UNIVERSITY OF KANSAS PUBLICATIONS

STATE GEOLOGICAL SURVEY OF KANSAS

BULLETIN 27

GROUND-WATER RESOURCES OF KANSAS

By RAYMOND C. MOORE

With chapters by S. W. Lohman, J. C. Frye, H. A. Waite, T. G. McLaughlin and Bruce Latta

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STATE GEOLOGICAL SURVEY OF KANSAS

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* Deceased.

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FOREWORD

People of Kansas are very much concerned about the subject of water resources, although some of them are inclined to give evidence of this concern only when there is a marked deficiency in supply of water or when danger to their property arises from floods. Well-informed citizens know that a state-wide policy of water control and conservation is necessary to the proper development of Kansas. Various federal, state, and local agencies are now engaged in work that is directed toward establishment of the best possible water economy in Kansas, providing for storage or other means of obtaining adequate water supplies in years of drought and regulating flood waters as far as possible. Practices for conservation of soil go hand in hand with conservation and control of water resources.

Water obtained or obtainable from zones below the surface of the ground constitutes a natural resource of Kansas that is comparable in importance to the soil. Both ground water and soil are essentially dependent on geological conditions and are properly included, therefore, as subjects of geological investigation. Advances in technical studies in these fields, however, have resulted in the development of special sciences. That relating to ground-water hydrology includes applications of geology, physics, chemistry, and engineering. The ground waters of Kansas are now being investigated by men specially trained along these lines, under a program of work arranged by the State Geological Survey and the United States Geological Survey in coöperation. This work is coördinated with other activities that are carried on by the Water Resources Division of the State Board of Agriculture, and the Division of Sanitation of the State Board of Health, the Soil Conservation Service, Bureau of Agricultural Economics, and Agricultural Adjustment Administration of the U. S. Department of Agriculture. There is urgent need for continuation and enlargement of this work to determine the nature of water-supply conditions in Kansas and the manner of conserving, controlling, and utilizing the water resources of the state.

The following paper on the ground-water resources of Kansas consists mainly of a discussion requested for inclusion on the program of the Farm and Home Week at Kansas State College. It was presented at Manhattan on February 9, 1940, and with some modifications it is printed in order to be available for circulation to the many people of Kansas who desire information concerning the ground-water resources of the state. The paper is entirely general in scope. It is hoped that such a presentation will be found useful as introduction to detailed ground-water reports on specific areas in Kansas, to be published later.

RAYMOND C. MOORE, *State Geologist and Director.*

Ground-water Resources of Kansas

Raymond C. Moore

INTRODUCTION

Water is a necessity of life. Accordingly, every person is deeply interested in the subject of water supply. He knows that he must have water to drink. He depends indirectly on water for all his food and clothing. He may want water in which to wash. Civilized man has learned also that water serves admirably for a large and ever enlarging list of uses that depend on its easy convertibility from a liquid to a solid or gaseous state and its adaptability as a chemical solvent, a medium for transfer of matter or energy, and a regulator of temperature.

The average consumption of water in towns and cities of the United States amounts to about 100 gallons per person per day. Because of long familiarity with never-failing supplies of water provided by nature, or equally, because of unthinking dependence on others, many individuals are probably unaware of their interest in water, but let water become difficult or impossible to obtain, or let the quality of obtainable water be greatly changed, and there is immediate lively concern. Many Kansas persons—without doubt too many—give little thought to the subject of water when rainfall is normal and when ponds and streams are full, but not too full. Kansas has a smaller natural water supply than many other regions, but we are used to these conditions, and it is the strongly marked departures from what we regard as normal that cause anxiety. Periods of excessive heat and drought such as have recurred in Kansas, especially during the last half-dozen years, bring hardships to very many persons, particularly dwellers on the farm. Alarm is felt when field crops and pasture shrivel from lack of moisture and from heat, when there is insufficient water for the stock, when wells go dry, and when even some towns and cities must haul water in tank cars. Everyone is then water-conscious, as is true also under reverse conditions, when overabundance of rainfall produces disastrous floods.

It is obvious, however, that the subject of water supply should not be given attention only in the times of deficiency or overabundance.

All citizens of Kansas should have enduring interest in questions of water control and conservation that will make for equable supply. No individual or governmental agency can increase or diminish the annual rainfall, nor safeguard wholly against occasional floods. It is possible, on the other hand, largely to avoid the distress due to severe shortage of water in recent years. This statement calls attention to the subject of water in the ground, or as commonly known, ground water. I have been asked to discuss the underground water resources of Kansas. I am asked to give answers to such questions as: In what places and under what conditions may water that is suitable for domestic and stock use be obtained from wells? Why are some water wells in Kansas never-failing large producers of excellent water, whereas others yield only small amounts of poor water and readily go dry? What improvements are possible in methods of finding and utilizing the ground-water resources that exist in Kansas? What provisions can be made to safeguard best against effects of prolonged drought?

These questions call for a discussion of some general principles that apply to accumulation and movement of water beneath the surface in Kansas, and especially to the various geologic conditions that are the fundamental factors in controlling variation in water supply from below ground. It will be desirable also to consider the characteristics of various districts in Kansas that may be differentiated as natural ground-water provinces, pointing out the distinguishing features of these districts. The basis for these distinctions is a difference in water-supply conditions that depends mainly on variation in the nature of underground rock structure.

Importance of ground-water resources.—The importance of Kansas' ground-water resources may be emphasized from various viewpoints and in different ways. More than three-fourths of the public water supplies of Kansas are obtained from wells. In 1939, only 60 out of 375 municipal water supplies in Kansas, which is 16 percent, utilized surface waters. If the water wells of cities and those located on all privately owned land in the state were suddenly destroyed, making it necessary to go to streams, springs, lakes (which are almost all artificial), and ponds for water to supply domestic, stock, and industrial use, there would be almost incalculable difficulty and expense. If one could not go to springs, or dig new wells, or use any surface water derived from underground flow, much of Kansas would become uninhabitable. These suggested conditions seem absurd, but they emphasize our dependence on ground-water resources.

From a quantitative standpoint, ground-water supplies existent in Kansas far outweigh surface waters that are present in the state at any one time. No exact figures for such comparison can be given, but, taking 384 square miles as the total surface water area of the state and estimating an average water depth of five feet, the computed volume of surface waters is found to be about 1/100th of that of the conservatively estimated ground-water storage in Kansas. The latter takes account only of potable fresh water and is based on an assumed mean thickness of ten feet of reservoir having an effective porosity of twenty percent. It is to be remembered, however, that most of the surface water is run-off, which soon leaves the state, stream valleys being replenished from rainfall and flow from ground-water reservoirs. Most of the ground-water supplies, on the other hand, have existed for many years with almost no appreciable movement—in fact, it is reasonably certain that some well water drawn from beneath the surface of Kansas in 1940 represents rainfall in this region at a time before the first white man entered Kansas, even before the visit of Coronado in the 16th century. Most ground water is to be regarded as water in storage rather than as water in transit.

Geological Conditions Affecting Occurrence of Ground Water

Nature and Distribution of Ground Water

Ground water is defined to include all water beneath the earth's surface that fills the pore spaces or other openings in rocks. The upper surface of this saturated zone is termed the water table. The space between the water table and the surface of the ground is designated as the region of suspended water, for water particles

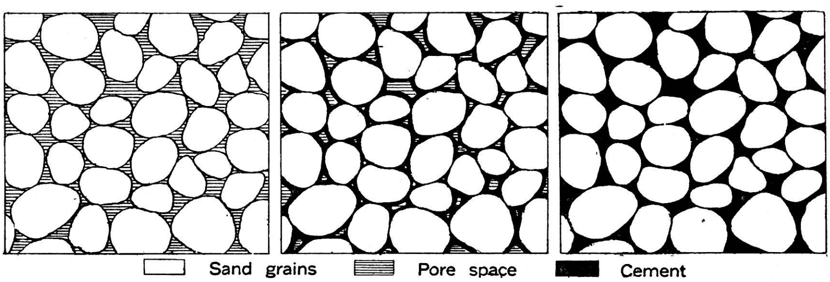


FIG. 1. Diagram showing the nature of pore spaces in sand and in sandstone, greatly magnified. Maximum porosity and permeability are found where spaces between the grains are not filled by finer sediment or by cementing material. Most ground water occurs as the filling of pore spaces, and not as freely moving underground streams in cavernous openings of the rocks.

that are present cling to the rock surfaces or are in transit downward to the zone of saturation. Because air may occupy underground spaces above the water table, the zone of suspended water is also termed the zone of aeration.

Ground water may be classified as pore water when it occupies small cavities or pore spaces in rocks, as fissure water when it is contained in cracks or fissures intersecting rocks of various sorts, and as cavern water when it fills large passageways dissolved in rocks, as in caves.

Study of the occurrence of water underground calls attention to the necessity of differentiating between so-called fixed ground water and free ground water. The fixed water remains indefinitely in the containing rocks because the capillary attraction in pores of extremely minute size holds the water. Free ground water is that contained in openings sufficiently large to permit relatively easy movement of the water.

Ground-Water Reservoirs

Relation to reservoirs above ground.—The occurrence of water below the earth's surface is closely related to conditions above ground. One of the natural modes of occurrence of water is vapor in the atmosphere. Moisture or water vapor above the earth, if all precipitated at one time, would make a layer of water about one inch deep over the earth's entire surface. This is not a large amount, but the atmosphere is extremely important as the agency for transporting the water that falls as rain, hail, and snow, and it is the ultimate source of the rivers, lakes, and ground waters.

Large quantities of water lie on the earth's surface. This includes the water of creeks, rivers, and lakes and, in addition, the snow and ice that for long or short periods lies on the surface of continents and islands. This water is fresh. Largest in volume is the great body of ocean water, which is salty. This is important as the chief source of atmospheric water, which in turn supplies the surface waters of land.

Water may be transferred from the atmosphere to the land surface, from the land surface to zones underground and to the atmosphere, or from zones below the ground surface to the surface.

Water movement and storage in the soil zone.—Water below the ground surface should be considered in two chief parts—that of the soil zone, and that of the ground-water reservoirs proper. The soil zone consists of mixed mineral and organic matter that is penetrated by roots, its average thickness being about five feet. This zone may be regarded as a water reservoir, its water being in the form of moisture that adheres to the soil particles. Soil structure is more important than soil composition in affecting water content, and the ease or difficulty with which water may penetrate the soil. Although the soil layer is generally only temporarily and occasionally saturated with moisture, on the average it holds water that would measure about one foot if it were separated and concentrated. Inasmuch as crops and other vegetation use one to four feet of water per year, it is evident that water in the soil must be replenished by rainfall or otherwise if crops are to mature. The crop-producing value of a soil depends largely on its capacity to hold water against the pull of gravity and to yield this water to roots of plants. Very sandy soil may retain little moisture even in moderately humid eastern Kansas, supporting only cactus and similar resistant plants. Clay soil may have large moisture-containing capacity that is little benefit to plants. Downward seepage of water from the soil zone can occur only when the soil is fairly well saturated and the water supply exceeds the needs of vegetation. Hence, additions to ground-water supply may be lacking in arid regions.

Most soils are more or less definitely divisible on the basis of physical characters into two or three distinct parts. The upper one comprises the surface soil, which is mainly a zone of decomposition and leaching of mineral matter. The removable of soluble substances, supplemented in many soils by action of burrowing animals, roots of plants, and the like, favors development of an unusually pervious structure. This upper soil is generally absorbent, acting like a sponge to collect rain water and frequently to deliver it to the subsoil and ground-water reservoirs.

Below the surface soil is a subsoil zone, which is characterized by precipitation of materials dissolved from the soil zone above. In addition to various chemical substances, especially calcium carbonate, fine clay may be brought downward to the subsoil. Concentration of such material produces hardpan, which is relatively impervious. In general, however, this zone has a structure that readily permits downward movement of moisture.

A third zone, the substratum, is present in many places and consists of the sediment or bedrock material from which the soil is derived when this is penetrated to some extent by roots. Its character, from the standpoint of water storage and movement, depends largely on that of the bedrock.

Water below the soil zone.—Locally in Kansas, the water table lies immediately below the soil zone, or intersects it. Elsewhere, a relatively dry zone of varying thickness occurs between the water table and the soil zone. In most places this dry zone actually contains films of water on rock particles, and the water evaporates very slowly or unites chemically with the rock materials in the course of weathering. As a whole, the zone is characterized by downward migration of water from the soil zone to the saturated area of the main ground-water zone.

We should expect to find that below a certain depth in any region all the pore spaces and larger openings in rock are filled with water

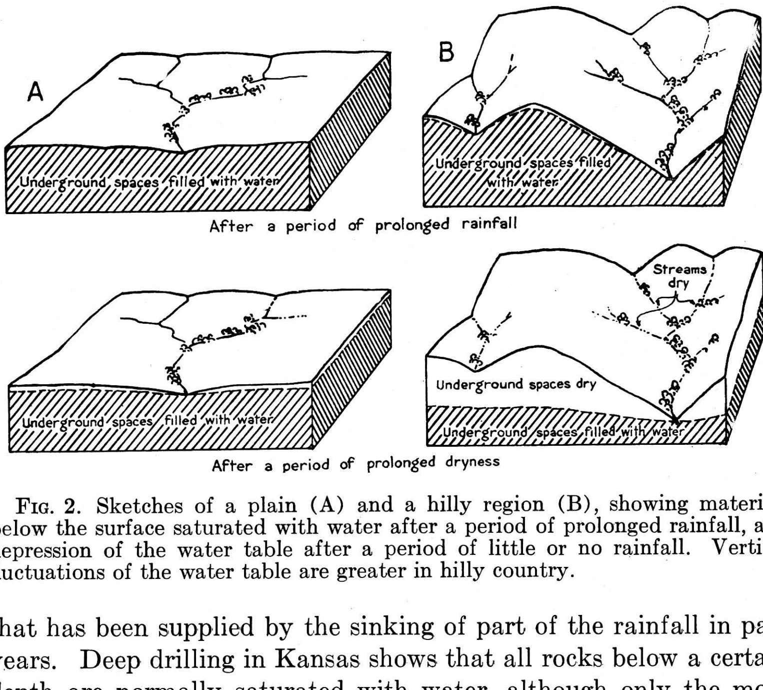
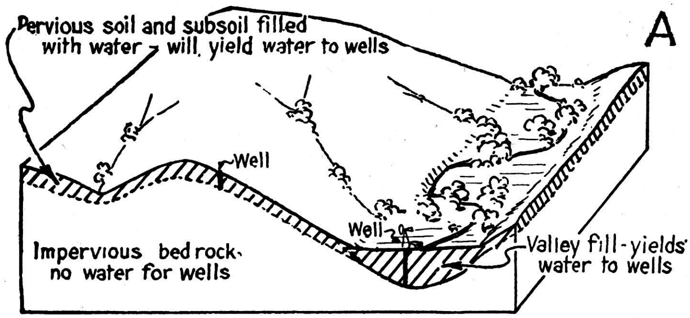


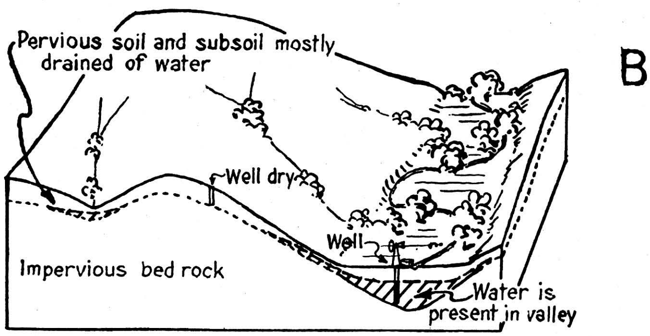
FIG. 2. Sketches of a plain (A) and a hilly region (B), showing materials below the surface saturated with water after a period of prolonged rainfall, and depression of the water table after a period of little or no rainfall. Vertical fluctuations of the water table are greater in hilly country.

that has been supplied by the sinking of part of the rainfall in past years. Deep drilling in Kansas shows that all rocks below a certain depth are normally saturated with water, although only the more permeable strata will yield some of their contained water to wells. Generally, however, the water of all deep zones is much too salty for farm or domestic use and therefore is of no interest to us here. Water at shallow depth, on the other hand, is mostly of good quality for it has not encountered much soluble mineral matter. Inasmuch as deeper spaces in the rocks underground are already water-filled, rain water sinking into the ground can travel downward only so far as unfilled pore spaces and other cavities are found. Beneath a very extensive plain where the water table is approximately horizontal and where possibility of lateral flow of water underground is very slight, continued additions of water from rainfall should result in filling all underground spaces except as the shallowest depths are emptied by capillarity, evaporation, and transpiration by plants. Beneath hilly country, however, there is always the opportunity and tendency for water in the ground to drain toward the valleys. The irregularities of the land surface throughout most of Kansas are sufficient to produce much diversity in the depths to the saturated underground zone in different places. After prolonged rainy periods the spaces beneath the hills are about as well filled with water as those under valleys, but after prolonged drought the water has largely drained from the spaces beneath high land. The principles that apply to this movement of ground water and to the fluctuation of depth to the water-saturated zone may be illustrated by assuming that the number and size of the underground pore spaces in equal rock volumes are the same in two regions, one of which is flat and the other hilly (see A and B in the accompanying diagrams). The freedom of movement of water in each is the same. It is clear that the depth to the permanently water-saturated zone will fluctuate much more in the hilly area than in the plain. In the hilly region (B) the underground water drains from the zones beneath the hills, sinking to a level near that of the deepest valley, but in the plains region (A) there is no opportunity for the underground water to drain, so the water table stays near the surface.

Effect of size of underground cavities.—If the number and size of underground cavities in the soil, subsoil, and different kinds of bedrock were approximately uniform, as assumed in the examples just considered (Fig. 2), it would be easy to locate good water wells. Thus, one location in a plains area would be about as good as any other and water could be found at shallow depth anywhere. Wells in any part of a hilly region would likewise obtain water, but it would be necessary to drill much deeper on hills or hillsides than in valleys in order to obtain a steady water supply. A shallow well at or near the top of a hill would go dry as soon as the water table had dropped below the bottom of the well.

As a matter of fact, the number and size of underground cavities in different sorts of rock material are not uniform, but differ enormously. Almost all rocks have some pore space, but in some rocks the cavities are so minute that water, although it will enter the pores, is held so tightly by capillary forces that it will not leave. Such





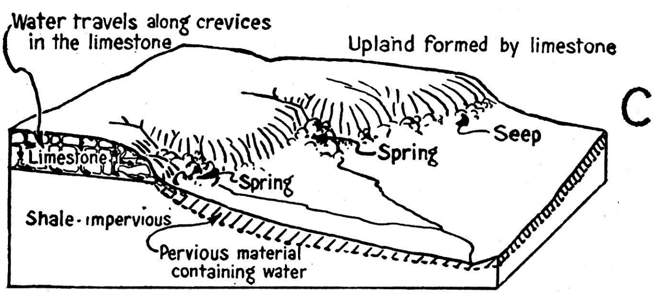


Fig. 3. Block diagrams illustrating lateral and downward movement of ground water. The upper figure (A) represents a hilly area in which pervious materials occur only in the valley bottoms and as thin wedges on hillsides; after a rainy period the ground is saturated with water. The middle figure (B) represents the same area after a period of dryness; ground water has drained from the hillside slopes, leaving dry an upland well, but the alluvial valley-fill still contains water supplies. The lower figure (C) shows geological conditions that produce springs at the horizon where pervious limestone rests on impervious shale; ground water in cavities of the limestone, unable to penetrate the fine-grained shale, emerges at various places along the outcrop.

rock, though saturated with water, will yield none of it to a well. If water will not travel through rock material or if its movement is extremely slow, the rock is said to be impervious. Some rocks, such as clay, are impervious, although they have a high porosity, because of the microscopic size of the spaces between the mineral grains. Shale ("soapstone") may be filled with water, but it is mostly of little value as a source of water supply. The pore spaces in sand or sandstone are generally large enough to permit slow but relatively easy flow of water. The passageways between the pebbles of a gravel bed commonly permit movement of water almost as readily as does a pipe, and similarly, passageways widened by solution in limestone allow water to travel freely. Limestone beds that are sufficiently far below the surface to have escaped weathering and those so situated that circulating water cannot readily reach them are not prolific water-bearing rocks.

In very many parts of Kansas where bedrock consists of impervious shale, only the near-surface weathered rock materials consisting of the soil, subsoil, and locally of other unconsolidated material, such as dune sand, certain glacial deposits, slope wash, and alluvium, are sufficiently open-textured to be considered as a source of supply for water wells. The thickness and topographic location of these water-bearing materials are the chief features to consider in searching for the best location for water wells.

Porous rock at shallow depth is all almost saturated with water after a rainy period, uplands and hillsides as well as valley bottoms, but after several weeks or months without rainfall, only the bottom lands will still yield water to wells. Even some valleys may in time be so drained of ground water that wells penetrating alluvial deposits in them fail. The bedrock will yield no water. In such regions, including much of eastern and north-central Kansas, there is no reason to dig wells deeper than the depth where bedrock is encountered, and the best wells are those at the foot of long slopes or in valleys where water in the porous earth above bedrock continues for the longest time to drain into a well.

Bedrock reservoirs.—Water is present in most bedrock and it fills the available pore spaces in the saturated zone. Where the pore spaces in the rock are too fine, however, the water cannot be drawn out. Therefore, most bedrock in Kansas consisting of shale, unweathered limestone, and some fine-grained or tightly cemented sandstone, is of no value as a source of water supply for wells. On the other hand, many porous sandstones and limestone beds that have been made porous or even cavernous by weathering are excellent water carriers that yield their contained water readily to wells. Many fine wells obtain their water directly from these porous types of bedrock. The water is more or less evenly distributed through sandstones, but the porosity and permeability of the Tertiary "mortar beds" appears to show considerable diversity. In limestone, the water is mostly confined to certain passageways that

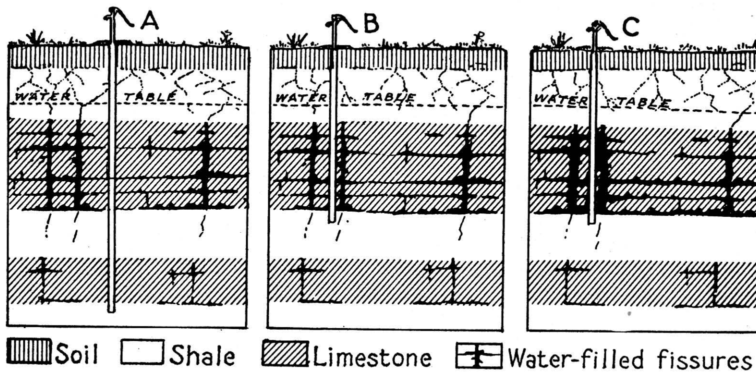


FIG. 4. Wells drilled to obtain water from limestone. *A*. The well shown in the diagram at left happened to miss water-filled openings in the upper limestone and was drilled into a lower bed, but it was unsuccessful in obtaining a good supply of water. *B*. The well shown in the middle diagram was located in a fortunate manner to intersect good water-bearing fissures in the limestone; this well has a fairly satisfactory yield. *C*. The right-hand figure shows the effect of acidizing the well represented in the middle diagram; the openings in the limestone have been enlarged by the acid and admit water to the well much more freely.

have been dissolved along joint cracks and bedding planes. A limestone well may obtain little water if it happens to be drilled in a part of the rock that lack these crevices, whereas a nearby well in the same rock may yield abundant water because it intersects water-bearing channels. Water production from some wells penetrating limestone has been greatly increased by treating the well with hydrochloric acid (30 or more gallons), so as to open or enlarge the passageways for water leading into the well. It should be obeserved that water in porous bedrock moves downward as far as possible, following the gentle inclination of the rock strata, which in most of Kansas is toward the west. Most springs are located at the bottom of a sandstone or limestone bed where the water, unable to move downward into underlying impervious rock, finds its way to the surface at the outcrop of the pervious bed.

If an upland area is extensive and not intersected by deep valleys, the occurrence of water underground is comparable to that in a plain. Depending upon supply from rainfall the water accumulates in the near-surface porous rocks and does not drain away readily. One location for a well is about as good as another, except that here also it is best to seek the lower parts of the land surface.

Where water occurs mainly in porous limestone or sandstone that, because of its resistance to erosion, forms the upland, the best water wells will be found at some distance from the outcropping edge of the rock formation in the direction in which the rock layers slope, because the water moves through the porous rock in the direction of dip or inclination of the beds (see Fig. 5). A well (c) that is located considerably down-dip may be expected to obtain a much

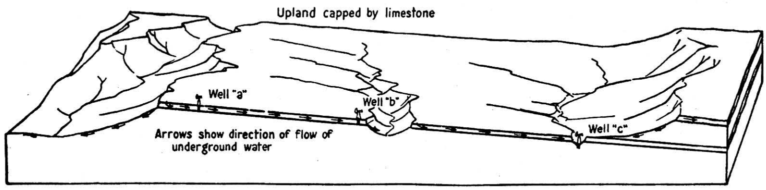


FIG. 5. Diagram showing conditions of ground-water supply for wells on a sloping plain formed by a pervious hard formation. The well at *a*, located near the escarpment formed by the hard rock, is likely to yield water only after times of rainfall, because its catchment area is small and soon drained. Wells at *b* and *c* are better placed in order to have a steady supply of water. The geological conditions shown here apply to many places in eastern Kansas.

better supply of water than one (a) near the edge of the escarpment, because it is supplied by a considerable water-collecting area in the higher parts of the rock.

Reservoirs in stream deposits.—Generally speaking, valleys are the best places for the location of water wells, (1) because the alluvial fill of valley bottoms is sufficiently pervious in most places to permit water to flow readily into a well, (2) because the water from neighboring slopes drains into the valley, so that a supply is commonly available there even in dry weather, and (3) because the depth to water is generally small. Obviously, the larger the valley and the bigger the drainage basin, the more water may reasonably be expected. Wells on the valley bottom of Kansas and Arkansas rivers, for example, yield sufficient water to supply large cities. The McPherson formation, in central Kansas, is an alluvial deposit that contains billions of gallons of excellent water, supplying wells at a rate of 2,000 gallons a minute or more. The underflow in small valleys may fail in time of prolonged drought, but some small valleys contain an unfailing water supply because they are fed by seepage from water-bearing bedrock that forms part of the valley sides.

A very important characteristic of alluvial ground-water reservoirs, which affects distribution of the best water wells in valley bottoms, is the fact that the water-bearing rock materials beneath the surface are by no means equally pervious. Clay or silt in the valley bottom may be saturated with water, but the flow of water into a well dug in this material is so slow that the well is quickly drained when pumped. Such a well is of little value. Sand and gravel yield their water freely to wells and accordingly it is de-

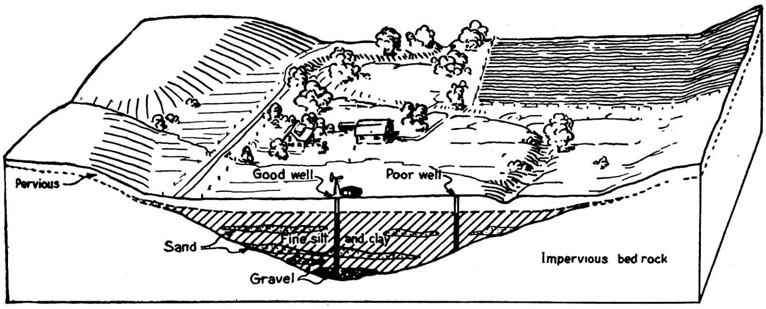


FIG. 6. Block diagram representing conditions affecting occurrence of ground water in the alluvial deposits of a stream valley. Good water wells may be obtained where the most pervious materials of the valley fill are penetrated, but wells that pass through only fine silt or clay yield little water despite the fact that these sediments are water-saturated. Stream deposits are notably irregular in texture.

sirable to penetrate the coarsest, most pervious parts of the valley filling. In order to find these coarse parts of the valley deposits it is best to resort to tests with an auger, sand bucket, or drill, for the sand and gravel occur in sinuous belts of varying width, often intersecting one another, and in irregular patches and lenses that have no relation, so far as distribution is concerned, to the location of the stream channel in the valley. The coarsest materials in small valleys are commonly found near the middle, in the deepest part of the depression carved in bedrock.

FILLING GROUND-WATER RESERVOIRS

The supply of water to underground reservoirs is affected by numerous factors, most important of which are, (1) the quantity and distribution of rainfall; (2) the perviousness of the reservoir and materials overlying or adjoining it; (3) the size and topography of the intake area of the reservoir, and (4) the effects of evaporation and transpiration.

