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GEOLOGY AND GROUND-WATER FEATURES OF SALT SPRINGS, SEEPS, AND PLAINS IN THE ARKANSAS AND RED RIVER BASINS OF WESTERN OKLAHOMA AND ADJACENT PARTS OF KANSAS AND TEXAS

by

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ABSTRACT

The salt springs, seeps, and plains described in this report are in the Arkansas and Red River basins in western Oklahoma and adjacent areas in Kansas and Texas. The springs and seeps contribute significantly to the generally poor water quality of the rivers by bringing salt (NaCl) to the surface at an estimated daily rate of more than 8,000 tons.

The region investigated is characterized by low hills and rolling plains. Many of the rivers are eroded 100 feet or more below the surrounding upland surface and in places the valleys are bordered by steep bluffs. The alluvial plains of the major rivers are wide and the river channels are shallow and unstable. The flow of many surface streams is intermittent, especially in the western part of the area.

All the natural salt-contributing areas studied are within the outcrop area of rocks of Permian age. The Permian rocks, commonly termed red beds, are composed principally of red and gray gypsiferous shale, siltstone, sandstone, gypsum, anhydrite, and dolomite. Many of the formations contain halite in the subsurface. The halite occurs mostly as discontinuous lenses in

shale, although some of the thicker, more massive beds are extensive. It underlies the entire region studied at depths ranging from about 30 feet to more than 2,000 feet. The salt and associated strata show evidence of extensive removal of salt through solution by ground water. Although the salt generally occurs in relatively impervious shale small joints and fractures allow the passage of small quantities of water which dissolves the salt.

Salt water occurs in the report area at depths ranging from less than 100 feet to more than 1,000 feet. Salt water occurs both as meteoric and connate, but the water emerging as salt springs is meteoric. Tritium analyses show that the age of the water from several springs is less than 20 years.

The salt springs, seeps, and plains are confined to 13 local areas. The flow of the springs and seeps is small, but the chloride concentration in the water ranges from a few hundred parts per million to about 190,000 ppm. The wide range of concentration is believed to be due, in part, to differential dilution by fresh water. Alluvium in the vicinity of the salt springs remains saturated with salt water and evaporation from the alluvial surface causes the formation of a salt crust during dry weather. Those areas appear as salt plains that range in size from less than an acre to as much as 60 square miles.

The rocks exposed at the surface in the vicinity of the salt springs are permeable enough to allow the infiltration of some precipitation. Under certain geologic and hydrologic conditions ground water percolates down and through salt-bearing rocks where it dissolves the salt. Hydrostatic pressure of ground water at higher elevations forces the salt water to emerge as salt springs at lower elevations.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

The U.S. Public Health Service initiated the Arkansas-Red River basins water quality conservation project on July 1, 1957, under the Water Pollution Act, Public Law 660 (84th Congress). The objectives of the project were to locate and measure the sources, establish the importance and type of pollutants entering the Arkansas and Red Rivers, and to devise practical means of controlling them. It was recognized soon after the project was started that damaging quantities of chlorides are contributed by natural salt springs and plains along some of the tributaries of the Arkansas and Red Rivers. As a consequence, the Public Health Service, in November 1957, contracted with the Ground Water Branch of the U.S. Geological Survey to participate in the study. The field studies by the Survey were begun in the spring of 1958 when the author was assigned to the project. In December 1959 the U.S. Corps of Engineers was authorized to participate in the project and in Janaury 1960 they began a study to devise means and methods for control or improvement of the water quality in the two river basins.

The chief objective of the Survey's investigation is to determine on a regional basis the source and occurrence of natural salt pollution of the Arkansas and Red Rivers, and to study the general geologic and hydrologic conditions pertinent to the understanding of that pollution. The results of the study presented will furnish the reader a general understanding of the sources of natural salt pollution in the Arkansas and Red River basins.

The investigation was under the supervision of A. R. Leonard, district geologist of the Ground Water Branch of the U.S. Geological Survey in Oklahoma.

GENERAL FEATURES OF THE ARKANSAS AND RED RIVER BASINS

The Arkansas and Red River basins area constitutes more than 250 thousand square miles. The two rivers and their tributaries drain approximately one-tenth of the Nation's land area including all of Oklahoma and parts of Colorado, New Mexico, Kansas, Texas, Missouri, Arkansas, and Louisiana. A map of the western part of the basin is shown on figure 1.

The Arkansas River and its upper tributaries originate in the southern Rocky Mountains in Colorado and New Mexico where the general mountain elevations are between 8,000 and 10,000 feet. The main stem of the river and its tributaries flow from the mountains across a piedmont and plains belt that extends for 50 to 100 miles from the mountain front. In the higher elevations the streams flow through canyons and gorges but emerge onto the adjoining High Plains as meandering rivers. The surface of the High Plains, from eastern New Mexico to western Kansas and the eastern part of the Texas Panhandle is undulating and nearly unbroken. The elevation of the plain diminishes gradually from 5,000 feet in the western part to less than 2,500 feet at the eastern edge.

