greenhorn limestone in the middle, and the Carlile shale above. Each of these formations contains horizons that can be traced more or less easily and that can be used in determining the structure of the Cretaceous rocks.

The information concerning structure that is afforded by exposures of the Greenhorn limestone has led to the discovery, in the northwestern part of Russell county, of a long, well-defined fold, which offered favorable conditions for the accumulation of oil or gas and on which a test well was drilled late in 1923. The preliminary geologic work in this area was done by Mr. V. H. McNutt, and the well was drilled by the M. M. Valerius Oil and Gas Company, whose president, Mr. Valerius, is also a geologist. The discovery of oil in commercial quantities by means of this test well is of great importance, not simply because of the additional oil that will be obtained from this new field, now more definitely indicated by other large producers, but because of its significance as to the possibility of obtaining oil in other parts of the Great Plains country of western Kansas.

Because of the importance of the new oil production in Russell county and the widespread interest in it, the State Geological Survey undertook to make field examinations in this and other parts of western Kansas in order to gather information that may aid in extending the area of this production. The geologic mapping done by the geologists of the oil companies has been confined essentially to areas where the Greenhorn limestone is exposed. In the course of these examinations several large questions arose: To what extent can the Graneros and Carlile shales be used in determining geologic structure? Can the surface structure be reliably ascertained in the thick Niobrara chalk, which covers large areas farther west? What is the producing formation in the Russell county field, and what are the prospects of production from greater depths? What is the structure of the rocks below the surface, especially at the producing horizon? Is there any indication as to the source of oil; that is, as to the "mother beds" in which the oil originated? What is the form or character of the particular fold on which oil and gas have been found here, and what bearing has it on other drilling in western Kansas? What probably produced the fold? How do the answers to these questions affect the prospects of obtaining oil in other parts of western Kansas?

The State Survey, unable with its present resources to undertake this investigation, turned to the United States Geological Survey for aid, and made arrangements for a coöperative study of the development of oil and gas in Kansas. A survey of the area in Russell county was first planned, and to this work Messrs. W. W. Rubey and N. W. Bass were assigned. At the same time Mr. M. N. Bramlette undertook a microscopic study of all available drill cuttings from deep wells in eastern, central and western Kansas, and, supplementing the information thus obtained with well records, endeavored to trace westward to Russell county the geologic divisions found in the eastern part of the state. After they had examined Russell county, Mr. Rubey and Mr. Bramlette were transferred to work outside of Kansas, but studies of oil and gas in the state are being continued by Mr. Bass, and the state geologist.

Methods of Field Work.

The work in Russell county on which this report is based was done between March and June, 1924. A brief reconnaissance of the formations exposed in eastern, central and southern Kansas was made at the beginning of the work by Raymond C. Moore, state geologist of Kansas; K. C. Heald, of the United States Geological Survey, and M. N. Bramlette, who was to make a special study of the subsurface geology and the correlation of the underground formations in Russell county. The field work in Russell county was done by W. W. Rubey and N. W. Bass.

Numerous sections of the outcropping rocks were examined and measured by Locke level or stadia, and the position of the outcropping formations throughout the county was sketched on the United States Geological Survey's topographic base maps of the region, which in all but a few very small areas were found to be sufficiently accurate for this purpose. Each drilling well was visited several times to collect records and samples of the formations drilled through.

Acknowledgments.

In collecting cuttings from the wells, in granting permission to inspect detailed structural maps, and in other ways assistance was generously given by M. M. Valerius, the Stearns-Streeter Drilling Company, Sidney Powers; E. A. Hall, of the Midwest Oil and Refining Company; H. L. Baldwin, of the Mississippi Valley Oil Company; E. R. Lloyd, H. E. Munson, J. L. Gallagher, V. H. McNutt, C. T. Lupton, and all the drillers in the field. The writers are deeply indebted to J. B. Reeside, Jr., of the United States Geological Survey, who spent several days in field conference with them, identifying fossils and determining the limits of the stratigraphic units. Thanks are also due J. L. Phinney, of Russell, who kindly guided the writers to a fossiliferous outcrop of Cenozoic deposits and donated to the State Museum an elephant tooth found there years before.

Geography and Topography.

Russell county, which is about thirty miles square, lies slightly northwest of the center of Kansas, near the eastern border of the Great Plains region. More than half a dozen towns, of which Russell, the county seat and headquarters of the new oil field, is the largest, stand along the two lines of the Union Pacific railroad that run through the county. Two other towns, Fairport and Milberger, are far from the railroad. The chief occupation of the residents of Russell county is agriculture, and the principal crop raised is wheat. The wagon and automobile roads throughout the county are well kept.

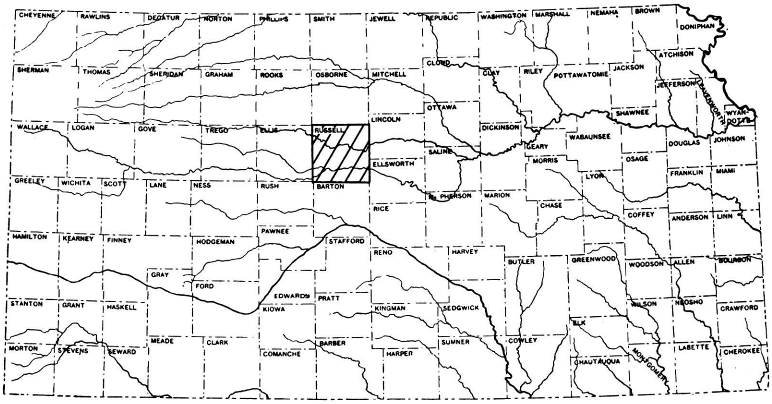

Fig. 1. Index map showing location of Russell county.

The highest point above sea level in Russell county, found on the high ridges in its northwest corner, has an elevation of about 2,050 feet, and the lowest point, where Saline river leaves the county, near the middle of its eastern boundary, has an elevation of about 1,430 feet. The uplands slope northeastward from above 2,000 feet in the northwest corner to 1,700 feet above sea level near the northeast corner of the county. Two rivers, the Saline and Smoky Hill, and Wolf creek, a large tributary of Saline river, flow eastward across Russell county. The other tributaries, several of which have large valleys, flow northeastward and southeastward into the main streams. Saline river falls about 265 feet in a straight-line distance of 32 miles across the county—a gradient of over 8 feet to the mile. The bed of Smoky Hill river is 200 feet lower at the eastern border of the county than at the western, where it is about 1,770 feet above sea level—a fall of less than 6½ feet to the mile. The relief along Saline river is 250 to 300 feet and that along Smoky Hill river is 150 feet or less, but the uplands are featureless and nearly flat.

The undissected uplands form nearly half the surface of the county, the steep to gentle slopes into the valleys make up most of the remainder, and the flat valleys comprise about a fifth.

The form of the treeless upland is controlled largely by the structure and the lithology of the surface rocks, the moderately resistant chalk beds of the Greenhorn and Carlile formations upholding it in all but the northwest corner of the county, where the higher Blue Hills scarp and plateau is made by chalk beds in the Niobrara formation.

The northern margins of the uplands between the larger streams terminate abruptly in steep slopes that lead down to the valleys, but the southern margins merge by gentle slopes into the valleys. This difference is noticeable even along the smaller tributary streams and on the valleys the trend of which inclines even less than 45° from north. The greater steepness of the northward-facing slopes is a characteristic feature of the topography of western Kansas. To one unacquainted with the region it suggests broken scarps at the north and dip slopes to the south, but the regional dip in central Kansas is northward.

The larger valleys are from less than one to several miles wide and their floors slope gently on the north sides, but commonly rise abruptly from the south sides. Of the tributaries from the south only the larger ones have noticeably flattened valley floors. The banks of the streams are commonly wooded. The capture of the headwaters of minor tributaries of Smoky Hill river by northward-flowing tributaries of Saline river is approaching, especially near the eastern border of the county.

Many of the spurs between the tributary streams are long and narrow, and those that run northward from the larger divides are steep-sided, prominently benched by beds of harder rock, and in places made irregular by small, isolated remnants of a higher, harder bed. These spurs are closely controlled by lithology, most of them being capped by one hard chalk bed of the Greenhorn limestone. The outcrops of rock in Russell county are essentially restricted to the valley walls and are generally best exposed in the northward-facing bluffs.

History of Oil and Gas Production.

In Russell county, as in many areas in western Kansas, there was considerable activity in leasing oil and gas as early as 1917, but no drilling was done until July, 1923, when the M. M. Valerius Oil and Gas Company, of Tulsa, Okla., "spudded in" a well in the southwest corner of the SE¼ of sec. 8, T. 12 S., R. 15 W., that was destined to open a new oil pool more than a hundred miles from the nearest commercial producing field. The well was drilled on the C. C. Oswald farm, on land leased from the Lucky Seven Oil Company, a local company holding leases on an area comprising nearly three-fourths of a township in the vicinity of the present Russell pool. Several encouraging shows of gas and oil were struck late in the fall. Late in November oil was produced at the rate of about 10 barrels a day, and early in December the sand now producing was struck at a depth of 2,998 feet. Drilling was continued to the depth of 3,037 feet; but the well was not shot. A pipe line was laid to connect the well with tank cars at Paradise, on the Union Pacific railroad. The output of the well at first was about 175 barrels of oil a day; it rose to 240 barrels, and by pumping has been maintained steadily for nearly six months at about 200 barrels a day.

Soon after this well was brought in, other locations were made in Russell and bordering counties. A flow of gas, reported to be 7,000,000 cubic feet daily, was struck in the Stearns-Streeter Company's Ed Oswald No. 1 well in the SW¼ SW¼, sec. 8, T. 12 S., R. 15 W., on May 15, 1924. The gas is produced from a sand 10 feet thick, at a depth of 2,461 feet. On June 8 the west offset of the discovery well, also belonging to the M. M. Valerius Oil and Gas Company, reached the oil-producing sand struck by the discovery well, and after being drilled but 10 feet into the "pay" was variously reported as being capable of producing from 500 to 1,600 barrels of oil a day. It is reported to have yielded, by swabbing, 1,260 barrels in a 19-hour test. This well is now [3] yielding 350

3. As of July, 1924, press reports indicate that at the date this bulletin is being sent to press (April 15, 1925) that there are sixteen wells in Russell county producing oil, all except one in secs. 5, 8, 17 and 18, T. 12 S., R. 15 W. One well is in sec. 29, T. 11 S., R. 15 W.

All producing wells are located on the Fairport-Natoma anticline. Approximately 1,600 barrels of oil are being shipped from the field daily. More than a dozen additional operations, either drilling or building rigs, are in progress in the near vicinity of the producing wells. Two wells are drilling several miles east of the pool. Twelve wells have been drilled in the county and abandoned, each having penetrated the rocks that produce oil in the wells described above. One well in eastern Ellis county, three miles west of the producing field, failed to obtain commercial production. More than a dozen wells are drilling in Kansas west of Russell county.

Recent drilling of wells in the Russell pool below the two producing horizons of the discovery well have shown the presence of a porous limestone a short way below the lower of the two "pays" that is barren of oil, and another porous limestone approximately 75 feet below the "Oswald" pay that gives some promise of production.

barrels a day. In the same week the Stearns-Streeter Company's Ed Oswald No. 1 was brought in as an oil well. After being drilled only 1 foot into the "pay" it was reported to be yielding oil at the rate of 25 or 30 barrels an hour. This well now [3] furnishes gas for drilling on near-by leases and produces 750 barrels of oil a day. A well known as the M. M. Valerius Oil and Gas Company's Muncell No. 1, drilled south of the discovery well, was reported on June 14 to be 1 foot into the "pay" and to contain 2,400 feet of oil. This well is now [3] yielding about 100 barrels a day, but is probably capable of producing at least twice this much when the hole is cleaned out. At the time this report was written [3] at least three other wells drilling on the Fairport-Natoma anticline are rapidly approaching the producing sand. At least 20 wells are now [3] either located, drilling or producing oil in Russell county. One other well in Russell county has reached the horizon of the sand that produces oil on the Fairport-Natoma anticline, but has struck no oil. This is the Phillips No. 1 well of the M. M. Valerius Oil and Gas Company, in the SW¼ SW¼, sec. 3, T. 13 S., R. 13 W.[3]

Character of the Oil.

The oil produced from the discovery well has a gravity of about 41 degrees Baumé. The producing rock is limestone which is parted near the middle by a bed of shale 1½ feet thick. According to report the oil produced above the shale had a temperature of 38 degrees Fahrenheit, and that produced below had a temperature of 70 degrees. Such a difference is unusual.

A sample of the oil from the discovery well, collected July 7, 1924, was analyzed by the Bureau of Mines, Department of the Interior, at the Bartlesville, Okla., office. The oil is of unusually light gravity for Kansas oils,[4] and its content of gasoline and naphtha is correspondingly large. However, the amount of asphalt, as indicated approximately by the Conradson carbon residue test, and termed *carbon residue of residuum* in the analysis, is somewhat larger than usual.

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3. See note 3 on page 13.

4. Dean, E. W., Cooke, M. B., and Bauer, A. D.: Properties of typical crude oils from the producing fields of Kansas: Bur. of Mines Serial No. 2322, 1922.

SAMPLE No. 24713. Taken from lead line when well was pumping approximately 200 barrels of oil a day. M. M. Valerius Oil and Gas Company's C. C. Oswald well No. 1, SW¼ SE¼, sec. 8, T. 12 S., R. 15 W. Specific gravity, 0.820. A. P. I. gravity, 41.1° (Baume gravity, 41.4°). Per cent sulphur, 0.41. Per cent water, nil. Saybolt Universal viscosity at 70° F., 45 sec. Saybolt Universal viscosity at 100° F., 20 sec. Pour point, below 5° F. First drop at 37° C.

Temperature, deg. C.	Air distillation barometer 739 mm.			Vacuum distillation at 40 mm.				
	Fraction per cent.	Total per cent.	Specific gravity.	Fraction per cent.	Total per cent.	Specific gravity.	Viscosity.	Cloud test, deg. F.
Up to 50	1.9	1.9	....	....	....	....	....	....
50 to 75	3.1	5.0	.681	....	....	....	....	....
75 to 100	5.8	10.8	.701	....	....	....	....	....
100 to 125	6.7	17.5	.728	....	....	....	....	....
125 to 150	6.0	23.5	.745	....	....	....	....	....
150 to 175	5.3	28.8	.762	....	....	....	....	....
175 to 200	4.3	33.1	.778	3.7	3.7	.842	41	....
200 to 225	5.3	38.4	.795	5.3	9.0	.852	46	32
225 to 250	5.5	43.9	.809	4.1	13.1	.866	60	50
250 to 275	6.4	50.3	.823	4.8	17.9	.885	83	66
275 to 300	....	....	....	5.0	22.9	.892	144	80

Residuum. 23.8 per cent. Distillation loss, 3 per cent. Carbon residue of residuum, 11.7 per cent. Carbon residue of crude, 2.8 per cent.

APPROXIMATE SUMMARY.

	Per cent.	Sp. gr.	°A. P. I.	Viscosity.
Light gasoline (end point 212° F.)	10.8	.692	73.0	....
Total gasoline and naphtha	33.1	.731	62.1	....
Kerosene distillate	17.2	.810	43.2	....
Gas oil	7.8	.847	35.6	....
Nonviscous lubricating distillate	9.1	.856–.886	33.8–28.2	50–100
Medium lubricating distillate	6.0	.886–.896	28.2–26.4	100–200
Viscous lubricating distillate	....	....	....	Above 200
Residuum	23.8	.965	15.1	....
Distillation loss	3.0	....	....	....

ROCKS EXPOSED.

The surface rocks in Russell county are all included in the Cretaceous and Cenozoic divisions of geologic time. They are younger than the stratified rocks of central and eastern Kansas, the equivalents of which in Russell county are buried more or less deeply. The following table shows the rock formations of this area in order from youngest (at the top) to oldest (at the bottom), including the main divisions of the rocks concealed below the surface as well as those which are exposed. Rocks older than the Dakota sandstone are not exposed, but were identified by M. N. Bramlette from a study of well cuttings and drillers' logs.

Table of rock formations in Russell county, Kansas.

Era.	System and series.		Group, formation, and member. *a*.		Lithologic character.	Thickness in feet.
CENOZOIC.	QUATERNARY.	Recent.			Alluvium, soil and talus material. Lower terrace deposits and gravels along streams.	
		Pleistocene.	McPherson (?) formation.		Upper gravel deposits along main streams.	0–50
	Tertiary (?).		Ogallala (?) formation.		High gravels on divides.	
MESOZOIC.	CRETACEOUS.	Upper Cretaceous.	Niobrara formation.	Smoky Hill chalk member.	Clayey chalk and chalky shale, with scattered ferruginous concretions.	0–50
				Fort Hays limestone member.	White or tan massive chalk beds.	55
			Carlile shale.	Blue Hill shale member.	Gray fissile clay shale, containing concretions, with sandstone near the top.	215
				Fairport chalky shale member.	Chalky shale and thin beds of chalk.	85
			Greenhorn limestone.	Upper member.	Chalky shale containing thin beds of chalk.	20
				Jetmore chalk member.	Alternating thin chalk beds and chalky shale.	20
				Unnamed member.	Chalky shale with a few thin beds of chalk.	28–40
				Lincoln limestone member.	Chalk, chalky shale, and thin beds of hard crystalline limestone.	20–25
			Graneros shale.		Dark bluish clay shale.	40
			Dakota sandstone.		Variegated and gray clay and sandy shale and evenly bedded s ndstone. Exposed in Russell county, 160 feet.	
				Rocktown channel sandstone member.	Lenses of cross-bedded sandstone in upper 125 feet of formation.	300–400
		Lower Cretaceous (?).			Bluish shale and brown sandstone containing leaves and marine invertebrates; exposed in western Saline county; may possibly extend under the Dakota of Russell county.	

a. A lithologic term, like sandstone or limestone, that is in current usage for a formation or member, has customarily been applied in local areas if this lithologic name emphasizes an important characteristic of the unit or if this lithologic type is the conspicuous one in the exposures, even though a large part of the unit is some other rock. Although the lithologic terms in the names, Smoky Hill chalk, Fort Hays limestone, Greenhorn limestone, and Dakota sandstone, are not exactly descriptive of these units in Russell county, they are used, in accordance with this custom, in this report.

TABLE OF ROCK FORMATIONS IN RUSSELL COUNTY, KANSAS—CONCLUDED.

Era.	System and series.		Group, formation, and member. *b*.	Lithologic character.	Thickness in feet.
PALEOZOIC.	CARBONIFEROUS.	Permian.	Cimarron group.	Predominantly red sandstone, and shale with anhydrite, and gypsum beds at some horizons.	400-600
			Sumner group: Wellington formation.	Gray shale, with anhydrite and massive rock salt.	300-400
			Sumner group: Marion formation.	Gray shale, anhydrite, and dolomite; red beds with fossiliferous cherty limestone in lower part.	400
			Chase formation.		
			Council Grove formation.	Shale, limestone, and red beds.	400
		Pennsylvanian.	Wabaunsee formation.	Blue shale, and thin beds of limestone and sandstone.	450
			Shawnee formation (to base of Topeka limestone member).		
			Shawnee formation (from base of Topeka limestone).	Limestone and small amounts of shale and sand. Yields oil in Russell county.	300
			Douglas formation (to base of Oread limestone member).		
			Pennsylvanian formations below the Oread.	Fossiliferous limestones and gray shales.	100-400
		Carboniferous (Pennsylvanian or earlier).		Shale, red rock, and thin limestones.	150±
		Ordovician (and earlier?).*		Shale, red rock, and cherty, sandy dolomite, containing Ordovician fossils at top.	500±

b. The United States Geological Survey classifies the units above the Cherokee shale as groups instead of formations, and divides the Marmaton into two major units—the Pleasanton and Henrietta groups.

* Unweathered fragments of granite were found by C. S. Ross, of the United States Geological Survey, in drill cuttings from the Producers and Refiners Oil Corporation, Haise No. 1 well, NW¼ SE¼, sec. 24, T. 12 S., R. 15 W., Russell county, from depths of 3,628 to 3,632 feet, nearly 700 feet below the Oread limestone. Although the rock penetrated is probably granite, it may possibly be arkose, a sedimentary rock made of granite pebbles.

Cenozoic.

The outcropping Cretaceous rocks in Russell county are overlain discontinuously by deposits of sandstone, gravel, and silt of Cenozoic age. In date of formation these rocks range from Recent to probably late Tertiary. Careful study of these scattered deposits was not attempted in the field because their possible economic value is not related to the oil and gas resources. They may be classified in the order shown in the table.

Recent.

Alluvium, Soil, and Talus Material.

A veneer of rock material is now being formed throughout Russell county. This veneer includes the alluvium that is accumulating in the channels and lower valleys of nearly all the larger streams, especially in the parts of Smoky Hill and Saline valleys where the river meanders. On the flat uplands and the gentle south slopes of the broad divides a mantle of soil a few feet thick, largely residual, is also being formed. The lithology of the soil varies in detail from place to place, but generally corresponds with that of the underlying bedrock. Its composition is considered more fully in the descriptions of the exposed subdivisions of the Cretaceous strata. Heaps of more or less weathered talus material abound at the bases of bluffs formed by the Dakota, the Niobrara, and especially the Greenhorn formation.

Lower Terrace Deposits.

Along Saline river and its larger tributaries, and less conspicuously along Smoky Hill river, a persistent terrace rises about 20 feet above the level of the streams. The deposits on this terrace are noted for their fertility, and form the soil of some of the best farms in the region. These deposits are conspicuously developed on the wide flat near the mouth of Paradise creek, in the western part of T. 12 S., R. 13 W.

The smaller tributaries throughout the county have recently cut into their stream beds and developed a terrace that may possibly be correlated with the 20-foot terrace of the Saline river valley.

Dune Sand (?).

Large deposits of dune sand lie in the valleys of some of the larger streams of western Kansas. No deposit of this type was found in Russell county, unless a few sod-covered sandy knolls on the north bank of Smoky Hill river are ancient dunes.

Pleistocene.

Gravel Deposits of Saline and Smoky Hill Rivers.

Subdivisions of the gravels. In the valleys of Saline and Smoky Hill rivers and their larger tributaries there are deposits of coarse gravel, which lie from 20 to 70 feet above the present streams. Volcanic ash was found near the top of such gravel beds north of Smoky Hill river. Along Saline river these beds can be subdivided into deposits at two levels: (1) the lower, and presumably younger, gravel ("Salt Creek gravel beds" of Logan[1]), which occurs rather uniformly about 50 feet above the present stream grades; and (2) the higher beds, which lie from 40 to 70 feet above the present streams. Where the two occur in the same section the lower gravel is about 15 feet below the higher.

Lower gravel beds on Saline river. The lower gravel is found at many places in northwestern Russell county, especially near the mouth of Salt creek, 5 miles north of the town of Russell. The deposit forms a stratum that is well cemented with lime, persistent over small areas and averages about 2 feet in thickness. It is in many places steeply crossbedded from the west and is composed chiefly of quartz pebbles, but at some places it contains abundant fresh fragments of pink orthoclase and flat pieces of chalk, some of which inclose *Inoceramus* shells. The individual pebbles range in diameter from a thirty-second of an inch to an inch.

Upper gravel beds on Saline river. Beds of unconsolidated gravel, 10 feet or more thick, of essentially the same composition as the lower gravel beds, but containing a few lenticular beds of sandy clay about a foot thick, are found along Saline river. This gravel is quarried north of Russell, and used locally in making cement. Possibly because the beds are less consolidated, cross-bedding is not so conspicuous in them as it is in the lower gravel.

Gravel beds near Smoky Hill river. Along the north bank and the tributaries of Smoky Hill river beds of gravel about 10 feet

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1. Logan, W. N.; The Upper Cretaceous: Kansas Univ. Geol. Survey, vol. 2, pp. 218-219; 1897.

thick, very similar to the upper beds of gravel on Saline river, are in some places found at levels ranging from 20 to 60 feet above the streams. This gravel consists chiefly of quartzite pebbles, some of which are made shiny by "desert varnish," bits of silicated wood, granite, basaltic rock and chert, and beds composed almost solely of flat, unweathered fragments of chalk about an inch across, deposited so as to show an imbricated structure. These gravel beds contain grains of pink feldspar, and are poorly sorted, the most abundant grains ranging in diameter from about 0.5 to 3 millimeters.[2] Some of the beds are slightly cemented with calcium carbonate. This gravel is quarried for local use as construction material. South of the town of Russell there are springs and large seeps at the base of this gravel.

Volcanic ash. On the west side of a small valley near the southwest corner of sec. 19, T. 14 S., R. 13 W., a lenticular bed of volcanic ash more than 5 feet thick is exposed for over 350 feet horizontally in the upper part of the gravel beds near Smoky Hill river, just described. The ash is white to cream colored and is very thin bedded. It lies with sharp contact on a bed of chalk pebbles, but its upper limit is obscured.

The grains of the ash are extremely small and very angular. Under the microscope they are seen to possess the vitroclastic and cellular texture and the isotropic optical properties characteristic of volcanic ash. The beds may be identified in the field by their inactivity with hydrochloric acid and the abundance of minute surfaces that reflect light (which distinguish them from loose lime), and by the extreme fineness and angularity of the grains, and their loose, unconsolidated texture (which distinguish them from sandstone).

No other deposit of volcanic ash was found in Russell county. In a well dug near the courthouse at Russell a bed of white, powdery substance 4 feet thick was encountered 8 feet below the surface and was reported to have "blown away when thrown out upon the ground." This may have been either volcanic ash or loose lime.

Fossils.

On the west side of Fossil creek, north of Smoky Hill river, in the southeast corner of sec. 25, T. 14 S., R. 14 W., in Russell county, J. L. Phinney, a resident of Russell, while excavating in a bed of

2. See Seaton, R. A., and Taylor, I. I.; Tests of Kansas sands for use in mortar and concrete; Kansas State Agr. Coll. Eng. Experiment Sta. Bull. 3, pp. 10, 16, 38; 1916.

gravel near some springs there, found a large tooth and a few bones. Mr. Phinney gave these fossils into the keeping of the writers until finally stored in the State Museum at Lawrence. He kindly accompanied the writers to the place where they were found, and through his guidance some additional bones were collected. J. W. Gidley, of the United States National Museum, to whom the fossils were submitted for identification, reported on them as follows:

"The broken tooth is a left lower molar of an extinct species of elephant. It seems to belong to the species known as *Elephas imperator*. The three splinters of bone are from the central portion or shaft of a metatarsal (the bone between the hock joint and the fetlock) of an extinct species of horse closely related to the domestic horse of the present day. Both these animals lived in the early part of the so-called 'Ice Age.'"

