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THE CHEYENNE SANDSTONE AND ADJACENT FORMATIONS OF A PART OF RUSSELL COUNTY, KANSAS

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ABSTRACT

The area described is part of an oil-field region in southwestern Russell County, in the Plains Border section of the Great Plains physiographic province.

The rocks encountered in test holes in this area are of Permian, Cretaceous, Tertiary (?), and Pleistocene age. They include the Cedar Hills sandstone (?) and Salt Plain formation (?) of Permian age; the Cheyenne sandstone, Kiowa shale, Dakota formation, Graneros shale, Greenhorn limestone, and Carlile shale of Cretaceous age; upland sand, silt, and gravel of Tertiary (?) age; and Pleistocene terrace deposits of sand, gravel, and silt. The Dakota formation and younger deposits listed are exposed in this area.

Petrographic methods of distinguishing between the various formations are discussed. It is concluded that the Cheyenne sandstone consists of two types of sand and that its eastern boundary is not in the area studied.

The waters sampled from test holes in the area generally are not potable, and the water in the deeper formations is highly mineralized. Some of the water in the Dakota formation is believed to have come from older Cretaceous and Permian rocks.

INTRODUCTION

Purpose of Study

At the request of the Division of Sanitation of the Kansas State Board of Health, a detailed investigation of the subsurface Cretaceous stratigraphy of southwestern Russell County was begun in September 1943 by the State Geological Survey of Kansas, the Division of Ground Water of the United States Geological Survey, and the State Board of Health. The purposes of the study were to determine the eastern boundary and diagnostic features of the Cheyenne sandstone, which is a legal shallow-disposal zone in the oil-field areas of Russell County, and, if possible, to propose criteria for differentiating the Cheyenne sandstone and adjacent beds by examining cuttings with a binocular microscope. The report is limited in scope to discussion of the subsurface geology of the area and the quality of ground water. The investigation was made under the general administration of John C. Frye, acting state geologist, and O. E. Meinzer, chief of the Division of Ground Water of the Federal Survey, and under the immediate supervision of S. W. Lohman, district geologist of the Federal Survey.

Location and Size of Area

The area discussed in this report is 11 miles long and 9 miles wide and is south and west of the city of Russell in Russell County.

It includes T. 14 S., R. 14 W. and parts of T. 13 S., R. 15 W.; T. 13 S., R. 14 W.; T. 13 S., R. 13 W; T. 14 S., R. 15 W.; and T. 15 S., R. 14 W. Its relation to the area studied by Frye and Brazil (1943) and to other areas in Kansas for which cooperative ground-water reports have been published or are in preparation is shown in Figure 1. Oil pools in this area during the test-drilling program in 1943 were the Donovan, Big Creek, Big Creek East, Big Creek South, Gideon, Rusch, Williamson, Mohl, Smoky Hill, Jerry, and parts of the Gorham, Atherton, Russell, Trapp, and Hall-Gurney (Ver Wiebe, 1944, pp. 74-79).

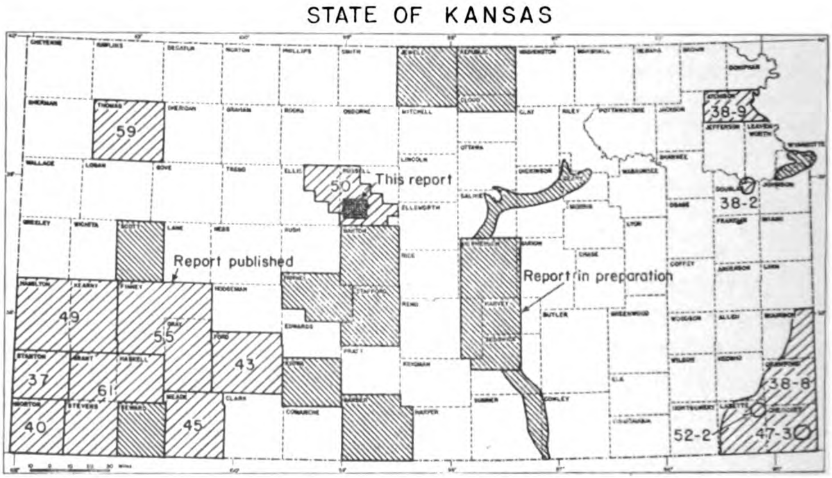

Fig. 1. Map of Kansas showing the location of the area discussed in this report and other areas for which cooperative ground-water reports have been published or are in preparation.

Previous Subsurface Geologic Work

One of the first publications touching on subsurface Cretaceous stratigraphy of Russell County appeared about 2 years after the discovery of oil in the area. Twenhofel and Stryker (1925), after studying a group of drillers' logs of Comanchean strata in western Kansas, concluded that "the strata assigned to the Cheyenne show an erratic distribution in harmony with what seems to have been the method and environment of their deposition." Five of the logs were from wells in Russell County, and in four of them no reference was made to the presence or absence of the Cheyenne sandstone. In the fifth well, in sec. 17, T. 12 S., R. 15 W., the authors inferred that the Cheyenne was not present.

Bramlette (1925) published logs of two holes in Russell County, one of which was based upon studies of samples from the Russell County discovery well, the M.M. Valerius Oil and Gas Company No. 1 C.C. Oswald, in the SW¼ SE¼ sec. 8, T. 12 S., R. 15 W. In this log less than 10 feet of sandstone is indicated a few feet above the Permian redbeds; however, Bramlette did not attempt to differentiate between the Dakota, Kiowa, and Cheyenne. The other log reported by him is of the M.M. Valerius Oil and Gas Company No. 1 Phillips well, in the SW¼ SW¼ sec. 3, T. 13 S., R. 13 W., a dry hole. In this log the lowermost 75 feet of Cretaceous deposits is described as limestone and shale.

A recent report by Frye and Brazil (1943) on ground water in the oil-field areas of Ellis and Russell Counties includes a description of the character and thickness of the Cretaceous rocks and the approximate location of the eastern edge of the Cheyenne sandstone based on examination of samples from 7 test holes and 35 oil and disposal wells in the area, supplemented by studies of many drillers' logs. Frye and Brazil placed the approximate eastern edge of the Cheyenne along a general north-south line 5 to 7 miles west of U.S. Highway 281 south of Russell in the area discussed in the present report.

Methods of Investigation

A test-drilling program was carried out by the State Board of Health using a cable-tool drilling machine owned and operated by the Stearns Drilling Company. Fourteen test holes were drilled specifically for this investigation under the supervision of John C. McFarland, geologist of the Oil-Field Section of the Kansas State Board of Health, and samples were also obtained from three shallow disposal wells drilled by the Stearns Drilling Company. Fifty-one water samples were collected from 12 of the test holes by McFarland and analyzed by Howard Stoltenberg, chemist in the Water and Sewage Laboratory of the Kansas State Board of Health. Altitudes of the test holes were determined by C. K. Bayne of the Geological Survey. The holes ranged in depth from 400 to 758 feet, and all penetrated Permian redbeds.

Examination of the well cuttings under a binocular microscope was followed by mechanical analyses, roundness evaluations, and studies of "light" and "heavy" fractions from Comanchean and Permian strata using a petrographic microscope. Fire tests were made on a few of the samples of finer grained clastics. J. M. Jewett, Bruce F. Latta, and Thad G. McLaughlin spent a few days with us in Kiowa County collecting sandstone samples from outcrops of the Kiowa shale and Cheyenne sandstone for comparison with the sands from Russell County.

Samples were taken from the bailer at intervals of 5 to 10 feet, and for most intervals two small cloth sample bags were filled in order to provide ample material for analysis. Each large sample of sand of pre-Dakota age and a few samples of sand from the Dakota formation were split in the laboratory with a Jones-type sample-splitter, and half of each was heated with hydrochloric and nitric acids to remove iron-oxide stain, calcite, and pyrite preliminary to determinations of roundness, grain-size, and mineralogy. The other half of each sand sample and the nonsand samples were examined under the binocular microscope. Particular attention was given to the color and surface texture of the grains, to the amount of pyrite, mica, and glauconite present, and to such features as the presence or absence of shell fragments, cone-in-cone structures, calcite cement, clay or silt matrix, siderite pellets from the Dakota formation, and type of "ironstone". Some samples of clay were boiled and washed for examination of the residue.

Approximately 50 grams of each sand sample after acid treatment was screened through sieves of half-Wentworth grades from 4 mm to 0.062 mm in a Ro-Tap sieve shaker for 10 minutes and weighed to the nearest one-hundredth gram. The logarithmic mean size was computed and converted to mean diameter in millimeters, and the results are tabulated in Table 2 and in the cross sections (Pl. 1). Samples which were too small or contained a large amount of shale or more than 50 percent silt by weight were not included. Fracturing of grains during drilling was found to have been negligible, for few of the angular grains associated with the rounder types of sand showed any remnants of rounded surfaces.

About 40 grams of the acid-treated fraction was taken for separation of the "heavy" minerals using bromoform. Heavy and light fractions were split by an Otto microsplit and mounted in Canada balsam. A minimum of 200 grains was counted on each slide of heavy minerals. Percentage occurrences of the heavy minerals, excepting barite, are listed in Table 3. The reader's attention is directed to the fact that the values in the table were derived from examination of well cuttings and are not comparable with mineral frequencies obtained from other types of samples.

In the determinations of roundness, "light" grains of the size range 0.177 to 0.125 mm were mounted under a cover glass on a glass slide in a mixture of one part glycerine to two parts water as suggested by Pye (1943), and the roundness values of a minimum of 50 grains were estimated by means of a visual comparison chart (Krumbein, 1941). The term "roundness" as used by Krumbein follows the practical definition by Wadell (1935), and relates to the degree of sharpness of edges and corners and not to the general shape of the grain. A particle having a roundness value of 0.1 has the sharp edges and general appearance of freshly crushed vein quartz, whereas a grain having a roundness value of 1.0 is without major surface irregularities or indentations.

Measurements were limited to grains of one size grade in order to eliminate the effect of size in comparison of samples. The particular size, 0.177 to 0.125 mm, was chosen because it constituted the major grade of most of the sands in the Kiowa and Cheyenne formations and the Permian rocks. The choice of a larger size would have produced higher roundness values. We did not differentiate between grains of quartz and feldspar in estimating roundness because the low percentage of feldspar could not materially affect the average values and because general observation indicated that the roundness of the feldspar grains was approximately the same as that of the quartz grains. Grains of chert and grains showing secondary growth were not included. The samples were examined by transmitted light under a petrographic microscope.

The roundness data are plotted as histograms in the cross sections (Pl. 1). Each bar represents one-tenth unit in the roundness scale, and the roundness values increase to the right. The final bar on the right-hand end represents the percentage of grains having a roundness value greater than 0.6. Along the vertical scale the distance representing 1 foot in the well log equals 20 percent on the histogram. Thus a histogram having most of the distribution on the left-hand side depicts an angular sand and one having most on the right-hand side depicts a rounded sand, and the general type may be determined at a glance.

In interpreting the results of detailed analyses of sand samples from well cuttings, the possibility of caving and its effects and the possibility of mixing of sands from two or more strata or sedimentation units must be carefully considered. In order to avoid the effects of caving as much as possible, casing was set at the top of some of the Comanchean sands in several of the test holes. At these particular points good samples are reasonably assured. The interpretation of most of the samples, however, requires careful scrutiny of the possibility of contamination from above. Siderite pellets from the Dakota formation in the upper part of the Kiowa shale in a few holes constitute indisputable evidence of caving. Samples from the uppermost 80 feet of the Kiowa shale in test hole 8 consist more largely of red clay and siderite pellets than of Kiowa shale, but this condition is rare. Caving, except from the Dakota, is believed by us to have been negligible for the following reasons: (1) in each test hole the break at the base of the micaceous sand of Kiowa type was fairly sharp; (2) shell fragments from the Kiowa were not found below the base of the formation; (3) although some samples from 5- or 10-foot intervals contain fragments of various lithologic types, some of these samples came from immediately below the bottom of the casing and nearly all were found in a limited area and are believed to be the result of environmental conditions; and (4) with one or two exceptions, no indisputable Comanchean material, such as shell fragments, cone-in-cone structures, or a large proportion of angular sand grains, has been found in samples of Permian rocks. Therefore as caving is demonstrably rare at most key horizons, its effect on the general picture seems to be unimportant.

Mixing of materials from adjacent sedimentation units or adjacent formations is inevitable in well cuttings in which the interval includes parts of both beds, and this fact must be kept in mind when interpretations are drawn from petrographic data. Although most of the data which follow are quantitative in character, it is not our intention to imply exact knowledge of the parameters of the sands which are supposed to have been sampled, but merely to point out general trends and diagnostic characteristics.

The stratigraphy was studied jointly by us, and the chemical analyses of ground water were studied by Swineford. Heavy-mineral analyses were begun by Williams and concluded by Swineford after the transfer of Williams to other work. The final report was prepared by Swineford.

Acknowledgments

Thanks are expressed to several members of the State and Federal Geological Surveys for advice and for assistance in collection of surface samples. We are particularly indebted to John C. Frye for innumerable suggestions and criticisms. The manuscript has been critically reviewed by S. W. Lohman and O. E. Meinzer of the Federal Geological Survey; George S. Knapp, chief engineer of the Division of Water Resources of the State Board of Agriculture; and Paul D. Haney, chief engineer, and Ogden S. Jones and John C. McFarland, geologists, of the Division of Sanitation of the State Board of Health. Excellent samples obtained by O. G. Stearns of the Stearns Drilling Company under the direction of John C. McFarland made the study possible. Carrie B. Thurber made slides and mechanical analyses of the sandstones. Eileen Martin drafted the illustrations, and Edith H. Lewis edited the manuscript.

GEOLOGY

Stratigraphy and Criteria Used For Subsurface Identification

The formations encountered in the test holes studied were of Permian, Cretaceous, Tertiary (?), and Pleistocene age. The Permian rocks have been tentatively classified as the Cedar Hills sandstone and the Salt Plain formation belonging to the Nippewalla group (Frye and Brazil, 1943, p. 16). Above the Permian, in ascending order, are the Cheyenne sandstone, Kiowa shale, Dakota formation, Graneros shale, Greenhorn limestone, and the Fairport chalky shale member of the Carlile shale. Where the Cheyenne sandstone is absent, the Kiowa shale lies directly upon Permian rocks. The uppermost deposits, unconformably overlying the Cretaceous rocks in the test holes, are here grouped as Tertiary (?) and Pleistocene rocks. A detailed discussion of the Cretaceous stratigraphy of the area has been given by Frye and Brazil (1943), and Rubey and Bass (1925) have also reported on the Cretaceous stratigraphy of Russell County. The physical characteristics of these formations as observed in test-hole samples are summarized below.

The formations are listed in Table 1, which is adapted from a similar table by Frye and Brazil (1943, p. 13). Locations of the test holes are shown in Figure 2. Numbers 22, 23, and 24 are commercial shallow disposal wells not drilled for the State Board of Health. Numbers 1, 5, 6, and 7 are holes drilled using a portable hydraulic-rotary drilling machine owned and operated by the State and Federal Geological Surveys for the investigation by Frye and Brazil (1943).

QUATERNARY AND TERTIARY (?) ROCKS

Deposits either of Pleistocene or Pleistocene and Tertiary (?) age were found immediately below the surface in all except three of the test holes. The material consists of buff-colored clay, silt, sand, and gravel, locally cemented by calcium carbonate. Where present it ranges in thickness from 10 feet in test hole 12, one of the upland holes, to 105 feet in test hole 17 near Fossil Creek, a

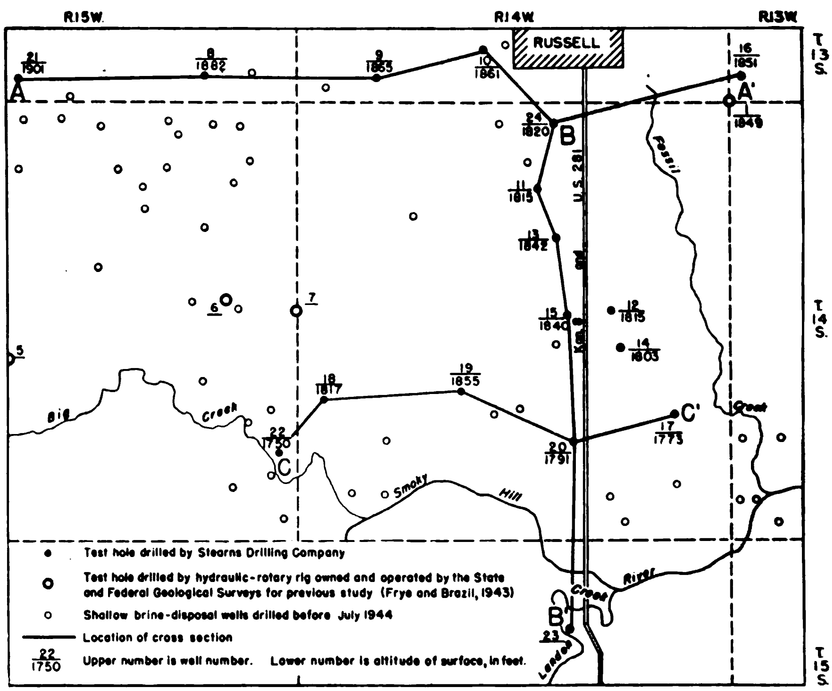

FIG. 2. Map of part of Russell County, Kansas, showing locations of test holes and brine-disposal wells.