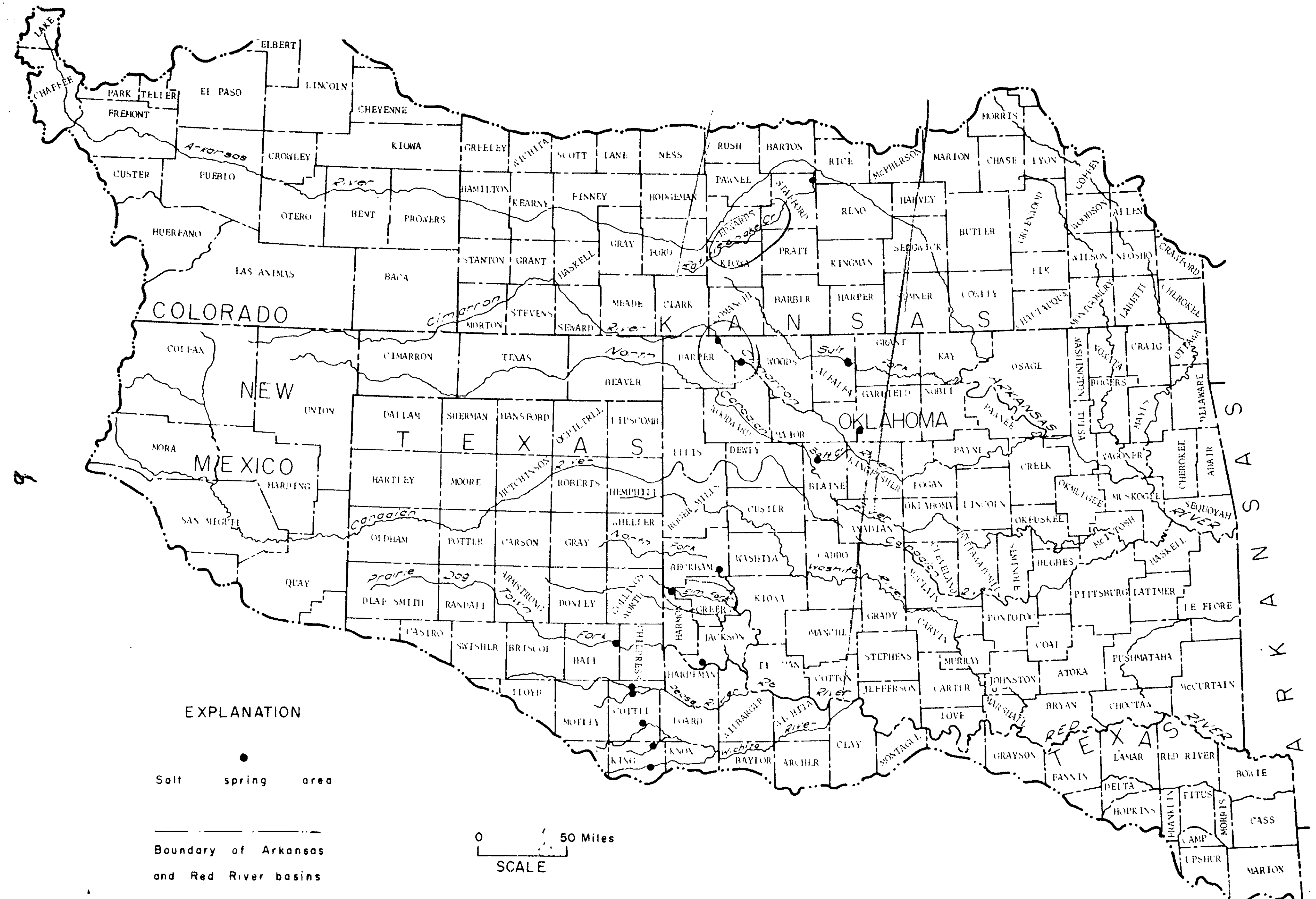


Figure 1.--Index map of the western part of the Arkansas and Red River basins showing the location of salt springs and plains.

The Red River rises in the High Plains in eastern New Mexico where the streams have intermittent flows. The Red and the Arkansas Rivers pass eastward from the High Plains into the more dissected rolling plains area that extends to the eastern part of Kansas, Oklahoma, and Texas where the regional elevation is less than 1,000 feet. Streamflow increases appreciably and drainage courses become more numerous in that area. The water in the rivers of the High Plains is of usable quality. However, the water in many of the streams becomes poor immediately east of the High Plains. The deterioration of the water quality is caused by the addition of chloride and sulfate to the water from natural sources.

In eastern Oklahoma and western Arkansas the Arkansas River flows from the plains area and traverses a region characterized by rugged hills and narrow, deeply incised valleys. East of Little Rock, Arkansas, the river flows for about 100 miles over a flat coastal plain area in southeastern Arkansas before entering the Mississippi River. The Red River leaves the plains area in southeastern Oklahoma and southwestern Arkansas to enter the coastal plain. A few of its northern tributaries drain south from the rugged hills area in Oklahoma and Arkansas to join the main stem on the coastal plain. From there the river meanders southeastward and empties into the Mississippi River in northern Louisiana where the elevation is less than 100 feet.

GENERAL FEATURES OF THE AREA INVESTIGATED

The area discussed in this report is restricted to that part of the Arkansas and Red River basins where most of the natural chloride pollution originates. That is in the area of rolling dissected plains and includes parts of western Oklahoma and adjacent areas in Kansas and Texas. The northernmost locality of significant natural pollution is along Rattlesnake Creek in Stafford County in southwestern Kansas and the southernmost salt-contributing area is along the South Wichita River in central King County, Texas (fig. 1). The distance between the two areas exceeds 300 miles. Red beds of Permian age, composed chiefly of red shale, siltstone, sandstone, and gypsum are the bedrock in that portion of the drainage basins containing the salt springs.