No other fossils except Cretaceous forms contained in pebbles of chalk were found in any of the Cenozoic deposits in Russell county.

Age and Correlation.

Although it is possible that these fossils may have been entombed in earlier deposits made quaggy by seepages of water, their Pleistocene age suggests that the gravel beds may be a part of the McPherson formation. This formation, formerly called the "Equus beds" because of the occurrence in it of bones of horses, is the only Pleistocene formation, aside from glacial drift and loess, that has been recognized in Kansas, and its type exposures are but 50 miles to the southeast, in McPherson county.[3] The one other gravel formation recognized in western Kansas is the Ogallala formation,[4] of Pliocene and late Miocene age.

The chief lithologic differences reported between these two formations are the absence of grains of feldspar in the McPherson beds,[5] and the greater degree of cementation by calcium carbonate in the Ogallala formation. The gravel beds along Smoky Hill river, in Russell county, are only slightly cemented, and in this respect resemble the McPherson formation, but the presence of grains of feldspar and of pebbles of igneous and metamorphic rocks gives them a strong likeness to the Ogallala formation. Volcanic ash is reported from the upper parts of both formations, but most of the well-authenticated occurrences appear to be younger than the Ogallala.

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3. Haworth, Erasmus, and Beede, J. W.; The McPherson Equus beds: Kansas Univ. Geol. Survey, vol. 2, pl. XLV; 1897.

4. Darton, N. H.; U. S. Geol. Survey Geol. Atlas, Syracuse-Lakin Folio (No. 212); 1920.

5. Haworth, Erasmus, and Beede, J. W.; The McPherson Equus beds: Kansas Univ. Geol. Survey, vol. 2, pp. 289-290, 295; 1897.

Both formations yield good water, and the springs in the gravel beds near Fossil creek are of no assistance in correlation.

The regional relations and lithology of the McPherson formation in McPherson county indicate that its sediments were deposited by a large stream that flowed southward from the Smoky Hill river to the Arkansas river.[6] Assuming that this interpretation is correct, and using a gradient for the stream of 2½ to 3 feet to the mile (derived from the slope of the upper surface of and the bedrock below the deposits of McPherson county[7]), we would expect the McPherson formation on Fossil creek at the elevation at which the bone-bearing gravel beds are found there. No thick beds of gravel have been reported along Smoky Hill river between Russell and McPherson counties, but such deposits may have existed and been largely removed by erosion or become obscured by the soil cover.

The Ogallala formation lies on a surface that is probably a hundred feet above the fossil-bearing gravel, a fact considered more fully under the heading "High terrace gravels (Ogallala? formation)." It is, of course, possible that the gravel beds on Fossil creek are a representative of a hitherto unrecognized Cenozoic terrane that is neither the Ogallala nor the McPherson formation.

The paleontologic and general lithologic content of the gravel beds on Fossil creek and their regional relations to the two formations point to their correlation with the McPherson formation. The only evidence contravening this correlation is the presence of feldspar and the supposed absence of gravel connecting with the McPherson county deposits. It is possible that these deposits might have been formed at the same time, but in separate areas, and the difference in their lithologic content might conceivably be explained in this way.

The absence of fossils and of volcanic ash and the slightly higher elevation above local grade level are the only features in which the upper gravel beds on Saline river differ from the beds near the Smoky Hill. The gravel beds on Saline river obviously cannot be an actual continuation of the McPherson formation of McPherson county if that formation was deposited by a stream flowing in the valley of the Smoky Hill river, but, in the absence of evidence to the contrary, the upper gravel beds on Saline river are here tentatively classed as contemporaneous with the beds near the Smoky Hill river.

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6. Haworth, Erasmus, and Beede, J. W.; The McPherson Equus beds: Kansas Univ. Geol. Survey, vol. 2, pp. 290-295; 1897.

7. Idem, p. 292.

Tertiary (?).

HIGH TERRACE GRAVELS (OGALLALA? FORMATION).

On the higher uplands in the northwestern part of Russell county scattered patches of gravel and grit are found from 70 to 100 feet above the local grade. Two distinct types are recognizable: (1) deposits of grit and clay several feet thick that are more or less closely cemented with calcium carbonate, and (2) a thin veneer of pebbles and cobbles, the largest 6 inches in diameter. These two types appear to grade laterally into each other. The beds of cal-

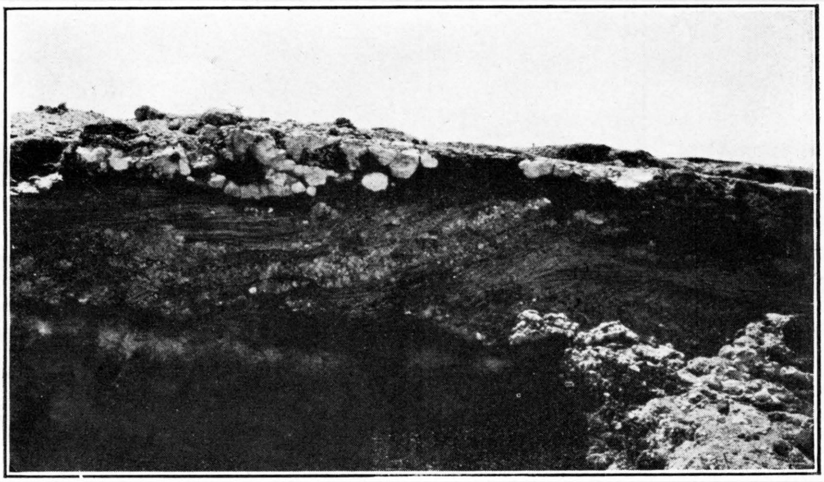

FIG. 2. High terrace gravels (Ogallala? formation) in sec. 18, T. 13 S., R. 15 W., Russell county. View southward, showing cross-bedding and spherical nodules of calcium carbonate.

careous grit [8] show strong cross-bedding and contain more or less spherical masses of soft, pure lime (Fig. 2). The "lime balls" are from 2 to 8 inches in diameter and a few contain small nuclei of hardened calcium carbonate. The pebbles and gravel in the thin layer at the same level consist chiefly of quartzite, dense tan limestone, and nodules of hard calcareous material resembling parts of the Ogallala formation farther west.

These beds occur on a more or less dissected surface that slopes gently southward and eastward from the high divides north of Smoky Hill and Saline rivers and Paradise creek. The gravel in

8. For an excellent discussion of the origin of calcium carbonate in similar gravels to the west, see: Johnson, W. D.; The high plains and their utilization: U. S. Geol. Survey, 21st Ann. Rept., pt. 4, pp. 639-656; 1900.

the northwestern part of Russell county lies on a surface that, south of Saline river, slopes gently south-southeastward toward Smoky Hill river at a rate of slightly more than 10 feet to the mile. This surface, though having little or no gravel on it, is more or less distinctly recognizable nearly to Fossil creek, and its extension would probably be about a hundred feet above the fossil-bearing gravel beds there. The highest elevation at which these high terrace gravels were recognized near Russell county is 2,000 feet above sea level, in

FIG. 3. A concretion in the lower part of the Fairport member of the Carlile shale, 10 feet above its base, sec. 3, T. 12 S., R. 16 W., Ellis county. Note the bending of the shale lamination around the concretion.

sec. 34, T. 12 S., R. 16 W., Ellis county, 2 miles west of Russell county, but they were seen at elevations of less than 1,850 feet at places in northern Russell county.

The Ogallala formation is widespread in western Kansas as a deposit of coarse materials at high levels.[9] It consists of gravel containing pebbles of igneous rock and much reddish feldspar, sand that is commonly cross-bedded, and clay and silt, and is irregularly cemented with calcium carbonate throughout.[1] The Ogallala formation is the platform of debris built by overladen rivers flowing eastward from the Rocky Mountains,[2] and its upper surface should

9. Darton, N. H.; U. S. Geol. Survey Geol. Atlas, Syracuse-Lakin Folio (No. 212); 1920.

1. Haworth, Erasmus; Physical properties of the Tertiary: Kansas Univ. Geol. Survey, vol. 2, pp. 247-284; 1897.

2. For an especially complete discussion of the origin of this and related formations, see: Johnson, W. D.; The high plains and their utilization: U. S. Geol. Survey, 21st Ann. Rept., pt. 4, pp. 612-656; 1900.

therefore be nearly a plane. Elevations throughout western Kansas show that the formation slopes eastward at an average rate of slightly more than 10 feet to the mile. To the west this slope is steeper, but eastward it becomes flatter. The base of the Ogallala is lower in the present large valleys than it is on the divides,[3] indicating that the present main lines of drainage are of pre-Ogallala age.

If the formation once extended farther east into Russell county —and it has been recognized north, west and south [4] of there—its elevation should be approximately 2,000 feet in the western part of the county and less than 1,800 feet in the eastern part, lying somewhat lower in the larger valleys than on the broad divides. The coincidence in elevation and slope, and the striking similarity of the lithology of the high terrace gravels of Russell county to those of the Ogallala formation, appear to justify their correlation with that formation.

Uselessness of Cenozoic Rocks for Structural Mapping.

No evidence was found to prove that the Cenozoic beds may not have been warped slightly by earth movements, or by settling of the buried strata during Recent time, but the discontinuity of the deposits and their irregular, unconformable contact with Cretaceous rocks, make them useless for structural mapping.

Mesozoic.

Cretaceous.

Niobrara Formation.

The Niobrara formation, consisting of a series of chalky beds, crops out only in the extreme northwest corner of Russell county, where a maximum thickness of about 100 feet remains uneroded. The lower part consists of massive beds of chalk containing few impurities, white and rather soft above and tan and harder below; the upper part consists of beds of soft chalk and chalky marl, silty and iron-stained.

The stratigraphic position, lithology and fossils of this formation establish its correlation with the Niobrara of Colorado, Wyoming,

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3. Darton, N. H.; Syracuse-Lakin Folio (No. 212): U. S. Geol. Survey Geol. Atlas, p. 5; 1920.

4. Haworth, Erasmus; Special report on the well waters in Kansas (geologic map of Kansas); Univ. Kansas Geol. Survey, Bull. 1, pl. 1; 1913.

South Dakota and Nebraska, and make highly probable its correlation with the Austin chalk of Texas.[5]

The formation was named by Meek and Hayden,[6] in 1861, from exposures near the mouth of Niobrara river in northeastern Nebraska. The Niobrara formation in Kansas has been subdivided into the Smoky Hill chalk member above and the Fort Hays limestone member below.

SMOKY HILL CHALK MEMBER.

Character and distribution. The argillaceous Smoky Hill chalk member of the Niobrara formation occurs only as thin remnants capping the higher hills in the northwestern part of the county. It consists of soft beds of chalky marl containing scattered ferruginous concretions and alternating thin beds of chalk rock, which together reach a maximum thickness of nearly 50 feet in Russell county.

Clear exposures of this member were not found in Russell county, but the exposures seen indicate that its composition is similar to that of beds found 30 miles to the west, in sec. 17, T. 11 S., R. 20 W., Ellis county, where the lower 90 feet or so of the Smoky Hill member—a soft chalky shale and alternating harder beds of chalk, and some very thin layers of clay—is exposed. Flat, more or less circular, impure limonitic concretions, many of which are about a foot in diameter in the plane of bedding and 3 or 4 inches thick, occur throughout the member, but are most abundant in the lower 30 feet. These concretions contain a central core of slightly weathered pyrite several inches in diameter and an inch thick, and at least some of them contain nuclei of thick *Inoceramus* shells. The cubical faces of the pyrite crystals are commonly a half to a quarter of an inch in diameter. G. E. Patrick[7] found that chalk beds of this member contain 84 to 98 per cent of calcium carbonate, and crude quantitative analyses made by the senior author show that some of the marly beds contain about 50 per cent of lime.

The marly parts of the Smoky Hill member are separated into thin beds by clayey partings, but the harder and less numerous chalk beds are commonly massive. The marly beds appear to soften and the chalk rocks to harden somewhat on weathering, so that on the freshest surfaces the two types are almost indistinguishable. Fresh exposures of the rocks are white, pale cream, or bluish gray, but

5. Stanton, T. W.; Later Mesozoic invertebrate faunas: Jour. Geology, vol. 17, p. 419; 1909.

6. Meek, F. B., and Hayden, F. V.; Descriptions of new lower Silurian (Primordial), Jurassic, Cretaceous and Tertiary fossils collected in Nebraska Territory [etc.]: Phila. Acad. Nat. Sci. Proc. for 1861, vol. 13, pp. 419-42; 1862.

7. Patrick, G. E.; Kansas chalk: Kansas Acad. Sci. Trans., vol. 4, pp. 13-15; 1875.

weathered surfaces have a yellowish tint, which ranges from a bright tan to a light cream. The concretions weather to a conspicuously darker rusty brown.

Joints are not readily recognizable in the member because of poor exposures, but at some localities outside of Russell county faults with displacements ranging from a fraction of an inch to a few feet are conspicuously marked by slickensided, coarsely crystalline veins of calcite, 1 to 6 inches thick. Mudge[8] mentions the occurrence of crystals of barite in some of these veins.

Fossils.[9] Large, thick, rather flat and coarsely ribbed shells, formerly referred to the genus *Haploscapha* Conrad, but now placed in the genus *Inoceramus,* are abundant from the base of the Smoky Hill upward, but were not found below that member. This *Inoceramus* has been designated by three specific names in the literature—*grandis* Conrad, *eccentrica* Conrad, and *niobrarensis* Logan—but it is very likely that the three are not distinct and should be included under the one name *I. grandis.* The small shells of the colonial oyster *Ostrea congesta* Conrad are common throughout the exposed portion of the member. Vertebrate remains, largely fragments of bone, have been found at many places, and the member contains abundant *Globigerina bulloides* D'Orbigny and *Textularia globulosa* Ehrenberg.

Means of recognition. The Smoky Hill chalk member does not form prominent topographic features in the eastern area of its outcrop, but makes long, gentle, sodded slopes with few exposures, benched by thin beds of chalk along the larger streams where vigorous tributaries have cut into it. The residual soils derived from the member range from gray to black, their color depending somewhat upon the siltiness of the underlying bed, but chiefly upon the extent to which the lime has been extracted by leaching and upon the amount of organic matter that has accumulated at the surface.

The Smoky Hill member, which somewhat resembles several other subdivisions of the Cretaceous of central Kansas, can be more or less readily distinguished from the Greenhorn limestone and the Fort Hays member of the Niobrara formation by its persistently yellower color and the absence of numerous thick beds of chalk rock or occasional thin beds of crystalline limestone. The Fairport chalky shale member of the Carlile shale, which it most closely resembles, contains fewer beds of chalk rock and no limonitic concretions.

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8. Mudge, B. F.; Notes on the Tertiary and Cretaceous periods of Kansas: U. S. Geol. and Geog. Survey Terr., Bull. 2, p. 215; 1876.

9. The discussion of fossils is based on identifications made by J. B. Reeside, Jr.

Difficulty of mapping. Detailed mapping of individual beds within the Smoky Hill member is practically impossible except along the larger stream courses, where adequate exposures permit their actual tracing or the recognition of distinctive sequences of beds. Throughout the remainder of its area the structure of the rocks can be determined only by shallow drill holes that penetrate to some easily recognizable horizon, such as the top of the Carlile shale—a slow and costly method.

Name. The Smoky Hill chalk member of the Niobrara formation was first known as the "*Pteranodon* beds,"[1] but later was named by Cragin[2] from Smoky Hill river, in Kansas. Geographic names are now preferred to paleontologic names for designing formations, and the term Smoky Hill is to-day in good standing. Cragin subdivided the Smoky Hill member into four parts—the bluish and marly "Trego zone" at the base, the yellow and more chalky "Norton zone" next above, the Graham jasper next, and a thin unnamed subdivision at the top. Williston,[3] later, in 1896, proposed to subdivide the Smoky Hill into two submembers—the "*Rudistes* beds" below and the "*Hesperornis* beds" above. Probably the portion of the member exposed in Russell county is equivalent to parts of the "Trego zone" of Cragin and the "*Rudistes* beds" of Williston.

FORT HAYS LIMESTONE MEMBER.

Character and distribution. The rim of the highest buttes in the northwest corner of Russell county is made by the Fort Hays limestone member of the Niobrara formation. This member, somewhat more than 50 feet thick, is in this area made up of massive beds of chalk, white and rather soft above and tan and harder below.

Complete exposures of this member were not found in Russell county, but partial sections found at a number of places near by indicate a widespread similarity of detail. Near the northwest corner of Ellis county the Fort Hays member appears to be about 55 feet thick, and this is probably near its average thickness in the area here considered.

The uppermost beds, where fresh, are commonly pure white, moderately hard, massive chalk, which weathers white or pale cream and develops a thin-bedded structure. Individual chalk beds of greater purity and hardness than the remainder are apparently

1. Credited to Marsh by Williston, S. W.; Smoky Hill chalk: Kans. Univ. Quarterly, vol. 4, p. 251; 1896.

2. Cragin, F. W.; On the stratigraphy of the Platte series, or the Upper Cretaceous of the Plains: Colo. Coll. Studies, vol. 6, pp. 51-52; 1896.

3. Williston, S. W.; Idem, p. 252.

most numerous near the middle of these white beds. Small limonitic concretions with nuclei of pyrite occur in the upper part. These upper beds are 20 to 30 feet thick.

The intermediate, or, in a few places, the basal beds of this member are harder and form more or less prominent bluffs of massive beds, 1 to 6 feet thick, of tan to dull buff chalky limestone. The rock is rather uniformly a light cream where fresh and it contains some thinner-bedded portions. Small limonitic balls about a quarter of an inch in diameter are sparingly distributed through the lower part. This unit is from 15 to 30 feet thick and probably averages about 20 feet in thickness in Russell county.

Farther west, at one or two localities in Ellis and Trego counties, the basal 20 or 30 feet of the Fort Hays member is softer and thinner bedded and contains layers of chalky shale. Slightly sandy layers; long, narrow, vertical worm tubes; and "conglomerates" made of fragments of *Inoceramus* shells, occur in some places. This phase appears to become thinner toward the east, until near Russell county it is absent or is represented by but 2 or 3 feet of soft, gritless chalk.

The hard beds throughout the Fort Hays member readily soil the fingers with a white chalky powder and especially the white upper beds easily leave a white mark. The rock contains Foraminifera of the *Globigerina* types, which, however, are apparently not common, the bulk of the rock being made up of very fine white grains of powder, 0.01 millimeter or less in diameter. These features[4] appear to make the lithologic name *chalk* or *chalkstone* more appropriate than the more general or more technically restricted term *limestone*.

This member, like the overlying Smoky Hill, is sufficiently brittle to resist slight deformation, and in places it has yielded to pressure or gravity by breaking, so that small faults are not uncommon in areas of its outcrop. The Fort Hays member is unique among the strata of central Kansas in its decided propensity to slump. Great blocks of the basal beds may be seen lying as much as 50 feet below their normal position. This slumping, however, is rarely accompanied by great fracturing of the rock.

Some indication of an unconformity at the base of this member was found near the northwest corner of sec. 32, T. 11 S., R. 16 W., Ellis county, 5 miles west of Fairport. Here vertical cracks, three-eighths of an inch wide, filled with fragments of the Fort Hays limestone, extend 20 feet into the underlying sandstone bed of the

4. De Lapparent, J.; Leçons de petrographie: pp. 359-361, Masson et Cie, Paris; 1923.

Carlile shale. It is probable that these filled joints are merely fractures formed by slumping.

Fossils. The thick-shelled, rather regular, and deeply cupped *Inoceramus deformis,* about 8 inches in diameter, and *Ostrea congesta*[5] occur throughout the member, but are especially abundant in its lower part. Except for the microscopic *Globigerina* and *Textularia,* no other fossils were noted in this member.

Topographic prominence. The Fort Hays member is topographically one of the most prominent of the rock units in central Kansas. As it is harder than the thick underlying beds of the Carlile shale, its lower part at many places caps an irregular line of hills that stand 100 feet or more above the surrounding country. Isolated buttes, some small and nearly conical, others long and flat-topped, are rather common near the boundary of the member with the Carlile shale, and some stand at distances of nearly a mile from it. A gentle upland slope, almost invariably developed on the upper softer beds, at many places reaches nearly to the base of the member. The upper part of the member is rarely well exposed, and is at most places represented by a white or light limy soil in which small chips of chalk are usually abundant. On the weathered south slopes of the divides and in similar areas of local relief the lower beds make a fairly conspicuous bench of very light tan soil that is relatively barren of vegetation. The severe slumping of the basal beds of the Fort Hays member gives rise to a distinctive topographic form that is misleading from a distance. At some places on the steeper bluffs below the Fort Hays scarp several lines of prominent benches or terraces may be seen, which when examined closely are found to be made by long slumped ledges of Fort Hays chalk that dip steeply back toward the hill and form bands of narrow undrained depressions behind them. Because of the moisture retained in these troughlike depressions, the vegetation grows more rankly in them than on the bordering slopes.

Means of recognition. The Fort Hays member somewhat resembles in its lithology the Smoky Hill member of the Niobrara, the Fairport member of the Carlile, and the Greenhorn limestone, all chalky. From the Fairport and Smoky Hill members it is distinguishable by its thick beds of hard chalk, the light color of its weathered surfaces, and the presence of clay shales below. The Greenhorn formation has thinner hard chalk beds, many layers of chalky marl, and thin beds of coarsely crystalline dark gray lime-

5. Identifications by J. B. Reeside, Jr.

stone near its base, and is about twice as thick as the Fort Hays member.

The contact of the Fort Hays limestone member with the overlying Smoky Hill chalk member is at many places difficult to recognize. Typically the lower beds of the Fort Hays member make a fairly prominent scarp, showing tan, hard, more or less massive beds of chalk or a light-colored soil sparsely strewn with small chips of hard chalk on which vegetation grows sparingly. Above this scarp the upper beds of the member form a gentler slope of very light soil. The Smoky Hill, however, almost uniformly makes a very gentle slope of dark clay soil, and in good exposures presents small scarps of conspicuously tan, soft, relatively thin-bedded chalky shales. Large limonitic concretions are abundant in the lower part of the Smoky Hill, but similar though much smaller ones are found in the upper part of the Fort Hays member. Because of its superior hardness and whiteness in contrast with the beds immediately overlying, the top of the Fort Hays member is usually recognized by drillers in well borings.

Unreliability of the Fort Hays member for detailed mapping. Its topographic prominence and more or less distinctive characteristics might seem to make the Fort Hays member a valuable unit for detailed structural mapping. Unfortunately, however, except for the general subdivisions of white and softer beds above and yellow and harder beds below, it is very difficult to recognize any of its individual components for distances sufficient to make their mapping profitable. The top of the basal Fort Hays bluff is held by the same bed for short distances only—a fact all too apt to be overlooked in mapping areas where exposures are poor. On many of the smaller isolated buttes near the Fort Hays-Carlile contact the capping basal Fort Hays strata are tilted and are rarely at the proper elevations for this horizon as judged from surrounding outcrops; and one is forced to the conclusion that even the narrower projecting arms of the Fort Hays member show the same tendency, for the strata gradually rise along these spurs to the main divides. These observations have led the writers to the conclusion that in areas of poor exposures the only uniformly reliable horizon in this member for detailed structural mapping is its contact with the underlying Carlile shale, and to the belief that even this contact is not reliable on narrow divides and isolated hills where small areas of the member may have slumped below their normal position. Shallow drill holes over much of the flat uplands might be used profitably to determine the structure of the beds at places where deformation is suspected.

Name. Because of an earlier miscorrelation by Hayden of the chalk beds at Wilson, Kan., Mudge, in 1876,[6] tentatively applied the name "Fort Hays division or group" to all the strata from the top of the Dakota to the base of the present Smoky Hill member of the Niobrara formation, being in doubt as to presence of the Benton in Kansas. Williston,[7] in 1892, restricted Mudge's name to the present Fort Hays member, and although Cragin[8] later proposed the name "Osborne limestone" for the same unit, Fort Hays has been used by all other writers on western Kansas since 1893.

The Term Benton.

"Fort Benton group" was the name applied by Meek and Hayden,[9] in 1861, to the Cretaceous strata (their No. 2) between the Dakota and the Niobrara. The name, which was taken from Fort Benton, Mont., continued to be used in that form for many years, but was finally shortened to Benton shale where the rocks are indivisible and to Benton group where they are divisible. The term Benton was long used for the corresponding unit in Kansas, but Logan,[1] in 1897, made comparisons with the Carlile, Greenhorn and Graneros formations of Colorado, and in 1899[2] he made these correlations more positively. Darton,[3] however, in 1904, was the first to apply these Colorado names in Kansas, retaining Benton as the group name for the three formations. The United States Geological Survey, however, many years ago abandoned the use of the term Benton group, because the Carlile, Greenhorn and Graneros formations, together with the overlying Niobrara formation, compose the Colorado group—a broader and more useful group name.

Carlile Shale.

About 300 feet of argillaceous and chalky shale that crop out in Russell county between the Niobrara and Greenhorn formations

6. Mudge, B. F.; Notes on the Tertiary and Cretaceous periods of Kansas: U. S. Geol. and Geog. Survey Terr. Bull. 2, pp. 218-221; 1876.

7. Williston, S. W.; The Niobrara Cretaceous of western Kansas: Kans. Acad. Sci. Trans. for 1891-1892, vol. 13, pp. 108-109; 1893.

8. Cragin, F. W.; On the stratigraphy of the Platte series [etc.]: Colo. Coll. Studies, vol. 6, p. 51; 1896.

9. Meek, F. B., and Hayden, F. V.; Description of new lower Silurian (Primordial), Jurassic, Cretaceous, and Tertiary fossils collected in Nebraska Territory [etc.]: Phila. Acad. Nat. Sci. Proc. for 1861, vol. 13, pp. 417-422; 1862.

1. Logan, W. N.; The Upper Cretaceous of Kansas: Kan. Univ. Geol. Survey, vol. 2, pp. 232-234; 1897.

2. Logan, W. N.; A discussion and correlation of certain subdivisions of the Colorado formation: Jour. Geology, vol. 7, pp. 83-91; 1899.