TABLE 1.—*Generalized section of geologic formations in test holes in southwestern Russell County*

System	Series	Subdivisions		Thickness (feet)	Physical Character
Quaternary	Pleistocene	McPherson (?) formation and younger and older beds.		0-105	Gravel, sand, silt, clay, and volcanic ash; locally cemented by calcium carbonate. Gravels contain igneous and limestone pebbles.
Tertiary (?)				0-40	Gravel, sand, silt, and clay; locally cemented by calcium carbonate.
Cretaceous	Gulfian*	Carlile shale	Fairport chalky shale member	45±	Shale, blue gray, massive to thin-bedded.
		Greenhorn limestone	Pfeifer shale member	90-98	Shale, and limestone, interbedded. Shale is calcareous, gray to black; limestone is thin-bedded, fossiliferous, gray.
			Jetmore chalk member		
			Hartland shale member		
			Lincoln limestone member		
		Graneros shale		14-40	Shale, blue gray to brownish black, locally contains clay, siltstone, and sandstone. Contains pyrite.
	——— ??? ———	Dakota formation	Janssen clay member	213-300	Clay, shale, siltstone, and sandstone interbedded and varicolored. Contains abundant siderite, hematite, and limonite, and some lignite.
			Terra Cotta clay member		
		Kiowa shale		50-105	Shale, dark gray to black, containing beds of sandstone and siltstone and crystals of pyrite.
	Comanchean*	Cheyenne sandstone		0-62	Sandstone, medium to fine-grained, gray, and some shale and siltstone
Permian	Leonardian*	Nippewalla group*			Siltstone, fine-grained sandstone, and shale; red and gray; loosely cemented.

*Classification of the State Geological Survey of Kansas.

tributary to the Smoky Hill River. A map by Frye, Leonard, and Hibbard (1943) indicates that test holes 17, 18, 20, 22, and 23 were drilled into a high-terrace deposit of Pleistocene age, which was referred by them to the McPherson (?) formation. The test holes to the north, nos. 8, 9, 10, 12, 13, 15, 16, and 21, were drilled on the upland. The silt and sand deposits on this upland have been described by Frye, Leonard, and Hibbard (1943, p. 34) as "probably younger than the Ogallala formation of central Ellis County and . . . . certainly older than the high-terrace deposits along the Smoky Hill Valley."

CRETACEOUS ROCKS

In the area under discussion the Tertiary (?) and Quaternary deposits are underlain unconformably by Cretaceous rocks which range downward from the Fairport chalky shale member of the Carlile shale to the upper part of the Dakota formation. The following descriptions apply only to the subsurface drill-hole cuttings and not to surface samples unless so stated. Contacts, particularly in the post-Kiowa formations, were picked with the aid of a report on the pre-Greenhorn Cretaceous rocks of north-central Kansas by Plummer and Romary (1942) and the report by Frye and Brazil (1943).

Carlile Shale

The lower part of the Fairport chalky shale member of the Carlile shale was encountered in the northwestern part of this area in test holes 8, 9, 10, and 21 and in test hole 10 reached a maximum thickness of 45 feet. The lower part of the member is dark blue-gray to black chalky shale including white specks of calcium carbonate. *Globigerina* are common in most of the samples, and shell fragments are present. The Fairport is lithologically similar to the upper part of the underlying Greenhorn limestone except that the chalk beds of the Fairport are thinner and not so closely spaced as those of the Greenhorn. The contact with the Greenhorn, which was based by Rubey and Bass (1925, p. 45) on a faunal break, is difficult to pick in well cuttings.

Greenhorn Limestone

The Greenhorn limestone consists of alternating beds of thin limestone and chalky shale similar to that of the Fairport. The upper limestones are chalky, whereas the lower ones are crystalline and harder. Shell fragments and *Globigerina* are common. The *Globigerina* in the well samples are identical to those identified by J. B. Reeside, Jr. as *Globigerina bulloides* D'Orbigny and *Globigerina* sp. undetermined (Rubey and Bass, 1925).

The top of the Greenhorn limestone is marked by a chalky limestone bed, and the contact with the Graneros shale below is indicated by the appearance of noncalcareous shale or sandstone. Blue-gray bentonite was seen near the base of the formation in cuttings from several test holes. Frye and Brazil (1943, p. 26) described the subsurface features of the Greenhorn in Ellis and Russell Counties as follows:

> Well cuttings from this formation consist of fragments of dark-gray calcareous shale and limestone. The shale fragments are typically speckled with light-gray flakes of calcium carbonate. These characteristics make the cuttings easily distinguishable from the Graneros shale below, but less easily distinguishable from the overlying Fairport chalky shale member of the Carlile shale. It is difficult to recognize subdivisions of the Greenhorn from well cuttings owing to the nearly uniform nature of the rocks. The hard limestone beds are, for the most part, too thin to distinguish and are fairly evenly distributed throughout the formation.

The Greenhorn limestone in this area ranges in thickness from 90 to 98 feet.

Graneros Shale

The Graneros shale in this area consists of dark-gray to brownish-black noncalcareous shale and thin beds of dirty, glauconitic, fine-grained sandstone. It differs from the Greenhorn limestone in the presence of sandstone and siltstone and the absence of *Globigerina* and calcareous matter; and from the underlying Dakota formation in the presence of glauconite and pyrite and the absence of kaolin and abundant siderite. Sandstone and siltstone occur in all the test holes penetrating the Graneros shale except 9, 10, 11, 21, and 23. In four test holes, 8, 13, 14, and 18, the Graneros is sandy throughout. In nos. 12, 16, and 19 sand is restricted to the basal part, and in no. 15 there is a thin siltstone near the top. Glauconite was found associated with the sandstones and siltstones in all the test holes.

The thickness of the Graneros shale seemingly ranges from 14 to 40 feet, although the minimum, which was encountered in test hole 9, is materially lower than the minimum of 25 feet given by Frye and Brazil (1943, p. 24). This discrepancy may be due to the presence of a thick, well-indurated bed of sandstone at the top of the Dakota formation in test hole 9, which may have formed a local topographic high at the time of Graneros deposition or have caused differential compaction of the clays.

Dakota Formation

The Dakota formation in this area is composed dominantly of varicolored clay and siltstone, including thin beds of fine-grained sandstone and numerous channel sandstones. It contains abundant siderite in the form of angular fragments and small pellets or botryoidal concretions, hematite, limonite, lignite, and charcoal. Crystals of pyrite are present in some of the sands. The formation ranges in thickness from 213 to 300 feet. The top of the Dakota is marked in some places by the presence of gray clay containing abundant concretionary siderite, and at other places by relatively coarse sandstone containing small amounts of siderite.

Lateral variation within the Dakota formation is pronounced, and although the area is small we have been able to identify only two zones with any degree of certainty in most of the test holes. The highest of these zones is the approximate contact between the Janssen clay member (upper) and the Terra Cotta clay member (lower), named from two railroad stations in Ellsworth County, Kansas, by Plummer and Romary (1942). The contact is described by them as follows:

> The Janssen-Terra Cotta contact is not a sharp one, but in most places it can be drawn within a 5-foot zone. This contact is arbitrarily placed by us at the top of a zone of concentrated concretionary siderite, limonite, or hematite, which is overlain by a bed of gray massive clay containing varying amounts of siderite (possibly ankerite, in some cases) pellets and with yellow to yellow-orange coloring along oblique joints.

In 9 of the 16 test holes a zone of concentrated concretionary siderite was found below gray massive clay 40 to 81 feet below the base of the Graneros shale. The average thickness of the Janssen clay member of the Dakota encountered in these test holes is 64 feet. We did not observe yellow coloring in the gray massive clay, but it may possibly be a near-surface feature.

The second persistent zone is in the Terra Cotta clay member of the Dakota 40 to 80 feet above the base of the formation. A fine-to medium-grained well-sorted sandstone, in part cemented by calcium carbonate, and containing well-rounded grayish-green grains of glauconite, was encountered in seven of the test holes. In three other wells sandstone having the same type of cement was encountered 50 feet above the base of the formation, but glauconite was not observed. Frye noted glauconite in the same zone in test hole 6 (unpublished sample log). Neither glauconite nor calcite-cemented sandstone was found higher in the Dakota section except in two test holes where traces 30 feet below the top of the Terra Cotta clay member were found.

The presence of glauconite in a persistent zone suggests a short period of marine deposition. Tester (1931) discussed the occurrence of glauconite in various parts of the Dakota formation of the type locality in eastern Nebraska and concluded that it indicated marine conditions, even though glauconite sometimes develops by the alteration of an alkaline feldspar.

Whether or not the zone is marine, it is a useful marker in determining the approximate depth to the Kiowa shale in southwestern Russell County. Its regional extent is not known, although Plummer has noted the presence of calcium-carbonate cement in sandstone in outcrops at the same stratigraphic horizon in Ellsworth, Ottawa, and Washington Counties (oral communication).

The lithology is variable below the calcite-glauconite zone. A thin bed of black shale was found to immediately underlie this zone in some test holes. Clay ranging in color from white to dark gray to red and gray mottled, siltstone, fine to coarse sand, lignite, and siderite pellets were encountered in a few test holes. Lower zones of calcitic and glauconitic sandstones were found in other holes. The base of the Dakota formation was defined in most test holes by a fine- to coarse-grained sandstone containing siderite pellets, much pyrite, and no glauconite, although in five test holes red and gray clay or siltstone was found in contact with the underlying dark Kiowa shale.

Kiowa Shale

General features.—The Kiowa shale consists of gray to black thinly laminated shale and interbedded thin white sandstone and siltstone. In several test holes a sandstone approximately 20 feet thick was found in the middle part of the Kiowa. Shell fragments are common; pyrite is present in every sample, occurring as cement in the sandstones, as large massive chunks, as replacements of wood, and as cubic crystals. Lignite, charcoal, thin beds of limestone, and fragments of cone-in-cone structures were seen in the cuttings from a few test holes. Abundant charcoal was observed in samples which contained little pyrite. A small amount of brown ironstone or impure siderite occurs in the samples of shale and siltstone.

Mineralogy.—The following heavy minerals were identified in 24 samples of sand of the Kiowa shale.

Zircon is common and consists primarily of subrounded and colorless euhedral grains, although some grains are pink and yellow. A few small, thin, colorless prisms of zircon occur in flakes of muscovite.

Most of the **tourmaline** grains are green but brown is also common. Others are bluish-green, blue, yellow to almost colorless, opaque, deep green to pale pink, and parti-colored in tones of brown and green. Most of the grains are angular or prismatic, but a few are well rounded. There are a few rounded grains of tourmaline having worn, colorless, authigenic terminations.

Ilmenite occurs as angular grains having rough surfaces. A few grains are partly altered to leucoxene.

Most of the **leucoxene** of the Kiowa consists of yellowish or brownish, angular, semitranslucent to opaque grains having rough surfaces. Leucoxene exceeds ilmenite by at least 2 to 1 in every sample (Pl. 1) and in a few samples it is more than three times as common as ilmenite.

Staurolite is not common, but a few grains are present in nearly every sample, and the grains are large and irregular in outline. Many of them have "concertina" boundaries, owing probably to solution. Pleochroism is marked (X = pale yellow or colorless; Z = russet brown).

Garnet occurs in most samples, but its concentration is less than 2 percent. All the garnet in the Kiowa is colorless. The shape of the grains is irregular, and the surfaces of some grains are pitted.

One or two small grains of reddish-brown **rutile** occur in most samples.

Titanite occurs as fairly small yellowish-brown grains having clouded interiors; it is present in most samples.

Two varieties of **hornblende** are present in sands of the Kiowa shale, although their occurrence is rare. Blue-green hornblende was observed in a few samples, but the green variety is more common.

Chlorite minerals were found in all the sands of the Kiowa. We did not attempt to differentiate between the various minerals of the group.

The occurrence of **barite** is highly variable both in quantity and appearance. There are rounded grains, angular fragments, and particles curved around grains of quartz and other minerals. Some grains are clear; others are clouded with carbonaceous inclusions. Nearly all, if not all, the barite is authigenic; therefore it was not included in the mineral counts.

One or two large, deep purplish-brown, almost opaque grains of **anatase** having crystal facets or irregular surfaces were found in about one-third of the samples; they are probably authigenic.

Only one grain each of the following minerals was observed; these may have been derived from the Dakota formation. One grain of **magnetite** was identified by its characteristic dodecahedral crystal form, but occasional tests with a bar magnet did not reveal the presence of any more magnetite. One grain of **diopside** having dentate ends occurred in cuttings from test hole 15.

The following minerals were lost on acid digest. **Calcite** and **aragonite** occurred in shell fragments, cone-in-cone structures, and as cement. **Pyrite** occurred as cement, massive chunks, radiating masses, and cubes, some of which are striated. **Anhydrite** seems to have had approximately the same occurrence as that of barite. Impure **siderite** was present (but not so abundantly as in the Dakota formation) in the form of clay-ironstone or brown ironstone or mudstone.

The light fraction is predominantly quartz including less than 5 percent **feldspar,** as determined by staining tests (Russell, 1935). The feldspars are largely partly decomposed **plagioclase** and **microcline.** Most of the **quartz** grains are characterized by many fluid and automorphic mineral inclusions whereas acicular inclusions are rare. **Chert** is present in all the samples, and quartzite fragments occur in most of them.

Muscovite is common in most sands of the Kiowa. It contains varied inclusions; the outlines of the flakes range from well rounded to ragged.

Several rounded, grayish-green particles of **glauconite** are present in nearly every sample of sand from the Kiowa shale.

Mechanical composition of sands.—Sands of the Kiowa shale are uniformly fine-grained; the mean diameters of all except two of the 19 sands analyzed fall within the limits 0.10 to 0.16 mm. One sample, from the base of the Kiowa in test hole 21, is coarser grained, having an average diameter of 0.20 mm, and possibly includes an admixture of the Cheyenne sandstone. The other sample, having a mean diameter not within the specified limits, is a very fine-grained sand from the middle of the Kiowa shale in test hole 19. Its mean diameter is 0.08 mm. The difference in size between the fine sands of the Kiowa and the basal sands of the Dakota formation generally is sharp.

The degree of sorting in the samples is highly variable, and has not been included in the cross sections because sorting values obtained from drill cuttings seem to be meaningless. In many samples, however, the logarithmic standard deviation (Krumbein and Pettijohn, 1938, p. 249f) is 0.5 or smaller. This value means that approximately 68 percent or two-thirds of the frequency distribution lies within one Wentworth grade. This high degree of sorting observed in samples of cable-tool cuttings taken from an interval of 5 feet or more, coupled with the low range in average size of sands of the Kiowa, may indicate uniform conditions of deposition.

Roundness evaluation of sands.—With one exception, all the sands of the Kiowa shale showed extreme angularity in quartz grains of the size studied (0.177 to 0.125 mm), where most of the roundness values occur between 0.1 and 0.3 (Pl. 2A). The exception is in cuttings from test hole 20, in which a mixture of rounded and angular grains was found immediately above red shale of Permian age. A similar low degree of roundness was also observed in the tourmaline, ilmenite, leucoxene, and, to some extent, zircon grains.

The Dakota-Kiowa contact.—The Dakota-Kiowa contact is not a sharp one, nor is it marked by any particular beds having distinctive lithology. The top of the Kiowa shale consists of gray to dark-gray shale in most test holes and fine-grained, micaceous, glauconitic sandstone in others. Fire tests on the gray shale below the basal sandstone of the Dakota formation show complete gradation from a dense, moderately light-firing material at the top to a dark, bloated clinker within about 20 feet. This gradation probably is due to surface weathering of the Kiowa shale before deposition of the Dakota formation (Plummer, oral communication); therefore, even though the light-firing clay is regarded by Plummer as typical of the Dakota formation, we have included it with the Kiowa in holes where it was found to grade into unquestioned Kiowa shale.

Diagnostic criteria for identification.—The Kiowa shale is a lithologic unit consisting of gray to black shale, light siltstone, and fine-grained, angular, micaceous, glauconitic sandstone. It differs from the overlying Dakota formation in the absence of coarse sand, siderite pellets, and red clay, and in the presence of shell fragments, abundant pyrite, and cone-in-cone structures. Its outstanding distinguishing characteristic is the presence of thick beds of dark-gray, thinly laminated shale.

Cheyenne Sandstone

General features.—The Cheyenne sandstone is predominantly buff to light-gray sandstone containing a small amount of shale and siltstone; in the area studied it ranges in thickness from a featheredge to 62 feet. In north-central Ellis County, west of this area, the formation attains a maximum thickness of more than 200 feet (Frye and Brazil, 1943, p. 17), and immediately east of the area studied the Cheyenne is reported to be absent. The Cheyenne sandstone unconformably overlies the Permian redbeds and is overlain by the marine Kiowa shale.

Mineralogy.—Heavy minerals identified in 51 samples from the Cheyenne sandstone include the following species: **zircon, tourmaline, ilmenite, leucoxene, staurolite, garnet, rutile, titanite, hornblende, barite**, purplish-brown **anatase, chlorite**, and one or two grains each of **topaz, pleonaste, and kyanite** (Table 3). Several grains of an unidentified colorless biaxial mineral having high refractive indices were observed, two grains of which were also found in the Kiowa.

The heavy mineral suite consists predominantly of zircon, tourmaline, ilmenite, and leucoxene, as in the sands of the Kiowa shale, except that the amount of ilmenite in many samples from the Cheyenne exceeds that of leucoxene (Pl. 1). All varieties of tourmaline found in samples from the Kiowa occur also in the Cheyenne. In addition there are parti-colored grains in combinations of green and blue; green and yellow; green, blue, and brown; yellow and blue; and brown and blue. Garnet occurs in the colorless form and also in a pink variety.

In the facies of the Cheyenne sandstone in which the quartz grains are predominantly angular the heavy mineral suite is somewhat similar to that in the sands of the Kiowa shale, except that chlorite is less common than in the Kiowa.

The samples in which the quartz grains are predominantly rounded are characterized by the same restricted mineral suite as that of the typical Permian sands—**zircon, tourmaline, ilmenite, leucoxene, staurolite, rutile, garnet,** and authigenic **barite.** There are fewer angular and prismatic grains of tourmaline in this type of Cheyenne sandstone than in the sandstones of the Kiowa shale and the tourmalines are predominantly brown instead of green. The leucoxenes and ilmenites are also well rounded, and a large proportion of the leucoxenes have the porcelanous texture typical of leucoxene in the Permian sands. As in the Permian, the leucoxene-ilmenite ratio is less than unity in the rounded sands, except in cuttings from the test holes south of the city of Russell, where the ratio is more nearly the same as it is in the Kiowa (Pl. 1), although the ilmenite and leucoxene from these test holes are of the Permian type.

