Geology and Ground-Water Resources of
ELLSWORTH COUNTY
Central Kansas

Charles K. Bayne
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By

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Prepared by the State Geological Survey of Kansas and the United States Geological Survey with the cooperation of the Environmental Health Services of the Kansas State Department of Health and the Division of Water Resources of the Kansas State Board of Agriculture.

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State Geological Survey of Kansas

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ABSTRACT

Ellsworth County comprises an area of about 720 square miles. The county lies in the Dissected High Plains section of the Great Plains physiographic province and is drained by the Smoky Hill River and its tributaries and tributaries of the Saline and Arkansas Rivers. The topography slopes generally eastward. The long-term mean precipitation at Ellsworth, the county seat, is 25.66 inches. Agriculture is the chief industry in the county, and petroleum, salt, and clay are the chief natural resources.

The oldest rock that crops out in the county is the Ninnescah Shale of Early Permian age. Rocks of Early to Late Cretaceous age unconformably overlie the Permian rocks. The Kiowa Formation is considered to be Early Cretaceous and the Graneros Shale is considered to be Late Cretaceous in age based on faunal evidence, but the age of the Dakota Formation, which occurs between the Kiowa Formation and the Graneros Shale, is problematic. Evidence indicates that the Upper-Lower Cretaceous boundary may lie within the lower part of the Dakota Formation. The Kiowa Formation and the Graneros Shale were deposited under marine conditions, whereas the Dakota Formation was deposited under terrestrial conditions.

The lithology most characteristic of the Dakota Formation is gray and greenish-gray siltstone and clay showing red and reddish-brown mottles. The contact between the Kiowa Formation and the Dakota Formation is placed at the base of the red mottled clay or siltstone.

The lower part of the Graneros was deposited in a shallow turbid sea. Later deposition occurred in deeper more saline water.

The contact between the Graneros Shale and the Greenhorn Limestone is placed at the base of the lowermost skeletal limestone in the Greenhorn that has a petroliferous odor. The upper boundary of the Greenhorn is conformable and gradational and is arbitrarily placed at the top of the Fence-post limestone bed.

Pliocene rocks in the county consist of remnants of a soil caliche formed during late Pliocene time.

Pleistocene rocks unconformably overlie Permian and Cretaceous rocks in the valleys and large parts of the upland area.

The Dakota Formation and the Pleistocene deposits in the valleys are the most important aquifers in the county. These ground-water reservoirs are recharged principally from local precipitation. Yields of properly constructed wells may be in excess of 250 gallons per minute in the most-productive areas.

The results of chemical analyses indicate that the water generally is suitable for most uses; however, the quality varies considerably from place to place, and locally a large amount of chloride is present.

INTRODUCTION

History and Purpose of the Report

This report was prepared by the State Geological Survey of Kansas and the U.S. Geological Survey, in cooperation with the Environmental Health Services of the Kansas State Department of Health and the Division of Water Resources of the Kansas State Board of Agriculture.

The report is based on data collected during three separate investigations, each of which was begun with a different objective.

In the summers of 1958, 1959, and 1960, William Ives, Jr., collected data on the stratigraphy of the outcropping rocks and the mineral resources of Ellsworth County. The main objective of this study was to assess the mineral resources being exploited and potentially exploitable in the county.

In the summer of 1964, P. C. Franks, assisted in the field by George L. Coleman and Pei-Lin Tien, made an intensive study of the Cretaceous rocks in Ellsworth County with special emphasis on the Kiowa Formation-Dakota Formation contact and the Lower-Upper Cretaceous boundary. Much of the data on cross-stratification and minor sedimentary structures presented in this report results from the work by Franks.

In 1964, C. K. Bayne studied the hydrology of the area and mapped the Tertiary and Pleistocene geology. He also did additional work on the stratigraphy of

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Geography and General Features

Location.—Ellsworth County is located near the center of Kansas; in fact, the geographic center of the State is only a few miles west of the southwest corner of the county (Schoewe, 1948). Ellsworth County comprises Tps.14 to 17 S. and Rs.6 to 10 W. and has an area of about 720 square miles. It is bounded by Lincoln County on the north, Saline and McPherson Counties on the east, Rice County on the south, and Barton and Russell Counties on the west.

Figure 1 shows the area discussed in this report and other areas in the State for which ground-water reports have been published or are in preparation.

Climate.—Ellsworth County lies on the western margin of the subhumid climatic zone (Trewartha, 1941). The area is characterized by a predominance of sunshine, moderate precipitation, moderate wind velocity, and a relatively high rate of evaporation. During the summer, days are hot with, generally, short periods in midsummer in which the maximum daily temperature exceeds 100°F. These days are generally moderated by persistent winds and low humidity. In the fall, days are pleasantly warm with cool nights. Winters are fairly moderate with sporadic snowfalls of variable intensity and generally only short periods of severely cold weather. Spring generally is the period of maximum precipitation.

Figure 2 shows the mean monthly precipitation for

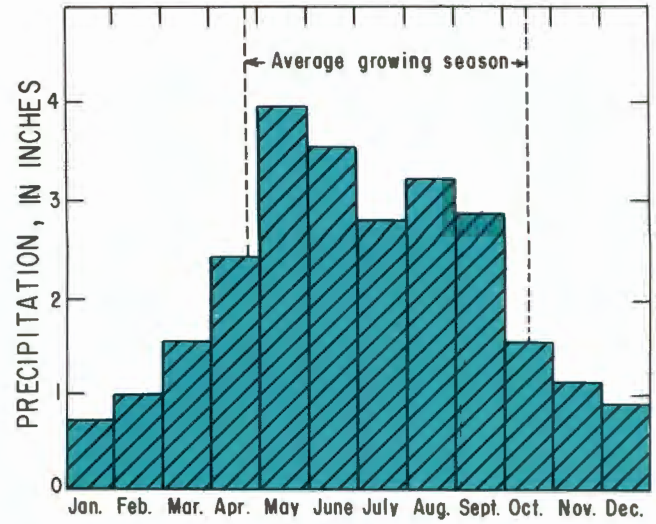

FIGURE 2.—Long-term mean monthly precipitation and average growing season at Ellsworth.

Ellsworth based on U.S. Weather Bureau records for the Ellsworth station, which has reported continuously since its establishment in 1904. The annual precipitation and the cumulative departure from long-term mean precipitation for the years since 1931 are shown on figure 3. January is generally the coldest month, with a mean temperature of 30.5°F, whereas July is commonly the hottest month, with a mean temperature of 82.2°F. The average length of the growing season is 176 days, the average date of the last killing frost is

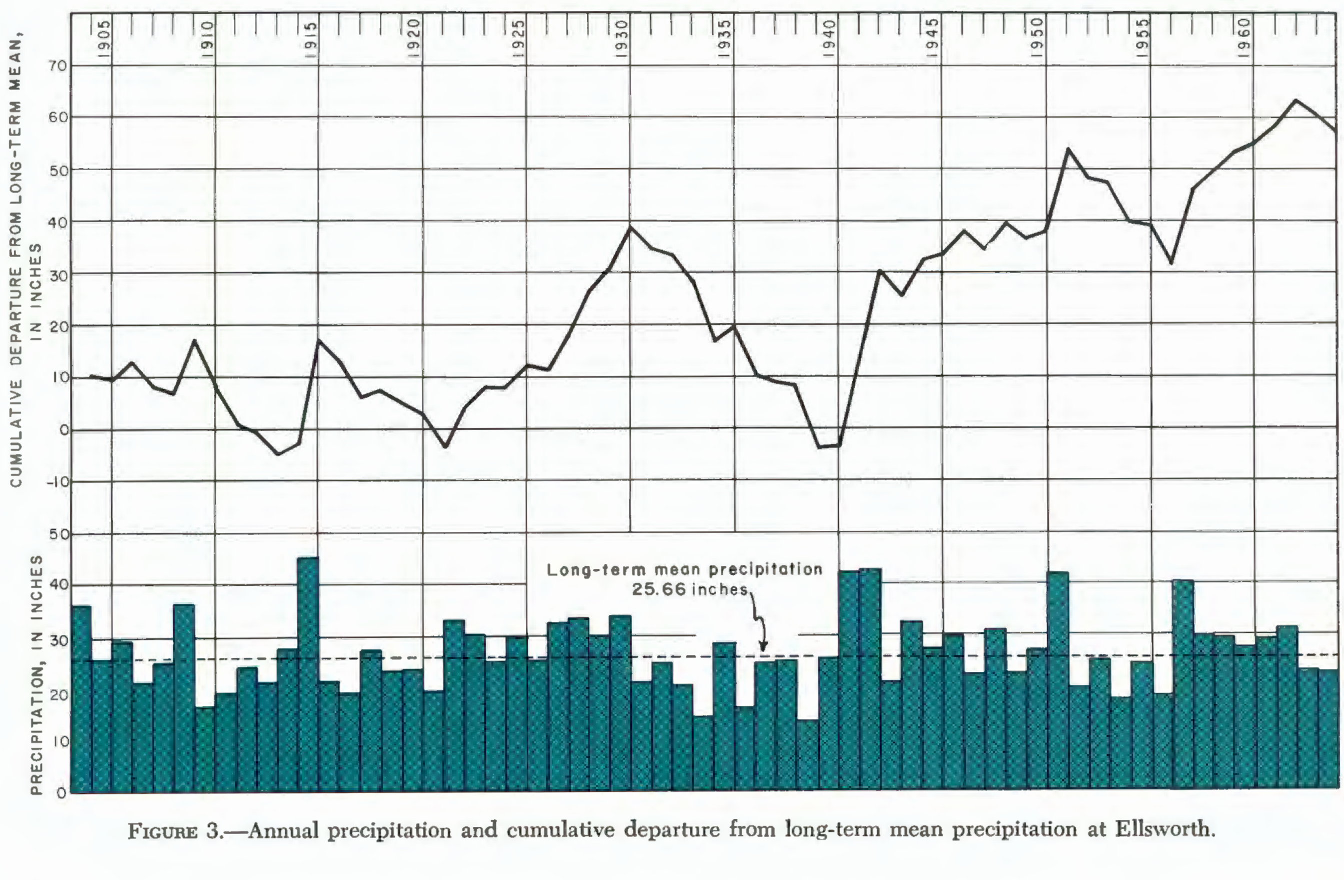

FIGURE 3.—Annual precipitation and cumulative departure from long-term mean precipitation at Ellsworth.

A summary of ceramic testing of Dakota clays by Plummer and Romary (1947) included several measured sections and photographs of outcrops in Ellsworth County. They studied samples from 102 test-pit locations in the county to verify stratigraphic conclusions reached in their publication. In his report on coal resources of the Kansas Cretaceous, Schoewe (1952) delineated parts of Ellsworth County where lignite is found. Plummer and others (1954) studied ceramic properties of four distinct Dakota clay beds of which two were in Ellsworth County. These studies resulted in the development of new industry in the county.

Methods of Investigation

During the field work for preparation of this report and the geologic map, contacts were mapped on 7½-minute topographic quadrangle sheets and vertical aerial photographs and then were transferred to a base map at a scale of 1:48,000 prepared by the Topographic Division of the U.S. Geological Survey.

Many exposures were examined and many sections were measured with tape and hand level. One hundred twenty test holes and auger holes were drilled for geologic and ground-water information and are incorporated in the report. Data for 311 wells and springs are given in table 6 and include depth of well and depth to water level. Information relating to the yield and adequacy of the wells was obtained from the owners when it was available. Location of wells and test holes was determined from aerial photographs and 7½-minute topographic sheets.

Samples of water from 29 wells were analyzed by the laboratory of the Environmental Health Services, Kansas State Department of Health.

Well-Numbering System

The well and test-hole numbers used in this report give the location of wells according to General Land Office surveys. The well number is composed of township, range, and section numbers, followed by letters that indicate the subdivision of the section in which the well is located. The first letter denotes the quarter section; the second letter, the quarter-quarter section or 40-acre tract; and the third letter, when used, the quarter-quarter-quarter section or 10-acre tract. The 160-acre, 40-acre, and 10-acre tracts are designated *a, b, c,* and *d* in a counterclockwise direction, beginning in the northeast quadrant. As an example, well 15-9W-22cbd is in the SE¼ NW¼ SW¼ sec. 22, T.15 S., R.9 W. (fig. 4). When two or more wells are located within a 10-acre tract, the wells are numbered serially according to the order in which they were inventoried.

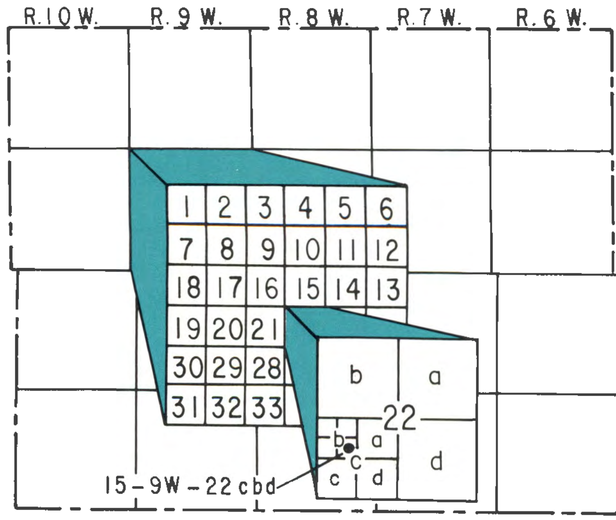

FIGURE 4.—Well-numbering system used in this report.

Acknowledgments

The authors are deeply grateful to many residents and landowners for their interest, courtesy, and cooperation during the work in Ellsworth County and wish to especially thank the following: Mr. and Mrs. Ernest Jiricek and Representative George Jelinek, Ellsworth; Aldon Annis and Winfred Holmes, Acme Brick Co., Kanopolis; Joe Jazek and Dallas Boeken, Holyrood; and V. L. Maxey, Resident Ranger, Lake Kanopolis.

Norman Plummer of the State Geological Survey of Kansas staff first introduced the junior authors to the Kiowa and Dakota Formations of central Kansas. We all are indebted to him for time spent in the field with us and for time spent in discussion.

STRATIGRAPHY OF SUBSURFACE ROCKS[1]

Ellsworth County is underlain by rocks that represent all the Paleozoic systems. Individual units within the system may not be present locally in the county, so that a well drilled in a specific location may penetrate only a part of the rocks that might be present in another part of the county. Table 1 is a generalized column summarizing the sequence of pre-Cretaceous rock units in the subsurface in Ellsworth County.

STRATIGRAPHY OF OUTCROPPING ROCKS

Rocks that crop out in Ellsworth County range in age from Early Permian to Recent and are described on the following pages. A generalized section of the outcropping rocks and their water-bearing characteristics is given in table 2.

[1] The classification and nomenclature of rock units used in this report are those of the State Geological Survey of Kansas and differ somewhat from those of the U.S. Geological Survey.

TABLE 2.—Generalized section of outcropping rock units and their water-bearing characteristics.

Era	System	Series	Stage or group	Formation or rock unit	Member	Thickness, feet	Character of material	Water supply
Cenozoic	Quaternary	Pleistocene	Recent and Wisconsinan	Alluvium and terrace deposits		30-60	Clay, silt, sand, and gravel in stream channels and underlying terraces adjacent to streams.	Yields moderate quantities of water to wells in larger valleys. Small supplies available in tributary valleys.
			Wisconsinan and Illinoisan	Peoria and Loveland Formations		0-10	Eolian silt locally present in upland areas and in Wilson valley.	Yields no water to wells.
			Illinoisan	Crete Formation		0-50	Clay, silt, sand, and gravel in principal stream valleys.	Yields small to moderate quantities of water to wells in principal valleys.
			Kansan	Sappa Formation		0-70	Clay, silt, and locally sand and volcanic ash in upper part; sand and gravel in lower part. In high terrace position.	Yields small to moderate quantities of water to wells adjacent to principal streams and in Wilson valley. Partly drained.
				Grand Island Formation				
			Nebraskan	Fullerton Formation		0-45	Clay, silt, sand, and gravel. In high terrace position and in the basal part of Wilson valley.	May yield small quantities of water to wells in Wilson valley. High terrace deposits largely drained.
				Holdrege Formation				
	Tertiary	Pliocene		Ogallala Formation		0-3.5	Soil caliche ("algal limestone") in highest topographic position in divide areas.	Yields no water to wells.
Mesozoic	Cretaceous	Upper Cretaceous	Colorado	Carlile Shale	Fairport Chalk	0-15	Shale, chalky shale, and chalk; some bentonite.	Yields no water to wells.
				Greenhorn Limestone	Pfeifer Shale	18-21	Chalky shale, chalk, and limestone; contains very thin bentonite beds.	Yields small quantities of water to wells from upper weathered zone in local areas.
					Jetmore Chalk	20	Chalk, chalky shale, and limestone.	
					Hartland Shale	20	Chalky shale containing several bentonite beds.	
					Lincoln Limestone	5-20	Chalky limestone and shale.	
				Graneros Shale		35-40	Shale and locally standstone and coquina limestone beds.	Yields small quantities of water to wells from sandstone in local areas.
		Upper Cretaceous / Lower(?) Cretaceous		Dakota Formation	Janssen Clay	0-250	Clay, silt, sand, sandstone, siltstone, shale, and lignite.	Yields small to moderate quantities of water to wells from sandstone beds.
					Terra Cotta Clay			
		Lower Cretaceous		Kiowa Formation		0-150	Shale, clay, sandstone, and siltstone.	Yields small to moderate quantities of water to wells from sandstone beds.
Paleozoic	Permian	Lower Permian	Sumner	Ninnescah Shale		0-15	Shale and siltstone.	Yields no water to wells.

a small part of the formation. The upper surface is a major unconformity. Overlying sediments in exposures along this creek are either the Kiowa Formation or Pleistocene deposits.

Ninnescah Shale-Kiowa Formation Contact

The contact between the Kiowa Formation and the underlying Permian rocks in Ellsworth County is part of an extensive regional erosion surface that transects rocks in the subsurface as young as Jurassic in southwestern Kansas (Merriam, 1963, p. 67) and as old as Late Permian (Wellington Formation) in north-central Kansas. In much of central Kansas the contact between Cretaceous and Permian rocks is a mature erosion surface that commonly shows as much as 50 feet of local relief (Plummer and Romary, 1942, p. 320) and in places as much as 75 or 100 feet of relief (Mack, 1962, p. 25; Greene, 1910). The unconformity is marked locally by a conglomerate or pebble zone composed largely of pebbles of chert and quartzite measuring as much as 3 inches in long diameter. The Permian rocks beneath the unconformity commonly have undergone extensive alteration so that they are greatly bleached and variegated, and in some places the normally chloritic and illitic clays of the Permian rocks have been converted largely to kaolin. Exposures of both the pebble zone and bleached, varie-

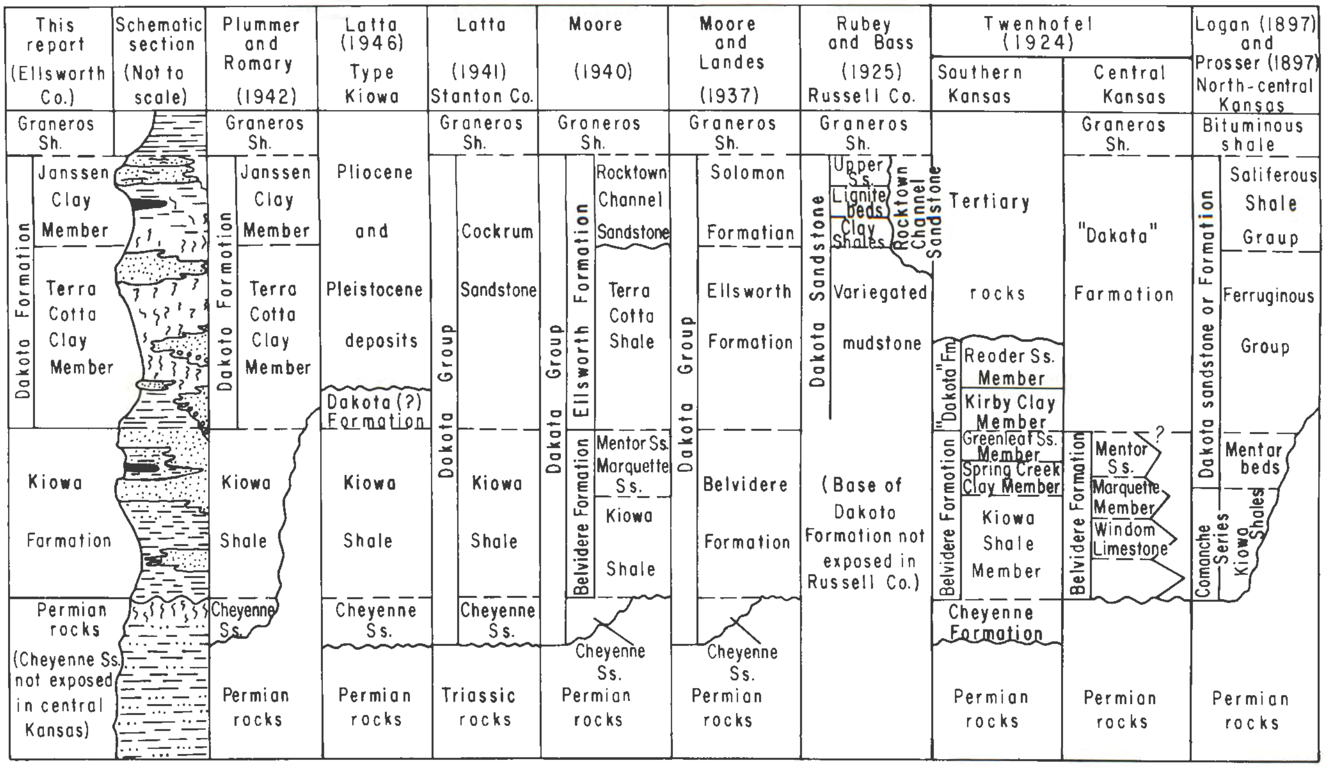

FIGURE 5.—Generalized section of Kiowa and Dakota Formations in Ellsworth County and some of the variations in nomenclature and interpretation of stratigraphic relationships in Kansas. The Cheyenne Sandstone, which underlies the Kiowa Formation in its type area in southern Kansas, is not exposed in Ellsworth County but may have equivalents in the subsurface of western Ellsworth County.

Members. For consistency, in this report, the Kiowa Formation is assigned to the Lower Cretaceous Series, whereas the Dakota Formation is assigned to the Lower(?) and Upper Cretaceous Series.

KIOWA FORMATION

Nomenclature, definition, age, and correlation.—Figure 5 is incorporated in this report to emphasize the complexity of nomenclature applied to rocks referred to here as the Kiowa Formation. Although the nomenclatural history of the Kiowa Formation is complex, excellent summaries are given by Bullard (1928, p. 40-47), Waite (1942, p. 135-137), and Latta (1946, p. 221-223). Considerable attention is given in this report to discussion of nomenclature of both the Kiowa and Dakota Formations, inasmuch as many of the stratigraphic problems associated with these rock units actually originated as problems in nomenclature and arose, in part, from study and differing interpretation of the rocks in this area by several authors.

Recognition of beds of Cretaceous age at and near the type area of the Kiowa Formation in Kiowa County, Kans., is attributed to Mudge (1878, p. 47, 55). St. John (1883, p. 571) recognized the occurrence of rocks that contained marine fossils of Cretaceous age near the base of the so-called Dakota group of Meek and Hayden (1861) not only near Brookville, a few miles east of the Ellsworth County line in north-central Kansas, but also in Kiowa County in southern Kansas. St. John noted (p. 588) that the fossil assemblage was in many ways similar to that contained in the Cretaceous of the north Texas coastal plain.

Cragin (1894, p. 49) first used the name "Kiowa shales" to designate ". . . the inferiorly dark-colored and superiorly light-colored shales that crop out in several of the counties of southwestern Kansas, resting upon the Cheyenne sandstone in their eastern, and upon the 'red-beds' in their middle and western exposures, and being overlaid by brown sandstones of middle Cretaceous age, or Tertiary or Pleistocene deposits, according to locality . . ." in southwestern Kansas. With publication of the study by Prosser (1897) of the so-called Comanche series of Kansas, the name "Kiowa shales" seems to have come into fairly general use in approximately the same sense that the name "Kiowa" now is used in southwestern Kansas. However, the names "Belvidere beds" and "Medicine beds" have been applied to the same rocks in whole or in part from time to time (*cf.* Cragin, 1895b; Twenhofel, 1924, p. 20-34; Latta, 1946, p. 222, fig. 2). Cragin (1889, p. 37) seems to have been the first to recognize that shale lithologically and paleontologically

FIGURE 7.—Exposure of Kiowa shale-Dakota Formation contact in cutback on the Smoky Hill River near the cen. S½ sec. 33, T.15 S., R.7 W. Topmost Kiowa sandstone forms ledge about 7.5 feet thick and contains abundant ellipsoidal masses of calcite cement in its upper parts. The sandstone is overlain almost directly by red-mottled Dakota siltstone (measured section 4). Within half a mile south (to right in photograph), the entire Kiowa section is replaced by sandstone.

siderite, but contain some clay. They occur in thin discontinuous zones parallel to the lamination of the enclosing shale, have a discoidal form, and are as much as 0.3 foot thick and 4 feet in diameter. On weathering, the concretions break into angular fragments composed largely of hydrated iron oxides and are a useful criterion for recognition of the Kiowa Formation in grass-covered areas.