3. Darton, N. H.; Comparison of the stratigraphy of the Black Hills, Bighorn Mountains and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 445; 1904.

make up the Carlile shale. The entire thickness of the formation remains in only a small area in the northwest corner of the county, but the lower 20 to 50 feet is found on the flat uplands that comprise a large part of its area. The formation was named by Gilbert[4] from exposures at Carlile Spring and at Carlile, Pueblo county, Colorado. In general the Carlile shale is argillaceous, but in its upper part it contains calcareous and ferruginous concretions, and in its lower fourth or third it is highly calcareous, and includes thin beds of chalk. This formation was conspicuously in the public eye for a few years before and after 1900 as the "gold shales" of western Kansas. Mills were erected in Ellis and Trego counties to recover gold and silver thought to exist in them in small quantities, but although minute traces of both metals were found in some samples of the shale, none contained sufficient quantities to make their mining profitable.[5] The Carlile shale in Russell county has been subdivided into the Blue Hill shale member above and the Fairport chalky shale member ("Ostrea shales") below.

BLUE HILL SHALE MEMBER.

More than 200 feet of gray, fissile, clay shale, containing beds of calcareous and sideritic concretions, constitute the Blue Hill ("Victoria") shale member of the Carlile shale. This member crops out on the higher ridges in the northwestern eighth of Russell county. It is strikingly uniform throughout, the chief vertical differences being in the number, size and composition of the calcareous concretions—those in the lower part being smaller, flatter, and more ferruginous—and in the presence of a bed of sandstone at the top. Its precise thickness is difficult to determine satisfactorily, because the slumping of the overlying Fort Hays member on narrow divides and isolated hills makes the location of its true upper boundary uncertain, but in sec. 29, T. 11 S., R. 16 W., in Ellis county, 5 miles west of Russell county, it is about 215 feet thick.

Upper sandstone division. The upper 20 to 25 feet of this member in Russell county is a "salt and pepper" gray, rather soft, massive, fine-grained argillaceous sandstone, which in its lower part, to the southwest, in Ellis county, becomes a finely gritty, fissile clay shale, containing one-inch beds of soft, very thin bedded sandstone. The rock is friable but not highly porous, and although its content of

4. Gilbert, G. K.; The underground waters of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey, 17th Ann. Rept. pt. 2, p. 565; 1896.

5. Lindgren, Waldemar; Tests for gold and silver in shales from western Kansas: U. S. Geol. Survey Bull. 202, pp. 5-19; 1902.

lime is so low as to be negligible, its content of clayey material is high. The grains range in diameter from 0.4 millimeters down to that of particles of fine clay. There is no great predominance of any one size, but the diameter of the larger particles averages about 0.125 millimeters. The grains are not much rounded and the largest ones are commonly much more angular than those of the intermediate sizes, an unusual feature. Most of the grains are quartz, chiefly colorless, a few of which show shadowy extinction under crossed nicols, but some are smoky gray and translucent and a few are pink and transparent. Dark gray chert, somewhat kaolinized orthoclase, and some black opaque fragments are rather common, and grains of clear orthoclase and some plagioclase (more calcic than An 30), faintly pinkish microcline, and perfect crystals of zircon showing no effects of abrasion are present. Much of the quartz shows abundant inclusions that are in part at least acicular crystals of brown tourmaline and apatite. This bed of sandstone is noteworthy in that it is immediately overlain by chalk and that it is the only thick bed of sandstone in the Cretaceous sections of Kansas above the Dakota sandstone, for at very few horizons above the lower part of the Graneros shale are the sediments even slightly sandy. A sandy unit at the top of the Carlile shale in South Dakota, Colorado and Wyoming,[6] the "Pugnellus" sandstone[7] in south-central Colorado, and the "Niobenton" sandstone[8] of the oil geologists in north-central Colorado, are comparable in lithology and stratigraphic position with and may be correlatives of this bed of sandstone in Kansas.

Lower shale and concretion division. The 190 feet or so of the Blue Hill member that lies below the upper sandy deposit is a uniformly gritless, noncalcareous, fissile, dark bluish-gray clay shale. It contains, especially in the lower part, scattered crystals and vertical veins of selenite one-eighth inch thick and some transparent barite. Some white, readily soluble salt ("alkali") stains the surface of the lower shale beds over small, poorly drained areas. Numerous concretions occur along definite bedding planes throughout these beds, and all those in any individual layer appear to be uniform in character. These beds of shale are very fissile, and where

6. Darton, N. H.; Comparison of the stratigraphy of the Black Hills, Bighorn Mountains and Rocky Mountain Front Range: Geol. Soc. America Bull. vol. 15, pp. 444-6; 1904.

7. Stanton, T. W.; The Colorado formation and its invertebrate fauna: U. S. Geol. Survey Bull. 106, p. 28, 1893.

8. Henderson, Junius; The foothills formations of north-central Colorado: Colo. Geol. Survey Bull. 19, p. 85, 1920.
Ball, Max W.; Gas near Fort Collins, Colorado: Bull. Am. Assoc. Petro. Geol., vol. 8, p. 83; 1924.

somewhat cracked by weathering they may properly be called "paper shales." This fissility and the accompanying minute joints make this member somewhat open-textured, at least near the outcrop.

For 120 to 150 feet below the sandstone bed the concretions are large, ellipsoidal and septarian, and are composed of argillaceous calcium carbonate. Their diameter parallel to the bedding of the shale ranges from about 2 feet for the concretions in the lower part of the member to 4 feet or more for those near its top. They are rudely circular in plan, and their vertical is about half their horizontal diameter. They are composed of finely crystalline to dense calcite, which on fresh surfaces is generally dark gray, but weathers lighter. The larger weathered concretions develop a pseudogranular texture, formed by a series of nodular radiating cylinders about an eighth of an inch in diameter. Veins of brown to colorless coarsely crystalline calcite,[9] from a quarter of an inch to an inch thick, fill joints in nearly all the concretions in this unit, but are most noticeable in those in the upper part. The distribution of the concretions, though more or less restricted to definite bedding planes throughout, becomes increasingly random upward, the largest, found near the top, being very irregularly spaced.

A group of concretions whose top is 25 to 40 feet below the base of the Niobrara formation is commonly very conspicuous, though it varies greatly in total thickness and detailed characteristics. Two layers of large, bright tan concretions, identical with the rest except in the color of the weathered surface, are notably persistent. The upper and generally the more prominent of these is about 100 feet below the Niobrara; the other, which is about 35 feet lower, is the lowest concretion zone recognized in this middle unit.

The basal 65 feet of the Blue Hill member contains but two persistent layers of concretions. Both layers are readily distinguishable from those in the upper zones, for the concretions are smaller, flatter, and contain more fossils. The upper concretions occur abundantly on a bedding plane 47 to 50 feet above the base of the member. They are commonly from 6 to 12 inches in greatest diameter, elliptical in plan, and about 2 inches thick. On fresh surfaces they are dark gray, but upon weathering they become brown.

The lower layer of concretions, which lies about 31 feet above the base of the member and averages about an inch in thickness, might be called a persistent concretionary bed of ironstone or partly oxi-

9. Erasmus Haworth, formerly director of the Kansas Geological Survey, orally mentioned to the writers the fact that barite and strontianite accompany the calcite crystals in some of these veins.

dized siderite. The concretions in this layer, which are similar in shape to those in the layer next above, are so abundant that they merge into one another. They contain but little lime, and only the thicker nodules show an unweathered center of blue-black siderite, the bulk of the bed being a hard, dense, somewhat clayey limonite concentrically banded with some hematite.

Fossils. No fossils were found in the upper three-fourths of the Blue Hill member, but other investigators have found at places near by a rather extensive, chiefly invertebrate fauna in the septarian concretions.[1]

The lower 50 feet of the member is, however, more uniformly fossiliferous. The concretions 50 feet above the base contain a few small gastropods and a large pointed-shelled *Inoceramus* related to if not identical with *Inoceramus fragilis* Hall and Meek; the ironstone concretions contain the small finely ribbed ammonite *Prionocyclus wyomingensis* Meek, the original nacreous luster of which is preserved in a number of the specimens; and the fine-ribbed *Inoceramus fragilis* of normal size. A few feet above the base thick *Inoceramus* shells occur, and at the very base of the member there is an accumulation of sharks' teeth (both the cutting and the crushing types), fragments of fish bones (largely centra of the vertebræ), and phosphatic reptilian coprolites.[2]

Topographic expression. The beds of the Blue Hill shale member are so slightly resistant to erosion that they form prominent topographic features only where they are capped by harder rock. The Fort Hays limestone member commonly forms such a capping, and the resulting flat-topped buttes and spurs, which stand high above their surroundings, have been noted in the description of the Fort Hays limestone member. The concretions in the middle and lower part of the member give rise to less prominent hills, the large, scattered concretions forming more or less conical buttes and the ironstone bed a low but very persistent flat-topped bench. In and near the northwest corner of Russell county a conspicuous terrace covered with younger gravels occurs for several miles at a nearly constant stratigraphic horizon about 80 feet below the top of the member.

1. Mudge, B. F.; Notes on the Cretaceous and Tertiary periods of Kansas: U. S. Geol. and Geog. Survey Terr. Bull., vol. 2, p. 219; 1876.
Cragin, F. W.; On the stratigraphy of the Platte series: Colorado Coll. Studies, vol. 6, p. 50; 1896.
Logan, W. N.; The Upper Cretaceous of Kansas: Kansas Univ. Geol. Survey, vol. 2, p. 219; 1897.
Logan, W. N.; Some additions to the Cretaceous invertebrates of Kansas: Kansas Univ. Quart., vol. 8, pp. 87-98, pls. 20-23; 1899.
Logan, W. N.; A discussion and correlation of certain subdivisions of the Colorado formation: Jour. Geology, vol. 7, pp. 88-99; 1899.

2. These determinations were made in the field by J. B. Reeside, Jr.

Soil and vegetation. The soil on the outcrops of the Blue Hill member is generally thin and is entirely absent from many of the steeper slopes, but it is fairly thick on the relatively flat uplands. The face of the terrace for about 20 or 25 feet below the ironstone bench is almost everywhere barren. Near the southeastern margin of its outcrop the member caps broad divides, on which it forms a black soil. Vegetation grows rather sparingly on the member, the characteristic coarse grasses being accompanied by small shrubs on the sandy unit and by a few yucca plants in places on the zones of larger concretions. The clay shales are commonly wet a foot or so back from the exposure, and an almost unbroken line of small seeps of water at the very base of the member supports a strip of ranker vegetation.

Means of recognition. The rocks of the Blue Hill member could be confused only with those of the Graneros shale, for all the other gray, gritless Cretaceous shales of central Kansas effervesce readily under hydrochloric acid. The presence of large calcareous concretions, the absence of an underlying series of sandstone and variegated shale, and the much greater thickness of the Blue Hill (215 as against 40 feet), readily distinguish it from the Graneros formation.

The boundary between the Blue Hill shale and the chalky Fort Hays limestone is at most places easily recognizable, for there is no confusing transition zone, clay shales are not found in the Fort Hays, and beds of chalk are not found in the Blue Hill. The upper limit of the sandy unit coincides with the base of the soft or hard chalk, and on clean exposures this contact is unmistakable. Where it is covered, the topography and the soil are generally reliable criteria by which to identify the boundary, the more or less conspicuous bench of white chalky soil almost everywhere marking the lower ledge of the Fort Hays, and the dark, sodded or bare slope of the Blue Hill member below showing a pronounced bluish-gray cast and being studded with large concretions. The Blue Hill member is not so hard and is more plastic than the Fort Hays, and these facts and the sandstone bed at the top of the Blue Hill should make the contact recognizable in all carefully taken records of drill holes.

Horizons suitable for mapping. As already noted, the widespread slumping of the Fort Hays member makes the contact of the Fort Hays and the Blue Hill member a key horizon that can be used successfully for detailed mapping only with the exercise of great care. The persistence, thinness and characteristic lithology of the ironstone bed near the base of the Blue Hill make it an excellent key

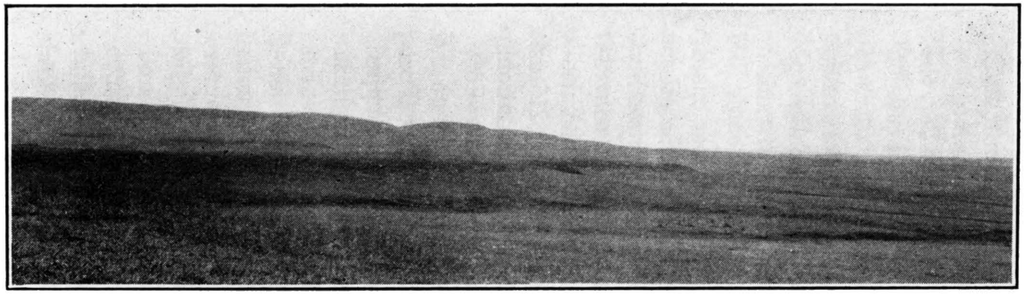

FIG. 4. A prominent bench capped by ironstone concretions in basal part of the Blue Hill shale member of the Carlile shale, in sec. 3, T. 11 S., R. 15 W., Russell county.

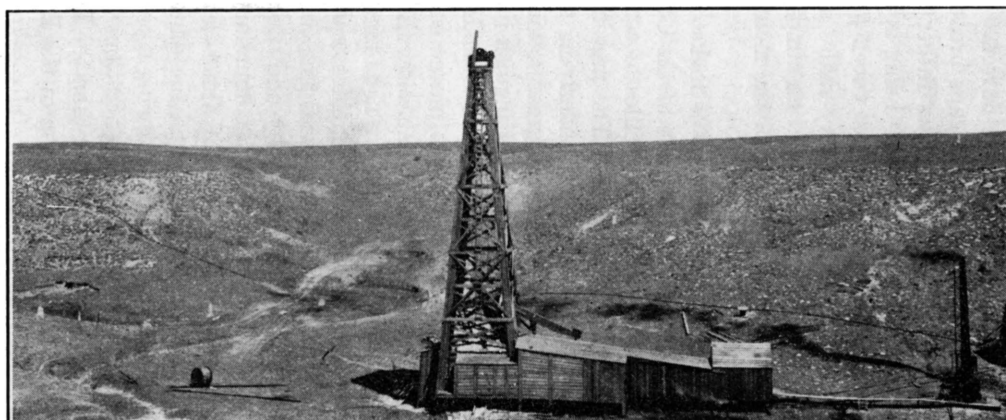

FIG. 5. Slabs of chalky limestone of the Jetmore member of the Greenhorn limestone, shown as they typically cover the surface in areas of rather poor exposures. Sec. 24, T. 12 S., R. 15 W., Russell county.

bed. The less closely spaced, flat calcareous concretions about 50 feet above the base of the member may also be used for this purpose, but they are somewhat less satisfactory than the ironstone bed. The higher concretions, because of their greater size and weight, tend to slide down the steeper slopes, making it difficult to determine their true stratigraphic position. The two lines of rusty-weathering concretions near the middle of the member are the most distinctive of the horizons of concretions and can be used if care is taken to find the highest individual concretions.

Name. The Blue Hill member was named by Cragin,[3] in 1896, the "Victoria clays," from the town of Victoria, and Victoria creek near by, in Ellis county, Kansas, six miles west of Russell county. In the following year Logan[4] called this member the Blue Hill shales, apparently from the Blue Hills, in Mitchell county, Kansas, which he stated "rest upon the Ostrea beds and are composed of the Blue Hill shale, capped by a layer of Fort Hays limestone." Logan's unit was limited below by his "Ostrea shales" (the Fairport chalky shale member of this report) and above by the Septaria horizon—the large septarian concretions in the upper part of the present Blue Hill member. The Septaria horizon he included in the Niobrara, although he stated that it is at many places embedded in the Blue Hill shale. Not only are the shale beds in and above the Septaria of Logan lithologically indistinguishable from those of his Blue Hill, but the diagnostic septarian concretions in and near Russell county extend much lower into his Blue Hill member than Logan suspected, and the fossils are Carlile and not Niobrara species.[5] Most later writers, including Logan,[6] have included the Septaria horizon in the Blue Hill, and it is here included in that member. Cragin described as the "Cannonball zone" a group of large concretions in the lower part of his "Victoria clays," apparently applying the term to the lower of the two brown-weathering concretion layers. Although Cragin's name "Victoria" has slight priority over Logan's name Blue Hill, and about equal usage with Blue Hill, it conflicts with three other uses of Victoria (for rocks of Devonian, Mississippian and Cretaceous ages) in American and Canadian literature, but there is no conflict with the name Blue Hill. For this reason Blue

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3. Cragin, F. W.; On the stratigraphy of the Platte series: Colo. Coll. Studies, vol. 6, p. 50; 1896.
4. Logan, W. N.; The Upper Cretaceous of Kansas: Kansas Univ. Geol. Survey, vol. 2, pp. 218-219, 225; 1897.
5. J. B. Reeside, Jr.; personal communication.
6. Logan, W. N.; The invertebrates of the Benton, Niobrara and Fort Pierre groups: Kansas Univ. Geol. Survey, vol. 4, pp. 434-436, 441; 1898.
———; A discussion and correlation of certain subdivisions of the Colorado formation: Jour. Geology, vol. 7, pp. 88-89; 1899.

Hill has been adopted for this member and the name "Victoria" has been discontinued. The fauna found in the Blue Hill member is an upper Carlile assemblage of species.[7]

FAIRPORT CHALKY SHALE MEMBER.

Character and distribution. The Blue Hill member is underlain by 85 feet of chalky marl and thin chalk beds that are here called the Fairport chalky shale member of the Carlile shale. Although this member crops out in its entire thickness only in the northwestern eighth of Russell county, its lower part is exposed on the uplands throughout the area. Its basal third or fourth contains nearly all the harder chalk of the Fairport member, the upper beds being composed almost entirely of chalky marl.

So persistent laterally in and near Russell county are even the thinnest beds of the Fairport member that the accompanying composite section is thought to be representative for the area. Minor variations in the thickness of the several beds and units, but no general directions of thickening were found, and the variations are in fact less than the probable error in measurement.

Average section of Fairport chalky shale member of the Carlile shale near Fairport, Russell county, Kansas (in descending order).

[Fossils identified by J. B. Reeside, Jr.]

	Ft.	In.
Blue Hill shale member of Carlile shale	..	..
Fairport chalky shale member of Carlile shale:		
1. Chalky, slightly sandy shale; dark where fresh; weathers yellow. Abundant fragments of thick shells of *Inoceramus* and some *Ostrea congesta*	11	0
2. Chalky, slightly sandy shale with one or more half-inch beds of medium gray, hard, crystalline limestone at top. Finely banded; weathers yellow; selenite crystals on surface. Very large, thin shells of *Inoceramus* near base	13	0
3. Sandy chalk, rusty brown, soft. *Inoceramus* (resembles *I. dimidius*), *Prionotropis woolgari*, *Scaphites*, fragments of teeth and bone	..	3
4. Chalky shale, very dark gray with half-inch bed of bluish-white clay near center. Contains *Ostrea*	2	2
5. Ocherous clay	..	2
6. Chalky shale	..	2
7. Sandy chalk, brown streaked with gray. Contains *Prionotropis woolgari* and *Serpula*	..	5
8. Chalky shale with beds of white clay one-eighth inch thick. Very large, very thin shells of *Inoceramus*	1	10
9. Argillaceous chalk, brown. No *Inoceramus* shells	..	2
10. Chalky shale with half-inch bed of clay at top	1	11
11. Argillaceous chalk, brown. No *Inoceramus* shells	..	2
12. Chalky shale	3	0

7. Reeside, J. B., Jr.; personal communication.

		Ft.	In.
13.	Sandy chalk, concretionary, ferruginous, soft. Abundant fragments of thick *Inoceramus* shells	..	3
14.	Chalky shale	2	5
15.	Sandy chalk, concretionary, ferruginous. Large, very thin shells of *Inoceramus*	..	3
16.	Chalky shale with thin beds of yellow clay. Contains *Ostrea*	6	3
17.	Sandy chalk, hard. Contains many fragments of *Ostrea, Inoceramus* and *Serpula*	..	2
18.	Chalky shale, white and buff mottled, with thin yellow clay at top. Contains smooth, white *Ostrea*	4	2
19.	Agrillaceous sandy chalk; tan, thin-bedded	..	2
20.	Chalkv shale	1	4
21.	Argillaceous, sandy chalk; hard, tan, thin-bedded	..	2
22.	Chalky, sandy shale, medium gray to drab where fresh, mottled white and buff where weathered; thin-bedded. Fragments of thick *Inoceramus* shells; abundant *Ostrea congesta*	11	3
23.	Slightly sandy chalk, rusty brown, fossiliferous	..	4
24.	Chalky shale, tan, with abundant *Ostrea congesta*	2	0
25.	Chalk, tan; contains a few fish scales	..	3
26.	Chalky shale, very slightly sandy; black where fresh, very light gray to tan where weathered. Contains abundant *Ostrea congesta*	2	3
27.	Chalk, hard, brown to pink (the Pink lime of some oil geologists)	..	4
28.	Chalky shale, tan, fissile. Fish scales and abundant *Ostrea congesta*	5	2
29.	Chalk, rather coarse grained, dark gray to buff. Contains *Inoceramus fragilis* and *Priontropis woolgari*	..	5
30.	Chalky shale, dark to white and tan mottled; fissile. Contains two horizons of concretions, the upper random and discontinuous, about 5 inches thick and less than 2 feet below top; the lower closely spaced, persistent; concretions ellipsoidal, about 8 inches thick, and about 3 feet below top. Many fish scales, *Inoceramus fragilis,* and *Prionotropis woolgari*	7	11
31.	Chalk, hard, gray. Contains *Inoceramus fragilis* and *Prionotropis woolgari*	..	5
32.	Clay, ocherous in color, highly calcareous; resembles bentonite	..	5
33.	Chalky shale, slightly sandy, fissile; medium gray where fresh, buff or tan where weathered; includes three horizons of concretionary, harder, crinkly bedded chalk in beds about 2 inches thick. Contains fish scales and *Ostrea*	4	10
	Greenhorn limestone	..	..
	Total thickness of Fairport member	85	0

Distinctive beds. The thin but persistent beds of yellow and white clay are valuable aids in identifying the adjacent chalk beds. They are easily recognizable by a peculiar jointing that has been appropriately likened to the texture of fish meat. The distinctive 5-inch bed of yellow clay near the base of the member (bed No. 32 of the accompanying section) is a means of identifying the overlying chalk bed as the one 5½ feet above the top of the Greenhorn limestone. The persistence and the structure of these beds of clay greatly resemble that of the layers of bentonite[8] which are so common in the Cretaceous sediments of Wyoming and elsewhere. The clays in Russell county, however, do not show the marked peculiarity of most bentonites—that of swelling to several times their original volume when immersed in water—and so, though they may be bentonitic, many geologists would not call them true bentonites.

The distinctive ellipsoidal calcareous concretions that lie about 11 feet above the base of the member (the lower of the two zones of concretions in No. 30 of the accompanying section) range from a foot to a foot and a half in diameter and from 6 to 10 inches in thickness and occur regularly every few feet horizontally in all the exposures examined. In many of the exposures the median plane carries abundant large *Inoceramus* shells. The bedding of the chalky shale bends sharply over and under the concretions (Fig. 3). The three horizons of much flatter concretions at the base of the member (No. 33 of section) are also distinctive.

An extreme example of the variation found in this member is seen in the bed of chalk that lies about 20 feet above its base—the Pink lime of some oil geologists (No. 27 of section). About 2 miles south of Fairport this bed is a hard, pink chalk about 6 inches thick, but a few miles to the northwest it becomes soft, rusty brown, and but 2 or 3 inches thick, and 3 miles north of Wilson it is a limestone or chalk breccia consisting of scattered, slightly tilted flat fragments of pink, dense limestone, from 2 to 8 inches across, embedded in porous gray chalk.

The chalky shale beds are dark gray, dark buffy gray, or nearly black on fresh exposures, but where weathered are light tan. The beds in the upper third of the member (Nos. 1 and 2 of the section) weather to a brighter yellow than those below.

Fossils.[9] Flattened shells of *Ostrea congesta* about half an inch in diameter abound throughout the member, occurring chiefly in the shale, but also in the chalk, both isolated and in clusters on clam shells. The ammonite *Prionotropis woolgari* occurs most abundantly in the lower 15 feet and about 20 feet below the top. Traces of the worm *Serpula tenuicarinata* Meek and Hayden were found in two of the upper chalk beds. A deeply cupped, coarsely ribbed *Inoceramus,* similar to but not identical with *Inoceramus dimidius,* less than an inch in diameter, occurs in a few beds about 25 feet below the top of the member. *Inoceramus* shells, many of them less

8. Bentonite is probably a decomposed volcanic ash. See Hewett, D. F.; The origin of bentonite [etc.]: Wash. Acad. Sci. Jour., vol. 7, pp. 196-198; 1917.

9. Identifications by J. B. Reeside, Jr.

than a quarter of an inch thick, but some measuring 32 inches or more across, are abundant from 20 to 45 feet below the top. Shells of this type are rarely found unbroken and generally are seen merely as cross sections of broken shells. Fragments of thick *Inoceramus* shells occur most abundantly in the upper beds, but are also found in the middle portion of the member. Fish scales, some of them an inch across, are commonest in the lower fourth, but some, which are associated with fragments of teeth, extend nearly to the top, though in fewer numbers. Near the west quarter corner of sec. 5, T. 13 S., R. 15 W., Russell county, lentils of brown lignite a foot or more long, containing thin layers of "glance" coal, occur at the base of a concretionary chalk bed 3 feet above the base of the member.

Means of recognition. Only the lower 20 or 25 feet of the Fairport member is hard enough to make conspicuous topographic features. This part makes benched slopes or small points and isolated hills on top of the persistent bench formed by the Greenhorn limestone. The middle and upper parts of the member make nearly flat weathered slopes with few exposures.

The soils derived from the lower and middle parts of the Fairport member are dark drab to black; those derived from beds near the top are sandy and bright yellow. The high fertility of these soils and the gentleness of the slopes on which they lie combine to make them some of the most desirable wheat-growing land in the region. Where the soils formed by this member are not under cultivation they bear an abundant growth of native short grasses.