Calcite, pyrite, anhydrite, siderite, and **hematite** were lost when the samples were treated with acid. Calcite occurred as interstitial material in cuttings from a few test holes. The occurrence of pyrite was similar to that in the Kiowa shale except that pyrite was much less common in the Cheyenne sandstone encountered by the western test holes than in the Kiowa or in the Cheyenne encountered by the eastern holes. Anhydrite was common. Impure siderite was present in the same form as in the Kiowa shale, and impure hematite in the form of red ironstone was associated with it. Siderite and hematite were more common in cuttings from the eastern group of test holes.

In the Cheyenne sandstone, as in the Kiowa shale, the light fraction is predominantly **quartz** and includes less than 5 percent **feldspar.** The angular quartz grains are similar in appearance to those of the Kiowa. Some of the quartz grains in the rounded group are without inclusions of any kind, and others are characterized by parallel and subparallel bands of fluid inclusions. In general, inclusions in the rounded grains are fewer than in quartz grains of the Kiowa. Automorphic and acicular mineral inclusions are rare. The surfaces of the grains in the rounded group are commonly frosted or pitted. In both groups a few of the grains exhibit undulatory extinction, as do a few of the grains of quartz and muscovite in the Kiowa. **Muscovite** is rare in the Cheyenne. **Chert** is present in all the samples, and **quartzite** is present in most of them. **Glauconite** is present in many samples, but it is not as common as in the Kiowa.

Mechanical composition of sands.—Those samples of Cheyenne sandstone in which the grains are predominantly rounded range in average size from 0.08 to 0.24 mm. In most of the test holes the grain size of the lowermost sample of the Cheyenne sandstone is slightly coarser than that of the Permian material immediately underlying it. The geometric mean diameter of the angular facies of the Cheyenne sandstone is much more uniform, ranging from 0.15 to 0.20 mm. This range is uniformly larger than the mean diameter of the sands of the Kiowa shale.

Roundness evaluation of sands.—On the basis of roundness, the Cheyenne sandstone may be subdivided into two types. One type has the low degree of roundness of the sands of the Kiowa shale, and the other type has the moderately high roundness of the underlying sands of the Permian beds. In the latter type, most of the roundness values of the size studied (0.177 to 0.125 mm) occur between 0.4 and 0.6. Some samples consist of mixtures of rounded and angular grains. The areal distribution and significance of the two types of sand in the Cheyenne will be discussed in the sections on lateral changes and depositional environment.

The Kiowa-Cheyenne contact.—In most of the test holes the Kiowa-Cheyenne contact was found to be marked by a sharp change from fine-grained, micaceous, angular sand to medium- or fine-grained, nonmicaceous sand which may be either angular or rounded. In a few test holes the top of the nonmicaceous sand was found to occur at the base of dark-gray or black Kiowa shale.

Diagnostic criteria for identification.—As work on the sand samples progressed, it became evident to us that the Cheyenne sandstone is comprised not only of sand from an immediate source (the underlying sandstones of the Permian) but also from a more distant region, which probably also supplied sand to the Kiowa shale. In parts of the area the sands in the Cheyenne were derived entirely from the Permian redbeds, but in other parts of the area the sands in the Cheyenne were derived almost entirely from a different source. It was therefore impossible to use the criterion of grain roundness to differentiate between the Cheyenne sandstone and the Kiowa shale, and comparative mineralogy was found to be useful only where it reflected the conditions under which the sand was deposited. As most of the beds of sandstone which are unquestionably part of the Kiowa shale consist of white, fine-grained, micaceous, glauconitic sand and silt, and as marine shell fragments do not occur below the lithologic unit comprised by these beds of sand and the dark Kiowa shale, we have included the material below the micaceous sand and dark shale and above the Permian redbeds in the Cheyenne sandstone. We could find no other definite lithologic break. Another criterion consists of the presence of red ironstone or impure hematite in the Cheyenne and its absence in the fine-grained micaceous sandstone and dark shale of the Kiowa. These criteria are intended for use only in the immediate area with which this report is concerned. Farther southwest the Kiowa shale probably also contains fine sand grains of the rounded type, which were transported by streams crossing the area of red Permian sands.

PERMIAN ROCKS

General features.—The Permian redbeds underlying the Cheyenne sandstone and Kiowa shale in Russell County consist of red and white sandstone, red siltstone, and red and gray shale. Beds of sandstone predominate in the western part of the area but are thin to absent farther east. The westward-dipping Cedar Hills sandstone (?) may possibly be truncated in the eastern part of the area, where the Salt Plain formation (?) may be in contact with the Comanchean.

Mineralogy.—The heavy mineral suite of typical sand from the Permian redbeds is restricted to **zircon, tourmaline, staurolite, rutile, ilmenite, leucoxene,** and authigenic **barite** (Table 2), as described in the section on mineralogy of the rounded sands of the Cheyenne. **Garnet**, some of which is pink, occurs in about a third of the samples. One or two grains of each of the following were seen: **epidote, spinel, hornblende,** and **anatase.** In general, the amount of ilmenite exceeds that of leucoxene. Titanite and chlorite, present in only a few samples, are much more rare than in the

Comanchean sands. The heavy mineral content of most of the Permian sands is less than 0.3 percent by weight.

Iron-oxide coating on the grains, fragments of impure **hematite,** and a variable amount of **anhydrite** were the major constituents removed during acid-treatment. **Pyrite** was rare to absent.

In the light fraction, the occurrence of **quartz** and **feldspar** is similar to that in the rounded facies of the Cheyenne sandstone. The quartz grains are commonly frosted. One grain of **orthoclase** surrounded by unworn authigenic feldspar was observed. The occurrence of **glauconite** is sporadic, and it is not so abundant as in the Kiowa shale. **Muscovite** is rare in the sand, but a moderate amount is present in some of the silty shale.

Mechanical composition of sands.—The average diameter of sands of Permian age in the area studied ranges from 0.08 to 0.22 mm. In general, Permian sands from test holes in the westernmost part of the area are slightly coarser grained than those from test holes in the central part; east of the approximate center of T. 14 S., R. 14 W., the Permian rocks are predominantly red siltstone and red shale. Test hole 20, in the eastern part, penetrated more than 300 feet of uniform brick-red shale and siltstone. At least 165 of the 198 feet of Permian rocks penetrated by test hole 8, one of the westernmost tests, was red sandstone. Such evidence suggests that the eastern edge of the Cedar Hills sandstone occurs within the area studied, but the data are too meager to permit the mapping of a definite boundary line.

Roundness evaluation of sands.—Quartz grains of the size for which roundness values were determined are essentially all fairly well rounded (Pl. 2B), and there are few particles having a roundness less than 0.4.

The Permian-Cretaceous contact.—The unconformity at the base of the Cretaceous rocks is marked in the outcrops by a weathered zone. A thin zone of weathered and bleached material was observed by McFarland in the drilling of the test holes (oral communication), but as a rule we were unable to detect it in the samples. This failure probably resulted from the finely divided character of the silt and from admixture with the underlying unweathered redrock and overlying gray sandstone and siltstone. McFarland reported the thickness of the zone to be approximately 2 feet, which is comparable with the thickness seen in surface exposures.

PLATE 2. Photomicrographs of quartz grains of the size range 0.125 to 0.177 mm from the Kiowa shale and Permian redbeds, showing difference in roundness: *A,* Kiowa shale, test hole 10, depth 472-481 feet; *B,* Permian redbeds, test hole 8, depth 560-565 feet.

In one or two test holes the color change from gray sandstone to red sandstone was found to be gradational within an interval of 10 or 20 feet, and in these tests the placing of the contact was somewhat arbitrary. Frye (oral communication) has found surface exposures in Kiowa County in which large amounts of red Permian material have been incorporated into the basal beds of the Cheyenne sandstone without loss of color. There is no way known to us to determine from well cuttings whether or not this has occurred in Russell County.

Diagnostic criteria for identification.—The outstanding distinguishing characteristic of the Permian redbeds is their red color. Although on the basis of roundness and mineralogy they can be distinguished from the sands of the Kiowa shale and angular facies of the Cheyenne sandstone, the red color and the associated scarcity of pyrite are the only features determinable by us which serve to differentiate between the Permian sands and the rounded facies of the Cheyenne .

Lateral Changes in Thickness and Character of the Kiowa and Cheyenne Formations

The Kiowa shale attains its greatest thickness in the northwestern part of the area, where it reaches a maximum of 105 feet in test hole 21. The formation gradually thins toward the east and southeast, where a minimum thickness of 50 feet occurs in test holes 18 and 20. Figure 3 is an isopachous map of the formation.

We were unable to trace any persistent lithologic zones within the Kiowa shale, although a fine-grained, micaceous sandstone, 5 to 30 feet thick, was found in the middle of the formation in several test holes. Micaceous sandstone occurred at the base of the formation in the northwestern test holes and was found to thin westward from 35 feet in test hole 10 to 10 feet in test hole 21. This basal sandstone was not encountered elsewhere except in test holes 12 and 15. Shell fragments were most abundant in samples from test holes south of the city of Russell. Fragments of cone-in-cone structures were present in samples of the Kiowa from test holes 13, 16, and 24.

The thickest occurrence of the Cheyenne sandstone in the area was penetrated by test hole 5 of the report by Frye and Brazil (1943). The formation thins toward the southeast and northeast (Fig. 4), where its thickness is 20 feet and less, and thickens to 55 feet in test hole 12, south of Russell in the east-central part of the area. The Cheyenne sandstone encountered in test holes 8, 9, 11, 18, and 22 was found to consist almost wholly of rounded grains of the Permian type. In test holes 10, 15, and 16, the top part of the formation was found to contain angular sand like that of the Kiowa except for its larger grain size and absence of mica. There is an abrupt transition to rounded sand below. The degree of roundness is variable in cuttings from the remaining test holes.

Figure 5 is an isopachous map of the Comanchean strata from the top of the Kiowa shale to the top of the Permian rocks. Under the assumptions that (1) the Kiowa shale is conformable on the Cheyenne sandstone, (2) the top of the Kiowa shale was a nearly flat surface at the close of Kiowa deposition, and (3) pre-Dakota erosion was negligible (as it seems to have been in surface exposures), the map becomes a paleotopographic map of the buried Permian surface in Comanchean time. The prominent features are a saddle between two high areas and a valley having a gentle slope

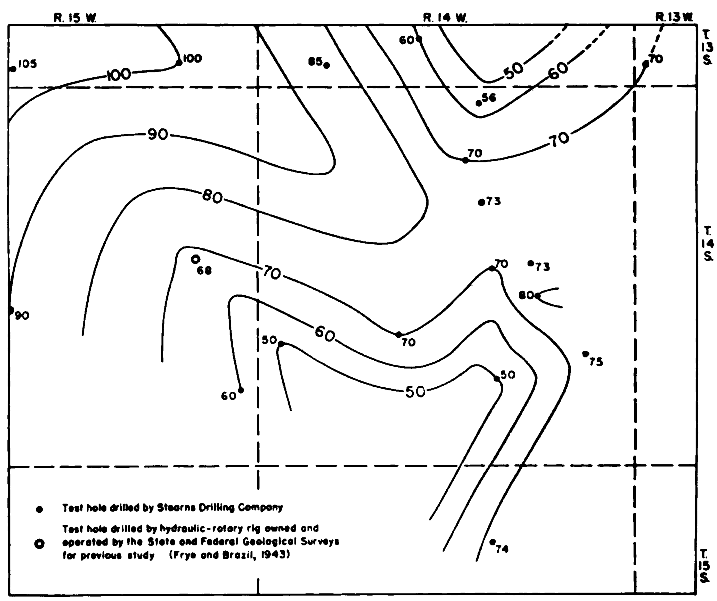

FIG. 3. Map of part of Russell County, Kansas, showing changes in thickness of the strata between the base of the Dakota formation and the base of the Kiowa shale.

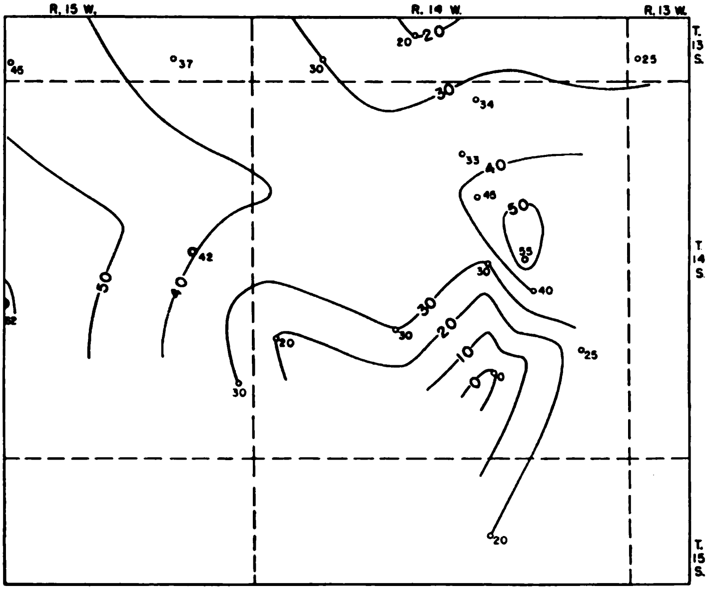

Fig. 4. Map of part of Russell County, Kansas, showing changes in thickness of the strata between the top of Permian redbeds and the base of the Kiowa shale. For explanation see Figure 3.

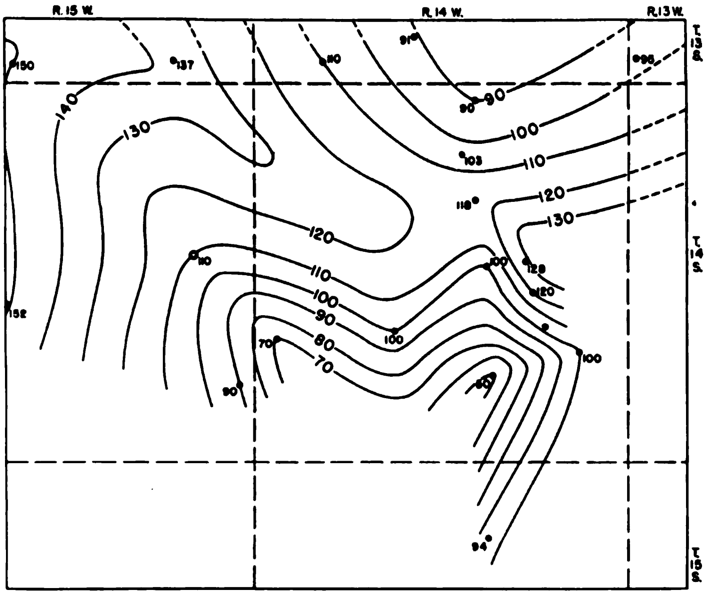

Fig. 5. Map of part of Russell County, Kansas, showing changes in thickness of the Kiowa shale and Cheyenne sandstone. For explanation see Figure 3.

downward toward the northwest. The pattern is reflected in the thickness maps of the Cheyenne and Kiowa formations (Figs. 4 and 5). The gradual slope of the Permian surface and the thickening of the Cheyenne sandstone toward the west are clearly illustrated in section AA′ (Pl. 1A). Section BB′ (Pl. 1B) shows the depression along a general north-south line across the saddle, and the corresponding thickening of the Cheyenne sandstone in the deepest part. The test holes in which the lower part or the entire thickness of the Cheyenne was found to consist largely of rounded sand grains are, with one exception, on the western flank of the Permian high area. The test holes in which the Cheyenne showed the lowest degree of roundness (12 and 17) are in areas east of the Permian "high," where the Permian rocks are composed of red clay and fine silt. Varying degrees of mixture of rounded and angular grains were found in test holes in the saddle and also in no. 21, in the northwest corner of the area. Silt and shale in the Cheyenne were found only in test hole 21 and in test holes in the saddle. Pyrite also was more common in the same test holes. The isopachous maps should not be regarded as accurate representations of fact because of the difficulty of picking contacts in several test holes. However, variation of a few feet in either direction should not significantly alter the general picture. Test hole 8, in which there was much caving, perhaps is not correctly represented in the Permian valley.