Amount and Distribution of Rainfall

In general, conditions are most favorable to addition of water to a ground-water reservoir when rainfall is considerable, but well

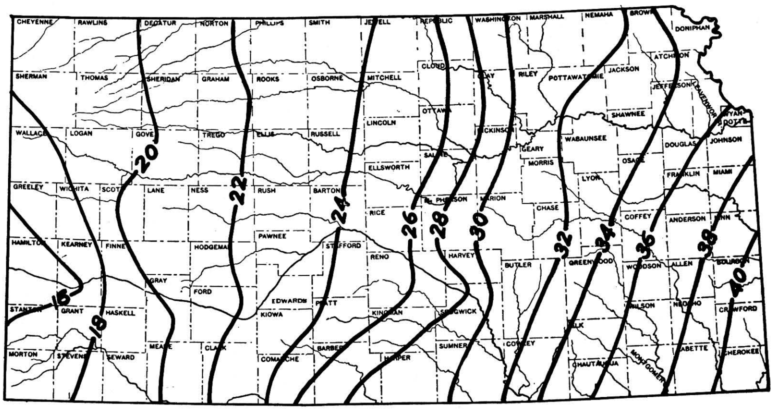


Fig. 7. Map showing average annual rainfall in Kansas, in inches. An outstanding feature of the climate of Kansas is variation from average conditions, and accordingly, in some years precipitation is materially smaller or greater than the mean.

distributed, so that downward-seeping water has time for travel, permitting voids to be refilled by additional rainfall. During short periods of torrential rains, such as visit Kansas frequently, a very large proportion of the precipitation runs off on the surface. The soil layer and superficial openings are quickly saturated with water and time is lacking for downward seepage of this water to make room for additional rain water. As much as fourteen inches of rain has been recorded at a single locality during a storm of a few days in eastern Kansas (Fig. 8). Even if somewhat favorable conditions for entrance of surface water into the underflow exist, little of the water in such a storm can be added to ground-water reservoirs. It is evident that whenever average rainfall is below normal, as during years since 1930, there will be less than normal replenishment to ground-water reservoirs. According to Weather Bureau records, the accumulated rainfall deficiency for the state during the last nine years is about thirty-three inches, this figure being based on averages for the entire state.

A most important characteristic of rainfall in Kansas is its variability. Some years bring higher than average precipitation and others much lower than average. Groups of successive years, also, may depart from normal in the direction of excess rain or of drought. In a dry year (1894) at Hays, for example, a total precipitation of 11.8 inches was received, whereas in the wettest year (1874), 35.4 inches, which is three times as great, was recorded. The periods of abnormal wetness and dryness appear to run in cycles.

FIG. 8. Map of southeastern Kansas counties showing concentrated rainfall during a twelve-day period in April, 1927. The figures indicate inches of rainfall in this period and areas of progressively greater precipitation are represented by increased density of shading (modified from J. O. Jones).

Nature of reservoir and cover.—In areas of very pervious bedrock, such as cavernous, fissured limestone in parts of eastern Kansas, or unconsolidated sediments, such as dune-sand areas in central, southern, and western Kansas, a considerable fraction of rain and snowfall finds its way quickly into the underflow. Tracts of land in Butler and Cowley counties, for example, have no surface run-off at all, for the water flows into sinks in the underlying limestone and disappears. Surveys of the water table (see Fig. 26) in dune-sand areas northeast of Hutchinson show that the zone of water saturation rises very noticeably in this district because of the "piling up" of ground water derived from infiltration through the sand. On the other hand, a comparatively impervious surface deposit, such as the widely distributed Sanborn loess in western Kansas, acts as a water-tight seal over reservoir beds that lie beneath the surface, retarding or preventing downward seepage of water.

Nature of intake area.—It is evident that the placement and structural nature of the ground-water reservoir has important bearing on addition of water supplies to it. If a reservoir is widely distributed and directly underlies the surface or occurs beneath a very

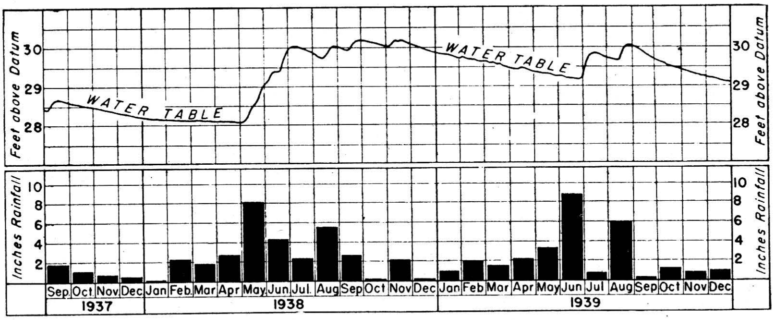


FIG. 9. Fluctuations in level of the ground-water table in alluvial deposits at Valley Center, about ten miles north of Wichita, in the 2.5-year period preceding January, 1940, compared with the record of monthly rainfall at Wichita. The varying water level, as recorded by an automatic gauge, shows a slow decline at a fairly uniform rate during the periods of little rainfall, for drainage of ground water from the reservoir then exceeds additions from infiltration of rain water. Relatively sudden rise of the water table is observed to follow promptly the times of considerable local rainfall, indicating that this precipitation tends to recharge the reservoir. (Data from Geological Survey observation well and Weather Bureau records.)

pervious cover, there is maximum opportunity for water from the surface to enter it. On the other hand, if the area of inlet to the reservoir is relatively small, the filling of the reservoir is impeded, even though the overlying materials are pervious. Other things being equal, a larger portion of the rainfall runs off as surface flow on steep slopes than on gentle ones or on nearly flat plains. It seems obvious that holding the water on the land surface, as by terracing operations in fields and by construction of lakes and farm ponds, tends to permit more of the water to sink below the surface and both to retard and to diminish runoff on the surface. There is little question, however, that cultivation tends to decrease the intake capacity of the ground by puddling the top layer of soil and choking available ducts that would remain unclogged under prairie sod. Also, deposition of silt and clay in surface reservoirs may be expected to diminish the percolation of water from them into subsurface channels.

Effects of evaporation and transpiration.—The nature and amount of vegetation that is responsible for removal of large quantities of water into the atmosphere by transpiration, and the extent of evaporation are important factors influencing addition of water supplies to ground-water reservoirs. Measurement of evaporation losses indicate that a water surface at Garden City, Kan., yields about seventy inches of water a year to the atmosphere, and in eastern Kansas the annual loss amounts to approximately fifty inches a year. It is certain that a very considerable part of the annual rainfall in Kansas, possibly more than eighty-five percent, is returned to the air by evaporation and transpiration of plants. Stream-flow records account for about 3.5 inches per year of the average annual thirty-three inches of rainfall in Kansas. The remaining 29.5 inches represents evaporation losses, water used by plants and animals (including man), and water added to ground-water reservoirs. The recharging of underground reservoirs is partly, or perhaps wholly offset by discharge from them into surface flow, computed at 0.5 inch per year (and included in 3.5 inches, already noted). There is considerable, but not entirely uniform, evidence of a gradual lowering of the water table in various parts of Kansas during recent decades, pointing to a decrease in ground-water storage.* Too few observation wells are available and their record is too short to permit reliable conclusions at present as to whether storage in ground-water reservoirs of Kansas as a whole is being depleted, being held approximately steady, or being increased. The first mentioned is regarded as most likely. In any case, it is not safe or proper to assume that all water from the rainfall that is not accountable as run-off (including water derived from zones below ground) is used by organisms or evaporated; a fraction of the rainfall may constitute a net addition to ground-water reservoirs.

Conservation efforts.—As has been noted, the content of ground water in reservoirs below the surface of Kansas is due to an accumulation of downward seepage that has occurred under normal con-

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* R. V. Smrha, discussion of S. W. Lohman, Ground-water Investigations in Kansas (Kansas Engineering Soc., Yearbook, p. 40, 1939), notes that a lowering of water table of ten to fifty feet reported in various parts of Kansas does not accord with information obtained for the period 1890-1934 along a north-south profile through Garden City. This showed that after forty-four years the ground-water level was about three feet lower in the plains country south of Arkansas river and about two feet higher in northern Finney county.

ditions during a considerable past period. Some of this water has come from rain and snowfall soaking into the ground, and some from streams crossing the exposed portions of porous deposits. When water is withdrawn from this storage, it may be recharged, generally very slowly, by natural conditions, or it may become necessary for us to aid in conducting surface waters to underground storage and reservoirs. This may be done through construction of lakes and ponds, through terracing of farm land, by leading surface water into wells that penetrate the underground reservoir, and by the building of dams and diversion ditches along stream courses. Generally speaking, all construction of farm ponds is an asset in conserving ground-water supply, as well as in storing surface water. It is interesting to note that a large proportion of 1,538 dams more than ten feet in height that are reported by George S. Knapp, chief engineer of the Division of Water Resources, to have been completed in Kansas in January, 1940, as well as 3,000 ponds constructed with A. A. A. aid in 1938 and 1939, are located in regions that lack important ground-water reservoirs. The ponds formed by these dams are, nevertheless, effective sources of shallow seepage that may supply wells located below the dams.

There is a common misconception as to the effects of dams along larger streams in conducting water to ground-water reservoirs in the stratified rock. Such dams serve to impound water in parts of the pervious alluvial fill above them and by regulation of flow they serve during drought to prolong the period of production of wells in the valley below them. It is almost wholly impossible, however, for such dams to contribute water effectively to rock strata that form the sides of these valleys. Thus, it is fallacious to assert, as some persons have asserted, that construction of a few such dams along streams in eastern Kansas would result in spreading ground water throughout territory in which reserves of ground water in general are small.

It is very desirable to locate farm wells down drainage from farm ponds. The seepage from the ponds tends to maintain a small but continuous supply of water that moves slowly through the pervious materials to wells thus located. In various parts of Kansas many springs and wells not thus fed from pond seepage quickly go dry during periods of drought.

Underground Movement of Water

Unconfined movement in rocks and sediments.—The pull of gravity causes movement of water underground just as it does on the surface, but in general the movement is very much slower. In porous unsaturated rock materials, as loose sand or gravel, the dominant direction of movement is straight downward until the zone of saturation is reached. If, as is almost universally true, the zone of saturation extends higher in the porous materials in some places than in others, the irregularities of the surface of the water table define slopes. In engineering terms, these slopes represent hydraulic gradients, and they determine a lateral movement of the water as it seeks to find a common level. As might be expected, tests show that the rate of movement depends on the steepness of the gradient and on the fineness or coarseness of the openings through which the water passes. Given a slope (hydraulic gradient) of the water table amounting to ten feet per mile, which approximately equals the downstream slope in many Kansas river valleys, water moves through sand of medium grain size at a rate of less than one foot per day and through fine gravel at an average rate only slightly more than ten feet per day. The average rate of ground-water travel in the alluvial fill of the Arkansas river valley in western Kansas has been determined to be about eight feet per day. The eastern slope of the ground-water table in the pervious alluvial materials of the Kansas river flood plain is approximately three feet per mile, and taking account of the average size of pore openings in this fill, it appears that more than a century would be required for ground water to move from Manhattan to Lawrence. This does not mean that if rainfall were utterly to cease in central and eastern Kansas, wells on the river flood plain at Lawrence would continue to yield water 100 years hence, for certain other factors would become felt. It is true, however, that the Lawrence wells would continue to yield water for decades, assuming no withdrawal at points higher in the valley. This emphasizes an essential difference between ground-water supplies and surface water. The latter moves with relative rapidity and is subject to maximum loss by evaporation. Ground water, on the other hand, moves very slowly or, in many places, not at all, and it is not depleted appreciably by evaporation. Flow of surface water fluctuates enormously, according to variation in rainfall, and in periods between rains would cease if it were not for water contributed to valleys from ground-water reservoirs. Even with this addition, surface flow ceases in some streams during times of drought. Ground water is water in storage that remains relatively constant. It may be conserved and augmented or it may be depleted. Ground water is like a slowly accumulated savings account in the bank, which is a reserve to be drawn upon at need, but if expended rashly it is a resource not speedily replaced.

Movement of the ground water in stratified rocks follows the same essential principles as in unconsolidated materials such as the alluvial filling of river valleys. The chief differences are due to an average smaller size and generally smaller pore content of these rocks, the general occurrence of alternating pervious and impervious strata, the influence of geologic structure, and the effect of

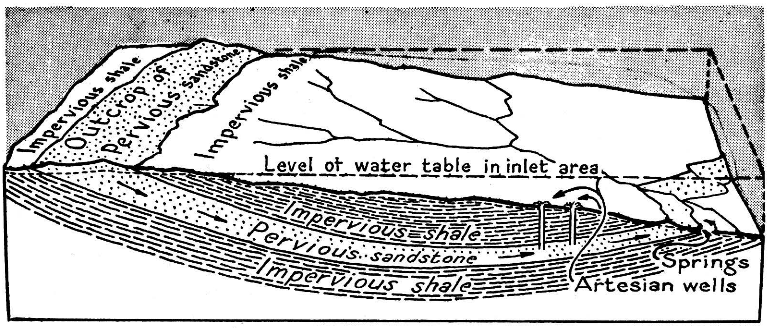

FIG. 10. Block diagram showing conditions of geologic structure that are requisite for artesian wells. Water that enters the pervious rocks at the higher outcrops is confined by impervious beds, and hydrostatic pressure is developed that may be sufficient to cause natural flow of water from wells drilled into the pervious strata. The water may emerge as springs at outcrops of the pervious rocks that are topographically lower than outcrops of the inlet area.

soluble minerals, particularly salt and gypsum, on the waters present in the porous rock. Many layers of bedrock are pervious in the areas close to their outcrops, but are virtually impervious at a distance from these places of exposure. This difference is due to the leaching effects of weathering and to other chemical and physical changes associated with weathering. Many limestone formations that are generally "tight" and dense deep below the surface are traversed at and near the outcrop by a network of openings that may conduct water in considerable quantities. Water in stratified rocks tends to move down in the direction of slope of the layer. In most parts of Kansas such rock layers are tilted at an angle measurable in a few feet per mile. Lateral movement of ground water down the slope of an inclined rock layer is halted when the openings in the formation are entirely filled by water, and accordingly there are many places in which such water reaches a condition of no motion at all.

Movement in porous rock confined by impervious layers.—In certain cases, as illustrated by the Dakota sandstone in north-central Kansas and in Colorado, where outcrops of a formation are much lower in one region than in another, water entering at the upper

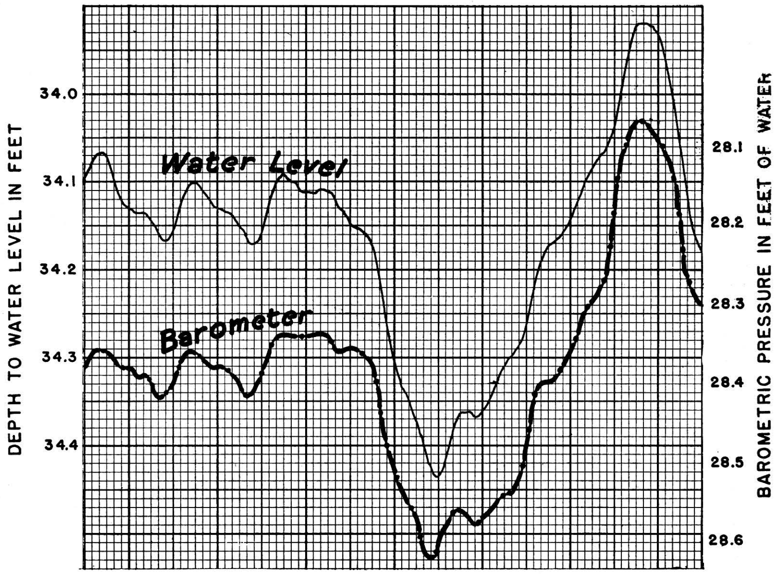

FIG. 11. Fluctuation of the water table in an observation well at Inman, Kan., compared with changes in barometric pressure. The records shown represent a period of about one week during which no water was taken from the well. The barometric curve is inverted in order to show similarity of form to the plotted record of water levels.

outcrop may find its way underground to emerge at the exposed lower level. In the case of the Dakota sandstone, water enters the formation at outcrops far west of Kansas at the eastern border of the Rocky Mountains. The water migrates slowly eastward and emerges as springs and seeps along the topographically much lower outcrop in Kansas, Nebraska, and other plains states. Confined between impervious shale beds, the water in such a pervious formation as the Dakota sandstone may exert considerable hydrostatic pressure, and where the formation is penetrated by a well, the water may rise close to the surface or flow from the well mouth. Such a well is termed an artesian well. Meade county contains artesian wells that yield water from porous Tertiary and associated beds.

An interesting phenomenon that is observable in some wells is a fluctuation of the water level in accordance with atmospheric pressure. When the barometer falls, indicating decreased air pressure, the water level in the well rises, and conversely. This is due to a partial enclosure of the ground-water reservoir in such a way that changing air pressure forces the water back or allows it to move outward slightly from the confined reservoir. Various Kansas wells show barometric fluctuations of level (see Fig 11).

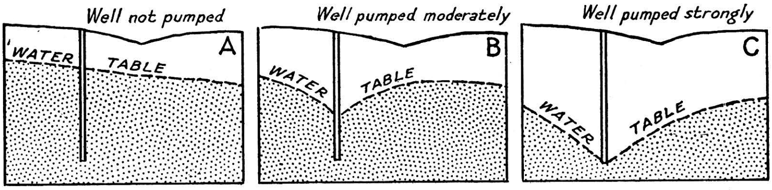

Fig. 12. Diagrammatic geologic sections showing position of the ground-water table during a period of no withdrawal of water from a well (A), after a time of moderate pumping of the well (B), and after a time of heavy pumping (C). The cone of depression in the water table surrounding a well commonly increases as the rate of pumping is increased, but in few cases are the outer limits of the cone more than a few tens or scores of feet distant from the well.

Quantity of Water Obtainable From Ground-Water Reservoirs

The amount of water that can be obtained from Kansas ground-water reservoirs depends on the areal extent and thickness of the reservoir, its porosity, and the extent to which it is water-filled. There is a difference, however, between amount of obtainable water and what may be termed the safe yield of the ground-water reservoir. The latter takes account of the fact that no ground-water supply is inexhaustable, and utilization of this resource should take account of the manner in which normal conditions operate to recharge the reservoir with new supplies of water. Otherwise demand will exceed the ultimate supply. Numerous cases of overdevelopment that has led to shortage can be cited, and such shortage may be disastrous. For example, excessive withdrawal of ground water in eastern North Dakota and South Dakota, and in the Roswell basin in eastern New Mexico has caused thousands of acres that were very productive to be abandoned. The land has reverted to native vegetation. Where rate of withdrawal from an underground reservoir exceeds the rate of recharge, the falling water table causes a steadily increased cost of lifting by the pump. Eventually, costs are greater than earnings, and communities and industries built on this receding resource decline or vanish.

It is to be remembered that not all of the water contained in a ground-water reservoir is capable of being produced from wells; also, that the rate at which the wells may obtain water from a reservoir varies greatly according to the perviousness of the reservoir, especially near the well. Two wells penetrating the same reservoir may obtain supplies at very different rates, one at only a few gallons a minute and the other at several hundred gallons a minute. The ease of movement of water from a reservoir into a well is commonly measured by the depression of the water table in the vicinity of the well. This cone of depression is very broad and shallow if water flows freely into the well, but is sharp and steep if the sediments are relatively "tight". Heavy pumping may result in such depression of the water table at the location of the well, that is, make such a great draw-down, that production is sharply reduced or stopped until the water has opportunity to flow inward from surrounding areas toward the well.

The amount of water that may be present in a given reservoir can be computed if knowledge is available of the area, thickness, porosity, and degree of saturation in the reservoir. For example, a water-filled sand ten feet thick covering an area of one square mile can supply more than 400 million gallons if the effective yield of the pore space is twenty percent, which is below the average of unconsolidated sands and of some sandstones. The ground-water reservoir north of Wichita, known as the Equus beds, undoubtedly contains billions of gallons of water in spite of the fact that field surveys have shown that only part of this deposit consists of very permeable deposits. Test wells located by the Geological Survey yielded 1,600 to 2,000 gallons a minute. Observations of this sort indicate the greatness of a natural resource, but it is obviously important that supplies of water should not be drawn from such reservoirs at a rate larger than that of their replenishment. Otherwise, the time is bound to come when the resource will no longer be available for use. An objective of the field work of the ground-water geologist is to determine not only the location and approximate quantities of water in underground reservoirs, but to determine what may be regarded as the safe yield.

Quality of Ground Waters

No ground water is chemically pure. Even rain water dissolves small amounts of substances in the atmosphere, and from the moment water starts to move through the soil or other parts of the ground, it takes up various sorts of mineral substances. Some minerals are much more soluble than others, and soluble mineral matter tends to dissolve in increasingly large amounts in proportion as the water has had opportunity to come in contact with it. Many of the ground waters of Kansas show appreciable contents of sodium chloride (salt) and calcium sulphate (gypsum). These make the water unfit for use if their quantities exceed a certain amount. Water containing as much as one-fourth of one percent dissolved mineral matter (2,500 parts per million) has been deemed to have reached the limit of fitness for domestic use by man. Stock water containing more than twice this amount is usable, although not very desirable.

A common constituent of almost all ground waters is calcium bicarbonate, and presence of this mineral in appreciable amounts (about 200 parts per million) makes the water classifiable as "hard". The presence of calcium sulphate and magnesium sulphate gives water a "permanent" hardness. Almost all of the ground-water supplies of Kansas have a moderate hardness, and some are decidedly hard. Iron, silica, and various other substances are common in ground water.

As might be expected, the extent to which ground waters are mineralized bears evident relation to the rock formations in which they occur. Some regions, such as the outcrop belt of Permian rocks that contain thick salt deposits, are noteworthy because of the amount of dissolved salt and gypsum that the waters contain. Likewise, some of the waters from the Dakota sandstone and other Cretaceous strata are salty and gypsiferous. On the other hand, water from the McPherson formation (Equus beds) north of Wichita and widely distributed in the Tertiary deposits of western Kansas has relatively slight mineralization and is relatively soft.

A feature connected with the study of quality of Kansas ground waters is the change in character of water in a given stratum with distance from the outcrop. Water of good quality may be obtained from many formations close to the outcrop, but at a distance of only a few miles from the outcrop, where these formations are buried a few tens or scores of feet, the water obtained from them is found to be so mineralized that it is not fit for use. This means that in its travel from the outcrop to the point where the formation is penetrated in the deeper wells, the water has dissolved so much mineral matter that it is no longer usable.

Virtually all of the water at considerable depth below the surface is very saline and entirely unfit for domestic or stock use. An exception to this generalization are rock formations penetrated in the extreme southeastern part of Kansas. Here, porous limestone (Mississippian) and sandstone (Ordovician) that collect water at their outcrops in the Ozark region of Missouri contain water still sufficiently unmineralized to be suitable for ordinary use. Some of these potable waters are reached at depths of several hundred feet below the surface in Kansas.

Ground-water Investigations by the Geological Survey in Kansas

Information concerning the nature and occurrence of ground-water reservoirs in various parts of Kansas has been gathered by geologists of the Kansas Geological Survey during many years. Special studies of ground-water development have been made from time to time in certain districts of the state. A systematic program of investigations was begun in 1937, when coöperative arrangements with the United States Geological Survey were made under which geologists and engineers specially trained in hydrology were assigned to work in Kansas on projects outlined by the State Survey.

The first special project was a careful study of the ground-water area north of Wichita known as the Equus beds. This study was undertaken coöperatively by the United States Geological Survey working with the Kansas Geological Survey and the State Board of Health. Later, the city of Wichita joined in support of the work, and, as one result of the investigation, has been served by the gathering of the information needed for installation of a new municipal water supply to be drawn from about twenty-five wells located in the southern part of this ground-water reservoir area, about twenty miles northwest of Wichita. In the course of this survey, the geology has been studied from surface outcrops and from artificial exposures, and more than 100 test wells have been put down in order to obtain information on the distribution and character of the water-bearing beds. A detailed map of the sloping water table has been prepared to show the direction of movement of the ground water, its relation to surface-water bodies, the areas of discharge and recharge, and the effects of heavy pumping and other conditions.

Information as to the permeability or water-transmitting capacity of the deposit has been obtained from laboratory studies of materials obtained in the field and from pumping tests on certain wells, supplemented by examination of the water level in surrounding observation wells. Analyses of the sands and other materials have also been made in the laboratory in order to show the porosity and water-transmitting capacity of the samples. Study of intake facilities of soil and other surficial deposits in the area gives basis for estimates of the rate of recharge of the ground-water reservoir. Comprehensive study of the chemical nature of the water in this region has been made with aid of the water laboratory of the State Board of Health, and special attention was given to study of conditions introduced by escape of oil-field brines from ponds in the neighborhood of wells penetrating the reservoir.

A grave danger to fresh-water beds in various parts of Kansas exists in the pollution of the ground-water reservoirs by oil-field brines. Salt-water ponds located in areas of pervious deposits, as in McPherson, Harvey, Reno, and other counties, permit the very saline water to seep downward into the underflow. Investigations of the Survey near the Burrton field indicate that the salt water sinks rapidly downward, and because its density exceeds that of the fresh water, it spreads as a sheet of bottom flow in the pervious sands, seemingly with a surprisingly small amount of mixture with the fresh waters.

It has been planned to extend the ground-water surveys to various other districts in eastern and western Kansas. Largely as a result of the severe drought of recent years, many inquiries as to possibility of utilizing ground water for at least local irrigation projects in western Kansas have led to reconnaissance surveys in several southwestern Kansas counties. The first of these to be undertaken was in Ford county, where work was begun in October, 1938, and a preliminary report completed in March, 1939. Further studies, accompanied by some test drilling, have provided material for a report on this county, which is now being completed. More recently, work has been in progress in Meade, Scott, Morton, and Stanton counties, and studies have been initiated in Hamilton, Finney, Kearny, and Gray counties. The Geological Survey is also assembling water-level records of the Soil Conservation Service in Jewell county, Kansas. Also, assistance has been rendered to several communities depending on ground water for public water supplies, some of these being Winfield, Hesston, Reading, Sterling, Council Grove, and Kanopolis.

A valuable tool of the Survey in its ground-water investigation is a portable hydraulic rotary well-drilling machine that was purchased from coöperative funds during July, 1939. The machine has been used to obtain samples and necessary information in the central Kansas district, and is now at work in the southwestern part of the state.

Coöperation and valued aid have been received from the Division of Water Resources of the Kansas State Board of Agriculture, George S. Knapp, chief engineer, and the western Kansas studies have been coördinated fully with work being undertaken through the Soil Conservation Service and other branches of the United States Department of Agriculture. This systematic geologic and engineering work under competent technical direction, coördinated with labor of other state agencies, may be confidently expected to supply vital information needed for the wise development and best utilization of the ground-water resources existing in various parts of Kansas.

Water-bearing Formations of Kansas

It is the purpose of this portion of the discussion of ground-water resources of Kansas to describe briefly the character and distribution of all main water-bearing formations of the state. Information on this subject has been acquired through experience by many water-well drillers, but much may be gained by better application of geologic knowledge to the search for good ground-water supplies and development of them. General facts concerning the distribution of Kansas ground waters are well known, but investigations are urgently needed in many areas in order to supply reliable information concerning ground-water geology, quality and amounts of available water, conditions affecting recharge of the underground reservoirs, and other important matters. As rapidly as possible the Geological Survey will determine local conditions, aiding drillers and coöperating with citizens in efforts to utilize best a natural resource that is one of the most important of any belonging to Kansas.

The following summary is arranged in the approximate order of the geologic age of the water-bearing formations, from youngest to oldest. This directs attention first to the unconsolidated surface materials, such as the alluvium of stream valleys, dune-sand deposits, and the so-called mantle rock, which consists of the loose rock materials covering (or mantling) bedrock almost everywhere.