The Fairport member somewhat resembles the Smoky Hill and Fort Hays members of the Niobrara formation and the Greenhorn limestone. From the Fort Hays member and from most of the Greenhorn limestone it can be readily distinguished by the facts that it does not contain numerous hard chalk beds, that its weathered color is yellower, and that it is underlain by a series of beds of chalk and chalky shale. It can be distinguished from the Greenhorn limestone by means of features mentioned in the description of that formation, and it can be distinguished from the Smoky Hill member by its lack of massive beds of chalk and large ferruginous concretions and its abundant content of shells of *Ostrea.*

The boundary between the Fairport and Blue Hill members of the Carlile shale is readily determinable. The beds below the contact effervesce with acid and weather to light yellowish tints; those above the contact are free from lime and are dark bluish gray. The high degree of fissility and the concretions and the ironstone bench in the Blue Hill, as well as the slight sandiness and bright yellow color of the upper part of the Fairport, afford additional means of recognizing this boundary. The striking change in the composition and stickiness of the shales at the upper limit of the member should be detectable in drilled holes, although few well logs show this change.

Beds useful in detailed mapping. The beds that form the lower 25 feet of this member are useful for detailed mapping, for they are distinctive and easily followed. With greater care, the chalk beds in the middle and upper parts can also be traced, but the poor exposures common to this part of the section make it generally less desirable for use than the easily recognized beds in the lower part of the overlying Blue Hill shale. Although the contact of the Blue Hill shale with the Fairport member cannot be followed as continuously as many of the hard beds, it is sufficiently distinctive to be mapped. The wide, soil-covered flat uplands that are underlain by the lower part of this member may most profitably be mapped by the use of numerous shallow drill holes. The sequence of the beds, which is especially distinctive in the lower 25 feet of the member, should make the recognition of key horizons in such borings possible.

Name and correlation. The name Fairport is here proposed for this member, from the exposures a few miles south and west of Fairport, Russell county. The lower 22 feet of the member are well exposed in the southeast quarter of sec. 7, T. 12 S., R. 15 W., Russell county, 2 miles south of Fairport. Good exposures of the lower 55 feet are found in Ellis county, in the southeast quarter of sec. 3, T. 12 S., R. 16 W., 2½ miles southwest of Fairport; of the lower 60 feet in the northeast quarter of sec. 29, T. 12 S., R. 16 W., 5 miles west of Fairport; and of the upper 28 feet in the southwest quarter of the same section. The name is proposed as a geographic name to replace Logan's "Ostrea shales," a term which he first used in 1897,[1] and which has been adopted by subsequent writers. Logan somewhat ambiguously defines the lower limit of his "Ostrea shales" by stating that the "Fence-post horizon" is "near the top of the (underlying) limestone group" (p. 217), but this ambiguity is cleared up by his statement that the "Ostrea shales rest conformably upon the Fence-post horizon of the lower group" (p. 217). His name was distinctive and appropriate, for the shales contain an abundance of *Ostrea*, but modern American stratigraphic names are geographic, taken from places where typical exposures are found.

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1. Logan, W. N.; The Upper Cretaceous: Kansas Univ. Geol. Survey, vol. 2, pp. 217, 218; 1897.

The fossils contained in the Fairport member are the species found in the lower part of the Carlile shale of Colorado, Wyoming and elsewhere.[2]

Greenhorn Limestone.

Below the Carlile shale lie about 100 feet of beds of hard chalk and chalky marl, which constitute the Greenhorn limestone. This formation crops out on both sides of the valleys of the tributaries of the three large streams that run eastward across Russell county—Smoky Hill and Saline rivers and Wolf creek. Hard chalk in beds less than a foot thick alternate with chalky shale in the upper three-fourths of the formation. The proportion of chalk to marl is highest about one-fourth way down from the top. The lower fourth of the formation contains, in addition to the chalk and chalky shale, thin beds of hard crystalline limestone. From several measurements it seems that the thickness of the Greenhorn formation decreases from 105 or 110 feet in the northern part of Russell county south-southeastward to 85 or 90 feet in the southern part.

The great abundance of the fossil *Inoceramus labiatus,* the stratigraphic position, and the calcareous composition of the formation permits a close correlation of the formation[3] with the Greenhorn limestone of parts of Colorado, Wyoming and elsewhere. The name Greenhorn was given by Gilbert,[4] in 1896, to corresponding beds in southern Colorado, which are typically exposed at Greenhorn station and on Greenhorn creek, south of Pueblo, Colo. The formation in Russell county, Kansas, is divisible into four members, here listed in descending order: (1) An upper unnamed member consisting of beds of chalky shale and fossiliferous chalk; (2) the Jetmore chalk member, which consists of regularly alternating beds of chalk and chalky shale; (3) an unnamed member of chalky shale containing few beds of chalk; and (4) the Lincoln limestone member, consisting of thin beds of crystalline limestone in a series of beds of chalk and chalky shale.

Upper member. The upper 20 feet of the Greenhorn limestone in Russell county is a chalky shale containing three beds of chalk, 4 to 10 inches thick. The uppermost one—the top bed of the member and of the formation—is the justly famous "fence-post limestone" or "post rock" of the farmers of western Kansas. It is a rather hard, slightly sandy, fairly coarse but even-grained and massive

2. J. B. Reeside, Jr.; personal communication.

3. J. B. Reeside, Jr.; personal communication.

4. Gilbert, G. K.; The underground waters of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey, Seventeenth Ann. Rept., pt. 2, p. 564; 1896.

chalk that maintains a thickness of 8 or 9 inches. Where it lies under cover it is softer. On fresh surfaces the rock is dark gray, but it weathers to a light yellow gray or cream and shows a prominent rusty median line. It contains relatively few fossils. The rock, which is nearly free from joints, is easily split with wedges to desired shapes, and so it is widely used as building stone, bridge masonry, fence posts, and even telephone poles throughout the Greenhorn area in western Kansas; in fact, in this nearly treeless region wooden posts are rarely seen, and at nearly every outcrop of this bed in Russell county the rock has been quarried to some extent for these uses.

The 8 or 9 feet of soft, chalky, slightly gritty shale below the "fence-post limestone" contains several layers of thin, flat, rather inconspicuous concretions. Beneath these beds of marl lies a layer of hard, iron-stained chalk, 5 inches thick, which contains many *Inoceramus* shells. Below the middle chalk lies 5 feet of chalky shale, which is in turn underlain by a zone 2½ feet thick of thin, highly fossiliferous concretionary chalk beds. In the southeast quarter of sec. 25, T. 15 S., R. 17 W., Ellis county, an elongate chalk concretion with a coarsely crystalline core of barite a few inches in diameter and several feet long was found at this horizon. The basal 4 feet of the member is chalky shale. Analysis of a sample of the marl shows that about 55 per cent of it by weight is insoluble silty material containing small flakes of muscovite. The thickness of this member in Russell county is nearly constant. Apparently it increases southward from 19 to 21 feet.

Jetmore chalk member. The group of alternating thin beds of chalk and chalky shale that occupy the interval from 20 to 40 feet below the top of the Greenhorn formation is the Jetmore chalk member. The uppermost bed of this group—the "*Inoceramus* limestone" or "shell bed" of oil geologists—is a hard, thin-bedded to massive, very fossiliferous fine-grained chalky limestone, which within narrow limits of variation is about a foot thick. It is a light buff gray on fresh exposures, but weathers almost white. A bed of flat, chalky concretions occurs in the shale about 2 feet below the top of the member. Below its upper bed the Jetmore member is an alternating series of layers of chalk and chalky shale, the layers of chalk decreasing downward in thickness from 6 inches to 1 inch, and the marl beds from about 2 feet to 2 inches. The upper 10 feet or so contain the most fossils, which are found in greatest abundance in the 1-foot bed at the top of the member. The base of the Jetmore member is not sharply defined, for by a progressive thinning of the lower chalk beds it grades into the underlying chalky shale. Clean exposures, such as those in secs. 17 and 20, T. 13 S., R. 14 W., Russell county, show that 12 or 15 layers of chalk more than 3 inches thick are contained in the upper 20 feet, but that thinner beds extend a few feet lower.

Unnamed member. Below the Jetmore chalk lies an unnamed member consisting of about 35 feet of chalky shale that contains a few thin beds of chalk and clay. A rough quantitative analysis indicates that a sample of this marl included 65 to 70 per cent of silty material which contained a few small flakes of muscovite. Perhaps the most prominent and most easily recognizable part of the member is a five-inch massive bed of hard medium-gray fine-grained chalk, which lies 14 or 15 feet above the base of the member and contains well-preserved *Inoceramus* shells, and flat vertical marks resembling blades of grass. Below this bed lies 1 or 2 feet of yellow or light bluish gray clay and some gray and green chalky shale, which overlie a softer, lighter colored, less fossiliferous bed of chalk of about the same thickness. Above the fossiliferous stratum lies a 2-foot or 3-foot bed of chalky shale, which is succeeded above by thin, slightly sandy, beds of chalk containing small pyritic nodules, and a few beds of yellow clay. This member thickens from 28 feet in the northern part of Russell county to about 40 feet in its southern part.

Lincoln limestone member. The lowermost subdivision of the Greenhorn limestone is here called the Lincoln limestone member. It consists of beds of chalk and chalky shale, with thin beds of hard dark gray crystalline slightly sandy fossiliferous limestone at its base and top and in some places near the middle. The limestones emit a strong odor of petroleum on fresh fracture. A few thin beds of yellow clay occur in the lower half of the member. The beds of crystalline limestone are commonly only 2 to 6 inches thick and are massive within this thickness. Under the microscope the rock is seen to be composed largely of fibers derived from the prismatic layer of *Inoceramus* shells, with lesser amounts of spherical foraminifera, and a few brown, probably phosphatic granules, the whole imbedded in a matrix of finely crystalline calcite. Although dark gray on fresh surfaces these beds are greenish or brownish gray where somewhat weathered. The Lincoln member ranges in thickness from 20 feet in the western part of the county to about 25 feet in its eastern part.

Distinctive colors of the members. The marly beds of the Greenhorn limestone are dark gray where fresh, but become light, more or less yellowish gray on weathering. The members apparently contain different quantities of iron, for on weathering each develops a distinctive shade of yellow. The Jetmore chalk is the lightest colored member of the formation, its beds becoming a very pale, faintly creamy gray or near-white. The Lincoln member appears to be the most ferruginous, for where weathered it is a rather bright tan. The members above the Jetmore and the Lincoln assume intermediate colors, the one at the top of the formation being lightest, but both are a rich cream color.

Fossils.[5] The Greenhorn limestone contains an abundance of shells of *Inoceramus labiatus* Schlotheim—flat, elongated, tongue-shaped bivalve shells, commonly about 6 inches long, that are ornamented by concentric rounded ribs which themselves bear finer ribs. This fossil is most abundant in the lower part of the upper member and in the top layer of the Jetmore chalk, and although it occurs throughout the formation, it was not found beyond its limits. Other large fossils are not common in this formation, but a few other interesting species occur sparingly: *Baculites gracilis* Shumard, *Metoicoceras whitei* Hyatt, *Helicoceras pariense* (White), a second species like *Helicoceras corrugatum* Stanton, and a new species of the ammonite genus *Puzosia.* There are also scattered oysters much like *Ostrea congesta* Conrad, worm-eaten pieces of wood,[6] small fragments of teeth, scales and bones, and possible plant stems in the lower part. The surfaces of many of the chalk beds show nearly microscopic *Globigerina,* and these minute fossils make up probably one-fourth of the volume of the samples of chalky shale examined.

Topographic expression. The Greenhorn limestone is second only to the Fort Hays member of the Niobrara formation in topographic prominence, the thick series of relatively hard chalk beds nearly everywhere forming a steep benched slope or actual bluff. The Jetmore member makes the most conspicuous and persistent scarp, its topmost bed capping a steep slope, 10 to 20 feet high, at all but the very poorest exposures. The "fence-post limestone," at the top of the upper member, also makes a persistent bench, but as the underlying 20 feet is chiefly soft chalky shale, the slope capped by this bed is gentle, no conspicuous bluff being formed. The thin-bedded crystalline limestone at the top of the Lincoln member commonly forms a minor bench on the faces of the steep slopes of the Greenhorn lime-

5. Identifications by J. B. Reeside, Jr.
6. Apparently coniferous, according to F. H. Knowlton.

stone in the larger valley, and at some places where the slopes are gentler it makes a scarp distinct from that formed by the upper members, and traceable for a mile or more. At many places the similar strata at the base of the Lincoln and other chalk beds here and there throughout the formation form minor benches.

Soil and vegetation. Owing perhaps chiefly to the steepness of the slopes, the soil on the outcrops of the Greenhorn limestone is commonly thin. On the gentler south slopes of the divides, however, the soil may be sufficiently thick to mask all but the most prominent hard beds. Throughout most of the county the Jetmore bluff is either quite barren or is covered with a nearly white, thin, chalky loam, but the other members permit the accumulation of a thicker soil. Tall, coarse, native grasses are the commonest growths on the formation, but on a few of its more sheltered cliffs the Jetmore member supports clumps of small conifers.

Resemblance to other Cretaceous strata. The Greenhorn limestone resembles in its chalkiness the Smoky Hill and Fort Hays members of the Niobrara formation and the Fairport member of the Carlile shale. Its beds of chalk are thicker and more numerous and its weathered exposures are less stained with yellow than those in the Fairport member. It differs from the Fort Hays and Smoky Hill members chiefly in containing no thick, massive beds of chalk and in its inclusion, near the base, of thin beds of crystalline limestone. It further differs from the Fort Hays member in containing much interlaminated marl.

The contact of the Greenhorn limestone with the overlying Carlile shale is rather arbitrarily drawn at the top of the "fence-post limestone." No real lithologic distinction can be made between the lower 25 feet of the Fairport chalky shale member and the uppermost member of the Greenhorn limestone. In fact, the unit containing flat chalk concretions extends from about 22 below to 12 feet above this boundary. The paleontologic change, however, is fairly distinct. *Inoceramus labiatus* occurs only below the boundary and *Inoceramus fragilis* and *Prionotropis woolgari* only above it, and no zone of admixture of faunas was noted. Fortunately, this paleontologic change occurs at the top of an easily recognizable stratum, the "fence-post limestone." Distinctive sequences of chalk, chalky concretions, yellow clay, and chalky shale make the horizon easily determinable where the overlying rocks are exposed; and the characteristics of the individual chalk beds in the two members below the contact aid in determining the position of the boundary where the underlying beds are exposed. In addition, the widespread quarrying of the "fence-post limestone" is in itself a valuable aid in the recognition of that bed, but it must be employed with care, for at some places the chalk bed 5½ feet above the "fence-post limestone," and at a few places other chalk beds above and below, have been similarly quarried. The gentle slope on the Fairport member is commonly farmed down to the chalk beds in the lower 25 feet of the member. From that point to the base of the Fairport member short grasses generally grow, but at the "fence-post limestone" there is a sharp change to taller, coarser grasses. The nearly white persistent bluffs on the Jetmore member are easily distinguished from the discontinuous exposures of cream and reddish tan shales on the gentler slopes of the upper member of the Greenhorn limestone and the lower part of the Fairport member. The contact is one that is not at all likely to be noted in well logs.

Value for detailed mapping. The thin but hard, persistent and widely distributed beds of chalk in the Greenhorn limestone make that formation almost an ideal one for detailed structural mapping, and the work done by commercial geologists in and near Russell county has been virtually restricted to two layers of chalk in the upper 20 feet of the formation—the "fence-post" and the "*Inoceramus*" beds. Throughout much of the area lower beds also may be profitably employed, the prominent upper and basal layers of the Lincoln member being good key beds for detailed mapping. For reconnaissance work the top of the conspicuous Jetmore member is the most satisfactory horizon in the Cretaceous section of western Kansas.

Names of members. Logan[7] divided his lower limestone group (the Greenhorn and Graneros formations of this report) into five members. Four of these—the Lincoln, "flagstone," "*Inoceramus*" and "fence-post"—constitute the present Greenhorn limestone. Between the Lincoln member and the "fence-post bed" of the upper member, Logan's subdivisions are not recognizable in Russell county, though his "*Inoceramus* horizon" probably comprises the upper part of the Jetmore and the lower part of the upper member as delimited in this report.

Cragin[8] proposed the name "Downs limestone" for the "fence-post bed." Although this bed is unusually persistent for one so thin, it does not merit classification as a separate member, and its local

7. Logan, W. N.; The Upper Cretaceous: Kansas Univ. Geol. Survey, vol. 2, pp. 215-217; 1897.

8. Cragin, F. W.; On the stratigraphy of the Platte series or Upper Cretaceous of the Plains: Colo. Coll. Studies, vol. 6, p. 50; 1896.

name, "fence-post limestone," is widely known and quite satisfactory.

The name Jetmore is proposed for the 20-foot member that lies from 20 to 40 feet below the top of the Greenhorn limestone. It is taken from prominent exposures south and east of Jetmore, along the south side of Buckner creek, in Hodgeman county, Kansas. Although its base is indefinite in many places, the progressively varying alternation of chalk and chalky shale stamps this member as a definite unit of sedimentation. The usage among oil geologists of the term "*Inoceramus* bed" for the top stratum of this member may lead to some confusion, for Logan's "*Inoceramus* horizon" probably included chalk layers above and below this bed, but its prominence and persistence make the upper bed of the member so valuable for structural mapping that a name to emphasize its value is well deserved.

Lincoln "marble" was a local name applied to crystalline limestone quarried in Lincoln county, and was apparently first used in the literature as the name for a geologic unit by Cragin[9] in 1896. As a name for the quarried stone, *marble* is justified by usage, but a more precise lithologic term for the rock would be *crystalline limestone*.

Graneros Shale.

The beds of clay shale that lie below the Greenhorn limestone and above the Dakota sandstone constitute the Graneros shale. This formation, which is about 40 feet thick, crops out as a continuous narrow band at the base of the Greenhorn bluffs along the larger streams in Russell county. It contains thin, hard, sandy layers, which are few and calcareous near the top and more abundant and highly ferruginous in the lower half. Irregular variations in the thickness of the formation of as much as 20 feet are due to the lenticular form of the beds of sandstone at the base of the Graneros shale and top of the underlying Dakota sandstone.

Lithology. The soft, noncalcareous, gritless shale of this formation is very fissile, and where naturally exposed is a dark bluish gray. In places the weathered slopes are strewn with crystals of selenite and stained rusty brown, and the minor joints are covered with a sulphur-yellow powder. The iron sulphate melanterite is abundant on the weathered outcrops, and its bitter taste is fairly characteristic of the formation.

Some one-inch beds of sandy limestone occur in the upper part of the Graneros shale. In the southwestern part of the county a thin-

9. Cragin, F. W.; idem.

bedded, somewhat iron-stained bed of sandstone a few inches thick, which lies about 10 feet below the top of the formation, is strongly ripple-marked on its upper surface. These ripples are of the symmetric or oscillation type, and commonly have an amplitude of about a quarter of an inch and are 2 inches from crest to crest. They trend about S. 30° W. In some localities a white to yellow clay bed, slightly more than an inch thick, occurs about 2 feet below the top of the formation. At many places the lower half of the formation contains numerous beds of hard, ferruginous, gypseous sandstone, from 1 to 6 inches thick. These beds are discontinuous laterally, few of them being traceable more than 200 or 300 feet.

Local zones of calcareous concretions were found at two horizons. In the southeast part of the county the upper concretions are about 2½ feet below the top of the formation; they are fossiliferous and distort the bedding of the overlying shale for as much as a foot with slender nodular protuberances that extend into the upper beds. The lower concretions, which occur about 20 or 25 feet below the top, are also fossiliferous and are very argillaceous and sandy. In places they contain cone-in-cone layers less than half an inch thick.

Fossils.[1] Several of the harder beds in the upper part and a few in the lower part of the Graneros shale are fossiliferous. The small oysterlike shell, *Exogyra columbella* Meek, with curled beak and rather fine, low-rounded ribs, occurs in the lower half of the formation and is usually accompanied by the small pelecypods, *Callista tenuis* Hall and Meek and *Corbula nematophora* Meek. At a few places in the lower part of the formation the high-spired gastropod, *Turritella whitei* Stanton, and fragments of fish teeth, bone and scales were found at several horizons throughout the formation. In the upper part a medium-sized undescribed oyster occurs abundantly at some places accompanied by a large undescribed species of *Prionotropis,* also known in the upper or Belle Fourche shale member of the Graneros shale of the Black Hills region.

Exposures. The Graneros shale is soft and at many of its outcrops makes a gentle slope. In parts of the larger valleys the hard overlying Lincoln member of the Greenhorn limestone and the sandstone beds in the underlying Dakota formation make a steep bluff in which the Graneros shale is well exposed, but at such places talus and slides from the Greenhorn exposures obscure parts of it.

Distinguishing features. This formation resembles only the Blue Hill member of the Carlile shale and some beds in the Dakota sand-

1. Identifications by J. B. Reeside, Jr.

stone. The dark fissile shales, with their persistent melanterite taste, are nowhere chalky, though in places they include thin, hard, calcareous layers. The occurrence of harder, sandy strata that are commonly ferruginous, the absence of abundant calcareous concretions, the thinness of the formation as a whole, and the underlying series of beds of sandstone and variegated shale serve to distinguish it from the upper member of the Carlile shale. The contact of the Graneros shale with the overlying Greenhorn limestone is not difficult to determine, even in places where a foot or more of transitional strata occur. The Greenhorn limestone contains no beds of argillaceous shale, and the beds of crystalline limestone at the base of the Lincoln member are sufficiently distinctive to permit ready recognition.

Unsuitability for mapping. The Graneros shale is not well adapted to detailed structural mapping, for it is well exposed at but few places. The thin, hard beds in its upper part are persistent, but the more ferruginous ones in the lower part are extremely lenticular and untrustworthy. Horizontal proximity to the persistent and easily recognizable base of the Lincoln member of the Greenhorn limestone makes the use of Graneros strata unnecessary at most places. However, the Graneros shale contains the stratigraphically lowest beds that may be relied upon for tracing, and in parts of the broader, deeper valleys of Russell county it contains the only key beds available.

Name and correlation. The Graneros shale was so named by Gilbert[2] from exposures at Graneros and on Graneros creek, in Pueblo county, Colorado. Although the beds in Kansas had previously been correlated with the Graneros of Colorado by Logan,[3] Darton,[4] in 1904, was the first to apply the name Graneros to the rocks in Kansas.

The fossils found in the Graneros shale in Russell county are typical of the Graneros[5] elsewhere, but they do not indicate clearly the particular part of the much thicker Graneros of the Rocky Mountain region to which the Kansas strata are most nearly equivalent. The abundant small pelecypods are similar to forms found in western Wyoming in the lower part of the Thermopolis

2. Gilbert, G. K.; The underground waters of the Arkansas Valley in eastern Colorado: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 2, p. 564; 1896.

3. Logan, W. N.; The Upper Cretaceous of Kansas: Kansas Univ. Geol. Survey, vol. 2, pp. 232-234; 1897. Also, A discussion and correlation of certain subdivisions of the Colorado formation: Jour. Geol., vol. 7, pp. 83-91; 1899.

4. Darton, N. H.; Comparison of the stratigraphy of the Black Hills, Bighorn Mountains, and Rocky Mountain Front Range: Geol. Soc. America Bull., vol. 15, p. 445; 1904.

5. J. B. Reeside, Jr.; personal communication.

shale (equivalent to basal Graneros), but the cephalopod found near the top of the formation in Russell county closely resembles a form found near the top of the uppermost member of the Graneros in northeastern Wyoming.

DAKOTA SANDSTONE.

The thick series of beds of variegated sandy shale and lentils of sandstone that make up the bed rock in the floors and sides of the larger valleys in Russell county is the Dakota sandstone. About 160 feet of the upper part of this formation is exposed in Russell county. More than half the beds consist of shale or sandy shale, but the most prominent constituent of the formation at its outcrops is the harder sandstone. The shale is variegated and gray, sandy and argillaceous; the sand in the sandstones is well sorted. Lignite and calcareous concretions occur at some horizons. The horizontal variation in the composition of the formation is great, sandstone bodies 50 to 100 feet thick in some places giving way entirely to variegated shale within distances of less than half a mile. In general the upper 10 feet or so is regularly bedded sandstone and the lower beds are shale, but thick lenses of crossbedded sandstone occur in places throughout the formation.

The formation was named by Meek and Hayden,[6] in 1861, from exposures near the town of Dakota, in northeastern Nebraska. In Russell county, Kansas, the Rocktown channel sandstone member occurs irregularly in the upper 125 feet of the formation.

EVENLY BEDDED STRATA.

Upper sandstone unit. At most of the outcrops in Russell county a series of beds of fine- to very fine-grained, evenly bedded or massive sandstone, from 5 to 20 feet thick, lies at the top of the formation, but in places this unit is absent. Wherever found, these beds of sandstone contain more highly ferruginous layers and fairly abundant plant remains consisting of pieces of carbonized wood, or flat, vertical, grasslike marks. Despite the regularity of bedding, the individual layers are very discontinuous, the top of the formation in some places varying 10 feet in stratigraphic position within a few hundred feet along the outcrop (Fig. 6). A few miles northwest of Lucas a concretionary bed of tan sandy limestone about an inch thick occurs at or near the top of the formation.

6. Meek, F. B., and Hayden, F. V.; Descriptions of new lower Silurian (Primordial), Jurassic, Cretaceous and Tertiary fossils collected in Nebraska Territory [etc.]: Phila. Acad. Nat. Sci. Proc. 1861, vol. 13, pp. 419-422; 1862.

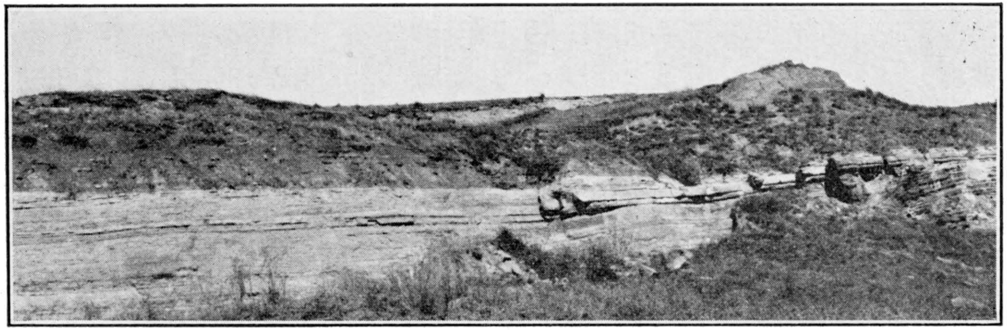

FIG. 6. Contact of the Graneros shale and Dakota sandstone. Lensing strata of evenly bedded sandstone at top of Dakota formation make contact about 8 feet lower stratigraphically in right foreground than in left. View southeastward in NE¼, sec. 33, T. 12 S., R. 14 W., Russell county.