Calcareous cone-in-cone structure forms ellipsoidal concretions (fig. 8) and lenticular beds in the Kiowa Formation in many parts of Ellsworth County. Concretions showing cone-in-cone structure are as much as 1 foot thick and generally less than 6 feet long, whereas the lenticular beds of cone-in-cone are as much as 0.5 foot thick and 30 feet long. Concretions have the apices of the cones oriented toward a central shaly parting (fig. 8). The apices of cones in the lenticular beds of cone-in-cone may point either up or down.

Twenhofel and Tester (1926) noted the abundance of cone-in-cone in southeastern Ellsworth County and parts of adjoining counties, and apparently suggested (p. 559) that the cone-in-cone formed a continuous layer that might be useful for correlation. Although zones of cone-in-cone are common in the lower parts of the Kiowa Formation in southeastern Ellsworth County, they occur at various stratigraphic positions within the Kiowa. Franks (1966) cites evidence that cone-in-cone in the Kiowa formed during early diagenesis when the enclosing sediments were still plastic and unlithified.

Commonly, sequences of brown or nearly black carbonaceous clay, siltstone, and shale are found near the top of the Kiowa Formation where they underlie and grade both laterally and vertically into what might be described as a cap sandstone (fig. 7). However, they are found in lower parts of the Kiowa Formation as well as along the bluffs and steep slopes in secs. 3 and 8, T.17 S., R.6 W. The fossil amber (jelinite) found in the NW¼ SW¼ sec. 18, T.17 S., R.6 W. (Buddhue, 1939a, 1939b), probably came from such a sequence in the lower parts of the Kiowa Formation.

Weathered slopes of argillaceous rocks belonging to the Kiowa Formation commonly are littered with abundant euhedral crystals of gypsum measuring as much as 2 inches in long dimension. In places abundant radial aggregates (sunbursts) of gypsum may be found on weathered exposures. The recrystallized

R.6 W., extends from near the top of the Permian rocks to the base of the Dakota Formation and is nearly 100 feet thick. The thick lenses of sandstone generally support rugged topography, but in many places they underlie a gentle upland topographic surface that is interrupted only by low rounded hills or steep outliers of the overlying Dakota Formation (fig. 6).

The sandstone generally is very light gray to pale grayish orange, but in places hematitic stain and cement color it reddish brown.

The sandstone shows a wide variety of cross-stratification that is mostly medium and large scale (McKee and Weir, 1953) and includes wedge-planar, tabular-planar, and trough-shaped sets of high-angle cross-strata (fig. 9). Only locally is simple cross-stratification (McKee and Weir, 1953, p. 385-387) obvious. Even, horizontal lamination and bedding are relatively scarce in thick accumulations of Kiowa sandstone.

Contacts between the thick lenticular deposits of sandstone and underlying Kiowa shale are both gradational and disconformable, even in different parts of the same sandstone body. Where the contacts are gradational, grain size of the sandstone decreases downward as interbeds and laminae of shale become more abundant. The gradational sequences are mostly less than 10 feet thick. Where scour and fill contacts with Kiowa shale occur, fragments and pellets of reworked shale are common in the basal parts of the sandstone and locally are abundant enough to form shale and pebble conglomerates.

Bedding in the thin sandstone beds includes even horizontal lamination, microcross-stratification, and several kinds of ripple lamination. Linguloid ripple marks, symmetrical transverse ripple marks, asymmetric transverse ripple marks (fig. 10), and interference ripple marks (fig. 11) are common features on bedding surfaces. Small- and medium-scale tabular,

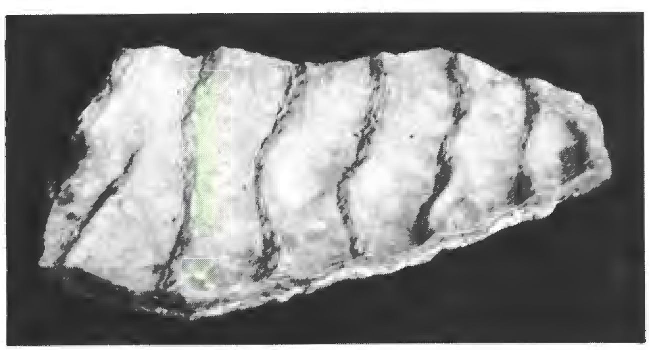

FIGURE 10.—Sample of calcite-cemented Kiowa sandstone exhibiting asymmetric transverse ripple marks. Wavelength ranges from about 2.5 to 3 inches. Sample is from topmost part of Kiowa Formation near the cen. sec. 24, T.16 S., R.8 W.

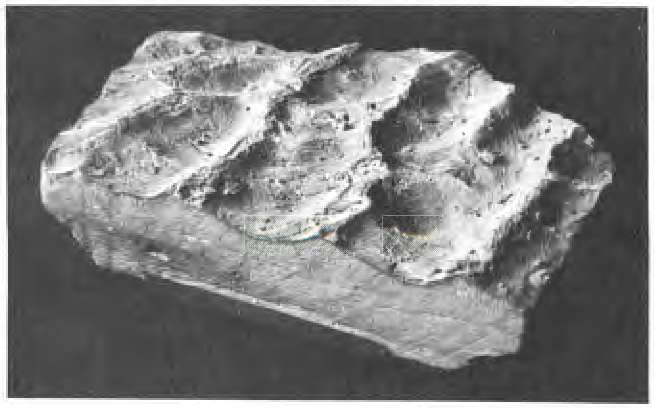

FIGURE 11.—Sample of Kiowa sandstone from the cen. W½ sec. 7, T.16 S., R.11 W., on the east shore of Kanopolis Reservoir. Note interference ripple marks and characteristic pairing of wartlike projections of sand fillings of U-shaped burrows attributed to *Arenicolites*.

wedge-planar, and trough cross-stratification also is seen. Tracks and trails of various burrowing or crawling organisms are common and *Arenicolites* burrows are characteristic (fig. 11). The sandstone may also contain molds and casts of pelecypods or *Turritella*.

Measurements of cross-stratification dip bearings of Kiowa sandstone were made at 11 localities in Ellsworth County (Franks, 1966). Vector resultants (vector averages or means) calculated for each of the 11 localities are plotted in a circular histogram (fig. 12). Although the grand vector resultant trends S.10°W., there is considerable dispersion of individual vector resultants and a prominent mode trends about S.10°E.

Thickness.—The thickness of the Kiowa Formation ranges from 110 to 150 feet in Ellsworth County as determined by well logs and altitudes of the contacts. Inasmuch as the Permian-Cretaceous contact in north-central Kansas is an uneven surface, considerable local variation in thickness of the overlying Kiowa Formation may be expected. Moreover, the altitude of the Kiowa-Dakota contact commonly is highest where thick accumulations of sandstone are in the Kiowa Formation. Thus, the Kiowa Formation may be thickest where sandstone is most abundant and perhaps where the overlying Dakota is thinnest.

Environment of deposition of the Kiowa Formation.—The Kiowa Formation was deposited in a transgressing sea that was connected with the Early Cretaceous seas in the coastal plain region of Texas and that formed part of a seaway that extended northward across the interior regions of the United States almost to the Canadian border (Reeside, 1957, p. 513-518). Measurements of directions of dip of cross-stratification in the overlying Dakota Formation in Ellsworth County (fig. 12), Ottawa County (Franks and others, 1959), and elsewhere in central Kansas (Franks, 1966) indicate that the regional direction of transport during

Kansas (Plummer and Romary, 1942, p. 322; Jewett, 1964) indicates that Kiowa sediments deposited in Ellsworth County may have accumulated near the margins of the sea.

Much of the shale was deposited in relatively quiet water where the bottom was only occasionally disturbed by currents and waves, but where conditions were not completely inhospitable to the maintenance of benthonic life. Neritic currents and wave action locally built deposits of interlaminated shale and sand or silt that grade upward into sandstone containing appreciable interstitial clay and commonly showing signs of an abundant bottom life. Oyster beds locally formed in estuarine bays or other places where low salinity and current or wave activity favored growth. When currents or waves acted somewhat more strongly, the oyster beds were destroyed and were reworked to form conquinoid "shell-beds." Where the supply of sand was sufficiently great, currents and waves built barrier bars and beaches behind which and between which carbonaceous muds were deposited and locally lignitic materials accumulated.

The climate on the nearby land to the east and northeast was mild. The upward increase in the abundance of sandstone and associated carbonaceous deposits in the Kiowa Formation in Ellsworth County is taken as evidence of regressive sedimentation that heralded deposition of the overlying, largely nonmarine Dakota Formation.

Kiowa Formation-Dakota Formation Contact

The Kiowa and Dakota Formations in Kansas generally have been considered to be conformable as well as vertically and laterally gradational. Twenhofel (1920, 1924) and Tester (1931) visualized large-scale and intimate intertonguing of the two units. Latta (1946, p. 249) stated, "In the upper part of the Medicine Lodge Valley in the Belvidere area, the Kiowa shale grades with apparent conformity into beds of sandstone, shale, and clay which contain fossil plants and are lithologically similar to certain beds in the Dakota formation of central Kansas." Swineford (1947, p. 58) stated, "The Dakota formation . . . is conformable on and intertonguing with the Kiowa shale, although in the northernmost part of the area it overlaps directly on Permian rocks." In his study of Rice County, Kans., Fent (1950, p. 57) described his placement of the Kiowa-Dakota contact as follows: ". . . the contact between the predominantly marine beds of the Kiowa shale and the nonmarine beds of the Dakota formation is arbitrarily placed at the top of the uppermost zone known to contain abundant marine fossils." On the other hand, Mack (1962, p. 17) indicated that the Dakota Formation rests unconformably on the Kiowa in Ottawa County, Kans.

Plummer and Romary (1942, p. 332) placed the Kiowa-Dakota contact at the base of one or more beds of siltstone or fine-grained sandstone containing ellipsoidal masses of calcite cement ("quartzites"). Locally, light-colored argillaceous rocks beneath the sandstone beds were included in the Dakota Formation. However, more than one bed of fine-grained sandstone containing ellipsoidal concretions of sandstone cemented by calcite can be seen in the Kiowa Formation along the shores of Kanopolis Reservoir. Fent (1950, p. 57-59) also noted the abundance of calcite-cemented sandstone in the Kiowa Formation in Rice County. Swineford (1947) examined calcite-cemented sandstone of the Kiowa not only in Ellsworth County but elsewhere in central Kansas. Thus, fine-grained sandstone containing abundant concretionary masses of calcite cement ("quartzites") may be more characteristic of the Kiowa Formation than of the Dakota Formation.

The lithology most characteristic of the Dakota Formation in Ellsworth County and elsewhere in north-central Kansas is gray to greenish-gray clay or siltstone showing red to reddish-brown mottles and commonly containing numerous spherules of siderite or its limonitic and hematitic alteration products. Accordingly, the contact between the Kiowa and Dakota Formations in much of Ellsworth County was placed at the base of red-mottled Dakota clay or siltstone or at the base of gray clay or siltstone enclosing lenses of red-mottled argillaceous rocks.

Red-mottled Dakota clay and siltstone commonly rest directly on or occur within a few feet above sandstone that grades downward into typical gray Kiowa shale or into carbonaceous deposits in the upper part of the Kiowa Formation (fig. 13). *Arenicolites* burrows are common both in the sandstone and in the underlying gradational sequences of interlaminated sandstone, siltstone, and shale.

A zone enriched in iron oxide commonly is found at the top of the "quartzite"-bearing sandstone or at the top of a thin shaly interval that grades laterally into such sandstone (see measured sections 4 and 5). This enriched zone was selected as the top of the Kiowa Formation in many parts of eastern Ellsworth County. For practical use, however, the top of the sandstone is a more convenient datum for mapping purposes inasmuch as it is exposed more prominently than the overlying argillaceous rocks.

Thick lenticular deposits of sandstone near the top of the Kiowa Formation generally are overlain almost directly by red-mottled Dakota siltstone or clay. In at least one locality (fig. 13), basal Dakota siltstone

Dakota Formation

Original definition.—The type area of the Dakota Formation is in northeastern Nebraska where it was defined as the Dakota group by Meek and Hayden (1861). They described it (p. 419) as "yellowish, reddish and occasionally white sandstone, with, in local areas, alternations of various colored clays and beds and seams of impure lignite . . ." and said it was found in the ". . . hills back of the town of Dakota [and was] also extensively developed in the surrounding country in Dakota County below the mouth of Big Sioux River, and thence southward into Northeastern Kansas[2] and beyond."

History of nomenclature.—Since its inception, the name "Dakota" has been used in different ways in different places. Variation in usage in Kansas alone has been manifold (fig. 5).

The classification used in this report ranks the Dakota as a formation and does not include the Cheyenne Sandstone and the Kiowa Formation as parts of a so-called Dakota Group (*cf.* Merriam, 1957, 1963). Ranking of the Dakota as a formation has been official usage of the State Geological Survey of Kansas since 1942. Although age considerations entered into acceptance of the Dakota as a formation in 1942 (Waite, 1942, p. 137), application of the name Dakota Formation originated directly from the work of Plummer and Romary (1942). Their classification was lithologic and was not founded on age considerations. However, they did recognize (p. 326) that the underlying Kiowa Formation thinned northward along the outcrop and did not extend into Nebraska. Moreover, the Cheyenne Sandstone is restricted essentially to its type area on the outcrop in southern Kansas, although subsurface extensions of the Cheyenne probably reach into north-central Kansas. Hence, rocks classed as Dakota Formation in Kansas and as Dakota Group in Nebraska (Condra and Reed, 1959) are lithogenetic and rock-stratigraphic extensions one of the other.

Plummer and Romary (1942) subdivided the Dakota Formation into two members—the Janssen Clay Member above and Terra Cotta Clay Member below. Both members have their type localities in Ellsworth County.

Lithology.—The Dakota Formation in Ellsworth County (and elsewhere in north-central Kansas) comprises a thick heterogeneous sequence of clay, siltstone, and sandstone. Particularly near its top and locally near its base, the Dakota contains both shaly and lignitic beds or lenses. If one lithology were selected as being typical of the Dakota Formation, however, it would be kaolinitic light-gray to light-greenish-gray siltstone or clay dappled with adundant red to reddish-brown mottles.

The argillaceous character of the Dakota Formation in Kansas and northward into Nebraska and Iowa has been emphasized repeatedly in the literature. It is the dominantly kaolinitic and argillaceous character of the Dakota Formation that accounts for the important ceramic industry, which supports brick plants not only in central and north-central Kansas, but across Nebraska and in the vicinity of Sioux City, Iowa, as well. Yet, the concept that the Dakota Formation is basically sandstone persists, owing largely to poor exposure of the argillaceous rocks.

Clay and siltstone are estimated to comprise as much as 70 percent of the thickness of the Dakota Formation in many areas. Only locally does the aggregate thickness of sandstone exceed 40 percent of the thickness of the Dakota Formation. However, owing in large part to case hardening by iron oxide (Rubey and Bass, 1925, p. 57; Swineford, 1947, p. 71), the sandstone is resistant to erosion and stands out as capping layers on hills and benches. This indurated sandstone mainly accounts for the relatively rugged and scenic topography in the area of outcrop of the Dakota.

The argillaceous rocks of the Dakota Formation range from massive red-mottled siltstone and clay to highly carbonaceous gray to dark-gray siltstone and clay, either shaly or massive. They also may contain thin seams of white to very light gray thin-laminated nearly pure kaolinite. The siltstone and clay generally show little or no sign of lamination and commonly have conchoidal or blocky fracture. Much of the clay parts along irregularly disposed slickensided surfaces. Even thin-laminated clay and siltstone in the Dakota Formation commonly show little or no fissility, but fissile material is found near the top and bottom of the formation, particularly where the argillaceous rocks contain abundant carbonaceous matter.

Spherulitic siderite in the form of pellets as much as 2 mm (millimeters) in diameter is a common component of Dakota siltstone and clay. In most surface samples, however, the siderite is partly or completely weathered to goethite or other iron oxides. Pyrite and marcasite are common in carbonaceous and lignitic gray siltstone and clay. Veinlets and aggregates of gypsum also are found in weathered samples of siltstone and clay.

Beds of clay and siltstone in the Dakota Formation are mainly lenticular. They pinch and swell, grade laterally into beds of somewhat different color or lithology, and enclose lenses of other lithology. How-

[2] "Northeastern Kansas" refers to the time when the Kansas Territory encompassed the eastern half of what is now Colorado. The area would be described as north-central and central Kansas today.

stained by iron oxide. Commonly, however, abundant iron-oxide cement is present, almost to the exclusion of quartz grains, where sandstone beds cap hills and benches. Where abundant iron oxide has accumulated in sandstone, bedding may be completely masked. The distribution of iron-oxide cement commonly is controlled by cross-stratification; the iron oxide forms bands that follow the cross-strata or pipe-like structures whose strike parallels the strike of cross-stratification. Elsewhere, iron oxide forms large tubular diffusion structures that follow the direction of dip of cross-strata.

In contrast to the abundance of calcite-cemented or dolomitic calcite-cemented sandstone in the Kiowa Formation in Ellsworth County, calcite or dolomite cement is scarce in sandstone of the Dakota Formation.

Sandstone lenses in the Dakota Formation show scour-fill contacts with underlying argillaceous rock. The sandstone at the top of measured section 4 is on the flanks of a scour-fill channel, the base of which is nearly 30 feet lower in altitude less than a quarter of a mile south of the described exposure and 15 or 20 feet lower than that 200 feet to the southeast. Similarly, the sandstone shown on figure 22, although it exhibits a nearly planar base in the photograph, has an obvious scour-fill relationship with the underlying contorted siltstone, clay, and sandstone. Generally, the size and shape of individual sandstone lenses are difficult to determine, but in places the lenses are elongate in the general direction of dip of contained cross-stratification. Laterally, sandstone lenses may either grade into or pinch out in sequences of siltstone and clay. Results of measurements of cross-stratification at 52 localities of the Dakota Formation are summarized on figure 12. The dominance of vector resultants to the west and southwest indicates that transport of most Dakota sandstone was from northeast or east to the southwest or west. An average direction of S.71°W. was calculated.

Sandstone in the Dakota Formation is erratically distributed and occurs as lenses of variable size, but the extent to which individual lenses are interconnected is problematic. Attempts to define such things as "first," "second," and "third sandstones" are unrealistic. Figure 15 is a detailed map for parts of Tps. 16 and 17 S., R.8 W., south of Ellsworth. Several prominent lenses of sandstone are exposed in the area and their bases have been mapped on aerial photographs. Cross-stratification measurements were made at several localities. As a result, the map illustrates both the local variability of cross-stratification and the lenticular nature of Dakota sandstone. The authors estimate that as many as five or six lenses of sandstone are present in the 7-square-mile area. Although little information is available concerning size and shape of sandstone lenses in the Dakota, figure 15 indicates that the dimensions of some of the lenses can be measured in miles.

Thus far in the discussion of the lithology of the Dakota Formation, emphasis purposely has been placed on the heterogeneity and lateral variability of the several rock types. However, the formation is not without some system. It is precisely that system that allowed definition of the Janssen Clay and Terra Cotta Clay Members by Plummer and Romary (1942). Gray and dark-gray beds of siltstone and clay, as well as beds of lignite, are confined mostly to the upper third of the Dakota Formation, whereas red-mottled siltstone and clay are found mainly in the lower two-thirds. However, the basal parts of the Terra Cotta Clay Member also contain gray and dark-gray lignitic beds where they are intercalated in varying degrees with beds of red-mottled siltstone and clay. Similarly, seams of porcelaneous kaolinite are found near the base and in the upper part of the formation. Within the whole sequence of the Dakota Formation, some similarities in zonation of lithologic types can be observed from place to place. These similarities enabled Plummer and Romary (1942) to devise a generalized sequence for the argillaceous rocks of the Dakota Formation. That sequence follows in modified form. Modification was made by the authors in consultation with Norman Plummer. The sequence, however, should not be taken as being everywhere applicable, but parts of it may be recognizable from place to place in the belt of Dakota outcrops. The generalized section summarizes briefly the nature of argillaceous rocks in the Dakota Formation. Sandstone, except for that near the top of the formation that locally contains molds and casts of marine and brackish-water pelecypods (Hattin, 1965b), generally has been omitted from the generalized section.

Generalized section illustrating overall nature of Dakota Formation in Ellsworth County. Sandstone lenses and beds may comprise from 30 to 50 percent of the sequence.

	Thickness, feet
Janssen Clay Member:	
17. Siltstone or shale, pale-yellowish-brown to brownish-gray, generally laminated to thin-laminated; commonly contains concretionary "limonite," hematite, or siderite, and laminae of fine-grained sandstone. May be a transition zone between typical Dakota and typical Graneros Shale. Locally grades laterally to fine-grained sandstone containing molds and casts of brackish water or marine pelecypods near top	0.1-5.0
16. Siltstone, gray to light-gray, generally resistant; contains carbonized plant debris as well as nearly vertical tubes that resemble molds of reed stems or roots or worm borings. Commonly supports a bench and is a good datum for mapping purposes. Locally grades laterally to sandstone like that noted above	0.5-4.0

massive, unlaminated character of much Dakota clay and siltstone, particularly in the Terra Cotta Clay Member, is suggestive of sedimentation by flocculation (Meade, 1964). Volcanic activity may have led to deposition of volcanic ash that locally was reworked and altered to seams composed almost completely of porcelaneous kaolinite in basal sequences of Dakota siltstone and clay.

Sandstone in the Dakota Formation is inferred to have been deposited mainly by streams and rivers. This conclusion is based partly on scour-fill contacts seen at the base of the many sandstone deposits, evidence of contemporaneous reworking of siltstone and clay, and directional orientation of cross-strata dip bearings in sandstone (fig. 12). The coarseness of some sandstone in the lower parts of the Terra Cotta Clay Member may be indicative of relatively rapid, though limited, uplift of the source areas of the sediments.

The dispersion of vector resultants of cross-strata dip bearings in the Terra Cotta Clay Member is markedly less than the dispersion shown by vector resultants in the Janssen Clay Member (fig. 12). The increased dispersion of vector resultants in the Janssen, combined with the finer grain size of Janssen sandstone compared with sandstone in the Terra Cotta, suggests a decrease in stream gradient and a consequent increased tendency for streams to meander or otherwise change course. The abundance of lignitic material in the Janssen may also indicate the onset of swampy conditions associated with the decrease of stream gradients as well as proximity to the shifting strand line of the encroaching Late Cretaceous sea.

Imprints of oak, willow, walnut, sycamore, magnolia, laurel, and sassafras leaves, among others, indicate that the climate was mild. The presence of fossils of cycads and figs may indicate that the climate was subtropical in some areas (Lesquereux, 1892, p. 256).

TERRA COTTA CLAY MEMBER

The lower member of the Dakota Formation is characterized by red-mottled gray to greenish-gray clay and siltstone. Measured sections 4, 5, and 6 span the Kiowa-Dakota contact and describe the lower parts of the Terra Cotta Clay Member. Section 6 was measured near the old town of Terra Cotta. None of the sections, however, spans the full thickness of the member. The relative proportions of clay and siltstone to sandstone are significant and indicate the extent to which the Dakota Formation is mainly an argillaceous unit. However, coarse-grained and conglomeratic sandstone in the Dakota Formation is restricted principally to the Terra Cotta Clay Member.

In many places this interval, which has been designated informally as the "Andrews section" (Plummer and others, 1963, p. 4), contains relatively few lenses and beds of red-mottled siltstone and clay, but it often grades laterally into sequences composed largely of red-mottled material. The sequence has large reserves of relatively plastic buff-firing clay and siltstone suited for the manufacture of facing brick. Clay pits operated by the Kanopolis plant of Acme Brick Co. are located in this part of the Dakota Formation in secs. 25 and 28, T.15 S., R.7 W. The pit in sec. 34, T.16 S., R.8 W., probably is in this part of the Dakota.

The direction of transport inferred from measurements of dip bearings of cross-stratification for Terra Cotta sandstone is mainly southwestward (fig. 12c). The calculated grand vector resultant is S.64°W., somewhat more southward than that calculated for the whole of the Dakota Formation. The likelihood is that channel deposits in the Terra Cotta Clay Member are elongate primarily in a southwestward direction in contrast to southward and southeastward elongation of sandstone deposits in the Kiowa Formation.

The contact between the Terra Cotta Clay Member and the overlying Janssen Clay Member does not constitute a stratigraphic datum. In contrast to the Terra Cotta, the Janssen is characterized by gray and dark-gray siltstone and clay, much of which is shaly, as well as beds and seams of lignite. The contact between the Terra Cotta and Janssen differs in stratigraphic position from place to place, and the beds or zones rich in iron oxide marking the separation are not everywhere present. However, it is not difficult to differentiate between the Terra Cotta Clay Member or the Janssen Clay Member, although it is difficult to determine the actual contact. The usefulness of the definition of the Terra Cotta Clay and Janssen Clay Members lies mainly in their gross lithologic differences and in the economic utility of the contained clays.