Unconsolidated Formations

Residual soils and mantle rock.—The fine to coarse fragmental rock materials, geologically recent in origin, that cover most of the land surface outside of stream valleys in Kansas, have been formed by the physical and chemical weathering of bedrock. In many places this porous mantle includes considerably more than the surface soil, for disintegration and decomposition of solid rock may proceed downward beyond the depth penetrated by roots. Locally, the thickness of this potential container of ground water may be 30 or 40 feet, and in places outside Kansas there are residual accumulations of weathered rock amounting to more than 100 feet. On hill slopes and valley sides there is generally some streamward shift of mineral particles and rock fragments, and this process may form accumulations (called colluvial) at and near the base of slopes. All this mantle rock material may collect water and some of it may hold water in considerable quantity for long periods of time. This is the source of water in thousands of good farm wells of shallow depth. Such wells are most likely to yield good supplies where there is an adequate catchment area, so located that subsurface drainage is directed toward the well. Such wells are also most steady and reliable in their supply if they are located below farm ponds in such manner as to gather part of the seepage water from these reservoirs. The water collected in residual soils drains downward into bedrock where the latter is sufficiently pervious, and otherwise it moves laterally into the alluvium of valleys. Locally, it may come to the surface, forming hillside seeps or marshy areas, and wherever it is reached by roots of plants it may be drawn upward by them.

Loess—Thousands of square miles in Kansas, especially in western, north-central, and northeastern counties of the state, are covered by a fine sandy or silty deposit called loess. Most of it is wind-laid material. A peculiarity of loess is the tendency that it shows to stand in vertical walls where exposed in creek banks and road cuts. The thickness of such material in Kansas ranges from a few inches to more than 180 feet in some western areas, and about 100 feet in northern McPherson county and along the Missouri river bluffs. The loess is very porous, but its fine texture makes it relatively impervious. Where water-bearing, it yields a slow flow into wells, and although these wells may be very steady as a source of supply, none of them furnish large quantities of water per day. All the loess in Kansas is classified as Quaternary in age; most of it was formed during Pleistocene time, the so-called Ice Age, during part of which time glacial ice covered northeastern Kansas.

Glacial deposits.—Gravel, sand, clay, and locally boulders, occurring in northeastern counties of Kansas, represent deposits made by Pleistocene glacial ice. Unsorted rock debris left by melting of the ice is termed till, or glacial drift, and more or less sorted sediments deposited by streams of melt water are classed as fluvio-glacial. Both types of deposits occur in Kansas, and in addition, there are beds of fine sand and clay that were laid in temporary lakes formed by glacial blocking of drainage. Thickness of the glacial deposits ranges from a few inches to 200 feet or more, and in many townships there are no outcrops of bedrock even in deepest valleys. Much of the glacial material is sufficiently pervious to form a good water container, and plentiful supplies of good water are found throughout most of the glaciated area. Irregularity in distribution of the most pervious deposits makes local water-supply conditions variable, however, good wells in some areas being only a short distance from poor ones.

Alluvium.—Valley deposits of Quaternary age (Pleistocene and Recent) comprise ground-water reservoirs that are probably to be valued more highly than any others in Kansas. The deposits consist of gravel, sand, silt, and clay laid down by streams in the valleys. In all larger valleys the alluvial deposits have a broad, almost flat surface, the flood plain, and in many valleys this broad plain is bordered by benches, also composed of alluvium, called terraces. The terraces are remnants of valley fills, or flood plains, formed at earlier stages than that of the present flood plain. The water table in valley alluvium of Kansas is almost invariably at the level or somewhat above the level of the water in the stream channel, and this denotes a general feeding of water into the valley from the sides. For example, along Arkansas river valley in Cowley county, municipal water supplies for Winfield and Arkansas City are obtained from wells in the river-valley alluvium at points near the border of the flood plain, and difference in chemical character of the well water as compared to normal Arkansas river underflow, together with the slightly higher elevation of the water table toward the sides of the valley, indicates that the well water comes mainly from local subsurface drainage into the valley. Surface flow in rivers is maintained between times of rainfall by seepage of ground water from the alluvium into the stream channel. The thickness of alluvial deposits in most valleys is generally less than 100 feet, but locally it exceeds 250 feet.

Not all alluvial deposits of Kansas are found along existing stream courses. The McPherson formation (restricted), north of Wichita, consists of gravel, sand, and other stream-borne materials that were deposited by an Ice Age (Pleistocene) river that flowed southward from the present Smoky Hill river valley near Lindsborg, joining the Arkansas above Wichita. It is one of the most prolific ground-water reservoirs in the state. The Gerlane formation, similarly, comprises stream deposits of Pleistocene age in Barber and adjoining counties of southern Kansas. It is a less important ground-water reservoir than the McPherson beds, but good wells in many places obtain water from it.

Dune sand.—Hills and broad hummocky areas composed of loose sand occur in many counties of central and western Kansas. This dune sand was deposited partly in Pleistocene time, as indicated by occurrence of old soils, relation to local fossil-bearing deposits, and other evidence. A considerable number of the dunes are to be classed as recent, as shown by topographic features and by their instability. This sand is very pervious, collects rain water like a sponge, and conducts it below ground. The water table is found at comparatively shallow depth in most of the sand-hills country, for ground water saturates the lower part of the dune sand or occurs in underlying deposits. The thickness of dune sand ranges widely, about 100 feet being a maximum.

Consolidated (Bedrock) Formations

Tertiary System.—One of the chief ground-water reservoir rocks of Kansas consists of the deposits of Tertiary age, which are widely spread on the High Plains of western Kansas. These deposits are collectively known as the Ogallala beds. They consist predominantly of sand that was deposited by streams flowing eastward from the Rocky Mountain area. Because of variation in the size of materials carried by these streams, according to the strength of their currents at different times and places, the texture of the Ogallala deposits is by no means uniform. In places there are lenses and sinuous bands of gravel, especially near the base of the deposits. Locally, there is much fine silt and clay, and calcium carbonate is widely, though irregularly, distributed through the sediments, serving to cement the grains to form so-called "mortar beds". At or near the top of the Ogallala in many places is a very persistent hard limestone, two to four feet thick. The occurrence of this bed and the finding of some persistent zones of small fossil grass seeds has aided geologic study of these deposits, because it has permitted identification and tracing of corresponding parts of the deposit in different regions. In most places north of Arkansas river, the thickness of the Ogallala deposits is less than 200 feet. In parts of southwestern Kansas, as near Liberal, study of samples from many deep wells indicates that as much as 500 feet of material next below the surface may belong to the Quaternary and Tertiary systems. Viewed as a whole, the Ogallala beds are a widespread sheet of comparatively uniform constitution and thickness, but there are local variations in the thickness and nature of the materials that are highly important in connection with ground-water studies. Where hills of Cretaceous bedrock project upward into the Ogallala deposits, the latter may be comparatively barren of water.

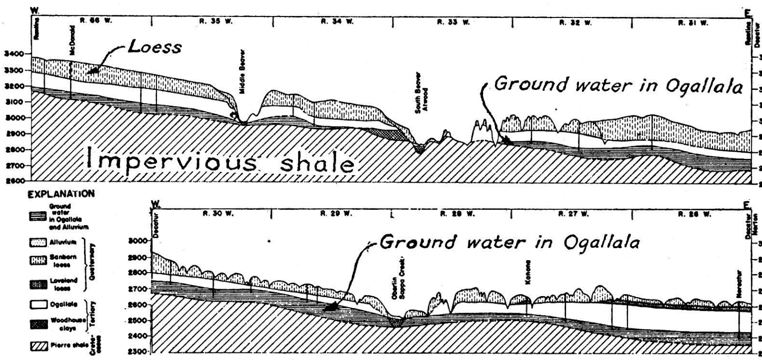

FIG. 13. Geologic sections in an east-west direction across central Decatur and Rawlins counties, northwestern Kansas, showing occurrence of ground water in the Ogallala beds, which rest on impervious Cretaceous rocks. Most of the surface of the country is covered by loess. (M. K. Elias.)

The Tertiary deposits of western Kansas are in general very permeable and they contain an extremely large amount of ground water of excellent quality. Surveys are yet insufficient to show the average quantity of this water and the rate of its movement and recharge. It is safe to conclude, however, that many square miles in the western Kansas region contain at least two billion gallons per square mile.

Clay deposits (Woodhouse) of very local distribution, 20 to 60 feet thick, underlie the Ogallala beds in places. They also belong to the Tertiary system.

Cretaceous system.—The uppermost Cretaceous deposits of Kansas consist of dark clayey strata belonging to the Pierre shale. This formation is exposed along the western part of the Smoky Hill river valley and underlies northwestern Kansas, the maximum thickness being about 1,400 feet in Cheyenne county. There are few water-bearing beds in the Pierre formation that will yield good supplies to wells.

The Niobrara chalk, about 500 to 700 feet thick, underlies the Pierre shale. A basal division, called the Fort Hays limestone, about 60 feet thick, consists of moderately hard even-bedded chalky limestone. The remaining part of the chalk consists of soft calcareous shale and soft chalk beds that are relatively impervious to water.

The Codell sandstone, about ten feet thick, underlies the Fort Hays limestone and is a good water-bearing zone that yields water to wells and that is marked along its outcrop by springs in numerous places. Although thin, this sandstone is very persistent

Beds next below the Codell sandstone comprise the Carlile shale, about 300 feet in thickness. These beds contain no ground water available for wells. The Greenhorn limestone, 75 to 100 feet thick, which underlies the Carlile shale, consists of thin beds of chalky limestone and chalky shale. Ground water is obtainable from joint cracks in the limestone beds, but the Greenhorn is not an important ground-water bearer. The Graneros shale, about 40 to 50 feet thick, below the Greenhorn, consists mostly of clay shale, but contains local lenses of sandstone and sandy shale that may yield some water to wells.

It may be noted that with the exception of the thin Codell sandstone, no part of the Cretaceous beds thus far considered, totaling about 2,500 feet in maximum thickness, can be relied upon to provide ground-water supplies. Accordingly, throughout the broad region of Cretaceous outcrops in north-central and northwestern Kansas, it is necessary, wherever water-bearing Tertiary beds are absent, to rely on surface-water storage or on the ground water collected in the comparatively thin zone of somewhat pervious materials formed by weathering of bedrock. Partly because these difficulties of obtaining water supply have been emphasized by experience in recent drought years, this part of Kansas has lately been the area of greatest activity in construction of farm ponds and other surface reservoirs. As the result of this activity, there has been relatively little distress due to lack of water for stock and domestic use in the north-central Kansas region.

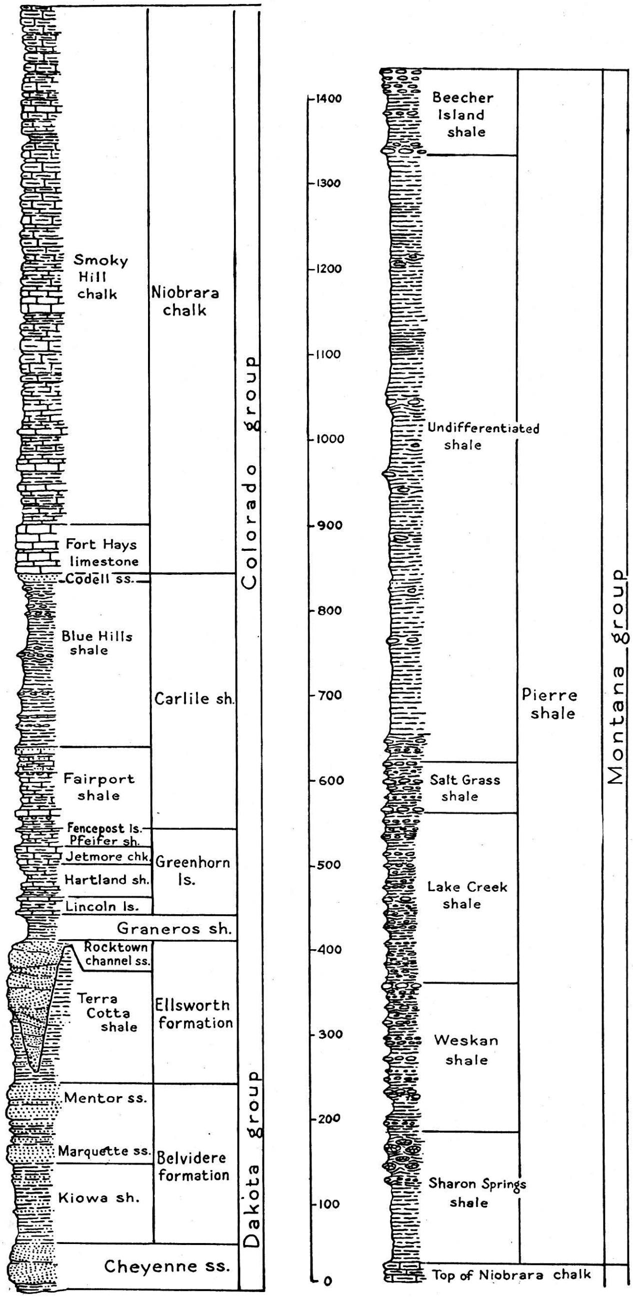

FIG. 14. Generalized section of the Cretaceous rocks of Kansas, showing the classification and order of succession of these strata. Sandstone beds of the Dakota group and the thin Codell sandstone, at the base of the Niobrara chalk, are almost the only parts of this system that yield water to wells in Kansas.

The Dakota sandstone comprises the lowest, oldest beds of Cretaceous age that are present in Kansas (various local Comanchean deposits not being differentiated here from the Dakota). The thickness of these beds, consisting mainly of iron-rich sandstone, ranges from a few feet near the eastern edge of the outcrop area to a maximum of about 600 feet. There are some zones of mottled red and dark-colored shale dividing the sandstone beds. The pervious nature of the sandstone layers makes them good water-bearing rocks. Accordingly, the Dakota sandstone is a formation that supplies large quantities of water to wells and springs in several districts. On the other hand, the occurrence of salt water in parts of this formation renders the Dakota water of certain areas too highly mineralized for domestic or stock use. The Dakota is widely known as an artesian water-bearing formation in the Great Plains region, but it is not an important source of supply in Kansas for relatively deep artesian wells. Wells in parts of Morton, Stanton, and Ford counties in southwestern Kansas penetrate Tertiary strata, but derive water only from the underlying Dakota sandstone.

Permian system.—The highest Permian rocks of Kansas are red sandstone and shale beds belonging to the Taloga and Whitehorse formations. These rocks, which have an aggregate total thickness of about 300 feet, underlie most of western Kansas, but are exposed only in parts of Meade, Clark, and Comanche counties. The sandstones contain water sufficient for farm wells in the outcrop area, but where the rocks are deeply buried they contain only salt water.

Below the Whitehorse sandstone are Permian red beds classed as belonging to the Nippewalla group, about 700 feet thick. Deposits of gypsum and thin beds of dolomite occur in parts of the section. Sandstone layers contain fresh water near the outcrop and supply farm wells, but most of the water in the Nippewalla beds is of poor quality, owing to high mineral content. None of the rock can be classed as valuable water-bearing reservoirs.

The next lower division of Permian strata is known as the Sumner group. It comprises the thin Stone Corral dolomite, red beds called the Ninnescah shale, and underneath this, the Wellington shale, which contains the thick Hutchinson salt deposits and many beds of gypsum and anhydrite. The Sumner beds crop out in a relatively broad band with north-south trend extending from Sumner county to Clay and Washington counties. Small quantities of ground water occur in the more pervious strata of the Sumner group, and locally, as near Hillsboro, in Marion county, there are wells yielding as

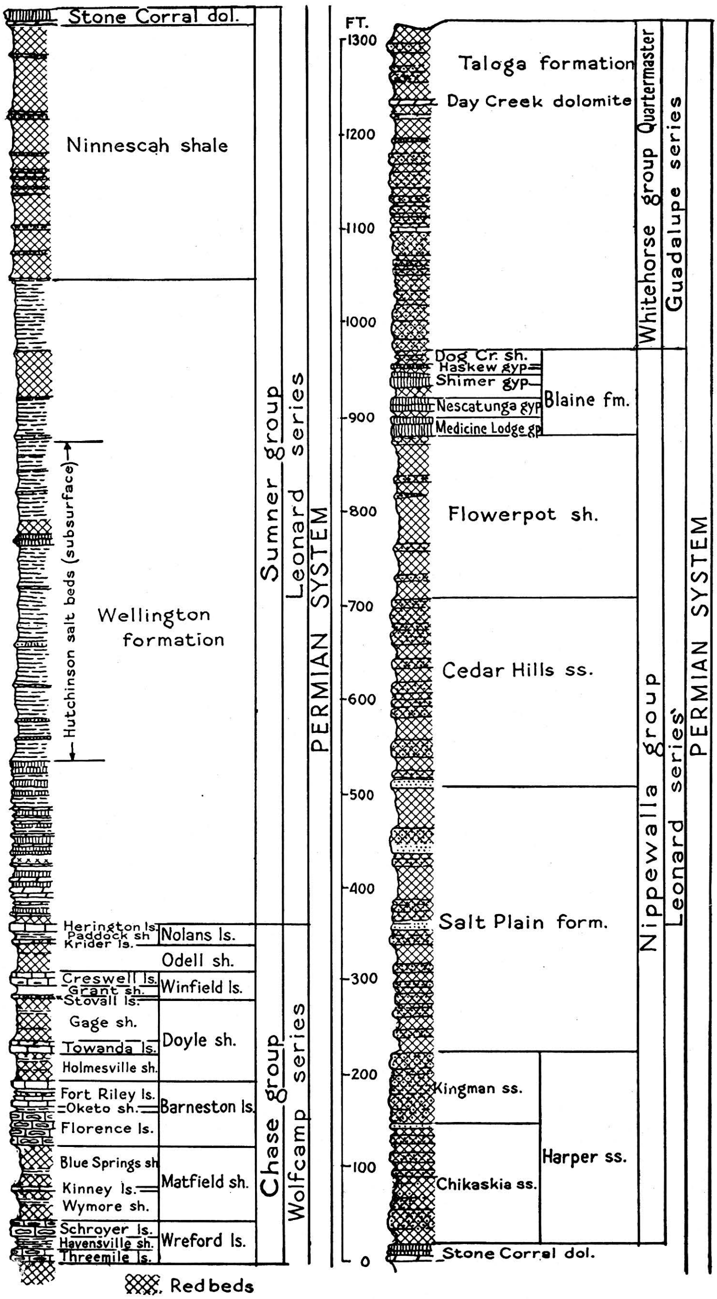

FIG. 15. Generalized section of the middle and upper parts of the Permian system in Kansas, based mainly on outcrops in south-central counties. Widespread salt deposits in the middle part of the Wellington formation are not indicated in the section because the salt is penetrated only in deep wells. Ground-water supplies in these rocks are scanty and poor.

much as seventy gallons a minute that obtain their supply from Sumner rocks. The water is of very poor quality because of its unusually large content of dissolved salt and gypsum. The average total thickness of these rocks is about 1,000 feet.

The Chase group, which underlies the Sumner beds, has a thickness of 300 to 350 feet. It is distinguished especially by the occurrence of hard flint-bearing limestones that form prominent escarpments along the outcrop. These are the rocks that cap the so-called Flint Hills, or Bluestem belt, that crosses the state from Cowley county to Marshall county. Shale beds that lie between the limestones are not a source of water supply, but several of the limestones, especially those that contain an abundance of flint, yield rather large supplies of water of good quality to shallow wells. Conditions of weathering that facilitate solution of passageways through these beds are most favorable where the rocks underlie broad dip slopes, as between the Flint Hills front in western Greenwood county and the valley of Walnut river in western Butler county, and in extensions of this belt farther south and north. The chief water-bearing formations of this group are the Florence limestone and the Wreford limestone. Somewhat smaller quantities of water are obtainable from the Winfield, Fort Riley, and other limestones.

The Council Grove group, about 300 feet thick, and the Admire group, 100 to 230 feet thick, underlie the Chase beds and form the lowermost part of the Permian system in Kansas. These rocks consist of alternating thin limestones and red or bluish shale beds. Few of the individual rock units exceed ten feet in thickness, and, excepting the Foraker limestone in parts of southern Kansas, none of these strata can be regarded as having any importance as ground-water reservoirs. Almost any of the limestone beds, however, may be sufficiently porous close to their outcrop to permit accumulation in them of small quantities of water that may be recovered by wells. The basal Admire deposits in parts of western Chautauqua, Wabaunsee, Shawnee, and Brown counties consist of thick porous sandstone that constitutes a locally important ground-water reservoir. This is the Indian Cave sandstone, a channel-filling deposit that ranges in thickness from a few inches to 120 feet.

Carboniferous system.—Outcrops of Pennsylvanian rocks, which comprise the upper part of the Carboniferous system, occupy the eastern one-third of Kansas, lying beneath Permian rocks and cropping out east of them. They consist of alternating thin limestone, shale, and sandstone beds, and at some horizons, thin coal beds.

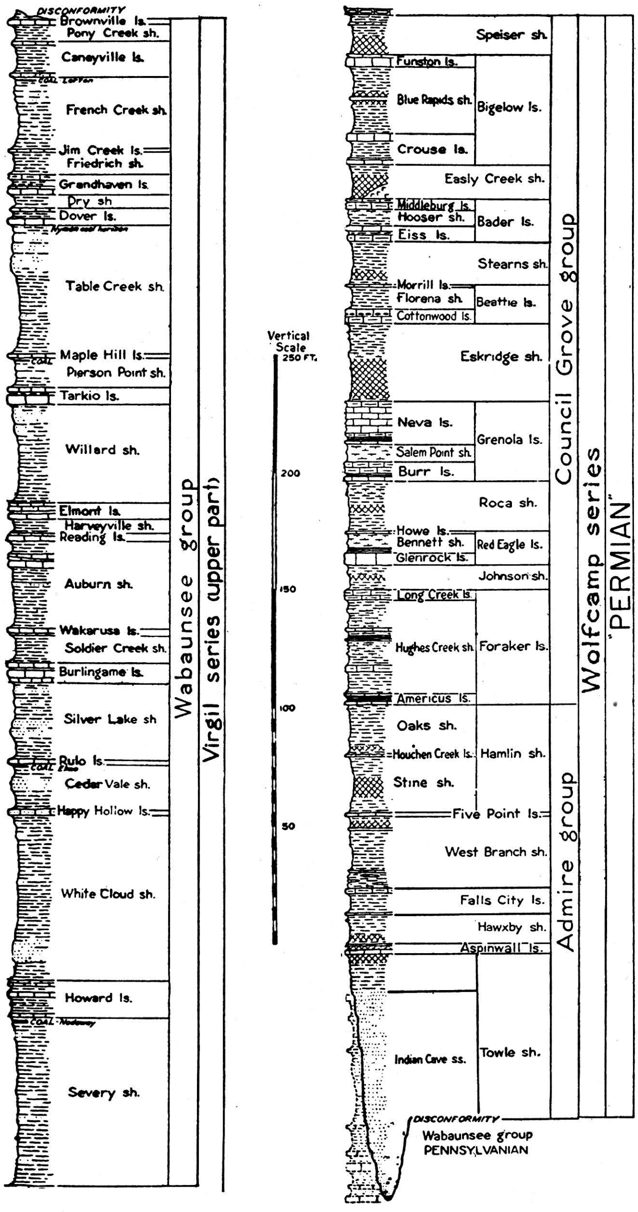

FIG. 16. Generalized section of lower Permian and uppermost Carboniferous (upper Pennsylvanian) rocks of Kansas. Some of the limestone formations and some sandstone deposits are good shallow ground-water reservoirs.

Broadly speaking, these rocks are deficient as ground-water reservoirs, but water derived from Pennsylvanian bedrocks is entirely sufficient in most places to supply farm-water needs.

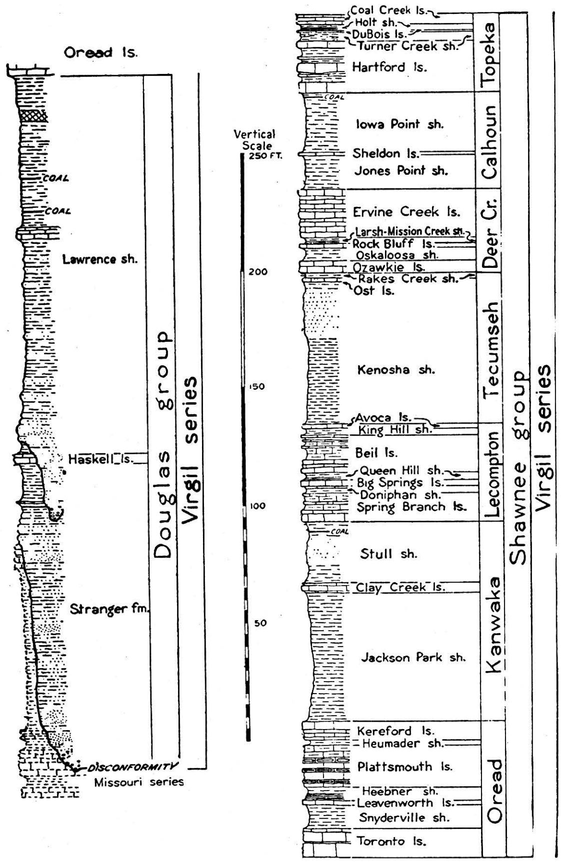

FIG. 17. Generalized section of Pennsylvanian rocks belonging to the middle and lower part of the Virgil series in Kansas. The best ground-water supplies occur in sandstone beds of the Douglas group.

The upper 1,000 feet of Pennsylvanian rocks consists of the Virgil series. Few of the upper Virgil limestones are more than five feet thick, but on dip slopes where there are adequate catchment areas, the Brownville, Dover, Tarkio, Reading, Burlingame, and Howard limestones may be water-bearing. The location of the outcrop of these individual units is shown on the detailed geological map of Kansas, published by the Survey (1937). In addition to the lime-

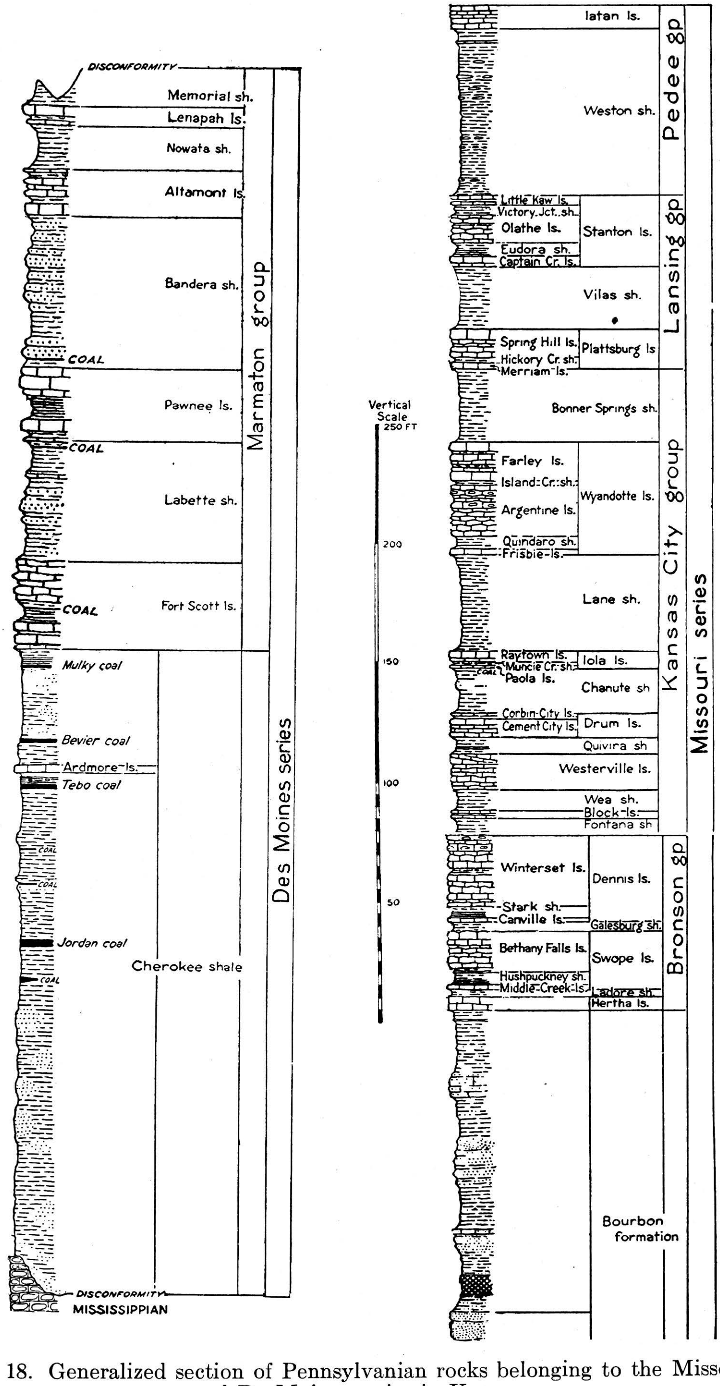

FIG. 18. Generalized section of Pennsylvanian rocks belonging to the Missouri and DesMoines series in Kansas.

stones, there are sandstones at several horizons that are reliable water-bearing strata, but fresh water is confined to the near-outcrop portions of their extent.