Depositional Environment of the Cheyenne Sandstone

The features described in the foregoing paragraphs suggest that more than one environment is represented in the Cheyenne sandstone of the area studied. The well-washed, well-sorted sands in the western part of the area were probably eroded from the underlying land surface by waves of an eastward-advancing early Cretaceous sea and deposited along a fairly open shore line, in part cut and planed by wave action. As the sea advanced beyond the edge of the Permian Cedar Hills sandstone (?) and cutting tools became less abundant, the effect of the pre-Cheyenne topography upon the environment may have been more important. The deposits of the Cheyenne associated with the Permian saddle have the following characteristics which may be attributed to deposition

TABLE 2.—*Mechanical analyses of sand samples from test holes in Russell County*

(By Carrie B. Thurber)

Test hole	Depth (feet)	Geologic subdivision	Mechanical Analysis (percent by weight)									
			Fine gravel	Coarse sand		Medium sand		Fine sand		Very fine sand		Silt and clay
			(1.41-1.0 mm)	(1.0-0.71 mm)	(0.71-0.50 mm)	(0.50-0.35 mm)	(0.35-0.25 mm)	(0.25-0.177 mm)	(0.177-0.125 mm)	(0.125-0.088 mm)	(0.088-0.062 mm)	(less than 0.062 mm)
8	518-28	Cheyenne				1.9	48.1	30.5	13.3	4.9	0.8	0.5
8	540-45	Permian				.9	21.4	26.3	32.9	14.0	2.8	1.6
9	487-97	Kiowa			0.0	.0	.1	.6	32.7	47.1	13.1	6.4
9	580-85	Permian					1.0	3.9	17.5	24.5	18.6	29.5
10	472-81	Kiowa				.5	1.6	12.9	27.9	26.5	20.1	10.5
10	505-15	Cheyenne				.1	3.5	18.3	42.9	21.2	10.6	3.5
10	560-70	Permian				.0	2.9	31.2	30.0	18.1	12.3	5.4
11	305-15	Dakota				12.0	47.6	21.0	10.1	3.5	1.7	4.0
11	400-10	Kiowa			.2	.9	1.2	4.2	21.6	38.5	13.2	20.2
11	457-65	Permian					1.2	10.6	22.8	32.6	19.3	13.5
12	418-23	Kiowa				.4	1.7	30.6	45.4	13.0	5.2	3.7
12	428-33	Cheyenne				.3	1.7	13.5	39.9	27.1	10.0	7.6
13	415-20	Kiowa				.5	2.9	18.8	44.1	22.9	5.8	5.1
13	445-54	Cheyenne				.4	16.8	47.2	29.6	4.1	1.0	0.9
14	320-25	Kiowa	0.1	0.1	.1	.6	4.5	27.7	51.1	10.5	2.4	2.9
14	415-20	Cheyenne			.4	3.3	8.7	20.1	37.6	15.4	6.7	7.8
17	195-205	Dakota			.4	4.2	17.3	31.5	33.8	9.1	1.8	1.9
17	375-80	Cheyenne				.2	3.5	50.4	35.8	6.9	1.7	1.6
17	425-30	Permian				1.0	11.0	36.5	42.5	6.7	1.7	0.7
18	420-25	Cheyenne				1.6	24.7	27.2	25.6	17.3	2.7	1.0
18	440-45	Permian				.4	11.1	21.7	35.5	26.0	3.0	2.3
19	460-65	Cheyenne				.3	8.9	37.1	29.7	19.9	2.3	1.8
19	485-95	Permian	0.9	1.2	1.6	1.8	5.3	25.4	37.4	15.6	5.1	5.7
20	380-85	Dakota		.6	.9	6.2	28.4	29.8	22.8	7.5	2.2	1.6
21	375-80	Dakota			.5	3.9	9.8	18.4	38.1	17.2	6.1	6.0
21	485-90	Kiowa (?)		.2	.5	10.3	29.6	22.8	20.5	10.5	2.6	2.9
21	500-05	Cheyenne			.3	4.8	12.2	16.6	32.9	22.4	5.6	5.2
21	540-45	Permian				1.7	9.5	11.0	24.1	30.6	10.8	12.2
22	260-65	Dakota				.3	.8	3.6	39.0	36.4	9.2	10.6
22	310-15	Kiowa					.4	1.3	43.3	36.9	7.0	11.1
22	330-35	Cheyenne				.7	9.1	11.6	29.2	39.8	5.6	3.9
22	360-65	Permian				.1	11.6	21.6	29.9	30.1	4.4	2.3
23	480-85	Cheyenne				.4	4.8	22.4	32.4	30.7	5.7	3.6
24	436-40	Cheyenne		.3	1.4	3.0	14.7	41.4	33.4	4.5	.8	.5

Table 3.—*Heavy mineral frequencies in cuttings from sands of the Kiowa and Cheyenne formations and the Permian redbeds, expressed as percentages*

Kiowa Shale

Test hole no.	Inclusive depths (feet)	Ilmenite	Leucoxene	Tourmaline	Zircon	Staurolite	Garnet	Rutile	Titanite	Hornblende	Chlorite	Anatase	Others
8	478-88	13	44	17	16	2	1	2	*	2	1	—	—
8	488-98	15	56	15	7	3	1	2	1	—	1	—	—
9	477-87	30	36	9	18	2	1	1	—	1	1	—	*
9	487-97	24	33	5	30	2	1	*	1	*	3	—	*
10	472-81	15	47	12	23	*	*	—	*	—	1	—	—
10	481-86	17	48	10	22	1	1	*	—	—	1	—	—
11	390-400	18	50	13	14	1	—	1	—	*	2	—	—
11	400-10	19	49	10	12	2	1	1	*	1	5	—	—
12	418-25	15	42	11	24	1	1	1	*	2	4	—	—
13	410-15	16	43	10	24	2	—	1	2	2	3	—	—
13	415-20	17	45	12	17	4	*	1	2	1	3	—	—
13	420-25	21	36	8	27	2	1	1	1	1	2	1	—
13	425-30	16	46	14	17	2	*	*	1	*	2	—	—
14	320-25	20	33	10	26	4	1	2	2	*	*	1	1
15	400-20	9	55	11	19	1	*	1	1	*	2	1	—
15	440-45	7	60	16	1	7	1	*	—	*	4	*	*
19	405-10	8	54	11	22	*	*	1	1	—	2	—	—
19	410-15	13	40	5	36	—	*	*	1	*	1	*	1
21	405-10	14	46	12	22	3	*	1	2	—	*	—	—
21	480-85	18	50	10	18	1	*	1	1	—	1	*	—
21	485-90	16	45	8	23	3	1	1	2	*	1	1	—
22	300-05	13	41	11	29	2	1	2	*	—	1	—	—
22	305-10	12	53	8	20	1	*	1	2	—	2	—	*
22	310-15	11	55	12	14	2	1	1	3	*	*	—	*

Cheyenne Sandstone

Test hole no.	Inclusive depths (feet)	Ilmenite	Leucoxene	Tourmaline	Zircon	Staurolite	Garnet	Rutile	Titanite	Hornblende	Chlorite	Anatase	Others
8	498-508	53	17	12	14	2	—	2	*	—	*	—	—
8	508-18	44	24	14	13	3	—	*	—	—	—	—	—
8	518-28	55	13	17	11	2	—	—	*	*	—	—	—
8	528-35	49	29	11	10	1	—	—	—	—	*	—	—
9	532-37	34	30	7	26	1	—	*	1	—	1	—	—
10	500-05	24	43	10	21	2	*	*	—	—	—	—	—
10	505-15	49	27	8	15	2	—	—	—	—	—	—	—
10	515-20	48	19	10	23	1	—	—	—	—	—	—	—
11	420-30	15	55	14	14	2	—	—	—	—	1	—	—
12	423-28	21	29	22	23	3	*	1	1	*	*	—	*
12	433-38	13	49	19	16	1	—	1	*	*	*	—	*
12	438-43	21	33	18	21	3	*	2	1	1	2	—	—
13	445-54	17	49	15	13	2	2	—	1	*	*	—	1
13	454-61	7	43	18	24	2	3	—	1	2	1	—	*
13	461-64	6	42	14	34	*	*	1	1	*	1	—	—
14	420-25	23	37	7	28	1	1	1	—	—	2	1	—
15	445-50	16	52	8	13	8	—	*	1	*	1	1	—
15	450-55	17	37	14	20	7	*	1	*	—	1	2	1
15	455-60	23	33	14	25	4	*	*	1	—	—	—	—
15	460-65	28	32	13	21	2	—	2	1	—	—	*	—
16	480-85	22	43	14	16	2	*	1	*	—	—	—	*
16	485-90	12	57	16	13	1	*	*	*	—	—	—	—
17	365-70	17	36	13	25	4	1	1	1	1	2	—	*
17	370-75	18	39	11	20	5	2	1	1	*	2	*	—
17	375-80	16	50	11	10	9	—	—	1	*	*	1	—
17	380-85	25	42	5	21	3	—	*	1	—	1	—	1
17	385-90	12	36	10	25	12	2	1	—	1	*	*	*
18	410-15	35	35	11	14	3	*	*	—	—	*	*	1
18	415-20	44	36	6	12	2	—	*	*	—	—	—	—

* Trace.

Test hole no.	Inclusive depths (feet)	Ilmenite	Leucoxene	Tourmaline	Zircon	Staurolite	Garnet	Rutile	Titanite	Hornblende	Chlorite	Anatase	Others
18	420-25	36	36	10	17	*	—	*	*	—	—	—	—
18	425-30	21	42	22	9	4	—	—	*	—	—	*	—
19	445-50	33	30	10	24	1	1	*	—	—	1	*	—
19	450-55	39	28	10	18	4	—	—	*	—	—	—	—
19	455-60	30	35	12	18	4	*	*	—	—	—	*	—
19	460-65	26	39	10	19	3	1	—	*	—	2	—	—
19	465-70	27	44	8	15	2	*	1	*	—	—	*	1
19	470-75	23	42	10	16	6	1	*	*	—	*	—	*
21	490-95	18	48	8	18	3	1	—	2	*	—	*	—
21	495-500	13	46	13	20	4	*	*	*	—	*	1	—
21	500-05	17	43	9	22	1	1	*	1	1	2	2	—
21	505-10	19	50	8	18	*	*	*	1	*	3	—	—
21	510-15	26	33	17	18	3	—	2	1	—	—	—	—
21	525-30	47	28	7	14	3	—	*	*	—	*	—	—
21	530-35	47	24	11	12	3	—	*	—	—	—	—	—
22	330-35	57	16	6	17	3	—	—	—	—	—	—	—
22	335-40	50	21	11	16	1	—	*	—	*	—	—	—
22	340-45	52	20	7	18	2	—	*	*	—	—	—	—
22	345-50	56	18	10	15	1	—	*	—	—	—	—	—
22	350-55	47	29	11	12	1	—	—	—	—	—	—	—
22	355-60	42	34	10	10	1	*	*	—	—	—	—	—
24	436-45	18	50	9	10	5	2	—	—	—	1	1	2

Permian Redbeds

Test hole no.	Inclusive depths (feet)	Ilmenite	Leucoxene	Tourmaline	Zircon	Staurolite	Garnet	Rutile	Titanite	Hornblende	Chlorite	Anatase	Others
8	535-40	53	15	8	22	2	—	—	—	—	—	—	—
8	540-45	47	21	13	16	2	—	—	—	—	*	—	—
8	545-50	60	17	7	15	1	—	*	—	—	—	—	—
8	550-55	52	17	13	15	3	—	*	*	—	*	—	—
9	537-42	35	32	10	20	1	—	—	2	—	*	—	—
9	542-50	98	68	3	26	2	1	1	1	—	—	—	—
9	550-60	36	36	5	19	2	—	*	1	—	1	—	—
10	520-30	44	28	12	15	1	—	—	—	—	—	—	—
10	540-50	39	34	7	19	*	—	—	—	—	—	—	—
11	457-65	22	38	11	25	1	1	1	*	—	*	—	*
11	465-75	27	43	12	14	1	1	*	1	*	—	—	*
11	475-80	28	41	14	13	2	1	*	2	—	—	—	—
11	480-85	21	42	14	16	3	2	1	1	1	*	—	—
18	430-35	49	30	8	13	*	*	—	—	—	—	—	—
18	435-40	49	22	9	17	2	*	*	—	—	—	—	—
18	455-60	44	26	6	22	1	—	1	—	—	—	—	—
18	465-70	42	32	10	15	*	—	—	—	—	—	—	—
19	475-85	33	34	10	18	2	*	1	1	—	—	—	—
19	485-95	34	36	10	15	2	*	2	1	—	—	—	—
19	510-16	44	27	7	19	1	*	1	—	—	*	—	—
21	535-40	50	20	13	14	3	—	—	—	—	—	—	—
21	540-45	58	16	5	21	*	—	—	—	—	—	—	—
21	545-50	46	29	8	14	2	—	1	—	—	1	*	—
22	360-65	41	33	5	19	2	—	*	—	—	—	—	—
22	365-70	47	32	6	12	1	—	—	*	—	—	—	—
22	370-75	51	23	9	13	2	—	*	*	—	—	—	—
22	375-80	50	28	7	13	1	—	*	*	—	—	—	—
22	380-85	39	33	10	15	1	—	1	—	—	—	*	—
22	385-90	40	35	12	11	1	—	*	—	—	—	—	—

* Trace.

in an inlet or estuary: abundant pyrite, suggesting poor circulation of water and reducing conditions; high leucoxene-ilmenite ratios in sands presumably derived from deposits in which leucoxene-ilmenite ratios were low, attributed to "sour" waters by Milner (1940, p. 509); and much shale and silt indicating less vigorous wave action. Shaly and silty samples of the Cheyenne are restricted to the estuary and to the vicinity of the Permian valley which slopes toward the northwest corner of the area (Fig. 5).

The angular sand typical of the Kiowa shale, which in the estuary is mixed with sand locally derived from the Permian beds, is believed to have had its source in the land area to the east and northeast and to have drifted across the Permian saddle after swampy areas east of the saddle had been filled with debris. Currents flowing across the saddle and down the valley in the Permian rocks may have supplied the angular sand observed in test hole 21. The Permian topographic "high" may have prevented the admixture of angular sand with the rounded type in the western part of the area, except in the valley associated with the saddle, until sea level rose above the area.

The low degree of roundness of the sand of the Cheyenne sandstone encountered in test hole 17 probably resulted from the sheltering effect of the shale hill of Permian age to the west, which prevented the accumulation of rounded Permian sands.

The surprising uniformity in average size of the angular facies of the Cheyenne sandstone should be noted. The upper average-size limit may have resulted from a lack of coarse grains in the source material or from their removal during transportation. The small amount of fine material probably resulted from the same wave action that removed the mica. The conclusion follows, then, that if wave action had been significantly less we would automatically have referred the angular sands to the Kiowa shale. Other conditions may have helped to determine the grain size.

The abrupt vertical change to micaceous sand of the Kiowa shale, coincidental with the absence of shell fragments in the underlying material, may indicate a transition from extremely shallow-water conditions and effective wave action, by means of which the mica flakes of the angular facies of the Cheyenne sandstone could have been winnowed out and removed seaward, to the quiescent and typically marine environment of Kiowa time. In this connection the absence of pink garnet and parti-colored (except the brown-and-green variety) tourmaline in the Kiowa is noteworthy, for it indicates that conditions precluded the possibility of the reworking of underlying sands during early Kiowa time. The advent of the Kiowa sea in the area seemingly corresponded to the covering of the Permian ridge or high areas.

The same conditions seem to have prevailed in the outcrop area of the Cheyenne sandstone in Kiowa County. Below the "Champion shell bed," which marks the base of the Kiowa shale in Champion Draw, the beds of sandstone and siltstone consist of fairly well-rounded grains and show marked current bedding. The bedding is horizontal above the shell bed, and any sandstone present is fine-grained, angular, and micaceous.

Conclusions

The Cretaceous formations encountered in drill holes in this area can be distinguished by lithology and stratigraphic position. The chief characteristics used in differentiating between sands of the Kiowa shale and the Cheyenne sandstones are grain size and amount of mica. The Cheyenne sandstone in the area includes material from at least two sources, and it is believed to consist of relatively coarse basal Cretaceous sands and associated deposits wherever they may occur in the immediate region. The eastern edge of the Cheyenne sandstone probably is not in the area studied.

QUALITY OF GROUND WATER

The chemical character of waters from the test holes of this area is indicated by the analyses of 51 samples given in Table 4. The analyses were made by Howard Stoltenberg in the Water and Sewage Laboratory of the Kansas State Board of Health, using the methods outlined by Collins (1928). All the samples of water were collected by McFarland. Each sample was taken from the bailer when water first appeared in the hole after casing had been set.

General Character of Waters

The following discussion is adapted from publications of the United States Geological Survey and the State Geological Survey of Kansas.

Dissolved solids.—The residue left after a natural water has evaporated consists of rock materials, with which may be included some organic material and a small amount of water of crystallization. Water containing less than 500 parts per million of dissolved solids generally is entirely satisfactory for domestic use, except for difficulties resulting from its hardness, and, in some areas, because of excessive iron or corrosiveness. Water having more than 1,000 parts per million is likely to contain enough of certain constituents to produce a noticeable taste or to make the water unsuitable in some other respects.

The dissolved solids in samples of water collected from test holes in this area ranged from 672 to 71,405 parts per million; hence none of the waters sampled is suitable for most ordinary purposes. Only one sample contained between 500 and 1,000 parts per million, and all except six samples contained more than 5,000 parts per million.

Hardness.—The hardness of water, which is the property that generally receives the most attention, is most commonly recognized by its effect when soap is used with the water in washing. Calcium and magnesium cause almost all the hardness of ordinary water. These constituents are also the active agents in the formation of the greater part of all the scale formed in steam boilers and in other vessels in which water is heated or evaporated.

In addition to the total hardness, the table of analyses indicates the carbonate hardness and the noncarbonate hardness. The carbonate hardness is that due to the presence of calcium and magnesium bicarbonate. It is largely removed by boiling. In some reports this type of hardness has been called temporary hardness. The noncarbonate hardness is due to the presence of sulphates or chlorides of calcium and magnesium, but it cannot be removed by boiling and has sometimes been called permanent hardness. With reference to use with soaps, there is no difference between the carbonate and noncarbonate hardness. In general, the noncarbonate hardness forms harder scale in steam boilers.

Water having a hardness less than 50 parts per million is generally rated as soft, and its treatment for removal of hardness under ordinary circumstances is not necessary. Hardness between 50 and 150 parts per million does not seriously interfere with the use of water for most purposes, but it does slightly increase the consumption of soap; its removal by a softening process is profitable for laundries or other industries using large quantities of soap. Water in the upper part of this range of hardness will cause much scale in steam boilers. Hardness exceeding 150 parts per million can be noticed by anyone; if the hardness is 200 or 300 parts per million it is common practice to soften water for household use or to install a cistern to collect soft rainwater. Where municipal water supplies are softened, an attempt is generally made to reduce the hardness to 60 or 80 parts per million. The additional improvement from further softening of a whole public supply is not deemed worth the increase in cost.

The hardness of samples of water collected from the test holes in this area ranged from 110 to 9,098 parts per million. The softest water analyzed was from a sandstone near the top of the Dakota formation encountered in test hole 20, and the hardest water was obtained from Permian redbeds in test hole 12. Only 1 sample had a hardness between 100 and 200 parts per million, 3 had a hardness between 200 and 300 parts, 3 had a hardness between 300 and 400 parts, 6 had a hardness between 400 and 1,000 parts, and 38 had a hardness of more than 1,000 parts. All except one of the samples having a hardness of less than 1,000 parts per million were obtained from sands in the Dakota formation. The other was obtained from Pleistocene deposits in test hole 20.