Thickness of the Terra Cotta Clay Member in Ellsworth County is difficult to determine, owing partly to lack of continuous exposure of the member; the lack of a definite stratigraphic datum separating the two members of the Dakota also makes thickness determinations difficult. However, the Terra Cotta comprises about two-thirds of the thickness of the Dakota Formation.

JANSSEN CLAY MEMBER

The Janssen Clay Member is composed mainly of gray and dark-gray siltstone and clay and contains lenticular beds of lignite and lignitic shale or clay. Carbonaceous siltstone is prominent in many areas and, locally, lenticular beds of red-mottled clay and siltstone montmorillonitic Graneros Shale. Together the siltstone and the overlying material often support a bench that precisely marks the base of the Graneros Shale. The top of the transitional interbedded sandstone, siltstone, and shale is indurated by iron oxide that may have been derived by oxidation of concretionary siderite.

Where ledge-forming siltstone has been replaced by sandstone, the top of the Dakota Formation can be placed at the top of the sandstone. Elsewhere, the ledge-forming siltstone may be missing and argillaceous rocks of the Janssen may be overlain directly by basal Graneros Shale. However, the kaolinitic content and consequent generally nonplastic aspect of the Janssen rocks together with the abundant carbonaceous material contained in them permit fairly clear demarcation from the overlying Graneros Shale.

Cretaceous System—Upper Cretaceous Series

COLORADO GROUP

Graneros Shale

Definition.—The name "Graneros" was proposed by Gilbert (1896) for his lower division of the Benton group in eastern Colorado. He described the Graneros (p. 564) as ". . . a laminated, argillaceous, or clayey shale with very little admixture of limy or sandy materials." He reported the unit to be from 200 to 210 feet thick and resting on the uppermost sandstone of the Dakota Group. The name is derived from a locality on Graneros Creek at lat 37°57′N.; long 104°47′E. (which places it approximately in T.24 S., R.66 W., Pueblo County, Colo.).

Logan (1899) concluded that the Bituminous shale, the name he gave the basal unit of his subdivision of the "Limestone group" of the Benton formation in 1897, was stratigraphically equivalent to the Graneros shale of Gilbert in Colorado. Gilbert (1896) in his original description included the lower two members of the Greenhorn Limestone in the Graneros. Moore (1920) includes only the bituminous shales in the Graneros and includes the Lincoln Limestone Member and the Hartland Shale Member in the Greenhorn Limestone. This usage of the Graneros has been followed in Kansas since that time.

Hattin (1965a) discussed the paleoecology and depositional environment of the Graneros in central Kansas.

Distribution and thickness.—In Ellsworth County the outcrop of the Graneros trends northeastward to southwestward. The outcrop extends westward up the Smoky Hill River valley about halfway across Russell County. The Graneros is best exposed in a narrow belt along steep slopes of the valley walls, which are capped by the Greenhorn Limestone, and in cuts along the highways.

The Graneros thickens westward from the outcrop belt in central Kansas. Scott (1962) reported 210 feet of Graneros in central Colorado, and Bass (1926b) reported 61 feet of Graneros in Hamilton and Kearny Counties in western Kansas. In central Kansas the thickness ranges from about 23 feet in eastern Mitchell County to about 40 feet in Russell and Ellsworth Counties. In Ellsworth County the thickness ranges from about 28 feet in the northwestern part of the area to about 40 feet in the southwestern part (see measured sections 9, 10). The thickness is commonly 35 to 40 feet.

Lithology.—The dominant lithology of the Graneros is noncalcareous montmorillonitic shale that ranges from slightly silty to fine sandy. In general, the shale is moderately silty (Hattin, 1965a). Unweathered Graneros shale breaks into irregular rather-tough blocks that split easily along obscure laminae. Upon weathering, the shale breaks into innumerable small flakes that characterize almost all Graneros exposures. The shale is soft and plastic when thoroughly wet, but is brittle when dry. The dominant colors of the partially weathered shale are medium light gray, olive gray, medium gray, and brownish gray. The highly weathered shale is generally moderate or dark yellowish brown, dusky yellow, or dark yellowish orange.

Most shale units in the Graneros contain numerous layers or lenses of silt or fine and very fine sand. These layers or lenses range from thin laminae to thin beds. The thinnest lenses and laminae are generally the most fine grained.

Most of the shale units contain gypsum either in finely granular or almost powdery form or as isolated platy aggregates of sclenite.

Although shale is the dominant lithology of the Graneros, other lithologies occur throughout the formation. Noncalcareous or calcareous lenses and laminae of sandstone or siltstone are conspicuous in many Graneros exposures. Although most sandstone occurs as laminae or very thin beds, numerous sandstone and siltstone bodies are sufficiently distinct to be described individually. In Ellsworth County the noncalcareous sandstone beds or lenses occur most commonly in the upper part of the Graneros. Calcareous sandstone is generally near the middle part of the formation (Hattin, 1965a).

Cementation of the sandstone is generally poor, and locally the rock is not cemented; however, well-cemented lenses are present. The cement where present in the noncalcareous lenses is usually limonite, but in some places it is gypsum. The dominant colors of the sandstones in the Graneros are light olive gray, yellow-

Inoceramus labiatus. This particular shell, though not absent in other formations, is abundant only in the Greenhorn beds and thus serves to mark the formation.

Correlation of the Greenhorn at the type locality in Colorado with similar beds in Kansas was made by Logan (1899). He regarded the upper four subdivisions (Lincoln marble, Flagstone beds, Inoceramus beds, and Fence-post beds) of his "Limestone group" of the Kansas Benton to be stratigraphically equivalent to the Greenhorn Limestone of Colorado.

Rubey and Bass (1925) again subdivided the Greenhorn into an upper unnamed member, the Jetmore chalk member, a lower unnamed member, and the Lincoln limestone member. These subdivisions were not proposed as "new labels" on Logan's units, but they have different boundaries. Bass (1926a) proposed names for the unnamed units, the upper becoming the Pfeifer shale member and the lower, the Hartland shale member.

The Greenhorn Limestone is not readily divisible into its members in the field. In Ellsworth County, except for the contact between the Pfeifer Shale Member and the Jetmore Chalk Member where the top of the "shell bed" is used, the contacts between the members of the Greenhorn are obscure. These contacts are gradational and may be arbitrarily placed within an interval several feet in thickness. The upper contact of the formation with the Carlile Shale, as it is defined, is sharp and can be easily seen in the field. The lower contact with the Graneros Shale is easily identified using a lithologic change from predominantly shale to limestone, a change from noncalcareous or only partly calcareous to very calcareous, and a petroliferous odor for the lowermost limestone.

LINCOLN LIMESTONE MEMBER

The basal unit of the Greenhorn Limestone is the Lincoln Limestone Member.

Definition.—Cragin (1896) in his proposal of the name "Russell formation" for the lower Benton of Kansas states that this new formation includes the "Lincoln marble." However, he does not comment further on the "marble." Logan (1897) designates the second unit from the base of the Benton as the Lincoln Marble, which he describes (p. 216) as consisting of ". . . from two to five layers of hard flinty limestone intercalated with shale." Invertebrate fossils, especially species of *Inoceramus,* are abundant. Logan (1899, p. 83) states that the term marble is applied because the stone will take a "moderate polish." Rubey and Bass (1925) substituted the term limestone in the unit name.

Lithology.—The Lincoln is described by Rubey and Bass (1925, p. 47) as

> . . . beds of chalk and chalky shale, with thin beds of hard dark gray crystalline slightly sandy fossiliferous limestone at its base and top and in some places near the middle. The limestones emit a strong odor of petroleum on fresh fracture. A few thin beds of yellow clay occur in the lower half. . . . The beds of crystalline limestone are commonly only 2 to 6 inches thick and . . . although dark gray on fresh surfaces these beds are greenish or brownish gray where somewhat weathered.

In the north-central part of the county where the Greenhorn Limestone is only about 65 feet thick, the rocks here considered to represent the Lincoln Limestone Member average less than 5 feet thick (see measured section 12). These rocks are composed of chalk, chalky shale, and crystalline limestone commonly found in the lower part of the Lincoln. In western and southwestern Ellsworth County where the Greenhorn is 80 to 85 feet thick, the Lincoln is about 20 feet thick. The contact with the overlying Hartland Shale Member of the Greenhorn Limestone is gradational and cannot be definitely placed.

HARTLAND SHALE MEMBER

The second unit above the base of the Greenhorn Limestone is the Hartland Shale Member.

Definition.—The presence of a member between the Lincoln Limestone and the Jetmore Chalk Members was acknowledged by Rubey and Bass (1925) in their classification of the Greenhorn, but no formal name was proposed for it. Bass (1926b) named this unit the Hartland Shale Member, a name derived from exposures near Hartland, Kearny County, Kans.

Lithology.—The original lithologic description of the Hartland Shale Member in Russell County by Rubey and Bass (1925, p. 47) is summarized below. The Hartland consists of about 35 feet of chalky shale containing a few thin beds of chalk and clay. A crude quantitative analysis of this shale revealed a 65 to 70 percent silt content with a few flakes of muscovite. The most prominent bed is a 5-inch-thick hard medium-gray fine-grained chalk, 14 to 15 feet above the base, which contains well-preserved *Inoceramus* and flat vertical marks resembling grass blades. Below this prominent bed is 1 or 2 feet of yellow or light-bluish-gray clay and some gray and green chalky shale, and then another 5-inch-thick chalk bed which is softer, lighter colored, and less fossiliferous than the prominent chalk. Overlying the prominent chalk is 2 or 3 feet of chalky shale, which in turn is overlain by thin beds of chalk containing pyritic nodules and a few beds of yellow clay.

In Ellsworth County the Hartland is commonly about 20 feet thick. The contacts with the Jetmore Chalk Member of the Greenhorn Limestone above and the Lincoln Limestone Member below are gradational (measured sections 11 and 12).

Ellsworth County, discussion of the Carlile is restricted to the lower member, the Fairport Chalk Member.

FAIRPORT CHALK MEMBER

The lower unit of the Carlile Shale is the Fairport Chalk Member.

Definition.—Fairport was proposed by Rubey and Bass (1925, p. 40-45) as a proper stratigraphic name for the Ostrea shale of Logan. The type exposures are in the vicinity of Fairport, a small community in northeastern Russell County, Kans. The Fairport chalk member, as it was called by Rubey and Bass, comprises 85 feet of "chalky marl and thin chalk beds." Only about 15 feet of this unit is present in Ellsworth County. Like Logan, they placed the lower boundary at the top of the Fence-post limestone bed (measured section 11). The upper boundary is placed at the contact between noncalcareous and calcareous strata (determined by using dilute hydrochloric acid). They note the presence of yellow clays (bentonite) and several zones of ellipsoidal calcareous concretions. The beds are dark gray when freshly exposed, but weather to light tan. Rubey and Bass found the oyster *Ostrea congesta* in abundance and some specimens of the ammonite *Prionotropis woolgari*, the worm *Serpula tenuicarinata*, and a clam regarded as similar to but not identical with *Inoceramus dimidius*.

Lithology.—Only the lower part of the Fairport is present in Ellsworth County, and exposures are relatively scarce. The lithology of the lower Fairport seems consistent and is comprised of soft laminated chalk containing several thin limestones and ovoid limestone nodules. Approximately the lowermost 5 feet of the Fairport is very similar in appearance and character to the upper part of the Greenhorn Limestone. Above this lower 5-foot zone the nodules become scarce and smaller, the limestone layers get thinner and occur less frequently, and the clay content of the sediments increases (measured section 11).

Stratigraphic relations.—The Fairport is conformable with the Greenhorn; in fact, deposition apparently was uninterrupted. From the description by Rubey and Bass (1925, p. 43) the Fairport-Blue Hill contact apparently is conformable also.

Environment of deposition.—The lower Fairport apparently originated in a continuation of the environment in which the Greenhorn was deposited—shallow, clear, fairly warm marine waters. Such conditions would have been ideal for the clams and lime-fixing protozoans found in abundance as fossils. As deposition continued, the amount of fine noncarbonate particles accumulating increased (perhaps from wind-blown volcanic ash or dust and settling of suspended terrigenous mud), but not at a rate sufficient to deter growth of lime-fixing animals.

Tertiary System—Pliocene Series

OGALLALA FORMATION

The name Ogallala Formation is applied to the sediments of Pliocene age in Kansas. A summary of the general aspect of the formation is given by Frye and others (1956, p. 8):

> The Ogallala formation of northern Kansas is a heterogeneous complex of clastic deposits. The thickness of the formation ranges from more than 300 feet to less than 3 feet; the texture ranges from coarse gravel containing pebbles as much as 3 inches in long diameter to clay; and the sorting ranges from good to poor. Cementing material, not everywhere present, includes tough opal, disseminated white opal, and various amounts of calcium carbonate. Colors of the deposits are dark to pale green, pink, reddish brown, tan, buff, pastel grays, and ash gray. Lentils of volcanic ash, marl or marly limestone, and bentonite contrast with the predominate stream-laid clastics. Throughout this heterogeneous assortment of sediments there is virtually no distinctive bed that can be traced appreciable distances in the field.

The Ogallala has been divided into three members in Kansas. The lowermost member is the Valentine Member, which is overlain by the Ash Hollow Member. The upper member is the Kimball Member. The upper surface of the Kimball is marked by the widespread occurrence of a distinctive bed called the "algal limestone." The name "algal limestone" was introduced by Elias (1931, p. 138) in the belief that the structures in the limestone were the work of algae, but Swineford and others (1958) present evidence that the bed resulted from soil-forming processes.

In Ellsworth County only the uppermost bed, the "algal limestone," is present. About 40 localities were visited during this investigation where the so-called algal limestone crops out. These outcrops occur in small knobs or ridges occupying the highest topographic positions in the general area of the outcrop. The thickness ranges from a few inches to about 3.5 feet. The "algal limestone" deposits in Ellsworth County do not represent clastic deposits but rather are the remnants of a widespread soil formed in this area during late Pliocene and possibly into early Pleistocene time. The deposits occur only in divide areas and serve as marker horizons, which have been relatively stable since the close of the Pliocene Epoch. Figure 16 shows contours on top of the "algal limestone" in and adjacent to part of Ellsworth County. The contours indicate a general slope toward the east and also show topographic highs near the present drainage divides between the Saline and the Smoky Hill Rivers and between the Smoky Hill and Arkansas Rivers. There is some indication that a drainage channel existed in or near the Smoky Hill Valley and the abandoned Wilson valley. Any clastic material that may have been de-

Arkansas River just west of Wichita in Sedgwick County. The lowermost deposits in McPherson channel are Pliocene in age (Lane and Miller, 1965).

Quaternary System—Pleistocene Series

Pleistocene deposits in Kansas are of continental origin and are composed of silt, clay, sand, gravel, and small amounts of volcanic ash. The Pleistocene Epoch as defined by the State Geological Survey of Kansas was the last of the major divisions of geologic time and has been called the "ice age" owing to the presence of continental glaciers in North America and elsewhere. The Pleistocene Series in Kansas has been divided into the Nebraskan, Kansan, Illinoisan, and Wisconsinan glacial stages and the Aftonian, Yarmouthian, and Sangamonian interglacial stages. Events in each of the periods of continental glaciation followed a cyclic repetition. Each cycle consisted of a glacial and an interglacial interval or stage. The cycle in a marginal belt around a glaciated area was characterized by a period of down-cutting in the valleys and some local deposition of sediments, in turn followed by a period of deposition of coarse material, deposition of progressively finer material as the glacier retreated, and finally, during the interglacial stage, little or no deposition and the development of a soil profile over a large area where surface conditions were relatively stable.

During the Nebraskan and Kansan Stages continental glaciers entered northeastern Kansas. During the Illinoisan and Wisconsinan Stages the continental glaciers did not reach Kansas, but the climatic changes accompanying their approach had a direct effect on the Pleistocene deposits in Kansas.

Ellsworth County is about 100 miles from the nearest approach of any of the ice sheets and did not receive outwash material from the glaciated area. The principal effect in Ellsworth County during the glaciations, therefore, was climatic. Ellsworth County is drained by the Smoky Hill and Saline Rivers, except for an area of about 80 square miles in the southwestern part of the county that is drained by the Arkansas River. The Smoky Hill and Saline Rivers headed in western Kansas and have never had direct connection with drainage from the Rocky Mountains. The Arkansas River in central Kansas probably had no connection with Rocky Mountain drainage until late Kansan or early Illinoisan time, indicating that mountain glaciation during the Pleistocene had no direct effect on the Pleistocene deposits in Ellsworth County. The source of the material comprising the Pleistocene deposits in the county has been the Ogallala Formation in the western part of the State and the local bedrock.

The Smoky Hill River in Ellsworth County has been cutting its channel at or near its present course throughout the Pleistocene and possibly during late Pliocene time. During each succeeding glacial stage, the channel has been incised to a lower altitude. The Saline River has followed closely its present course from western Kansas to a point near the northwest corner of Ellsworth County throughout the Pleistocene. During early Pleistocene and probably late Pliocene time, the Saline River entered Ellsworth County near the northwest corner and flowed southeastward through the now abandoned Wilson valley into the Smoky Hill River at a point just west of Ellsworth.

NEBRASKAN AND AFTONIAN STAGES

Holdrege and Fullerton Formations

During the Nebraskan and Aftonian Stages, the Smoky Hill River did not head in western Kansas. The upper Smoky Hill drainage during this time was through Galatia channel to the ancestral Arkansas River (Bayne and Fent, 1963). That part of the Smoky Hill River below Galatia channel was tributary to drainage through Wilson valley and the Saline River, which drained through McPherson channel to the ancestral Arkansas River.

Deposits representing the Holdrege and Fullerton Formations of Nebraskan age are locally present along the edges of the valleys of the Smoky Hill River and Wilson valley. These deposits are discontinuous and have little surface expression. Generally the Holdrege and Fullerton underlie the dissected slope between the relatively flat surface of Kansan age deposits and the valley wall. Test holes and geologic sections (A-A′, B-B′, and D-D′, pl. 2) indicate that these deposits rest on a bedrock bench and are in a terrace position relative to the younger Kansan deposits. The Holdrege and Fullerton Formations were not mapped, because they are poorly exposed. They are included in the area mapped as the Grand Island and Sappa Formations of Kansan age on the geologic map (pl. 1).

In Ellsworth County the Holdrege and Fullerton Formations are composed of silt with minor amounts of clay and generally some sand and gravel in the basal part of the deposit. Locally, some caliche is present in the upper part. These deposits may be as much as 40 feet thick but more commonly are about 15 or 20 feet thick.

KANSAN AND YARMOUTHIAN STAGES

Grand Island and Sappa Formations

During early Kansan time, the streams in Ellsworth County deepened their channels. The valleys were incised below the base of the Nebraskan deposits, and most of the Nebraskan deposits were removed (A-A′ and D-D′, pl. 2). Galatia channel, which had drained

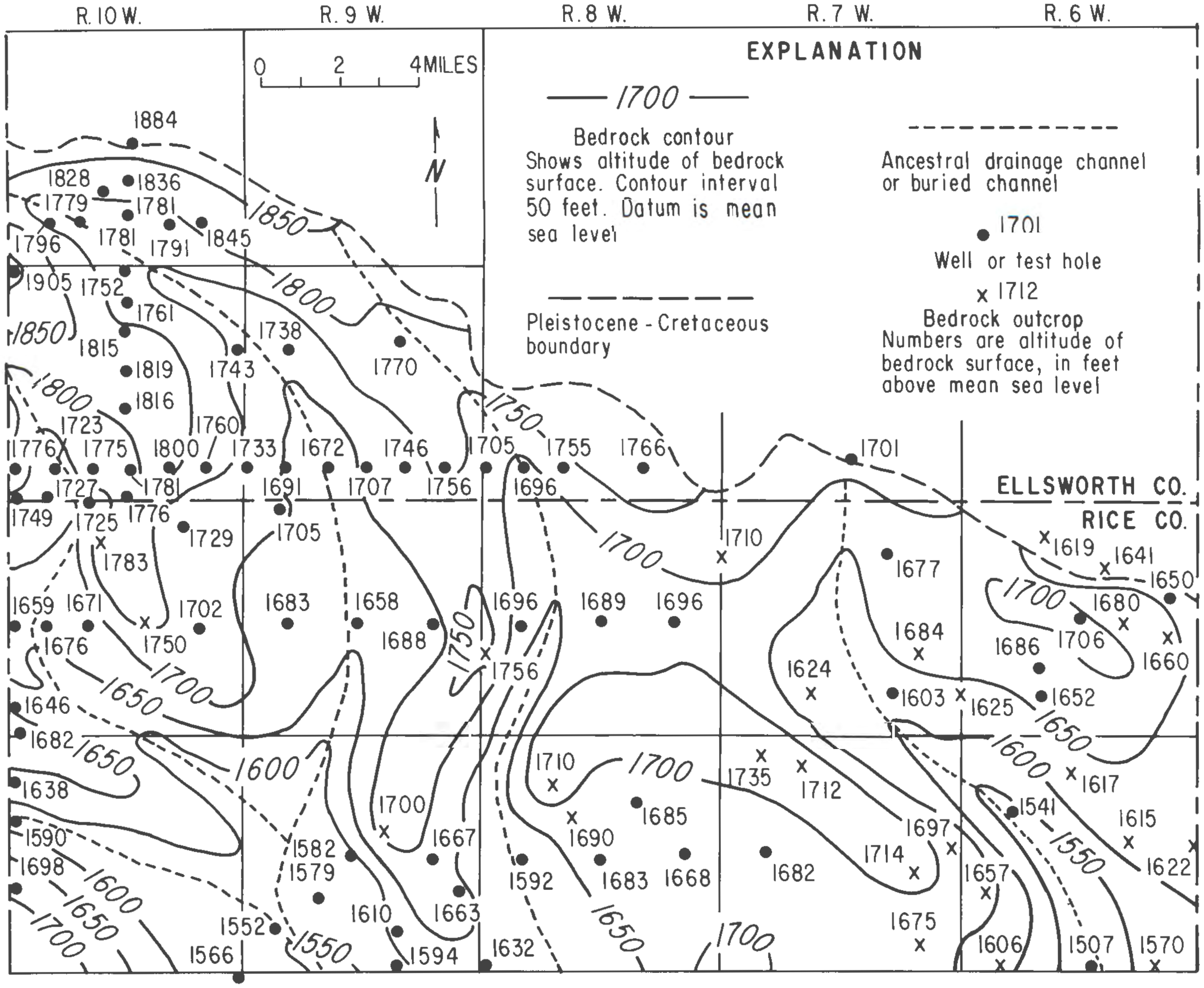

FIGURE 18.—Configuration of the bedrock surface and buried channels in southwestern Ellsworth County and northern Rice County.

more than short distances. Silt and clay are the dominant materials comprising the deposits, although locally sand and gravel derived from the local bedrock are present in the basal part of the deposits. These deposits are not shown on the geologic map (pl. 1).

A triangular-shaped area in southern and southwestern Ellsworth County, the northern boundary of which nearly coincides with the drainage divide between the Smoky Hill and Arkansas Rivers, is underlain by Pleistocene deposits (pl. 1). The upper part of these deposits is nearly everywhere composed of silts of late Pleistocene age; however, several buried channels which drained the area during early Pleistocene time are present. Figure 18 shows the contours on the bedrock surface and the location of these buried channels. The deposits in these channels consist principally of silt and clay, but sand and gravel derived from the local bedrock is present in the lower part of the deposits. They may be as much as 60 feet thick, but are commonly less than 30 feet thick. These channel deposits are assigned a Kansan age and are considered to be part of the Grand Island and Sappa Formations.

Fent (1950) considered the deposits in the extensions of the channels in Rice County to be of Kansan age, because water-worn pebbles of caliche are common throughout the deposits. He considered the caliche to have been derived from a soil caliche formed during the Aftonian interglacial stage. This caliche differs from the "algal limestone" caliche of late Pliocene age in that the distinct banding in the "algal limestone," which gives it the appearance of being algal in origin, is missing.

ILLINOISAN AND SANGAMONIAN STAGES

Drainage in central Kansas at the beginning of the Illinoisan Stage was probably through the same channels as in the Kansan Stage; however, Wilson valley

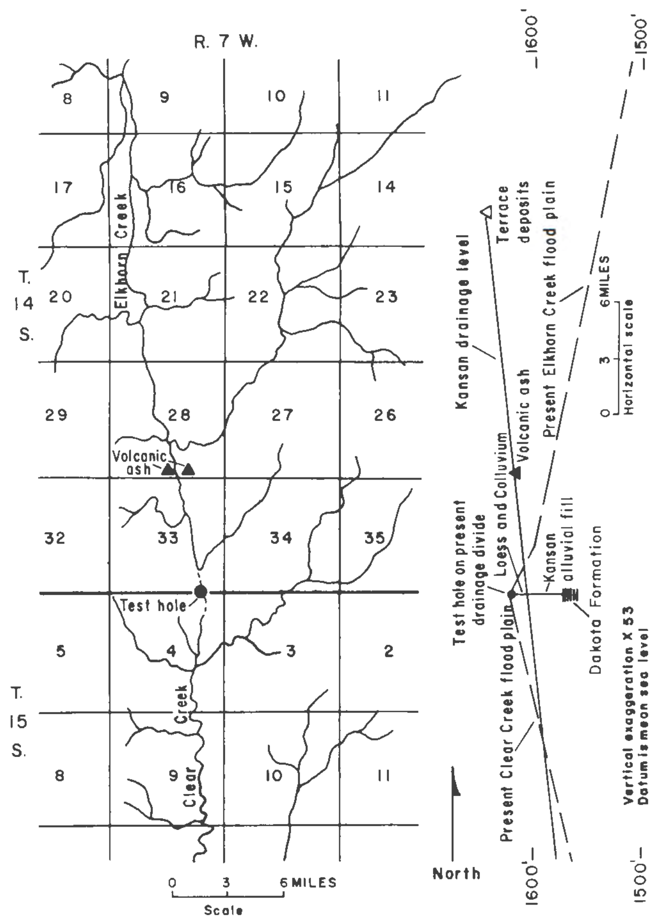

FIGURE 20.—Map illustrating capture of headwaters of Clear Creek by Elkhorn Creek.