The middle Virgil beds, known as the Shawnee group, are characterized by greater prominence of limestone strata. Conditions along the outcrop belt are somewhat similar to those in the Chase group of the Permian, except that these Pennsylvanian rocks are less cherty and their content of water is generally less than that of the Permian beds. The best places for water development are long dip slopes. Sandstone beds occur in the shale between these limestones and yield water in many places. The chief water-bearing formations in this part of the bedrock section are the Topeka limestone, Deer Creek limestone, Lecompton limestone, Elgin sandstone member of the Kanwaka shale, and Oread limestone. The Shawnee beds have a total thickness of about 350 feet.

The Douglas group, which includes the lowermost Virgil deposits, has a thickness of 200 to 300 feet. This division is characterized especially by the occurrence of fairly thick and widespread sandstone deposits, which contain good supplies of water near the outcrop. Several towns draw their municipal supplies from wells penetrating these sandstone beds. As shown on the state geologic map, the outcrop belt of the Douglas group extends from eastern Leavenworth county to central Chautauqua county.

The Missouri series underlies the Virgil series and crops out just east of it. The total thickness of this division is about 600 feet. It is characterized especially by prominence of numerous limestone beds separated by thin deposits of clayey to somewhat sandy shale. Limestones that are water-bearing on dip slopes near the outcrops include especially the Stanton, Plattsburg, Wyandotte, Iola, and Dennis. Local sandstone deposits in the Bourbon formation, at the base of the Missouri series, are good water containers in areas close to the outcrop.

The lowest main division of the Pennsylvanian rocks in Kansas consists of the Des Moines series, about 400 to 600 feet thick. The outcrop of these rocks lies along the eastern border of the state and is widest near the Oklahoma boundary. The upper part of the Des Moines beds includes alternating limestone and shale beds that are essentially similar to those of the Missouri and higher divisions. The Pawnee and Fort Scott limestones, and, in southern Kansas, the Altamont and Lenepah limestones may collect and yield water in areas where they underlie long dip slopes. The Cherokee shale comprises the lower part of the Des Moines series and includes 400 to 500 feet of beds, mostly shale. In places there are fairly thick sandstones that yield water close to the outcrop. One of the main water-bearing rocks is the Bluejacket sandstone, which crops out just east of Columbus. The water in this sandstone is sufficient to supply small towns as well as numerous farm wells.

Mississippian rocks, which form the lower part of the Carboniferous system, crop out in a few southeastern townships of Cherokee county, but the exposures in western Missouri are extensive. These rocks consist mainly of limestone, and the passageways for water in this rock have been made by solution along joints and bedding planes. Rainfall on the Mississippian outcrop is conducted into subsurface channels and carried down the dip with only moderate increase of dissolved mineral content. Large quantities of ground water are obtained from Mississippian limestones, 400 to 500 feet thick, in wells drilled in Cherokee and Crawford counties.

Ordovician and Cambrian systems.—The pre-Carboniferous rocks of a small part of southeastern Kansas contain ground water that is sufficiently low in mineral content to be used for domestic supplies. This water is found chiefly in porous sandstone layers. Wells, 1,000 to 1,700 feet deep, have been drilled in southeastern Kansas cities, such as Columbus, Pittsburg, Girard, and others, finding usable water in the deep formations. The considerable depth of this ground water, and its increased salt and other mineral content in a northwestward direction, limit utilization to a few places in the counties mentioned.

Ground-water Regions of Kansas

For purposes of brief description of the essential character and extent of the main ground-water resources of Kansas, it is convenient to divide the state into regions that are defined by characters of water-supply conditions. There are four such regions. The boundaries of these regions and subdivisions of them that may be recognized are shown on the accompanying map, designated by letters and numbers.

A. The eastern Kansas region, comprising the eastern one-third of the state, is essentially characterized by outcrops of Carboniferous and Permian bedrocks that dip gently westward. The topography is characterized by a succession of eastward-facing escarpments; the land surface is moderately rough. As a whole this region is lacking in ground-water reservoirs capable of yielding large

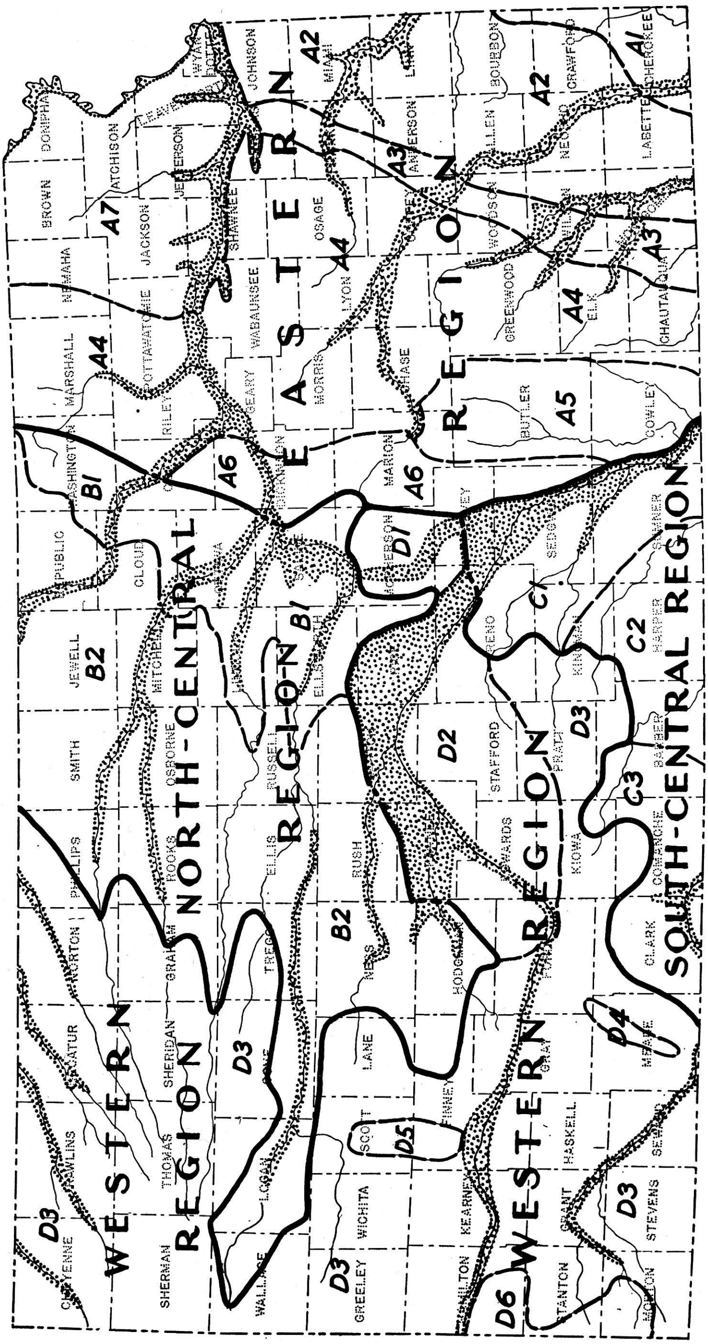

FIG. 19. Ground-water provinces of Kansas. The four regions and subdivisions of them that are indicated on this map are differentiated by prevailing conditions of ground-water occurrence. These conditions reflect essential differences in geologic structure.

quantities of good water, though all the larger stream valleys and a few of the bedrocks yield good supplies.

B. The north-central Kansas region comprises chiefly the area of Cretaceous outcrops. At its eastern margin, the Dakota sandstone provides good water in many places, although in others this water is too salty for use. Otherwise, this region is very similar to the eastern Kansas province in lacking large supplies of ground-water.

C. The south-central Kansas region comprises the Permian red-beds country, in which few good water supplies are obtainable from bedrocks, but in which there are adequate supplies from some of the surficial sediments.

D. The western Kansas region includes the most widespread and one of the most reliable ground-water reservoirs in the state. This consists of a mantle of partly consolidated sediments of comparatively recent geologic origin, which contain large quantities of water of fine quality.

Eastern Kansas Region

In addition to the ground-water reservoirs of major stream valleys, there are seven subdivisions of this region that may be differentiated according to significant variation in conditions of the ground-water supplies.

A—1, Cherokee District.—This district includes the southeastern corner of the state, comprising most of the area of Cherokee county and small parts of adjoining Labette, Crawford, and Bourbon counties. The region is characterized by a lowland plains surface topography in which shale and local beds of porous sandstone underlie most of the country. Water is obtainable from the porous soil cover above the shale, and in the near-outcrop portions of the various sandstone beds. Throughout most of this region also, waters of good quality are obtainable from the Mississippian limestone, 400 to 500 feet thick, which next underlies the relatively impervious Cherokee shale. The water in the Mississippian is derived from rainfall entering the formations at outcrops farther east in Missouri. Several cities, such as Columbus and Pittsburg, obtain supplies for municipal use from deep wells penetrating the Mississippian and underlying rocks.

A—2, Neosho District.—In this district, named from Neosho county, which typically represents the general ground-water conditions of the district, all or parts of several other counties extending southward from Kansas City to the Oklahoma line are here naturally

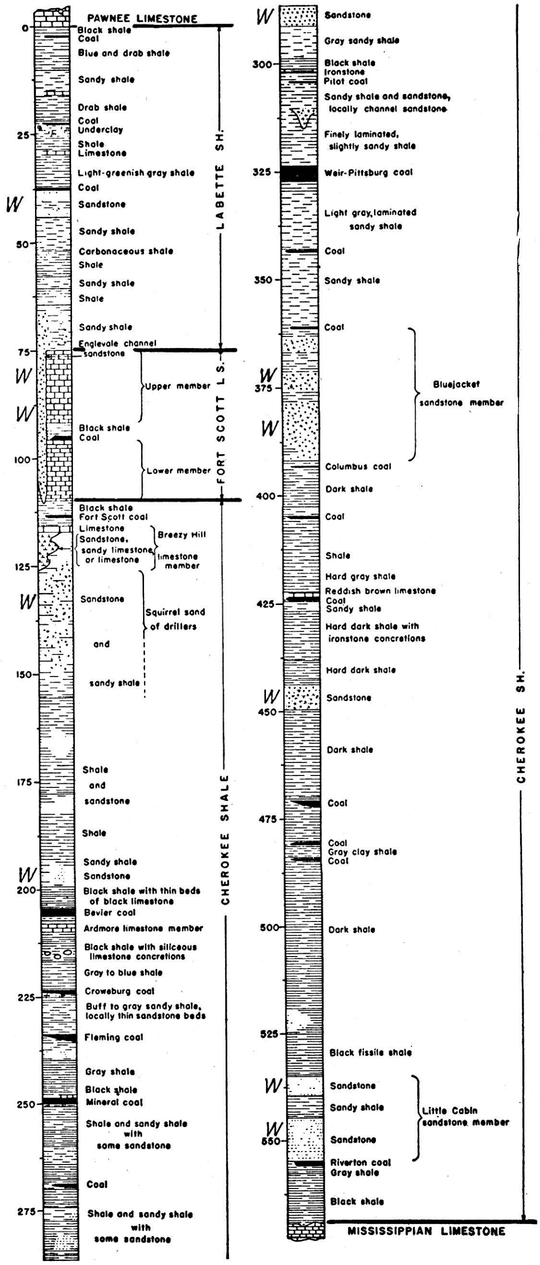

FIG. 20. Generalized section of Pennsylvanian rocks exposed in the Cherokee district of southeastern Kansas. Strata that yield good supplies of water locally near their outcrop are indicated by *W* (W. G. Pierce and W. H. Courtier).

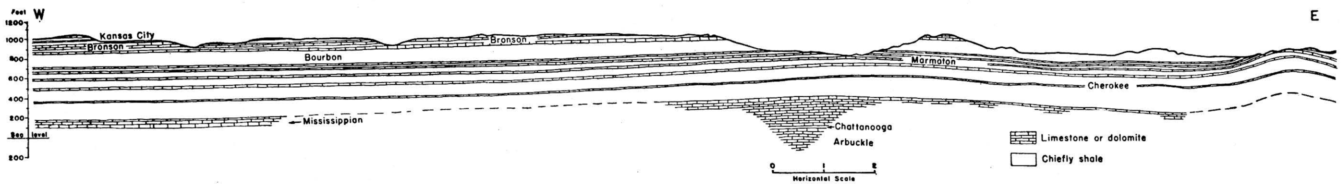

FIG. 21. Geologic section in an east-west direction across central Linn county. Limestone beds that occur next below the land surface over many square miles are good sources of ground-water supply. The water is collected in openings dissolved along bedding planes and joint cracks and it tends to migrate slowly in the direction of dip of the beds. (J. M. Jewett.)

grouped together because of similarity of the bedrocks, consisting predominantly of shale and escarpment-making limestone. There are few, if any, formations that bear large quantities of water, although supplies adequate for farm wells are found throughout the region in thin surficial porous materials and in the sandy layers of some of the shales. Limestone beds yield water where the formations are close to the surface and where there is an adequate catchment area in which the water may be collected and conducted through fissures and other openings in the rocks to well locations.

A—3, Woodson District.—This is a relatively narrow belt crossing Woodson county and reaching from the Oklahoma line to Kansas river. Its trend is a little east of north to west of south. The district comprises the outcrop belt of Pennsylvanian rocks (Douglas group) consisting largely of sandstone and shale that occur between prominent groups of limestone. The sandstone layers are important water-bearing reservoirs in parts of this region and, close to the outcrops, yield water of good quality.

A—4, Lyon District.—Larger than any other of the subdivisions of the eastern Kansas region is the district here treated. It is essentially like district A—2 in that the most important geologic elements consist of escarpment-making limestone formations that are separated by relatively impervious clay and calcareous shale. There is little sandstone. Most of the area is distinctly hilly. Ground-water supplies sufficient for ordinary farm and stock use are obtainable from porous surficial deposits and in places from the fissured near-surface limestones, but these ground-water reservoirs are too limited to be of much importance. Farm ponds are especially important as an adjunct to a steady supply of water on farms.

A—5, Butler District.—West of the Flint Hills escarpment in south central Kansas is the Butler district, comprising most of Butler and Cowley counties and small parts of Marion and Chase counties. It is differentiated because of the long dip slopes underlain by limestone that yield water collected from the area of the dip slopes. This is a region in which water wells depend almost wholly on locating belts or joints or other openings in the limestone. Wells in these formations may be treated successfully by acid in many cases to increase the freedom of circulation of water in the rocks.

A—6, Marion District.—The outcrop area of Permian shales, belonging mostly to the Wellington formation, which comprise a belt from eastern Sedgwick county northward to Clay county, is characterized by the very local and poor quality of the ground-water supplies that may be developed. The water is obtained from surficial materials and the weathered outcrop of more porous strata in the shaly rock. It is generally highly mineralized because of the abundance of gypsum in the underlying bedrock. Also, salt from the same beds gives a greater content of sodium chloride than is present in most of the ground waters of the state.

A—7, Jackson District.—Northeastern Kansas, comprising counties north of Kansas river and east of central Nemaha and eastern Pottawatomie counties, is essentially characterized by its widespread cover of glacial drift. This entirely conceals the underlying bedrock in most places, although near Missouri river and other large streams there are outcrops of bedrocks. The glacial deposits consist of "boulder clay" and in places of very porous sand and gravel that are good water containers. There are few parts of this district that do not yield good supplies of well water, although the quantities in most places are not large enough to supply communities. There has as yet been no systematic study of the glacial materials in order to determine trends of essentially pervious gravels that may be better than other parts of the district as ground-water reservoirs. There are virtually no ground-water supplies in the bedrocks at all.

North-Central Kansas Region

B—1, Ellsworth District.—The outcrop of the Dakota sandstone, which is characterized topographically by the prominent irregular Smoky Hills, constitutes a distinct part of the north-central Kansas region. It is here designated as the Ellsworth district because this area shows very typical features of the geology and water-supply conditions. Wells generally obtain good supplies from either an upper or lower zone in the sandstone. The middle part of the Dakota commonly contains impervious shale. Because of salt or salt-bearing shale in parts of the Dakota deposits, some of the water has become so highly mineralized that it is not fit either for domestic or stock use. Salt marshes occur locally, as in Cloud county.

B—2, Osborne District.—The Cretaceous outcrop areas, exclusive of the Dakota Sandstone, are grouped together as the Osborne district. In the eastern part of the belt are shales and thin limestones (Greenhorn) in which water-supply conditions are difficult and the water obtained is generally hard and gypsiferous. The middle part of the belt includes the Niobrara chalk country, in which waters are hard and limy and the formation is comparatively impervious. The thick Pierre shale, overlying the Smoky Hill, is a clayey impervious

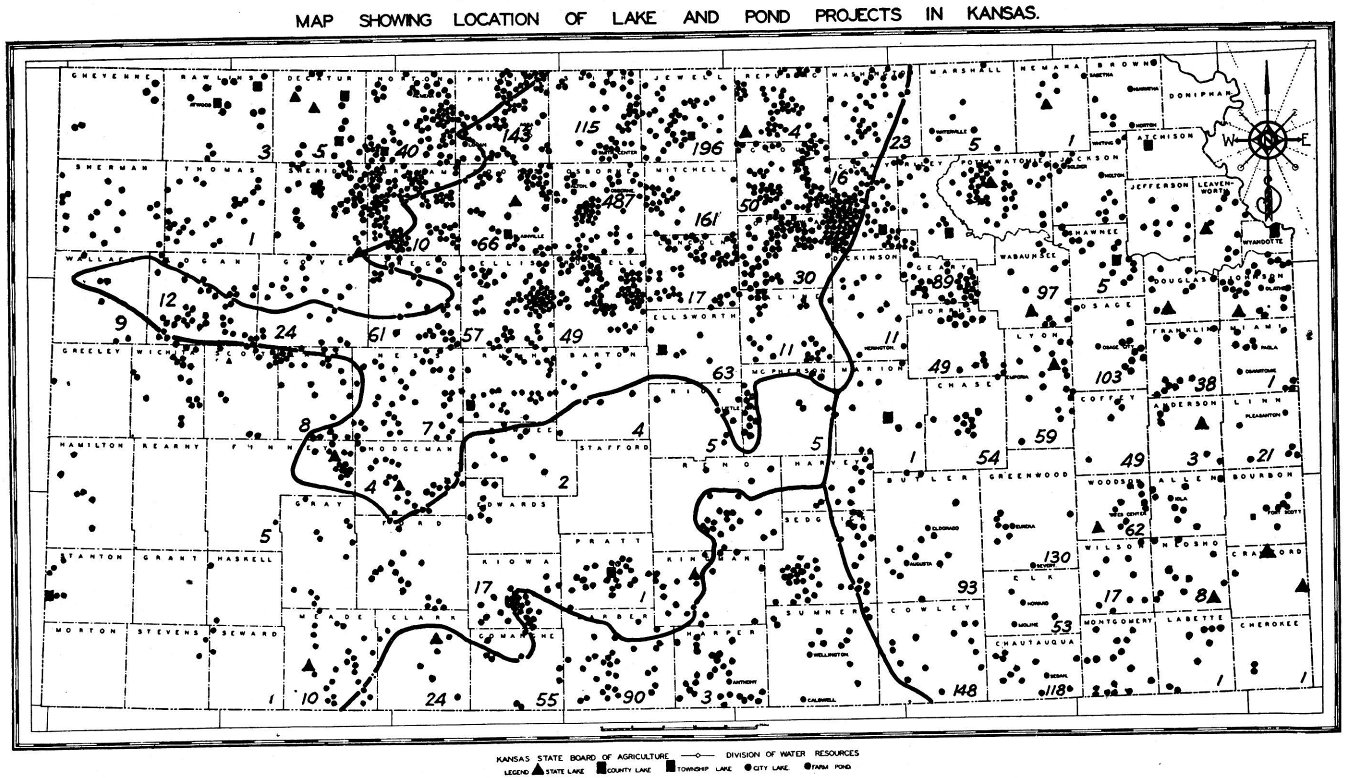

FIG. 22. Map showing distribution of lakes and farm ponds that have a maximum depth of ten feet or more in Kansas (modified slightly from map published by the Division of Water Resources, State Board of Agriculture). Also indicated (by figures) is the distribution of more than 3,000 ponds that have a maximum depth of seven feet or more, constructed in 1938 and 1939 with aid of the Agricultural Adjustment Administration.

formation that generally lacks ground-water reservoirs, and in all this district, excepting weathered surficial deposits, there is little or no water to be obtained from wells. Construction of farm ponds and utilization of water carried by shallow streams and other alluvial fillings are the lines of development required in this part of Kansas to assure needed domestic- and stock-water supplies.

South-Central Kansas Region

C—1, Sumner District.—Territory west and south of Arkansas river, extending from central Reno county to southeastern Sumner, is here designated as a subdivision of the south-central Kansas district. It is underlain by gray and red shale belonging to the Sumner and Nippewalla groups of the Permian system. The water-supply conditions are essentially the same as in district A—6.

C—2, Harper District.—This portion of the south-central Kansas region comprises almost all of Harper county and adjacent portions of Barber, southern Kingman, and western Sumner counties. It is underlain by Permian red beds consisting largely of fine- to medium-grained sandstone, but also containing some red and gypsiferous shale. The sandy beds are water bearing in places close to the outcrops and the problem of obtaining supplies is somewhat simpler than in the immediately adjoining shale territory farther east. Also, the widespread cover of porous surficial materials of Quaternary age serves as a collector of rainwater and yields this water to wells. There are no large supplies of ground water of good quality in this district.

C—3, Comanche District.—From the regions of the gypsum hills in central Barber county westward to the edge of the Tertiary outcrops in southeastern Meade county is a Permian red-beds country in which the rock strata consist predominantly of shale rather than sandstone, and the presence of gypsum tends to make the supplies of ground water hard and highly mineralized. Good supplies of ground water are virtually lacking outside of local deposits in stream valleys.

Western Kansas Region

D—1, McPherson District.—Almost all of McPherson county and northwestern Harvey county are here differentiated, and although located in central Kansas slightly east of the middle line of the state, this district is grouped with the western Kansas region. Such classification is due to the general nature of the water-supply conditions and the fact that the reservoir consists of Tertiary and Quaternary sediments that are mostly unconsolidated. A depression formed in the relatively impervious Permian shale is here filled by sand, gravel, and some clay that was deposited mainly by streams. Recent field studies and test drilling have shown that the deposits may be classed in two main parts, one of which, the older, extends over most of the region as a fairly pervious water-bearing deposit. This is the Emma

FIG. 23. Dissected block diagram showing the geologic structure of a part of central Kansas lying northwest of Wichita. Chiefly noteworthy are the broad alluvial deposits of the Arkansas valley and the McPherson county region. These fill depressions in the impervious Permian bedrocks and overlap on Dakota and other Cretaceous rocks. Locally there are deposits of dune sand.

Creek formation of Pliocene age. In a belt trending southeastward from the vicinity of McPherson is a very porous valley filling in the older materials, the McPherson formation (restricted). This is the main water-bearing zone in the area and may be compared, so far as water conditions are concerned, to alluvial fillings in main stream valleys. The quality of water is excellent and it is utilized by several cities, including McPherson, Inman, Buhler, and Newton. It is interesting to note that the source of the water in these deposits is not the underflow of Smoky Hill river, as commonly supposed, but the reservoir is replenished by rainfall within the district and in part it appears to be fed by seepage from the sand hills along parts of the southwest edge. In this area the ground-water table shows a distinctly higher area as it does also along part of the divide north of McPherson.

A special summary of studies made by Survey geologists in this region is given in a following section by S. W. Lohman.

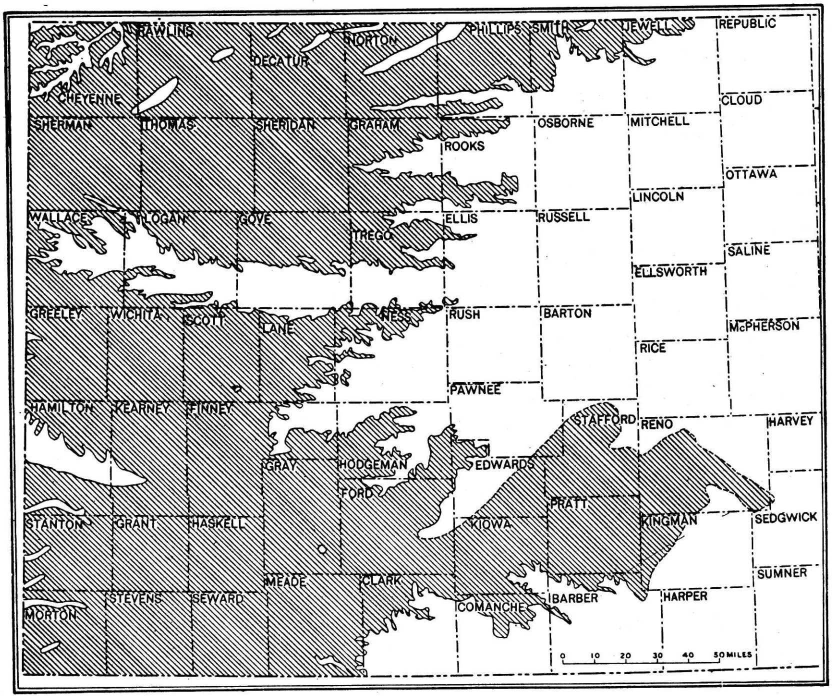

FIG. 24. Map of western Kansas showing outcrop area of Tertiary deposits.

D—2, Stafford District.—Territory surrounding Great Bend and including counties both north and south of Arkansas river, from the eastern edge of Ford county to Harvey county, is here grouped because of the general prevalence of alluvium and sand-hills ground-water conditions. Good water can be obtained almost anywhere, and the sand hills and sandy river bottoms form excellent porous media for the downward seepage of any rainfall in the area. Waters of the underflow of Arkansas river are distinctly salty, especially east of the mouth of Rattlesnake creek. It is apparent that general water movement in the district is slowly northeastward.

D—3, Greeley District.—This district comprises all the western Kansas High Plains Tertiary deposits, excepting small areas that are differentiated from it and treated separately hereafter. A northern subdistrict is partly separated from the rest by the excavation of the Smoky Hill river valley. Also, the main district, south of the Smoky Hill, is divided along the line of Arkansas river by the belt of sand-hills deposits just south of that stream. There are no good reasons for recognizing these subdivisions as separate ground-water units, for all the Tertiary district is characterized by occurrence of sheet water in one or two main zones and is characterized further by the irregularly varying, coarse and fine water-bearing grits. The deposits were made by former streams carrying sediments from the Rocky Mountain front. The variations in the coarseness of the Tertiary sediments affect the local water productivity of the deposits importantly. In places where the sediments are coarsest, it is possible to obtain the largest quantities of water from pumping wells. Geologic field studies by M. K. Elias, H. T. U. Smith, and other geologists of the Survey, supplemented by exploration with the drilling machine, has shown the widespread occurrence of loess, a fine, relatively impervious surficial deposit that retards entrance of rain directly into the underflow. It is very difficult to obtain well water from the loess, which in places may be 100 feet or more in thickness.

The water in the Tertiary beds of this district is derived partly from the local rainfall and partly from water brought eastward from Colorado. It is evident from the low rate of surface rainfall and from studies of evaporation and transpiration in western Kansas that the annual rate of ground-water recharge is very low. It is therefore an important part of ground-water investigations in this region to determine the rate of safe use so that this enormously important resource may not be expended unwisely for such things as general crop irrigation. Somewhat intensive agricultural developments, as in the vicinity of Garden City, depend mostly on ground water carried in the underflow of Arkansas river. It is undoubtedly possible and may be deemed desirable to develop various small districts utilizing Tertiary ground water in order to irrigate stock-feed crops for local use.

A summary of field studies of ground-water conditions in Ford county is given by H. A. Waite in a later section of this paper.

D—4, Meade District.—This includes a relatively small part of eastern Meade county, comprising mainly the valley of Crooked creek. It is differentiated because of the artesian water conditions that exist in this part of the Tertiary district. Water in pervious strata is confined beneath impervious beds, and the structure of the rock locally is such that the water is confined under pressure and will rise of its own head to the surface. These conditions are peculiarly favorable for development of the ground-water supplies and are being studied from the standpoint of possible local irrigation.

A summary of field conditions, as observed in reconnaissance investigations by J. C. Frye, follows in a separate section.