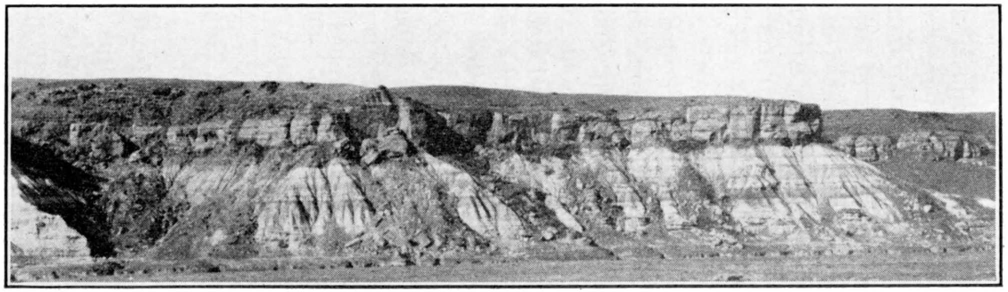

FIG. 7. Evenly bedded sandstone at the top of the Dakota formation, underlain by variegated shale that is intricately dissected into "bad-land" slopes. View northeastward, sec. 34, T. 12 S., R. 14 W., Russell county.

Lignitic beds. In the southeastern half of Russell county beds of lignite from 1 to 2 feet thick are found near the base of the upper sandstone unit, where it is present, or at the top of the formation where the sandy beds are absent. Although two coal beds were not seen in any one section, the different outcrops of coal probably do not lie at the same horizon, although all may fall within one general zone. The lignite in these beds is apparently composed entirely of broken fragments of carbonized wood with which some silty material is intermixed. Abandoned caved prospect tunnels and mounds of shale dumps at many places in the area show that rather extensive but futile efforts have been made to discover commercial deposits of coal. It is reported that considerable coal was actually mined many years ago on Coal creek near the southwestern corner of the county.

Clay shale beds. Under the evenly bedded sandstone and lignite beds in Russell county lies a series of light gray, fissile, gritless clay shale, containing some hard, ferruginous and sandy beds a few inches thick. This unit is generally 15 to 40 feet thick, but in many places it is absent. Some of the thin layers of sandstone contain fragments of carbonized wood. Ferrous sulphate occurs on weathered surfaces of these beds, giving them a peculiar bitter taste.

Variegated mudstone unit. The gray clay grades downward and in some places laterally into hard, massive light greenish gray shale or mudstone mottled with subordinate amounts of bright to dull cherry, maroon, lavendar, brown, and tan. The beds of variegated mudstone alternate with layers of dark gray to black carbonaceous clay. This variegated mudstone is chiefly sandy, but some layers in nearly every section examined are grit-free clay. Small, limy, nodular lenses cut more or less obliquely through the exposures, and thin discontinuous beds of white to heavily rust-stained sandstone occur throughout the unit. At one place, in sec. 4, T. 13 S., R. 11 W., Russell county, a very hard, pyritiferous, sandy, calcareous concretion about 4 feet in diameter was found about 125 feet below the top of the Dakota sandstone. The bedding of the surrounding sandstone is continuous into the concretion. Ferrous sulphate and layers of carbonized wood occur at a few horizons in this unit. The variegated shale extends at least to the lowest strata of the Dakota sandstone exposed in Russell county; that is, to a depth of 160 feet below the top of the formation.

ROCKTOWN CHANNEL SANDSTONE MEMBER.

Occurring locally at almost any horizon from the top to 125 feet below the top of the Dakota sandstone there is a series of very discontinuous, highly cross-bedded sandstone strata that is here named the Rocktown channel sandstone member of the Dakota sandstone.

Lithology. These beds are generally hard where exposed to weathering, but unconsolidated back an inch or so from the outcrop. Although the rock is rather uniformly a light buffy gray where fresh, the weathered exposures of it show all shades of brown, yellow, red, and gray. A few thin lenses of fissile, bluish-gray shale are interbedded with the sandstone. The beds of sandstone vary greatly in thickness within short distances. In sec. 3, T. 13 S., R. 14 W.; secs. 5 and 9, T. 13 S., R. 12 W., and elsewhere in Russell county, cross-bedded sandstone crops out in thicknesses of more than 25 feet on one side of a narrow valley, but only gray and variegated shale is seen at the same stratigraphic position on the opposite side. Clean exposures show that changes of thickness so abrupt take place either by interfingering of the sandstone and shale, as in sec. 11, T. 13 S., R. 12 W., where the cross-bedded sandstone strata thicken 15 or 20 feet at their base in about 200 feet along the outcrop (Fig. 8), or by local unconformity, as in sec. 22, T. 12 S., R. 13 W., where the base of the sandstone cuts more than 25 feet into the underlying shale (Fig. 9).

The sandstone is fine to coarse grained, its grains ranging from less than 0.06 to more than 10 millimeters in diameter, but most of them in nearly all the samples examined ranged from 0.1 to 0.5 millimeters, with 0.25 the commonest diameter. The grains of sand are finer where the sandstone grades laterally into shale. Despite the great difference of size of grains in different pieces of the rock, individual samples were nearly all very well sorted, the largest grains being uniformly only twice the diameter of the smallest abundant grains. The sandstone consists mainly of grains of colorless quartz, but it includes grains of pink transparent quartz, black opaque fragments, and pebbles of clay, the largest 10 millimeters in diameter. Clay pebbles are generally considered proof that the beds containing them were exposed to the air during at least part of the time of their deposition. The finer-grained samples contain also flakes of muscovite, and a red, probably secondary powder

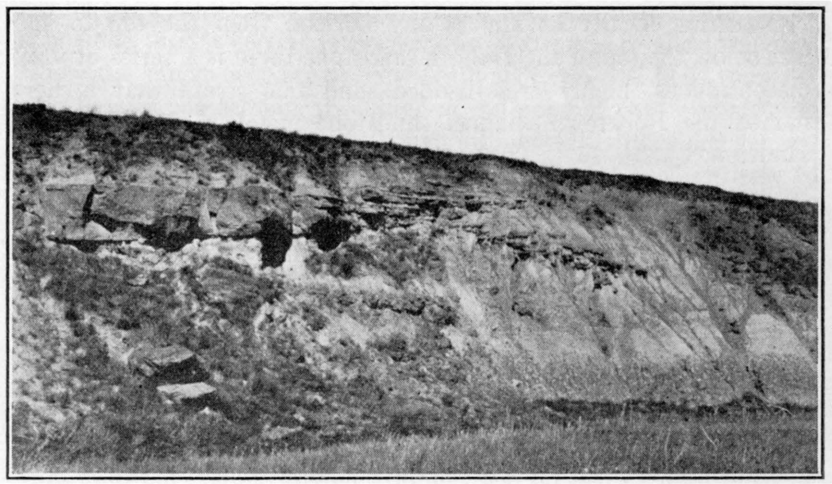

Fig. 8. Interfingering of Rocktown channel sandstone member and variegated shale in the Dakota sandstone, in sec. 11, T. 13 S., R. 12 W. View westward.

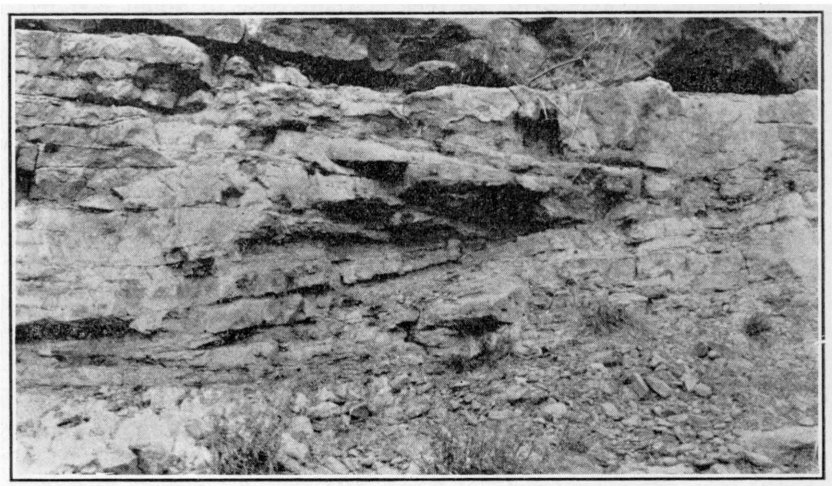

Fig. 9. Local unconformity of the Rocktown channel sandstone member on shale beds in the Dakota sandstone. Sec. 22, T. 12 S., R. 13 W., Russell county. View northward.

fills the interstices of some of the weathered samples. The grains range from highly angular to well rounded, but in almost every hand specimen collected most of them are subangular. Some at least of the extreme angularity found is due to recrystallization. The larger fragments in general are better rounded and show more or less of the "ground-glass" or "frosted" surface generally thought to be produced by wind action.

The cross-bedded laminæ in this member dip from 5° or less to nearly 30° in every direction, but dips of about 22° southwest, west or northwest are most common. Within one stratum that shows oblique bedding the dip is slightly steeper at the top and flatter at the base—that is, the lower cross-bedded laminæ become more nearly tangent to the base of the stratum—and in the thicker strata this condition is at some places very striking. The diagonal laminæ are in beds from 1 inch to 8 feet thick, though 6 inches to 3 feet is the more usual range; or, to put it in another way, the foreset beds are commonly from 1½ to 8 feet long. The beds that show oblique lamination are generally separated by evenly bedded, somewhat thinner strata, but at many places two cross-bedded layers are in immediate contact and the top of the lower layer is abruptly truncated by the upper. In general, though not in detail, the cross-bedding has the same direction throughout any particular vertical series. The bounding planes between the cross-bedded and non-cross-bedded strata are nearly but not strictly parallel; that is, each individual stratum, although of nearly uniform thickness throughout, varies somewhat. In some places these bounding planes dip a few degrees either at right angles to or nearly in the opposite direction from that of the cross-bedded laminæ. Nearly all these features (alternating and essentially parallel layers of rather thin, cross-bedded and thinner evenly bedded strata with the successive cross-bedded layers dipping in the same direction) are peculiar to the torrential type of cross-bedding[7] that is characteristic of stream-channel deposits. However, it is conceivable that this type of cross-bedding might be formed in the sediments deposited in delta distributaries and marine straits.

Distribution of the sandstone lenses. The lenticularity, composition and bedding of the member afford much evidence that it was deposited by streams, and with this interpretation in mind an attempt was made to determine the course of the possible streams

7. Grabau, A. W.; Principles of stratigraphy, pp. 590, 702-703, 704-706; 1913.

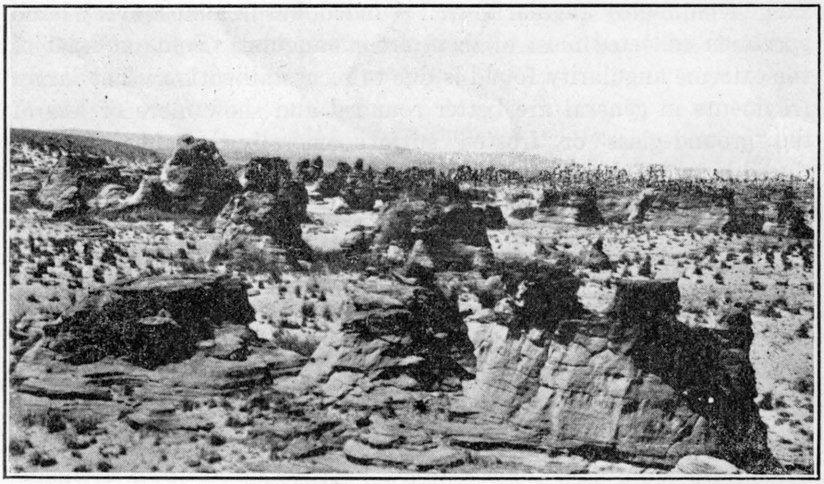

FIG. 10. Sandstone "hoodoos" in Rocktown, in sec. 4, T. 13 S., R. 11 W., Russell county. Rocktown channel sandstone member of Dakota sandstone weathered into vividly stained houselike blocks.

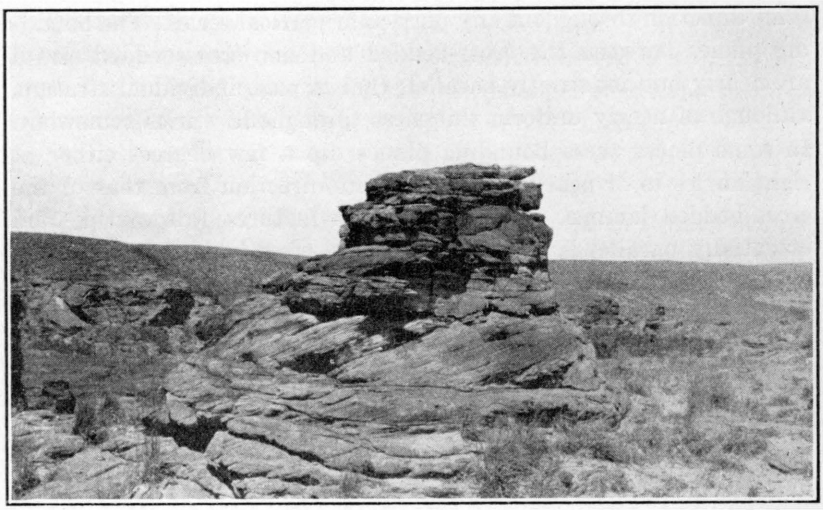

FIG. 11. A sandstone "hoodoo" in Rocktown. A weathered projecting mass of Rocktown channel sandstone, in sec. 4, T. 13 S., R. 11 W., showing oblique laminæ dipping westward.

from the now disconnected lenses of sandstone. These sandstone lentils appear to lie in long, more or less sinuous belts a few miles or less wide, the most conspicuous of which are those in the valley of Saline river, in the eastern part of Russell county. The approximate parallelism of the direction of cross-bedding with the elongation of these lenses observed at a number of places furnished a clue for the interpolation of the supposed channels where the sandstone lenses are buried by younger rocks or removed by later erosion. By this process it was found that all but a very few of the sandstone lenses near Saline river fall into one meandering zone that indicates a general westerly direction of flow of the depositing stream. The remaining isolated lenses suggested tributary streams, and in some places a braided condition of the channel, and even channels that diverged westward from the main zone. However, in determining this preliminary zone the stratigraphic position of the different sandstone lenses had not been considered. By taking into account the relative ages of the lenses (the interval to the top of the Dakota sandstone), the direction of cross-bedding at different stratigraphic positions, and the usual changes in the course of a meandering stream, a second series of zones was drawn (Plate III). For instance, in sec. 22, T. 12 S., R. 13 W., and in sections to the northwest, the sandstone is from 20 to 75 feet below the top of the Dakota sandstone and cross-bedded northwestward, but from sec. 31, T. 12 S., R. 13 W., to sec. 6, T. 13 S., R. 14 W., it is at or near the top of the formation and the cross-bedding dips west-southwestward. This was taken to mean that the stream first flowed northwestward from sec. 22, T. 12 S., R. 13 W., but that after the valley had been more nearly filled by alluviation it flowed westward in a new channel. Also, in sec. 31, T. 12 S., R. 13 W., where the stream may have flowed but a short time, the sandstone is only 15 feet thick, but in sec. 4, T. 13 S., R. 11 W., where the stream is supposed to have remained much longer, the sandstone accumulated to a thickness of 100 feet. This conception of various stages of meanders seems to explain all the sandstone lenses observed in the valley of Saline river as the deposits from one continuous, meandering, shifting stream with one or two smaller tributaries.

Plate III shows the outcrops of cross-bedded sandstone and the observed directions of most prominent cross-bedding in the member. It also shows approximately the location of the more or less obscured and eroded connections between the isolated lentils of sandstone.

Cross-bedded sandstone was noted in other outcrops of the Dakota sandstone in Russell county, but the lenses are thinner and the outcrops more isolated. The fortunately close coincidence in the position of the old channel with the present valley of Saline river makes possible a reconstruction of the old stream course, and whether or not there are other parallel or tributary channels is not definitely known.

Name. The Rocktown channel sandstone member is named from the excellent exposures of the member at and near the large group of "hoodoos" or houselike blocks of sandstone in the northwest quarter of sec. 4, T. 13 S., R. 11 W., locally known as Rocktown.

ORIGIN.

The Rocktown member was evidently laid down by a rather large stream, which in Cretaceous time flowed westward through Russell county. The ground-glass surface found on some of the sand grains may have been developed far to the east and the grains transported to Russell county by the stream; or wind drifting of sand on bars and shores much nearer may have caused it.

The environment assumed in explanation of the origin of this member suggests interpretations of the conditions of deposition of some of the associated units in the Dakota sandstone. The variegated and carbonaceous mudstones in which the Rocktown member is interbedded might be interpreted as silts and fine sands deposited in the back waters of wide flood plains, the various colors possibly being due to different degrees of oxidation. The gray clay shale might by the same reasoning be explained as muds deposited in deeper, more permanent bogs where they were at no time exposed to the effects of weathering. The occasional lenticular ferruginous layers might be the result of the precipitation of iron carbonate in local bogs. The evenly bedded sandstone unit at the top of the Dakota may have been deposited as beach sands, the immediately ensuing marine Graneros shale and the general aggradation of the stream valley suggesting an encroachment of the sea. The fragmental silty lignite beds may have been transported from elsewhere and formed from buried accumulations similar to log jams, but their position just below the possibly marine upper sandstone unit suggests that they may be the result of tidal marsh deposition.

FOSSILS IN THE DAKOTA SANDSTONE.

Plant remains are essentially the only fossils found in the Dakota sandstone in and near Russell county. Well-preserved leaves of

Lomatia? saportanea (Lesquereux) Lesquereux, *Sassafras mudgii* Lesquereux, *Celtis? ovata* Lesquereux and *Populus* sp.,[8] were obtained in a highly ferruginous layer at the very top of the Rocktown member (there about 20 feet below the top of the Dakota sandstone) in the southwest quarter of sec. 22, T. 12 S., R. 13 W. Fragments of leaves occur in heavily iron-stained beds in the shale and at the top of the cross-bedded sandstone at several places in and near Russell county, from 20 to 55 feet below the top of the formation. Indistinct plant stems and fragments of carbonized wood were noted at many places throughout the formation. Cylindrical marks that are probably worm tubes were found in the uppermost regularly bedded sandstone of the Dakota sandstone in sec. 6, T. 15 S., R. 10 W., Ellsworth county. No vertebrate or invertebrate remains were noted, but northeast of Russell county, in Lincoln and Mitchell counties, marine invertebrates of Upper Cretaceous age [9] have been found in the beds near the top of the formation. Southeast of Russell county, in Saline, Ellsworth and McPherson counties, marine invertebrates have been found in Comanche strata in the lower 100 feet[1] of the sandstones and shales immediately below the Dakota sandstone.

VARYING PROMINENCE.

The Dakota sandstone, because of the extreme lenticularity of its harder beds and the wide range in the color of its beds of shale and sandstone, is one of the most striking formations that crop out in Russell county. Except for the lentils, however, it is rather soft, and makes broad, flat valleys. The hard variegated shale is at many places prominently exposed in intricately dissected bluffs—a typical "bad-lands" surface on a small scale (Fig. 7)—but the dark clay shale near the top of the formation is soft and is well exposed at but few places. The uppermost evenly bedded, fairly persistent sandstone makes a series of flat benches below the Graneros outcrop, the number of scarps depending upon the number of hard ferruginous or sandstone layers in the section. The Rocktown sandstone member forms a peculiar topographic feature where slightly harder parts of its outcrops weather to groups of "hoodoos"—more or less isolated, irregularly shaped cones or blocks from 5 to 15 feet high (Figs. 10

8. F. H. Knowlton, who identified these fossil plants, reports that all are well-known Dakota species.

9. Stanton, T. W.; Some problems, connected with tht Dakota sandstone: Bull. Geol. Soc. America, vol. 33, pp. 259-261; 1922.

1. Twenhofel, W. H.; The Comanchean of central Kansas: Kansas Acad. Sci. Trans., vol. 28, pp. 213-223; 1917.

——— The Comanchean and Dakota strata of Kansas: Am. Jour. Sci., 4th ser. vol. 49, pp. 281-297; 1920.

and 11). The sandstone in these weathered blocks shows vivid colors—bright reds, yellows and rich browns alternating with buff, white and gray.

The residual soils on the outcrop of the Dakota sandstone are usually very sandy, but in most of Russell county the formation is obscured by a later covering of alluvium. In many places yucca grows rather abundantly where this formation is at the surface. Seeps of water from the base of sandstone ledges are fairly common in the deeper valleys.

SIMILARITY TO OTHER STRATA.

The Dakota sandstone is the only Cretaceous formation in Russell county that contains variegated shale and much sandstone. Cenozoic deposits are also sandy, but are almost invariably coarser and contain many fragments of feldspar and particles of rock not found in the Dakota sandstone. The soft beds of fissile clay shale generally found near the top of the Dakota resemble those of the Blue Hill member of the Carlile shale and the Graneros shale. The abundant calcareous concretions in shale beds of the Blue Hill member and the thin sandy layers common in the shale in the Dakota sandstone serve readily to distinguish the two. The Graneros shale, however, cannot be easily differentiated from the Dakota sandstone everywhere, for sandstone and clay shale beds are found in both. At most places the base of the fissile gray shale coincides with the top of a hard, regularly bedded sandstone, from 5 to 20 feet thick, which lies about 40 feet below the top of the Graneros shale, but interfingering of the layers of shale and sandstone at many localities causes this contact to range through a stratigraphic interval of about 20 feet. Logs of wells in Russell county indicate that the evenly bedded sandstone is not present in some places at the top of the Dakota formation, and the underlying clay shale is quite indistinguishable from the Graneros shale. In these wells the top of the variegated shale or sandy shale, which is recorded in the logs as red shale or red rock, is doubtless at a variable distance below the top of the Dakota sandstone.

USELESSNESS OF THE DAKOTA SANDSTONE FOR MAPPING OF STRUCTURE.

The Dakota sandstone is practically useless for detailed mapping. No bed within the formation is persistent throughout the county, and possibly no one layer can be traced more than a few thousand feet horizontally, and many lenses extend much less than a thousand feet. Discontinuity alone is not the only characteristic that renders most of the beds unsuitable for use in detailed mapping of structure, for many strata cut obliquely through the adjacent beds of shale, and some of the intervals between different hard layers vary greatly within short distances. No beds in the Rocktown member are suitable for structural mapping, the lenticularity and (where the sand was deposited on a sloping surface) the primary dips of the strata and the continuous shifting of the course of the stream leaving no layers that can be depended on. The carbonaceous and lignitic beds are discontinuous, and the fragmental nature of the constituent woody material suggests that they were not deposited in a widespread swamp of growing vegetation, as most coal beds are supposed to have been formed elsewhere, but may have been formed from flood-carried debris deposited in local backwaters. The flatness of the flood plain suggested by the aggradation that evidently occurred and by the meandering of the channel would seem to make some of the layers of silt or mud deposited on the flood plain fairly reliable key beds, but these silty strata are soft and sufficiently well exposed for recognition and tracing in but a few places in Russell county. The evenly bedded sandstone strata at the top of the formation most nearly fill the requirements for this type of mapping, but the individual layers of even this unit are highly lenticular (Fig. 7). It seems that detailed structural mapping is impossible in the area of the Dakota outcrop in Russell county. It is also impracticable to drill shallow holes to some easily recognizable horizon, for the well logs show that the series of beds of shale and sandstone that form the Dakota (and possibly the Comanche) is from 300 to 400 feet thick in Russell county and is underlain unconformably by a thick series of equally variable beds of red shale and sandstone.

Rocks Concealed.

Beneath the Cretaceous rocks in Russell county lie strata that belong to older geological divisions, which are more or less closely equivalent to those that appear at the surface farther east and south. The only direct information concerning these concealed rocks is that given by records of deep borings. The field work in Russell county included the collection of records of drilled wells and numerous samples of drill cuttings from operators and drillers, who generously coöperated in this work. A detailed study of these data and a tentative correlation (Plate VI) of the rock formations with those in the oil fields of central and eastern Kansas has been made by Mr. Bramlette, whose report forms a part of this bulletin.

STRUCTURE.

The beds in and near Russell county lie essentially flat and undisturbed, showing only a slight regional inclination, which differs in amount and direction in different beds and is interrupted by gentle folds and small faults.

Surface Rocks.

Throughout western Kansas[2] the dip of the surface rocks is in general northward, and in Russell county, where it is north-northeastward, it averages about 7 feet to the mile. In the northern part of the county the regional dip per mile is about 12 feet, but in the southern part it is only 5 feet.

The northward dip is not perfectly smooth, for it is modified by numerous local variations. Throughout Russell county there are low domes, anticlines, terraces, structural noses, synclines and basins, so that the facetious remark that is occasionally made by geologists who have worked in the region, that a "ten-foot closure can be found in every section," is not so gross an exaggeration as it might seem. (As is discussed under the heading, "Economic significance of method of origin," very few of these small folds are thought to be favorable for the accumulation of oil.) Faults, however, are remarkably uncommon in Russell county.

Structural contour map of the top of the Greenhorn limestone. The accompanying structure contour map of Russell county (Plate IV) has been constructed almost entirely by combining the horizontal locations of the different beds sketched with the elevations shown on the topographic maps of the Russell, Osborne, Plainville, Ellsworth, Beloit and Hays quadrangles. The structure contour lines thus derived obviously cannot be correctly placed in detail. Where the regional dip is less than 10 feet to the mile, an error of 25 feet in the elevation of a key bed might cause a horizontal misplacement of a contour line of nearly 3 miles, and such an error could result (1) from uncertainty as to the surface elevation of a point between contour lines on a topographic map having a 20-foot contour interval, (2) from an inaccurate location of the outcropping strata in hasty reconnaissance mapping, and (3) from slight errors in the topographic maps. However, an attempt was made to smooth out the contour lines by using average key-bed elevations for each square

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2. Darton, N. H.; The structure of parts of the central Great Plains: U. S. Geol. Survey Bull. 691, Pl. I; 1918.

mile, and rejecting even these averages if they stood above or below the surrounding area and were not verified by additional information. This smoothing and the interval chosen for the contours—50 feet—make the structure map a fairly reliable representation of the broader structure of the county. Comparisons with detailed maps prepared by company and independent geologists indicate that the map is essentially correct in its major features, but that many irregularities of small horizontal extent are omitted.