Ellsworth County has been essentially unchanged; however, the valleys have been deepened.

Early in the Wisconsinan Stage the stream valleys in Ellsworth County were deepened to a point well below the deepest Illinoisan incision (D-D′, I-I′, and J-J′, pl. 2) and later filled with alluvial materials to a point 20 to 30 feet below the surface of the Illinoisan alluvial deposits. In other areas in Kansas, a second phase of cutting and filling occurred during late Wisconsinan time, but this twofold sequence of cutting and filling during the Wisconsinan was not recognized in Ellsworth County.

The Wisconsinan alluvial deposits in the stream valleys in Ellsworth County are similar in mode of occurrence and composition to those of the other stages of the Pleistocene inasmuch as they are composed of silt, clay, sand, and gravel; the coarse material generally occurs near the base of the deposit, and silt or sand generally comprises the upper part of the deposit. Wisconsinan fluvial deposits in the Smoky Hill Valley are generally better sorted and more permeable than the materials deposited in the earlier stages of the Pleistocene. Wisconsinan fluvial deposits in the Smoky Hill River valley are as much as 60 feet thick. In the tributary valleys, these deposits are commonly less than 30 feet thick.

Peoria Formation

During the Wisconsinan Stage loess was deposited in Kansas in two separate phases. The earlier Wisconsinan loess comprises the Peoria Formation, and the later loess comprises the Bignell Formation in the Kansas classification. The Peoria Formation is probably equivalent in age to the lower Wisconsinan fluvial deposits, and the Bignell Formation is probably equivalent to upper Wisconsinan fluvial deposits. The greatest thickness of Wisconsinan loess was deposited in northern Kansas. In northwestern Kansas the Peoria may exceed 50 feet in thickness, whereas the Bignell probably does not exceed 10 feet. In northeastern Kansas near the Missouri River both the Peoria and Bignell may exceed 50 feet in thickness. In Ellsworth County the Peoria is thin, having an observed maximum thickness of about 10 feet. The Bignell was not observed in the county. Although some Bignell probably was deposited in the county, the loess was thin and either has been eroded or is included in the modern soil and is not identifiable.

In the channel areas in southwestern Ellsworth County, silts that resemble loess overlie similar deposits of Illinoisan age and are believed to be Wisconsinan in age. These deposits are believed to be water-laid silts and colluvium derived from the Peoria loess and to be essentially of the same age as the Peoria (A-A′, E-E′, F-F′, G-G′, and H-H′, pl. 2).

RECENT STAGE

In Ellsworth County geologic processes in the upland areas during the Recent Stage have consisted of erosion, downslope movement, deposition of colluvium, and formation of soil. In the valley areas Recent deposits consist of alluvium, which occurs in a narrow band mostly within the active channel of the streams. Recent alluvium has not been differentiated from the Wisconsinan fluvial deposits on the geologic map (pl. 1). In the Smoky Hill River valley during the Recent Stage, the stream has been entrenched below the surface of the adjacent Wisconsinan fluvial deposits. The Recent alluvial fill is composed of silt, sand, and gravel which cannot be differentiated from the Wisconsinan fluvial deposits except for position. These deposits probably are no more than 25 to 30 feet thick and, although hydrologically similar to the Wisconsinan deposits, they are utilized only at a few locations because of their limited areal extent and subject to flooding.

FIGURE 22.—Deformed beds near the base of the Dakota Formation in a roadcut near the SE cor. sec. 20, T.16 S., R.7 W.

tion of Permian evaporites in the subsurface and consequent collapse of overlying strata or other structural movement remains problematic.

In sec. 33, T.17 S., R.6 W. (pl. 1), the fault involves displacements locally approximating 30 feet. It strikes northwest and is downthrown to the southwest. Rotational movement along the fault plane is indicated inasmuch as the block of Dakota Formation preserved on the downthrown side of the fault seems to have been tilted several degrees to the southeast. Dips measured on the downthrown side of the fault are as great as 45°S.10°E.; dips measured on the upthrown side of the fault in the Kiowa Formation are as great as 40°S.60°E. The seemingly haphazard strikes and dips shown by beds on both the upthrown and downthrown sides of the fault may mean that the structure was caused by solution of Permian evaporites in the subsurface and consequent collapse of overlying strata.

The fault exposed in a roadcut near the common corner of secs. 20, 21, 28, and 29, T.16 S., R.7 W., has been described previously by Ver Wiebe (1937). It is near the contact between the Kiowa and Dakota Formations, and considerably disturbed beds dipping at angles as great as 70° are truncated by sandstone within the Dakota Formation (fig. 22). The basal parts of the sandstone bed are locally involved in the deformation. Ver Wiebe (1937) assigned the disturbed rocks beneath the sandstone to the Comanche (Kiowa Formation), but widening of the roadcut in 1965 showed that the strata include gray siltstone and clay with red mottles characteristic of the Dakota Formation. Involvement of siltstone and clay in the basal parts of the Dakota Formation, together with the local involvement of the truncating sandstone, shows that the deformation was contemporaneous with Dakota sedimentation. Owing to the complexity of deformation of beds beneath the capping sandstone, the thickness of the basal Dakota clay and siltstone involved is difficult to estimate. However, approximate measurements made in the roadcut indicate that as much as 60 feet of basal Dakota sediments may be present in the disturbed sequence.

Although the Dakota-Graneros contact follows a relatively uniform surface in most of Ellsworth County, minor structural variation can be detected along it in some parts of the county. Many of the abrupt changes in altitude probably reflect local monoclinal structures. An excellent example of small-scale monoclinal folding is shown on figure 23, where the fold, which strikes about N.70°W., is cut by a steep valley tributary to Wolf Creek. The thin siltstone bed that is just below the top of the Dakota Formation in much of Ellsworth County is warped downward about 20 feet or more to the north along the fold. Dips to the north along the flexure are as great as 15°. Similar monoclinal folding may be common in much of the area along the Dakota-Graneros contact in Tps. 14 and 15 S., R.8 W., and one monoclinal fold showing dips of about 10°S. 80°E. is near the cen. E½ sec. 13, T.17 S., R.7 W., along the Kiowa-Dakota contact.

water-bearing zone at the intake area, percolates downdip and accumulates. As water continues to accumulate in the aquifer, it is placed under pressure by the weight of the water accumulating farther updip. This pressure is called *hydrostatic pressure.* When an aquifer under hydrostatic pressure is penetrated by a well, water will rise in the well to a height determined by the magnitude of the hydrostatic pressure. The imaginary surface connecting this level in artesian wells is called the *piezometric surface.* For an artesian well to flow, the piezometric surface must be at an altitude higher than the land surface at the well site.

The Water Table

The water table is defined as the upper surface of the zone of saturation in a porous rock (Meinzer, 1923b). Where the upper surface of the zone of saturation is intersected by an impermeable rock, the water table is interrupted and artesian conditions exist. If an aquifer lies above an impermeable bed, the water contained in the aquifer may be perched, and the upper surface of the perched aquifer is called a perched water table.

The water table is not a plane surface, but is generally a sloping surface that has irregularities caused by differences in permeability of water-bearing materials, by unequal additions or withdrawals from the aquifer, and by topographic features. The water table is not stationary, but fluctuates in response to additions of water to, or withdrawals of water from, storage. Plate 1 shows the location of wells, springs, and test holes in Ellsworth County in which measurements were made of the depth to water, the altitude of the water surface with respect to sea level, and contours of the water table. Data concerning these wells are given in table 6. On plate 1 the water table is shown in the valleys and upland areas. Locally in the uplands the water may be confined, and water will rise above the aquifer in a drill hole. In these localities the contours represent a piezometric surface of an artesian aquifer rather than a water table. In the upland areas very shallow wells generally were not used in drawing the water-table contours, because in many of these wells the water appears to be perched above the principal aquifer. In southwestern Ellsworth County, in an area of about 36 square miles, water contained in Pleistocene deposits is perched as much as 100 feet above the water table in the Dakota Formation. The base of the perched aquifer and the surface of the Dakota aquifer converge southeastward, and the two aquifers merge into a single water-table aquifer.

The contours on plate 1 show the shape and slope of the water table in Ellsworth County. Each point on the water table on a given contour is at the same altitude, and the water moves downslope in a direction at right angles to the contour at any given point. The rate of ground-water movement is controlled by the geology. The Dakota Formation is composed of much finer-grained materials than the Pleistocene alluvial deposits in the valley and, therefore, has a lower permeability. Movement of water through the finer material is slower than through the coarser material, and steeper slopes or a higher head are required to move the same quantity of water through the finer upland deposits. The water-table contours on plate 1 are generally more closely spaced in the upland areas than in the valley areas because the water table generally reflects the surface topography as well as the permeability of the aquifer. In the valleys of the major streams, the contours are more widely spaced and uniform than in the upland. This is a reflection of the more gentle slopes of the topography in the valley areas as well as an indication of greater permeability. The ground-water divides roughly coincide with the topographic divides in Ellsworth County, although the ground-water divide in the southwestern part of the county appears to be somewhat south of the topographic divide.

Recharge and Discharge

Recharge is the addition of water to the ground-water reservoir and may occur in several ways; however, the original source of all recharge is precipitation. In Ellsworth County the principal source of recharge is by direct infiltration and percolation of precipitation to the zone of saturation. Some recharge occurs through infiltration of water from streams and by subsurface inflow from adjacent areas.

Water upon reaching the zone of saturation, continues moving down the slope of the water table toward a point of discharge. Ground-water movement in most of the county is toward the Smoky Hill River valley, but some water in the southwestern part of the county moves toward the Arkansas River drainage, and in the northern part of the county water moves toward the Saline River. Water may be discharged from an aquifer by evaporation, transpiration, seeps, springs, wells, and subsurface outflow. In Ellsworth County water is discharged by all these methods although some are much more important than others. Over a period of several years in which the average climatic conditions are about equal to long-term normal conditions, recharge is about equal to discharge, unless outside influences such as heavy pumping create an imbalance. In Ellsworth County only minor fluctuations of the water table are known to have occurred in the past, indicating that the quantity of water in storage has remained about the same.

Long-term mean annual percipitation in Ellsworth County is about 26 inches. This amounts to about 1 million acre-feet of precipitation a year in the county. About 2 inches of the precipitation, or 70,000 acre-feet, leaves the county as runoff. Of the remaining 24 inches of precipitation, most of the water is evaporated and transpired from the surface or the zone of soil water, but a part percolates down to the zone of saturation to become recharge. Probably about 10,000 acre-feet of water per year is pumped from storage, and because storage remains nearly constant, this water, about 0.3 inch of the annual precipitation, represents recharge. Seeps and springs, which discharge water from storage throughout the year, probably represent 3 to 4 inches or more of recharge although most of this water is lost by transpiration and evaporation a short distance from the point of discharge.

Subsurface inflow of ground water from the west into Ellsworth County probably is slightly greater than the subsurface outflow to the east, but more water is discharged through springs and seeps in the eastern part of the county.

Quality of Water

Water, as it is precipitated and as it percolates through the sediments and rocks, takes into solution various gases and mineral salts. The amount of these impurities can be very important in the consideration of ground water for a specific use. The kind and amount of impurities in ground water can be determined by quantitative chemical analyses. The chemical character of ground water in Ellsworth County is indicated by analyses of 29 samples of water (table 3). Figure 24 shows the chemical character of the sampled water and the location of the sampled wells. These analyses show only the dissolved-mineral content and do not indicate whether the water meets sanitary requirements.

The chemical analysis of a water may be expressed in milligrams per liter (mg/1) or milliequivalents per liter (me/1). In an analysis expressed in milliequivalents per liter, unit concentrations of all ions are chemically equivalent. To convert milligrams per liter to milliequivalents per liter, the values for concentration of mineral constituents should be multiplied by the factors in table 4 (Hem, 1970).

Chemical analyses presented in graphic form may, in many cases, be more easily interpreted than analyses presented in tabular form. Many graphic methods of presentation and study of water analyses have been used. Graphic methods should not be considered a universal explanation for all problems related to water quality but should be used as tools, along with all other methods related to the interpretation of water quality, in the study of such problems.

Figure 24 shows in graphic form the chemical character of water and the location of the wells listed in table 3. Expressing the analyses in this manner is a convenient way to visually compare the analyses of several different waters. The lower end of the line marking the center of each bar graph is at the point corresponding to the location of the well. Vertical scales of each bar graph are the same, and the constituents are plotted in the order shown in the explanation.

A graphic method of interpreting water analyses suggested by Stiff (1951) utilizes four horizontal axes and one vertical axis. The principal cations are plotted, one along each axis to the left of the vertical axis, and the principal anions are plotted in a similar manner to the right of the vertical axis. Ionic concentrations are expressed in milliequivalents per liter. When the plotted points are connected, a figure or pattern that is characteristic of a given type of water is obtained.

Figure 25 shows the patterns obtained by plotting milliequivalents for analyses of eight samples of water from wells in Ellsworth County using the Stiff method of graphic interpretation. The patterns show the predominant ions, which determine the chemical type of the water. Numbers 1 and 8 are calcium sulfate waters, 17 and 18 are sodium chloride waters, 10 and 5 are calcium bicarbonate waters, and 29 is a calcium bicarbonate water containing an appreciable quantity of nitrate.

Casual study of the patterns shown by the analyses could lead to erroneous interpretation as to the source of the waters. Although the pairs of analyses shown on figure 25 are similar and one might assume that similar patterns represent waters from the same aquifer, a study of the records of wells and springs in table 6 indicates that, in each case, similar patterns are from different aquifers, and three separate analyses of water from the Dakota Formation, analyses 8, 17, and 5, have different patterns.

If one considers only the major dissolved constituents and groups together certain dissolved ions whose properties are similar, most natural waters can be represented as solutions of the cationic constituents, calcium, magnesium, and the alkali metals, and the anionic constituents, sulfate, chloride, and those contributing to alkalinity. The alkali metals are principally sodium and potassium, and the constituents contributing to alkalinity are principally bicarbonate and carbonate. When the constituents are grouped in this manner, the composition of a water can be rep-

TABLE 3.—Chemical analyses of water from selected wells and one spring.[1]
[Dissolved constituents and hardness in milligrams per liter.]

Well number	Sample number (figs. 25-26)	Depth, in feet	Geologic source[2]	Date of collection	Temperature (°F)	Dissolved solids (evaporated at 180° C)	Silica (SiO_2)	Total iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate[3] (NO_3)	Hardness as $CaCO_3$ Total	Hardness as $CaCO_3$ Noncarbonate	Specific conductance (micromhos at 25° C)	pH
14- 6W- 7aaa	1	18	Terrace Dep	11-21-61	53	1,350	17	0.19	.00	318	40	61	388	680	45	0.6	1.5	958	640	1,910	----
26adc	2	99	Dakota Fm	11-21-61	55	468	7.5	2.3	.03	38	14	112	222	138	46	1.4	1.5	152	0	840	----
14- 7W-26dcc	3	106	do	11-17-61	53	129	16	.11	.00	29	4.3	8.1	102	5.8	9.0	.2	6.2	90	6	220	----
14- 8W- 8cbb	4	21	Greenhorn Ls	11-20-61	53	983	13	.07	.00	195	19	109	300	122	204	.4	173	564	318	1,800	----
28cbd	5	74	Dakota Fm	11-20-61	57	363	17	1.6	.00	106	7.7	14	300	37	25	.2	8.9	296	50	640	----
14- 9W-28ccd	6	51	Sappa Fm, Grand Island Fm	11-18-61	56	328	25	.17	.00	100	5.5	12	324	4.1	19	.1	2.7	272	6	600	----
34adb	7	63	Dakota Fm	11-18-61	57	364	19	.56	.00	102	8.2	18	305	21	29	.2	17	288	38	670	----
14-10W- 9ddc	8	88	do	11-16-61	57	1,590	13	3.5	.67	389	56	39	356	802	111	1.2	.4	1,200	908	2,230	----
20cda1	9	25	Grand Island Fm, Sappa Fm	10-10-56	----	775	22	.10	.00	156	12	90	356	119	96	.2	102	438	146	------	7.3
15- 6W-14cda	10	49	Kiowa Fm	11-20-61	57	421	15	.14	.11	77	23	38	268	116	18	.5	1.5	286	66	730	----
35aaa	11	Spring	Dakota Fm	11-20-61	55	126	15	.01	.00	26	3.7	11	90	8.2	11	.2	6.2	80	6	230	----
15- 7W-22ccd	12	28	Terrace Dep	11-20-61	56	200	25	.18	.28	35	7.9	20	140	30	11	.3	1.5	120	5	340	----
15- 8W-19bad2	13	50	do	4- 9-56	----	649	27	1.0	.35	119	15	91	357	109	102	.5	6.2	358	65	------	7.2
25dca	14	40	Grand Island Fm	5- 2-60	----	412	16	.03	.00	101	10	19	195	59	36	.2	75	293	138	690	----
34caa	15	60	Daokta Fm	11-20-61	57	297	6.0	7.3	.17	49	10	48	212	54	25	.3	.4	163	0	540	----
15- 9W-24ddd	16	18	Terrace Dep	11-21-61	58	306	5.5	22	.22	52	15	48	283	1.6	44	.1	.4	191	0	590	----
15-10W-36ccb	17	152	Dakota Fm	11-16-61	56	2,450	8.0	2.6	.14	144	55	714	373	171	1,170	.8	2.2	585	279	4,840	----
16- 8W-10daa	18	90	Kiowa Fm	11-18-61	56	1,610	9.0	.79	.08	146	49	376	307	284	590	1.0	1.9	566	314	3,050	----
16- 9W-19ccd	19	57	Pleistocene Ser	11-21-61	56	648	5.5	3.0	.09	98	16	114	202	140	174	.4	.4	310	144	1,220	----
16-10W-26ccc1	20	111	Dakota Fm	11-21-61	56	362	21	168	.34	96	11	22	317	15	40	.2	.4	284	24	660	----
17- 7W-10cca	21	65	do	11-20-61	----	395	14	.06	.00	69	14	53	244	74	42	.5	8.9	230	30	720	----
17- 8W- 4add	22	59	do	11-18-61	57	350	9.0	2.1	.11	70	15	44	310	18	40	.6	.4	236	0	650	----
7cba	23	6	Colluvium	11-18-61	53	272	3.0	.42	.02	75	14	12	288	2.1	19	.4	4.2	244	8	510	----
25ccc1	24	95	Dakota Fm	5- 8-61	----	318	16	.01	.00	73	12	28	264	18	39	.4	1.8	232	16	580	7.4
17- 9W-13abb	25	112	do	11-16-61	51	341	9.0	11	.21	72	19	33	334	20	22	.7	.4	258	0	610	----
16dab	26	210	do	4-24-61	----	372	23	.55	.12	84	15	32	322	18	40	.4	1.1	271	7	680	7.6
17-10W-10dbd2	27	190	do	3-23-61	----	419	20	.01	.00	90	13	47	342	35	42	.4	3.2	278	0	770	7.5
27aac	28	84	do	11-16-61	57	353	14	.80	.00	73	15	40	310	16	41	.4	1.5	244	0	650	----
33ccd	29	36	Pleistocene Ser	11-21-61	55	637	22	.48	.00	176	11	21	346	22	82	.1	133	484	200	1,140	----

[1] Samples analyzed by Kansas State Department of Health.
[2] *Dep*, deposits; *Fm*, Formation; *Ls*, Limestone; *Ser*, Series.
[3] In areas where the nitrate content of water is known to exceed 45 mg/l, the public should be warned of the potential dangers of using the water for infant feeding (U.S. Public Health Service, 1962, p. 7).

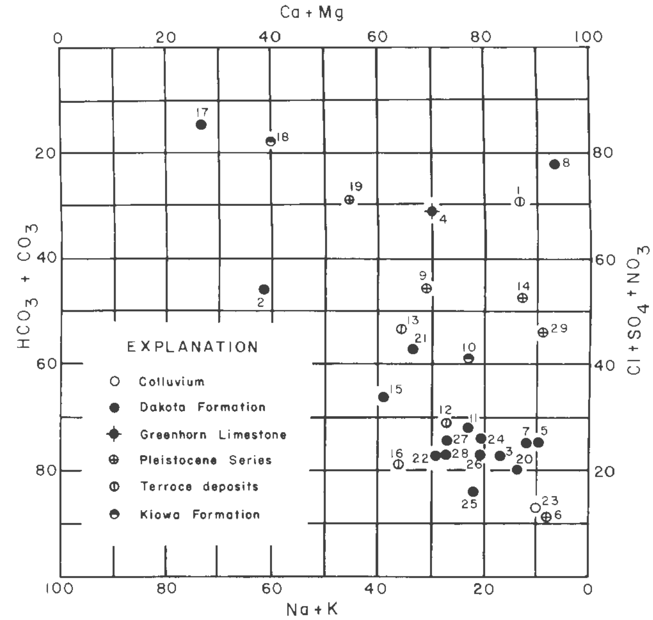

FIGURE 26.—Modified Piper diagram showing grouping of analyses of water from wells. Numbers by symbols are sample-identification numbers from table 3.

contrast to the characteristic red stain caused by iron. The recommended maximum concentration for manganese is 0.05 mg/l for domestic use. In Ellsworth County 13 of the samples contained manganese in excess of the recommended limit.

Chloride.—Chloride is abundant in nature and many rocks contain small to large amounts of chloride salts that may be dissolved by ground water. Water containing less than 250 mg/l of chloride is satisfactory for domestic use. Cattle can drink water containing as much as 5,000 mg/l of chloride; however, they will lose weight until they become adjusted to the water. Only two samples contained more than 250 mg/l of chloride in Ellsworth County.

Fluoride.—Fluoride in concentrations greater than 1.5 mg/l in drinking water used regularly by children during the formation of the permanent teeth may cause mottling of the tooth enamel (Dean, 1936, p. 1270). However, a moderate concentration (1.0 to 1.5 mg/l) of fluoride helps to prevent tooth decay. Only two samples of water had concentrations of fluoride greater than 1.0 mg/l, and no concentration exceeded 1.5 mg/l.

Nitrate.—The recommended maximum concentration of nitrate in water for domestic supply is 45 mg/l. The use of water containing an excessive amount of nitrate in the preparation of a baby's formula can cause cyanosis (blue baby), or oxygen starvation. Water containing more than 90 mg/l of nitrate is regarded by the Kansas State Department of Health as likely to cause severe, possibly fatal, cyanosis if used continuously (Metzler and Stoltenberg, 1950). Nitrate poisoning appears to be confined to infants in their first few months of life. Adults drinking the same water are not affected; however, breast-fed babies of mothers drinking such water may be affected. Cows drinking water containing a high concentration of nitrate may produce milk high enough in nitrate to cause cyanosis in infants. Nitrate cannot be removed from water by boiling or other simple treatment.

The source of nitrate in natural water in Ellsworth County is not known. In Kansas, nitrate-bearing rocks sufficiently high in nitrate to contribute the quantities that occur in water are not known to exist. Chemical fertilizers and certain legumes are sources of nitrate in some local areas, and seepage from sewage sources or barnyards may also contribute nitrate. The quantities that have been pumped over a period of several years from wells known to yield water with a high nitrate content would indicate a continuing source of the nitrate. Bacteria, which have the ability to "fix" or convert the nitrogen of the air or of organic material to nitrate, may be the principal source of nitrate in water.

In 1958 the Kansas State Department of Health investigated the water supplies of several cities in Kansas in which the concentration of nitrate was higher than the desirable limits set by the Department of Health. Wilson in Ellsworth County was one of these cities. Conclusive results were not obtained in this investigation; however, certain factors were common to all the water supplies and may be important to the presence of nitrate in these water supplies. In all the cities the supplies were from thin aquifers of low transmissibility. The wells were relatively low-yielding wells having appreciable drawdown when pumped. Nitrate concentrations were higher at or near the water table than in the lower part of the aquifer. Wilson, in a 16-year period, pumped an estimated 370 tons of nitrate in water from the east city well. This quantity of nitrate would indicate that a continuing source of nitrate was necessary.