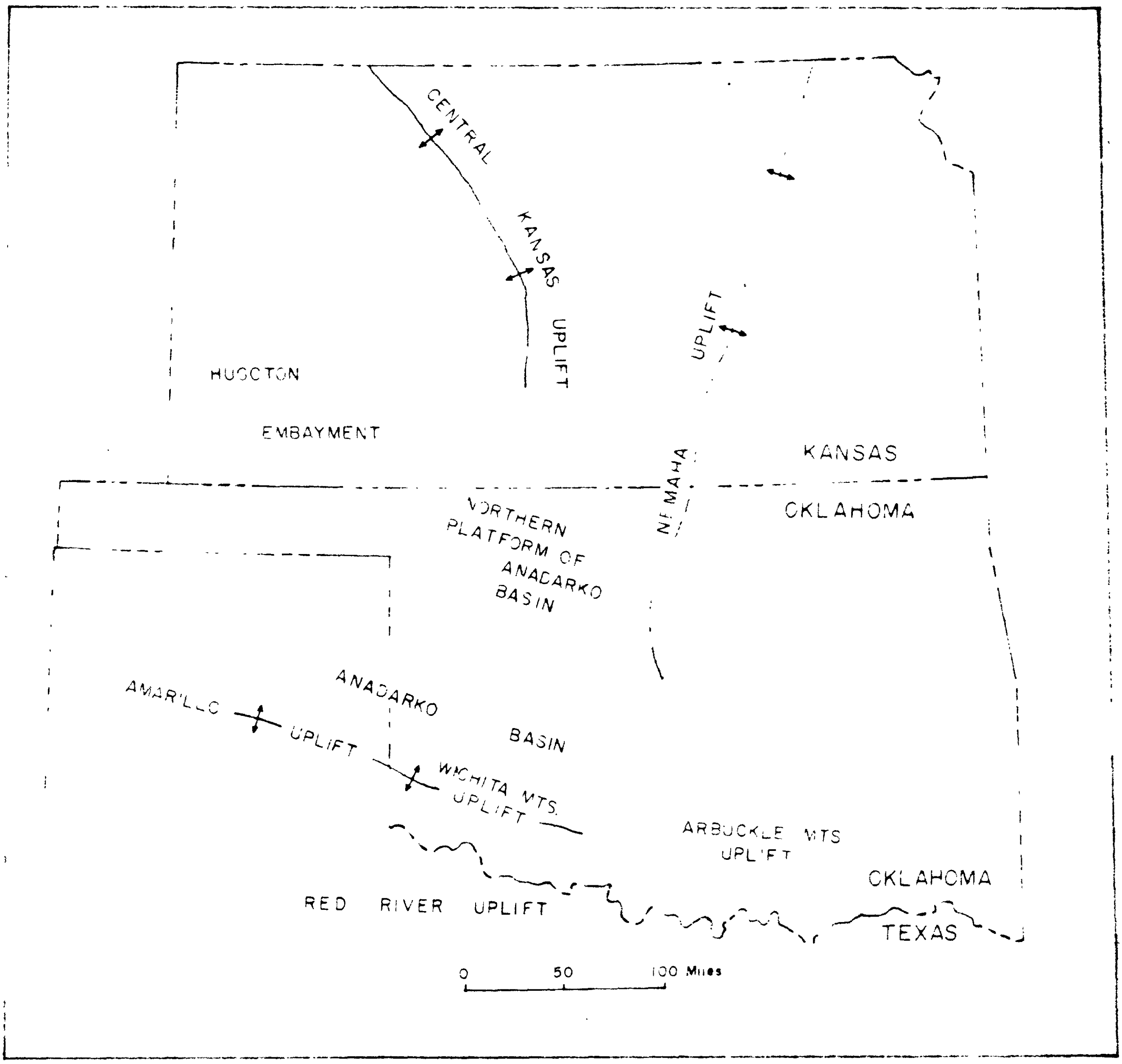
Regionally the area underlain by the Permian rocks is characterized by low hills and rolling plains. The rivers for the most part are incised more than 100 feet below the upland surface and in many places the valleys are bordered by steep bluffs. The alluvial plains of the major rivers commonly are wide and the rivers typically are braided. Some reaches of the rivers and many smaller tributaries flow intermittently. Broad terraces of unconsolidated sand and gravel and expanses of sand dunes parallel the major streams in many places.

PREVIOUS WORK RELATED TO SALT SPRINGS

One of the earliest technical references to salt springs in the Arkansas and Red River basins was a brief discussion of the salt plains in Oklahoma by Gould (1901). Bailey (1902) in his report on the mineral waters in Kansas made general reference to the salt marshes in Stafford County and discussed the quality of the mineral springs on Slate Creek near the Sumner-Cowley line. Snider (1913) described the appearance of several salt-spring areas in Oklahoma. Theis (1934) wrote a general preliminary geologic report on the Great Salt Plain in Alfalfa County, Oklahoma. A memorandum report by Bloesch (1942) discussed the possibility of preventing the salt springs in Harmon County, Oklahoma, from polluting the Elm Fork Red River and recommended that additional studies be made. Frye and Schoff (1942) theorized that deep circulation of ground water through faulted saliferous rocks was responsible for the salt springs in northwestern Oklahoma. Williams and Lohman (1949), in their ground-water report of part of south-central Kansas, included a short section on the poor quality of the water in the Rattlesnake Creek area. A geology and ground-water report by Latta (1950) contained a relatively detailed study of the Rattlesnake Creek area. Other writings make general references to salt springs but none of them were written specifically about salt springs.

ACKNOWLEDGMENTS

The data on which this report is based were obtained from many sources including published and unpublished reports of the U.S. Geological Survey. With few exceptions the well logs used in subsurface mapping were obtained from oil companies without whose cooperation this work would have been impossible. Some subsurface data and maps were furnished by the U.S. Corps of Engineers and are hereby gratefully acknowledged. Personnel of the U.S. Public Health Service were especially helpful during early phases of the field investigations. The writer is grateful for the assistance furnished by Dr. Louise Jordan and R. O. Fay of the Oklahoma Geological Survey. David Vosburg and Tom Roland, formerly of the Oklahoma Geological Survey, facilitated the collection of subsurface geologic data.



Structural features adapted from Fox and Sheldon, 1957.

Figure 2.--Map showing the major structural features in Kansas, Oklahoma, and part of northern Texas.

GEOLOGY

REGIONAL STRUCTURE

The major structural features in the area covered by this report are shown in figure 2. The regional dip of the rocks of Permian age is south and west but the structural features modify and reverse the rock dip in several areas. The structure that has the most influence on the attitude and lithology of the Permian deposits is the Anadarko Basin. The basin is an elongate assymmetric, northwestward-trending trough whose deepest part is adjacent to the Wichita Mountains uplift (Adkinson, 1960). The Permian rocks dip toward the axis of the basin and many formations thicken considerably as the axis is approached. Other major structural features influenced the beds of Permian age both during and after deposition. However, the occurrence of salt springs is apparently influenced less by those structures than by topography and rock lithology. Local structure exerts an undetermined degree of control over the occurrence of some of the salt springs.