D—5, Scott District.—An area in south-central Scott county and northwestern Finney county is differentiated because of the availability of large quantities of water at relatively shallow depth, and the local use of this water for irrigation. Two water-level observation wells, which have been maintained by the Water Resources Division of the State Board of Agriculture, and 29 observation wells (two equipped with automatic recorders) of the Geological Survey indicate fluctuations of water level with variation in withdrawal from the reservoir by pumping. No exhaustive ground-water studies have yet been completed, but it appears evident that there is no reason to encourage enlargement of irrigation activities to such a point that withdrawals of water are likely to deplete the reservoir.

A brief discussion of the Scott area is given in a following section by H. A. Waite.

D—6, Stanton District.—Western Stanton and adjoining parts of northwestern Morton and western Hamilton counties are separated from the other western Kansas districts because of the cropping out at many points of the Dakota group. The Tertiary cover is thin, and in places it has been removed so as to expose these underlying bedrocks. The water-supply conditions are, therefore, somewhat more variable than in adjoining territory. Also, the water obtained in parts of this district is evidently Dakota water, instead of water obtained from the Tertiary Ogallala deposit.

A summary of reconnaissance studies in this southwestern Kansas district is added in a later section, written by T. G. McLaughlin and Bruce Latta.

Alluvial Deposits

The alluvial deposits of various stream valleys, which are one of the most important sources of ground water in all regions of Kansas, are not differentiated as special districts. All are similar in that the water-bearing materials consist of sand and gravel of various coarseness and the contained water is derived from the streams flowing through the valleys, from seepage from the uplands and sides of the valleys, or from water-bearing formations that crop out in the sides of the valleys. All these factors influence the quantity and quality of the water that is carried in these alluvial deposits. As noted in an earlier section of this paper, the ground water moves very slowly in a downstream direction. It may be depleted in almost any desired degree with the comforting prospect that water from the stream and recurrent rains will generally recharge the reservoir quickly.

Acknowledgments

Preparation of this paper has been aided by data and illustrations provided by S. W. Lohman, H. A. Waite, and J. C. Frye, geologists on the staff of the Division of Ground Water, United States Geological Survey, who are engaged in coöperative studies with the State Geological Survey and the State Board of Health on ground-water resources of Kansas. I am indebted to these men also, and to my colleague, K. K. Landes, for reading of the manuscript and for suggestions. Short reports on ground-water studies in various districts have been contributed by S. W. Lohman, H. A. Waite, J. C. Frye, T. G. McLaughlin, and Bruce Latta. These coöperative ground-water studies are being made under the immediate supervision of S. W. Lohman, geologist in charge of ground-water investigations in Kansas.

Ground Water in the McPherson District, Kansas

By S. W. Lohman

The following discussion treats only of the occurrence of ground water in the unconsolidated Tertiary and Quaternary beds in the district; the ground-water conditions in the older rocks in the district have been described adequately in preceding pages by R. C. Moore. The unconsolidated deposits of the McPherson district comprise the Emma Creek formation of Pliocene age, the McPherson formation (restricted) of Pleistocene age, Pleistocene loess, and Pleistocene and Recent alluvium and dunes.

The Emma Creek formation crops out over a large area in southeastern McPherson county and northern Harvey county. It comprises beds of clay, silt, sand, and gravel, and ranges in thickness from less than ten feet to about 180 feet. The content of sand and gravel is low, except locally in channels, and in general the Emma Creek is only a fair water bearer. The waters are of good quality, except in places where they have been contaminated by oil-field brines.

The McPherson formation (restricted) occupies the filled channel of an ancient stream that once united Smoky Hill and Arkansas rivers. Although it consists in part of silt and clay, it contains beds of coarse sand and gravel that generally yield large supplies of good water. Two of the municipal wells at McPherson yield 1,400 and 2,000 gallons a minute. In the vicinity of Halstead the McPherson waters are of very good quality and have a hardness of less than 150 parts per million. The McPherson waters are much harder near the city of McPherson, and in some places south of McPherson these waters contain appreciable amounts of iron.

In the vicinity of McPherson the formations described above are covered with a mantle of loess that is more than 100 feet thick locally. This fine-grained material yields virtually no water to wells, and where thick, as at McPherson, it prevents or greatly retards movement of rainfall into underlying water-bearing formations.

Sand dunes occupy a hilly belt about five miles wide that extends from a point north of Hutchinson and Burrton eastward to Little Arkansas river. The dune sand is very porous, and, where free of soil or vegetation, is able to take up considerable water from rainfall. The sand is very fine-grained and therefore supplies but little water directly to wells, but a large part of the recharge received by

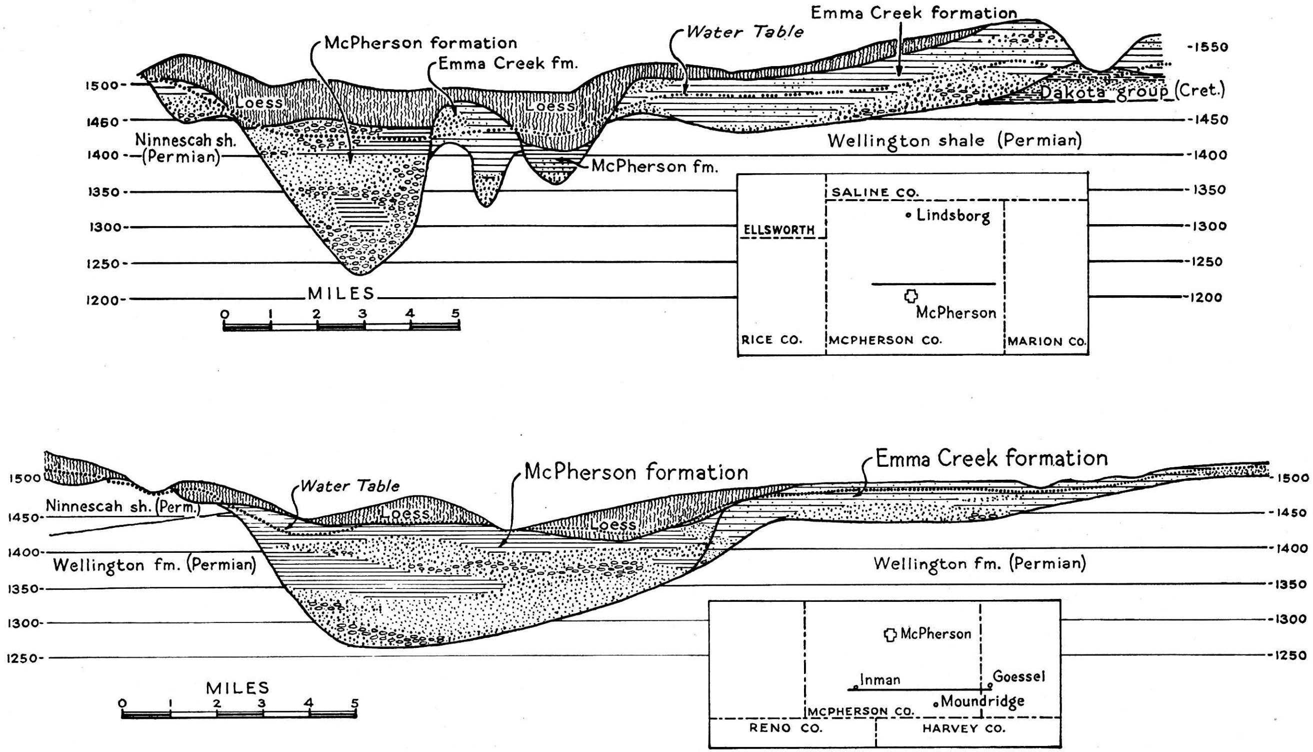

FIG. 25. Geologic sections of water-bearing alluvial deposits belonging to the Emma Creek (Tertiary) and McPherson (Quaternary) formations in McPherson county. Very large quantities of good ground water are obtainable from the McPherson deposits. (J. C. Frye.)

the dunes migrates into adjacent formations where it becomes available for recovery by wells.

The alluvium of the Arkansas valley is the most productive water bearer in the McPherson district. Although the alluvium is more than 250 feet thick in some places, in general the most productive gravels and sands occur within a depth of 75 to 100 feet. The yields from properly constructed wells range from 750 to more than 2,000 gallons a minute. The alluvium supplies the cities of Wichita,

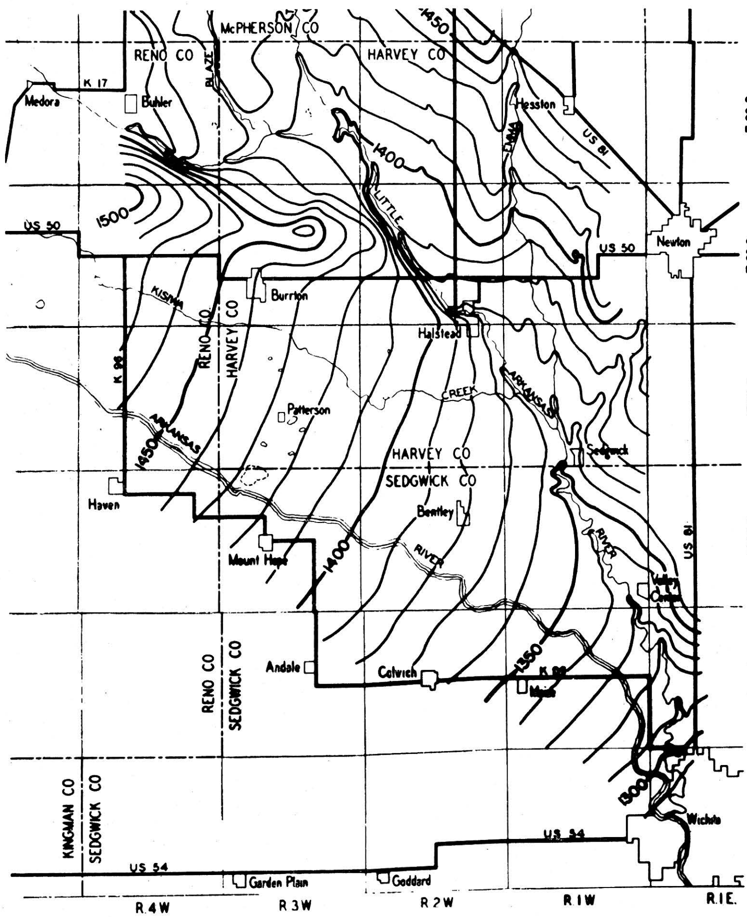

FIG. 26. Map of the ground-water table in an area surrounding Halstead, Kan. The progressively lower elevation of the table from northwest to southeast indicates that the general direction of ground-water movement is southeastward. The relatively high position of the table adjacent to the sand-hills area northeast of Hutchinson reflects the influence of favorable recharge conditions in the sand area.

Hutchinson, Burrton, Sedgwick, and Valley Center. The water in the alluvium is of good quality except that obtained from a belt about a mile wide on both sides of Arkansas river, in which belt the water is hard and saline, and that from places in which it has been contaminated by oil-field brines.

A detailed report is now in preparation describing the geology and occurrence of ground water in the McPherson district. This report is based on field and laboratory studies conducted by the Ground-Water Division of the United States Geological Survey, working in coöperation with the State Geological Survey of Kansas and the State Board of Health, with support for part of the investigation, also, provided by the City of Wichita.

Occurrence of Ground Water in Ford County, Kansas

By H. A. Waite

The occurrence of ground water in Ford county may be classified under three separate hydrologic units: (1) The Arkansas valley alluvium; (2) the Upland Plains, underlain to depths of 200 feet or more by the Ogallala formation; and (3) a shallow-water region in the northeastern one-fourth of the county that is underlain by the Dakota sandstone.

Abundant supplies of potable ground water are obtained from wells that penetrate the alluvial sands and gravels of the Arkansas valley. Numerous wells have also been drilled into the basal sands and gravels of the Ogallala formation, which underlies the alluvium, for domestic, municipal, irrigation, and industrial purposes.

In 1938 there were about 190 large and small irrigation wells in the Arkansas valley. Approximately 130 of these were located near Dodge City. The yields of irrigation wells in the valley ranged from 50 to 1,500 gallons a minute. The municipal wells and nearly all industrial wells at Dodge City are deriving water from the Ogallala formation.

The basal sands and gravels of the Ogallala formation are the source of ground water for the Upland Plains areas of the county, with the exception of the shallow-water region in the northeastern part, where the Dakota sandstone is present at relatively shallow depth over a large area. In this district the depth to water ranges from about 20 to 80 feet. Some of the wells obtain water from the Ogallala formation, which in most places mantles the Dakota sandstone, but many more wells tap the underlying Dakota sandstone and derive adequate supplies of water of good quality. There is evidence of a mingling of the Ogallala and Dakota waters in this region.

The depths of wells in Ford county range from about ten feet in the Arkansas valley bottom to 250 feet or more on the Upland Plains. The depth to water below the land surface ranges from a few feet in the valley wells to about 200 feet in the upland wells. In the southwestern corner of the county the wells are shallow, the depths to water ranging from a few feet to about fifty feet. This part of the county is the northeastern extension of the Meade artesian basin and is topographically lower than the surrounding plains country, particularly in the vicinity of Crooked creek. Small flowing wells are encountered in a belt extending a half mile or more on each side of Crooked creek. The wells range in depth from about 100 to 250 feet and flow 1 or 2 gallons a minute. The water is derived from the underlying Quaternary and Tertiary formations.

In general, the ground waters of Ford county are moderately hard; the amount of total solids ranges from about 200 to 400 parts per million, and averages about 250 parts per million. Several samples of water from Ogallala and Dakota sources show a fluoride concentration exceeding 1.5 parts per million, which is sufficient to cause some damage to children's teeth.

A report on the ground-water resources of Ford county, based on studies begun by the federal and state Geological Surveys in October, 1938, is now being prepared.

Ground Water in the Meade Artesian Basin, Southwestern Kansas

By John C. Frye

This report is a very brief preliminary statement of the conditions of ground-water occurrence in a part of Meade county and southwestern Ford county, Kansas, as determined by coöperative federal and state Geological Survey studies that have been initiated in the area.

The Meade district is of particular interest primarily because it contains the only artesian basin of appreciable extent in the state, outside of the broad Dakota basin, which embraces parts of several Great Plains states. The first flowing well in the Meade basin was drilled in 1886, and since that time approximately 1,000 wells have been drilled, but only a very few of these are in usable condition at the present time.

The area within which flowing wells may be obtained is sharply defined, and is controlled by the structure of the rocks underlying the area. The eastern edge of the artesian basin is defined by a fault, or break in the rock strata. This is particularly prominent south of Meade. The rocks west of this fault dip to the east-southeast, and in places where the land surface is sufficiently low, flowing wells may be obtained. The eastern edge of Crooked creek valley, in general, closely parallels this fault. North of Meade, solution of salt and gypsum beds in the underlying Permian rocks has caused the surface to be lowered, so that the area containing flowing wells is much wider.

The wells range in depth from 60 to 350 feet, and as many as three water-bearing zones may be encountered in a single well. In northeastern Meade county and southwestern Ford county, the deepest bed from which flowing water may be obtained is the Dakota sandstone. Over the entire area artesian water occurs in the Tertiary rocks, and locally also in the Pleistocene rocks. The water-bearing beds are separated and overlain by beds of silt and clay that are relatively impervious. These impervious beds confine the water in the sand, and as the area of recharge to the northwest is higher than the land surface in the basin, enough pressure is developed to lift the water to the surface so that it flows from wells without pumping.

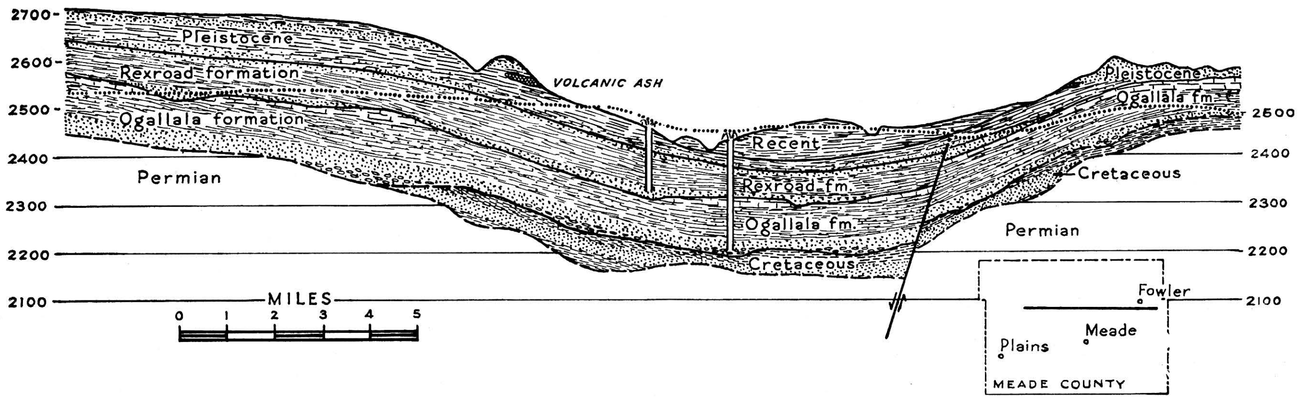

FIG. 27. Geologic section of a portion of the Meade artesian basin, Meade county. Structural conditions that are responsible for the local artesian flow of wells are represented. The pre-Tertiary and Ogallala rocks are displaced by a fault that is observed to mark the local boundary of distribution of certain Pleistocene deposits (lower and middle Rexroad beds), which indicates that the displacement is mostly pre-Pleistocene in date. The thickness of Cretaceous rocks and the structure of the pre-Teritary rocks are interpreted from studies in adjacent areas; they are not based on information from wells in this region. (J. C. Frye.)

From very meager data it appears that the artesian pressure in this basin has declined only slightly in the last forty years. It is reported that in 1900 the water in some wells rose as much as 22 feet above the surface. The strongest wells in the area at the present time have heads of 17 to 18 feet. The flows range from less than one gallon a minute to 100 gallons a minute. The artesian water is relatively soft; however, some waters contain considerable fluoride. It is interesting to note that south of Meade, west of the fault, the sodium chloride content of the water is less than 25 parts per million, whereas east of the fault it is several hundred parts per million.

In the parts of Meade county adjacent to the artesian basin, water occurs in Permian and Tertiary rocks. The depth to water is more than 200 feet in a few places in the western and southern parts of the county.

Ground Water in the Scott District, Scott and Finney Counties, Kansas

By H. A. Waite

The greater part of the area comprising the Scott District is in central and southern Scott county, but a part of the area extends southward into northern Finney county. This so-called shallow-water basin derives its name from the fact that water is obtained at depths ranging from 20 to 90 feet and that there is no surface drainage from the area. The land surface is for the most part flat and smooth, and the region is characterized by numerous shallow undrained basins.

Whitewoman creek, which has a drainage area of approximately 1,175 square miles, terminates in a large depressional area just south of Scott City. Occasional flood flow from Whitewoman creek deploys over this broad sink forming a shallow lake for short periods, and contributes water to the underground reservoir.

The importance of the ground-water resources in the Scott county shallow-water area has long been recognized. The development and use of ground water for supplemental irrigation began about 1910. Probably the greatest development has been made as a result of the prolonged drought during the last decade. According to records of the Division of Water Resources of the State Board of Agriculture, the irrigated acreage in the Scott basin has increased steadily from 1,021 acres in 1932, to 3,859 acres in 1934, to 5,300 acres in 1936, and to more than 12,000 acres in 1939—more than twice the acreage irrigated in 1936. At the end of 1936 there were approximately forty operating irrigation wells in the area, whereas at the end of 1938 there were more than sixty. Several new irrigation wells were drilled in 1939.

The Ogallala formation supplies all the wells in the Scott district. The Ogallala beds are composed of complexly interbedded lenses of clay, silt, sand, and gravel, and their total thickness in the area ranges from about 80 to 150 feet. This formation rests on an uneven, impervious floor of Cretaceous chalky shale belonging to the Niobrara formation. Sand and gravel generally are most abundant in the middle and lower parts of the Ogallala. The yields of irrigation wells in the Scott basin range from about 500 to 2,000 gallons a minute. One well, when operated to maximum capacity on state test, produced 2,900 gallons a minute and the draw-down was 30.7 feet.

An investigation of the geology and ground-water resources of Scott county was started in October, 1939, and will be continued during the field season of 1940. The water levels in 29 observation wells, selected at strategic points throughout the entire area, are being measured monthly in order to obtain essential information concerning the effects of recharge and depletion of the ground-water reservoir. Two wells of this group are equipped with automatic water-stage recorders for the purpose of obtaining continuous records of water-level fluctuation. The Division of Water Resources of the State Board of Agriculture has maintained similar records on two other wells in the same area for several years. The study of trends in movement of water levels in areas such as the Scott basin is very important in measuring periodically the effects of pumpage and in determining the safe yield of the water-bearing formations.

Ground-water Investigations in the Stanton District, Southwestern Kansas

By Thad G. McLaughlin, and Bruce F. Latta

The following statement gives a preliminary account of studies of the occurrence of ground water in Stanton and Morton counties, Kansas, undertaken by the United States Geological Survey and the Kansas Geological Survey. Work in this region was begun in July, 1939.

Wells in Morton and Stanton counties obtain water from one or more of four geologic divisions: (1) the Ogallala formation of Tertiary age, (2) the Dakota group of Cretaceous age, (3) the Triassic(?) red beds, and (4) the Permian red beds.

The sands and gravels of the Ogallala formation are the most productive water bearers. They provide water to about two-thirds of the wells in the two counties.

The Dakota group is second in importance as a water bearer, and yields abundant supplies of water to wells in northwestern Morton county, western Stanton county, and southwestern Hamilton county. The Dakota consists of two water-bearing sandstones separated by shale. Of the two sandstones, the lower is coarser grained and by far the better water bearer.

Triassic (?) red beds yield moderate supplies to a few wells in southwestern Morton county.

The depth to water level ranges from less than 10 feet to about 250 feet. Shallow water, less than 100 feet below the land surface, may be found in about half the area. The principal shallow-water localities are the northeastern part of the area, including eastern Stanton county and northeastern Morton county; the western part of the area, including northwestern Morton county and southwestern Stanton county; and a narrow strip along Cimarron river in south-central Morton county. Deep-water areas, in which the water level stands more than 200 feet below the land surface, are found in southern Morton county and south-central Stanton county.

Several artesian wells, ranging in depth from 200 to 600 feet, have been drilled in western Morton county. The water in these wells comes from red sandstones of Permian age. This water is highly mineralized, excessively hard, and unsuited for domestic use. One sample, obtained from a flowing well at Richfield, has a hardness of 1,935 parts per million, chiefly calcium and magnesium sulphate.

The water from both the Ogallala and the Dakota is hard, the average hardness being about 225 parts per million. Thirty-three of the 76 samples of water analyzed contained more than 1.5 parts per million of fluoride, which is an amount sufficient to produce mottled enamel on children's teeth. In general, the water from the Ogallala in this area is of better quality than the water from the Dakota.

The most suitable area for irrigation in Stanton county is the eastern and northeastern part; here large yields of water may be had from the Ogallala formation at relatively shallow depths. At the present time five wells in this area are pumping water for irrigation and of these, three have been drilled within the last year. They range in depth from 83 to 280 feet, and the depth to water level ranges from 52 to 63 feet.

One well is 182 feet deep, the static water level is 63 feet below the surface, the yield is 800 gallons a minute, and the reported draw-down is 27 feet. Another well is 280 feet deep, the static water level is 56 feet below the surface, the yield is 650 gallons a minute, and the reported draw-down is only 13 feet.

The most favorable areas for irrigation in Morton county are the northwest corner, the northeast corner, and the central-eastern part, between Rolla and Cimarron river. Seven irrigation wells have been drilled, of which three are now in use. One well has a reported yield of 750 gallons a minute. The depths of the wells in the northeast and northwest parts range from 60 to 100 feet, and static water levels are 30 to 80 feet below the land surface. In the central-eastern part, the wells are about 400 feet or more in depth, and the static water levels are 85 to 100 feet below the land surface.

Gaging the Ground-water Reservoirs of Kansas

By S. W. Lohman

Of special importance in ground-water investigations are the periodic measurement of water levels in numerous observation wells, in order to determine the magnitude and character of water-level fluctuations and the rate at which the underground reservoirs are being replenished by rainfall or depleted by seepage from springs or swamps, by direct evaporation, by plant transpiration, or by heavy pumping. The federal and state Geological Surveys now obtain accurate records of water-level fluctuations in 436 wells located in 13 western counties of Kansas, as shown in figure 27. Part of these records are obtained through the coöperation of the Soil Conservation Service at Mankato and of the city of Wichita.

In most of these wells the water level is measured weekly or monthly, but in a few it is measured quarterly. Nine of these wells are equipped with weekly automatic water-stage recorders that give a continuous record of all fluctuations and permit detailed study (see fig. 9). In addition to these wells, three other wells equipped with recorders in the shallow-water area of Scott and Finney counties have been under observation for eight or nine years by the Division of Water Resources of the Kansas State Board of Agriculture.

The value of periodic water-level measurements is in direct proportion to the length and continuity of the record, as is true of stream-flow measurements. The importance of such long-time records of ground-water levels has been realized more fully in recent years, particularly during the droughts of the last decade. The United States Geological Survey now publishes annually a water-supply paper devoted to tabulated measurements of water levels and artesian pressure in observation wells in the United States, including records from one or more projects in about 28 states and the territory of Hawaii.* The 1939 volume, now in preparation, will include 10 separate sections for Kansas, containing records of water levels in about 364 of the 439 observation wells in the state. It is hoped that in the future many more wells in Kansas will be selected for periodic observation and that their distribution will become more widespread throughout the state.

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* Water levels and artesian pressure in observation wells in the United States in 1935: U. S. Geol. Survey Water-Supply Paper 777, 268 pp., 1936.
Same publication for 1936, 817, 511 pp., 1937.
Same publication for 1937, 840, 657 pp., 1938.
Same publication for 1938, 845, 724 pp., 1939.

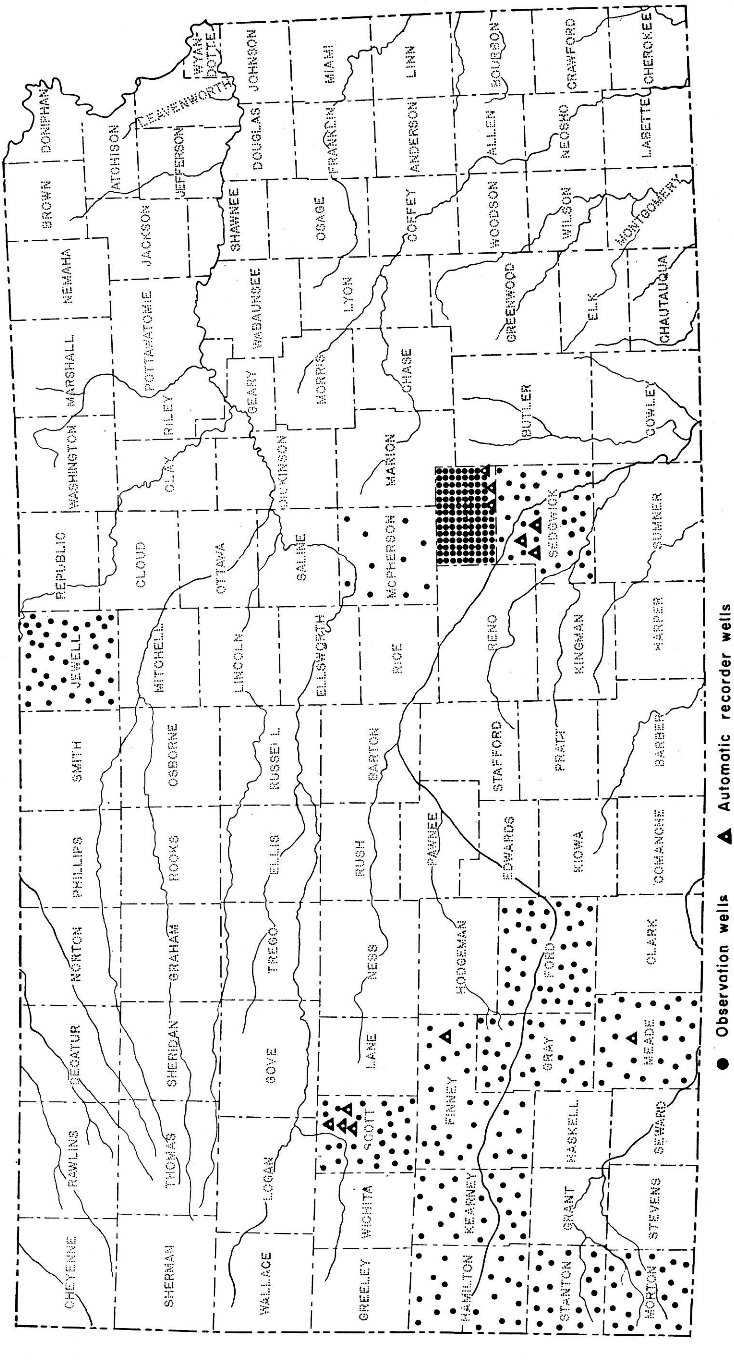


Fig. 28. Map of Kansas showing schematically the distribution of ground-water observation wells, in which water levels are regularly determined by the Geological Survey.