Wells yielding water with a low nitrate content have been constructed in areas known to contain water with a high nitrate content. In such a well the aquifer must be more than 10 or 15 feet thick. The well should be screened only in the bottom of the aquifer and tightly cased to the surface. The well should be pumped at a low rate to take water out of the bottom of the aquifer with little disturbance of the water having high nitrate content at or near the water table.

In only four samples of water from Ellsworth County (table 3) was the nitrate concentration greater than 45 mg/l. Two of these samples were from municipal supplies (Wilson and Kanopolis). The geologic little or no drawdown in the water table, and appreciably greater amounts of water probably could be safely withdrawn at these places. Although very few individual wells are pumped in excess of 10 gpm, yields of as much as 250 gpm probably could be sustained by cyclic pumping in a number of places.

The directions of dip of cross-stratification in sandstone generally are conceded to indicate the directions of flow of currents that deposited the sandstone. The relationship between dip bearings of cross-stratification and the trend of elongation of scour-fill channels at the base of the Shinarump Formation proved a useful tool in locating drill holes in uranium exploration on the Colorado Plateau (Finnell and others, 1963). Cross-stratification studies such as those described above conceivably could be equally useful in establishing locations for water wells in the Kiowa and Dakota Formations in central Kansas. For example, vector resultants of cross-stratification dip bearings are mainly westward and southwestward in the Dakota Formation in Ellsworth County and average S.71°W. (fig. 12b). Thus, one might infer that the most likely locations for a second productive well tapping a given aquifer in the Dakota Formation would be to the west or southwest of the first well. If the direction of dip of cross-stratification can be determined from outcrop studies of an aquifer, it might be possible to determine more accurately the direction in which the location of a well should lie. However, the length of sandstone-filled channels in both the Kiowa and Dakota Formations would be an important consideration in deciding on exact locations for water wells, and data on the overall dimensions of the sandstone deposits are scarce. Field studies indicate that the dimensions of many thick deposits of sandstone in the Dakota Formation can be measured in miles (fig. 15), and the same appears to be true for thick lenticular deposits of sandstone in the Kiowa Formation. It seems likely, however, that the direction of elongation of deposits of Kiowa sandstone commonly is southward and southwestward in Ellsworth County (fig. 12).

GRANEROS SHALE

The Graneros Shale is generally not an aquifer in Ellsworth County. However, in a few locations wells obtain small yields of water from a sandy zone within the unit.

GREENHORN LIMESTONE

The Greenhorn is not an important aquifer. However, a small amount of ground water moves through the unit and upon encountering one of the several bentonite layers within the unit is discharged through seeps at the downdip exposure of the bentonite. Only a few wells are known which obtain water from the Greenhorn, and the yield from these wells is generally only a few gallons an hour.

CARLILE SHALE

This unit does not yield water to wells in Ellsworth County.

PLIOCENE AND PLEISTOCENE DEPOSITS

The Ogallala Formation in Ellsworth County consists entirely of a soil caliche formed during late Pliocene time. These deposits everywhere lie above the water table and yield no water to wells.

Rocks representing all stages of the Pleistocene are present in Ellsworth County. These deposits are of both eolian and fluvial origin. Most of the eolian deposits occur in the uplands and yield no water to wells. The fluvial deposits range in age from Nebraskan to Recent and occur as Recent alluvium in the major valleys and as terrace deposits adjacent to these valleys. These deposits are comprised of a heterogeneous mixture of silt, clay, sand, and gravel. The fluvial deposits of Nebraskan and Kansan age occur in a high terrace position adjacent to the Smoky Hill River and as the lower part of the valley fill in Wilson valley. In much of the area underlain by Nebraskan age deposits, these fluvial deposits are near the dissected valley wall and are drained; however, in local areas small quantities of water, probably less than 10 gpm, are available to wells. The Grand Island and Sappa Formations of Kansan age in the Smoky Hill River valley and Wilson valley yield small to moderate quantities of water to wells in the area. Locally these deposits lie above the water table and yield no water. Where the deposits are saturated, yields are commonly less than 50 gpm, but in areas where the Grand Island is thick and is composed predominantly of sand and gravel, yields of more than 100 gpm could be obtained, although no wells having this large a yield were visited during the investigation. In the tributary streams the Kansan age deposits lie above the water table and do not yield water to wells. In southern and southwestern Ellsworth County the channel deposits of Kansan age are lithologically similar to the Kansan age deposits in the streams tributary to the Smoky Hill River, but they are somewhat thicker and lie below the water table. Wells in these deposits generally yield only a few gallons per minute; however, yields up to 50 gpm probably could be developed in local areas.

Pleistocene fluvial deposits of Illinoisan, Wisconsinan, and Recent age occur in the valleys of the major streams and are the principal alluvial aquifers in the county.

treated by chlorinators on each well and is stored in a 50,000-gallon steel standpipe near the center of town. About 120 acre-feet of water is pumped annually by the city.

INDUSTRIAL SUPPLIES

The principal industrial user of water in Ellsworth County is the Northern Natural Gas Co., operator of a hydrocarbon-extraction plant in the southwestern part of the county. In 1960, six wells were drilled into the Dakota Formation to obtain water for injection into the Wellington salt to dissolve the salt, creating cavities for storage of propane. These wells were tested at about 250 gpm. The production rate ranges from 150 gpm to 250 gpm. Water from this well field is now used for cooling purposes only.

IRRIGATION SUPPLIES

One well (17-9W-19aaa) was used for irrigation during this investigation. This well yields about 100 gpm and obtains water from gravel deposits in a buried Pleistocene channel in southwestern Ellsworth County. The gravel deposits are not continuous in the buried channel, and development of additional irrigation in the area is dependent on the location of additional gravel in the basal part of the channel deposits.

Water in sufficient amounts for large-scale irrigation is not available in the county. Maximum known yields are about 250 gpm from alluvial deposits adjacent to the Smoky Hill River and from the Dakota Formation, and yields this large can be obtained only in local areas.

MINERAL RESOURCES

The known mineral resources of Ellsworth County include petroleum, salt, ceramic material (clay and shale), sand and gravel, natural gas, lignite, limestone, sandstone, volcanic ash, and raw materials for production of cement; however, only petroleum, salt, ceramic material, and sand and gravel are produced commercially at the present time. Mineral production is an important contribution to the economy of Ellsworth County. The value of minerals produced annually amounts to about $8 million as compared with the $16 million value of livestock and crops produced annually.

Oil and Gas

Petroleum is the principal mineral resource of Ellsworth County. The first oil production was in October 1930. The 1964 production was 1,470,103 barrels, and the cumulative production at the end of 1964 was 101,724,299 barrels (Beene and Oros, 1965). Production was from 564 wells in 17 fields. Oil is produced from rocks of the Shawnee Group, Lansing-Kansas City Group, Pennsylvanian basal conglomerate, Simpson Group, Arbuckle Group, and the Reagan Sandstone.

Natural gas is not produced commercially in the county.

Salt

Ellsworth County is one of five Kansas counties that produces salt. Salt is extracted from the Hutchinson Salt Member of the Wellington Formation of Early Permian age. The Hutchinson salt underlies nearly all central Kansas (Bass, 1926c).

Salt was first discovered in Ellsworth County in 1887 (Hay, 1889, p. 199). A shaft was started to mine the salt at Ellsworth but was abandoned before reaching the salt. At Kanopolis the Royal Salt Mining Co. started producing salt in 1891. The Ellsworth Salt Co. started producing salt from a plant which evaporated brine from wells in 1903. Operation of this plant stopped in 1913. The Independent Salt Co. sank a shaft at the cen. SE¼ NW¼ NW¼ sec. 29, T.15 S., R.7 W., in 1914 (Vincent, 1918). This mine is in operation at present and is the oldest continuously operated salt mine in Kansas. Salt is mined from a 10-foot face at a depth of 850 feet. Production figures for recent years are not available.

Ceramic Materials

A mineral resource of Ellsworth County, which currently is being exploited and which has a great potential for additional development, is ceramic materials. Two types, clay and shale, are known, but only the clays are being utilized. The Kanopolis plant of the Acme Brick Co. uses clay from the lower part of the Terra Cotta Member of the Dakota Formation to manufacture face brick. The Terra Cotta Member contains the largest reserves of light-burning or buff-firing clay in Kansas.

Clay suitable for manufacture of structural clay products is found in the Dakota Formation. It occurs in irregular elongate lenses and generally proves difficult to prospect. As a part of their field exploration program, the Ceramics Division of the State Geological Survey of Kansas has dug test pits at 105 locations in Ellsworth County (Norman Plummer, oral commun., 1961). Samples taken from these test pits have been fired to determine suitability of the clay for manufacture of structural clay products. Table 5 lists properties of selected clay samples from Ellsworth County.

Dakota clay was used for several years by Dryden Potteries, Ellsworth. In addition to pottery bodies nite mining will be revived. Schoewe (1952) estimated 8,800,000 tons of marginal reserves of lignite in Ellsworth County.

Limestone

The only limestones in Ellsworth County are the thin layers occurring within the Greenhorn. They are unique in that most layers on fresh exposure are soft enough to be sawed or chiseled readily into long rectangular blocks, which have served admirably as fence posts and building stone. Upon prolonged exposure to air, this stone "case-hardens" and resists weathering. The early farmers and ranchers quarried thousands of these stone fence posts, a fact obvious to anyone driving through the county.

The stratigraphic classification of the State Geological Survey (Jewett, 1959) recognizes the Fence-post limestone as the uppermost bed of the Greenhorn, and some persons presume that it is the source of all the stone posts. Actually at least three different limestone beds of the upper Greenhorn have been quarried for posts in Ellsworth County. Limestone fence posts have not been quarried in Ellsworth County for many years as increasing costs of production and handling have made them non-competitive with other types of posts. Some old buildings remain which are built of Fence-post limestone. As the limestones are single beds separated by chalk intervals, the cost of producing them as building stone is prohibitive. Parts of the Greenhorn Limestone are suitable for agricultural limestone and for cement raw material. There is no production of limestone for commercial purposes in Ellsworth County at the present time.

Sandstone

The sandstone bodies within the Dakota Formation differ greatly in degree of cementation, even within the individual body. The color is generally some dull shade of brown. At the present time, the sandstone has little appeal as a building stone. Weathering and erosion of the sandstone removes the poorly cemented parts and leaves behind a jumbled mass of loose slabs, each one well cemented within itself. The early settlers used Dakota sandstone slabs to construct houses, barns, corrals, fences, and other structures, probably as a means of getting these slabs out of their cultivated fields and also for want of better material. Today the only feasible use apparently is quarrying of some of the sandstone bodies to produce a combination of sand and aggregate suitable for subbase for highway and other construction.

Volcanic Ash

Volcanic ash has many uses. It is used as an abrasive in cleansers and rubber erasers. Some very fine ash is used in toothpastes and powders, and extremely fine ash has been used for polishing plate glass. It is used in ceramic bodies and glazes. It has been "popped" to produce lightweight aggregate. Ash when mixed with portland cement will produce a concrete resistant to disintegration by sea water. The State Highway Commission of Kansas has used volcanic ash extensively as a top dressing on newly constructed bituminous mat (black top) roads.

Six deposits of volcanic ash, which are assigned to the Pearlette ash bed of the Sappa Formation of the Kansan Stage of the Pleistocene Series, are known to be present in Ellsworth County. Three of these deposits have been previously reported by Carey and others (1952). These include an impure deposit near the cen. S½ sec. 29, T.15 S., R.9 W., a deposit 9 feet thick exposed in a cut on the Union Pacific Railroad at the cen. NW¼ SW¼ sec. 22, T.15 S., R.7 W., and a third deposit exposed near the top of a vertical bank on the south side of Thompson Creek in the cen. SE¼ NW¼ sec. 28, T.16 S., R.7 W.

Three deposits of ash not previously reported were found during this investigation. A thin ash deposit in the spillway of a farm pond is located in the SW¼ SE¼ SE¼ sec. 7, T.17 S., R.7 W. A deposit observed in a road ditch on the east side of Elkhorn Creek in the SE¼ SW¼ SE¼ sec. 28, T.14 S., R.7 W., is about 5 feet thick, and across the creek valley in the south road ditch in the NW¼ NW¼ NE¼ sec. 33, T.14 S., R.7 W., 1 foot of ash is exposed.

Volcanic ash has not been produced commercially in Ellsworth County, but in Lincoln County in Wilson valley about 1 mile north of Ellsworth County several pits have been opened in the ash, and it is possible that deposits found in Ellsworth County may be developed.

RECORDS OF WELLS AND SPRINGS

Information pertaining to 311 wells and springs is given in table 6. The number of wells and springs listed according to use is as follows:

Domestic and stock wells and springs	181
Public supply wells	24
Industrial wells	4
Observation wells	1
Irrigation wells	1
Unused wells	100

9dad	C. Weinhold	113 R	6	G	Ss	Dakota Fm	Cy, W	S	101	7-61	1,708	
14aad	F. H. Schultz	171.0	4	G	Ss	do	Cy, W	S	140	7-61	1,731	
15bab	Fred Peterman	78.0	4	G	Ss	do	Cy, W	S	58.0	7-61	1,680	
18adb	Marie Kubicek	57.0	4	G	Sd, Gr	Sappa Fm, Grand Island Fm	Cy, W	S	51.5	7-61	1,676	
20caa	Evelyn Kellner	68.0	4	G	Sd, Gr	do	Cy, W	S	55.6	7-61	1,670	
22dcc	Edward Vaque	46.3	6	G	Sd, Gr	do	Cy, W	S	17.4	7-61	1,632	
24ddc	Randolph Eilrich	186.0	4	G	Ss	Dakota Fm	Cy, W	S	164	7-61	1,756	
28ccd*	Smith Hunter	51.0	40	R	Sd, Gr	Sappa Fm, Grand Island Fm	Cy, W	S	49.0	7-61	1,652	
31cba	J. J. Kottas	43.5	6	G	Sd, Gr	do	Cy, W	S	39.0	7-61	1,644	
34adb*	R. Richard	63 E	4	G	Ss	Dakota Fm	Cy, W	S	62.5	7-61	1,653	
36ccd	Wm. Strode	73.0	4	G	Ss	do	Cy, W	S	64.0	7-61	1,677	
14-10W- 1ccc	John Soukup	45.0	6	G	Sd, Gr	Sappa Fm, Grand Island Fm	Cy, W	S	42.0	7-61	1,664	
4ddd	Frank Mares	21.0	4	G	Ss	Dakota Fm	Cy, W	S	6.9	7-61	1,663	
5bbb	J. F. Zaloudak	57.0	6	G	Ss	do	Cy, W	S	16.5	7-61	1,670	
8bcb	Frank Kuck	92.0	36	R	Ss	do	Cy, W	S	44.0	7-61	1,736	
9ddc*	Albert Klaus	88.0	4	G	___	do	Cy, W	S	28.0	7-61	1,801	
12cdd	Frank Prachar	33.0	6	G	Sd, Gr	Sappa Fm, Grand Island Fm	Cy, W	S	26.0	7-61	1,664	
14bab	V. Hanzlicak	65.0	12	G	Ss	Dakota Fm	Cy, W	S	54.3	7-61	1,705	
15cbc	J. Hanzlicak	13.0	6	G	Gr, St	Colluvium	Cy, W	S	12.0	7-61	1,730	
20bcb	Dept. of Health	48.8	2	G	Sd, Gr	Sappa Fm, Grand Island Fm	N	O	41.9	7-61	1,682	
20cda1*	City of Wilson	25 R	120	C	Sd, Gr	Grand Island Fm	T, E	PS	10 R	6-61	1,645	
20cda2	do	25 R	8	S	Sd, Gr	do	C, E	PS	8 R	6-61	1,643	
21bad	J. V. Vopat	99.0	6	G	Sd, Gr, St	Alluvium, Dakota Fm	Cy, W	S	34.6	7-61	1,690	
24cbb	Fred Dolezal	12.0	6	G	Sd, Gr	Sappa Fm, Grand Island Fm	Cy, W	S	7.0	7-61	1,688	
25bcc	L. E. Greenbough	89.0	6	G	Ss	Dakota Fm	Cy, W	S	81.5	7-61	1,685	
27bac	Katharine Wanasek	120.0	6	G	Ss	do	Cy, W	D	48.6	7-61	1,671	
34aac	Albert Meigl	24.4	6	G	Sd, Gr	Alluvium, Grand Island Fm	Cy, H	S	8.1	7-61	1,620	
36dca	Joseph Mottas	77.0	12	G	Ss	Dakota Fm	Cy, W	D, S	19.0	7-61	1,621	
15- 6W- 2acb	Anna Reiter	100.0	5	G	Ss	do	Cy, W	S	90.2	9-61	1,628	
4add	Joe Straka	43.0	6	G	Ss	do	Cy, H	N	17.8	9-61	1,602	
6ccd	S. A. McManes	Spring	___	H	Ss	do	___	S	___	___	1,630	
7dac	E. G. McManes	100.0	6	G	Ss	do	N	N	35.9	9-61	1,618	
10bbc	John Cleverdon	100 R	6	G	Ss	do	Cy, W	S	19.1	9-61	1,586	
13aca	John Vanier	92 R	5	G	Ss	do	T, E	D, S	57.0	9-61	1,450	
14cda*	A. Pafford	49.0	5	G	Ss	Kiowa Fm	Cy, W	S	44.3	9-61	1,490	
15cdb	Milas Doubrava	85 R	8	G	Ss	Dakota Fm, Kiowa Fm	Cy, W	D	21.0	9-61	1,528	
18adc	L. Shade	47.0	5	G	Ss	Dakota Fm	N	N	36.8	9-61	1,613	
19bdd	Unknown	22.2	50	R	Sd, Gr, St	Terrace Dep	Cy, W	N	12.0	9-61	1,539	
22ccc	R. A. Hall	65.0	6	G	Ss	Dakota Fm	Cy, W	S	42.1	9-61	1,552	
28dcb	William Webster	56.0	6	G	Ss	do	Cy, W	S	53.2	9-61	1,623	
30bbc	Sam Johnson	48.0	5	G	___	do	Cy, W	N	40.8	9-61	1,561	
32cda	S. A. McManes	86.0	5	G	Ss	do	Cy, W	S	70.0	9-61	1,645	
35aaa*	Emil Flemming	Spring	___	C	Ss, Sh	do	___	S	___	9-61	1,570	
15- 7W- 1bcd	R. Allen	112.0	5	G	Ss	do	N	N	80.2	8-61	1,620	
4bca	Fred Eilrich	139 R	6	G	Ss	do	Cy, W	S	49.0	8-61	1,630	
6aba	Frank Plantz	54.0	6	G	Ss	do	Cy, W	N	49.1	8-61	1,712	
10dbd	J. B. Griffith	54.0	6	G	Ss	do	Cy, W	S	31.3	8-61	1,623	
13abc	G. Suberly	126 R	6	G	Ss	do	Cy, W	S	80.1	8-61	1,585	
16ccc	L. Clafin	89.0	6	G	Ss	do	Cy, W	N	86.0	8-61	1,666	
18cbc	Kate Atwood	94.0	6	G	Ss	do	Cy, W	S	29.2	8-61	1,605	
19cba	City of Kanopolis	35 R	___	___	Sd, Gr	Grand Island Fm	T, E	PS	___	___	1,592	60 R
20ccd	Ben Basye	54.0	6	G	Ss	Dakota Fm	Cy, H	N	33.5	___	1,612	
22ccd*	Ella Faris	28.0	4	G	Sd, Gr, St	Terrace Dep	Cy, W	S	15.9	9-61	1,553	
23dad	John H. Gust	85.0	6	G	Ss	Dakota Fm	Cy, W	S	70.8	9-61	1,659	
25adc	Frank Cates	55 R	4	G	Ss	do	Cy, W	S	48.3	___	1,543	
28dcb	C. A. Andrews	136.0	5	G	Ss	do	Cy, W	S	66.1	9-61	1,605	
33bbc	M. E. Tompkins	37.0	5	G	Sd, Gr	Sappa Fm, Grand Island Fm	Cy, W	S	3.3	9-61	1,526	
35ccc2	Frank A. Bates	26.0	6	G	Sd, Gr	Grand Island Fm	N	N	24.2	9-61	1,520	
15- 8W- 2acc	Charles M. March	19.0	36	R	Sd, Gr, St	Alluvium	Cy, W	N	5.3	8-61	1,645	

16- 6W- 2abc	F. Sabesta	97.0	6	G	Ss	Dakota Fm	Cy, W	N	27.0	9-61	1,605
5dcb	M. Webster	135 R	8	S	--	do	Cy, W	N	87.6	9-61	1,578
10ccb	J. Welley	116 R	6	G	--	do	Cy, W	N	110	9-61	1,604
12bbd	S. Anderson	72.0	6	G	Ss	do	Cy, W	N	17.6	9-61	1,565
14abd	E. Tetshgraeber	55.0	6	G	Ss	do	Cy, W	N	34.2	9-61	1,550
18cdd	C. Ogden	23.0	6	G	Sd, Gr	Grand Island Fm	Cy, W	N	21.7	9-61	1,520
19aad	do	13.0	6	G	Sd, Gr	do	Cy, H	D	10.0	9-61	1,515
25adc	Evangel. Mission Church	23.0	6	G	Sd, Gr, St	Alluvium	N	N	7.2	9-61	1,472
28abb	N. Hackley	65 R	6	G	Ss	Kiowa Fm	J, E	D	35.0	9-61	1,508
16- 7W- 1aad	P. Aylward	88 R	6	G	Ss	Dakota Fm	Cy, W	S	84.1	9-61	1,560
4acd	J. Faris	56.0	6	G	Ss	do	Cy, W	S	34.6	9-61	1,533
5ada	do	18.0	6	G	Sd, Gr	Terrace Dep	N	N	17.2	9-61	1,490
10cdd	H. Gilkison	48.0	30	R	Ss	Dakota Fm	N	N	42.1	9-61	1,542
12dcc	P. Aylward	100 R	6	G	Ss	do	Cy, W	S	24.1	9-61	1,528
14aac	do	42.0	6	G	Ss	Terrace Dep	Cy, W	S	23.7	9-61	1,512
15cad	T. Kanack	21.0	6	G	Ss	Dakota Fm, Grand Island Fm	Cy, W	S	1.4	9-61	1,520
18aaa	R. B. Reed	106 R	6	G	Ss	Dakota Fm	Cy, W	D	53.2	9-61	1,550
20caa	J. P. Reed	37.0	40	R	Ss	do	Cy, W	N	27.3	9-61	1,631
22abb	E. Cipra	Spring	----	H	Ss	do	----	S	-------	9-61	1,510
24ddc	E. Bettenbrock	62.0	6	G	Sd	Grand Island Fm, Dakota Fm	Cy, W	S	55.0	9-61	1,571
25acc	H. Lapham	55.0	6	G	--	Dakota Fm	Cy, W	S	41.8	9-61	1,572
28dbc	L. D. McLaughlin	143 R	6	G	Ss	Kiowa Fm	Cy, W	N	18.0	9-61	1,528
30abc	F. Nienke	42.0	6	G	Ss	Dakota Fm	N	N	37.8	9-61	1,631
33aca	Cen. Nat. Bank, Ellsworth	56.0	6	G	Ss	do	Cy, W	N	38.5	9-61	1,587
35ddc	H. Lapham	53.0	6	G	Ss	do	Cy, W	N	28.7	9-61	1,571
16- 8W- 1bcb	J. J. Dolechek	14.5	5	G	Sd, Gr	Grand Island Fm	N	N	8.6	9-61	1,560
4daa	E. Westermeier	52.0	6	G	Ss	Dakota Fm	N	N	32.2	9-61	1,580
6bcd	Anna Vance	88.0	6	G	Ss	do	Cy, W	S	48.0	9-61	1,598
7bba	S. Malaby	33.0	5	G	Sd, Gr	Terrace Dep	N	N	25.0	9-61	1,600
10daa*	C. Prochaska	90.0	8	G	Ss	Kiowa Fm	Cy, W	S	30.4	9-61	1,541
12bba	G. Andrews	69.0	6	G	Ss	do	Cy, W	S	49.1	9-61	1,544
13caa	J. E. Palmquist	200 R	6	G	Ss	Dakota Fm, Kiowa Fm	Cy, W	N	52.2	9-61	1,617
16cdb	J. Krupp	91.0	6	G	Ss	Dakota Fm	Cy, W	S	45.2	9-61	1,615
17cdc	Alice Wright	36.0	6	G	Ss	do	Cy, W	N	23.1	9-61	1,643
19bca	A. F. Becker	79.0	6	G	---	do	Cy, W	S	46.7	9-61	1,655
23ada	J. Balin	65 R	6	G	Ss	do	Cy, H	N	53.7	9-61	1,595
26aad	V. Slechta	99 R	6	G	Ss	do	Cy, W	N	16.5	9-61	1,615
27cab	G. Soukup	101 R	6	G	Ss	do	N	N	39.0	9-61	1,602
30cbc	G. Freshe	100 R	6	G	Ss	do	Cy, W	N	36.1	9-61	1,760
34ddc	L. Hysell	38.0	6	G	Ss	do	Cy, W	S	22.8	9-61	1,623
36dcc	A. Vopat	85.0	6	G	Ss	do	N	N	81.7	9-61	1,671
16- 9W- 1bcd	M. F. Harts	114.0	6	G	Ss	do	Cy, W	N	92.8	9-61	1,713
6cca	J. Kraft	174.0	6	G	Ss	do	Cy, W	S	89.0	9-61	1,752
7bdc	F. Jirik	194 R	6	G	Ss	do	Cy, W	S	163	9-61	1,840
10aac	L. Katzemeier	43.0	8	G	Ss	do	Cy, W	N	27.0	9-61	1,680
11dcd	A. Mache	40.0	6	G	---	do	Cy, W	S	28.4	9-61	1,688
18ccc	T. R. Kihn	165 R	6	G	Ss	do	N	N	123	9-61	1,868
19ccd*	Steinberg	57.0	8	G	Sd, St	Pleistocene Ser	Cy, W	N	12.4	9-61	1,847
22aca	A. D. Morrison	53.0	6	G	Sd, St	Terrace Dep, Dakota Fm	Cy, H	N	12.7	9-61	1,742
24cbd	Prudential Insurance Co.	94.0	6	G	Ss	Dakota Fm	Cy, W	N	83.4	9-61	1,753
27cdc	H. Kruse	106 R	5	G	Ss	do	N	N	84.0	9-61	1,840
30bcc	Ben Gust	91.0	6	G	Sd, St	Pleistocene Ser	Cy, W	N	11.3	9-61	1,831
31ccd	T. Stratmann	75.0	6	G	Sd, St	do	Cy, W	S	28.4	9-61	1,816
16-10W- 3bbb2	E. Borecky	100 R	6	G	Ss	Dakota Fm	Cy, W	N	75.2	9-61	1,740
8aac	J. Talsky	110.0	6	G	Ss	do	Cy, W	S	103	9-61	1,786
10cdd	W. Skalicky	262 R	5	G	Ss	do	Cy, W	S	206	9-61	1,883
12baa	Frank Adamek	212 R	6	G	Ss	do	Cy, W	S	120	9-61	1,756
14dcd	M. Mehl	154 R	6	G	Ss	do	Cy, W	S	154	9-61	1,875
18bac	E. Kolouch	297 R	6	G	Ss	do	Cy, W	N	192	9-61	1,890