Prominent northward-trending anticlines. The folds in Russell county and its vicinity appear to be divisible into two more or less distinct types—the prominent, northward-trending anticlines near the east and the west border of the county, and the smaller, less systematic folds in the remainder of the area. The persistent northward trend of some of the larger folds in Russell and adjoining counties is striking. These larger anticlines, such as the Fairport-Natoma fold and the more or less connected structurally high area in Lincoln county, near the Russell county line, are topographically rather prominent, due to the fact that they stand somewhat above the general structural level. The eastern one is not a long, simple anticline, however, for it consists of a series of elongate domes separated by structural saddles. At some places, as in an area extending northward from a point near Gorham to the northwest corner of the county, and in an area that extends northward from Wilson through the western part of Lincoln county, these anticlines are bounded on the west by a parallel but rather discontinuous syncline. An additional peculiarity of these anticlines is their parallelism to a very irregular, structurally high area west of the bounding syncline, as in the northeast corner of Ellis county and in the area extending from Dorrance through Lucas, in eastern Russell county.

The Fairport-Natoma anticline. The best developed example of the larger folds in the vicinity of Russell county is the Fairport-Natoma anticline, which is traceable in a line that runs uniformly 8° or 10° east of north for at least 20 miles along the northern half of the western border of Russell county. The dips on the west side are steeper, the rocks commonly descending at rates of 50 to 200 feet to the mile into a parallel syncline in which the beds are 100 feet or more below their elevation on the axis of the anticline. East of the axis the beds dip 15 to 40 feet to the mile. Minor domes and depressions occur on top of the anticlinal axis and in the syncline. It is in a dome on this anticline that oil and gas have been found in Russell county.

Lesser folds. The characteristics of the prominent anticlines are in contrast to the structural habit of the remainder of Russell county. The regional north-northeast dip in the wide area between the prominent anticlines is interrupted very irregularly by numerous domes, terraces and basins that are in general of small horizontal extent and that have slight structural relief or closure and no definite trends or approach to systematic arrangement. The crests of these lesser folds appear to fall into a general structural level in a way that is comparable with the accordance of summit levels in a maturely dissected peneplain topography. The synclinal and anticlinal axes are somewhat continuous over the county, but in general they are very sinuous. However, a few of these lesser structural features show alignments, though no constant structural trend is recognizable. A persistent, even if discontinuous, anticlinal axis extends northeastward from a region near Gorham to one north of Russell, and possibly to the vicinity of Lucas. A syncline trends westward from an area near the northeast corner of the county to one north of Luray. A low anticline that trends slightly east of north extends from Milberger, in T. 15 S., R. 14 W., to an area a few miles southeast of Russell. An elongation of both anticlines and synclines west-northwestward is recognizable throughout much of the northwestern quarter of Russell county. A fairly sharp anticlinal nose extends northeastward from near the southwest corner of the county for about 10 miles. (See Plate IV.)

Although the structural features in the county are divisible into the two types described, an almost perfect gradation between them may be found. In places the northward-trending axes appear to merge for miles into the homoclinal slope, as one of them seems to do south of Gorham, and the trend of one of the most persistent of the lesser folds, the one extending northward through townships 15 and 14 S., R. 14 W., is almost identical with that of the Fairport-Natoma anticline. The differences in the characteristics and the areal distribution of the two types, however, are so striking as to justify the division made, especially as these differences seem to indicate different conditions of origin. Furthermore, oil and gas have been found in paying quantities on one of the northward-trending anticlines, but neither has been found (June, 1924) on the less prominent, unsystematically arranged folds.

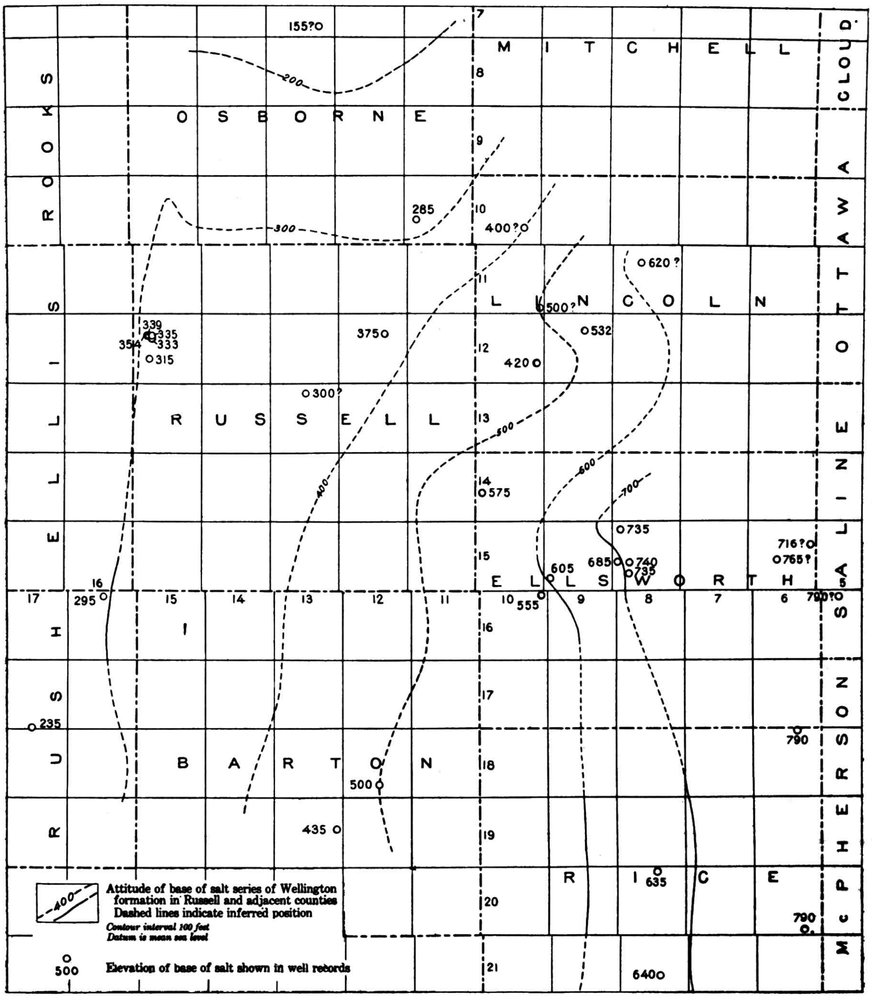
Faults. Almost all of the faults that have been found in the vicinity of Russell county are in the Niobrara formation. Three parallel faults found in the Fairport member of the Carlile shale in the NW¼, sec. 29, T. 11 S., R. 16 W., in Ellis county, 5 miles west of Russell county, strike S. 10° W., and are each downthrown a few feet on the western side. The fissures along these fault planes, which dip westward at an angle of less than 45°, are filled with veins of crystalline slickensided calcite several inches thick. The strata between these faults dip rather steeply. Farther west, in the area of outcrop of the Smoky Hill member of the Niobrara formation, faults that are similarly marked by veins of calcite are locally common and the associated beds show dips that are unusual in their direction and steepness. The faults trend in many directions. Sufficient observations were not made to justify any generalization regarding their alignment or their most persistent course. The clean exposures of brittle rock beds in the Carlile and Greenhorn formations indicate strongly that faults are not equally common east of the Niobrara outcrops. Possibly the boundary of the Niobrara outcrop chances to coincide closely with the margin of a separate structural province, but it seems much more likely that the faults are restricted essentially to the Niobrara rocks and that the lower formations have yielded to the fault-forming stresses by folding, not by breaking.

Attitude of Rocks Not Exposed.

Logs of wells drilled in and near Russell county show that the deeper beds lie nearly flat, although these deeper beds, like those at the surface, show gentle regional inclinations, which differ in amount and direction because of progressive changes in the thickness of some of the beds.

Thinning of shallower rock units northeastward. The units of rock below the top of the Dakota sandstone, recorded in well logs chiefly as sand, red rock and shale, representing the Dakota and possibly some rocks of Lower Cretaceous age, decrease in thickness eastward across Russell county from more than 400 feet near the western border of the county to 300 feet or less near its eastern boundary. The "Red Beds," which underlie the Cretaceous strata unconformably, are cut into more deeply to the east and northeast, so that over 300 feet more of this series remains uneroded near the southwest corner of the county than in its northeastern part. These two units together decrease 600 to 700 feet in thickness from east-central Rush county northeastward to northwestern Lincoln county, a distance of 60 miles. The combined effect of this thinning of Mesozoic and greater erosion of Paleozoic strata eastward is to

STATE GEOLOGICAL SURVEY OF KANSAS. PLATE V.



Attitude of base of salt series of Wellington formation in Russell and adjacent counties.

shift the regional dip in Russell county from north-northeastward in the Cretaceous rocks to westward or northwestward in the strata below the top of the Permian "Red Beds."

Map of the elevations of the base of the salt series. The accompanying map (Plate V) shows the elevation above sea level of the horizon usually recorded in logs as the base of the salt in those wells near Russell county that have been drilled to this depth. The elevations given for the mouths of wells are taken chiefly from topographic maps and are therefore only approximately correct. The logs of a number of wells in and near Russell county show a thin bed of salt from 25 to 50 feet below the thick, more or less unbroken salt unit, and in the logs of a few wells this lower bed or series of beds has apparently been included in a thick series recorded as entirely salt. For example, this appears to have been done in the M. M. Valerius Oil and Gas Company's Phillips No. 1 well, in sec. 3, T. 13 S., R. 13 W., and the base of the salt as recorded for this well is therefore probably too low. The wide, almost perfectly flat structural terrace or nose indicated in Russell county and in areas farther west presents a notable contrast to the relatively steeply inclined, westward dipping series of beds in western Lincoln and Ellsworth counties.[3]

The regional inclination of the strata below the top of the "Red Beds" is essentially parallel to that of the base of the salt series, though a gradual westward thinning of 150 to 200 feet in a 1,500-foot section of the beds below the base of the salt makes the westward dip somewhat gentler in the lower beds.[4] The records of wells that are near together, however, show significant differences in the thickness and structure of the buried rocks.

Increasing steepness of dip with depth below surface. The logs of the first four wells drilled in secs. 8 and 17, T. 12 S., R. 15 W., on the Fairport-Natoma anticline, show a progressive divergence of the buried strata that results in steeper dips on the successively lower beds. The westernmost of these four wells, the Stearns and Streeter Company's Ed Oswald No. 1, in the SW¼ SW¼ of sec. 8, starts at a point that is about 15 feet higher structurally than the

3. Wells drilled since this report was written indicate some errors in the location of the contour lines in Lincoln and Rice counties. The necessary changes are so small and the information is still so very incomplete that a revision of Plate V at this time seems unnecessary.

4. Wells in and near Russell county that have been drilled recently indicate the presence of an unconformity 100 to 400 feet below the oil-bearing horizon. These wells indicate that from the producing field the early Paleozoic rocks slope gradually eastward about 10 or 15 feet to the mile to the eastern part of the county, and that they fall on an average of about 30 feet to the mile northward along the axis of the Fairport-Natoma anticline to the north line of the county, about 15 feet to the mile southward to the southwest corner of Russell county, and perhaps more than 100 feet to the mile westward for three miles.

Valerius Oil and Gas Company's Jesse Muncell No. 1 well, in the NW¼ NE¼ of sec. 17, less than half a mile to the east. The top of the 40- to 50-foot bed of anhydrite encountered at a depth of about 900 feet, however, is about 32 feet lower structurally in the southeast than in the west well. The top of a 20- to 30-foot series of red rock or red shale that was found at depths ranging from 1,624 to 1,659 feet in these four wells shows an eastward dip that makes the bed about 49 feet lower in the Valerius company's well than in the Stearns and Streeter well. The top of a series of beds recorded as red rock or red shale at depths of 2,057 to 2,116 feet is about 73 feet lower structurally in the southeastern than in the western well. The bed of rock 4 to 10 feet thick, recorded as sand, lime or sandy shale, and as yielding water or showings of oil, occurring from 2,590 to 2,658 feet in these wells, is about 82 feet lower in the Valerius than in the Stearns-Streeter well. That is to say, a divergence of about 65 feet occurs rather uniformly through a stratigraphic interval of 2,600 feet in a horizontal distance of less than half a mile. The resulting increase in the steepness of dip with increase of depth is a feature that is common in the oil fields of the Midcontinent region.

Origin.

By W. W. Rubey.

The origin of the structure of an isolated oil field cannot be determined, nor even satisfactorily discussed, until a great deal of drilling has been done in the region; that is, no final statements can be made about the origin of its structure until a field has passed its period of maximum productivity. However, many facts bearing on the manner in which the deformation occurred are known early in the history of a region, and additional inferences may be made by comparison of the region with near-by, similar and better-known fields. Since a knowledge of the origin of the structure of a field is an extremely valuable guide to the prospecting of it for oil, it is desirable to bring together these scattered bits of evidence and to formulate whatever theories seem justified before complete information is available. Theories so formulated, even if erroneous, are valuable in that they point out critical observations that can be made later.

The origin of the structural features in Russell county is probably closely related to the origin of similar features elsewhere in the

Midcontinent oil field, for both geographically and in the structure of its surface rocks, Russell county seems to be a part of that field. As sufficient drilling has not been done to determine the structure of the buried rocks in Russell county, it is helpful in discussing the method of formation of the folds there to make use of the more complete data that have been gathered and partially analyzed in other parts of the Midcontinent field.

The widespread presence in the Midcontinent oil field of minor folds at great distances from areas of orogenic disturbance has given rise to much speculation regarding the origin of these folds. Simple horizontal compression has been generally considered inadequate to form them, because of the incompetency of the soft shale beds, in which the folds are usually developed, to transmit thrusts for these great distances. The explanations of Midcontinent structure that seem most plausible may be mentioned briefly, and their possible application to the structure of Russell county considered.

Conformity of Strata to the Shape of Buried Land Forms.

Blackwelder,[5] Mehl,[6] and more recently, Powers,[7] have developed a theory that surface folds may originate by the deposition and consolidation of sediments over an old, eroded, irregular surface. The idea common to the three authors cited is that some deposits, notably those of mud, are much more compactible than others. Thus, according to the theory proposed, beds of mud deposited around a hill of hard rock—granite, limestone or sandstone—would be more greatly reduced in volume by the pressure of beds subsequently deposited upon them than would the harder rocks, and the beds above the hill, therefore, would form an anticline or dome that would conform in shape with the buried mass of hard rock. Satisfactory data on the amount of cubic compressibility of mudstones are apparently lacking, and quantitative tests of the adequacy of the process outlined, though highly desirable, cannot readily be made. However, the theory merits consideration, for it accounts for features that are not readily explainable otherwise, and as deeper wells are being sunk in many oil fields from Texas to Kansas, evidence is accumulating to strengthen it.

If this process produced anticlines over large buried hills of hard

5. Blackwelder, Eliot; The origin of the central Kansas oil domes: Am. Assoc. Petroleum Geologists Bull., vol. 4, pp. 89-94; 1920.
6. Mehl, M. G.; The influence of the differential compression of sediments on the attitude of bedded rocks: Science, new ser., vol. 51, p. 520; 1920 (abstract).
7. Powers, Sidney; Reflected buried hills and their importance in petroleum geology: Econ. Geology, vol. 17, pp. 233-259; 1922.

rock, it should likewise produce, although less conspicuously, a reflection of the entire buried topography, for few hills are truly isolated, and in some land surfaces, valleys that lie below the general level cause greater local relief than do hills and ridges. It would therefore appear that structural features caused by the unequal settling of sediments over an irregular surface should show in a broad way, though of course with gentler slopes, the configuration of the old surface. If the old surface had been more or less reduced to slopes, broadly sinuous anticlinal axes—the old divides—from which more or less elongated structural noses extend, should be definitely recognizable if sufficiently large areas are studied. Stream valleys should appear as intricately curving and repeatedly branching but gentle synclinal axes. Domes, generally more or less elongate, would commonly be found on the anticlinal folds over the junctions of the primary, secondary and tertiary stream divides, but, if no other factor had been operative in the formation of the structure, basins or "closed" synclines should be very rare. Wells drilled in areas where the structure was so formed would find the deeper beds dipping more and more steeply and more nearly in conformity with the buried land surface, but the form or structure of the beds beneath the unconformity would have little relation to that above.

EFFECT OF BURIED LENSES OF SANDSTONE.

A modification of the theory of settling, held by Gardescu and Johnson,[8] and others,[9] is that lenses of some less compactible rock, such as sandstone, would, by the greater consolidation of the surrounding shale, be reflected as anticlinal ridges in the structure of the overlying beds. Interfingering of sandstone and shale is commonly observed in the younger Paleozoic sediments of the Midcontinent oil field at their outcrops, and well logs show that similar lensing occurs in beds not exposed.

The shape and arrangement of folds formed by the compacting of sediments over lenses of sandstone should be governed by that of the lenses: (1) Lenses made by stream deposition would be elongate, generally curving, occasionally branched or braided, and would vary in thickness because of changes in the course or rapidity of flow of the stream. The structure developed over such a body of sand, according to this theory, should be a sinuous, elongate, but more or less discontinuous anticline from which but few subsidiary axes (the

8. Gardescu, I. I.; and Johnson, R. H.; The effect of stratigraphic variation on folding: Am. Assoc. Petroleum Geologists Bull., vol. 5, pp. 481-483; 1921.

9. Monnett, V. E.; Possible origin of some of the structures of the Midcontinent oil field: Econ. Geol., vol. 17, pp. 194-200, 1922.

tributaries) extend. Because of variations in thickness, small, elongate domes and basins should be superimposed upon the anticlinal axis. If no other factors were at work, the area on both sides of the anticlinal axis should be structurally flat. (2) Sandstone lenses formed in the sea by offshore bars would be extremely elongate, very straight (except for occasional sharp offsets and terminal curves), and, if restricted to one horizon, relatively narrow. Anticlines formed over such beds of sandstone should be nearly unbroken for miles and should have few irregularities along the crest line. (3) A lens of sandstone deposited at a shore line would be elongate in a more or less irregular line, and whether derived from streams or caused by local weathering, would become gradually and unequally thinner seaward and along the shore from its source. Structure resulting from the consolidation of beds over such a body of sand should show a gentle terrace, merging into a flat area on one side—the seaward—and possibly to structure characteristic of that formed over a buried land surface on the other. Few irregularities should occur on the very gentle, broad fold formed on the lens of sandstone of this origin. (4) The relatively extensive deposits of sand formed by tidal or current sweeps would not be likely to result in folds sufficiently acute to be discernible in surface structure. (5) Wind-blown sandstones accumulated on land would be so rarely preserved as thick detached masses that lenses thus formed may be disregarded in the present discussion.

An important characteristic of any folds that might be formed over lenses is that the structure below the horizon of the lenses would be relatively flat; no corresponding anticline would be found deeper.

Structure in Surface Rocks Formed by Movement Along Deep-seated Faults.

Fath[10] has called attention to the regional alignment of *en échelon* faults, of folds, and of the buried "granite ridge" of eastern Kansas, and has pointed out that recurrent horizontal and vertical movements along buried fault planes or shear zones in more competent rocks would account for these features. Fath's explanation of the *en échelon* faults, which is the key to his interpretation of the other features, follows R. T. Chamberlin's[1] conception of the origin of a similar series of oblique faults in south-central Montana. Briefly,

10. Fath, A. E.; The origin of the faults, anticlines and buried "granite ridge" of the northern part of the Midcontinent oil and gas field: U. S. Geol. Survey Prof. Paper 128; 1921.

1. Chamberlain, R. T.; A peculiar belt of oblique faulting: Jour. Geology, vol. 27, pp. 602-613; 1919.

it is that horizontal differential movement will produce cracks at angles of about 45° to the direction of the movement. Fath's major contribution to the idea was his recognition that the deeply buried, more competent rocks would transmit a horizontal thrust for great distances and that planes or zones of weakness in these rocks would serve to localize the effect of the differential movement and form a series of parallel faults. The folds he interpreted as the effect of slumping of higher soft beds over minor fault planes, that, starting just above the more competent rocks, did not reach the surface. Subsequent investigations[2] in Osage county, Oklahoma, and elsewhere have further verified the facts demonstrated by him and strengthened the validity of his major premises.

Fath also carried his conception of zones of weakness in deeper rocks to the parallel "granite ridge" of Kansas, pointing out that the great length of this ridge—more than 170 miles—and its straightness could more plausibly be explained as a result of faulting or slipping along zones of weakness in pre-Pennsylvanian rocks than of folding or of purely erosional development of the mountains before younger deposits buried them. Moore,[3] in a summary of the known facts regarding the "granite ridge" of central Kansas, which he calls the Nemaha mountains, concludes that the igneous rocks could not be intrusive, but that the younger beds must overlie the crystalline rocks unconformably. The evidence indicates that this unconformity is probably post-Mississippian and pre-Pennsylvanian. According to these interpretations, the ridge was formed by the faulting of early Paleozoic beds of limestone, which were deeply eroded before the Pennsylvanian sediments were laid down upon them. The major lines of weakness postulated by Fath might possibly have been formed at the time of this faulting, but the great extent of the ridge and its great distance from areas of pronounced orogenic activity in Mississippian time make it appear more probable that such lines were first blocked out during a time of great widespread disturbance—perhaps pre-Cambrian—and that regional stresses at the close of the Mississippian caused the early Paleozoic rocks to break along these old lines.

The series of faults in northern Oklahoma, along which slight movements have obviously occurred since the Pennsylvanian strata were deposited, led Fath to suppose that the folds at the surface over the "granite ridge" were formed by repeated movements along

2. By members of the U. S. Geological Survey, the writer among others.

3. Moore, R. C.; Geologic history of the crystalline rocks of Kansas: Am. Assoc. Petroleum Geologists Bull., vol. 2, pp. 98-113; 1918.

the major zones of weakness. By postulating these recurrent later movements and local unconformities, he seeks also to explain the progressively greater steepness of the beds of rock on the anticlines with increase of depth.

More recent drilling in Kansas, Oklahoma and Missouri indicates that other "granite ridges" lie parallel to the Nemaha mountains and the oblique fault belts in northeastern Oklahoma. Wells drilled near the Missouri-Kansas line have found igneous rocks above their expected depth from Miami, Okla., north-northeastward to a point less than 75 miles south of Kansas City, Mo., and scattered wells drilled farther east in Missouri have also reported granite at unexpectedly high elevations. In northeastern Oklahoma granite has been reported in a number of wells that are so located as to suggest several roughly parallel ridges extending (1) from Muskogee to Vinita, (2) through Rogers and Nowata counties, (3) from a point south of Tulsa past Bartlesville to a well near Iola, Kan., and (4) from the Cushing oil field to Hominy. Other wells drilled into granite east and west of the Nemaha mountains in Kansas suggest the existence of other parallel ridges.

R. C. Moore, in a forthcoming paper, considers the relation of the "granite ridge" to the structure of the overlying rocks and calls attention to certain structural features of the outcropping beds that seem to mark the position of the buried ridge. He points out that the parallel line of similar structural features in the outcropping beds from a point southwest of Eureka, Kan., nearly to Frankfort, Okla., may also overlie a buried ridge.

The scattered granite wells, combined with the evidence of the line of steeply dipping surface rocks and the belts of *en échelon* faults, indicate more than a half-dozen long parallel ridges or deep-seated faults in eastern Kansas, northeastern Oklahoma and western Missouri.

Several bits of evidence indicate that long and straight northward-trending lines of deformation exist west of eastern Kansas in many parts of the Great Plains area. Rich,[4] calling attention to the narrow northward-trending area of pre-Cambrian outcrops south of Pedernal mountain and east of the southern prolongation of the Front Range in central New Mexico, to a few wells in northeastern New Mexico that were reported to have struck granite, and to small outcrops of gneissoid granite in southeastern Colorado, suggests that the

4. Rich, John L.; A probable buried mountain range of early Permian age east of the present Rocky Mountains in New Mexico and Colorado: Bull. Am. Assoc. Petroleum Geologists, vol. 5, pp. 605-608; 1921.

large northeast-trending anticline in northeast New Mexico and southeast Colorado [5] may overlie the northward buried continuation of the mountain range exposed in the vicinity of Pedernal mountain.

In a discussion of a paper by W. J. Miller, entitled, "Pre-Cambrian Folding in North America,"[6] Miss Margaret Fuller states that a recent detailed field study of the pre-Cambrian geology of the Front Range in Colorado discloses the presence of numerous batholiths, which have arched and metamorphosed the sediments in a long northward-trending belt, and suggests that the recent arching took place along the old pre-Cambrian line of diastrophism. In eastern Wyoming, north of the Laramie mountains, the eastern margin of the Hartville uplift, the Old Woman anticline, and a steep monocline on the west side of the Black Hills, are prominent structural features trending slightly east of north that are apparently aligned.[7] The pre-Cambrian rocks exposed in the Black Hills in South Dakota are reported to have a cleavage that trends northward except where it has been destroyed by later intrusions.[8]

It is noteworthy in this connection that the broad northward-trending anticline mapped by Darton [9] in western Kansas may extend northward instead of turning northwestward as shown, for Darton admits there is little evidence for connecting the fold on the Republican river near the southern border of Nebraska with the Chadron anticline in the northwestern part of the state.[1]

Folds formed largely by readjustments along buried tectonic lines would probably possess some distinctive characteristics. Simple vertical movements would produce faults in the strata immediately above the buried lines, but soft shale beds would cause small faults of this type to be dissipated upward and expressed only as steep dips. Simply vertical movements would produce no anticlines at the surface; it would form only a monocline—a narrow line along which the beds dip steeply in one direction—with flat-lying beds on both sides. If a narrow block between two fracture lines were

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5. Darton, N. H.; Geologic structure of parts of New Mexico: U. S. Geol. Surv. Bull. 726, fig. 16; 1922.
———— The structure of parts of the central Great Plains: U. S. Geol. Survey Bull. 691, pl. 1; 1918.