QUATERNARY SYSTEM

Because the deposits of Quaternary age are not related directly to the occurrence of salt springs a study of them was not undertaken. The general distribution of the Quaternary sediments is shown on plate 1. They are composed mainly of alluvial gravel, sand, silt, and clay, and dune sand. The thickness of the deposits differs greatly from place to place, being thin along the smaller streams and relatively thick along major rivers and in some of the sand-dune areas. Notable areas of extensive dune development are south of the Arkansas River in Kansas, along parts of the Cimarron River in northwestern Oklahoma, along the Red River in Texas, and in the central part of Cottle County, Texas. A test hole near the Big Salt Plain in sec. 18, T. 27 N., R. 19 W., in Woods County, Oklahoma, penetrated 72 feet of alluvial sand and silt before entering bedrock. A test hole near the salt springs on sec. 21, T. 18 N., R. 12 W., in Blaine County, Oklahoma, passed through 61 feet of terrace deposits that consist of sand, silt, and clay.

PERMIAN SYSTEM

The rocks of principal concern in this investigation are those of Permian age. They are distributed widely in southwestern Kansas, western Oklahoma and adjacent parts of Texas (pl. 1). Bedrock around all the salt springs is of Permian age but at some of the springs the bedrock is masked by unconsolidated deposits of Quaternary age.

The Permian rocks are difficult to correlate over long distances because they tend to grade locally, both laterally and vertically, into equivalents of different character and texture. Nevertheless, the rocks are remarkably similar in overall appearance from southern

Table 1.--Description of P[illegible] rocks [illegible] in south-[illegible] Kansas.
[illegible]
[illegible], 1[illegible].

Subdivision	Approximate thickness (feet)	Description: General lithology	Description: Salt	Salt water
[illegible] formation, [illegible] Creek dolomite, and Whitehorse sandstone	Clark and Meade Counties, 30[illegible].	Red fine-grained sandstone, shale, and siltstone. Few thin dolomite beds and gypsum stringers.	Salt was not reported in the well logs studied.	Lower part may contain salt water, especially where deeply buried.
Dog Creek shale	Barber County, 14-53.	Maroon, silty shale, siltstone and very fine-grained sandstone. Thin beds of dolomite, dolomitic sandstone, and gypsum.	Data not sufficient to establish the presence of salt but it may be present locally in small amounts.	Contains salt water locally.
Blaine formation	Barber and Clark Counties, 50.	Massive beds of gypsum separated by red gypsiferous shales. Discontinuous thin dolomite beds underlie the gypsum beds.	Contains salt zones locally where deeply buried.	Contains salt water in some areas, particularly in the basal part. A small amount of salt water may seep from the Blaine into the Cimarron River in southwestern Comanche County.
Flowerpot shale	Barber and Clark Counties, 1[illegible]0.	Brownish-red, silty, gypsiferous shale and occasional thin, fine-grained sandstone. Formation characterized by numerous intersecting veins of satin spar and selenite crystals.	The shale is salty in many places and it contains bedded salt in many others, particularly west of Comanche County.	Salt water is widespread. A small amount of salt water may seep into the Cimarron River in southwestern Comanche County either directly or upward through the gypsum of the overlying Blaine formation.
Cedar Hills sandstone	Barber and Harper Counties, 180.	Alternating thin beds of red, very fine-grained sandstone and clayey siltstone, and red silty shale. Beds of white sandstone occur locally in upper and lower parts.	Contains salt locally.	Locally contains salt water especially where buried beneath permeable rocks. Small amounts of salt water may seep into alluvium along Salt Fork Arkansas River in Barber County.
Salt Plain formation	Harper County, 265?	Red, silty, flaky, gypsiferous shale and some siltstone and sandstone.	Salt occurs in many areas particularly west of Comanche County.	Contains salt water in many localities.
Harper sandstone	Harper County, 220.	Red and reddish-brown siltstone, very fine-grained sandstone, and some silty shale.	Probably contains salt locally.	Probably contains salt water, especially where deeply buried.
Sumner group (Stone Corral dolomite, Ninnescah shale, and the Wellington formation)	Ford County, 1,200.	Upper part: mostly brownish-red, silty, blocky dolomitic shale. Lower part: chiefly gray and green silty shale and some red shale. Beds of halite make up a significant part of the Wellington formation in the subsurface.	Massive beds of salt occur in much of western Kansas. The salt-bearing horizon attains a thickness of more than 700 feet in Clark County.	Contains salt water near the eastern margin of the salt zone in the central part of the state.

Table 2.--Description of Permian rocks cropping out in western Oklahoma.
(Geologic names as used on the U.S. Geological Survey Geologic map of Oklahoma, 1954)