	13abb*	John Dressler	112.0	6	I	Ss	do	Cy, W	S	60.6	9-61	1,795	
	16cda	K. Mohlmann	51.0	6	G	Ss	do	Cy, W	S	42.4	9-61	1,790	
	16dab*	City of Lorraine	210 R	12	S	Ss	do	T, E	PS	--------	--------	1,792	100 R
	16dca	do	210 R	12	S	Ss	do	T, E	PS	--------	--------	1,792	100 R
	18cbb	O. Wilkins	63.0	7	G	Ss	do	Cy, H	N	45.4	9-61	1,801	
	19aaa	G. E. Mehl	84 R	12	S	Ss, Gr	Pleistocene Dep	T, T	I	35.0	4-66	1,781	100 R
	20ccb	H. Schroeder	25.0	36	R	Sd, St	Pleistocene Ser	Cy, W	N	14.6	9-61	1,762	
	22aba	A. Kreasch	70 R	6	G	Ss	Dakota Fm	Cy, W	N	58.0	9-61	1,778	
	27abd	A. Groth	39.0	6	G	Sd, St	Pleistocene Ser	Cy, W	S	29.2	9-61	1,761	
	30daa	H. Mollhage	79.0	8	I	Sd	do	Cy, W	N	10.7	9-61	1,752	
	32add	Northern Nat. Gas Co.	197.0	10	I	Ss	Dakota Fm	T, E	ID	48 R	12-60	1,765	250 R, 50
	32bdd	do	240.0	10	I	Ss	do	T, E	ID	56 R	11-60	1,765	250 R, 35
	32dcc	L. Alden	34.0	7	I	Sd, St	Pleistocene Ser	N	N	33.1	9-61	1,752	
	34cbc	C. Ogden	22.0	6	G	Sd, St	do	Cy, W	N	18.2	9-61	1,748	
17-10W-	2cdd	P. Phelan	9.0	36	R	Sd, St	do	Cy, W	N	3.9	9-61	1,808	
	8aad	L. Alden	111 R	6	G	Ss	Dakota Fm	Cy, W	S	62.7	9-61	1,835	
	9ddd2	L. G. Roth	90 R	8	G	Sd, St	Pleistocene Ser	Cy, W	S	14.0	9-61	1,828	
	10aca	City of Holyrood	105 R	12	----	Ss	Dakota Fm	T, E	PS	--------	--------	--------	50 R
	10abd	do	165 R	12	----	Ss	do	T, E	PS	--------	--------	--------	60 R
	10cab	do	175 R	12	----	Ss	do	T, E	PS	--------	--------	--------	50 R
	10dbd1	do	110 R	12	----	Ss	do	T, E	PS	--------	--------	--------	85 R
	10dbd2*	do	190 R	12	----	Ss	do	T, E	PS	--------	--------	--------	185 R
	11ddd	F. Petermann	74.0	6	G	Sd, St	do	Cy, W	S	44.8	9-61	1,805	
	14cac	H. Shepmann	61.0	6	G	Ss	do	Cy, W	N	42.7	9-61	1,802	
	16baa	C. Frevert	159 R	6	G	Ss	do	Cy, W	D	96.2	9-61	1,858	
	17dda	W. Voss	123 R	6	G	Ss	do	Cy, W	N	70.3	9-61	1,836	
	19ccc	E. Mathews	142 R	6	G	----	do	Cy, W	N	48.4	9-61	1,827	
	24ddd	E. Bunce	43.5	6	G	Sd, St	Pleistocene Ser	N	N	26.7	9-61	1,771	
	26daa	Bill Becker	61.0	6	G	Ss	Dakota Fm	Cy, W	N	35.8	9-61	1,772	
	27aac*	L. Nagle	84.0	6	G	Ss	do	Cy, W	S	35.6	9-61	1,808	
	30caa	C. Stumps	64.0	6	G	Ss	do	Cy, W	N	34.3	9-61	1,812	
	31cbc	M. Moran	73.0	6	G	----	do	Cy, W	S	24.2	9-61	1,802	
	33ccd*	W. Stumps	36.0	6	G	Sd, St	Pleistocene Ser	Cy, W	S	17.7	9-61	1,778	
	36cbb	J. Kuntz	52.0	6	G	Ss	Dakota Fm	Cy, W	S	44.4	9-61	1,776	

[1] Asterisk following well number indicates analysis of water is given in table 3.
[2] *E*, estimated; *R*, reported.
[3] *B*, brick; *C*, concrete; *E*, contact spring; *G*, galvanized; *H*, fracture spring; *I*, black iron; *R*, rock; *S*, steel.
[4] *Cl*, clay; *Gr*, gravel; *Ls*, limestone; *Sd*, sand; *Sh*, shale; *Ss*, sandstone; *St*, silt.
[5] *Dep*, deposits; *Fm*, Formation; *Ls*, Limestone; *Ser*, Series; *Sys*, System.
[6] *C*, centrifugal; *Cy*, cylinder; *J*, jet; *N*, none; *T*, turbine.
[7] *E*, electric; *G*, gasoline; *H*, band; *LPG*, liquefied petroleum gas; *T*, tractor; *W*, wind.
[8] *D*, domestic; *I*, irrigation; *ID*, industrial; *N*, none; *O*, observation; *PS*, public supply; *S*, stock.

	Thickness, feet	Depth, feet
KANSAN STAGE		
Sappa and Grand Island Formations		
Silt, medium-light-brown	40	45
Sand, fine to coarse; contains fine gravel in middle part	21	66
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, light-gray, some brown mottling	4	70

14-9W-18bbb.—Sample log of test hole in the NW cor. sec. 18, T.14 S., R.9 W., east side of road, 105 feet south of intersection; augered August 29, 1961. Altitude of land surface, 1,671 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
RECENT AND WISCONSINAN STAGES		
Eolian deposits		
Silt, dark-grayish-brown	4	4
KANSAN STAGE		
Sappa and Grand Island Formations		
Silt, light-brown; contains some fine sand	36	40
Silt, light-brown, grading downward to silty sand	10	50
Sand, fine to medium in upper part, grading downward to coarse sand and some fine gravel	10	60
Gravel, fine, and coarse sand in upper part, grading downward to coarse gravel, cemented in lower part	9	69
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, medium- to light-gray	7	76

14-9W-23bbb.—Sample log of test hole in the NW cor. sec. 23, T.14 S., R.9 W., east side of road, 50 feet south of intersection; augered June 16, 1961. Altitude of land surface, 1,704 feet; dry hole.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
RECENT AND WISCONSINAN STAGES		
Eolian deposits		
Silt, dark-grayish-brown	2	2
Silt, brown; contains caliche nodules	4	6
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
COLORADO GROUP		
Greenhorn Limestone		
Chalk, yellowish-orange	3	9

14-9W-23bcc.—Sample log of test hole in the SW¼ SW¼ NW¼ sec. 23, T.14 S., R.9 W., east side of road at ½-mile line; augered June 16, 1961. Altitude of land surface, 1,685 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Nebraskan Stage		
Fullerton and Holdrege Formations		
Silt, dark-grayish-brown	5	5
Silt, medium-brown	5	10
Silt, light-brown; contains some caliche	10	20
Silt, light-brown	21	41
Silt, yellowish-brown; contains some fine to coarse gravel	3	44
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, yellowish-orange	4	48
Clay, medium-light-gray	5	53

14-9W-26bcc.—Sample log of test hole in the SW¼ SW¼ NW¼ sec. 26, T.14 S., R.9 W., east side of road at ½-mile line; augered June 16, 1961. Altitude of land surface, 1,668 feet; dry hole.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Nebraskan Stage		
Fullerton and Holdrege Formations		
Silt, clayey, dark-grayish-brown	5	5
Sand, medium	4	9
Sand, coarse to very coarse; contains much caliche	3	12
Sand, coarse	3	15
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, light-gray	4	19
Clay, medium-gray	5	24

14-9W-31bab.—Sample log of test hole in the NW¼ NE¼ NW¼ sec. 31, T.14 S., R.9 W., edge of field, 0.35 mile east of section corner; augered June 22, 1961. Altitude of land surface, 1,660 feet.

	Thickness, feet	Depth, feet
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
COLORADO GROUP		
Graneros Shale		
Shale, weathered, clayey and silty, light-gray to grayish-brown, some yellowish-orange mottling	15	15
Lower Cretaceous Series		
Dakota Formation		
Siltstone, light-gray and dark-yellowish-orange; contains some fine sand	4	19

14-9W-31bbb.—Sample log of test hole in the NW cor. sec. 31, T.14 S., R.9 W., east side of road, 100 feet south of intersection; augered June 14, 1961. Altitude of land surface, 1,684 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
RECENT AND WISCONSINAN STAGES		
Eolian deposits		
Silt, clayey, dark-grayish-brown	4	4
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
COLORADO GROUP		
Graneros Shale		
Shale, weathered, clayey, dark-gray	2	6
Shale, weathered, clayey, light-brown and medium-gray; some reddish-brown staining	4	10
Shale, medium-gray, and some yellow streaks	7	17

14-9W-32baa.—Sample log of test hole in the NE¼ NE¼ NW¼ sec. 32, T.14 S., R.9 W., center of road at ½-mile line; augered June 22, 1961. Altitude of land surface, 1,646 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
RECENT AND WISCONSINAN STAGES		
Eolian deposits		
Silt, clayey, dark-grayish-brown	4	4
KANSAN STAGE		
Sappa and Grand Island Formations		
Silt, light-brown; contains some fine sand in lower part	20	24
Sand, fine to coarse; contains silt in lower part	17	41
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, yellowish-gray	2	43

14-9W-32bbb.—Sample log of test hole in the NW cor. sec. 32, T.14 S., R.9 W., east side of road at fence corner; augered June 14, 1961. Altitude of land surface, 1,618 feet; depth to water, 12.0 feet.

	Thickness, feet	*Depth, feet*
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
COLORADO GROUP		
Greenhorn Limestone		
Chalk, yellowish-orange; thin bentonite seams	3	6
Graneros Shale		
Shale, yellowish-orange in upper part, dark-gray in lower part; contains bentonite at 23 feet and thin sandstone beds below 25 feet	24	30

14-10W-8ddd.—Sample log of test hole in the SE cor. sec. 8, T.14 S., R.10 W., west side of road, 30 feet north of intersection; augered June 22, 1961. Altitude of land surface, 1,744 feet; depth to water, 5.4 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
RECENT AND WISCONSINAN STAGES		
Eolian deposits		
Soil, silty, dark-grayish-brown	2	2
Silt, olive-gray	2	4
Silt, light-brown; contains residual limestone gravel in lower part	7	11
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
COLORADO GROUP		
Greenhorn Limestone		
Shale, clayey, calcareous, light-gray and light-brown	8	19

14-10W-13abb.—Sample log of test hole in the NW¼ NW¼ NE¼ sec. 13, T.14 S., R.10 W., south side of road, 14 feet east of ½-mile line; augered August 28, 1961. Altitude of land surface, 1,662 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
RECENT AND WISCONSINAN STAGES		
Eolian deposits		
Silt, clayey, dark-grayish-brown	5	5
KANSAN STAGE		
Sappa and Grand Island Formations		
Silt, light-brown and light-pinkish-gray	15	20
Clay, very silty, light-brown	8	28
Sand, medium to coarse in upper part grading downward to fine to coarse gravel in lower part	25	53
Gravel, medium to coarse	7	60
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, fine-grained	10	70
Sandstone and interbedded brown clay	10	80

14-10W-13bbb.—Sample log of test hole in the NW cor. sec. 13, T.14 S., R.10 W., east side of road, 116 feet south of intersection; augered August 28, 1961. Altitude of land surface, 1,679 feet; depth to water, 56.0 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
RECENT STAGE		
Soil	6	6
KANSAN STAGE		
Sappa and Grand Island Formations		
Silt, clayey, grayish-brown	7	13
Silt, reddish-brown	17	30
Sand, very fine to medium; contains material derived from rocks of Cretaceous age	40	70
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Shale, clayey, dark-gray	1	71

14-10W-14baa.—Sample log of test hole in the NE¼ NE¼ NW¼ sec. 14, T.14 S., R.10 W., south side of road at ½-mile line; augered June 13, 1961. Altitude of land surface, 1,697 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
RECENT AND WISCONSINAN STAGES		
Eolian deposits		
Soil, dark-grayish-brown	5	5
Silt, greenish-gray	5	10
Silt, light-brown; contains caliche pebbles near base	13	23
NEBRASKAN STAGE		
Fullerton and Holdrege Formations		
Silt, dark-gray; contains much fine to coarse sand and fine to medium gravel; gravel increases downward	11	34
Sand, fine to coarse, and fine silty gray gravel	4	38
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
COLORADO GROUP		
Greenhorn Limestone		
Shale, medium-dark-gray and yellowish-orange	2	40

14-10W-15aaa.—Sample log of test hole in the NE cor. sec. 15, T.14 S., R.10 W., south side of road at west fence line; augered June 13, 1961. Altitude of land surface, 1,726 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
RECENT AND WISCONSINAN STAGES		
Eolian deposits		
Soil, dark-grayish-brown	5	5
Silt, light-brown	10	15
Silt, yellowish-gray, some caliche nodules and gravel derived from the Greenhorn Limestone in lower part	20	35
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
COLORADO GROUP		
Greenhorn Limestone		
Limestone, chalky, light-yellowish-orange	2	37

14-10W-15baa.—Sample log of test hole in the NE¼ NE¼ NW¼ sec. 15, T.14 S., R.10 W., south side of road at ½-mile line; augered June 13, 1961. Altitude of land surface, 1,763 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
RECENT AND WISCONSINAN STAGES		
Eolian deposits		
Silt, dark-grayish-brown, grading downward to brown	6	6
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
COLORADO GROUP		
Greenhorn Limestone		
Limestone, chalky, yellowish-orange	9	15

14-10W-15bbb.—Sample log of test hole in the NW cor. sec. 15, T.14 S., R.10 W., south side of road, 35 feet east of intersection; augered June 13, 1961. Altitude of land surface, 1,773 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
RECENT AND WISCONSINAN STAGES		
Eolian deposits		
Silt, clayey, brown; contains a few caliche nodules in lower part	5	5
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
COLORADO GROUP		
Greenhorn Limestone		
Limestone, chalky, yellowish-orange	1	6

14-10W-32aaa.—Sample log of test hole in the NE cor. sec. 32, T.14 S., R.10 W., west side of road, 35 feet south of section line; augered June 21, 1961. Altitude of land surface, 1,622 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
recent stage		
Silt, sandy, dark-grayish-brown	1	1
kansan stage		
Sappa and Grand Island Formations		
Sand, coarse to very coarse; contains some fine to coarse gravel	8	9
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, yellowish-orange and medium- to light-gray	2	11

14-10W-32daa.—Sample log of test hole in the NE¼ NE¼ SE¼ sec. 32, T.14 S., R.10 W., center of road, 130 feet south of ½-mile line; augered June 21, 1961. Altitude of land surface, 1,568 feet; depth to water, 7.0 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan stage		
Fluvial deposits (terrace)		
Silt, dark-grayish-brown	4	4
Sand, fine; contains much silt	5	9
Silt, clayey, dark-brown	5	14
Sand, fine to medium, silty	5	19
Sand, coarse to very coarse, and fine to medium gravel	13	32
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, light-gray	1	33

14-10W-32ddd.—Sample log of test hole in the SE cor. sec. 32, T.14 S., R.10 W., west side of road, 30 feet north of intersection; augered June 21, 1961. Altitude of land surface, 1,628 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
recent and wisconsinan stages		
Eolian deposits		
Silt, clayey, dark-grayish-brown	6	6
kansan stage		
Sappa and Grand Island Formations		
Sand, coarse to very coarse, and fine to very coarse gravel	9	15
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, fine-grained, and interbedded grayish-yellow shale	3	18

15-7W-35bbb.—Sample log of test hole in the NW cor. sec. 35, T.15 S., R.7 W., south side of road, 40 feet east of intersection; augered June 22, 1961. Altitude of land surface, 1,574 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
recent and wisconsinan stages		
Eolian deposits		
Silt, dark-grayish-brown	4	4
Silt, light-grayish-brown; contains some fine locally derived gravel in lower part	2	6
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Siltstone, light-gray	3	9

15-7W-35bcc.—Sample log of test hole in the SW¼ SW¼ NW¼ sec. 35, T.15 S., R.7 W., east side of road at ½-mile line; augered June 22, 1961. Altitude of land surface, 1,507 feet; depth to water, 5.6 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
recent and wisconsinan stages		
Colluvium		
Sand, medium, and brown silt	4	4
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Kiowa Formation		
Sandstone, light-yellowish-orange	5	9

15-7W-35ccc1.—Sample log of test hole in the SW cor. sec. 35, T.15 S., R.7 W., in triangle at road intersection; augered June 22, 1961. Altitude of land surface, 1,518 feet; depth to water, 23.0 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
kansan stage		
Sappa and Grand Island Formations		
Sand, fine to medium, very silty	4	4
Sand, medium; contains some fine gravel	5	9
Sand, medium to coarse; contains some fine gravel and much silt	19	28
Sand, medium	23	51
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Kiowa Formation		
Clay, medium-light-gray	4	55

15-8W-19ccc.—Sample log of test hole in the SW cor. sec. 19, T.15 S., R.8 W., north edge of road, at east end of bridge; drilled by O. S. Fent, December 1, 1947. Altitude of land surface, 1,555 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
recent and wisconsinan stages		
Fluvial deposits		
Silt, brown (road fill and soil)	8	8
Silt, sandy, grayish-tan	2	10
Silt, sand, and gravel, fine to medium	5	15
Silt, sandy, tan; contains pebbles of red and brown sandstone	1	16
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, white and red	1	17
Clay, sandy, white and red, interbedded with white sandstone	3	20

15-9W-2bbb.—Sample log of test hole in the NW cor. sec. 2, T.15 S., R.9 W., east side of road, 30 feet south of intersection; drilled August 29, 1961. Altitude of land surface, 1,640 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
kansan stage		
Sappa and Grand Island Formations		
Silt, clayey, dark-brown	5	5
Silt, brown; contains caliche	4	9
Sand, very fine, silty, light-brown	10	19
Clay, dark-grayish-brown; contains much fine sand	1	20
Silt, dark-brown	5	25
Sand, very fine, silty, light-brown	4	29
Silt, grayish-brown; contains some caliche	7	36
Sand, medium	14	50
Sand, coarse, and fine gravel	22	72
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, hard, dark-reddish-brown	8	80

	Thickness, feet	*Depth, feet*
Sand, fine, tan; contains some silt	4	25
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, fine-grained, yellowish-orange	5	30

15-9W-27aaa.—Sample log of test hole in the NE cor. sec. 27, T.15 S., R.9 W., west side of road at section corner; augered June 20, 1961. Altitude of land surface, 1,639 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Nebraskan stage		
Fullerton and Holdrege Formations		
Silt, clayey, dark-grayish-brown (fill)	3	3
Silt, clayey, medium-brown; contains some coarse sand and caliche	19	22
Silt, clayey, medium-dark-gray	1	23
Gravel, fine to coarse; contains limestone and sandstone pebbles, very sandy (arkosic) in lower part	6	29
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, very hard	1	30

15-9W-34aaa.—Sample log of test hole in the NE cor. sec. 34, T.15 S., R.9 W., south side of road, 50 feet west of section corner; augered June 20, 1961. Altitude of land surface, 1,659 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Recent and Wisconsinan stages		
Eolian deposits		
Silt, clayey, light-brown	9	9
Nebraskan stage		
Fullerton and Holdrege Formations		
Gravel, very fine to coarse, silty; contains much gravel derived from local rocks	7	16
Silt, brown; contains pebbles of locally derived gravel and caliche	6	22
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, fine-grained, very hard	1	23

15-10W-5add.—Sample log of test hole in the SE¼ SE¼ NE¼ sec. 5, T.15 S., R.10 W., west side of road at ½-mile line; augered June 21, 1961. Altitude of land surface, 1,637 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Recent and Wisconsinan stages		
Eolian deposits		
Silt, dark-grayish-brown	4	4
Kansan stage		
Sappa and Grand Island Formations		
Silt, clayey, medium-dark-brown; contains caliche nodules in lower part	12	16
Sand, coarse to very coarse; contains much silt in lower 2 feet	5	21
Gravel, fine to coarse, and fine to coarse sand; contains much silt in lower part	9	30
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Siltstone, light-gray	0.5	30.5

15-10W-9bbb.—Sample log of test hole in the NW cor. sec. 9, T.15 S., R.10 W., east side of road, 50 feet south of intersection; augered June 21, 1961. Altitude of land surface, 1,660 feet; depth to water, 42 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Recent and Wisconsinan stages		
Eolian deposits		
Silt, dark-grayish-brown	4	4
Kansan stage		
Sappa and Grand Island Formations		
Silt, medium-light-brown	7	11
Silt, medium-light-brown; contains medium to coarse sand	8	19
Silt, medium-dark-brown; grades into sandy silt in middle part and sandy and fine gravel in lower part	15	34
Sand, coarse to very coarse	10	44
Sand, coarse to very coarse, and fine gravel	5	49
Sand, coarse to very coarse	17	66
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Siltstone, fine, gray	1	67

16-6W-25bbb.—Sample log of test hole in the NW cor. sec. 25, T.16 S., R.6 W., at section line on east road shoulder; augered June 27, 1961. Altitude of land surface, 1,545 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Kansan stage		
Sappa and Grand Island Formations		
Silt, dark-grayish-brown	4	4
Silt, light-brown	18	22
Sand, medium, silty, tan	2	24
Sand, fine, silty, brown	4	28
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Kiowa Formation		
Shale, clayey, fissile, dark-gray	6	34

16-6W-25bcc.—Sample log of test hole in the SW¼ SW¼ NW¼ sec. 25, T.16 S., R.6 W., in east road ditch at ½-mile line; augered June 27, 1961. Altitude of land surface, 1,503 feet; depth to water, 0.9 foot.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Kansan stage		
Sappa and Grand Island Formations		
Sand, medium to very coarse, and fine silty gravel	8	8
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Kiowa Formation		
Shale, clayey, dark-gray; fissile streaks	1	9

16-6W-25ccc.—Sample log of test hole in the SW cor. sec. 25, T.16 S., R.6 W., in road ditch, 45 feet east of center of intersection; augered June 27, 1961. Altitude of land surface, 1,452 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan stage		
Fluvial deposits (low terrace)		
Silt, dark-grayish-brown; contains fine sand	13	13
Gravel, fine, and medium to coarse sand	1	14
Silt, light-brown; contains much coarse to very coarse sand	25	39
Sand, fine to coarse; contains much silt	20	59
PERMIAN SYSTEM		
Lower Permian Series		
Cimarronian stage		
Sumner Group		
Ninnescah Shale		
Shale, dark-grayish-red	1	60

16-9W-17bcc.—Sample log of test hole in the SW¼ SW¼ NW¼ sec. 17, T.16 S., R.9 W., east side of road at ½-mile line; drilled August 31, 1961. Altitude of land surface, 1,827 feet.