6. Bull. Geol. Soc. America, vol. 34, No. 4, pp. 700-701; 1923.

7. Darton, N. H.; The structure of parts of the central Great Plains: U. S. Geol. Survey Bull. 691, pl. I; 1918.
———— U. S. Geol. Survey Geologic Atlas, Newcastle Folio (No. 107), fig. 3; 1904.

8. Van Hise, C. R.; The pre-Cambrian rocks of the Black Hills: Geol. Soc. America Bull., vol. 1, pp. 209, 231-233, 241; 1890.

9. Darton, N. H.; The structure of parts of the central Great Plains; U. S. Geol. Survey Bull. 691, pl. I; 1918.

1. Idem, p. 12.

uplifted, the surface result would probably be a broad, flat anticline with abrupt and steeply dipping limbs. Vertical movement, accompanied by a tilting of the blocks between the major fault zones, however, might produce anticlines and synclines with dips much steeper on one limb than on the other. Horizontal movement along the tectonic lines would produce minor faults, many of which would not reach the surface, and above them folds might be formed in the manner that Fath suggests. These folds, like others formed along buried lines, would have one limb steeper than the other; they would be elongated at angles of about 45° to the buried line of weakness, and should occur *en échelon*. Pressure folds, likewise running at angles of 45° to the buried line, but lying at right angles to the commoner faults and folds produced by tension and slumping, might also be produced, but they would probably be smaller and more inconspicuous in the higher beds. Finally, none of the structural features thus produced would necessarily be long and continuous, for the amount and direction of movement along the buried tectonic lines, as Fath points out, might vary greatly within rather short distances.

Folds Formed by Leaching of Salt Beds.

Leaching of easily soluble beds might cause slumping of the overlying beds on a scale sufficiently large to form folds. This mode of origin cannot be ascribed to the folds in most of the Midcontinent oil fields, for no easily soluble beds are found there in sufficient thickness to make the effects of this leaching significant. In western Kansas, however, a persistent series of beds of salt, from 200 to 400 feet thick, underlies the surface rocks. The high solubility of salt and the saltiness of most of the ground waters in that region suggest that the thinning of this series of beds by partial solution might there produce features of the structure. Basins that have sunk several feet within historic time, in Meade county, Kansas, have been thus accounted for by some writers.[2] Unsaturated water capable of dissolving the salt out of these beds would presumably come from near-lying aquifers or would seep down from the surface. It would probably find access to the salt beds only in faulted zones and at places where porous beds lay in contact with them.

Logs of wells in central Kansas show only slight variations in the

2. Coffey, G. N., Rice, T. D., and others; Reconnaissance soil survey of western Kansas: U. S. Dept. Agric., Bur. Soils, p. 10; 1912.

thickness of the salt beds, whether the wells are or are not on anticlines—a fact that tends to weaken the theory. This process is not regarded as impossible, but it is probably not of great importance nor of wide applicability in western Kansas. The structural features developed by this means should be wide flats, interrupted locally—or possibly in zones along faults—by basins or closed synclines.

Application of Principles to Structure of Russell County.

The regional dip of the rocks in Russell county may be the result of broad deformation or tilting, but it is believed that the folds superimposed upon the regional homocline must have been caused by processes other than horizontal compression.

Gentle, unsystematic folds. The irregularity of trend of the axes of the folds throughout the greater part of Russell county suggests a mode of origin other than by horizontal compression, localization along buried tectonic lines, or consolidation over long lenses of sandstone formed as offshore bars, all of which methods of origin would probably form long, straight folds. It does not seem that the larger, at least, of these unsystematic folds can be explained as due to the compacting of sediments over local lenses of sandstone or the leaching out of salt beds. Rather, the sinuous and branching character of the gentle anticlines and synclines suggests that they may be largely due to unequal consolidation of the beds laid down on an old land surface.

According to this explanation, the structurally flat areas in the southern part of the county would be the surface reflection of a fairly smooth buried surface, on which the valleys and ridges ran in general northeastward or northward. The more steeply dipping beds in the northern part of the county would have derived their inclination from a more intricately dissected surface, on which most of the stream valleys and interstream divides extended eastward. The direction or directions of slope of these two hypothetical surfaces is unknown. Similar studies of adjacent counties may show whether the valleys enlarge to the northeast or southwest, or in both directions.

Basins or closed synclines, such as those in the northeastern part of Russell county and many smaller irregularities of structure not shown by the generalized contour lines of Plate V, seem to demand another explanation, however. Sandstone lenses that lie above and are elongated across buried valleys might produce in the overlying rocks anticlinal folds that cross the "valley" synclines and thus give rise to closed basins on their "upstream" sides. The thicker parts of the Rocktown channel sandstone member of the Dakota sandstone, though perhaps never deeply buried, coincides in position with structurally high areas in central and east-central Russell county in such a way as to suggest that they may have modified somewhat the structure that was produced chiefly by other agencies. Sandstone lenses in the more deeply buried Pennsylvanian sediments would produce similar and perhaps more acute effects. Slumping over dissolved salt beds might also form some basins.

Prominent, northward-trending anticlines. The foregoing theory of origin may apply to the unsystematic gentle folds that are widely scattered over most of Russell county, but the prominent northward-trending structural features call for a different explanation. The linear trend and the length of these folds suggest that they may have been caused by horizontal compression of the rocks or consolidation over deposits made by offshore bars, or that they are in some way related to buried zones of weakness, such as those considered by Fath.[3]

It seems to the writer that horizontal compression will not satisfactorily account for such structural features as the Fairport-Natoma anticline, for it is hundreds of miles from areas of pronounced folding, and there are no series of folds of equal or greater size in the areas intervening. The structural relief across the Fairport-Natoma anticline, amounting to 100 feet or more, makes it difficult to accredit the offshore bar theory highly. In the absence of exact data it may not be unjustified to assume that, in a section of 4,000 feet of strata, shale would be compacted to 80 per cent of its original volume, and that under similar pressure sandstone would remain relatively uncompacted. To form anticlines and synclines having a difference in elevation between crests and troughs of 100 feet, a sandstone lens would need to be 400 feet thick—an improbable thickness for such a migratory and shallow-water shore form as an offshore bar.

The most probable cause of the Fairport-Natoma anticline may be found in a relation to a buried tectonic line. The prominent folds in Russell county trend in a direction that is nearly identical with that of the *en échelon* fault series of northeastern Oklahoma, the "granite ridge" or Nemaha mountains, more than 100 miles to the east in Kansas, and other possibly related major structural

3. Fath, A. E.; The origin of the faults, anticlines and buried "granite ridge" of the northern part of the Midcontinent oil and gas field: U. S. Geol. Survey Prof. Paper 128, pp. 75-84; 1921.

features mentioned under the heading, "Structure in surface rocks formed by movement along deep-seated faults."

Raymond C. Moore, in an unpublished study of the detailed structure of the surface beds overlying the Nemaha mountains, has found that the domes and short anticlinal folds that lie near the crest of the ridge are parallel to it, and that gentle, variable westward dips and a continuous line of steep eastward dips mark the position of the ridge. Except that the Fairport-Natoma anticline is steepest on its west instead of its east side, its structure is similar to that of the surface beds overlying the "granite ridge."

Fath discussed two principal types of relation between the deeper lines of weakness and the structure of the surface rocks—slumping of the higher beds over the minor faults produced in intermediate strata by horizontal movement along the buried lines, and conformity of the surface beds to vertical displacements along the deep-lying zones of weakness themselves. The first process should produce a series of short folds elongated at angles of about 45° to the lines of weakness in the deeper beds. This type of structure is not that of the Fairport-Natoma anticline, though it is suggestively similar to that of the northward-trending line of domes and basins in western Lincoln county near the Russell county border, which may have been so formed in part. Slumping of the surface beds over a deep-lying zone of weakness would more probably cause a long, straight anticline such as the Fairport-Natoma anticline in the higher beds, but in order to produce this anticlinal structure the fault would need to be paralleled by other near-by faults, for if isolated it would be likely to produce only a narrow monocline at the surface. Gentle tilting of the blocks between several such fault lines would form long anticlines and synclines in the higher beds; one limb, overlying the fault, dipping gently, and the other, overlying the tilted surface, relatively steeply—a form most nearly agreeing with that of the Fairport-Natoma anticline.

However, the explanation cannot be as simple as this. The east limb of the Fairport-Natoma anticline dips from 25 to 40 feet to the mile in the surface rocks, and is steeper below, but the average inclination of the beds from the crest of this anticline eastward for 30 miles to the next hypothetical large fault zone is only 10 feet to the mile; that is, the eastward dip of the surface rocks on the anticline is at least twice as great, and in the deeper beds more than ten times as great, as that which would be caused by merely regional tilting between two fault lines. This steeper dip may be due to a bending upward of the upthrown edge of the block between the faults, or to local irregularities either on the surface of the tilted block or in the beds above.

The upthrown edge of the block would probably be bent upward only if the region were under horizontal compression—a condition that seems improbable. Local irregularities in the beds above the old surface of the tilted block that might account for the steeper dip would be either a long, straight lens of sandstone lying exactly along the upthrown edge of the block, or a narrow area in which the salt beds had been partially dissolved parallel to and east of the edge of the block. Of these two possibilities, an area of leached salt beds east of the edge of the block seems the more plausible, but neither explains these steeper dips as satisfactorily as would local irregularities on the buried surface of the tilted block. A more or less curving synclinal axis east of the anticline (Plate V) is the complement of this steeper eastward dip on the side of the anticline, and such a syncline may be interpreted as the surface reflection of a buried stream valley.

This interpretation, which is in harmony with the explanation offered for the gentle unsystematic folds in Russell county, suggests three alternative explanations of the origin of the Fairport-Natoma anticline: (1) that a land surface on which valleys and ridges had been developed and which was buried beneath younger sediments was at some later time faulted; (2) that a land surface was faulted after valleys and ridges had been developed but before the overlying beds were deposited; or (3) that a land surface was faulted and afterwards valleys and ridges were developed upon it. In the first alternative the valleys would show no relation to the fault zone and erosion would not have had an opportunity to modify the upthrown edge of the buried block. In the third alternative those valleys near the fault zone would tend to be elongated either parallel or at right angles to it, and the buried fault scarp would have been cut into by erosion. Long-continued erosion after the faulting would make the second alternative essentially the same as the third.

The synclines in Russell county and its vicinity appear to follow the directions streams would take on a land surface that had been previously faulted and slightly tilted. The synclines immediately west of the two prominent north-trending folds occupy positions where consequent valleys would be expected to develop—at the foot of fault scarps—and the curving syncline east of the Fairport-Natoma anticline suggests a valley so situated as to drain the hypothetical fault scarp ridge. As would be expected under this interpretation, the synclines and anticlines in the remainder of the county show no close relation to the assumed fault scarp.

No direct evidence is available regarding the possibility that erosion modified the upthrown edge of the buried block that is assumed to have formed the Fairport-Natoma anticline, but analogy with the Nemaha mountains in eastern Kansas, upon which erosion seems to have acted before Pennsylvanian deposition, likewise suggests that in Russell county streams modified an old land surface that had been previously faulted.

The interpretation that seems most consistent with the facts is that the Fairport-Natoma anticline was formed, not by movement along a buried fault, but chiefly by consolidation of sediments over a buried fault scarp.

Probable origin of structure of Russell county. Summarizing the foregoing assumptions and conclusions, the structure in the Russell county region may possibly be explained as follows:

Block faulting or differential movements between blocks of rigid pre-Cambrian rocks capped by Ordovician or Mississippian sediments took place along preëxistent fault lines or sheer zones and exposed to erosion a surface of gentle slopes and steep fault scarps. The displacement along the faults varied from place to place, ranging from several hundred feet, as in the northwest corner of Russell county, to nearly nothing, as south of Gorham. Streams flowing on this land surface cut deeper the original depressions at the base of the fault scarps, and probably shifted backward, but did not eradicate the cliffs. Meanwhile streams developed upon and carved their channels into the tilted uplands, leaving the divides near the top of the fault scarps the most prominent features of the topography.

The sea later encroached on this old land surface and covered it with sediment. After the deepest and most irregular depressions in the sea bottom had been filled, the layers of sediments deposited conformed more or less closely to the form of the old buried surface. Later the deposits were shifted by waves and currents until the bottom of the sea became nearly horizontal; that is, a greater thickness of sediments was deposited around than upon the former hills and ridges. Occasional partial withdrawals of the sea may have permitted erosion of the sediments on the higher areas over the buried hills. With the increase in the thickness of the sediments, the lower mud deposits were continuously squeezed to a smaller volume, but the old hard rocks below the plane of unconformity underwent little or no corresponding compression. The result was nearly the same as if buried hills and ridges had been thrust upward into the overlying strata, the higher hills and ridges in the harder rocks serving to localize the bending and consequently the slight stretching and thinning of the overlying strata. Minor faults and fractures produced at the fault scarp by this settling died out in the overlying beds. Thus the deposition of thicker sediments around the higher areas on the buried surface, and the stretching, and in some places local erosion, of the overlying strata above these higher areas, might combine to account for the uniformly increasing dip of the beds downward toward the plane of unconformity.

If this theory of origin is correct, granite may or may not be encountered by wells drilled deeper on these anticlines, but hard limestone, sandstone, igneous or metamorphic rock will probably be found at much higher elevations under the crests of the folds than in the corresponding synclines.[4]

Economic Significance of Method of Origin.

If the foregoing conclusions are even approximately correct, some inferences may be made that have a direct economic bearing. The anticlinal folds formed over buried hills and ridges should become progressively steeper with increase of depth until the plane of unconformity is reached, and the effectiveness of the folds as traps for the accumulation of oil and gas should likewise increase downward until this plane is reached. The folds formed over buried scarps should develop steeper dips and sharper anticlines with increase of depth than would those formed over gentler-sloping ridges and hills. Accumulation of oil and gas in commercial quantities is more probable in an anticlinal trap immediately over a buried scarp than in the higher beds or in the smaller folds formed over gentler hills, because in differential compacting, local deformation of the sediments is likely and the faults and fractures formed increase the porosity and number of avenues for the migration of oil and escape of gas. The plane of the preëxistent major fault itself, if the unconformity lay above Paleozoic sediments, might be a path of upward migration of older oil and gas, and minor movements along it after burial would develop other stresses and fractures that

4. Since this report was written granite or arkose was encountered at a depth of 3,628 feet in the Producers and Refiners Oil Corporation Haise No. 1 well, NW¼ SE¼, sec. 24, T. 12 S., R. 15 W., Russell county, six miles east of the Fairport-Natoma anticline.

might be favorable to the origin and accumulation of petroleum. Thus the chance of finding oil in the Fairport-Natoma anticline probably increases with depth, at least until the plane of the unconformity is reached.[5]

Structural features developed by the consolidation of sediments about sandstone lenses that lay near the surface, and by slumping at places over dissolved salt beds, would be unfavorable to the accumulation of oil and gas in all but the shallower sands. Basins or "closed" synclines, unless in part the result of deeply buried lenses of sandstone, would be a criterion of these unfavorable types of structure.

It is therefore concluded that the prominent anticlines that show steep dips and are developed more or less continuously along the persistent northward-trending lines of deformation in western Kansas are the most promising places for tests for oil and gas. The recognition of such a fold, however, by no means assures the discovery of oil, for the almost unpredictable factors—an adequate source of petroleum, suitable paths of migration, porous reservoir rock, and an impervious cover—must be combined to produce an oil field. Folds that lie along but at an angle to lines of deformation, and that are steeper on one limb than on the other, should be almost equally favorable. The gentler folds of no well-defined trend that occur at varying distances from the northward-trending lines are much less likely to yield oil. Other things being equal, the larger and the steeper-dipping of these gentler anticlines should be the more favorable for tests. Least promising of all the structural features in the Russell county region are the anticlines far from the regions of more intense deformation, which are inferred by their association with structural basins, by observations of outcrops, or by well logs, to be the result of compacting of sediments over shallow-lying sandstone lenses or of slumping of the strata into places from which beds of salt have been dissolved.

5. Wells drilled recently suggest that an unconformity separates early and late Paleozoic sediments in Russell county and that this unconformity in the producing field is probably about 100 feet below the oil-bearing horizon. Beds yielding water or small amounts of oil or gas have been found in the 100 feet below the producing horizon in wells throughout the county, and it is possible that the lower beds may be found to yield oil on the Fairport-Natoma anticline.

PART II.

A Subsurface Correlation of the Stratigraphic Units from Russell County to Marion County, Kansas.

By M. N. Bramlette.

THE correlation presented in Plate VI* is not so definite as could be desired, since cuttings from only widely separated wells were available for microscopic examination, and even the wells for which logs could be obtained in much of the area between Russell county and the eastern part of the state, where the various formations are more clearly identified, are too far apart to permit precise correlations. Correlation of the beds from Russell county northeastward to Osborn and Lincoln counties and thence southeastward to Ellsworth county is less definite than along the rest of the line, but the northerly wells were included because of the drilling activity in Lincoln county. The correctness of the correlation in the region to the north is checked by the evidence derived from the correlation of the beds between Russell county and Ellsworth county. The basis for some of the correlation lines that seem unjustified by the driller's logs will be found in the descriptions of the well cuttings. The several stratigraphic units discriminated are described below.

The attempt to make correlations from logs of wells, especially wells that are far apart, may lead to minor errors or even to complete misinterpretation. For areas where logs are numerous such misinterpretation may be avoided by tracing as far as possible thin individual beds that should be nearly equivalent stratigraphically; thicker beds or series of dominantly calcareous, arenaceous or argillaceous rock may be transgressing, and unless that fact is discovered serious errors may be made that can be corrected only by studies of collections of fossils. The surest way to avoid error in stratigraphic correlation is to preserve for examination numerous fossiliferous well cuttings, the supreme value of which should constantly be impressed upon the oil operator.

Unit 1. The first unit discriminated includes the formations above the Dakota sandstone of the Russell county region. Individual

* Plate VI, Correlation of well records, showing tentative determinations of geologic units extending from Marion county into Russell county, will be found in pocket on inside of back cover of this bulletin.

formations cannot be separated and correlated from the drillers' logs, and are generally classed as brown, blue or grey shale, and an occasional thin bed of other lithologic type.

Unit 2. The Dakota sandstone is logged as a heterogeneous series of brown sands, blue shales, red rock and gray shales, the individual beds of which cannot be correlated definitely, though the uppermost red beds, in the upper part of the formation, seem to mark a fairly constant key horizon for correlation in the region near the original producing well of Russell county. The top of the Dakota sandstone is not easily recognized in the drillers' logs, and the line marking it in the cross section is based on information obtained in the field. Cuttings from this formation show that the sand is highly variable and poorly sorted, some of it very well rounded, some angular, at some places with an admixture of argillaceous material, at others with glauconite, and commonly with much pyrite. Some of the sand beds are water-bearing. The lower part of this series possibly belongs to the Comanche (Lower Cretaceous), but the Upper and Lower Cretaceous rocks are similar lithologically and cannot be separated with confidence in well records.

Unit 3. The top of the Permian "Red Beds," or Cimarron group, is a rather distinct horizon in Russell county, and though these beds cannot be subdivided into the units recognized at the outcrop in the southern part of the state, they include units that are of value for local correlation. One unit that is of especial value is the 50-foot bed of anhydrite that occurs about 330 feet below the top of the red series in the western part of Russell county. This bed, which is found throughout Russell county and in parts of adjoining counties, affords a valuable check on subsurface structure in the region. It is logged by the drillers as lime. Another bed, measuring something less than 50 feet, occurs in this series a little more than 100 feet below the base of the 50-foot bed of anhydrite. This is logged as brown or gray or blue shale by the drillers, and an examination of a few of the cuttings shows that it probably consists of anhydrite or gypsum and gray shale. The "Red Beds" generally consist of a red siltstone and some red, fine sandstones and red shales, with interbedded green-gray rock of the same lithologic character as the associated red rock. Finely granular gypsum occurs at irregular intervals through the "Red Beds." The Cimarron is more than 600 feet thick in western Russell county, but it becomes thinner eastward and northward and disappears altogether in McPherson county. The well-log cross section suggests that some of the beds in the thick series of gray shales above the salt in McPherson county may be gray equivalents of the red Cimarron.

Unit 4. Below the red strata there is about 100 feet of material, usually logged as blue shale, consisting of gray shale and anhydrite and probably belonging to the Wellington formation. This overlies the salt beds of the lower part of the Wellington formation. The bed of rock salt included in the Wellington is variable in thickness, ranging from less than 200 feet to more than 300 feet in Russell county and adjacent regions, but thinning toward the east, in McPherson county, and disappearing in eastern McPherson county and at the western edge of Harvey county. The salt is usually recognized by the drillers, but its exact upper and lower limits are often doubtful. In places it seems to be a bed of almost pure salt; at others it includes interbedded gray and red shale and anhydrite.

Unit 5. Below the rock salt lie about 400 feet of alternating gray shale, gray anhydrite, impure dolomite and red beds, without limestone and with only a few fossils in its lower part. This series might well be classed as a part of the Wellington, though in the area to the east the base of the salt is considered the base of the Wellington. Whether these beds represent a formation that has no stratigraphic equivalent in the area to the east, or whether they are a much thicker development of the gypsiferous Pearl shale member of the Marion formation, or the nonmarine equivalents of some of the fossiliferous marine upper Permian in the region of its outcrop, has not been determined. The cross section suggests the relation last mentioned, and indicates that these anhydrite, shale and dolomite beds may be equivalents of the Marion formation and part of the Chase formation of the region to the east. The beds of anhydrite and dolomite are logged by the driller as limestones. In a few of the wells, such as the Denmark well in Lincoln county (sec. 9, T. 11 S., R. 8 W.), some thin fossiliferous limestones are interbedded with the lower part of this series, and some anhydrite occurs below the first very fossiliferous cherty limestone of the underlying unit, showing that there was an alternation of conditions in some regions.

Unit 6. The first distinctly fossiliferous marine limestone occurs at a depth of 1,915 feet in the original producing well in Russell county, the Valerius Oil and Gas Company's C. C. Oswald No. 1. The upper part of this limestone, containing crinoids, ostracods, bryozoa, a small foraminifer, and other fossils, is somewhat cherty, and at a depth of 1,950-1,970 feet the limestone is more cherty.

This unit cannot be exactly correlated with the outcropping marine Permian until more cuttings from intermediate wells have been examined, but a similar cherty, fossiliferous limestone containing an unusually large number of bryozoa occurs at apparently the same horizon in the Denmark well (sec. 9, T. 11 S., R. 8 W.), Lincoln county; in the Sheridan well (sec. 21, T. 15 S., R. 6 W.), Ellsworth county; in the Allison well (sec. 28, T. 19 S., R. 3 W.), McPherson county; and at a depth of about 260 feet in the Batt well (sec. 9, T. 19 S., R. 4 E.), Marion county. This horizon in the Batt well is apparently that of the Wreford, according to correlations made by the Kansas Geological Survey in Marion county. This cherty, very fossiliferous unit of the western region may possibly be correlated with beds that lie at a higher horizon farther east, such as the Fort Riley limestone or the Florence flint; but its relation to adjacent beds, its lithologic character, and its fossils—though all the species of Bryozoa are not identical—make its correlation with the Wreford of Marion county seem the most probable.

Unit 7. Below unit 6 in the original producing well there are about 400 feet of shales, limestones and red beds, and below these lie 450 feet of blue shale and thin layers of limestone and sand. Individual beds in this thick series cannot be certainly correlated with units recognized farther east, but the entire series would seem to be equivalent to formations extending downward from the Council Grove (Permian) through the Wabaunsee and part of the Shawnee to the Topeka limestone. Individual red beds of this series correlate well through Ellsworth, Saline and McPherson counties and check the general correlation shown on the cross section. In Marion and McPherson counties the lower part of this series, including the Scranton and Severy shale members of the Shawnee formation, is distinctly arenaceous.

Unit 8. Below unit 7, at a depth of 2,753 feet in the original producing well, the Valerius Oil and Gas Company's C. C. Oswald No. 1, begins a series of limestones and thinner beds of shale and sand that extend downward for 284 feet to the bottom of the well. These limestones are light gray to yellow brown, fossiliferous (many *Fusulina*), somewhat cherty, and at certain horizons oölitic, notably at a depth of 3,010-3,014 feet. The whole group seem to correlate with the Shawnee from the top of the Topeka limestone and the Douglas to the base of the Oread limestone. The cuttings from the oil-producing rocks are limestone and a little dark gray shale and chert, but no sand, and would seem to correlate with the Oread limestone of eastern Kansas.

Unit 9. In wells drilled below this limestone series in Ellsworth county and to the east there is an aggregate of beds of shale, sandstone and limestone 200 or 300 feet thick, which is classed as Douglas below the Oread, including the thick Lawrence shale, and there is a very considerable amount of sand in the upper part of this series corresponding to the sandy facies of the Lawrence shale at many of its outcrops. These sands are at many places water-bearing. Some beds of red shale occur in this series in Ellsworth, Saline and Russell counties, but they do not seem to persist at any definite horizon.

Unit 10. Beneath this clastic series for about 300 feet the strata, which consist largely of limestone, but include a few thin beds of shale and sand, seem to correlate with the thick Lansing and Kansas City calcareous formations of eastern Kansas. Oölitic limestone is common and is often logged by drillers as sand, as is some of the cherty limestone in these formations. *Fusulina* is seldom found in this series, and is usually represented by a small species, such as is found in this part of the Pennsylvanian section in eastern Kansas.

Unit 11. The series of shales, sandstones, red shales and thin limestones under the limestones of the Lansing and Kansas City formations may be correlated with the Marmaton and Cherokee formations. The red shales usually encountered in the lowest part of this group are much thicker than any encountered in eastern Kansas.

Unit 12. Below the Cherokee shale at many places lies a bed of cherty limestone that is considered of Mississippian age. It is generally water-bearing and in a few wells it gives showings of oil. Beneath this bed lies a series of beds of limestone, shale, dolomite and sand, the lower part of which is undoubtedly Ordovician. In the Urschell No. 4 well, in T. 21 S., R. 5 E., Marion county, the formation immediately under the Cherokee shale is a cherty dolomite and is probably Ordovician, indicating that the Mississippian has been eroded from this region, though the typical chert is found in the Batt well, in T. 19 S., R. 4 E. Well cuttings from these pre-Pennsylvanian rocks have been very commonly preserved, especially in eastern Kansas, and a stratigraphic study based on these cuttings may yield some very definite results.

ADDENDA.