Subdivision	Approximate thickness (feet)	Description: General lithology	Description: Salt	Salt water
Quartermaster formation	Southwestern Oklahoma (Beckham and Washita Counties), 350.	Upper 190 feet is composed chiefly of reddish-brown, fine-grained and medium-grained sandstone, and some coarse-grained sandstone and discontinuous beds of siltstone. Lower part consists of brownish-red shale and thin beds of siltstone.	None known.	None known.
Cloud Chief formation	Southwestern Oklahoma (Beckham and Washita Counties), 430.	Red, very fine-grained, gypsiferous sandstone and thin interbedded, silty shale, and thin, irregular beds of gypsum, anhydrite, and dolomite near the top and bottom.	None known.	May contain salt water in some localities.
Whitehorse group	Northwestern Oklahoma (Harper County), 200. Southwestern Oklahoma (Beckham County), 390.	Northwestern Oklahoma: red sandstone, siltstone, and shale, and thin irregular beds of gypsum and dolomite. Southwestern Oklahoma: dominately pink and red, shaly, silty fine-grained sandstone, and a few irregular thin beds of gypsum and dolomite.	None known.	Contains salt water locally.
Dog Creek shale	Northwestern Oklahoma (Woodward County), 100. Southwestern Oklahoma (Beckham County), 80.	Dominately red, brown, and green silty, blocky shale and thin dolomite. Locally shale is dolomitic and sandy.	Contains small amount of salt in parts of southwestern Oklahoma and in the Panhandle.	Probably contains salt water locally especially where deeply buried.
Blaine gypsum	Northwestern Oklahoma (Woodward County), 90. Southwestern Oklahoma (Beckham County), 140.	Massive, white beds of gypsum interbedded with red and gray gypsiferous shale. Dolomite beds underlie the gypsum beds locally. In some localities gypsum makes up 70 percent of the total thickness.	Blaine County and parts of northwestern Oklahoma.	Contains salt water in several areas. Salt springs issue from the formation in southwestern Beckham County and southern Jackson County.
Flowerpot shale	Northwestern Oklahoma (Woodward County), 200. Southwestern Oklahoma (Beckham County), 160.	Red, brown, and maroon, silty, blocky, gypsiferous shale characterized by intersecting veins of satin spar and selenite crystals.	Salt occurs in many places in northwestern and southwestern Oklahoma including the Panhandle. Salt is within 70 feet of the surface locally in Woods County; within 100 feet in southern Woods County, and within 200 feet in northern Harmon County.	Salt water is widespread. Salt springs issue from the formation in several localities in northwestern and southwestern Oklahoma.
Hennessey shale	Central-northern Oklahoma, 300-600. Central-western Oklahoma (Canadian County), 850.	Yellowish-gray, buff, and red blocky shale and a few thin, fine-grained, calcareous sandstones. Includes the Cedar Hills sandstone member in northern Oklahoma which is composed of red, fine-grained sandstone.	Probably contains a small amount of salt locally in northwestern Oklahoma.	Probably contains salt water in part of northwestern Oklahoma.
Garber sandstone	Central-northern Oklahoma (Grant County?) and southwestern Oklahoma (Caddo County), 600.	Predominately reddish-brown shale, and red to brown and light-gray siltstone, and very fine to fine-grained sandstone.	Contains a small amount of salt in central-western Oklahoma where it is deeply buried.	Contains salt water in many places.
Wellington formation	Northwestern Oklahoma (Alfalfa County), 1,100.	Northwestern Oklahoma: light-gray anhydrite with gray shale in the lower part. The rocks become more shaly southward. Contains thick beds of halite in the subsurface.	Massive beds of salt occur in much of northwestern Oklahoma.	Salt water is found locally, and may be widespread.
Wichita formation (southwestern Oklahoma)	Not determined but may exceed 1,500 feet locally.	Equivalent to the Garber sandstone and Wellington formation. Near the Wichita Mountains it includes the Post Oak conglomerate member and other beds. Generally red-brown shale, siltstone, sandstone, impure limestone, and anhydrite.	The well logs studied showed stringers of salt locally.	Contains salt water in many places.

Table 3.--Description of Permian rocks cropping out in parts of northwestern Texas and the Texas Panhandle.
(Geologic names as used on the U.S. Geological Survey Geologic map of Texas, 1937)

Subdivision	Approximate thickness (feet)	Description		Salt water
		General lithology	Salt	
Quartermaster formation	Northwestern Texas (Dickens, Hall, and Motley Counties), 200-300.	Predominately red, thin sandstone and gypsiferous shale.	Not known to contain salt in areas studied.	May contain salt water in some localities, especially where buried.
Cloud Chief gypsum	Northwestern Texas (Hall County), 300?	Red, fine-grained sandstone, with irregular beds of gypsum, thin dolomite, and red shale.	Unknown but may contain salt in the basal part.	Probably contains salt water locally.
Whitehorse sandstone	Northwestern Texas (Hall County), 400?	Red, fine-grained sandstone and irregular beds of dolomite and gypsum. Contains thick beds of halite locally.	Contains thick beds of salt locally, especially south and west of Cottle County and probably in the Panhandle.	Contains salt water in many areas in northwestern Texas. Salt springs may issue from near the base locally.
Dog Creek shale	Northwestern Texas (Childress and Hardeman Counties), 280.	Red and brown, silty, blocky, gypsiferous shale and irregular beds of dolomite and massive gypsum.	Contains salt locally in northwestern Texas and probably in the Panhandle.	The occurrence of salt water probably is widespread. Salt springs issue from the formation in Cottle and King Counties.
Blaine gypsum	Not determined, but may be 250 feet in Hall County.	Red and brown gypsiferous silty shale, massive beds of white and light-gray gypsum, and several discontinuous impure beds of dolomite.	Contains salt in parts of northwest Texas and it may be widespread in the Panhandle.	Contains salt water in many localities in northwest Texas and the Texas Panhandle. Salt water may seep from the rocks locally in northwestern Texas.
San Angelo sandstone	Northwestern Texas (Foard County), 100-160.	Brown and red-brown, massive sandstone and siltstone, silty shale, and conglomerate.	May contain salt locally in northwestern Texas. Salt is present in the Panhandle.	Salt water is present in the Panhandle and occurs locally in northwestern Texas.
Clear Fork group	Northwestern Texas (Childress County), 1,200.	Red silty gypsiferous shale, fine-grained sandstone, and irregular thin beds of dolomite and gypsum. Contains halite in many places.	Salt is widespread in the Panhandle and is present locally in northwestern Texas.	Contains salt water locally in many areas.
Wichita group	Northwestern Texas (Childress County), 900; Panhandle (Gray County), 700.	Panhandle (Gray County), anhydrite with streaks of gray shale and shaly dolomite.	May contain a small amount of salt in the Panhandle.	Contains salt water where deeply buried.