In general, the major fluctuations have been found to be related directly to the amount of precipitation and to changes in the rates of withdrawal. (See fig. 9.) Over a period of years the water level of an underground reservoir may show successive annual declines caused by less than normal recharge from precipitation. Such declines may not indicate a permanent depletion of supply or future failure, but may only indicate a part of a major fluctuation. The water level in such instances may be expected to rise again with a recurring series of wet years.

There may, however, be a withdrawal of ground water for public supply or other use in excess of the normal rate of replenishment, and the water level may suffer net declines year after year, even under conditions of normal rainfall. If the storage capacity of the underground reservoir is large, this excessive rate of withdrawal may not become apparent for many years unless careful observations are made, and the storage capacity may be seriously depleted before the situation is realized. Failure on the part of many municipalities, irrigation districts, and other users of ground water to collect adequate information in regard to the changes in storage capacity of the ground-water reservoirs may have resulted from a common misapprehension that ground-water supplies are inexhaustible.

It would be unthinkable for a power company to attempt to run a hydroelectric development without knowing at all times the amount of water entering the reservoir, the quantity of water in storage, and the quantity being discharged through the turbines or over the spillway. Unfortunately, however, many large ground-water developments are operated year after year without such essential records being kept. Without such records the gradual depletion of the underground reservoir may escape attention until it is too late and the supply may suddenly fail. Properly kept records of ground-water levels and pumpage would show whether the safe yield of the underground reservoir was being exceeded, and whether steps should be taken to augment the supply from other sources or by increasing the recharge by artificial methods.

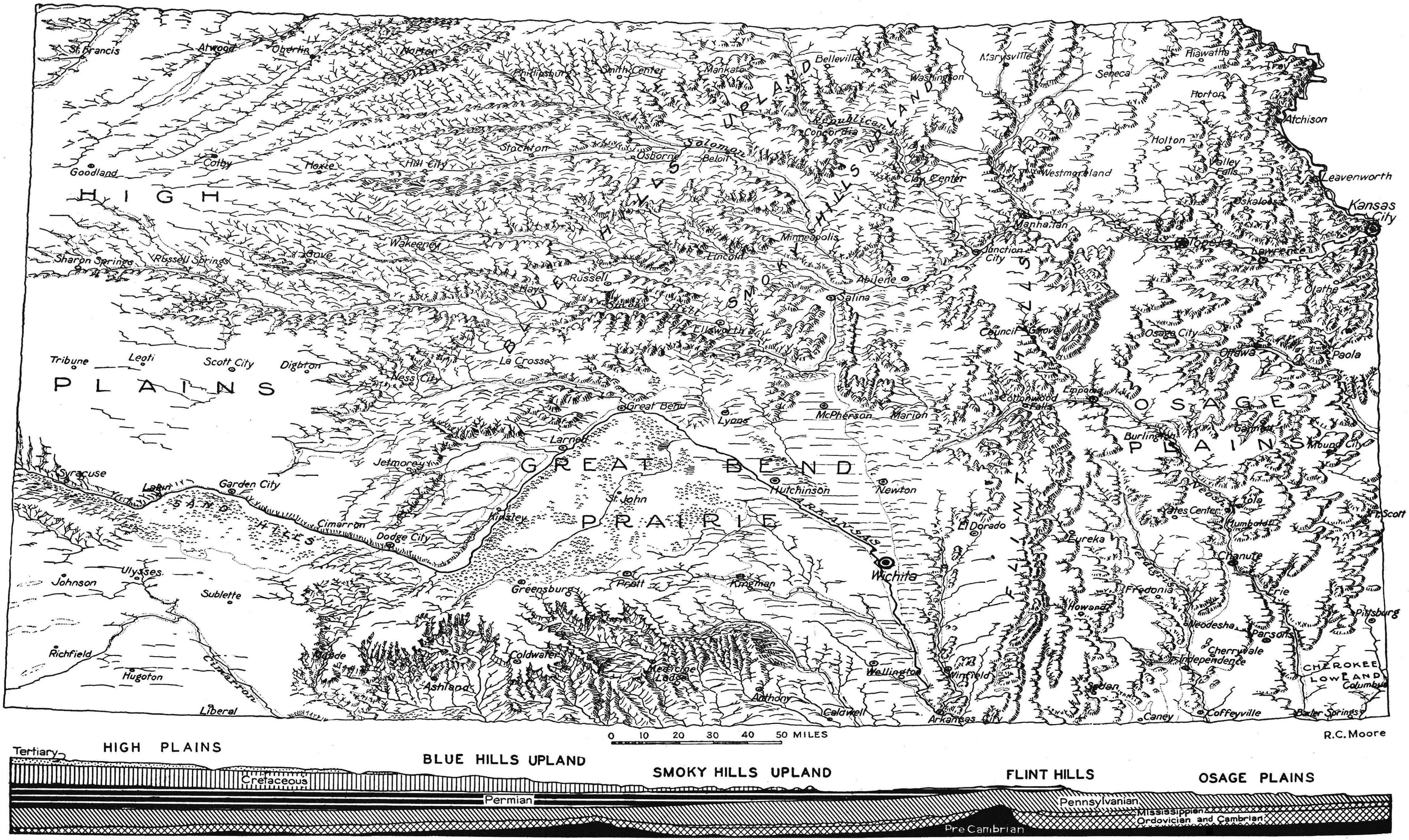


PLATE 1. Surface features of Kansas. The diagram represents the topographic characteristics of different parts of the state, many of which depend closely on geologic structure and influence conditions of ground-water occurrence. Eastward-facing escarpments formed by west-dipping beds of differing hardness distinguish the eastern Kansas region. The Smoky Hills Upland and Blue Hills Upland are formed by Cretaceous rocks. The Great Bend Plain is a nearly level sandy area that is locally dotted by dunes. Father south is the red-rock country of Permian outcrops, which is relatively rugged. The western Kansas High Plains region is mostly a very gently sloping area, but it is intersected by many valleys that are bordered by low bluffs.

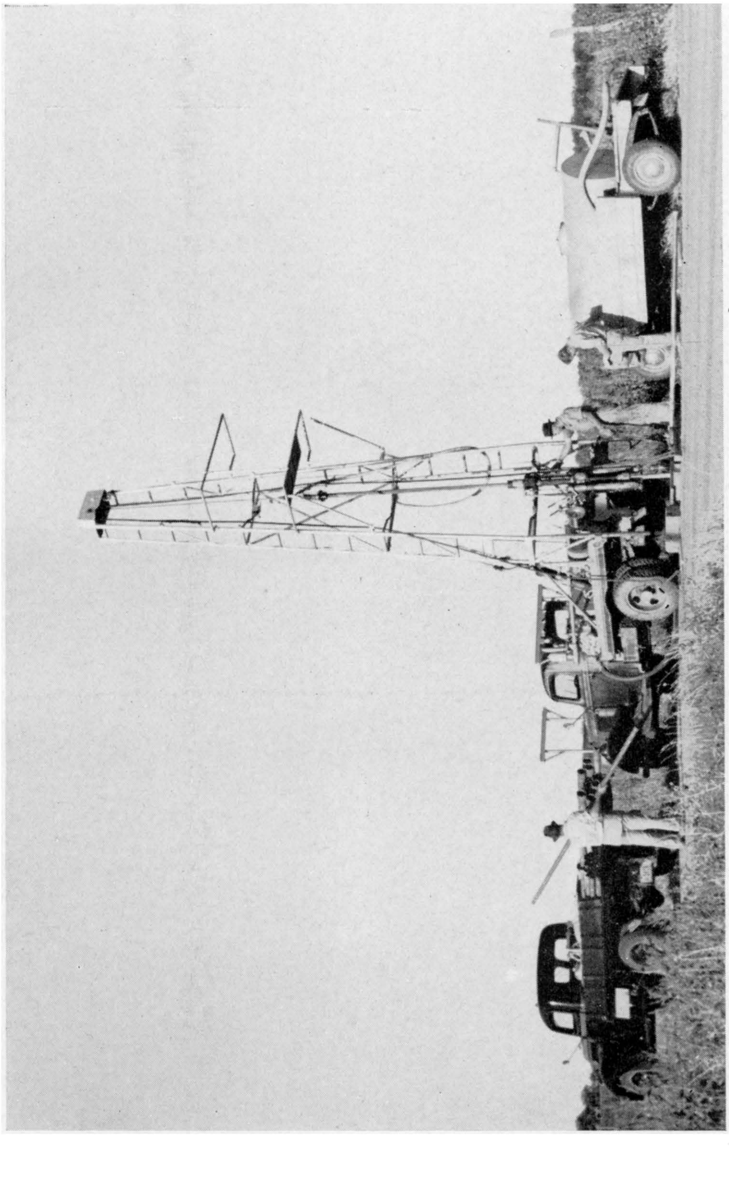


Plate 2. Portable drilling machine belonging to the Ground-water Division of the Geological Survey (co-operative state and federal). This is an invaluable tool for study of the ground waters of Kansas. It is operated by a crew of specially trained young geologist-engineers. (Oren Bingham.)

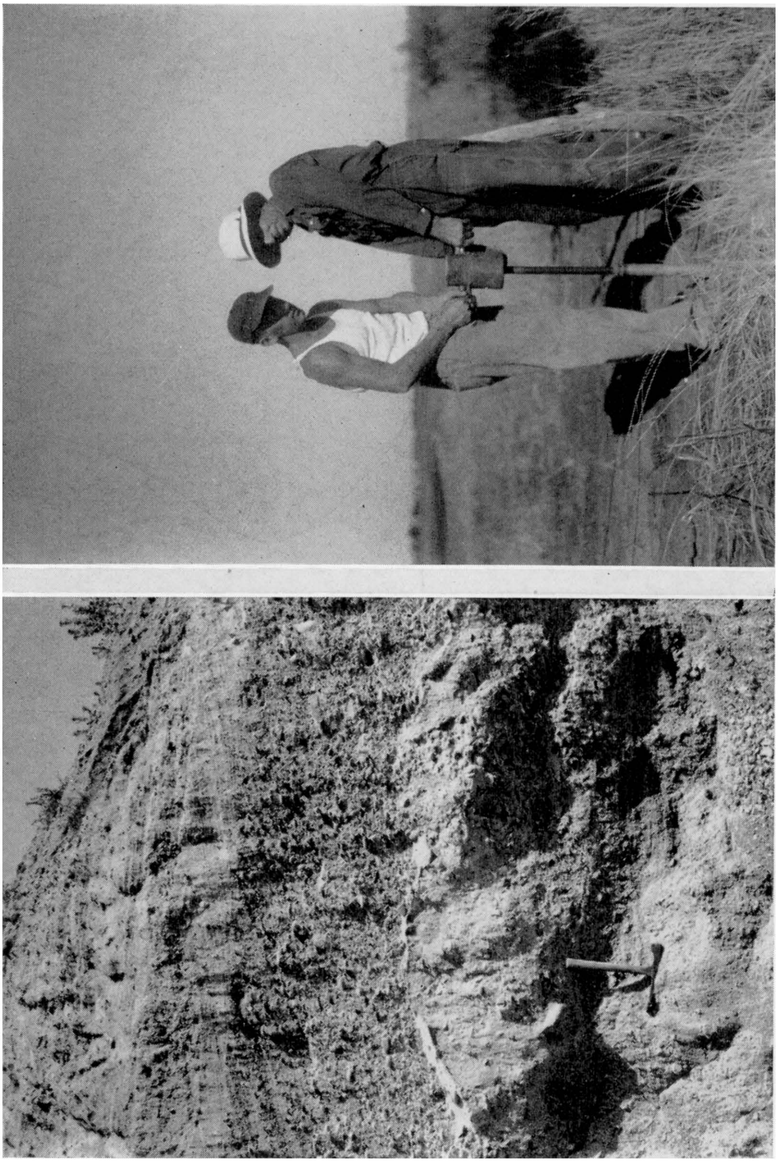


PLATE 3. *Left*, Exposure of coarse gravelly Ogallala deposits in Meade county (SE sec. 17, T. 33 S., R. 28 W.), showing type of stream-borne materials that is very pervious. *Right*, Field workers in Sedgwick county putting down an observation well, using hand driver. (S. W. Lohman.)

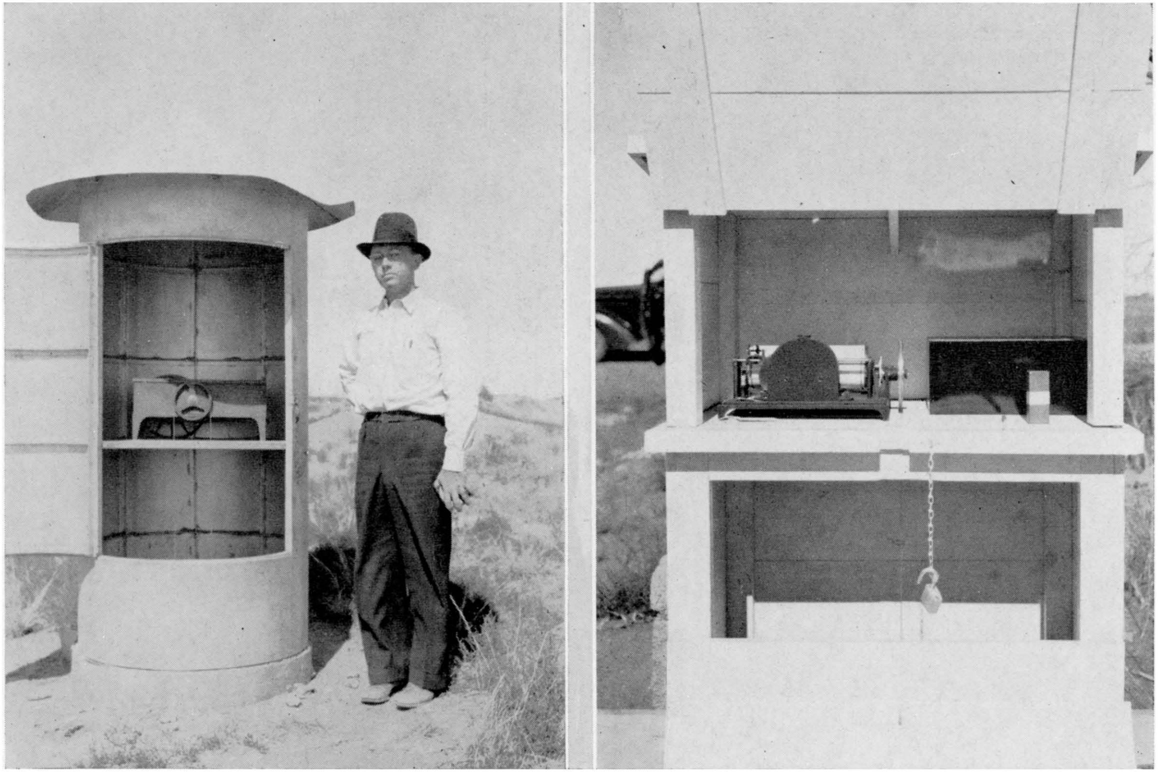


PLATE 4. Ground-water level automatic recorders. The well at left is one mile south of Scott City; installation of the Water Resources Division, State Board of Agriculture. The well at right is a Geological Survey installation in northern Ford county. (H. A. Waite.)

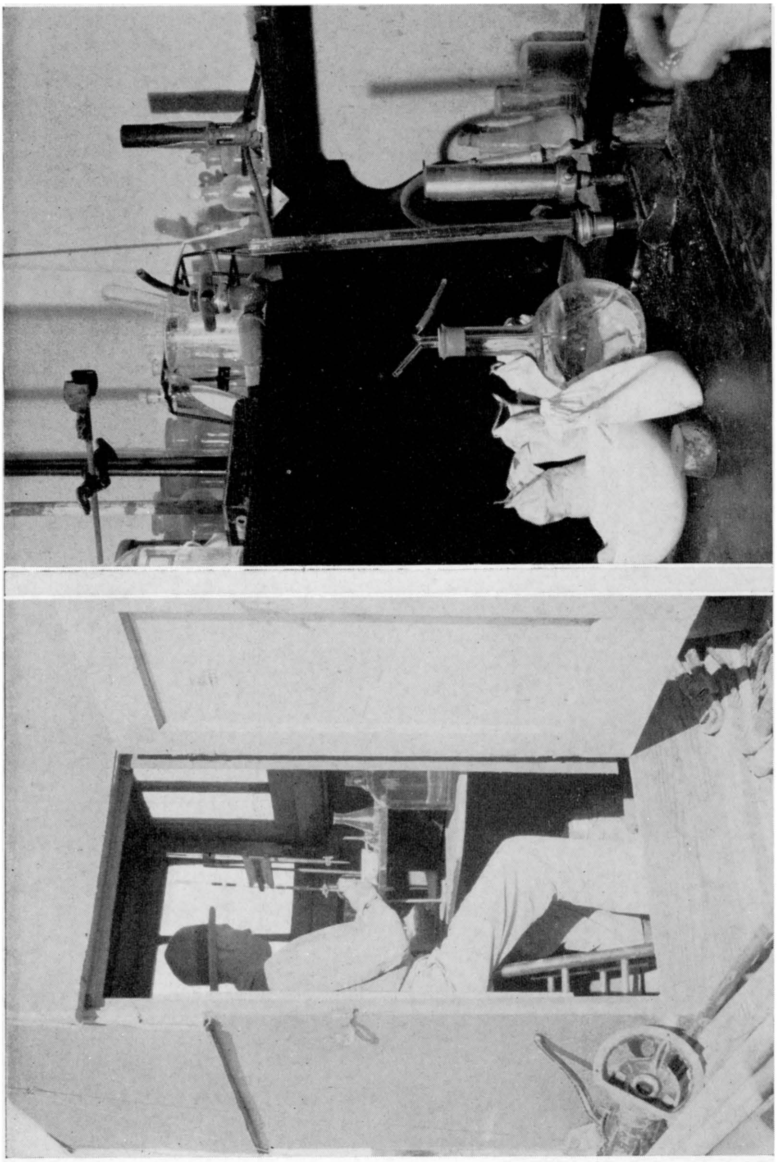


PLATE 5. *Left*, Portable chemical laboratory, testing chlorides in ground water north of Wichita. *Right*, Apparatus used in Survey work to test permeability of sedimentary materials. (S. W. Lohman.)

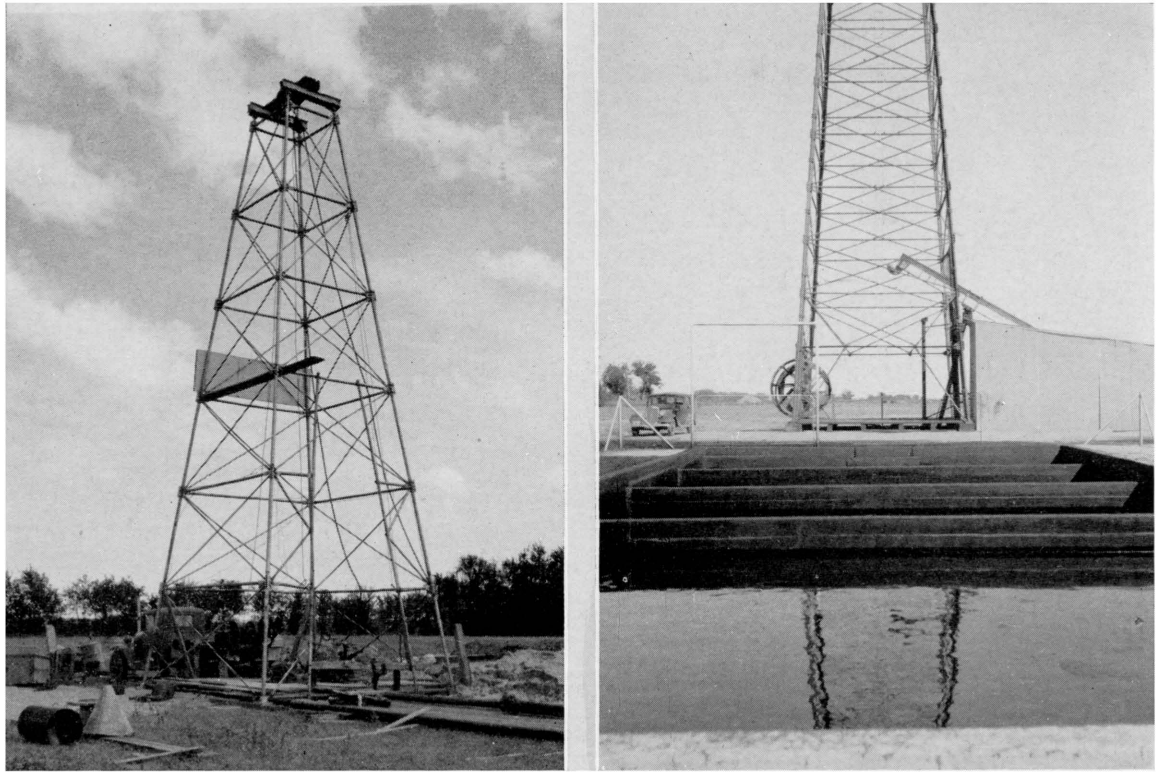


PLATE 6. *Left,* One of the new water wells of the city of Wichita, which will develop a supply located by the Geological Survey near Halstead. *Right,* A brine-disposal well in the Burrton field. The salt water is conducted to porous rock far below the surface where it cannot contaminate fresh water supplies. (S. W. Lohman.)

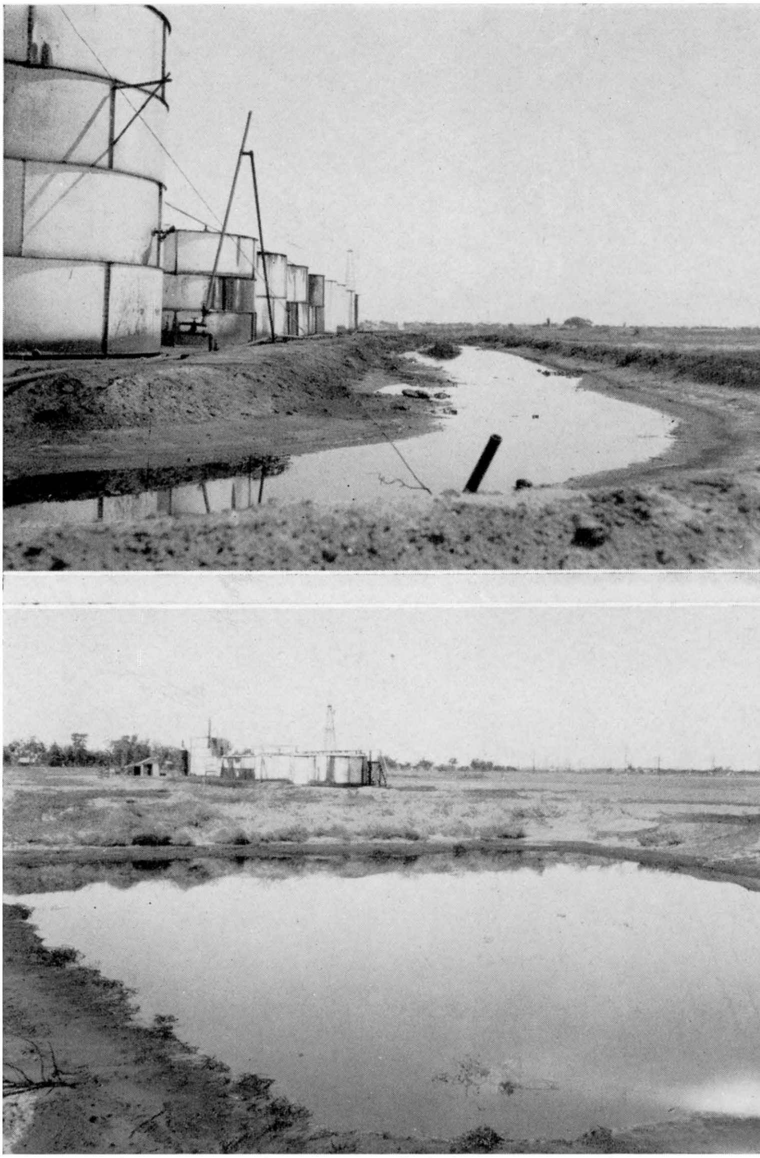


PLATE 7. Salt water containing about 50,000 parts per million of chlorides in the Burrton field. Contamination of fresh water by the sinking of this brine into the pervious ground is not actually visible here, but it is none the less real. (S. W. Lohman.)

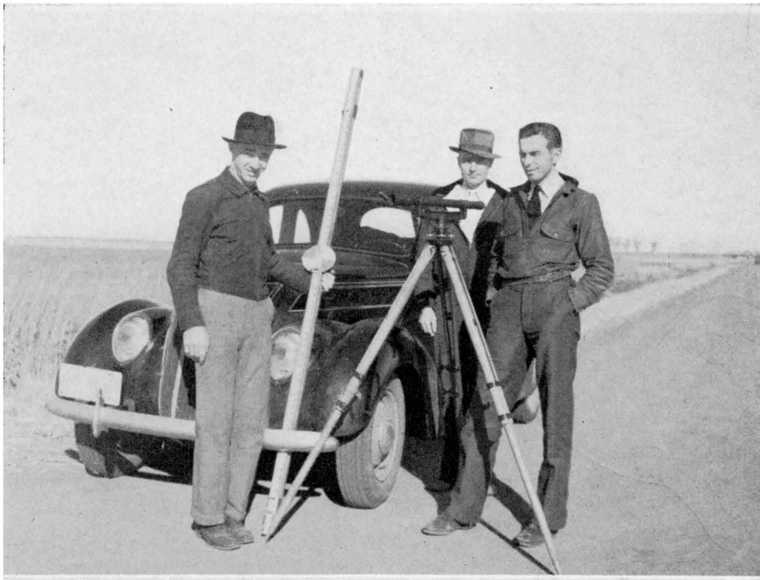
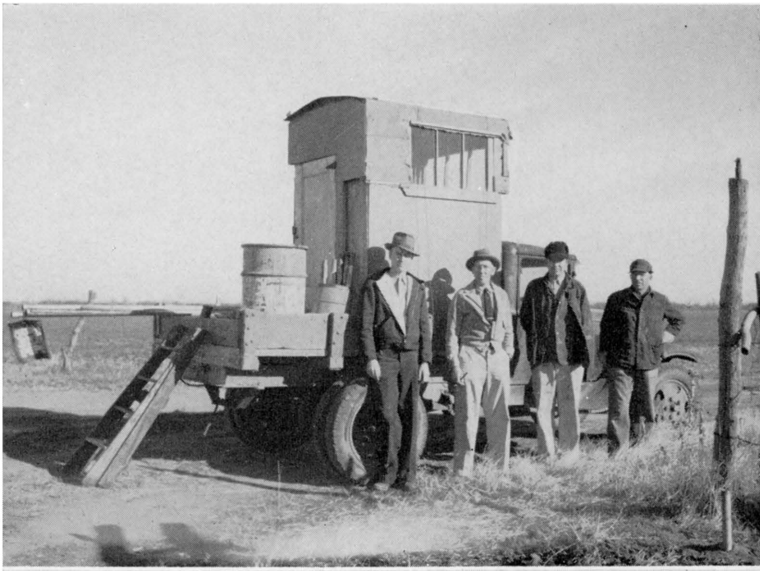


PLATE 8. Engineering work of several sorts is an important adjunct of ground-water investigations. *Upper,* Level party in Sedgwick county area. *Lower,* Testing the flow of a Ford county well with the Collins meter (Geological Survey in coöperation with Division of Water Resources). (S. W. Lohman, H. A. Waite.)