	Thickness, feet	*Depth, feet*
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
colorado group		
Greenhorn Limestone		
Limestone, chalky, pale-yellowish-orange; contains some bentonite seams	20	20
Limestone, dark-gray; contains some bentonite seams	20	40
Graneros Shale		
Shale, dark-gray, slightly calcareous	10	50

16-10W-3bbb1.—Sample log of test hole in the NW cor. sec. 3, T.16 S., R.10 W., east side of road, 115 feet south of section corner; augered July 7, 1961. Altitude of land surface, 1,755 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, dark-grayish-brown	5	5
Silt, brown; contains some small caliche nodules	3	8
Silt, tan; contains some fine locally derived gravel in lower part	4	12
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, light-gray and yellow	3	15

16-10W-9aaa.—Sample log of test hole in the NE cor. sec. 9, T.16 S., R.10 W., west side of road, 50 feet south of intersection; augered July 7, 1961. Altitude of land surface, 1,824 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, brown; contains some coarse sand and caliche nodules	5	5
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
colorado group		
Greenhorn Limestone		
Chalk, light-yellowish-orange	2	7

16-10W-15ccc.—Sample log of test hole in the SW cor. sec. 15, T.16 S., R.10 W., north side of road, 20 feet east of intersection; augered July 7, 1961. Altitude of land surface, 1,884 feet; dry hole.

	Thickness, feet	*Depth, feet*
Soil	1	1
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
colorado group		
Greenhorn Limestone		
Chalk, dark-grayish-yellow	7	8

16-10W-16aaa.—Sample log of test hole in the NE cor. sec. 16, T.16 S., R.10 W., west side of road, 75 feet south of section corner; augered July 7, 1961. Altitude of land surface, 1,857 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, clayey, dark-grayish-brown	5	5
Silt, brown	7	12
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
colorado group		
Greenhorn Limestone		
Chalk, dark-grayish-yellow	3	15

16-10W-21ddd.—Sample log of test hole in the SE cor. sec. 21, T.16 S., R.10 W., west side of road at section corner; augered July 7, 1961. Altitude of land surface, 1,845 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, dark-grayish-brown	5	5
Silt, medium-brown	4	9
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
colorado group		
Graneros Shale		
Shale, clayey, light-tan and yellowish-orange	2	11

16-10W-26ccc2.—Sample log of test hole in the SW cor. sec. 26, T.16 S., R.10 W., 35 feet north and 10 feet east of center of intersection; augered July 11, 1964. Altitude of land surface, 1,818 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, dark-grayish-brown	15	15
Silt, tannish-brown; contains much caliche	5	20
kansan stage		
Sappa and Grand Island Formations		
Silt, fine, sandy, tan	7	27
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
colorado group		
Graneros Shale		
Shale, yellowish-brown	5	32

16-10W-26ddd.—Sample log of test hole in the SE cor. sec. 26, T.16 S., R.10 W., in north road ditch, 200 feet west of intersection; augered July 11, 1964. Altitude of land surface, 1,855 feet; dry hole.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, clayey, dark-gray	15	15
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
colorado group		
Greenhorn Limestone		
Shale, limy, very dark gray	5	20

16-10W-28baa.—Sample log of test hole in the NE¼ NE¼ NW¼ sec. 28, T.16 S., R.10 W., on west edge of oil service road, 63 feet south of county road; drilled August 31, 1961. Altitude of land surface, 1,855 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, grayish-brown	10	10
Silt, light-brown; contains some caliche	17	27
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
colorado group		
Greenhorn Limestone		
Limestone, chalky, yellowish-orange, some light-gray	3	30
Graneros Shale		
Shale, clayey, yellowish-orange, noncalcareous, contains some bentonite seams	28	58
Clay, dark-gray	2	60

16-10W-28ddd.—Sample log of test hole in the SE cor. sec. 28, T.16 S., R.10 W., west side of road, 60 feet north of intersec-

	Thickness, feet	*Depth, feet*
Silt, dark-grayish-brown; contains some sand	4	4
Silt, dark-brown	5	9
Silt, dark-brown, and fine sand	5	14
Silt, brown; contains much coarse to very coarse sand	46	60
PERMIAN SYSTEM		
Lower Permian Series		
CIMARRONIAN STAGE		
Sumner Group		
Ninnescah Shale		
Siltstone, clayey, reddish-gray	5	65

17-7W-31aaa.—Sample log of test hole in the NE cor. sec. 31, T.17 S., R.7 W., south side of road, 40 feet west of intersection; augered June 28, 1961. Altitude of land surface, 1,730 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
WISCONSINAN AND ILLINOISAN STAGES		
Peoria and Loveland Formations		
Silt, clayey, medium-dark-brown	7	7
Silt, reddish-brown; contains some caliche	8	15
Silt, light-brown; contains much caliche in lower half	15	30
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Siltstone, grayish-yellow	9	39
Sandstone, yellowish-orange	9	48

17-7W-32aaa.—Sample log of test hole in the NE cor. sec. 32, T.17 S., R.7 W., south side of road, 80 feet west of intersection; augered June 28, 1961. Altitude of land surface, 1,736 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
WISCONSINAN AND ILLINOISAN STAGES		
Peoria and Loveland Formations		
Silt, dark-grayish-brown	5	5
Silt, brown; contains caliche nodules	4	9
Silt, light-brown; contains some caliche	5	14
Silt, yellowish-orange; contains some locally derived gravel in lower part	1	15
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, yellowish-orange	2	17

17-7W-33aaa.—Sample log of test hole in the NE cor. sec. 33, T.17 S., R.7 W., south side of road at corner; augered June 28, 1961. Altitude of land surface, 1,710 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
WISCONSINAN AND ILLINOISAN STAGES		
Peoria and Loveland Formations		
Silt, dark-grayish-brown	5	5
Silt, light-olive-gray	4	9
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Siltstone, reddish-brown	3	12
Sandstone, light-gray and red	3	15

17-8W-27ddd.—Sample log of test hole in the SE cor. sec. 27, T.17 S., R.8 W., north side of road, 45 feet west of intersection; augered June 29, 1961. Altitude of land surface, 1,786 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
WISCONSINAN AND ILLINOISAN STAGES		
Peoria and Loveland Formations		
Silt, clayey, dark-grayish-brown	5	5
Silt, brown	8	13
Clay, silty; contains much caliche	2	15
Clay, yellowish-gray	2	17
Silt, light-gray	3	20
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Siltstone, pale-yellowish-orange	2	22

17-8W-31aaa.—Sample log of test hole in the NE cor. sec. 31, T.17 S., R.8 W., south side of road, 40 feet west of intersection; augered June 29, 1961. Altitude of land surface, 1,768 feet; depth to water, 37.2 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
WISCONSINAN AND ILLINOISAN STAGES		
Peoria and Loveland Formations		
Silt, clayey, dark-grayish-brown	3	3
Silt, medium-brown	2	5
Silt, grayish-brown; contains caliche nodules	5	10
Silt, light-grayish-brown	4	14
Silt, dark-brown, sandy in lower part	22	36
KANSAN STAGE		
Sappa and Grand Island Formations		
Silt, light-greenish-gray	14	50
Silt, tan	12	62
Sand, fine to medium	5	67
Gravel, fine to coarse; derived from local rocks	5	72
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, light-yellowish-orange and light-gray, some red mottling	3	75

17-8W-32aaa.—Sample log of test hole in the NE cor. sec. 32, T.17 S., R.8 W., south side of road, 60 feet west of intersection; augered June 29, 1961. Altitude of land surface, 1,783 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
WISCONSINAN AND ILLINOISAN STAGES		
Peoria and Loveland Formations		
Silt, clayey, dark-grayish-brown	4	4
Silt, dark-brown	6	10
Silt, medium-brown	9	19
Silt, tan; contains much caliche	9	28
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, fine-grained, gray	5	33

17-8W-33aaa.—Sample log of test hole in the NE cor. sec. 33, T.17 S., R.8 W., south side of road, 90 feet west of intersection; augered June 29, 1961. Altitude of land surface, 1,770 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
WISCONSINAN AND ILLINOISAN STAGES		
Peoria and Loveland Formations		
Silt, clayey, dark-grayish-brown	10	10
Silt, brown; contains caliche	10	20
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, yellowish-orange	1	21

17-8W-35aaa.—Sample log of test hole in the NE cor. sec. 35, T.17 S., R.8 W., south side of road, 60 feet west of intersection; augered June 28, 1961. Altitude of land surface, 1,758 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
WISCONSINAN AND ILLINOISAN STAGES		

	Thickness, feet	*Depth, feet*
Silt, medium-brown; contains caliche nodules	12	21
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, medium-tannish-brown	3	24

17-9W-35aaa.—Sample log of test hole in the NE cor. sec. 35, T.17 S., R.9 W., south side of road, 65 feet west of intersection; augered June 29, 1961. Altitude of land surface, 1,773 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, clayey, dark-grayish-brown	5	5
Silt, tannish-gray	6	11
Silt, light-brown; contains caliche	10	21
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Siltstone, light-gray; contains some red spots	2	23

17-9W-36aaa.—Sample log of test hole in the NE cor. sec. 36, T.17 S., R.9 W., south side of road, 35 feet west of intersection; augered June 29, 1961. Altitude of land surface, 1,787 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, black	4	4
Silt, dark-brown	4	8
Silt, light-brown; contains caliche nodules	10	18
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Siltstone, light-grayish-yellow	7	25

17-10W-4aaa.—Sample log of test hole in the NE cor. sec. 4, T.17 S., R.10 W., west side of road, 131 feet south of intersection; augered June 30, 1961. Altitude of land surface, 1,823 feet; depth to water, 33.3 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, dark-grayish-brown	6	6
Silt, light-brown	19	25
Silt, brown; contains much caliche	13	38
kansan stage		
Sappa and Grand Island Formations		
Silt, fine sandy, tan	20	58
Gravel, fine to coarse, and sand; composed of Dakota sandstone and siltstone, and caliche	13	71
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, light-yellowish-orange, some red mottling	6	77

17-10W-6bbb.—Sample log of test hole in the NW cor. sec. 6, T.17 S., R.10 W., in field 20 feet south of center of road and 144 feet east of section corner; drilled August 31, 1961. Altitude of land surface, 1,907 feet.

	Thickness, feet	*Depth, feet*
Soil	2	2
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
colorado group		
Greenhorn Limestone		
Limestone, chalky, and shale, yellowish-orange	18	20
Limestone, chalky, and shale, dark-gray; contains some bentonite seams	59	79
Graneros Shale		
Shale, clayey, dark-gray	21	100

17-10W-9aaa.—Sample log of test hole in the NE cor. sec. 9, T.17 S., R.10 W., west side of road, 80 feet south of intersection; augered July 7, 1961. Altitude of land surface, 1,809 feet; depth to water, 14.0 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, dark-grayish-brown	5	5
Silt, brown; contains caliche in lower part	15	20
kansan stage		
Sappa and Grand Island Formations		
Silt, fine sandy, tan	17	37
Silt, tannish-brown; contains much sand and some locally derived gravel in lower part	11	48
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, dark-gray, some red mottling	7	55

17-10W-9ddd1.—Sample log of test hole in the SE cor. sec. 9, T.17 S., R.10 W., west side of road, 80 feet north of intersection; augered July 7, 1961. Altitude of land surface, 1,824 feet; depth to water, 10 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, clayey, black	7	7
Silt, dark-yellowish-orange; contains some caliche	2	9
CRETACEOUS SYSTEM		
Upper Cretaceous Series		
colorado group		
Graneros Shale		
Shale, clayey, medium-gray	1	10

17-10W-11dcd.—Sample log of test hole in the SE¼ SW¼ SE¼ sec. 11, T.17 S., R.10 W., north side of road, 200 feet east of bridge; augered July 12, 1964. Altitude of land surface, 1,780 feet; depth to water, 22.0 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, brown	7	7
Silt, tannish-brown; contains caliche nodules	13	20
kansan stage		
Sappa and Grand Island Formations		
Silt, tan	25	45
Silt, tan, and fine sand	12	57
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Shale, clayey, dark-gray	1	58

17-10W-13aaa.—Sample log of test hole in the NE cor. sec. 13, T.17 S., R.10 W., west side of road, 50 feet south of intersection; augered July 12, 1964. Altitude of land surface, 1,777 feet; depth to water, 20.8 feet.

	Thickness, feet	*Depth, feet*
QUATERNARY SYSTEM		
Pleistocene Series		
wisconsinan and illinoisan stages		
Peoria and Loveland Formations		
Silt, dark-grayish-brown	5	5
Silt, brown	5	10

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan and Illinoisan stages		
Peoria and Loveland Formations		
Silt, clayey, light-grayish-brown	5	5
Silt, clayey, medium-brown; contains caliche nodules in upper half	21	26
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, light-red and yellowish-orange	9	35

17-10W-34aaa.—Sample log of test hole in the NE cor. sec. 34, T.17 S., R.10 W., south side of road, 75 feet west of intersection; augered July 6, 1961. Altitude of land surface, 1,806 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan and Illinoisan stages		
Peoria and Loveland Formations		
Silt, clayey, dark-grayish-brown	4	4
Silt, reddish-brown	2	6
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, light-gray with much red mottling	4	10

17-10W-34bbb.—Sample log of test hole in the NW cor. sec. 34, T.17 S., R.10 W., south side of road, 70 feet east of intersection; augered July 6, 1961. Altitude of land surface, 1,811 feet; dry hole.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan and Illinoisan stages		
Peoria and Loveland Formations		
Silt, clayey, dark-grayish-brown	5	5
Silt, dark-brown	4	9
Silt, medium-brown; contains small caliche nodules	14	23
Silt, grayish-yellow; contains much caliche	7	30
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Siltstone, light-grayish-yellow and tan	10	40

17-10W-35aaa.—Sample log of test hole in the NE cor. sec. 35, T.17 S., R.10 W., south side of road, 85 feet west of intersection; augered July 6, 1961. Altitude of land surface, 1,794 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan and Illinoisan stages		
Peoria and Loveland Formations		
Silt, light-grayish-brown; contains caliche in lower part	5	5
Silt, brown	15	20
Silt, light-brown; contains caliche	6	26
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, gray, mottled red; contains hematite pebbles	11	37

17-10W-36aaa.—Sample log of test hole in the NE cor. sec. 36, T.17 S., R.10 W., south side of road, 45 feet west of intersection; augered July 6, 1961. Altitude of land surface, 1,744 feet; depth to water, 4.4 feet.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan stage		
Fluvial deposits		
Silt, clayey, grayish-brown	3	3
Silt, grayish-brown	8	11
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Clay, dark-gray	14	25

17-11W-36aaa.—Sample log of test hole in the NE cor. sec. 36, T.17 S., R.11 W., south side of road, 50 feet west of intersection; augered July 7, 1961. Altitude of land surface, 1,818 feet; dry hole.

	Thickness, feet	Depth, feet
QUATERNARY SYSTEM		
Pleistocene Series		
Wisconsinan and Illinoisan stages		
Peoria and Loveland Formations		
Silt, clayey, dark-grayish-brown	5	5
Silt, medium-brown; contains very fine sand and some caliche	29	34
Silt, medium-brown; contains caliche nodules	8	42
CRETACEOUS SYSTEM		
Lower Cretaceous Series		
Dakota Formation		
Sandstone, very fine grained, brown	15	57

STRATIGRAPHIC SECTIONS

The following measured sections represent typical exposures of outcropping rocks in Ellsworth County.

1. *Section across Kiowa Formation-Ninnescah Shale contact in cutbank in the NE¼NW¼SW¼ sec. 1, T.17 S., R.6 W., Ellsworth County, Kans. Measured by Paul C. Franks.*

	Thickness, feet
Kiowa Formation:	
Covered.	
4. Shale, medium-gray with olive-gray to reddish-brown overtones and jarosite stain, weathers moderate olive gray; clay fraction composed mainly of illite and montmorillonite but contains appreciable kaolin; thin-laminated; fissile. Top marked by weathered zone of cone-in-cone concretions as much as 1 foot thick; upper parts of sequence contain scattered gypsum crystals. Base marked by silty limestone or coquina bed about 0.1 foot thick; dusky-red to blackish-red; contains *Turritella, Ostrea,* and other pelecypods. Sparse discoidal impure siderite concretions	12.2
3. Shale, medium-gray with olive-gray to reddish-brown stain, weathers moderate olive gray; clay fraction composed largely of illite and montmorillonite but contains appreciable kaolin; very sparse chlorite near base; thin-laminated; fissile; plastic. Wavy contact with next below. Base Kiowa Formation	22.0
Thickness of exposed Kiowa Formation	34.2
Unconformity.	
Ninnescah Shale:	
2. Siltstone, moderate-light-green to light-greenish-gray, thin-laminated but poor fissility, blocky fracture; illitic and chloritic; sparse expansible mixed-layer clay. Top 0.1 to 0.4 foot stained moderate reddish brown to dark yellowish orange by iron oxide; dolomitic cement near top forms thin resistant ledge. Grades irregularly into next below	2.9
1. Siltstone, moderate-reddish-brown to grayish-red, blocky to conchoidal fracture, locally indistinctly laminated; illitic, chloritic, and contains sparse vermiculitic or chloritic mixed-layer clay; contains sparse irregular seams of pale-green to light-greenish-gray dolomitic siltstone as much as 1 foot thick. Sparse beds less than 0.1 foot thick of silty micaceous white to light-greenish-gray dolomite; scat-	

	Thickness, feet
22. Siltstone, medium-light-gray, sparse lenticular siltstone laminae, blocky fracture; clay fraction largely composed of kaolin. Grades sharply into next below	1.7
21. Siltstone or sandstone, yellowish-gray with "limonite" stain, silt-sized to very fine grained; sparse films and laminae of gray shale carrying carbon flecks; ripple-laminated; micaceous; sparse carbonized wood fragments	1.4
20. Siltstone, medium-light-gray with brown overtones, thin-laminated, non-fissile, blocky fracture; abundant carbon as flecks and woody fragments; most argillaceous near base. Grades sharply into next below	1.0
19. Siltstone and clay. Largely light-gray and very light gray to light-greenish-gray siltstone with abundant moderate-red mottles as much as 0.15 foot in long dimension . Mottles form aggregates or nearly vertical streaks as much as 1 foot in long dimension . Top 1 foot is light gray with sparse mottling. Encloses lenses of plastic medium-gray to medium-dark-gray clay as much as 3 feet thick and about 5 feet above base of unit; clay fraction composed largely of kaolin	11.4
18. Covered interval. Scattered exposures of gray to greenish-gray kaolinitic siltstone and clay with red mottles	14.0
17. Clay grading down to shale and siltstone. Clay, light-gray with dark-reddish-brown mottles; mottling less apparent downward. Basal 1 to 2 feet of sequence is shale containing siltstone laminae. Shale, light-gray to very light gray. Siltstone laminae concentrated in basal 0.5 foot, dusky-yellow to moderate-red; abundant iron-oxide stain in basal silty interval. Clay fraction composed mainly of kaolin. Laterally becomes medium-light-gray and light-gray siltstone and clay with moderate-red mottling; dark yellowish-orange "limonite" stain common; blocky fracture; sparse gypsum crystals on fracture surfaces; contains sparse subspherical clay-siderite(?) concretions as much as 1 foot in diameter near base. Base Dakota Formation	6.0
Thickness of exposed Terra Cotta Clay Member	59.2
Kiowa Formation:	
16. Zone of iron-oxide concentration, moderate-reddish-brown to dark-yellowish-orange, abundant gypsiferous coatings along subhorizontal wavy hematitic veinlets, silty, argillaceous; clay fraction composed mainly of kaolin and "degraded" illite. Grades irregularly into next below and next above. Laterally becomes ripple-laminated and horizontally laminated sandstone containing shaley laminae, U-shaped *Arenicolites* burrows, and abundant iron-oxide stain and cement in top 2.5 feet	0.5
15. Intercalated siltstone and sandstone. Siltstone is very light gray to medium-gray; sandstone is yellowish-gray, very fine grained, friable except where locally cemented by calcite; clay fraction composed mainly of kaolin and "degraded" illite; micaceous; contains sparse carbon flecks along bedding surfaces; laminated to thin-bedded; interfingers laterally with sandstone next below and with sandstone like that described above. Thickness variable but approximates	1.3
14. Sandstone, yellowish-gray, stained pink and red by clay wash from basal Dakota, very fine to fine-grained; sparse clay pellets in basal 2 feet; small- and medium-scale wedge-planar to tabular high-angle cross-lamination; cross-stratification dip bearings highly varied but mainly to southwest; set boundaries about horizontal or inclined a few degrees in direction of dip of cross-strata; sparse microcross-beds. Symmetrical transverse cord interference ripple marks common on set boundaries; wave lengths less than 0.3 foot. Ripple and even lamination more common than cross-stratification in upper 2 to 3 feet. Calcite cement locally forms calcareous concretions as much as 6 feet long and 3 feet thick near top of sandstone. Friable, micaceous, sparse shaley partings, grains of pink chert; sparse U-shaped *Arenicolites* burrows in upper 2 to 3 feet. Sharp contact with siltstone next below. Thickness variable; thickens southward to interfinger with and to replace most of the section described below. Measured	7.5
13. Siltstone, light-gray grading down to medium-light-gray; kaolinitic and illitic; indistinct lamination; sparse carbon flecks; jarosite stain near base; silty near middle of unit. Sharp contact with next below. Pinches out to south	1.5
12. Sandstone and siltstone grading down to argillaceous siltstone, very light gray grading to medium-light-gray in basal 1 foot; sparse yellowish-orange "limonite" stain; very fine grained to silt-sized; ripple-laminated in upper parts; sparse clay films in upper parts; bedding indistinct in lower parts. Undulose contact with next below; seems to grade laterally into sandstone	3.0
11. Siltstone, brownish-gray, indistinctly laminated, plastic; contains abundant dissiminated carbon flecks; clay fraction largely kaolinitic. Grades sharply into next below; pinches out to south	1.0
10. Siltstone and sandstone interlaminated with shale, very light gray with medium-gray shale laminae, weathers dark yellowish-orange, ripple-laminated. Sandstone, very fine-grained, most abundant at top and bottom of sequence. Sequence contains sparse U-shaped *Arenicolites* burrows; micaceous; carbon as flecks and woody fragments; sparse marcasite and siderite nodules. Grades laterally into sandstone; sharp contact with next below	3.1
9. Siltstone and shale, interlaminated, very light gray and medium-gray, weathers dark-yellow-orange; clay fraction largely kaolinitic but with appreciable "degraded" illite; ripple-laminated; proportions of shale increase downward. Where shale is more abundant than siltstone, siltstone forms bands and contorted laminae less than 1 cm thick. Jarosite stain in basal 2 feet; scattered marcasite nodules; micaceous; sparse carbon flecks on bedding surfaces. Grades laterally into sandstone and siltstone like next above; grades sharply into next below	3.7
8. Clay grading down to siltstone, dark-gray grading down to light-gray with brown overtones; poor fissility in upper 0.5 foot; clay fraction largely kaolinitic; yellowish-gray to brownish-gray argillaceous veins penetrate into siltstone from upper clay; sparse carbonaceous flecks and fragments, mainly in lower 5.5 feet	7.0
7. Clay, grayish-black grading down to brownish-gray; clay fraction composed mainly of kaolin and "degraded" illite and montmorillonite. Upper 2 feet very carbonaceous or lignitic and transected by yellowish-gray to brownish-gray veinlets less than 4 mm thick; veinlets decrease in abundance downward. Blocky fracture, indistinct lamination in upper 1.5 feet. Scattered carbonaceous flecks, carbonized wood fragments, and leaf imprints below upper lignitic clay	4.3
6. Clay, as above, with carbonaceous or lignitic top; medium-light-gray at base and carrying	