Kansas to northern Texas. The outcropping rocks are composed chiefly of red and gray gypsiferous shale, siltstone, and fine-grained sandstone containing massive beds of gypsum and anhydrite, especially in the upper part. Thin impure beds of dolomite characterize many of the formations. Subsurface equivalents of most of the Permian rocks shown on plate 1 contain deposits of rock salt (halite).

A presentation of the detailed stratigraphy and regional correlations between widely separated areas or between states is beyond the scope of this report. The geology is given in a manner to show the relationship between rock units, salt deposits, and salt springs on a regional basis.

The areal distribution of the Permian rocks is shown on the geologic map (pl. 1). The map was prepared by joining maps adapted from published geologic maps and reports. The Texas and Oklahoma portions were taken from the respective state geologic maps. The Kansas portion was modified from a map by Norton (1939). The geologic names used by Norton have been changed slightly to conform to usage in Kansas (Moore and others, 1951). Summary descriptions of the units shown on the geologic map are given in tables 1, 2, and 3. The tables are based on data from published and unpublished reports and from surface and subsurface studies made during this investigation.

The cross sections (pl. 2) are based on data from oil-well logs and show the general position of salt-bearing rocks in the subsurface. The smaller cross sections drawn through individual salt-spring areas (for example, fig. 17) are interpretative and are based on surface observations and on data from one core hole in each area except for the Big Salt Plain area in northwestern Oklahoma (fig. 11) where several core holes were drilled.

Salt Deposits

Rock salt (halite) is present in the subsurface throughout the region of salt springs in the Arkansas and Red River basins (pl. 3). The salt occurs in some localities as nearly pure layers of halite and in other areas it is intermixed with shale or siltstone. It is found occasionally as crystals in anhydrite and gypsum. At places the aggregate thickness of salt and salt-bearing rocks is many hundreds of feet.

The Salt Map

Plate 3 shows the depth in feet to the top of the first detectable trace of salt. The contours were based on the depth to salt reported in individual wells. The configuration of land surface between wells was not taken into account. For instance, the depth to salt in a topographic low, such as a river valley, may be less between control points than the map indicates. Also, if a topographic high lies between control points of lower altitude, the salt will be deeper beneath the higher area than indicated on the map.

The salt zones shown are not continuous; that is, a zone may consist of an assemblage of salt lenses and patches. In order to contour the top of the salt zones it was necessary in most places to treat them as continuous beds. In a few areas the salt in an individual salt zone is clearly isolated in extensive areas of nonsalt-bearing rocks. In such cases no attempt was made to connect the salt between areas and they are shown as patches. An example is salt-zone A in northwestern Oklahoma. The cross sections (pl. 2), although generalized, portray the discontinuous lenticular nature of the salt deposits.

Purpose.--The main purpose of plate 3 is to show the location of salt and salt-bearing deposits and their relationship to salt springs and plains which are the major source of natural pollution of the Arkansas and Red Rivers. The salt deposits are the ultimate source of the natural salt pollution to the rivers; consequently to fully understand that pollution, some knowledge of the salt deposits is necessary.

Methods of preparing the map.--Plate 3 was compiled from data of several types obtained from several sources. The principal source was oil companies and the principal type was lithologic well logs. The salt is difficult to detect in samples from a well drilled by the rotary method especially where it is mixed with large amounts of other rock materials. The salt may be dissolved from the drill cuttings by drilling fluids. It may also be dissolved when the cuttings are washed prior to examination. Salt casts were common in shale cuttings and were used as a criterion for denoting salt horizons where other avaiable data, such as electric logs, also indicated salt.

Numerous electric logs were examined but only a few extended near enough to land surface to log the upper salt zones. Also, unless several log types were available from the same well salt could not be noted with certainty. On these logs salt could not readily be distinguished from anhydrite and gypsum. Salt was particularly difficult to detect where it was intermixed with large proportions of shale or gypsum and anhydrite.

Emphasis was placed on data from core holes where available. Drillers' logs of wells drilled by the rotary method were of little value. Drillers' logs of old wells drilled by the cable-tool method were found to have a high degree of accuracy and were used in some areas. To supplement the data available, core holes were drilled by the U.S. Corps of Engineers at strategic sites near seven of the spring areas.

Stratigraphic Position

All the salt mapped on plate 3 and referred to in this report is of Permian age. Nearly all the Permian rocks shown on plate 1 contain salt at one or more localities in the area studied. (See tables 1, 2, and 3.) Generalized cross sections of the salt-bearing rocks are shown on plate 2.

For mapping purposes the salt deposits were divided into three units labeled as zones A, B, and C. Salt-zone C is stratigraphically below the other two zones and is generally the deepest. In southwestern Kansas salt-zone C is confined to the salt named the Hutchinson salt member of the Wellington formation. The salt in the Wellington is widespread and the salt-bearing portion of the formation attains a thickness of 700 feet or more in southwestern Kansas (Kulstad, 1959). The salt in some places appears to be solid beds of halite whereas in other places it interfingers with beds of other composition. Salt in this zone does not cause high salinity in any springs except possibly the few small ones near the Sumner-Cowley County line 8 miles north of the Oklahoma State line. In the extreme western part of Kansas the salt in zone C pinches out. It is traceable south into Oklahoma where it dips steeply southward into the Anadarko Basin. The percentage of salt apparently diminishes as the basin is approached (Adkinson, 1960). The salt was found in many wells in the eastern part of the Texas Panhandle but to the west it fingers out rapidly into a thick section of anhydrite.