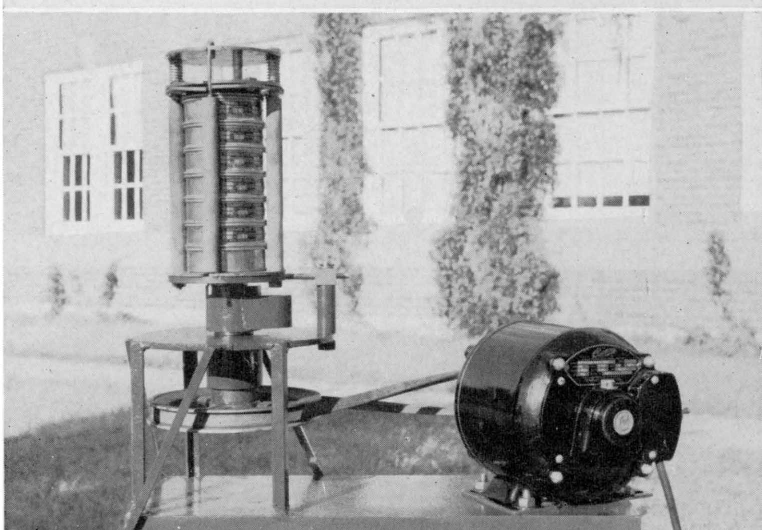


PLATE 9. *Upper,* Truck equipped for chemical analysis of ground-water samples in field, at work in McPherson county. *Lower,* Rotary shaker and screens for making mechanical analysis of sediments obtained at various depths in test wells; designed by S. W. Lohman. (S. W. Lohman.)

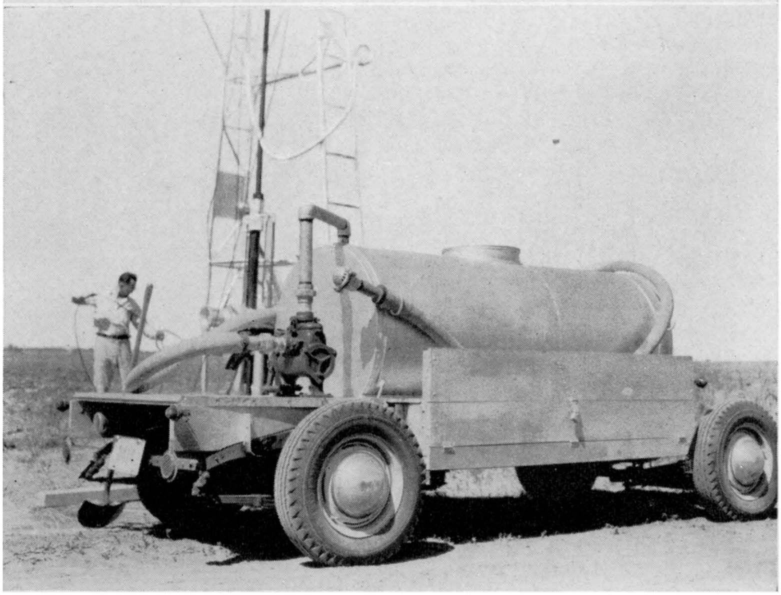


PLATE 10. *Upper,* Apparatus for filtering and testing of water samples in the field, Harvey county, Kansas. *Lower,* Trailer and large water tank, used with the Geological Survey drilling machine, on location in McPherson county. (Fred Holden, S. W. Lohman.)

PLATE 11. *Upper,* The first Wichita city well in the new supply area near Halstead, located by Geological Survey investigations. This well tested 1,600 gallons a minute; the flow is from a 10-inch orifice. The drawdown in the well at the close of a 36-hour pumping test was 25 feet. *Lower,* Measuring the flow of water obtained from shallow wells in the Arkansas river alluvium near Dodge City (Geological Survey in coöperation with Division of Water Resources). (S. W. Lohman, H. A. Waite.)

PLATE 12. *Upper,* Water pumped from the Ogallala beds in Meade county. *Lower,* Pond on the Marrs farm in the Meade artesian basin, fed from a naturally flowing well, shown in center background, which yields about 75 gallons a minute. (J. C. Frye.)

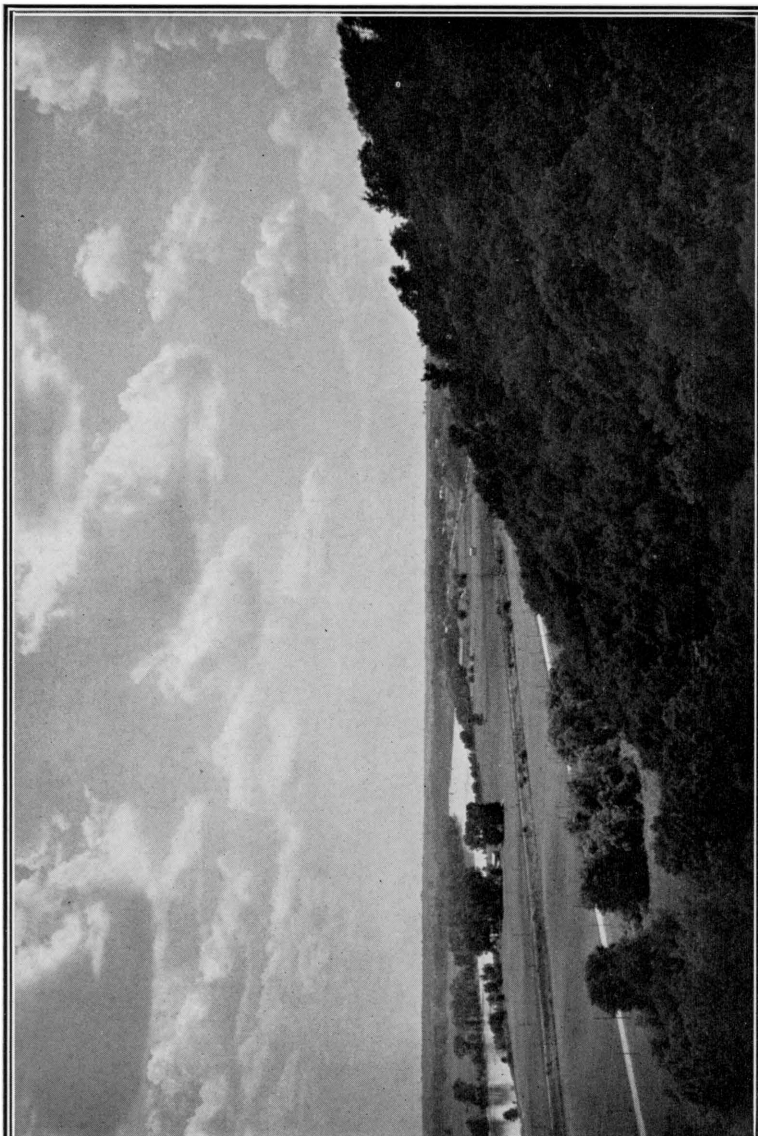


PLATE 13. The Kansas river valley, a well-watered alluvial plain, bordered by bluffs of Pennsylvanian rocks; view near Bonner Springs. (K. K. Landes and Oren Bingham.)

PLATE 14. Glacial deposits, which cover most of the land in northeastern Kansas, produce the gently rounded surfaces of this Doniphan county landscape. Ground-water supplies are good. (K. K. Landes and Oren Bingham.)

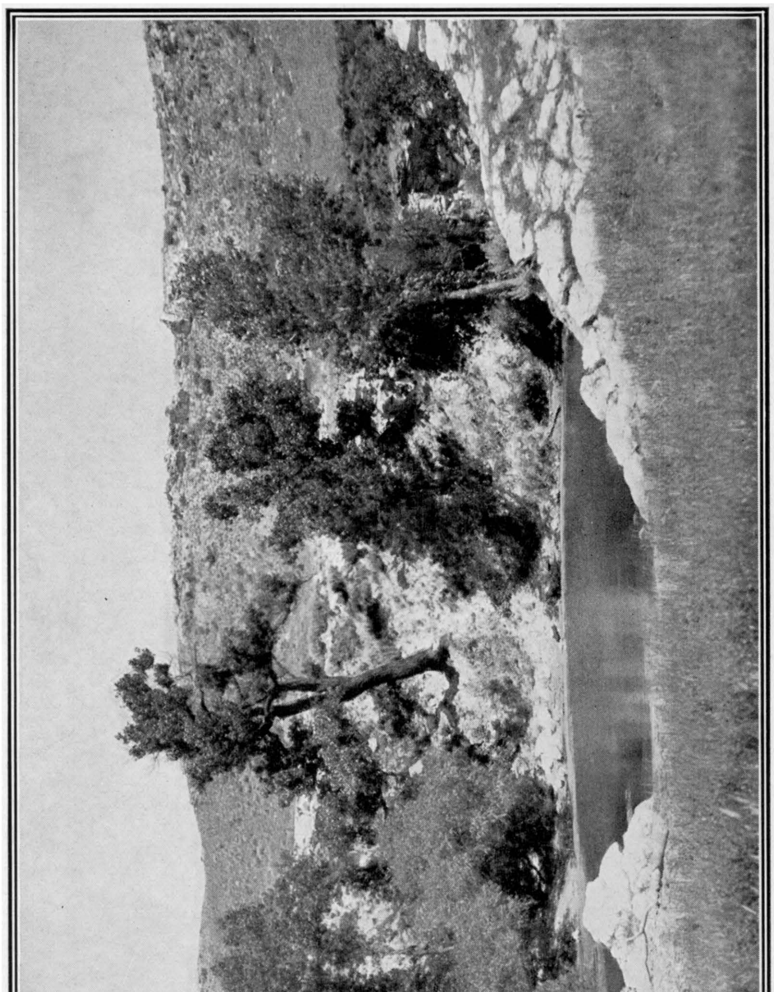


PLATE 15. St. Jacob's Well, a picturesque sink in Meade county, formed by underground solution of rock, followed by local collapse of the surface to a position below the water table. (K. K. Landes and Oren Bingham.)

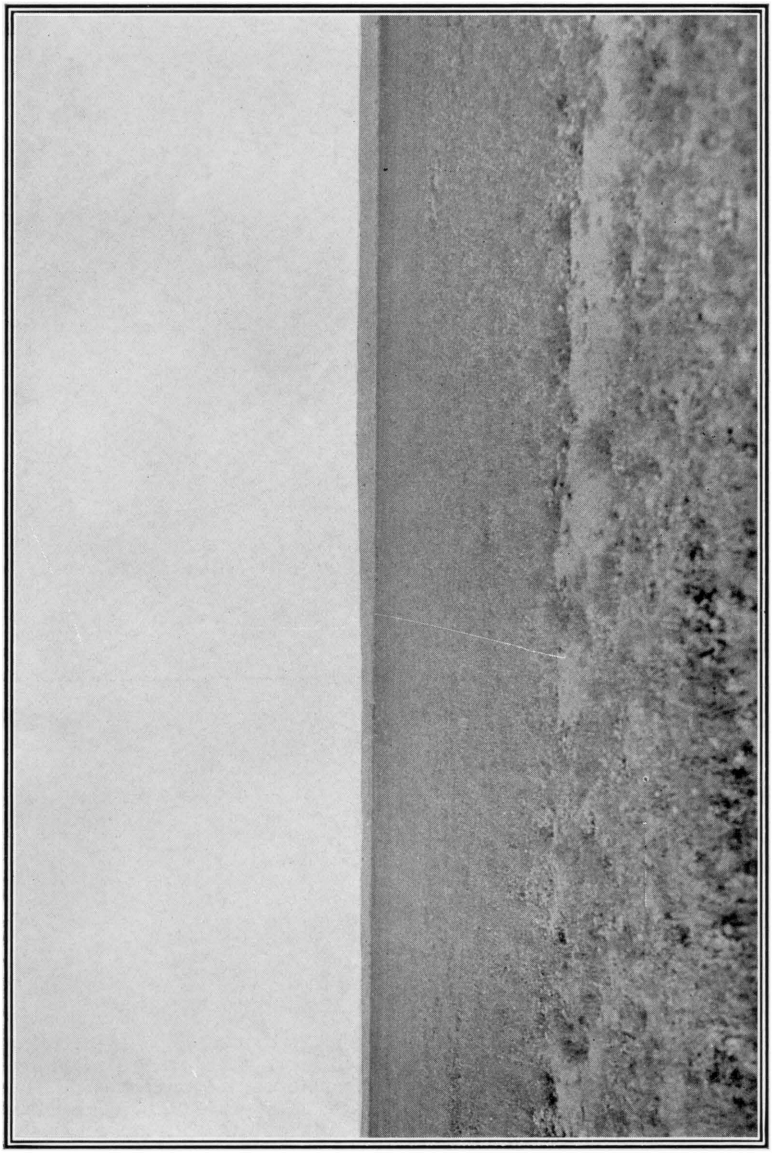
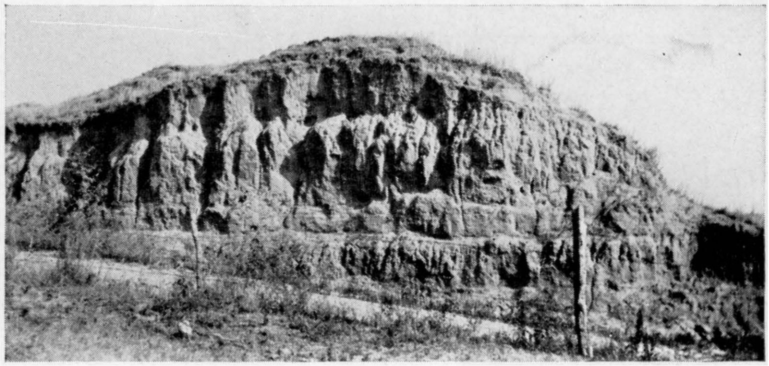


PLATE 16. The High Plains region in western Kansas is characterized by its treeless and generally featureless surface; view near Garden City. (K. K. Landes and Oren Bingham).



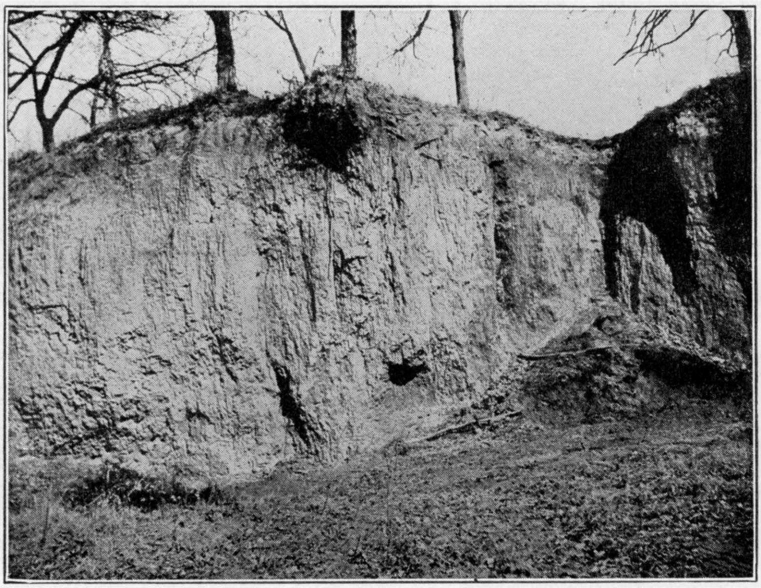


PLATE 17. *Upper,* Exposure of loess in Republic county. This is part of a widespread cover of relatively impervious sediment that was deposited by winds; it retards seepage of rainfall into ground-water reservoirs. (M. E. Wing.) *Lower,* A typical exposure of alluvium in a small valley (One Mile creek) tributary to Republican river. Deposits of this sort are relatively pervious.

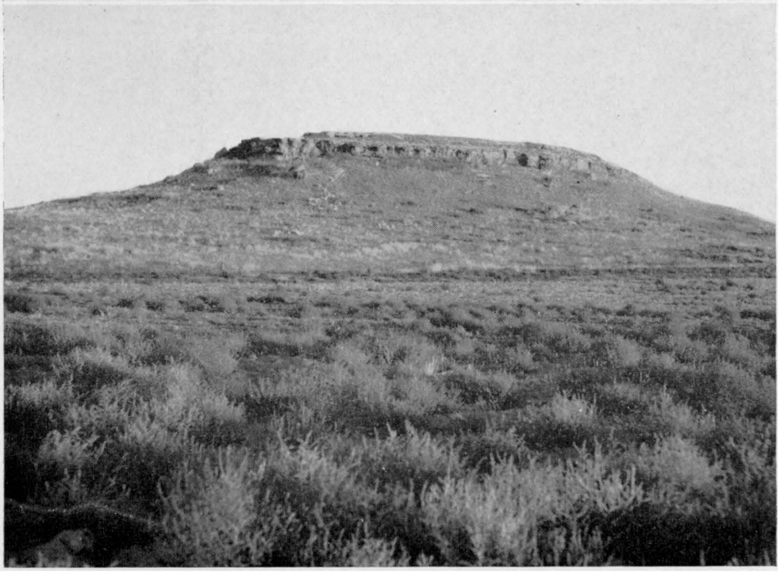
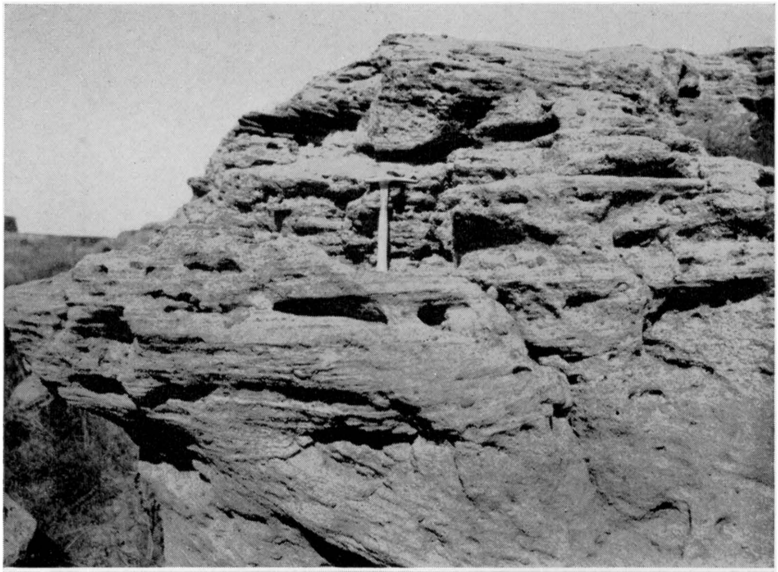


PLATE 18. *Upper,* Sand dunes about five miles northwest of Hutchinson. Rainfall in the dunes area sinks readily into the ground and a proportionally large part of the precipitation may become ground water. *Lower,* Alluvial plain of a western Kansas stream (Sawlog creek), bordered by a Dakota sandstone hill that is capped by a remnant of Ogallala beds. The Ogallala is not a source of ground water in isolated outcrops, but the Dakota of this region yields large quantities of water. (J. C. Frye, H. A. Waite.)



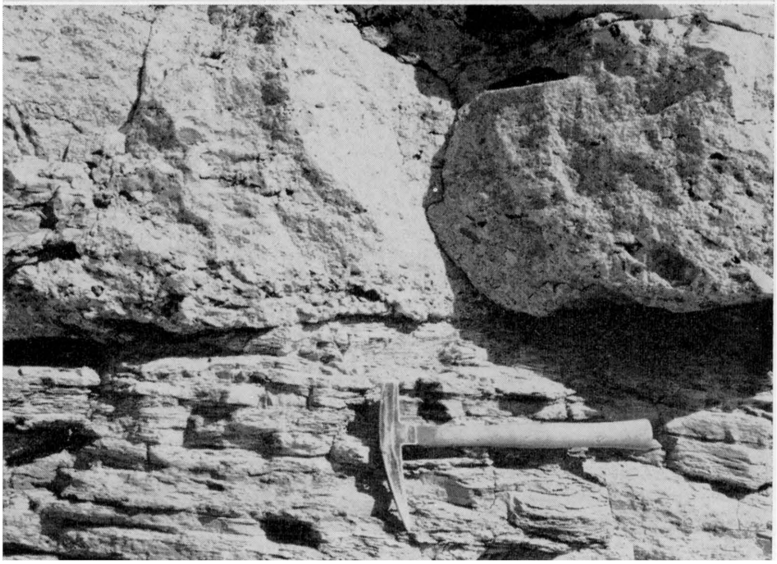
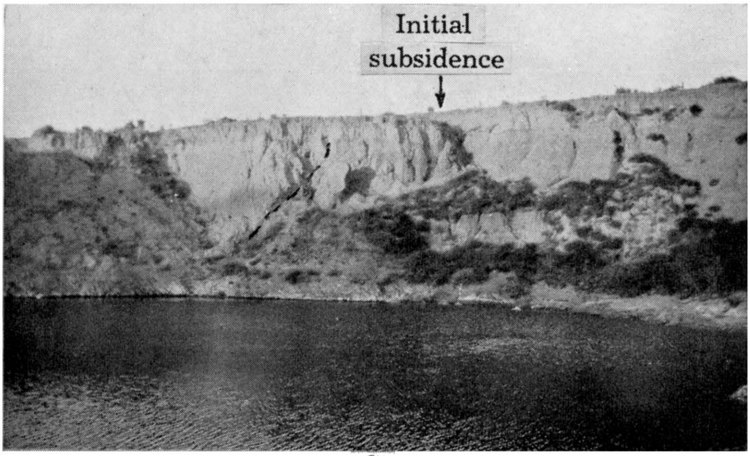


PLATE 19. *Upper,* Exposure of typical "mortar beds" of the Ogallala formation about three miles west of Dodge City (H. A. Waite). *Lower,* Basal Ogallala deposits resting unconformably on Cretaceous shale belonging to the Dakota group, on Bear creek, Stanton county (SW sec. 15, T. 29 S., R. 43 W.) (S. W. Lohman.)



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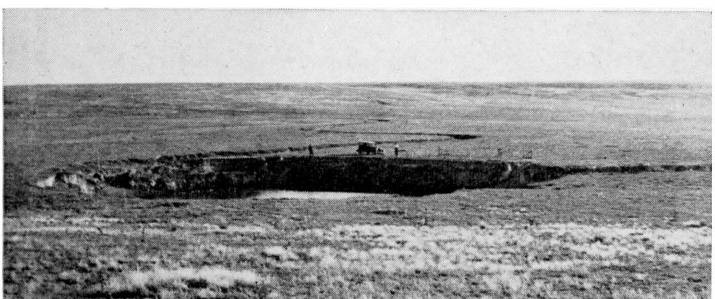

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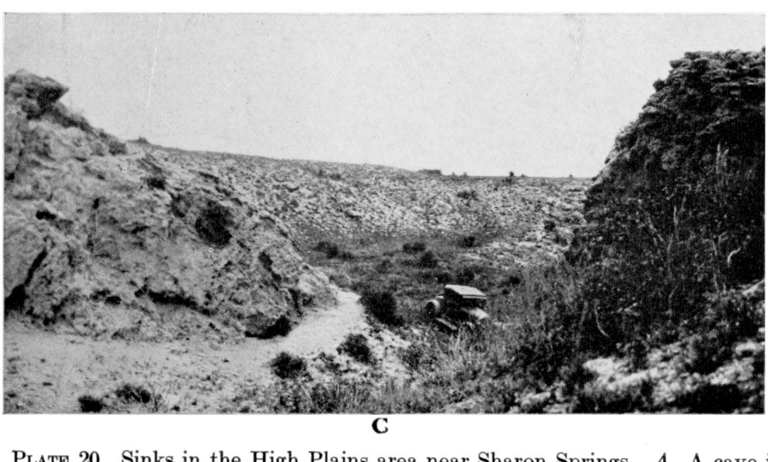

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PLATE 20. Sinks in the High Plains area near Sharon Springs. *A*. A cave-in formed in 1929. *B*. A sink in sec. 27, T. 12 S., R. 41 W., developed in 1901. (M. K. Elias.)

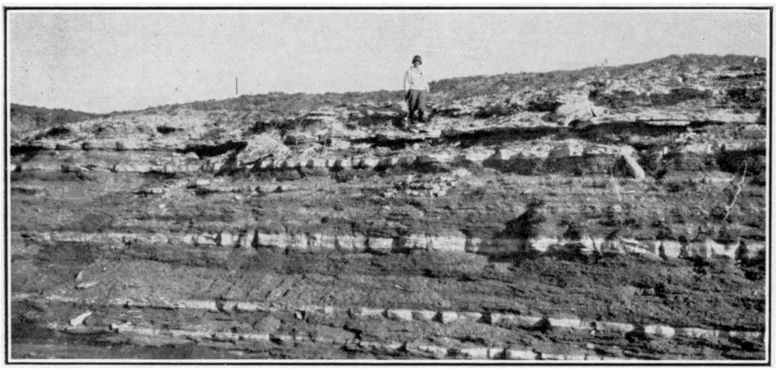
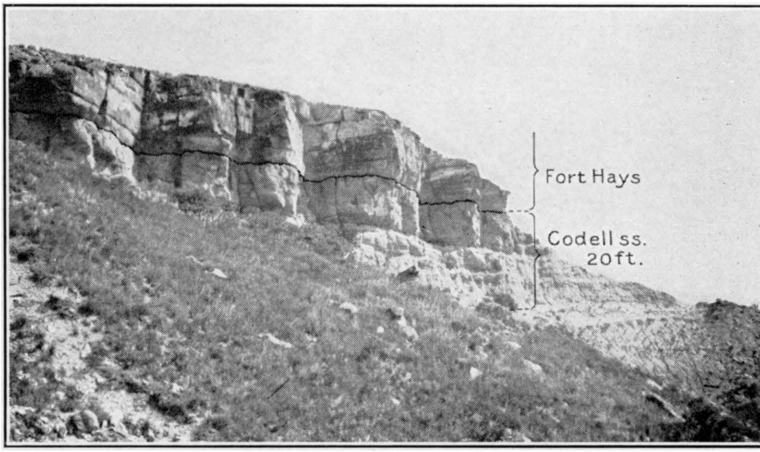


PLATE 21. *Upper,* Exposure of Greenhorn limestone, Cretaceous. The alternating thin limestone and shale beds of the formation are well shown. *Lower,* Impervious clay shale belonging to the Carlile part of the Cretaceous deposits; a large concretion, formed by concentration of calcareous matter, is shown. The thick shale divisions of the Cretaceous system in Kansas yield virtually no ground-water supplies.



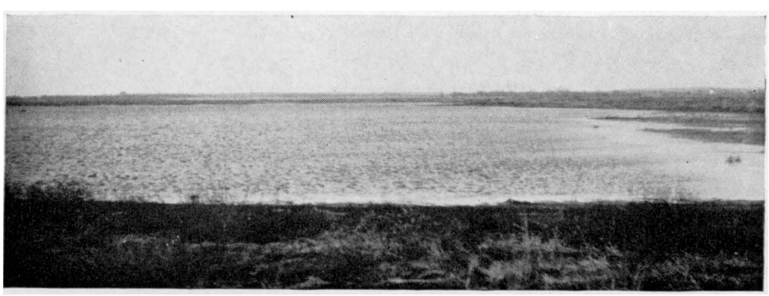
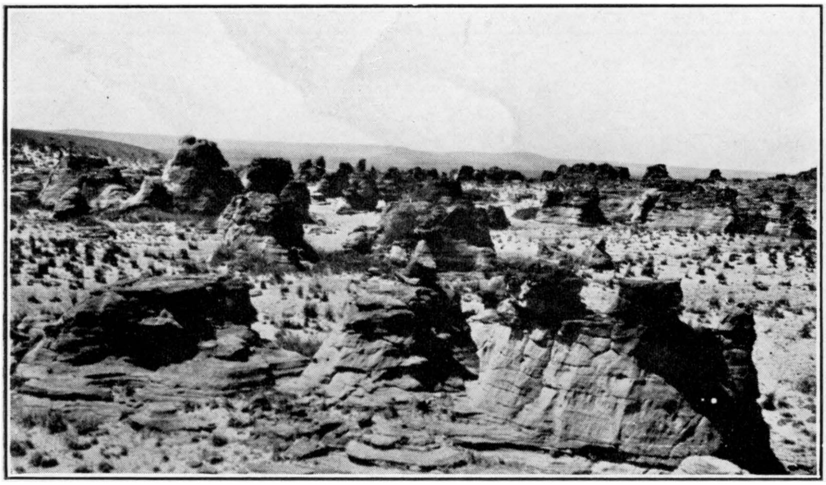


PLATE 22. *Upper,* Outcrop of basal Niobrara formation consisting of even-bedded limestone (Fort Hays), underlain by water-bearing sandstone (Codell), in Ellis county (N. W. Bass). *Lower,* A salt-water pond in a marshy area near Jamestown, Cloud county, located on outcrops of the Dakota group. The salt water is derived from the Dakota beds. (M. E. Wing.)