Iron.—Next to hardness, iron (Fe) is the constituent of natural waters that receives the most attention. The quantity of iron in ground waters may differ greatly from place to place, even though the waters are from the same formation. If a water contains much more than 0.1 part per million of iron, the excess may separate out and settle as a reddish sediment. Iron, which may be present in sufficient quantity to give a disagreeable taste and to stain cooking utensils, may be removed from most waters by simple aeration and filtration, but a few waters require the addition of lime or some other substance. Because the samples of water collected from the bailer in drilling the test holes contained sufficient silt and other rock cuttings to make them cloudy, it was not practicable to determine the iron content.

Fluoride.—Although determinable quantities of fluoride (F) are not as common as fairly large quantities of other constituents of natural waters, it is desirable to know the amount of fluoride present in water that is likely to be used by children. Fluoride in water has been shown to be associated with the dental defect known as mottled enamel, which may appear on the teeth of children who drink water containing excessive quantities of fluoride during the period of formation of the permanent teeth. It has been stated that waters containing 1 part per million or more of fluoride are likely to produce mottled enamel, although the effect of 1 part per million is not usually very serious (Dean, 1936). If the water contains as much as 4 parts per million of fluoride, 90 percent of the children exposed are likely to have mottled enamel and 35 percent or more of the cases will be classed as moderate or worse.

No samples of water collected in this area in which fluoride was determined contained less than 1 part per million of fluoride, and one sample obtained from a sandstone in the upper part of the Dakota formation in test hole 9 contained 4.5 parts per million of fluoride. The water is generally not potable and therefore is not likely to be used by children.

Calcium.—Calcium (Ca) is taken into solution as the bicarbonate by the reaction of natural waters containing carbonic or organic acids with calcium carbonate, which is the principal constituent of limestone and an important constituent of dolomite. It is also dissolved in large quantities from gypsum (calcium sulphate).

Calcium is the least abundant metallic element in all except eight of the samples here considered; its concentration ranges from 21 parts per million in water from a sandstone in the Dakota in test hole 20 to 2,468 parts in water from Tertiary (?) deposits in test hole 10.

Magnesium.—Magnesium (Mg) is dissolved from practically all rocks, but mainly from dolomite and dolomitic limestones, by reactions similar to those for calcium. In most natural waters magnesium is much less abundant than calcium, but in this area the relative abundance of the two constituents is reversed. Magnesium is the only element besides calcium that causes any appreciable amount of hardness in most natural waters.

The concentration of magnesium ranges from 12 parts per million in water from Pleistocene rocks in test hole 20 to 1,796 parts per million in water from the Permian redbeds penetrated by test hole 12.

Sodium and potassium.—Sodium (Na) and potassium (K) are dissolved from practically all rocks, and they are present in large quantities in most of the samples of water from this area. The two elements were not determined separately in any of the analyses.

Their concentration ranged from 97 parts per million in water from the Pleistocene deposits tapped by test hole 20 to 23,652 parts per million in water from the Permian redbeds encountered by test hole 12. Twenty-four (nearly half) of the samples contained a larger amount of sodium and potassium than is found in average sea water.

Moderate quantities of sodium have little effect on the suitability of water for ordinary use, but if the quantity is much more than 100 parts per million, foaming in steam boilers may result unless special precautions are taken. Some natural waters contain such large quantities of sodium salts that they are injurious to vegetation. Most of the waters from the test holes in this area would injure vegetation and would foam in steam boilers.

Carbonate and bicarbonate.—Carbonate (CO_3) and bicarbonate (HCO_3) in natural waters result from solution of carbonate rocks (such as limestone, dolomite, and calcareous shale) through the action of carbonic acid in the waters. Carbonate is not generally present in appreciable quantities in natural waters but it is found in some treated waters. In most of the analyses here considered there is less bicarbonate than any other negative ion; it ranges in concentration from 120 parts per million in water from the Greenhorn limestone encountered in test hole 18 to 1,879 parts per million in water from the Cheyenne sandstone encountered in test hole 21. The bicarbonate as such has little effect on the use of a water.

Sulphate.—Sulphate (SO_4) in ground waters is derived principally from gypsum (calcium sulphate) associated with limestone, from the oxidation of pyrite (FeS_2) and other sulphides, or from connate waters. The concentration of sulphate here ranges from 14 to 8,550 parts per million, but its relative abundance with respect to the other constituents remains fairly constant.

Sulphate itself has little effect on the general use of a water. Magnesium sulphate and sodium sulphate, if present in sufficient quantity, impart a bitter taste. Sulphate in a hard water may increase the cost of softening and form a hard scale in steam boilers which is difficult to remove.

Chloride.—Chloride (Cl) is an abundant constituent of sea water and is dissolved in small quantities from rock materials or in some localities comes from sewage. However, the sources of chloride are many; therefore its presence in large quantities cannot be taken as a definite indication of pollution. The chloride content of samples from this area ranges from 70 to 36,500 parts per million. In most of the waters analyzed it is the most abundant constituent by weight.

Chloride has little effect on the suitability of water for ordinary use, unless there is enough to impart a salty taste. There is enough chloride in 20 of these samples to impart a taste saltier than that of sea water. Waters high in chloride may be corrosive if used in steam boilers.

Nitrate.—Nitrate (NO_3) in otherwise potable water is generally considered a final oxidation product of nitrogenous organic material. Therefore a large quantity of nitrate in ground water suggests the possible presence of harmful bacteria derived from privies, cesspools, barnyards, cultivated fields, or other places where oxidized nitrogenous matter is common.

The nitrate content, in samples in which it was determined, ranges from 4.0 parts per million in two samples from sandstones of the Dakota formation to 66 parts per million in the Greenhorn limestone (test hole 9). A sample from the Permian redbeds from a depth of 710 feet in test hole 8 contained 28 parts per million of nitrate. This does not necessarily indicate the presence of bacteria, for a certain amount of nitrate is to be expected in waters in which the total concentration of dissolved solids is large. Values for nitrate and fluoride have been omitted from most of the analyses because analysis of these two ions is difficult and time-consuming when the total concentration is high, and the information is not necessary unless the water is potentially potable. As nitrate was determined in only six samples, it was omitted from Table 4.

Range in Quantity of Dissolved Solids

Except in near-surface samples, the amount of dissolved solids was found to increase with increasing depth of sampling in the test holes. This relationship is shown in Figure 6, where each point represents the average concentration for samples within that particular 100-foot interval. The small numerals at each point refer to the number of samples from which each average was computed. The value for the top 100 feet is meaningless, for variation near the surface is extremely great. The number of parts per million of dissolved solids is plotted separately for each analysis from beneath the Greenhorn limestone in Figure 7A, where a general trend toward higher concentrations at greater depths is easily discernible. In this diagram the position of each point in relation to the vertical axis refers to the middle of the interval from which the sample was taken.

If the data are plotted with respect to geologic formations, however, the points become less scattered and the trend more decisive (Fig. 7B). The thickness of each formation represented on the vertical axis is a mean value obtained by averaging the thicknesses in all the holes from which samples were obtained from that for-

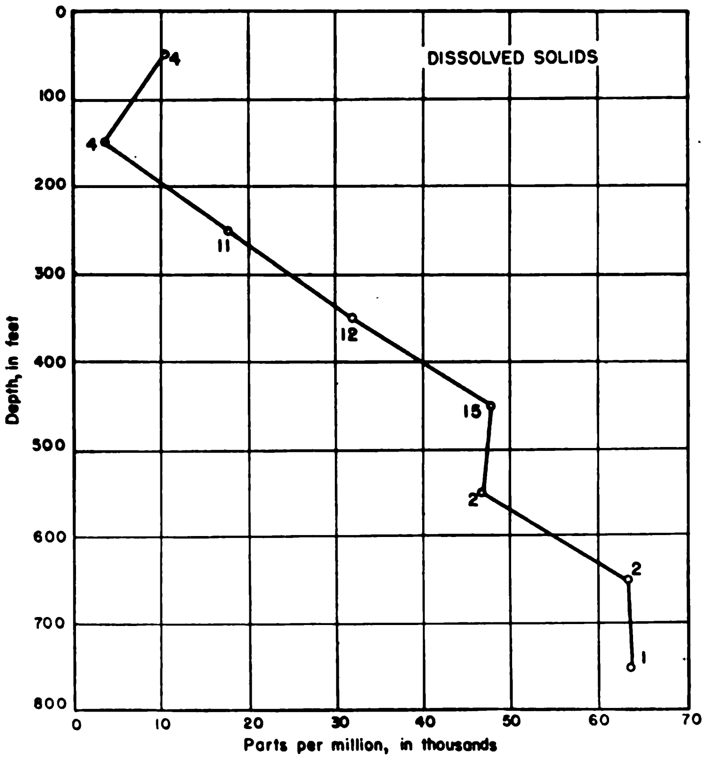

FIG. 6. Graph showing the relationship between the depth from which water samples were obtained and the concentration of dissolved solids. The numerals at each point refer to the number of analyses from which the average was computed. Each point represents the mean concentration for samples within that particular 100-foot interval.

mation. The point for each sample is spotted according to its relative position with respect to the boundaries of the formation from which it came. Thus, if a sample from a particular test hole came from a position nine-tenths the distance from the top of the Dakota formation, it is plotted nine-tenths of the distance from the top of the interval shown on the graph.

It may be seen from the graph (Fig. 7B) that the concentration of dissolved solids in all the samples from approximately the upper half of the Dakota formation is less than 9,000 parts per million, whereas the concentration in samples from the lower half of the Dakota ranges from 9,000 to 61,000 parts and in more than half of the analyses is between 10,000 and 30,000 parts. Thus the ranges in dissolved solids for the two approximate halves of the Dakota formation are mutually exclusive. The halfway mark has no relation to the boundary between the Terra Cotta clay and Janssen clay members, which is much nearer the top of the formation. The concentration of dissolved solids in waters from the Kiowa and Cheyenne formations ranges from 33,000 to 62,000 parts per million. There is no appreciable difference in concentration of dissolved solids between waters from the two formations, although the average concentration in the samples from the Kiowa shale (49,358 parts per million) is slightly less than that in samples from the Cheyenne sandstone (51,082 parts per million). The sharp increase in concentration between waters of the Dakota and the Kiowa is noteworthy. The concentration of dissolved solids is greater than 47,000 parts per million in all except one of the samples from the Permian redbeds, and the range is from 31,000 to 71,000 parts.

Relative Concentrations of Constituents

The discussion that follows is based on the results given in equivalents per million in Table 4. Percentages of equivalents per million are used for convenience in comparing different waters. Equivalents per million are the units in which the bar diagrams of Figures 8 and 9 are plotted. Percentages of equivalents make possible the direct comparison of two or more waters of different concentrations of dissolved solids.

Four samples of water were obtained from post-Dakota formations, and these are extremely variable in character. One sample from the Greenhorn limestone (test hole 9, dissolved solids 3,399

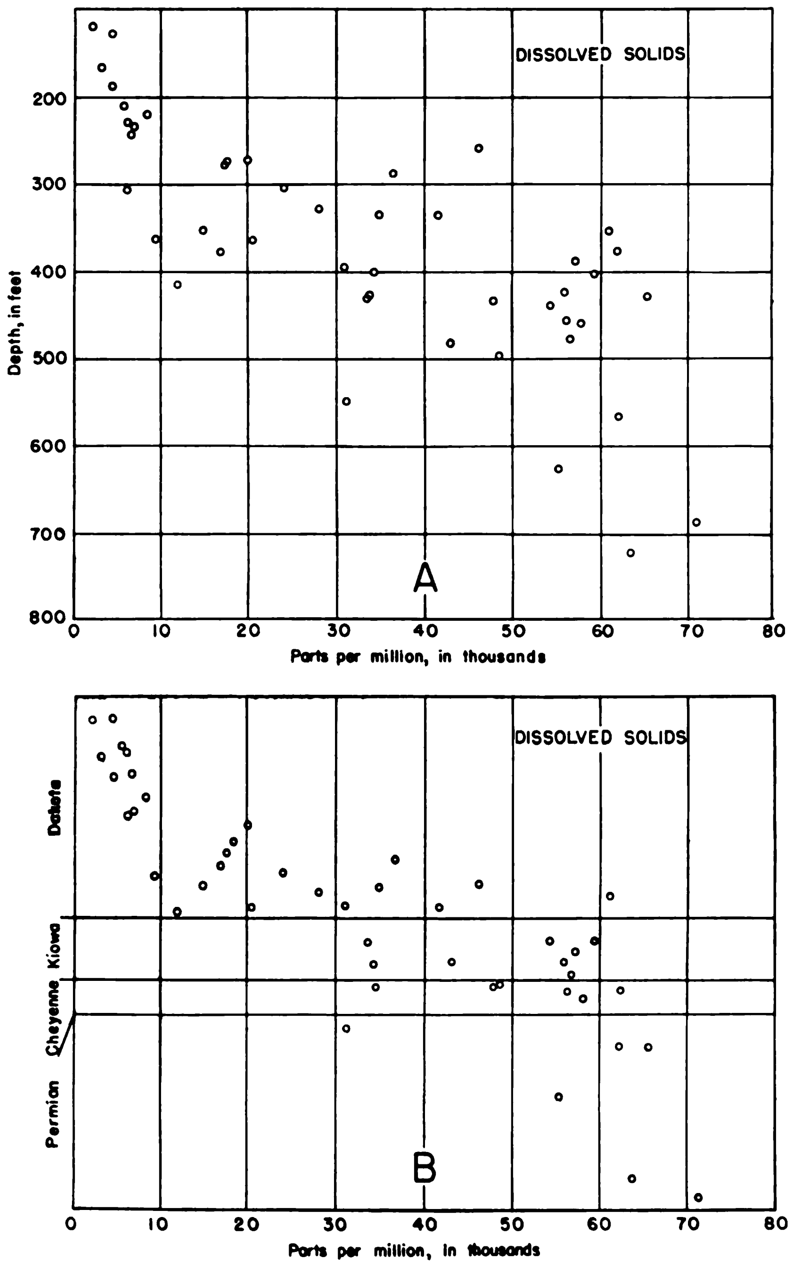

FIG. 7. *A*, Scatter diagram showing the relationship between the concentration of dissolved solids and the depths from which water samples were obtained. *B*, Scatter diagram showing the relationship between the concentration of the dissolved solids and stratigraphic zones. Each circle represents one analysis.

parts per million) contained 14 percent sulphate and 17 percent calcium, while another from the Greenhorn (test hole 18, dissolved solids 13,764 parts per million) contained about the same relative amount of calcium (19 percent) but only 1.7 percent sulphate. This latter water has some of the characteristics of brines from oil wells in the area. A water from the Pleistocene rocks (test hole 20, total solids 672 parts per million) contained 37 percent bicarbonate, 23 percent sodium, and only 1.6 percent sulphate. Water from the Tertiary (?) (test hole 10, total solids 23,812 parts per million) contained 4.5 percent sulphate, 29 percent sodium, and only 0.5 percent bicarbonate.

All the other water samples came from the Dakota, Kiowa, and Cheyenne formations and the Permian redbeds; they exhibit remarkable uniformity in percentages of their constituents (Fig. 8). The percentage concentrations of calcium range from 0.9 to 12.4 percent; all except one are between 0.9 and 4.3 percent. The concentration of magnesium ranges from 1.1 to 6.1 percent, and that of sodium from 42.2 to 47.8 percent. The same narrow range may be observed in the variation of the negative ions. The concentrations of bicarbonate range from 0.1 to 9.3 percent, those of sulphate from 3.8 to 7.4 percent, and those of chloride from 34.8 to 44.5 percent.

There is a consistent difference between waters of the upper half of the Dakota formation and waters of the Kiowa shale, Cheyenne sandstone, and Permian redbeds, however. The character of water from the lower half of the Dakota is variable. All samples of water from below the Dakota except one sample from test hole 21 contained less bicarbonate than any other constituent. All samples of water from the upper half of the Dakota except one sample from test hole 17, which may be affected by water from the overlying Pleistocene sands and gravels, contained more bicarbonate than calcium, and most samples contained more bicarbonate than calcium and magnesium together. This may have resulted from base exchange of sodium for calcium and magnesium caused by clay minerals of the Dakota formation (Latta, 1944, pp. 136, 137).

Approximately half the samples of water from the lower part of the Dakota formation contained the same relative proportions of constituents as those from the upper part; the rest contained an excess of calcium over bicarbonate. The former samples came from test holes outside or on the edges of oil-field areas as they existed at the close of 1942 (Frye and Brazil, 1943, pl. 1); the latter came from test holes which were, as a rule, well within the oil-field areas. These relationships seemingly can result from one or more of at least three situations. (1) The chemical composition of the water may be related to Cretaceous structures which reflect oil-pool structures in the underlying Paleozoic rocks and somehow control the concentration of the constituents; (2) brine from disposal wells may pollute the lower part of the Dakota; and (3) unplugged holes or pressure from shallow disposal wells may cause the mixing of water from pre-Dakota beds with water from the lower part of the Dakota.

(1) Lower Cretaceous structure on the top of the Kiowa shale does not seem to have much relationship to the oil-field areas or to the test holes in which the waters in the lower part of the Dakota formation differ chemically from those in the upper part of the Dakota; therefore, the first suggestion probably may be eliminated.

(2) Brine which has been pumped into shallow disposal wells in Russell County was derived from the Kansas City-Lansing, Arbuckle, and Gorham producing zones. Analyses of these brines by R. Q. Brewster and Calvin Vander Werf have been published in a report by Schoewe (1943), and the analyses of two typical oil-field brines, one from the Arbuckle and one from the Kansas City-Lansing, are given in Figure 9. The following relationships are characteristic of the published analyses: calcium exceeds magnesium, in the general proportion of 2 to 1; the amount of chloride is at least 5 percent greater than that of sodium, and in some brines is as much as 14 percent greater; the sulphate does not exceed 1 percent and the bicarbonate does not exceed 1.4 percent; the amount of calcium is at least 5 times that of bicarbonate.