Salt-zone B in southwestern Kansas and much of western Oklahoma is separated from the salt in the Wellington by shale whose thickness ranges widely from place to place (pl.2, cross-section B-B'). In Kansas salt-zone B is confined to the Ninnescah shale and the overlying Stone Corral dolomite, the top of which marks the top of the zone. The Stone Corral can be traced for a short distance into Oklahoma but farther south it was not identified and criteria were not found by which the contact between zone B and C could be identified with certainty. In the northeastern part of the Texas Panhandle merging of salt zones prevented the division of the salt into zones (pl. 2, cross section F-F'). Salt B in Oklahoma is principally in the Garber sandstone but the upper part of the salt probably is in the lower part of the Hennessey shale.

Salt-zone A is the youngest salt of Permian age in the region. Due to its generally shallower depth it is the source of the salt in all the salt springs and plains studied; consequently, it is the salt of greatest interest and concern. The salt in this zone is not continuous although it is widespread from southern Kansas through western Oklahoma, and the Texas Panhandle to northern Texas. It is of a lenticular nature and on a map, such as plate 3, it often appears in patches. A more detailed study of this salt probably would show that the discontinuous nature is widespread. The nearest to the surface that salt was found was 70 feet in northwest Oklahoma.

In Kansas salt-zone A is in the Nippewalla group as used by the Kansas Geological Survey and ranges from as high in the section as the Blaine formation to as low in the section as the Harper sandstone. In Oklahoma salt was found at one or more localities in all rocks extending from the Dog Creek shale downward through the Hennessey shale. The youngest salt found in zone A in Texas is of Whitehorse age.

One of the most widespread and persistent salt horizons in this zone is the Flowerpot shale and its equivalents. Salt in the Flowerpot shale is the source of salt dissolved in the salt springs in Blaine, Beckham, and Harmon Counties, Oklahoma, and in the salt springs and plains along the Cimarron River in northwestern Oklahoma. It is thought to be the salt source for the spring at Estelline in Hall County, Texas. The source of the salt dissolved in the springs in Cottle and King Counties, Texas, is salt in zone A that is in the Dog Creek shale and Blaine gypsum interval.

Origin

Halite or common table salt, gypsum, and anhydrite are the most important sediments belonging to the group of sedimentary rocks termed evaporites. Evaporites are deposits that are due largely to evaporation of sea water in subsiding bays, lagoons, and shallow inland seas. The climate at the time of deposition most likely was arid. Great volumes of sea water had to be evaporated to produce the immense volume of salt that occurs. Basins of accumulation probably were fed continually with new sea water while evaporation and precipitation of salt continued. The red shales and siltstones mixed with the salt probably were deposited under fluviatile and deltaic conditions by rivers and streams flowing from nearby regions. The shale and siltstone grade laterally into the salt and other sediments of different texture and lithologic characteristics. Frequent and continued small oscillations of sea level repeatedly created numerous desiccation basins in which salt, gypsum, and anhydrite formed. Such depositional conditions account, at least in part, for the lenticular nature of many of the salt deposits.

Composition

The salt observed is crystalline and composed primarily of sodium chloride with small amounts of sulfate, magnesium, and calcium. Some of the salt is clear and almost free of impurities but most of it contains shale inclusions and shale partings, and is occasionally tinted reddish or orange with small quantities of iron. A large proportion of the salt contains so much red clastic material that the salt has a dull reddish-brown appearance.

Salt from zone C is mined commercially at several localities in the central part of Kansas. The composition of that salt, shown in table 4, is believed to be representative of most of the salt in the area studied.

Solution Features

The salt deposits of Permian age are the source of salt emerging from the salt springs in the area covered by this investigation, therefore features indicative of solution are evident in the salt deposits and associated rocks. Some of the features are:

1. The eastern margin of the salt deposits are, in places, too sharp and steep to be explained by any process of

deposition. This indicates that salt has been removed along its margin through solution.

2. The salt springs occur within a wide belt that trends northeastward. The belt lies within the outcrop area of rocks that contain salt in the subsurface to the west and the springs lie very near the present eastern limit of the salt deposits. Also, the springs are down-slope relative to the ground-water gradient and the topographic slope which is regionally east and southeast. As the salt is removed its margin probably shifts westward. Differential removal through solution has left patches of salt east of the main body of salt deposits. This is especially noticeable in salt-zone A in northwestern Oklahoma.

3. Surficial solution and collapse features such as slumped and contorted strata and sinkholes that occur especially along the eastern margin of the salt deposits are due to removal of salt and gypsum. These features are well demonstrated near spring areas in Woods County, Oklahoma, and in Cottle, Hall, and King Counties, Texas. In central Kansas a series of undrained depressions and sinks occur in a line extending from central Sedgwick County to southern McPherson County. Williams and Lohman (1949) state that the depressions have been developed in recent times and many of them are still subsiding owing to the removal of salt by solution from the underlying Permian rocks. The

depressions coincide closely with the present eastern margin of the salt beds. A sink, probably resulting from the removal of salt, developed in 1879 in Meade County, Kansas, and filled with salt water to within 14 feet of the surface.

4. Southwest of Wichita, Kansas (Sedgwick County), brine is present in the Sumner group (Permian) in strata that contain salt a short distance to the west. The brine is the result of ground water dissolving salt from the Wellington formation.

5. Broken shale containing salt casts was observed in cores near some of the salt springs. The shale has slumped and become broken as a result of salt removal.

6. Equivalents of rocks that contain salt in the subsurface contain salt casts and cubic voids in surface exposures which are evidence of the former presence of salt. Salt is missing from the rocks at the surface because of its removal through solution.

Table 4.--Average of three analyses of salt from the Wellington formation (salt-zone C) between the depths of 634 and 644 feet in central Reno County, Kansas. Analyses courtesy of the Carey Salt Co.