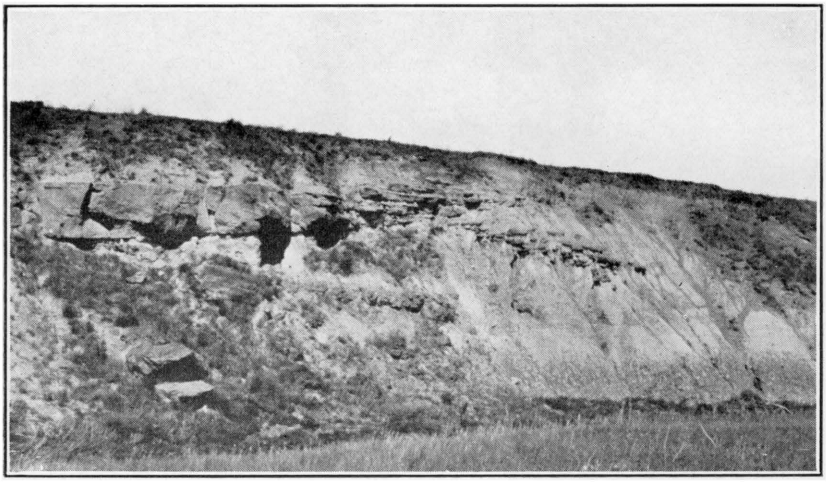


PLATE. 23. *Upper and lower.* Exposures of Dakota sandstone in Russell county. The sandstone is yellowish-brown in color, owing to the iron oxide that covers the grains, cementing them together. The rock is pervious and it both collects rainfall in areas of its outcrop and yields ground water thus derived from local precipitation and from distant sources. (W. W. Rubey and N. W. Bass.)

PLATE 24. *Upper,* Red shale and thin silty sandstone of the Nippewalla group, of Permian age, near Medicine Lodge, Barber county. The bedrock of this region contains little usable ground water. (S. W. Lohman.) *Lower,* Flowing well in Richfield, Morton county. The water, which is derived from Upper Permian strata, is highly mineralized, containing more than 2,600 parts per million of solids. (H. A. Waite.)

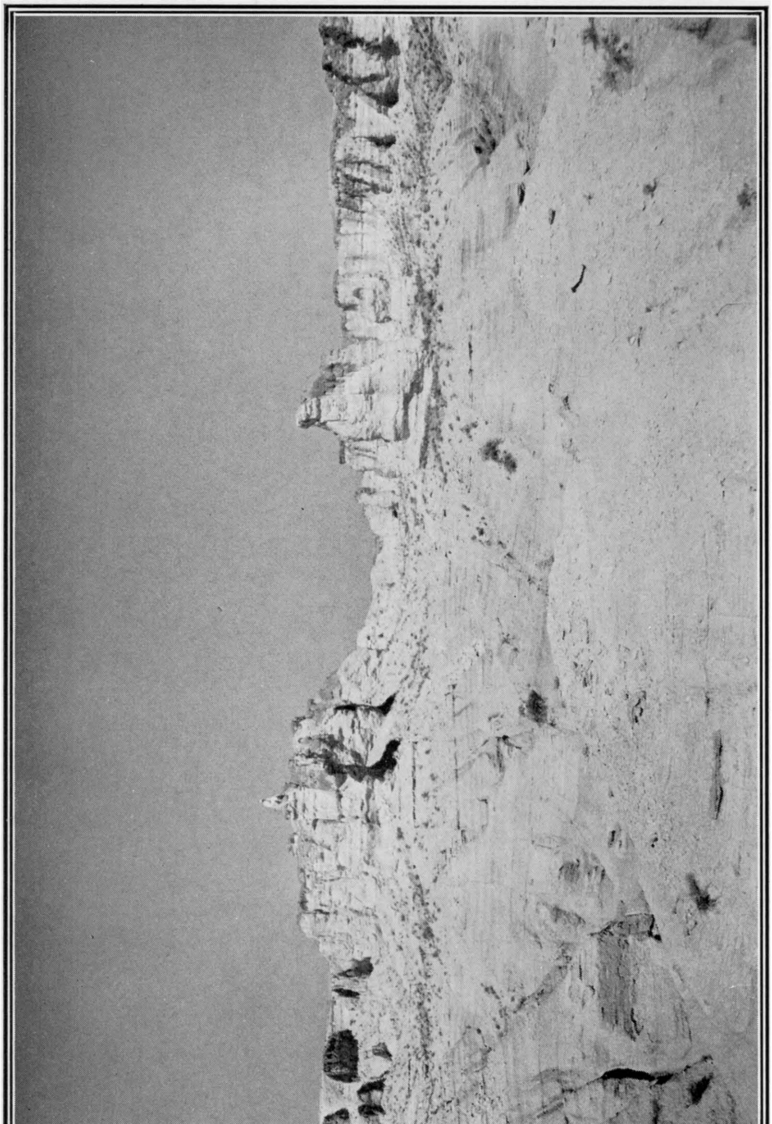


PLATE 25. Bluffs of Niobrara chalk in Logan county. This type of Cretaceous rock, which underlies thousands of square miles in western and north-central Kansas, is almost impervious to ground water. (K. K. Landes and Oren Bingham.)

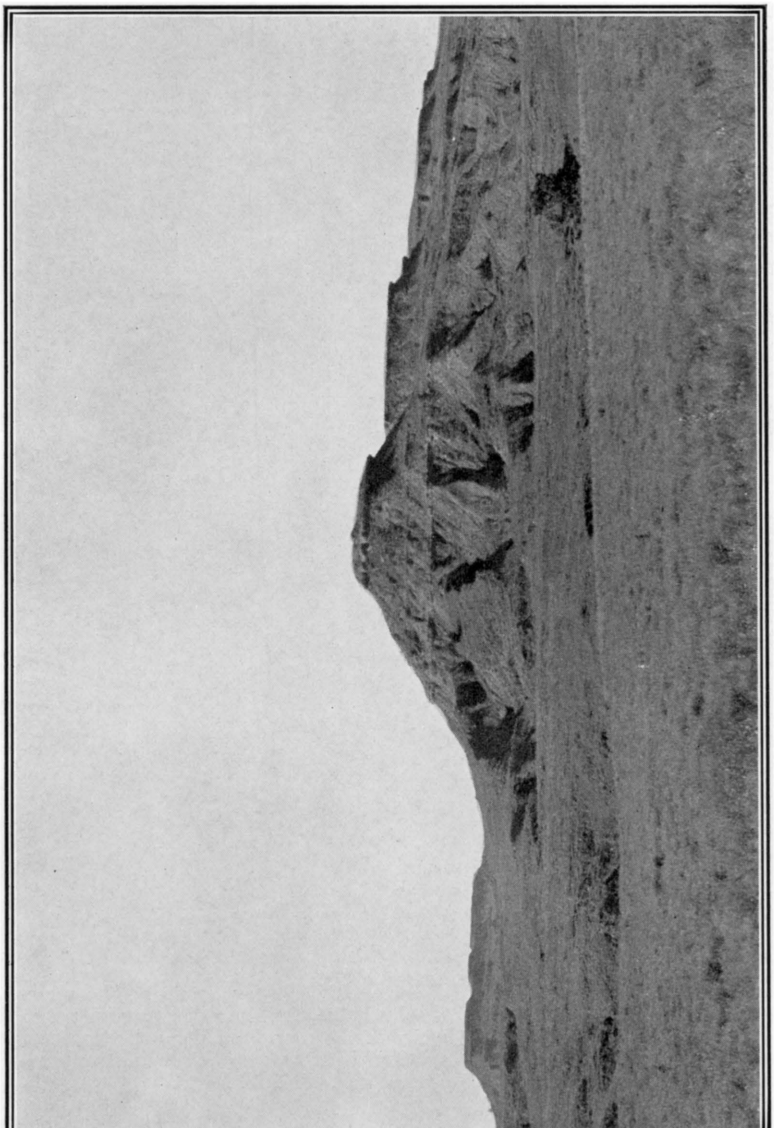


PLATE 26. Gypsum-capped hills in the Permian red-beds country near Medicine Lodge, Barber county. Ground-water supplies are difficult to find or lacking here. (K. K. Landes and Oren Bingham.)

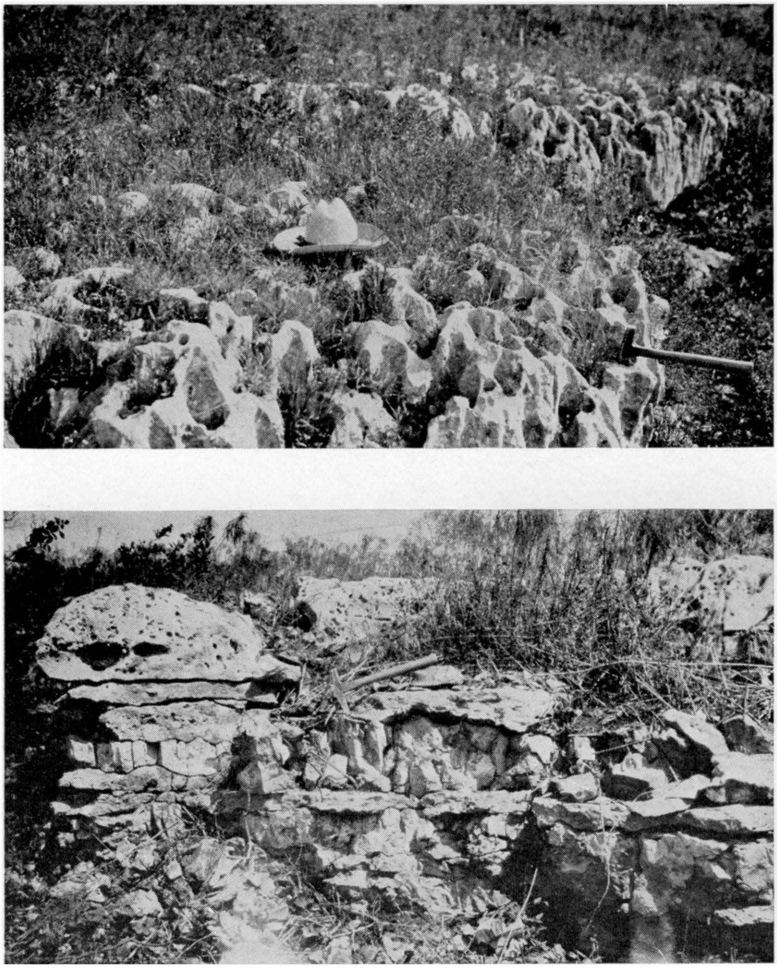


PLATE 27. Exposures of Wreford limestone in Cowley county. The upper view shows very clearly the effects of solution of the limestone by rain water. The lower photograph also shows cavities in the rock formed by solution, and in addition, indicates the manner in which beds of very hard, relatively insoluble chert (or flint) occur with the limestone. (N. W. Bass.)

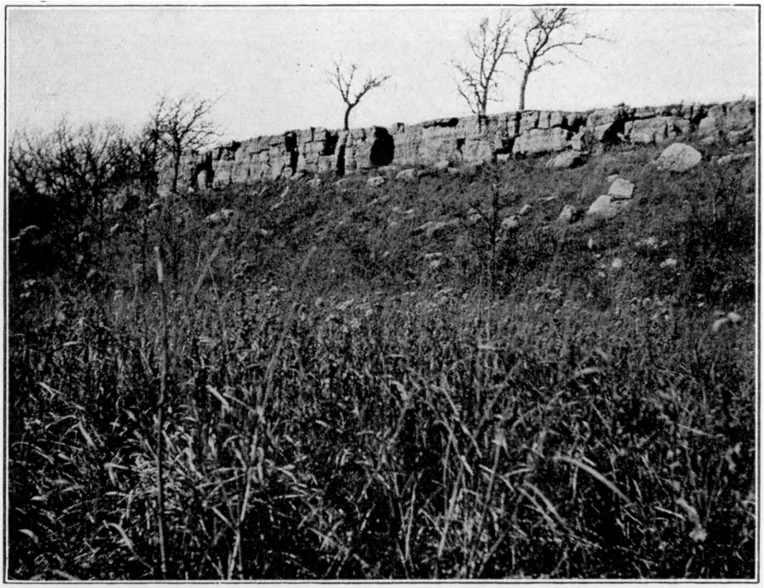


PLATE 28. *Upper and lower.* Typical outcrops of limestone belonging to the Chase group, Lower Permian, in Riley county. The wall-like outcrop is made by the upper division (Fort Riley) of the Barneston limestone. Water is conducted along joint cracks and other crevices in the limestone and it emerges at places along the contact of the limestone and underlying shale.

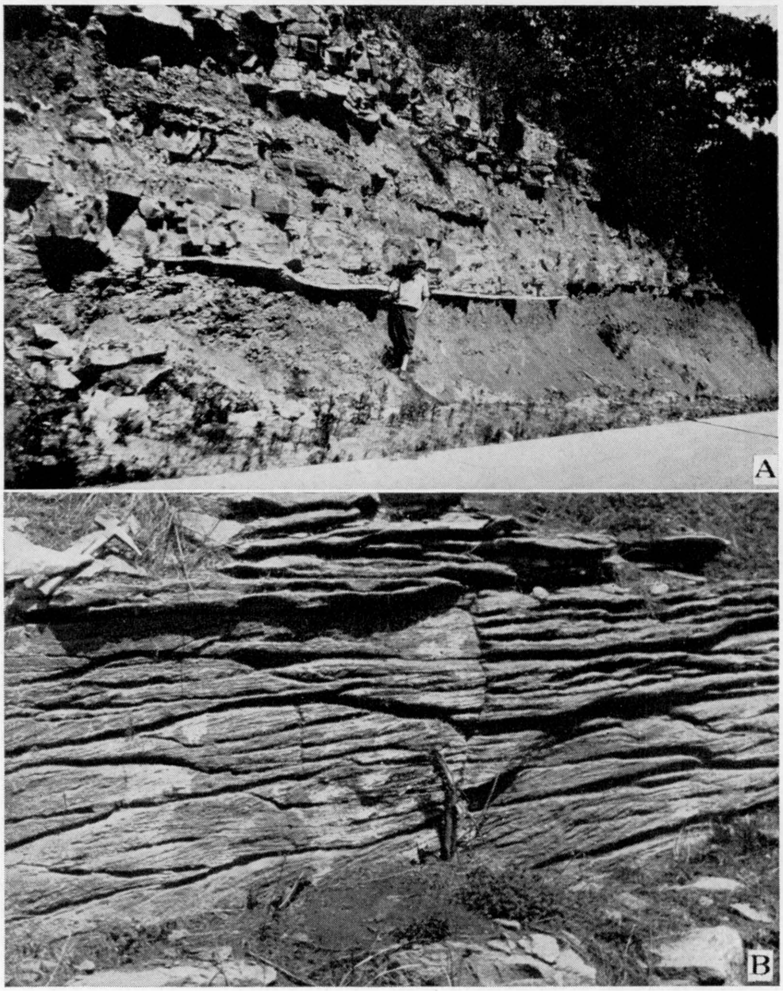


Plate 29. Pennsylvanian shale and limestone in Leavenworth county. The upper view shows interbedded thin limestone and shale beds, which are mostly valueless as ground-water reservoirs, even locally. The lower view shows the manner in which limestone is rendered pervious by the widening of bedding surfaces through solution (Lansing group, near Bonner Springs). (N. D. Newell and J. M. Jewett.)

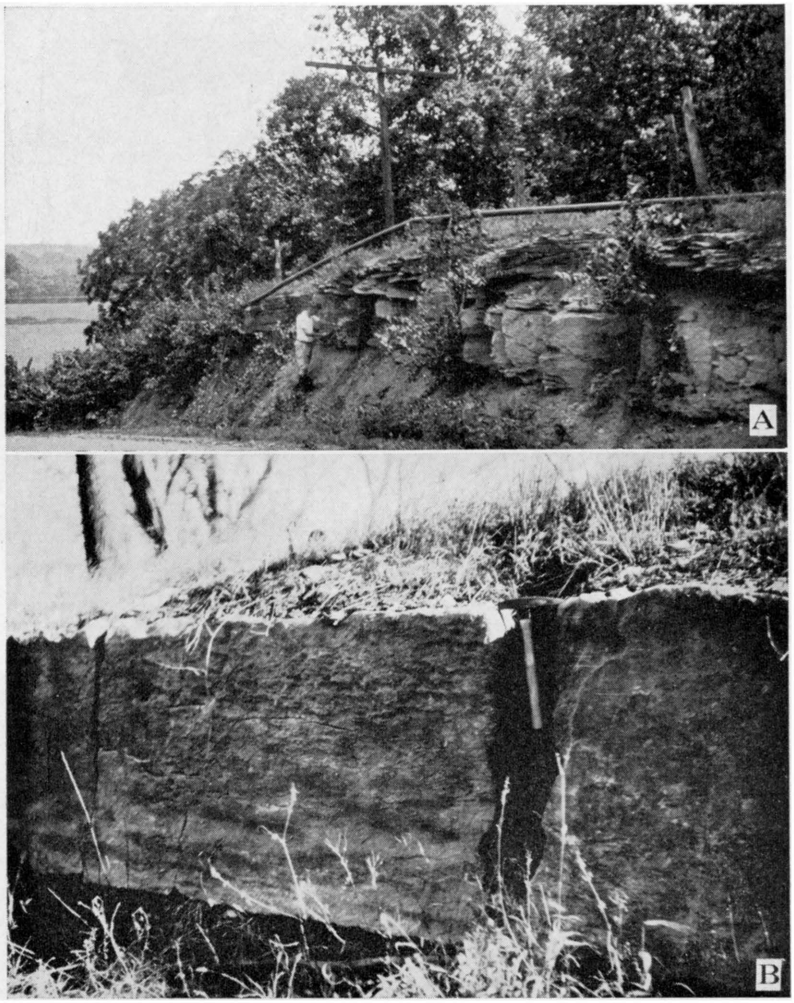


PLATE 30. Exposures of the Drum limestone, a typical subdivision of the Pennsylvanian rocks of eastern Kansas. Note the joint cracks that have been widened by solution. Miami county. (N. D. Newell.)

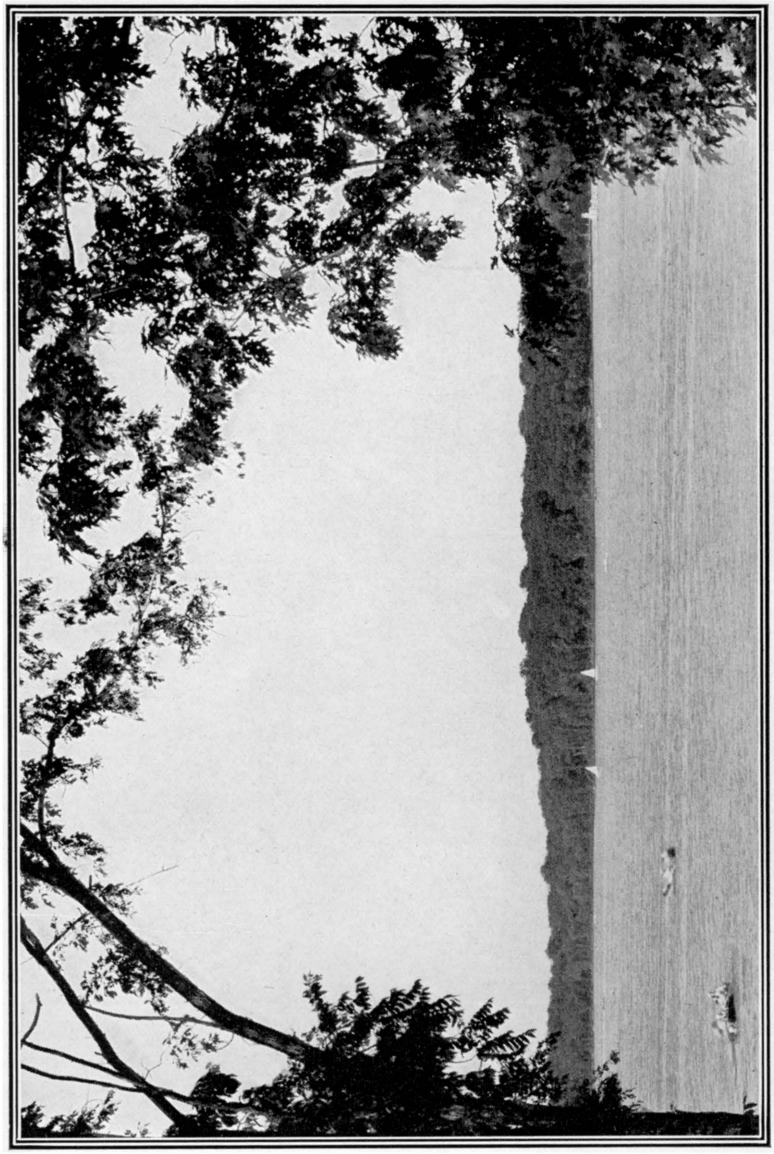


PLATE 31. Ponds and lakes, such as this one in Leavenworth county state park, near Tonganoxie, are important aids in conserving and utilizing water resources of Kansas.

PLATE 32. Flood waters are a menace to life and property, to be avoided as far as possible by practices that retard run-off and add to ground-water supplies. These views show parts of Kansas river valley during the flood of 1903.

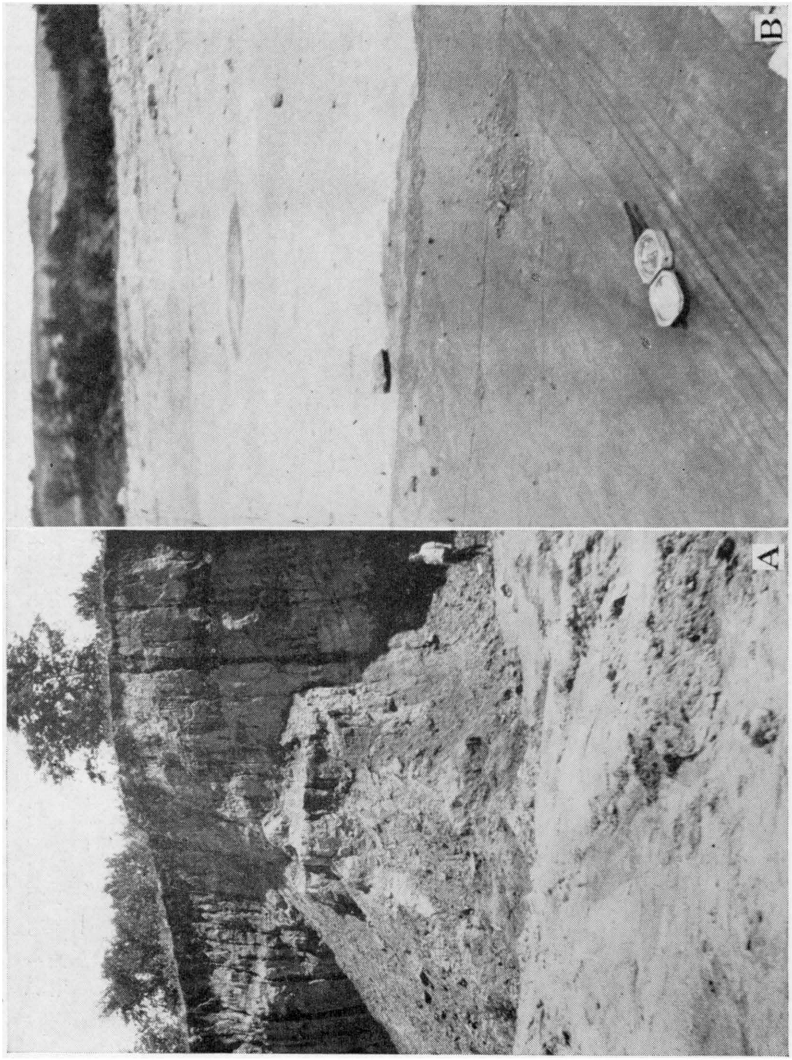


PLATE 33. *Left.* Exposure of loess of Pleistocene age in Kansas City, Kan. *Right.* Smoothed and scratched surface of bedrock exposed by stripping of glacial deposits in a quarry in Wyandotte county. The bedrock was eroded by a glacial ice sheet. (N. D. Newell and J. M. Jewett.)

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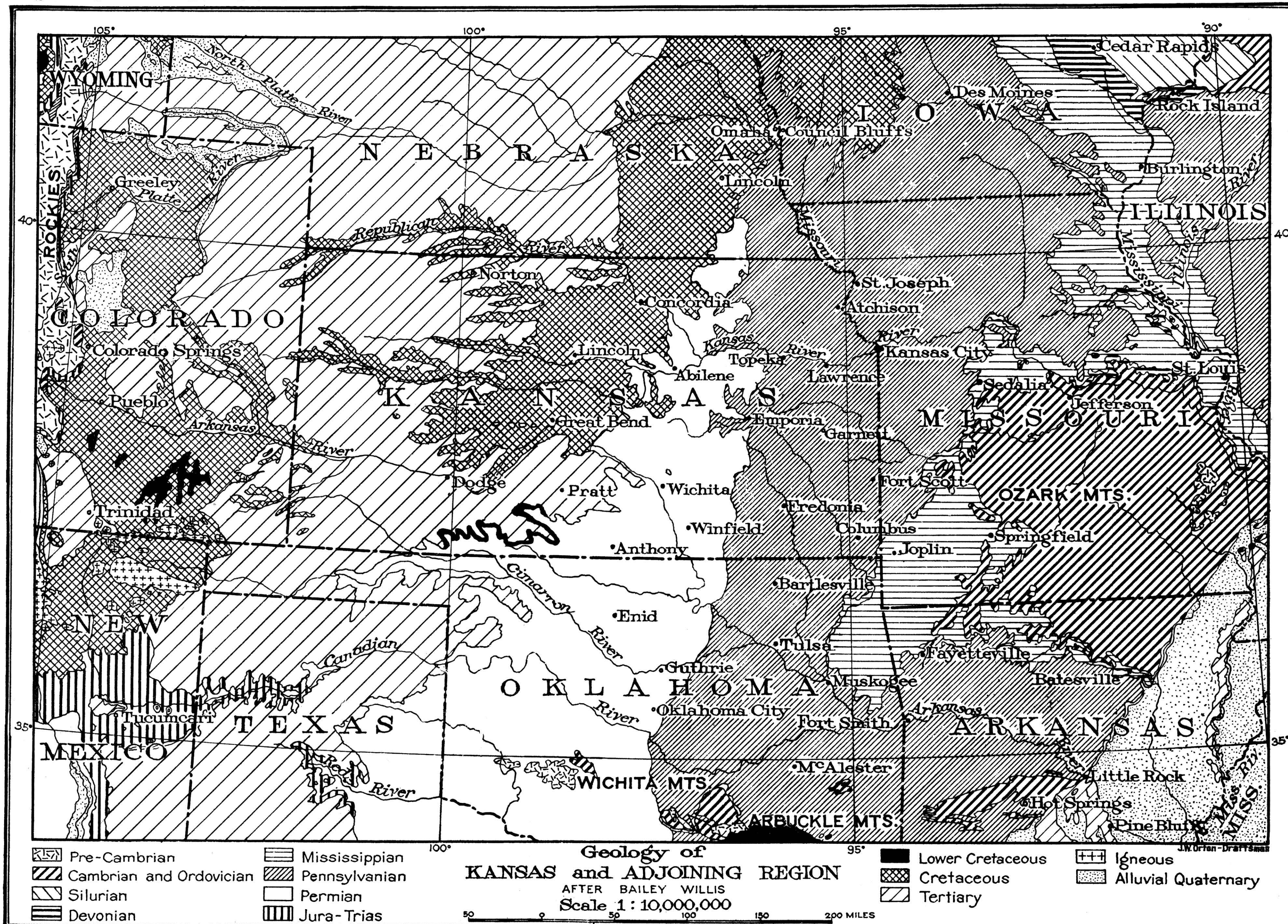

PLATE 34. Geologic map of Kansas and surrounding states. The areas of outcrops of rocks belonging to the geologic systems are dependent mainly on regional structure, topography, and the thickness of the systems. This distribution affects local ground-water conditions importantly.