	Thickness, feet
15. Siltstone, light-gray with brown overtones, argillaceous; clay fraction kaolinitic but contains appreciable illite and "degraded" illite; plastic; bedding indistinct; micaceous. Generally stained by wash from next above. Grades into next below	1.5
14. Siltstone and sandstone. Siltstone grades down into interlaminated siltstone and sandstone in basal 3 feet. Siltstone, medium-light-gray, weathers very light gray; clay fraction kaolinitic, but contains appreciable illite; plastic; micaceous; contains carbon flecks and fragments; laminated where intercalated with sandstone. Sandstone, grayish-orange, weathers very light gray, very fine grained, micaceous. Sequence thickens to south and interfingers with sandstone next below	5.7
13. Sandstone, very pale orange, weathers white to light-grayish-orange and very light gray, very fine- to fine-grained, crossbedded; sparse horizontal laminae; cross-strata mainly in tabular sets as much as 2.5 feet thick, sparse wedge-planar sets; set boundaries locally dip as much as 5 degrees in reverse direction from cross-strata; vector resultant of cross-stratification dip bearings is N. 55° W.; horizontal laminae in sets as much as 1.5 feet thick; sparse gray shaly partings; micaceous; sparse grains of pink chert and black opaques. Forms prominent bench and thins southward. Scour-fill contact with next below	12.0
12. Siltstone grading down into clay, very light gray grading down to light-gray and light-greenish-gray with pale-red to dark-reddish-brown mottles, weathers white to very pale orange with moderate-reddish-orange to dark-grayish-pink stain in mottled parts; clay fraction contains kaolin and some illite and "degraded" illite; blocky to conchoidal fracture; waxy luster in basal 2 feet. Grades into next below	3.9
11. Clay, light gray, weathers very light gray, non-fissile but laminated to thin-laminated; composed largely of kaolin but contains appreciable illite and "degraded" illite; hard; waxy luster; contains carbon flecks and fragments. Grades sharply into next below	1.2
10. Siltstone, very light gray with moderate-reddish-brown mottles in lower half, weathers white or very pale orange with moderate-reddish-orange to pale-reddish-brown stain; clay fraction composed largely of kaolin, illite, and "degraded" illite; hard; blocky fracture; indistinctly laminated in basal and top 0.5 foot; contains sparse grains or pellets of hematite probably derived from siderite	3.9
9. Clay, grayish-black grading down to moderate-olive-gray, weathers medium light gray to very light gray with olive to brown overtones; composed largely of kaolin, illite, and "degraded" illite; plastic; weathers to puffy slope littered with sparse gypsum crystals. Indistinctly laminated but nonfissile; contains carbon as flecks, fragments, and films; thin-laminated and lignitic in upper 0.5 foot. Grades sharply into sandstone next below by increasing silt and sand content. Base Dakota Formation	2.4
Thickness of exposed Terra Cotta Clay Member	110.3
Kiowa Formation:	
8. Sandstone, moderate-red to dark-yellowish-orange, fine-grained, very argillaceous; bedding indistinct; abundant iron-oxide cement; weathers to concretionary masses, lumps, and aggregates less than 1 foot thick and 2 feet in long diameter cemented by iron oxide. Grades irregularly into next below	1.0
7. Siltstone grading down into shale, medium-light-gray to medium-gray, weathers light gray; upper parts stained dark yellowish orange by wash from next above; laminated toward base; clay fraction composed largely of kaolin, illite, and "degraded" illite; silt content decreases downward; sparse jarosite stain. Basal 0.5 foot contains siltstone or very fine grained sandstone laminae. Grades sharply into next below by alternation of lithology	3.1
6. Sandstone, siltstone, and shale, interbedded. Shale laminae increase in abundance downward. Siltstone and sandstone, very light gray to light-gray; shale, medium-gray; sequence weathers very pale orange to dark yellowish orange. Thin-bedded and ripple- and even-laminated. Prominent close-spaced vertical joints in sandy and silty parts. Contains sparse marcasite or pyrite nodules; nodular concentrations of calcite cement; disseminated iron-oxide cement in upper foot; micaceous; small, nearly vertical burrows about 2 mm in diameter in sandy and silty parts. Grades sharply into next below by loss of lamination and decrease in abundance of silt	7.5
5. Siltstone and shale, medium-gray, weathers light gray to light olive gray; composed largely of kaolin, illite, and "degraded" illite; non-fissile in upper 1 foot; otherwise thin-laminated. Abundant discoidal concretions of impure siderite as much as 0.3 foot thick and 3.5 feet long along bedding planes	13.8
4. Shale, medium-gray, weathers light gray to light olive gray; composed mainly of illite and montmorillonite, but contains appreciable kaolin; thin-laminated; abundant discoidal concretions of impure siderite as much as 0.1 foot thick and 2 feet in long diameter below zone of cone-in-cone. Top marked by sandstone bed about 0.2 foot thick, medium-gray to pale-yellowish-orange, calcareous cement, glauconitic; numerous marcasite nodules. Concretions of cone-in-cone with radial arrangement of cones locally project downward into the shale from the base of the sandstone bed; concretions as much as 0.5 foot thick and 2 feet in long diameter	5.8
3. Shale, medium-dark-gray, weathers medium light-gray; clay fraction composed largely of illite and "degraded" illite; laminated, silty; abundant gypsum crystals on weathered slope. Contains beds of very fine grained dark-yellowish-orange sandstone as much as 1 foot thick; laminated, calcareous, glauconitic, marcasite nodules. Sequenee grades sharply into next below	4.7
2. Siltstone, brownish-gray, weathers light gray with brown overtones; abundant carbon as fragments, flecks, and film; micaceous. Basal 0.5 foot has laminae of dark-yellowish-orange siltstone or very fine grained sandstone; sandy base grades laterally into ripple-laminated and cross-bedded very fine grained sandstone; bedding surfaces of sandstones show nearly symmetrical transverse ripple marks striking N. 40° W.	4.2
1. Shale, medium-dark-gray, light-brown to dark-reddish-brown stain along sandstone seams, dominantly illitic; thin-laminated; gypsum crystals on weathered slopes. Sandstone seams as much as 0.1 foot thick; very fine grained, micaceous, calcareous	3.3
Thickness of exposed Kiowa Formation	43.4

6. *Section across Dakota Formation-Kiowa Formation contact at Buzzard's Roost (Needle's Eye) in the SE¼NE¼ sec. 15, T.15 S., R.6 W., Ellsworth County, Kans. Measured by William Ives, Jr.*

	Thickness, feet
carbonaceous, kaolinitic, laminated in upper part but with poor fissility, blocky to platy fracture. Scattered argillaceous "limonite" concretions as much as 0.5 foot in diameter. Grades into next below	4.7
5. Siltstone and sandstone, medium-dark-gray to dark-gray, weathers medium light gray. Very fine grained sandstone at base, siltier in upper parts; indistinct wavy and contorted thin-bedding or thin-laminae. Abundant interstitial kaolin; abundant carbon as fragments, flecks, and films; sparse jarosite and "limonite" stain. Forms crumbly ledge. Wavy contact with next below	2.1
4. Siltstone, very light gray with abundant moderate-red mottles, weathers to puffy very pale orange to dark-grayish-pink slope, abundant yellowish-orange iron-oxide stain in top 2 feet, kaolinitic, plastic near top, non-plastic below; very silty near base. Abundant siderite spherules disseminated in gray parts; much of the siderite largely oxidized to hematite. Grades sharply into next below	7.7
3. Siltstone, very light gray but much weathered and stained dark yellowish orange by iron oxide, moderate-red mottles where fresh; contains abundant limonite speckles relict from siderite(?) spherules; thin- to medium-bedded; sparse gray shaly laminae	4.5
2. Clay, medium-light-gray grading down to medium-dark-gray with sparse dusky-red mottles, weathers to puffy light gray slope stained pale grayish orange by wash from next above, dominantly kaolinitic, plastic; laminated and fissile in upper parts; no obvious bedding in lower parts. Grades sharply into next below	5.6
1. Siltstone, medium-light-gray with sparse moderate-red mottles, weathers to puffy light-gray and yellowish-gray slope, abundant yellowish-orange iron-oxide stain in top 0.1 foot, dominantly kaolinitic, hard, blocky to conchoidal fracture; contains abundant siderite spherules as much as 1 mm in diameter in gray siltstone between mottles	1.7
Thickness of exposed Janssen Clay Member	35.8

8. *Section across Graneros Shale-Dakota Formation contact 0.1 mile northwest of the cen. N½ sec. 6, T.15 S., R.10 W., Ellsworth County, Kans., on the west side of the road. Section starts at base of Dakota siltstone and clay exposed in road ditch. Measured by Paul C. Franks.*

	Thickness, feet
Graneros Shale:	
Covered.	
15. Shale, medium-dark-gray, weathers medium light gray with brown overtones and to puffy light-olive-gray slope, kaolinitic but contains appreciable illite and illite-montmorillonite mixed-layer clay, thin-laminated, fissile; sparse very light gray to dark-yellowish-orange siltstone laminae; sparse white kaolin seams containing appreciable montmorillonite as much as 0.1 foot thick; abundant jarosite stain; sparse imprints of pelecypods. Sharp contact with next below	6.0
Thickness of exposed Graneros Shale	6.0
Dakota Formation:	
Janssen Clay Member:	
14. Sandstone, grayish-orange, weathers pale grayish orange to dark yellowish orange, very fine grained, laminated to thin-bedded; laminae commonly wavy; bedding commonly masked by calcite cement; sparse dark-gray shaly partings. Abundant limonitic speckles and stain; sparse gypsum as crystals and cement; locally may contain siderite cement. Grades into next below	1.5
13. Shale, medium-dark-gray with brown overtones, weathers medium light gray to light brownish gray, dominantly kaolinitic but contains appreciable illite and mixed layer clay, nonsilty, thin-laminated; contains intercalated sandstone laminae near top and siltstone laminae near base; scattered lenses as much as 0.5 foot thick of interlaminated siltstone and shale. Abundant carbonized plant debris; carbon flecks, fragments, and films; jarosite stain. Grades into next below by alternation of lithology	4.2
12. Siltstone, very light gray to very light brownish gray, weathers very light gray to yellowish orange depending on abundance of "limonite" and jarosite stain, thin even laminae in upper parts, wavy laminae at base, carbon as flecks and fragments, micaceous. Nearly vertical tubes about 1 cm in diameter and up to 10 cm long may be either root impressions or burrows. Contact with next below is both scour-fill and gradational by alternation of lithology. Thickness somewhat variable, but approximates	2.1
11. Shale, dark-brownish-gray to dark-gray, weathers medium gray with blue to brown overtones, thin-laminated, fissile, papery to platy, dominantly kaolinitic but contains appreciable illite and chloritic and vermiculitic mixed-layer clay; abundant carbon as flakes, films, and fragments; sparse jarosite stains. Grades into next below	0.9
10. Lignite, brownish-black, thin wavy laminae, papery, argillaceous; contains abundant fragments of carbonized wood, imprints of stems and leaves; sparse jarosite stain. Grades sharply into next below	0.6
9. Shale, medium-dark-gray with brown overtones, weathers medium light gray, dominantly kaolinitic, thin-laminated to indistinctly laminated; sparse very light gray siltstone laminae with faint jarosite stain. Silt content increases downward. Grades sharply into next below	1.6
8. Lignite, as above, but with dark-yellowish-orange limonitic stain	0.4
7. Shale, medium-dark-gray grading down to dark-gray, fissile, carbonaceous towards base, kaolinitic but contains sparse montmorillonite and vermiculitic mixed-layer clay; contains laminae and beds of very light gray siltstone as much as 0.1 foot thick in upper half; siltstone shows wavy thin laminae and plant imprints. Gypsum crystals on weathered slopes. Grades into next below	2.6
6. Lignite, as above	0.8
5. Siltstone grading down to sandstone, medium-light-gray with brown overtones grading down to very pale orange, weathers pinkish gray grading down to light gray or moderate yellowish brown. Contains abundant medium-gray siltstone laminae in lower parts. Sandstone, very fine grained and silty. Upper parts of sequence show no obvious bedding; becomes progressively thin-laminated and ripple-laminated downward. Micaceous; abundant carbon as flecks, fragments, and films; limonitic stain in basal sandstone. Grades sharply into next below	5.4
4. Lignite, as above. Grades sharply into next below	0.3
3. Shale grading down into siltstone, brownish-black grading down to medium-dark-gray, weathers medium gray grading down to light gray, dominantly kaolinitic but contains sparse illite and vermiculitic mixed-layer clay, fissile, thin-laminated and papery becoming blocky	

	Thickness, feet
feet below top is a thin bed of bentonite; lines of concretionary or nodular limestone beds occur at about 1-foot intervals separated by yellowish-orange chalky shale; contains clams and other fossils	8.9
28. Limestone, pale-orange, fossiliferous	.3
27. Chalky shale, dark-grayish-orange, poorly laminated, fossiliferous	5.4
Thickness of exposed Carlile Shale	14.6
Greenhorn Limestone:	
Pfeifer Shale Member:	
26. Limestone (Fence-post bed), light-grayish-orange with a middle band of dark-grayish-orange	1.0
25. Chalky shale, dark-grayish-orange, poorly laminated	2.9
24. Limestone, light-pinkish-gray	.3
23. Chalky shale, dark-grayish-orange	.9
22. Limestone, light-pinkish-gray	.4
21. Chalky shale, dark-grayish-orange	.9
20. Limestone, light-pinkish-gray	.4
19. Chalky shale, grayish-orange	.8
18. Limestone, pale-orange	.2
17. Chalky shale, grayish-orange and light-gray; contains nodules of limestone	2.1
16. Limestone, pale-orange	.4
15. Chalky shale, light-grayish-orange	2.1
14. Limestone, light-grayish-orange	.3
13. Chalky shale, pinkish-gray to grayish-orange, fossils, poorly laminated	2.2
12. Limestone, light-grayish-orange	.4
11. Chalky shale, pinkish-gray and grayish-orange	1.0
10. Limestone, light-grayish-orange	.2
9. Chalky shale, pinkish-gray to grayish-orange	1.3
Thickness of Pfeifer Shale Member	17.8
Jetmore Chalk Member and Hartland Shale Member, undifferentiated:	
8. Limestone, light-grayish-orange; contains numerous clams	0.4
7. Chalky shale, very pale orange with darker bands 4.2 feet and 8.2 feet below top; contains a 0.4-foot-thick bentonite bed 5 feet above base, and another 0.5-foot-thick bed at the base; fossiliferous	16.6
6. Limestone, brownish-gray, finely crystalline	.2
5. Chalky shale, yellowish-orange with some lighter and darker bands throughout	12.5
4. Limestone, brownish-gray, finely crystalline	.1
3. Chalky shale, yellowish-orange with lighter and darker bands throughout	15.6
Total thickness of exposed Jetmore Chalk and Hartland Shale Members, undifferentiated	45.4
Lincoln Limestone Member:	
2. Limestone, brownish-gray with some light-gray, thin-bedded; separated by thin chalky shale beds; petroleum odor on fresh break; contains fossil fragments. Thin bentonite bed 1.6 feet below top	2.6
Thickness of Lincoln Limestone Member	2.6
Graneros Shale:	
1. Shale, dark-yellowish-brown in upper part grading to light-gray in lower part, laminated in upper 15 feet; contains small selenite crystals; unfossiliferous	24.2
Thickness of exposed Graneros Shale	24.2

12. *Section from Fairport Chalk Member of Carlile Shale down into Graneros Shale in the NE¼ sec. 11, T.14 S., R.8 W., Ellsworth County, Kans. Section measured in east and west road ditches along Kansas Highway 14. Measured by William Ives, Jr.*

	Thickness, feet
Carlile Shale:	
Fairport Chalk Member:	
34. Chalky shale, light-grayish-orange mottled both lighter and darker, poorly laminated, weathers platy or flaky; contains several lines of nodular pale-orange limestone. Bentonite 6.5 feet above base	9.4
Thickness of exposed Fairport Chalk Member	9.4
Greenhorn Limestone:	
Pfeifer Shale Member:	
33. Limestone (Fence-post bed), very light gray, weathers light grayish orange; contains darker streak in middle part; fossiliferous	1.1
32. Chalky shale, pale-orange containing darker zones, poorly laminated, weathers platy; contains nodular limestone in middle part	2.7
31. Limestone, light-grayish-orange; speckled appearance; very fine sand-sized grains; contains much crystalline calcite	.3
30. Chalky shale, very pale orange, poorly laminated, weathers platy, fossiliferous	1.1
29. Limestone, very light gray, mottled yellow, fossiliferous	.4
28. Chalky shale, very pale orange, poorly laminated	.7
27. Limestone, light-gray	.4
26. Chalky shale, pale-orange, poorly laminated	1.0
25. Limestone, light-gray	.2
24. Chalky shale, grayish-orange	1.0
23. Limestone, light-gray	.2
22. Chalky shale, very pale orange	1.0
21. Limestone, very light gray, mottled yellow	.4
20. Chalky shale, very pale orange; contains darker bands	2.4
19. Limestone, light-grayish-orange, mottled dark-yellowish-orange, weathers into irregular slabs	.5
18. Chalky shale, pale-orange, poorly laminated	1.4
17. Limestone, very light gray, mottled yellow	.3
16. Chalky shale, pale-orange grading to pinkish-gray in lower part	2.5
15. Limestone, light-gray; contains few clam molds and isolated sharks' teeth	.3
14. Chalky shale, pinkish-gray, poorly laminated	1.3
13. Limestone, light-gray, few fossils	.3
12. Chalky shale, dark-pinkish-gray, poorly laminated	1.4
Thickness of Pfeifer Shale Member	20.9
Jetmore Chalk Member and Hartland Shale Member, undifferentiated:	
11. Limestone, light-pinkish-gray, many clam molds and a few isolated cephalopod molds	0.6
10. Chalky shale, light-gray to grayish-orange; contains two darker bands near middle; poorly laminated	9.7
9. Shale, olive-gray, poorly laminated, weathers platy, very calcareous, unfossiliferous	1.8
8. Bentonite, yellowish-orange	.5
7. Covered interval	11.0
6. Limestone, light-olive-gray, weathers light grayish orange, fossiliferous	.3
5. Clay shale, light-brown, very calcareous, unfossiliferous	.8
4. Bentonite, light-yellowish-orange, calcareous in lower part	.5
3. Chalky shale, pale-orange, poorly laminated, weathers crumbly or blocky; contains thin laminae of limestone in lower part. Bentonite beds 3.0 feet above base and 5.0 feet above base; limestone bed 3.2 feet above base	15.5

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GEOHYDROLOGIC MAP OF ELLSWORTH COUNTY, KANSAS

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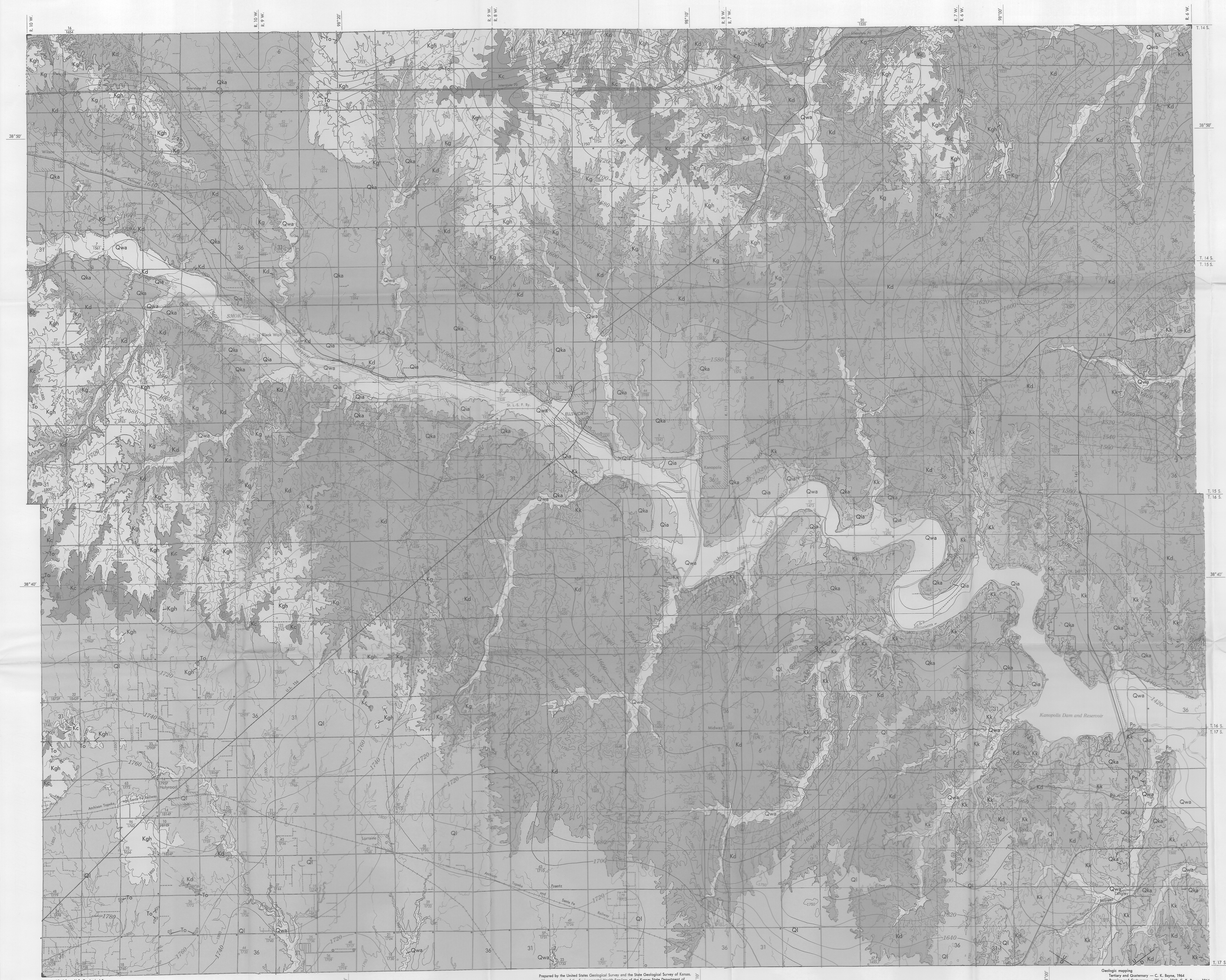
Plate 1



EXPLANATION

QUATERNARY SYSTEM — Pleistocene Series

Qwa — Recent alluvium and Wisconsinan fluvial deposits

Stream-laid deposits of clay, silt, sand, and gravel along principal streams. Wisconsinan age deposits occur in a terrace position to the present stream. Yields moderate quantities of water to wells in principal stream valleys and smaller quantities in tributary valleys.

Ql — Loess

Silt, mostly eolian. Principally Loveland loess of Illinoisan age and Peoria loess of Wisconsinan age but may contain some Bignell loess of Wisconsinan age. Locally present in thin deposits in upland areas and overlies fluvial deposits in abandoned channel areas. Yields no water to wells.

Qia — Loveland and Crete Formations

Alluvial deposits of Illinoisan age in terrace position to younger deposits in principal valleys. Composed of clay, silt, sand, and gravel. Yields small to moderate quantities of water to wells in the major valleys.

Qka — Sappa and Grand Island Formations

Stream-laid deposits of Kansan age consisting of clay, silt, sand, and gravel, and minor amounts of volcanic ash. In terrace position to younger deposits in Smoky Hill River valley and present in lower part of Wilson valley and abandoned channels in southwestern part of county. Locally includes the Fullerton and Holdrege Formations of Nebraskan age. Yields small to moderate quantities of water to wells locally.

TERTIARY SYSTEM — Pliocene Series

To — Ogallala Formation

Soil caliche with distinctive pink banding occurring as thin deposits marking topography at end of Pliocene. Yields no water to wells.

CRETACEOUS SYSTEM — Upper Cretaceous Series

Kc — Carlile Shale

Chalky shale, yellowish-gray to dark-gray, containing persistent beds of chalky limestone and nodular chalky limestone in the lower part. Thin but persistent nearly white, weathering to yellowish orange, bentonite seams are present in the formation. Only the lower part of the Carlile is present in the county. Yields no water to wells.

Kgh — Greenhorn Limestone

Limestone, chalky shale, and chalk, thin-bedded, yellowish-gray to gray, and yellowish-orange bentonite. Yields small quantities of water from upper weathered part in local areas.

Kg — Graneros Shale

Shale and clay shale, fissile, largely noncalcareous, dark-gray to bluish-black on fresh surface, weathering to yellowish brown. Contains thin sandstone beds throughout and locally thin fossiliferous limestone beds. Contains a thin but persistent bentonite bed near the top. Yields small quantities of water locally from sandstone beds.

CRETACEOUS SYSTEM — Lower Cretaceous Series

Kd — Dakota Formation

Clay, silt, shale, sandstone, and siltstone, locally cemented with hematite and limonite. Contains lignite and locally beds of quartzitic sandstone. Colors are white, red, gray, brown, and tan. Yields small to moderate quantities of water to wells from sandstone beds.

Kk — Kiowa Formation

Shale, fissile, light-gray, dark-gray, and black. Contains thin sandstone bodies throughout and a persistent thick light-colored sandstone at top. Beds of cone-in-cone, quartzitic sandstone, siltstone, and thin limestone are common. A marine molluscan fauna occurs in the limestone. Yields small to moderate quantities of water to wells from the sandstone.

PERMIAN SYSTEM — Lower Permian Series

Pn — Ninnescah Shale

Shale and siltstone, reddish-gray and gray. Poorly exposed in the county. Yields no water to wells.

Contact
Dashed where approximately located

U / D
Fault
U; upthrown side
D; downthrown side

1500
Water-table contour
Shows altitude of water table, 1964. Contour interval 20 feet. Datum is mean sea level

62 / 1796P
Upper number is depth to water, in feet below land surface. Lower number is altitude of water table, in feet above mean sea level. P indicates perched water table

Domestic or stock well

Spring

Municipal supply well

Industrial supply well

Irrigation well

Test hole

True North / Magnetic North 11°
APPROXIMATE MEAN DECLINATON, 1961

Scale 1:62 500
1 0 1 2 MILES
Contour interval 50 feet
Datum is mean sea level

Base modified from U.S. Geological Survey

Prepared by the United States Geological Survey and the State Geological Survey of Kansas, with cooperation of the Environmental Health Services of the Kansas State Department of Health and the Division of Water Resources of the Kansas State Board of Agriculture.

Geologic mapping
Tertiary and Quaternary — C. K. Bayne, 1964
Permian and Cretaceous — W. Ives, 1960; C. K. Bayne, 1964
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GEOLOGIC SECTIONS IN ELLSWORTH COUNTY, KANSAS

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Plate 2