It is possible to postulate a mixture of water from the Dakota formation with oil-field brine which will give the approximate proportions of constituents observed in waters from the lower part of the Dakota in the oil-field areas. Thus a mixture of 95 percent of the lowest sample of water from the Dakota in test hole 9 and 5 percent of water sample 96 from the Arbuckle of the North Trapp pool (Brewster and Vander Werf in Schoewe, 1943, pp. 58, 59) will produce the hypothetical water shown in Figure 9, which has almost the chemical characteristics of the waters from the lower part of the Dakota in the oil-field areas. In most analyses, how-

TABLE 4.—*Analyses of waters from test holes in Russell County, Kansas*

Analyzed by Howard Stoltenberg. Parts per million[a] and equivalents per million[b] (in italics)

Test Hole no.	Location	Depth	Geologic source	Date of collection	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)[c]	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids[e]	Hardness (Calculated as $CaCO_3$)		
													Total	Carbonate	Non-carbonate
8	T. 13 S., R. 15 W. NW SE sec. 35	710-732	Permian	11/43	437 *21.81*	1,490 *122.54*	21,540 *936.56*	610 *10.00*	7,550 *157.19*	32,400 *913.68*	1.8 *.09*	63,750	7,214	500	6,714
9	T. 13 S., R. 14 W. NW SW sec. 32	60-65	Greenhorn	11/43	374 *18.66*	84 *6.91*	714 *31.04*	132 *2.16*	769 *16.01*	1,325 *37.36*	1.0 *.05*	3,399	1,278	108	1,170
9	"	225-233	Dakota[d]	11/43	42 *2.10*	48 *3.95*	2,136 *92.87*	512 *8.39*	531 *11.06*	2,810 *79.24*	4.5 *.24*	5,832	302	302[f]	0
9	"	303	Dakota[d]	11/43	51 *2.54*	50 *4.11*	2,250 *97.83*	546 *8.95*	555 *11.56*	2,970 *83.75*	4.0 *.21*	6,157	332	332[g]	0
9	"	412-420	Dakota[d]	11/43	129 *6.44*	132 *10.86*	4,132 *179.66*	600 *9.83*	1,019 *21.22*	5,875 *165.68*	3.6 *.19*	11,897	864	492	372
9	"	475-485	Kiowa	11/43	500 *24.95*	688 *56.58*	14,740 *640.90*	986 *16.16*	4,260 *88.69*	21,900 *617.58*	1.4 *.07*	43,091	4,075	808	3,267
9	"	625	Permian	12/43	616 *30.74*	922 *75.83*	18,885 *821.12*	1,530 *25.08*	5,444 *113.34*	28,000 *789.60*	1.8 *.09*	55,399	5,326	1,254	4,072
10	T. 13 S., R. 14 W. NW NE sec. 33	20	Tertiary (?)	12/43	2,468 *123.15*	630 *51.81*	5,482 *238.36*	261 *4.28*	1,770 *36.85*	13,200 *372.24*	1.2 *.06*	23,812	8,747	214	8,533
10	"	377	Dakota[d]	12/43	284 *14.17*	223 *18.34*	5,770 *250.88*	351 *5.75*	1,348 *28.07*	8,850 *249.57*	2.4 *.13*	16,828	1,625	288	1,337
10	"	560-570	Permian	12/43	578 *28.84*	1,257 *103.38*	21,061 *915.73*	894 *14.65*	6,713 *139.76*	31,700 *893.94*	1.8 *.09*	62,205	6,608	733	5,875
11	T. 14 S., R. 14 W. NE NW sec. 10	295-310	Dakota[d]	12/43	211 *10.53*	268 *22.04*	8,400 *365.23*	996 *16.32*	2,479 *51.61*	11,700 *329.94*	2.6 *.14*	24,057	1,630	818	812
11	"	400	Kiowa	12/43	333 *16.62*	501 *41.20*	11,818 *513.85*	954 *15.64*	3,348 *69.71*	17,250 *486.45*	2.4 *.13*	34,206	2,890	782	2,108

11	"	422-430	Cheyenne	12/43	340 *16.97*	493 *40.54*	11,637 *505.98*	961 *15.75*	3,560 *74.12*	16,800 *473.76*	2.4 *.13*	33,793	2,874	788	2,086
12	T. 14 S., R. 14 W. SE SW sec. 14	270-280	Dakota[d]	1/44	269 *13.42*	203 *16.69*	6,036 *262.45*	798 *13.08*	1,100 *22.90*	9,100 *256.62*	1.6 *.08*	17,508	1,506	654	852
12	"	330-340	Dakota[d]	1/44	586 *29.24*	625 *51.40*	14,167 *615.98*	1,283 *21.03*	3,747 *78.01*	21,200 *597.84*	1.5 *.08*	41,610	4,031	1,052	2,979
12	"	423-443	Cheyenne	1/44	640 *31.94*	748 *61.52*	16,270 *707.42*	1,400 *22.95*	4,192 *87.28*	24,500 *690.90*	1.6 *.08*	47,752	4,671	1,148	3,523
12	"	680-692	Permian	1/44	688 *34.33*	1,796 *147.70*	23,652 *1,028.39*	217 *3.56*	8,550 *178.01*	36,500 *1,029.30*	2.0 *.11*	71,405	9,098	178	8,920
13	T. 14 S., R. 14 W. SW SE sec. 10	270-275	Dakota[d]	1/44	175 *8.73*	249 *20.48*	7,013 *304.93*	739 *12.11*	1,519 *31.63*	10,300 *290.46*	2.0 *.11*	19,997	1,460	606	854
13	"	355-370	Dakota[d]	1/44	227 *11.33*	233 *19.16*	7,175 *311.97*	732 *12.00*	1,417 *29.50*	10,675 *301.04*	1.4 *.07*	20,460	1,524	600	924
13	"	412-432	Kiowa	1/44	618 *30.84*	976 *80.27*	19,141 *832.25*	1,222 *20.03*	5,222 *108.72*	28,900 *814.98*	1.6 *.08*	56,081	5,554	1,002	4,552
13	"	448-465	Cheyenne	1/44	612 *30.54*	972 *79.94*	19,254 *837.16*	1,144 *18.75*	5,354 *111.47*	29,000 *817.80*	1.6 *.08*	56,338	5,522	938	4,584
16	T. 13 S., R. 13 W. NW SW sec. 31	240-245	Dakota[e]	3/44	40 *2.00*	43 *3.54*	2,303 *100.13*	849 *13.92*	616 *12.83*	2,800 *78.96*		6,651	276	276[h]	0
16	"	355-368	Dakota[d]	3/44	62 *3.09*	71 *5.84*	3,248 *141.22*	908 *14.88*	839 *17.47*	4,180 *117.88*		9,308	446	446[i]	0
16	"	380-410	Dakota[d]	3/44	380 *18.96*	398 *32.73*	10,687 *464.67*	1,069 *17.52*	2,843 *59.19*	15,600 *439.92*		30,977	2,584	876	1,708
16	"	435-440	Kiowa	3/44	676 *33.73*	999 *82.16*	18,425 *801.12*	898 *14.72*	5,298 *110.30*	28,100 *792.42*		54,396	5,792	736	5,056
16	"	465-486	Kiowa	3/44	700 *34.93*	1,090 *89.64*	19,158 *832.99*	1,078 *17.67*	5,479 *114.07*	29,300 *826.26*		56,805	6,226	884	5,342
17	T. 14 S., R. 14 W. NE NW sec. 25	110-125	Dakota[e]	3/44	167 *8.33*	39 *3.21*	508 *22.09*	373 *6.11*	194 *4.04*	830 *23.41*	1.2 *.06*	2,112	577	306	271
17	"	255-260	Dakota[d]	3/44	582 *29.04*	664 *54.61*	15,790 *686.55*	1,566 *25.67*	4,290 *89.32*	23,250 *655.65*	1.4 *.07*	46,143	4,181	1,284	2,897
17	"	370-380	Cheyenne	3/44	768 *38.32*	918 *75.50*	21,530 *936.12*	917 *15.03*	5,039 *104.91*	33,000 *930.60*	1.4 *.07*	62,173	5,689	752	4,937
17	"	420-433	Permian	3/44	790 *39.42*	1,142 *93.92*	22,440 *975.69*	698 *11.44*	6,136 *127.75*	34,400 *970.08*	1.8 *.09*	65,608	6,664	572	6,092

TABLE 4.—*Analyses of waters from test holes in Russell County, Kansas, Concluded*

Test Hole no.	Location	Depth	Geologic source	Date of collection	Calcium (Ca)	Magnesium (Mg)	Sodium and Potassium (Na+K)[c]	Bicarbonate (HCO_3)	Sulphate (SO_4)	Chloride (Cl)	Fluoride (F)	Dissolved solids[c]	Hardness (Calculated as $CaCO_3$) Total	Carbonate	Non-carbonate
18	T. 14 S., R. 14 W. NE NW sec. 30	20-43	Greenhorn	5/44	1,820 *90.82*	250 *20.56*	2,986 *129.83*	120 *1.97*	388 *8.08*	8,200 *231.24*		13,764	5,568	98	5,470
18	"	120-130	Dakota[c]	5/44	46 *2.30*	27 *2.22*	1,510 *65.65*	659 *10.80*	441 *9.18*	1,780 *50.20*		4,463	226	226[j]	0
18	"	186-190	Dakota[e]	5/44	62 *3.09*	36 *2.96*	1,307 *65.52*	490 *8.03*	398 *8.29*	1,960 *55.27*		4,453	302	302[k]	0
18	"	275-300	Dakota[d]	5/44	460 *22.95*	549 *45.15*	12,500 *543.50*	1,093 *17.91*	3,213 *66.89*	18,700 *527.34*		36,515	3,404	896	2,508
18	"	320-335	Dakota[d]	5/44	336 *16.77*	374 *30.76*	9,662 *420.10*	1,152 *18.88*	2,600 *54.13*	14,000 *394.80*		28,124	2,376	944	1,432
18	"	384-391	Kiowa	5/44	672 *33.53*	908 *74.67*	19,640 *853.95*	1,576 *25.83*	5,163 *107.49*	29,400 *829.08*		57,359	5,408	1,292	4,116
18	"	420-460	Cheyenne and Permian	5/44	644 *32.14*	916 *75.33*	19,725 *857.64*	1,425 *23.36*	5,162 *107.47*	29,600 *834.72*		57,472	5,372	1,168	4,204
19	T. 14 S., R. 14 W. SE SW sec. 21	235-250	Dakota[d]	6/44	192 *9.58*	96 *7.90*	2,186 *95.05*	730 *11.96*	429 *8.93*	3,250 *91.65*		6,883	874	596	278
19	"	265-290	Dakota[d]	6/44	192 *9.58*	225 *18.50*	6,383 *277.53*	683 *11.19*	1,687 *35.12*	9,200 *259.44*		18,370	1,404	560	844
19	"	320-350	Dakota[d]	6/44	714 *35.63*	551 *45.31*	11,550 *502.19*	1,064 *17.44*	3,344 *69.62*	17,600 *496.32*		34,823	4,046	872	3,174
19	"	440-475	Cheyenne	6/44	648 *32.34*	878 *72.21*	20,064 *872.38*	925 *15.16*	5,041 *104.95*	30,400 *857.28*		57,956	5,226	758	4,468
20	T. 14 S., R. 14 W. NE SE sec. 27	78-85	Pleistocene	6/44	74 *3.69*	12 *0.99*	97 *4.22*	405 *6.64*	14 *0.29*	70 *1.97*		672	234	234[l]	0

20	"	160-170	Dakota[e]	6/44	21 *1.05*	14 *1.15*	1,104 *48.00*	568 *9.31*	183 *3.81*	1,315 *37.08*	3,205	110	110[m]	0
20	"	215-225	Dakota[e]	6/44	142 *7.09*	113 *9.29*	2,791 *121.35*	581 *9.52*	810 *16.86*	3,950 *111.39*	8,387	819	476	343
20	"	345-360	Dakota[d]	6/44	672 *33.53*	910 *74.84*	21,252 *924.04*	837 *13.72*	5,203 *108.33*	32,300 *910.86*	61,174	5,416	686	4,730
20	"	400-405	Kiowa	6/44	684 *34.13*	864 *71.06*	20,706 *900.30*	581 *9.52*	4,855 *101.08*	31,750 *895.35*	59,440	5,258	476	4,782
21	T. 13 S., R. 15 W. NW SW sec. 33	200-220	Dakota[e]	7/44	118 *5.89*	62 *5.10*	1,866 *81.13*	425 *6.97*	611 *12.72*	2,570 *72.47*	5,652	550	348	202
21	"	330-375	Dakota[d]	7/44	176 *8.78*	213 *17.52*	5,037 *219.01*	845 *13.85*	1,438 *29.94*	7,150 *201.63*	14,859	1,314	693	621
21	"	425-435	Kiowa	7/44	410 *20.46*	554 *45.56*	11,264 *489.76*	1,532 *25.11*	3,424 *71.29*	16,300 *459.66*	33,484	3,300	1,256	2,044
21	"	495	Cheyenne	7/44	538 *26.85*	803 *66.04*	16,450 *715.25*	1,879 *30.80*	4,712 *98.10*	24,100 *679.62*	48,482	4,643	1,540	3,103
21	"	545-550	Permian	7/44	368 *18.36*	491 *40.38*	10,561 *459.19*	1,386 *22.72*	3,074 *64.00*	15,300 *431.46*	31,180	2,936	1,136	1,800

[a] One part per million is equivalent to one pound of substance per million pounds of water or 8.33 pounds per million gallons of water.

[b] An equivalent per million (e.p.m.) is a unit chemical equivalent weight of solute per million unit weights of solution. Concentration in equivalents per million is calculated by dividing concentration in parts per million by the chemical combining weight of the substance or ion.

[c] Calculated.

[d] Lower one half of formation.

[e] Upper one half of formation.

[f] Total alkalinity, 420 parts per million, excess alkalinity, 118 parts per million.

[g] Total alkalinity, 448 parts per million, excess alkalinity, 116 parts per million.

[h] Total alkalinity, 696 parts per million, excess alkalinity, 420 parts per million.

[i] Total alkalinity, 744 parts per million, excess alkalinity, 298 parts per million.

[j] Total alkalinity, 540 parts per million, excess alkalinity, 314 parts per million.

[k] Total alkalinity, 402 parts per million, excess alkalinity, 100 parts per million.

[l] Total alkalinity, 332 parts per million, excess alkalinity, 98 parts per million.

[m] Total alkalinity, 466 parts per million, excess alkalinity, 356 parts per million.

ever, the percentage of sulphate in the supposedly affected waters from the lower part of the Dakota is as high as that in waters from the upper part of the formation. The concentration of dissolved solids in the Paleozoic brines of Russell County, particularly in that from the Kansas City-Lansing producing zone which averages 132,690 parts per million in the analyses by Brewster and Vander Werf, is much greater than that in the Dakota formation; and an admixture of these brines large enough to reverse the calcium-bicarbonate ratio should also produce an excess of calcium over magnesium and materially lower the percentage of sulphate. However, such is not the case in samples from test holes drilled for the present study. Addition of more than a very small amount (*ca.* 5 percent) of brine to the water from the Dakota would also raise the chloride content to more than that of the sodium, so that the possible range of admixture to produce the required result is very small, being limited in one direction by the calcium-bicarbonate ratio and in the other by the sodium-chloride ratio, amount of sulphate, and relative abundance of calcium and magnesium.

Waters from test holes 6 and 7 (Frye and Brazil, 1943, p. 67), however, do have the characteristics of Paleozoic brines, including high chloride content (greater than sodium), high bicarbonate content with respect to calcium, more calcium than magnesium, and low content of sulphate (Fig. 9). Test hole 6 was put down in an area in which there were several shallow disposal wells (Frye and Brazil, 1943, pl. 1), and test hole 7 was drilled 1 mile to the southeast and in the direction of the hydraulic gradient from no. 6.

(3) There remains the third alternative, for analyses of samples other than those from test holes 6 and 7, that pressure from shallow disposal wells or conditions resulting from drilling operations such as unplugged holes may have caused the entrance of water from the Kiowa shale, Cheyenne sandstone, or Permian redbeds into the lower part of the Dakota formation. This is supported by the close similarity between the waters of the lower part of the Dakota in the oil-field areas (Fig. 9) and waters from sands in the Kiowa and Cheyenne formations and the Permian redbeds (Fig. 8).