After this correlation was completed, some paleontologic work was done on the faunas obtained from the cuttings. In general this work corroborated the conclusions reached by the lithologic and well-log correlation, but it developed one important difference. A very fossiliferous sample taken from a depth of 3,500 feet in the Sheridan well, in sec. 21, T. 15 S., R. 6 W., Ellsworth county, proved to be of Pennsylvanian age. If this sample is representative of the formation at 3,500 feet, it disproves the conclusion as to age arrived at in the correlation, and the very cherty horizon classed as Mississippian chert in this region would be of Pennsylvanian age. As this particular sample is very different both in lithology and in its abundant fossils from the samples above and below, and as such a horizon has not been found in this part of the section elsewhere, it seems possible that it may be a caved sample and so of no significance. All other evidence seems to favor the Mississippian age of this cherty horizon, and the writer believes that the sample is not representative. However, its value must remain an open question until more paleontologic evidence from the chert zone or from the underlying shales is obtained. Since this is an important question, any such evidence, if found, should be made known.

Some samples received from the M. M. Valerius Oil and Gas Company's Phillips well, sec. 3, T. 13 S., R. 13 W., Russell county, after the completion of this study, show that there is a series of limestones and some shales, with *Fusulina,* down to a depth of 3,135 feet that is certainly of Pennsylvanian age, and the limestone from 3,000 feet to about 3,150 feet are tentatively considered to be representative of the dominantly calcareous Lansing and Kansas City formations of eastern Kansas. A fossiliferous horizon at 3,160 feet was examined by P. V. Roundy, of the United States Geological Survey, and found to contain *Glyptopleura* sp., *Bairdia* sp., *Fusulinella* sp., *Cytherella* sp., *Endothyra?* sp., *Meekospira?* sp., and *Natacopsis* (immature) sp. He considers this fauna of early Pennsylvanian age. In this well the Pennsylvanian rocks below the main producing horizon of Russell county are thus about 200 feet thick. This is much less than the thickness of the equivalent beds in eastern Kansas which contain more coarse clastic material. No cherty horizon like that classed as Mississippian in the region to the east is present here.

The shales, red rock and thin limestones between 3,200 feet and 3,300 feet may be basal Pennsylvanian, Mississippian or Ordovician, as samples were not available for examination. Red rock of Ordovician age occurs at 3,400 feet in this well, and there is red rock in the basal Pennsylvanian east of Russell county. The red rock between 3,220 feet and 3,285 feet may represent residual or weathered material formed between Ordovician and Pennsylvanian times.

Fossils definitely of Ordovician age have been found in this well at a depth of 3,335 feet. A few samples were examined from depths of 3,465 feet to 3,554 feet that were a brown crystalline, cherty, sandy dolomite identical lithologically with the material classed as Ordovician dolomite in the region to the east.

PART III.

Fossils from Wells in Central Kansas.

By Raymond C. Moore.

General Conditions.

IN his microscopic study of cuttings from deep wells in central Kansas, Mr. Bramlette discovered a considerable number of fossils. Some of these are small fragments of shells that were so much broken up by the drill that their specific, or even their generic, identification is impossible. The cuttings also contain diminutive, even microscopic, fossils which are so small that they were not destroyed by the drill, and may be separated, practically unbroken, from the cuttings. These small fossils are the most valuable for subsurface correlation, because in most well cuttings they are much more abundant than the larger fossils; because they are, in general, sufficiently complete to permit rather precise identification; and because most of them are as good stratigraphic markers as the large fossils. Unfortunately, however, although most of the larger fossils in the rocks of Kansas have been studied and described, the microscopic fossils are not yet generally known.

An examination of the cuttings from wells in Russell, Lincoln, Ellsworth, McPherson and Marion counties showed the occurrence in several wells of a cherty limestone containing many microörganisms. In the more westerly wells this limestone was everywhere found at about the same stratigraphic distance below the base of the Permian salt beds. In the wells in McPherson and Marion counties, where there are no salt beds, the most fossiliferous zone is found in the upper part of the stratigraphic section, and evidently corresponds to one of the cherty limestones of the marine Permian which crop out farther east. The fossils obtained from the cuttings were studied in order to ascertain, if possible, whether the fossiliferous zone in the different wells belongs to one formation. and to identify that formation. The similar position of the fossiliferous zone as recorded in the logs, especially the logs of wells in Russell, Lincoln and Ellsworth counties, strongly indicates stratigraphic equivalence, and the general similarity of the faunas, which are composed of foraminifers, bryozoans and ostracods, is suggestive, though not conclusive, of equivalence, for these are the classes of organisms that would normally be preserved in well cuttings. However, as other comparable lots of small fossils are not found in beds above and below the fossiliferous zone, and as the fossils in the several wells occur in similar rock, as the stratigraphic position of the fossiliferous zone is about the same in all the wells, and as the general composition of the faunas is identical, it may reasonably be assumed that the fossiliferous bed in each of these wells lies at the same stratigraphic horizon. If so, it is a valuable marker in stratigraphic correlation and in the determination of structure. Even if one or another of the different kinds of microscopic fossils is not found in all the collections, and even if there is some variation in species, they may still represent a single formation, for the small amount of cuttings preserved from any one well may not adequately represent the formation as a whole, and a certain amount of variation in genera and species may be expected from place to place within a single formation.

The Oswald Well, Russell County.

The fossils listed below come from a depth of 1900-1920 feet in the Stearns-Streeter Company's No. 1 Ed Oswald well, in the southeast corner of the southwest quarter of the southwest quarter of sec. 8, T. 12 S., R. 15 W., Russell county:

Fauna from 1900-1920 feet in the Stearns-Streeter Ed. Oswald well, Russell county, Kansas.

Bryozoa:
- Acanthocladia sp. A.
- Acanthocladia sp. B.
- Fenestella sp.
- Batostomella? sp.
- Rhombopora sp. A.
- Rhombopora sp. B.
  aff. R. lepidodendroidea.
- Rhombopora? sp.
- New genus aff. Leioclema.

Ostracoda:
- Bythocypris sp. A.
- Bairdia sp. A.
- Bairdia sp. B.

This fauna shows a predominance of ramose bryozoans, all very well preserved except *Fenestella,* which is represented by a single fragment. The specimens of *Acanthocladia* are not like those of any species yet described, and probably represent new species. There are specimens of two distinct types of *Rhombopora,* the larger of which resembles closely specimens of *R. lepidodendroidea* identified from upper Pennsylvanian and lower Permian formations in Kansas. The specimen listed as a new genus is a striking little fossil that shows the large, rounded, rather well-spaced zoöecia of *Leioclema* with intervening angular mesopores opening on the surface, but this, unlike that genus, has a prominent tubular axial canal, somewhat like that in *Rhabdomeson.* Among the ostracods *Bairdia* is strongly predominant, most of the specimens from the Stearns-Streeter well belonging to a single species, which resembles *B. beedei,* but is smaller and somewhat longer than that form. A single specimen belonging to the genus *Bythocypris* was found. All the ostracods are smooth-shelled.

THE THURMAN WELL, LINCOLN COUNTY.

Cherty limestone at a depth of 1,382 feet in the Thurman well, sec. 25, T. 12 S., R. 10 W., near the town of Sylvan Grove, in Lincoln county, yielded a collection of small fossils that is somewhat larger and more varied than that obtained from the Stearns-Streeter Ed Oswald well. The fauna is made up nearly equally of foraminifera, bryozoans and ostracods.

Fauna from 1,382 feet in the Thurman well, Lincoln county, Kansas.

Foraminifera:
- Tetrataxis sp. A.
- Tetrataxis sp. B.
- Fusulina sp. A.
- Fusulina sp. B.

Bryozoa:
- Acanthocladia? sp. aff. A. sp. B., Oswald well.
- Fenestella sp. ? aff. F. inaequalis Ulrich.
- Fenestella sp. aff. F. limbata Foerste.
- Fenestella sp. A.
- Fenestella sp. B.
- Fenestella sp.
- Polypora sp.
- Septopora sp. A. aff. S. biserialis (Swallow).
- Septopora sp.

Worm tube:
- Spirorbis sp.

Ostracoda:
- Bythocypris sp. A.
- Bairdia sp. A.
- Bairdia sp. C.
- Bairdia sp. D.
- Bairdia sp. E.
- Cytherella? sp.

Echinodermata:
- Crinoid stems.

The Thurman fauna is marked first by the presence and relative abundance of foraminifera, and second by the dominance of the fenestelloids among the bryozoans. The number and the variety of ostracods is greater than in the Stearns-Streeter Ed Oswald well.

The minute shells identified as *Tetrataxis* are very well preserved and under the microscope show clearly the arrangement of the chambers that make the low cone typical of a member of the *Valvulina* group. The base of the cone-shaped shell is flat or concave and is marked by the irregularly stellate opening to the interior. Species A, which is generally the more abundant, is about 0.5 mm. in diameter or less; species B has a diameter across the base of the cone of about 1.4 mm. and is more strongly concave beneath. *Fusulina* sp. A. is a moderately robust species, about 4 mm. long and 1.5 mm. in diameter. Its internal structure has been studied, but shows no features that definitely distinguish it from other species of *Fusulina*. *Fusulina* sp. B. is a diminutive species, which is apparently distinct from A.

Among the bryozoans, the genus *Fenestella* predominates, being represented by four or five species. Specific identification of these forms is difficult, because much of the material is fragmentary and because the bryozoans from this horizon have not been thoroughly studied. *Polypora* and *Septopora* are also represented.

A simple, moderately large and well-preserved worm tube belonging to the genus *Spirorbis,* with flat base, low spiral coil, and spire having a diameter at base of 1.8 mm., was obtained from the Thurman well.

There are several types of ostracods, but the smooth, unsymmetrical-shelled *Bairdia* predominates. The form listed as species A appears to be the same as one of the types from the Oswald well. Some of the species, especially *Bairdia* sp. C, which is the smallest of the group, measuring 0.6 to 0.7 mm. in length by 0.4 mm. in height, are represented by a number of excellently preserved specimens.

The Sheridan Well, Ellsworth County.

The Sheridan well, drilled in sec. 21, T. 15 S., R. 6 W., southeast of Carneiro, Ellsworth county, has yielded a micro-fauna from a depth of 1,250 feet, which appears to represent the fossiliferous horizon already noted. The species distinguished are as follows:

Fauna from 1,250 feet in the Sheridan well, Ellsworth county, Kansas.

Foraminifera:
- Tetrataxis sp. A.
- Fusulina sp. B?
- Fusulina sp. C.

Bryozoa:
- Rhombopora sp. cf. R. lepidodendroidea.
- Rhombopora sp.
- Batostomella? sp.
- Acanthocladia sp. A?
- Fenestella sp.
  aff. F. conradi-compactilis Condra.
- Fenestella sp. A.
- Fenestella sp. B?
- Fenestella sp. C.
- Fenestella sp. D.
- Fenestella sp. E.
- Polypora sp.
- Septopora? sp.

Ostracoda:
- Bythocypris sp. aff. sp. A.
- Bairdia sp. A.
- Bairdia sp. C.
- Bairdia sp. F.
- Kirkbya sp. A.
- Kirkbya sp. B.

Echinodermata:
- Crinoid stem.
- Archeocidaris sp. A.
- Archeocidaris sp. B.

This fauna is similar in general composition to those already listed, and a number of the species are identical, but it includes some interesting additional species. The most striking are the beautifully and delicately marked undescribed species of *Kirkbya*. *Archeocidaris* is represented by coarse and very fine spines. Among the rest, the genus *Fenestella* is dominant among the bryozoans, and there are numerous specimens of *Bairdia,* especially the rather distinctive little form here called species C.

The Allison Well, McPherson County.

At a depth of 980-1,005 feet in the Allison well, in sec. 27, T. 19 S., R. 4 W., there is a cherty limestone containing numerous very small fossils which appear to lie at a stratigraphic horizon found at greater depths in wells farther west. The fauna obtained from the cuttings is as follows:

Fauna from the Allison well, McPherson county, Kansas.

Foraminifera:
- Nodosinella sp. A.
- Tetrataxis sp. A.
- Tetrataxis sp. B.
- Fusulina sp. B.

Bryozoa:
- Rhombopora sp.
- Fenestella sp.
  - cf. F. conradi-compactilis Condra.
- Fenestella sp. A.
- Fenestella sp. C.
- Fenestella sp. F.
- Fenestella sp.
- Polypora sp. A.
- Polypora sp.
- Septopora sp. A.
- Septopora sp. B.

Ostracoda:
- Bythocypris sp. A.
- Bairdia sp. C.
- Bairdia sp. E.
- Bairdia sp. G.

Echinodermata:
- Crinoid stems.

In addition to the two species of *Tetrataxis* and the small *Fusulina* which are found in other wells, the collection from the McPherson well contains a number of small nodose uniserial foraminifers which appear to belong in the genus *Nodosinella.* This type of fossil protozoan has been found at several places elsewhere in Permian and Pennsylvanian rocks, but not in Kansas.

Fenestella is the most abundant genus of Bryozoa in this lot, as well as in the collection from the Sheridan well, and three of the species listed appear to be common to both lots. The fragments of *Polypora* and *Septopora* are also closely similar to species of these genera found in other wells, but the specimens are so incomplete that they cannot be referred to the same species with certainty.

The ostracods, which are relatively numerous, belong to the smooth types, *Bythocypris* and *Bairdia.* The small species of *Bairdia* listed as species C, which is found in most of these collections, is the most abundant.

The Batt Well, Marion County.

A fairly complete series of cuttings from the Argus Oil Company's Batt No. 1 well in sec. 9, T. 19 S., R. 4 E., Marion county, which were made available for microscopic examination, yielded a fairly prolific micro-fauna from a cherty limestone that lay at a depth of 265 to 275 feet. As this well is much farther east than those already mentioned, the cherty limestone in it might be expected to lie nearer the surface. The fauna identified from the cuttings at 265-275 feet in the Batt well contains the following species:

Fauna from 265 feet in the Batt well, Marion county, Kansas.

Foraminifera:
- Tetrataxis sp. A.
- Tetrataxis sp. B.
- Fusulina sp. B.

Bryozoa:
- Rhombopora sp A?
- Rhombopora sp. C.
- Rhombopora sp. D.
- Rhombopora sp. E.
- Streblotrypa sp. A.
- Streblotrypa sp. B.
- Cystodictya sp. A.
- Cystodictya sp. B.
- Acanthocladia sp. A?
- Acanthocladia sp. C.
- Thamniscus sp. A.
- Fenestella sp.
  - cf. F. conradi-compactilis Condra.
- Fenestella sp. F.
- Fenestella sp. G.
- Polypora sp.
- Polypora sp.
- Polypora sp.
- Septopora sp.
- Acanthoclema? sp.

Ostracoda:
- Bairdia sp. A.

Echinodermata:
- Crinoid stems.
- Archeocidaris sp.

The number and the variety of the bryozoans in this lot are its most noteworthy feature. Associated with types found in collections obtained from wells to the west are several new genera, among them *Streblotrypa, Cystodictya* and *Thamniscus.* The character of the Foraminifera, the occurrence of *Bairdia* sp. A as a representative of the ostracods, and the composition of the bryozoan division of the fauna, indicate the probable equivalence of. this fauna to those already described. A fairly large content of *Rhombopora* is suggestive of the fauna found in the Oswald well; the numerous fenestelloids relate it to the collections made in McPherson and Ellsworth counties.

Correlation.

Because of the similar composition of the faunas, the similar place of their occurrence in the well sections, the lithologic similarity of the beds containing them, and the apparent absence of like fossiliferous beds near by, it seems probable that all of the lots of fossils listed above belong to a single fossiliferous zone. There are, of course, a number of more or less fossiliferous zones in the upper Pennsylvanian - lower Permian section, but only a few notably cherty formations. As the fossil-bearing cherty rock in the wells is the uppermost rock of this character, its reference to the part of the Permian section that includes the Florence and Fort Riley formations is at once suggested, though a comparison of the available well records indicates that it may be the equivalent of the flinty Wreford limestone. Several fairly large collections of fossils taken from the outcrops of the Florence, Fort Riley, Wreford and adjacent formations were examined and fossiliferous fragments of these rocks were broken up in a search for microscopic organisms similar to those obtained from the well cuttings. Fragments of the Fort Riley, Florence and some other formations that showed numerous fenestelloid and other bryozoans on the surface yielded more or less broken bryozoan material, but the ground-up rock did not contain the foraminifers and ostracods that are characteristic of this horizon in the well cuttings. However, a small piece of Wreford limestone, which happened not to be a cherty fragment, contained the following species:

Fauna from crushed fragment of Wreford limestone from near Strong City, Chase county.

Foraminifera:
- Nodosinella sp.
- Valvulina (Tetrataxis?) sp. aff. V. bulloides Brady.
- Fusulina sp. B.?

Bryozoa:
- Rhombopora sp.
- Fistulipora sp.
- Fenestella sp. B.?
- Fenestella sp.
- Polypora? sp.
- Septopora sp.

Gastropoda:
- Murchisonia? sp.
- Small species aff. Bulimorpha.

Ostracoda:
- Bairdia sp. A.
- Bairdia sp. C.
- Bairdia sp.
- Kirkbya sp. B.

Echinodermata:
- Crinoid fragments.
- Archeocidaris sp.

Though it doubtless affords a very incomplete representation of the minute fossils in the Wreford formation, this small lot shows obvious similarities to lots obtained from the well cuttings. The *Nodosinella* closely resembles the forms referred to this genus from the well in McPherson county. The species of *Fusulina* is small and appears to correspond to species B of the well collections. The specimens from the Wreford formation called *Valvulina sp. aff. V. bulloides* are different from the species of *Tetrataxis* in the cuttings, but although they are here placed in the broadly inclusive genus *Valvulina,* these shells may belong in the subgenus *Tetrataxis.*

The bryozoans of the Wreford suggest in general corresponding elements in the collections made from the wells, but the specimens are not sufficiently complete to permit detailed comparison.

Among the ostracods are species of *Bairdia* that are apparently identical with forms obtained from the wells, and also a good specimen of *Kirkbya,* which is the same as *Kirkbya* sp. B. from the Sheridan well, in Ellsworth county.

It appears that the fossiliferous zone described represents the

Wreford limestone, and the persistence of the zone to the west, coupled with its rather distinctive fauna, lithology, and position in the section, indicates that it may be used readily as a key horizon in subsurface studies—a much more definite and reliable horizon than the base of the salt, the base of the red beds, or other beds that are less readily identified with certainty and that may differ in stratigraphic position in different places.

From other horizons in the deep wells of central and western Kansas small fossils, especially *Fusulina,* have been obtained. Examinations recently made at the outcrop of the Pennsylvanian rocks in Kansas and a study of well cuttings show that this genus extends downward at least to the Fort Scott limestone, at the base of the Marmaton formation. *Fusulina* obtained from a depth of 3,905 feet in the Whiteside well, in sec. 2, T. 24 S., R. 23 W., Ford county, indicates the presence of Pennsylvanian sediments at least to that depth in that well. In Russell county and adjacent parts of west-central Kansas, Pennsylvanian fossils have been obtained at intervals to the bottom of the deepest wells yet drilled. The specific variation in *Fusulina* and the accompanying stratigraphic distribution of the species of that genus have not been fully investigated. Opportunity for obtaining valuable aid in subsurface work is here evident.

Notes on Other Fossils from Kansas Wells.

During the recent examination of drill cuttings from Kansas wells the following occurrences of fossils were noted in addition to those described above. Most of these have not yet been carefully studied.

In the Batt well, in sec. 9, T. 19 S., R. 4 E., Marion county, large *Fusulina* were found at a depth of 1,240-1,260 feet; numerous rather large *Fusulina* at 1,500, and 1,515-1,525 feet; and *Fusulina* sp. at 2,300 feet. Thin sections were made of these and other specimens of *Fusulina* from wells, but the several species have not been satisfactorily differentiated.

A large and a small species of *Fusulina* were found in cuttings obtained at depths of 1,080-1,105 feet in the Urschel well, in sec. 16, T. 21 S., R. 5 E., Marion county.

The Sheridan well, in sec. 21, T. 15 S., R. 6 W., showed *Fusulina* in cuttings from 1,500 feet, from 1,700 feet, from 2,100 feet (two species), and from 2,300 feet.

Drillings from the Schubert well, a shallow well drilled near Bonner Springs, in Leavenworth county, show, in a limestone at depths of 67-73 feet that probably belongs in the Kansas City formation, specimens of *Bythocypris* sp., *Macrocypris* sp., *Bairdia* (a very minute species and a larger one), and an ostracode (new genus?) belonging to Beyrichiacea.

Drillings from the Phillips well, in sec. 3, T. 13 S., R. 13 W., Russell county, show a limestone at a depth of 1,981 feet that contains numerous small foraminifers, mostly of the types of *Valvulina* and *Globigerina.*

In the Stearns-Streeter Company's No. 1 Ed Oswald well, Russell county, a sample taken from a depth of 1,925 feet, just below the horizon of the bryozoan-ostracod fauna already described, contains *Tetrataxis* sp. B. and *Bairdia* sp. A. Samples from a depth of 1,985-2,010 feet contain *Valvulina bulloides* Brady?, *Fusulina* sp., *Murchisonia?* sp., *Macrocypris?* sp., *Bythocypris* sp., and *Bairdia* sp. A. A large species of *Fusulina* occurs rather abundantly at a depth of 2,753-2,795 feet in this well and also at a depth of 2,875-2,880 feet.

A sample of oölitic limestone in the producing zone of the discovery well, the M. M. Valerius Company's No. 1 C. E. Oswald well, taken from a depth of 3,010-3,014 feet, was ground to a thin section that showed a variety of small Foraminifera, *Globigerina, Nodosellina* and other forms in the centers of the grains of oölite. These grains are irregular in size and shape and show well-defined radial structure in their outer parts—the parts surrounding the central granules, most of which appear to consist of fragments of fossils. A small gastropod of the *Sphærodoma* type was shown in the thin section. It should be easy to identify this horizon from similar samples obtained from other wells.

ADDENDA.

Under date of April 3, 1925, P. V. Roundy made the following report on cuttings from the Phillips No. 1 well, sec. 3, T. 13 S., R. 13 W.:

All cuttings represent beds of Pennsylvanian age except possibly the cuttings from 3,170. The cuttings from 2,800 feet to 3,145 do not contain sufficient evidence to place them within any definite subdivisions of the Pennsylvanian.

The cuttings from 3,160 feet have an abundant fauna. The Ostracoda and Foraminifera represent a fauna that I have found only in beds of Pottsville age. It is possible in the present state of our knowledge of these forms that this fauna *may* occur in beds a little younger than Pottsville, but I do not think it probable. The mollusks, of which there are many, are all minute in size; many appear to be immature, and some probably are mature. These forms, Doctor Girty considers, are more apt to belong in a fauna of Pottsville age than in a younger fauna. The only objection to placing this fauna as of Pottsville age is the lack of known outcrop beds of that age in Kansas. However, since these fossils come from underground beds, so far geographically from the surface exposures of the lowest Pennsylvanian beds in Kansas, I feel that this factor should have little weight.

The cuttings from 3,170 feet have only three species, two of which are doubtfully identified and might represent either Mississippian or Pennsylvanian beds, and the third species, a single specimen, known only from the Pennsylvanian, is very abundant in the cuttings from 3,160, and might have actually slumped in the well from that horizon when the sample from 3,170 was taken by the driller.

A faunal list is given below:

2800. Fusulina inconspicua? Crinoid stem segments.
2815. Fusulina inconspicua? Crinoid stem segments.
——. Bairdia n. sp.
2825. Fusulina sp.; crinoid stem segments.
——. Bairdia sp.
2835. Nothing determinable.
2856. Fusulina sp.; indet. brachiopod.
2930. Bairdia sp.
3000. Crinoidal fragments; bryozoan fragment.
3020. Fusulina sp.; crinoidal fragments; Rhombopora? sp.; brachiopod fragment; Productus spine.
3030. Crinoid stem fragment; Productus spine.
3055. Fusulina sp.
3060. Fusulina sp.
3100. Fusulina sp.
3115. Fusulina; spine fragment.
3145. Immature cephalopod; Cytherella sp.
3160. Endothyra? sp.; Fusulinella n. sp.; Fusulina sp; Aclisina 2 sp.; Bulimorpha? sp.; Meekospira sp.; Pleurotomaria? sp.; Holopea? sp.; Naticopsis sp.; Nucula sp.; Pteria sp.; Astartella? sp.; Bairdia 2 sp.; Glyptopleura healdi n. sp.; Amphissites symmetricus n. sp.; Sansabella? n. sp.; Paraparchites sp.
3170. Meekospira sp.; Batostomella? sp.; Fusulinella sp.

A well known as Whiteside No. 1, drilled in the NW corner SW¼, sec. 2, T. 24 S., R. 23 W., Hodgeman county, Kansas, has contributed some definite information regarding the age of and the faunas carried by certain formations in western Kansas. The cuttings were studied by P. V. Roundy, who has made the following determinations:

3640-3650. Imperfect gastropod, probably Pleurotomaria sp.
Productus spine fragments.
Echinoid spine fragment.
Minute pelecypod, probably a Nucula.
Cytherella n. sp.
Hollina n. sp.
Amphissites centronatus var.
Amphisites n. sp.
3240. Lingula sp. fragment.
3650-3665. Fusulinella? sp.
Hollina sp.
Cytherella n. sp.
Amphissites n. sp.
Productus spines.
3743. Bairdia, 2 species.
Fusulina sp.
Productus spines.
3750-3756. Fusulina sp.
Productus spines.
3822. Ambocoelia sp.
3810. Bairdia sp.
Fusulinella sp.
Fusulina sp.
3870. Ostracod (new? genus).
3905. Fusulina sp. (Very abundant.)
3935. Fusulinella sp. (These look as if they were water-worked.)
3980. Polygnathus n. sp.
3980-3990. Bairdia of B. beedei var.
Fragment Fusulina. (Certainly not water-worn.)
3993. Fusulina sp.
Composita? sp.
4000. Endothyra sp. (This form, although distinct from the Mississippian E. baileyi, is much closer to it than to the Endothyras found by Mr. Roundy in the Pennsylvanian.)
Composita? sp.

It will be noted that the evidence of Mississippian age is not conclusive, but there can be no question about the Pennsylvanian age of the strata to a depth of 3,993 feet. As the well was carried to 4,055 feet, and as there was abrupt change in the type of rock at 4,010 feet, it is quite possible that the lower 45 feet are Mississippian or even older rocks.

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