None of the samples of water collected from the upper part of the Dakota formation for the present investigation was potable, although it is believed that waters from this zone formerly were potable. Two problems, then, are involved: (1) What is the source of the water that was introduced into the upper part of the

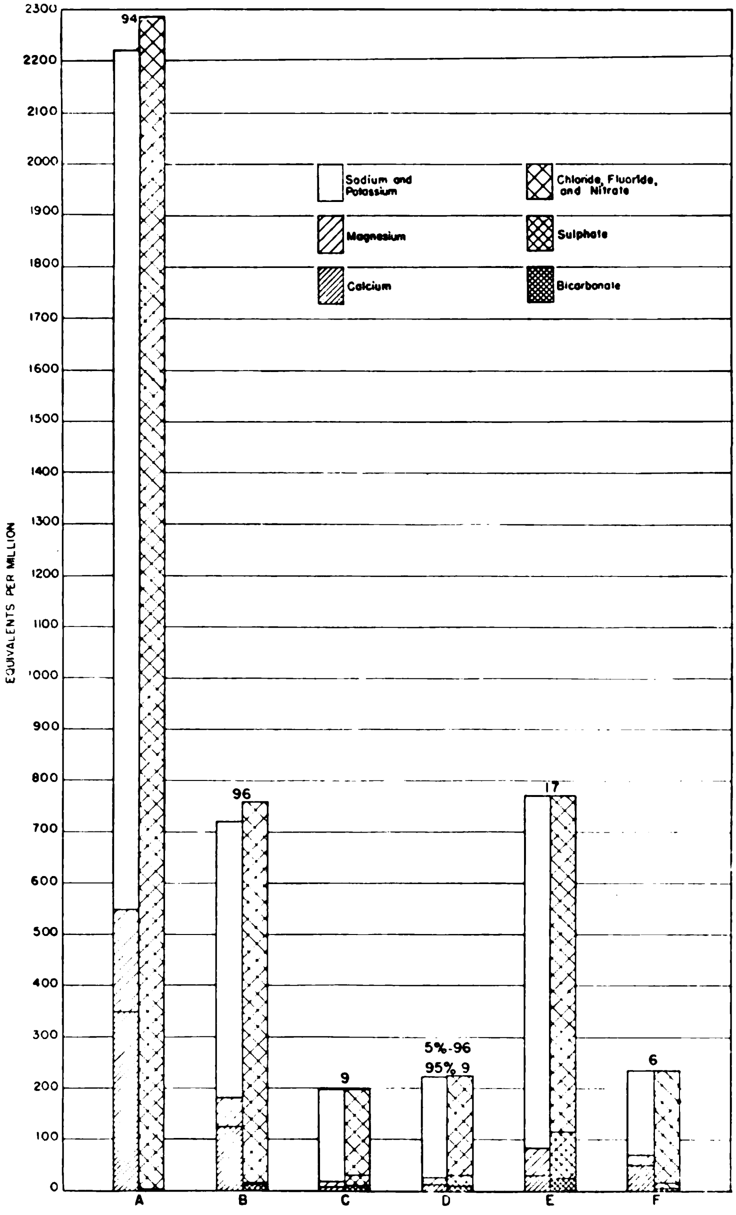

FIG. 8. **Analyses of typical waters from the Dakota, Kiowa, and Cheyenne formations, and Permian redbeds in a part of Russell County, Kansas.**

The above illustration should be **Fig. 9** (see caption on p. 152) and the illustration on page 152 should be **Fig. 8.**

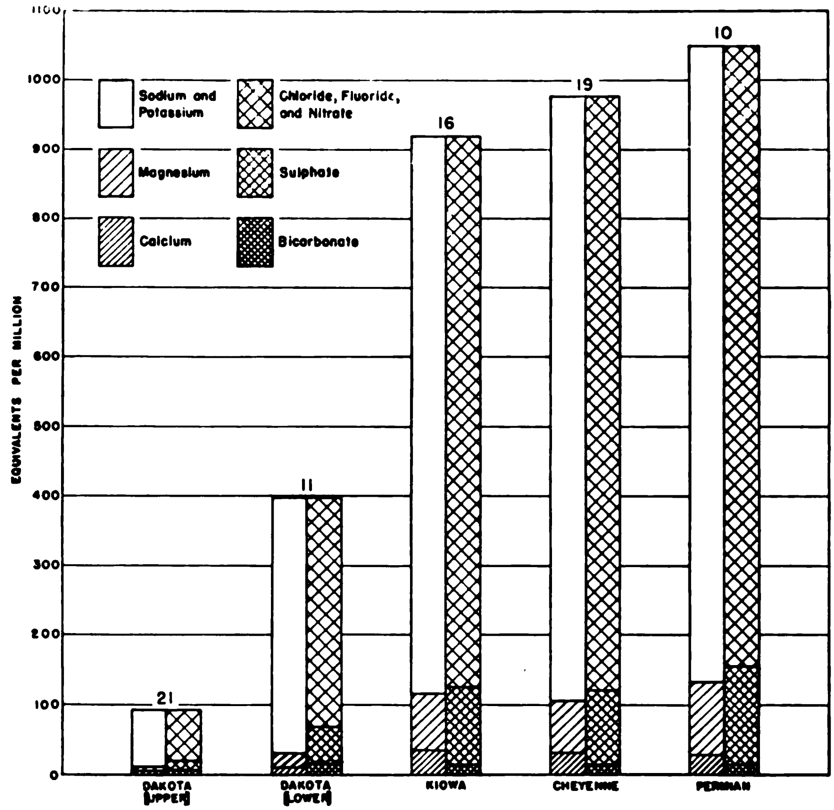

FIG. 9. Analyses of waters from the test holes and of brines from Russell County, and an analysis of a hypothetical mixture of brine with water from the lower part of Dakota formation. *A*, Typical water from the Kansas City-Lansing oil-producing horizon[1]. *B*, Typical water from the Arbuckle horizon[1]. *C*, Water from the lower part of the Dakota formation having characteristics of waters outside oil-field areas[2]. *D*, Hypothetical mixture of 5 percent B and 95 percent C, showing similarities to E. *E*, Water from lower part of the Dakota formation in an oil-field area[2]. *F*, Water from the middle part of the Dakota having characteristics of oil-field brines[2] (Frye and Brazil, 1943). [1]Analysis by R. Q. Brewster and Calvin Vander Werf (Schoewe, 1943). [2]Analysis by Howard Stoltenberg.

Dakota; and (2) why does this water differ from water in the lower part of the Dakota in the oil-field areas?

The most likely sources are the oil-field brines from the Paleozoic rocks and the waters from the Lower Cretaceous and Permian rocks, as in the case of affected waters in the lower part of the Dakota formation. The brines from the Paleozoic rocks are not adequate as a source because of their small percentage of sulphate and their calcium-magnesium ratio. The waters from the Lower Cretaceous and Permian rocks differ from the water in the upper part of the Dakota in the proportion of calcium to bicarbonate, but they may have been modified by base exchange in the clay of the Dakota. Base exchange may have been a more important factor in this zone in the modification of introduced waters from the Lower Cretaceous and Permian, either because their total concentration is lower than in waters in the lower part of the Dakota or because they have been in the upper part of the Dakota for a longer period of time. The high degree of uniformity in the waters from the upper part of the Dakota formation favors the latter suggestion.

Summary

Waters sampled from the test holes put down in the area had high concentrations of total solids and were not potable. The concentration of total dissolved solids increases with depth and with increasing age of the deposits. Waters from the Dakota and deeper formations were characterized by high percentages of sodium and chloride, moderately low percentages of magnesium and sulphate, and very low percentages of calcium and bicarbonate. Waters from the upper part of the Dakota and some waters from the lower part of the Dakota differed from the rest in their lower percentages of calcium and magnesium, resulting probably from base exchange. It is suggested that waters have entered the Dakota from the Lower Cretaceous and Permian rocks as a result of drilling operations, and, according to Ogden S. Jones, geologist of the Kansas State Board of Health (personal communication), it would seem imperative to use extreme care in setting up adequate cementing and casing programs in these zones.

LOGS OF TEST HOLES AND DISPOSAL WELLS

Samples of drill cuttings from 17 test holes and shallow disposal wells drilled by the Stearns Drilling Company were examined using binocular and petrographic microscopes, and the following logs were prepared.

1. Log of test hole 8, 2,140 feet north and 1,430 feet west of the SE corner sec. 35, T. 13 S., R. 15 W. Surface altitude, 1,882 feet.

	Thickness, feet	*Depth, feet*
Tertiary (?)		
Clay, silt, sand, and gravel; contains fragments of rock, foraminifera, and aragonite prisms	33	33
Cretaceous		
Carlile shale		
Fairport chalky shale member		
Shale, calcareous, dark gray, contains many foraminifera	35	68
Greenhorn limestone		
Limestone and shale; interbedded. Shale, dark, and containing many foraminifera	90	158
Graneros shale		
Shale, black, and thin beds of fine, angular, micaceous sand	24	182
Dakota formation		
Sand, fine to medium-grained, angular, containing siderite	8	190
Shale, light gray, micaceous	17	207
Sand, poorly sorted, angular, containing charcoal	17	224
Shale, dark greenish gray, poorly laminated; contains mica, charcoal, pyrite, and siderite	7	231
Clay, light gray, blocky; contains sand and abundant siderite pellets	37	268
Clay, light greenish gray to tan mottled, containing mica, charcoal, and siderite	20	288
Clay, mottled red, gray, and tan, containing siderite, hematite, and charcoal	80	368
Clay, silty, light gray, containing abundant siderite pellets and mica	20	388
Sand, poorly sorted, micaceous, containing abundant siderite pellets and pyrite	10	398
Kiowa shale		
Shale, dark gray, containing much red and pink clay; probably caved from above	80	478
Sand, poorly sorted, angular, containing pyrite, mica, and glauconite	20	498
Cheyenne sandstone		
Sand, buff, fine-grained, well sorted; grains well rounded and frosted. Mica and glauconite absent	37	535
Permian		
Sand, red, poorly sorted, fine-grained	90	625
Shale, light gray	10	635
Sand, red, and shale, gray	65	700
Shale, red, and siltstone, red	33	733

2. Log of test hole 9, 2,000 feet north and 650 feet east of the SW corner sec. 32, T. 13 S., R. 14 W. Surface altitude, 1,865 feet.

	Thickness, feet	*Depth, feet*
No samples	25	25
Cretaceous		
Carlile shale		
Fairport chalky shale member		
Shale, gray, calcareous; contains foraminifera and aragonite prisms	32	57

Greenhorn limestone		
Limestone and shale; interbedded	93	150
Graneros shale		
Shale, dark greenish to brownish gray	14	164
Dakota formation		
Sandstone, fine- to medium-grained, tight, subangular, containing charcoal and siderite	26	190
Sandstone, fine to coarse, angular, micaceous, containing siderite and pyrite	22	212
Sand, shaly, gray, containing much siderite	13	225
Clay, mottled light gray and dull pink, containing abundant siderite pellets	75	300
Sand, poorly sorted to well sorted, micaceous, angular, containing pyrite	81	381
Sandstone, white, well sorted, cemented by calcite, containing trace of black shale	12	393
Sand, poorly sorted, angular, containing pyrite	29	422
Kiowa shale		
Shale, dark gray, having greenish-brown tints	3	425
Sand and shale; containing mica and siderite, probably caved from above	15	440
Shale, dark gray	12	452
Sandstone, fine, cemented by pyrite	2	454
Shale, dark gray and light pink, probably caved from above	18	472
Sand, very fine, angular, micaceous, glauconitic, well sorted	35	507
Cheyenne sandstone		
Sand, rounded, plastered on dark shale (probably sampled from bit), and shale gray	30	537
Permian		
Sand, red, very fine-grained, containing glauconite	53	590

3. Log of test hole 10, 1,950 feet west and 1,300 feet south of the NE corner sec. 33, T. 13 S., R. 14 W. Surface altitude, 1,861 feet.

	Thickness, feet	*Depth, feet*
Tertiary (?)		
Clay and sand, light yellowish tan	20	20
Cretaceous		
Carlile shale		
Fairport chalky shale member		
Shale, light to dark gray, calcareous; contains foraminifera, limonite, and streaks of coarse siltstone	45	65
Greenhorn limestone		
Limestone and shale; interbedded; contains foraminifera	90	155
Graneros shale		
Shale, dark gray to black	19	174
Dakota formation		
Silt and sandstone, fine- to medium-grained, angular to rounded; containing pyrite, siderite, and mica	5	179
Clay, dark gray, containing siderite	16	195
Sand, fine, poorly sorted, containing siderite	10	205
Clay, silty, gray to buff, containing mica and siderite pellets	80	285
Clay, mottled brown and gray, containing mica, pyrite, siderite, and sandstone	38	323

Clay, light to dark gray, containing mica and charcoal	12	335
Clay, mottled red and gray, containing mica and siderite pellets	45	380
Sand, angular, containing mica, pyrite, charcoal, and siderite	10	390
Sandstone, fine, cemented by calcium carbonate	14	404
Sand, angular, containing mica, pyrite, charcoal, and siderite	35	439
Kiowa shale		
Shale, light to dark gray, containing pyrite, charcoal, mica, and scattered sand grains	24	463
Sand, very fine, angular, containing glauconite, pyrite, mica, and streaks of shale	37	500
Cheyenne sandstone		
Sand, fine, angular, glauconitic, containing pyrite and a trace of mica	5	505
Sand, fine, well rounded, fairly well sorted, containing much pyrite	15	520
Permian		
Sand, dull light pink, very fine-grained	10	530
Siltstone, light red but having light greenish-gray spots, containing scattered fine rounded grains of sand and much pyrite	30	560
Sand, pale red, fine-grained, moderately well sorted, containing glauconite	30	590
Siltstone, red but having greenish-gray streaks	36	626

4. Log of test hole 11, 1,620 feet east and 100 feet south of the NW corner sec. 10, T. 14 S., R. 14 W. Surface altitude, 1,815 feet.

	Thickness, feet	*Depth, feet*
Cretaceous		
Greenhorn limestone		
Limestone and shale; interbedded	98	98
Graneros shale		
Shale, light gray, containing mica and limonite	21	119
Dakota formation		
Sandstone, fine-grained, poorly sorted, angular, containing siderite	14	133
Clay, gray, containing siderite pellets and some silt	47	180
Clay, mottled gray and red, containing siderite pellets partly stained by limonite	100	280
Clay, light gray, sandy	15	295
Sand, angular, well sorted, medium-grained, containing pyrite	10	305
Sand, medium-grained, angular, and siltstone	8	313
Clay, dark gray, finely laminated	22	335
Sandstone, silty, angular to rounded, containing pyrite and siderite	10	345
Sand, angular, fine-grained, poorly sorted, containing mica and some pyrite	5	350
Kiowa shale		
Shale, gray to dark gray, thinly laminated	40	390
Sand, white, very fine-grained, angular, containing mica, glauconite, and pyrite	20	410
Shale, dark gray	10	420

Cheyenne sandstone		
Sand, rounded, fine-grained	23	443
Silt and sand, very fine-grained, rounded, containing glauconite	10	453
Permian		
Sandstone, red, very fine, silty, poorly sorted, micaceous	4	457
Sandstone, white, very fine, poorly sorted, glauconitic	23	480
Sandstone, red, and siltstone, red	32	512

5. Log of test hole 12, 720 feet north and 1,460 feet east of the SW corner sec. 14, T. 14 S., R. 14 W. Surface altitude, 1,815 feet.

	Thickness, feet	*Depth, feet*
Tertiary (?)		
Clay, silt, and sand; contains fragments of foraminifera	10	10
Cretaceous		
Greenhorn limestone		
Limestone and shale; interbedded; contains bentonite and abundant foraminifera	70	80
Graneros shale		
Shale, almost black, and sandstone, fine, glauconitic	25	105
Dakota formation		
Shale, gray, containing siderite	15	120
Clay, light gray, silty to sandy, containing mica and siderite	20	140
Clay, light to greenish gray, containing lignite and siderite pellets	50	190
Clay, mottled red and gray, containing siderite	40	230
Clay, silty to sandy, light to dark gray	30	260
Sand, coarse, fairly well rounded, containing siderite pellets	8	268
Clay, greenish gray and chocolate brown, containing streaks of fine sandstone	41	309
Sandstone, fine, containing glauconite and pyrite	21	330
Sand, fine- to coarse-grained, containing pyrite, mica, and charcoal	20	350
Kiowa shale		
Shale, light gray, containing siderite, mica, and streaks of highly glauconitic silty sandstone	20	370
Shale, light gray, containing a little fine sandstone, siderite pellets and pyrite	30	400
Shale, gray, sandy, containing lignite, silt, mica, pyrite, and a little glauconite	15	415
Shale, very dark; contains small fish scale	3	418
Sand, fine-grained, angular, containing pyrite, a little siderite, and much glauconite and mica	5	423
Cheyenne sandstone		
Sand, rounded, fine-grained, poorly sorted, containing a little mica and glauconite	20	443
(No samples recovered)	10	453
Shale, sandy, gray; contains much pyrite, rounded and angular grains of sand, and a little glauconite	25	478
Permian		
Shale, silty, red, micaceous	219	697

6. Log of test hole 13, 900 feet north and 2,140 feet west of SE corner sec. 10. T. 14 S., R. 14 W. Surface altitude, 1,842 feet.

	Thickness, feet	Depth, feet
Tertiary (?)		
Clay, silt, and sand; buff; contains foraminifera	30	30
Cretaceous		
Greenhorn limestone		
Limestone and shale; gray and dark gray; interbedded; contains bentonite and foraminifera	70	100
Graneros shale		
Shale, dark gray, sandstone and siltstone, fine, contains much glauconite	40	140
Dakota formation		
Shale, gray, silty, containing many siderite pellets	25	165
Clay, light gray, containing siderite pellets	20	185
Clay, yellow, red, gray, brown, containing siderite	95	280
Clay, chocolate brown, and siltstone, containing a few grains of glauconite	20	300
Clay, light chocolate red	30	330
Clay, dark greenish gray	10	340
Clay, dark gray and chocolate brown	10	350
Clay, dark gray and chocolate brown, containing silt, sand, and siderite pellets	15	365
Sandstone and clay; gray and red	7	372
Kiowa shale		
Shale, dark gray, thinly laminated, in part silty	28	410
Sand, fine, angular, micaceous; contains glauconite, pyrite, and shell fragments	20	430
Sand, fine, micaceous, and shale, dark gray, thinly laminated; contains much pyrite	10	440
Shale, dark gray	5	445
Cheyenne sandstone		
Sand, fine, angular, slightly glauconitic, containing much pyrite	9	454
Sand, fine, angular to rounded, containing pyrite	10	464
Sand, fine, silt, light gray, silty shale, gray, and some dense, dark, limestone; contains much pyrite	26	490
Permian		
Sand, red and gray, poorly sorted, and shale, dark	10	500
Silt, sandy, red	35	535

7. Log of test hole 14, 2,240 feet east and 1,980 feet south of the NW corner sec. 23, T. 14 S., R. 14 W. Surface altitude, 1,803 feet.

	Thickness, feet	Depth, feet
Cretaceous		
Greenhorn limestone		
Limestone and shale; gray and dark gray; interbedded	60	60
Graneros shale		
Shale, dark, and sandstone, fine, glauconitic	20	80
Dakota formation		
Clay, gray, containing a few grains of sand, pyrite, fragments and pellets of siderite, and charcoal	70	150
Silt, light gray	5	155
Clay, silty, light gray, having faint red streaks	70	225
Sandstone, poorly sorted, cemented by siderite	20	245
Sand, fine- to medium-grained, containing pyrite, mica, and siderite. Some is cemented by pyrite	50	295

Clay, gray, contains pellets of sand, pyrite, and siderite	25	320
Kiowa shale		
Sand, fine-grained, angular, containing mica and glauconite	5	325
Shale, dark gray, sandy, containing pyrite and glauconite	10	335
Shale, gray, silty, micaceous, containing pyrite and siderite	25	360
Sandstone, fine, containing pyrite and shell fragments	5	365
Shale, dark gray, sandy	10	375
Sandstone, very fine- to fine-grained, angular, containing glauconite, pyrite, shell fragments, and mica	10	385
Shale, light to dark gray, containing pyrite	15	400
Cheyenne sandstone		
Shale, sandy and silty, light gray	15	415
Sand, fine-grained, fairly well sorted, containing glauconite and a little mica. Coarse grains become more common and sorting becomes poorer toward bottom	15	430
Shale, gray, sandy, containing pyrite and glauconite; and sand, fine- to coarse-grained	10	440
Permian		
Siltstone, red	50	490
Siltstone, red, and shale, greenish gray	40	530
Siltstone and shale; red	20	550

8. Log of test hole 15, 900 feet west and 600 feet north of SE corner sec. 15, T. 14 S., R. 14 W. Surface altitude, 1,840 feet.

	Thickness, feet	*Depth, feet*
Tertiary (?)		
Clay, silt, and sand; buff	25	25
Cretaceous		
Greenhorn limestone		
Limestone and shale; interbedded	55	80
Graneros shale		
Shale, dark, and siltstone, glauconitic	35	115
Dakota formation		
Clay, pale gray, having yellow streaks toward bottom	30	145
Clay, mottled light gray and red	25	170
Sand, faint pink, fine, angular, well sorted, micaceous	25	195
Clay, mottled light gray and red	40	235
Clay, silty, grayish pink	15	250
Clay, light gray	10	260
Sand, white, angular, fine- to medium-grained	8	268
Clay, mottled light gray and red	27	295
Clay, light gray, containing siderite	10	305
Silt and sandstone, fine, angular; contains mica and glauconite	5	310
Clay, mottled dark gray and red, containing siderite	28	338
Sand, angular, well sorted	12	350
Clay, silty, mottled pink and gray	20	370
Clay, sandy, light gray	5	375
Kiowa shale		
Shale, dark gray, containing pyrite	20	395
Shale, gray, and sand, glauconitic; contains shell fragments	5	400

Sand, angular, poorly sorted, micaceous, containing glauconite	20	420
Shale, dark, containing much pyrite; lower part sandy	20	440
Sand, fine-grained, angular, micaceous	5	445
Cheyenne sandstone		
Sand, angular at top, rounded below	20	465
Shale, dark gray, and sand, silty, poorly sorted, glauconitic. May have caved from above	10	475
Permian		
Sand, silty, gray and pink	5	480
Siltstone, red	20	500

9. Log of test hole 16, 2,340 feet north and 300 feet east of the SW corner sec. 31, T. 13 S., R. 13 W. Surface altitude, 1,851 feet.

	Thickness, feet	*Depth, feet*
Tertiary (?)		
Clay and silt; light yellow	25	25
Cretaceous		
Greenhorn limestone		
Limestone and shale; gray; interbedded	95	120
Graneros shale		
Shale, dark gray to greenish black, and sandstone, fine, angular, containing glauconite	31	151
Dakota formation		
Clay, gray, containing siderite, sandstone, fine, and siltstone	89	240
Sandstone, fine-grained, well sorted, cemented by calcite or ankerite	14	254
Clay, gray, yellow, and chocolate-brown, containing siderite	81	335
Clay, light gray, containing siderite pellets	20	355
Clay, gray, sandy, containing red streaks	15	370
Clay, light gray, containing siderite	15	385
Sandstone, white to brown, angular, well sorted, cemented by calcite	5	390
Sandstone, white to brown, fine- to medium-grained, containing pyrite and siderite	20	410
Kiowa shale		
Shale, gray to dark gray	25	435
Sand, fine, cemented by pyrite, black shale, glauconite, and pieces of cone-in-cone structures	15	450
Shale, gray, containing much pyrite	10	460
Siltstone, gray, shaly, containing cone-in-cone structures	5	465
Siltstone, gray, and shale, dark	15	480
Cheyenne sandstone		
Sand, fine- to medium-grained, angular to rounded, containing much pyrite, and cone-in-cone structures	10	490
Sand, rounded, slightly shaly, cemented by pyrite	10	500
Sand, rounded, containing pyrite and glauconite	5	505
Permian		
Shale, brownish red, silty to sandy	25	530

10. Log of test hole 17, 1,000 feet south and 1,000 feet east of the NW corner sec. 25, T. 14 S., R. 14 W. Surface altitude, 1,773 feet.

	Thickness, feet	*Depth, feet*
Quaternary		
Pleistocene		
Clay, silt, sand, and gravel; yellow to pink to gray; contains lignite, feldspar, and a trace of pyrite	105	105
Cretaceous		
Dakota formation		
Sand, fine-grained, angular, well sorted	30	135
Sand, fine to medium, containing siderite fragments	20	155
Sand, fine, containing siderite and hematite	20	175
Sand, fine- to medium-grained, angular, fairly well sorted	50	225
Silt, white, containing sand and pyrite	20	245
Sandstone, gray to white, cemented with calcite and pyrite, and much glauconite	10	255
Clay, silt, and sand; gray; containing much pyrite and a little siderite	35	290
Kiowa shale		
Shale, dark gray	5	295
Shale, silty, gray	5	300
Shale, dark gray, containing much pyrite	5	305
Shale, gray	15	320
Shale, dark gray, containing shell fragments	5	325
Shale, gray to dark gray; contains pyrite, silt, sand, shell fragments, and glauconite	25	350
Shale, gray	10	360
Shale, dark gray, and sandstone, containing pyrite and glauconite	5	365
Cheyenne sandstone		
Sand, fine-grained, angular, containing glauconite and a little mica	25	390
Permian		
Sand and siltstone; red and gray	5	395
Siltstone, pink and gray, sandy	25	420
Sand, fine, red	15	435
Siltstone, sandy, red and gray	9	444

11. Log of test hole 18, 2,400 feet east and 300 feet south of the NW corner sec. 30, T. 14 S., R. 14 W. Surface altitude, 1,817 feet.

	Thickness, feet	*Depth, feet*
Quaternary		
Pleistocene		
Clay, silt, and sand; buff	20	20
Cretaceous		
Greenhorn limestone		
Limestone and shale; gray to dark gray; interbedded	48	68
Graneros shale		
Shale, gray to light gray; containing sandstone, very fine, angular, highly glauconitic	32	100
Dakota formation		
Clay, light gray, containing fragments of siderite	20	120
Sand, fine to coarse, white to gray	41	161
Clay, silty, gray, containing fragments of siderite and siderite pellets	34	195

Sandstone, gray	5	200
Clay, red and gray, containing siderite pellets	80	280
Sandstone, fine to coarse, containing siderite and glauconite	17	297
Clay, green, having red and yellow streaks, containing pyrite and siderite	8	305
Clay, gray, silty, containing spots of siderite and hematite	15	320
Sand, white, well sorted, fine- to medium-grained, mica and pyrite absent	15	335
Clay, gray and red, containing silt and siderite pellets	25	360
Kiowa shale		
Shale, dark gray, containing pyrite and siderite pellets	10	370
Shale, gray, silty, containing charcoal	5	375
Shale, dark gray, silty to sandy, containing pyrite and charcoal	10	385
Sandstone, fine, poorly sorted, micaceous, cemented with pyrite and containing a trace of glauconite	5	390
Shale, dark, containing much pyrite and pockets of fine sandstone and siltstone	20	410
Cheyenne sandstone		
Sand, fine, rounded	20	430
Permian		
Sand, fine, pink and red	40	470
Siltstone, shale, and sand, red	45	515

12. Log of test hole 19, 200 feet north and 1,640 feet east of the SW corner sec. 21, T. 14 S., R. 14 W. Surface altitude, 1,855 feet.

	Thickness, feet	Depth, feet
Cretaceous		
Greenhorn limestone		
Limestone and shale; light to dark gray, interbedded; containing bentonite	80	80
Graneros shale		
Shale, dark gray to black	15	95
Shale, dark gray, and sandstone, fine, angular, glauconitic	5	100
Dakota formation		
Clay, gray, sandy, containing siderite	20	120
Sand, very fine, containing a little pyrite	20	140
Clay, gray, silty to sandy, containing fragments of siderite and a trace of charcoal	30	170
Sand, fine to coarse, containing abundant siderite pellets	10	180
Clay, light gray, silty, containing siderite	55	235
Sand, fine, well sorted, containing siderite in lower part	20	255
Clay, light gray	5	260
Sand, fine to coarse, poorly sorted, containing many siderite pellets	35	295
Clay, red	5	300
Clay, gray, containing fragments of siderite	20	320
Sand, fine to medium, poorly sorted, white	30	350
Clay, gray, silty, containing fragments of siderite	10	360
Sandstone, poorly sorted, fine to coarse, containing many large siderite pellets and pyrite cemented with calcite	5	365

	Thickness, feet	Depth, feet
Clay, silty, gray, containing fragments of siderite	10	375
Kiowa shale		
Shale, dark gray, containing pyrite and few siderite pellets	20	395
Siltstone and sand, very fine; containing pyrite	20	415
No sample recovered	5	420
Shale, dark, containing pyrite	25	445
Cheyenne sandstone		
Sand, fine, angular and rounded	30	475
Permian		
Sand, fine, red	20	495
Shale, silty, red	20	515

13. Log of test hole 20, 1,000 feet west and 1,740 feet north of the SE corner sec. 27, T. 14 S., R. 14 W. Surface altitude, 1,791 feet.

	Thickness, feet	*Depth, feet*
Quaternary		
Pleistocene		
Clay, silt, and sand; gray and buff	85	85
Cretaceous		
Dakota formation		
Clay, silty, light gray and red, containing siderite pellets	70	155
Sand, very fine- to medium-grained, well sorted, containing siderite and a little pyrite	57	212
Clay, light gray, silty and sandy, containing siderite pellets and a few streaks of lignite	98	310
Clay, light bluish gray	25	335
Clay, silty, light gray	10	345
Sand, fine, poorly sorted, containing trace of calcite	5	350
Sand, fine, containing small siderite pellets	29	379
Shale, dark bluish gray	1	380
Sand, fine to coarse, poorly sorted, containing much pyrite	5	385
Kiowa shale		
Shale, dark gray to gray, containing pyrite	25	410
No sample recovered	10	420
Shale, light gray, containing glauconite and fine micaceous sandstone	10	430
Shale, light to dark gray, in part silty	5	435
Permian		
Siltstone and shale; red	320	755
Shale, red, and anhydrite	3	758

14. Log of test hole 21, 1,940 feet north and 400 feet east of the SW corner sec. 33, T. 13 S., R. 15 W. Surface altitude, 1,901 feet.

	Thickness, feet	*Depth, feet*
Tertiary (?)		
Silt and sand; buff; in part cemented by calcium carbonate	20	20
Cretaceous		
Carlile shale		
Fairport chalky shale member		
Shale, dark gray, calcareous	30	50
Greenhorn limestone		
Limestone and shale; gray; interbedded; containing bentonite in lower part	95	145

Graneros shale		
Shale, dark gray to black, and bentonite, blue	27	172
Dakota formation		
Sandstone, dark, and light gray clay; containing fragments of siderite and hematite	8	180
Clay, dark gray, containing fragments of siderite	20	200
Sandstone, fine, containing fragments of siderite and cemented with siderite	20	220
Sandstone, fine to coarse, cemented with siderite and hematite	10	230
Sand, fine, silty, in part cemented with siderite	10	240
Siltstone, white, containing charcoal, siderite pellets, and mica	10	250
Clay, pink, gray, white, and yellow mottled, containing charcoal and siderite pellets	30	280
Clay, sandy, light gray, containing abundant siderite pellets	5	285
Clay, mottled red, yellow, gray, and white, containing siderite pellets and a small amount of sand	40	325
Sand, silty, poorly sorted	5	330
Sand, fine-grained, well sorted, in part cemented by calcium carbonate	15	345
Sand, fine, poorly sorted, in part cemented with siderite	30	375
Sandstone and matrix of white clay	10	385
Kiowa shale		
Shale, black, containing lenses of sand	5	390
Shale, dark gray, containing pyrite	10	400
Shale, dark gray, and siltstone, light colored, sandy	5	405
Sandstone, fine, micaceous, and matrix of white clay	10	415
Shale, black, sandy	5	420
Shale, silty, gray and yellow	5	425
Shale, dark gray, sandy	5	430
Sandstone, siltstone, and dark shale	5	435
Shale, dark gray, containing pyrite	20	455
Shale, silty, gray to dark gray, containing glauconitic sandstone	10	465
No sample recovered	5	470
Shale, dark gray, silty	5	475
Shale, dark gray, containing pyrite	5	480
Sandstone, very fine, shaly, containing pyrite	5	485
Sand, fine, micaceous, containing glauconite	5	490
Cheyenne sandstone		
Sand, fine, poorly sorted, mostly angular, containing pyrite	15	505
Sand, clayey, dark, angular to rounded, containing cone-in-cone structures	5	510
Sand, fine, clayey, light colored, well rounded	5	515
Clay, silty, gray	8	523
Sandstone, silty, rounded, containing glauconite	12	535
Permian		
Sand and siltstone; red; containing shale, dark gray, and glauconite	10	545
Sand, fine, red	15	560
Sand and siltstone; red	5	565
Shale, gray	5	570
Sand, red, and shale, gray	15	585
Siltstone, red	30	615

15. Log of test hole 22, 900 feet north and 1,000 feet west of the SE corner sec. 25, T. 14 S., R. 15 W. Surface altitude, 1,750 feet.

	Thickness, feet	*Depth, feet*
Quaternary		
Pleistocene		
Silt, sand, and gravel; buff	50	50
Cretaceous		
Dakota formation		
Clay, gray, sandy to silty	50	100
Clay, gray	20	120
Sand, fine- to medium-grained	30	150
Clay, gray, containing fragments of siderite	20	170
Sand, clayey, fine to coarse, poorly sorted, containing siderite pellets	10	180
Clay, red and white, silty	20	200
Clay, light gray, silty	5	205
Clay, dark gray and red	10	215
Clay, dark gray, containing lenses of fine glauconitic sandstone cemented by calcium carbonate	5	220
Clay, dark gray, containing fragments of siderite	10	230
Clay, silty, light gray and red	20	250
Clay, gray, containing fragments of siderite	10	260
Sand, very fine, white, containing pyrite and siderite	10	270
Kiowa shale		
Shale, dark gray, containing pyrite. Some sand and siltstone in upper part	20	290
Shale, light to dark gray	10	300
Sand, very fine, angular, micaceous, containing shell fragments and glauconite	15	315
Shale, gray to dark gray, containing pyrite. Silty in upper part	15	330
Cheyenne sandstone		
Sand, fine-grained, rounded, buff	30	360
Permian		
Sand, fine, red	30	390
Siltstone, sandy, mottled red and gray	10	400

16. Log of test hole 23, NE¼ sec. 10, T. 15 S., R. 14 W.

	Thickness, feet	*Depth, feet*
Quaternary		
Pleistocene		
Silt and sand; buff	45	45
Cretaceous		
Greenhorn limestone		
Shale, black, and limestone, light colored, interbedded; containing foraminifera and blue-gray bentonite	60	105
Graneros shale		
Shale, dark gray, containing pyrite	24	129
Dakota formation		
Clay, gray, containing siderite pellets and charcoal	36	165
Clay, silty, light gray	30	195
Clay, gray, yellow and pink	15	210
Clay, silty, light gray, containing fragments of siderite	20	230
Sand, medium-grained, containing siderite pellets	65	295
Clay, sandy, light gray, containing siderite pellets	10	305
Clay, red and white, containing siderite pellets	30	335

Clay, dark gray, sandy, containing well-cemented fine-grained sandstone and a trace of glauconite	15	350
Sandstone, fine, well sorted, cemented with pyrite, siderite, calcium carbonate and containing abundant glauconite	10	360
Clay, gray	20	380
Sandstone, fine-grained containing siderite, pyrite, red clay, and gray clay	17	396
Kiowa shale		
Shale, gray, and limestone	9	405
Shale, dark gray, containing pyrite, siderite pellets and red clay. (Red clay and siderite caved from above)	20	425
Shale, dark gray to black, containing pyrite, charcoal, and material that caved from the overlying Dakota formation	25	450
Shale, black, containing pyrite and fine glauconitic sandstone	10	460
Shale, dark gray	10	470
Cheyenne sandstone		
Sand, fine-grained, mostly rounded	15	485
No sample recovered	5	490
Permian		
Shale, red and black, sandy	5	495
Siltstone, red	28	523

17. Log of test hole 24, 1,650 feet south and 2,310 feet west of the NE corner sec. 3, T. 14 S., R. 14 W. Surface altitude, 1,750 feet.

	Thickness, feet	*Depth, feet*
(No samples)	350	350
Cretaceous		
Dakota formation		
Sand, fine- to medium-grained, containing siderite and pyrite	25	375
Sand, fine- to medium-grained, containing abundant pyrite and siderite	5	380
Kiowa shale		
Shale, gray	10	390
Shale, dark gray	20	410
Shale, dark gray to gray, sandy, containing pyrite and glauconite	20	430
Shale, dark gray, containing angular-grained sandstone, pyrite, and cone-in-cone structures	6	436
Cheyenne sandstone		
Sand, fine, angular to rounded, poorly sorted, containing much glauconite but little mica	9	445
Shale, gray, sandy, containing pyrite	5	450
Siltstone, gray, and sand, very fine; containing much pyrite, and some cone-in-cone structures in upper part	20	470
Permian		
Shale, red, and siltstone, gray	7	477
Shale, siltstone, and sandstone; red	8	485
Sandstone, fine, red	27	512
Shale, brownish red	16	528

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Cross sections plotted from sample logs of test holes and brine-disposal wells. Locations of cross sections are shown in figure 2.