Constituent	Percentage
Sodium chloride (NaCl)	96.41
Calcium sulfate ($CaSO_4$)	3.02
Calcium (as bicarbonate)	0.28
Magnesium chloride (MgCl)	.22
Magnesium sulfate ($MgSO_4$)	.07
Calcium chloride (CaCl)	.004
Iron oxide	.01
Moisture	.09
TOTAL	100.104

SALT WATER

Two types of salt water are prevalent in the region. The first type is termed connate water and supposedly was trapped with the rock sediments at the time of deposition in sea water. The region studied, with the exception of the Wichita Mountain area in southwestern Oklahoma, is underlain by this type of salt water. It is likely that the water has become more mineralized through natural processes because it is considerably saltier than modern sea water. Most oil-field brines are commonly believed to be of this type. The second type of saline ground water is water derived from precipitation (meteoric water) that has become salty through solution of minerals in the rock over which and through which the water passes. It is the second type that is of importance to this study because saline connate water is not known to reach the surface anywhere in the area by natural means. The areal extent of meteoric salt water is not known but is probably widespread, certainly it underlies all the salt-spring areas.

DISTRIBUTION

Salt water occurs at depths, ranging from less than 200 feet to more than 1,000 feet, throughout the area studied. Figure 3 shows in a general manner the approximate depth to salt water in western Oklahoma and adjacent parts of Texas. Data were not obtained to show the depth to salt water in Kansas, though it is known to be

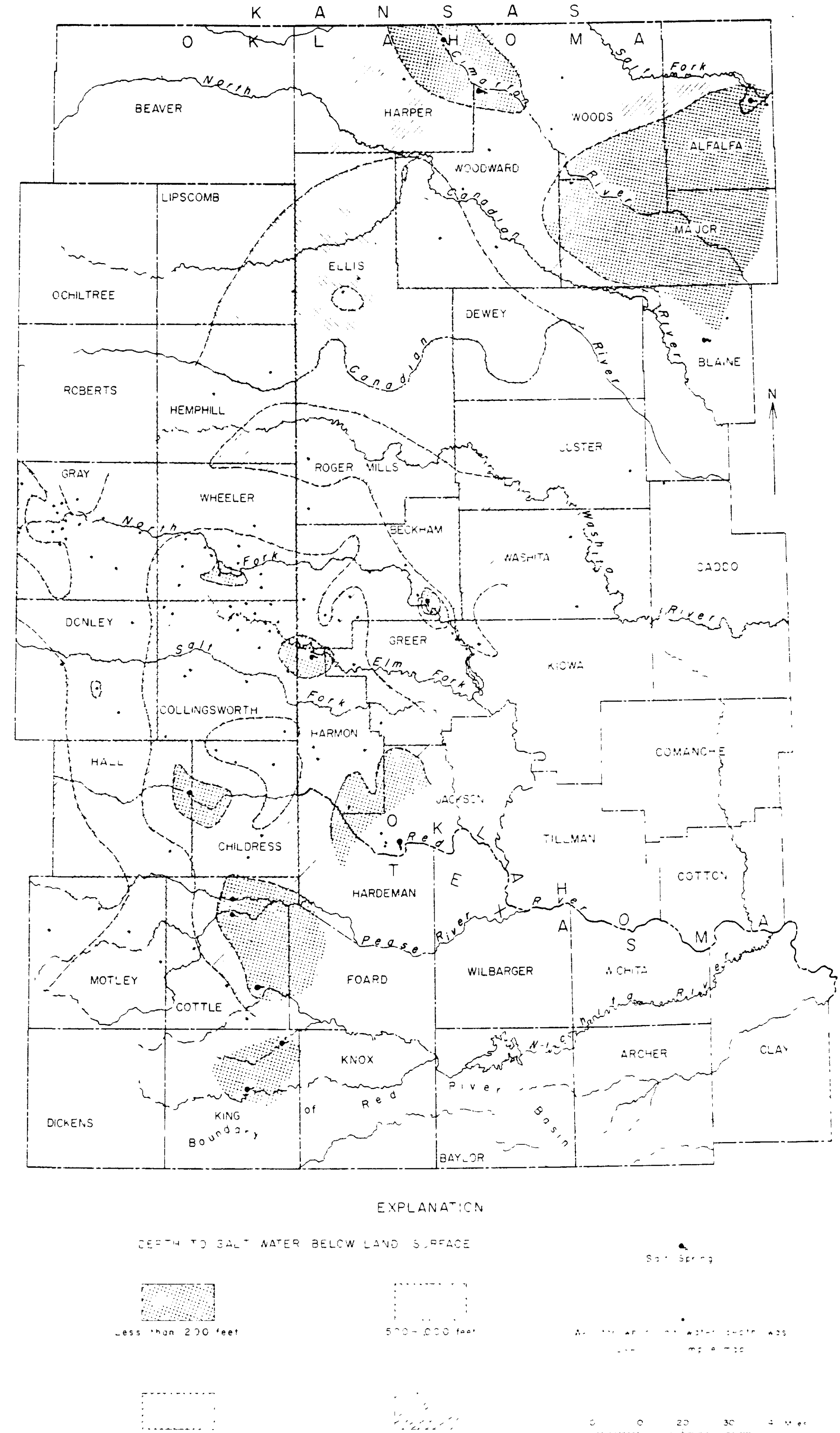


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Figure 3.--Map of western Oklahoma and adjacent parts of Texas showing the general depth of salt water.

Table 5.--Selected analyses of water from salt springs and salt-spring areas.
(Analyses by U.S. Geological Survey. Analytical results in parts per million except as indicated.)

Source	Date of collection	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium and potassium (Na+K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Hardness as $CaCO_3$		Specific conductance (Micromhos at 25°C)
									Noncarbonate	**Calcium, magnesium**	
Hole 1 ft. deep on the Great Salt Plain, Alfalfa Co., Okla.	5-14-59	.....	.....	.....	71,300	82	......	114,000	5,240	70	181,000
Spring at base of bluffs on the south side of the Big Salt Plain, Woodward Co., Okla.	11-17-59	1.5	1,120	896	100,000	25	3,750	156,000	6,460	20	215,000
Salt-water seep on the Little Salt Plain, Woods Co., Okla.	11-17-59	2.5	1,280	758	104,000	27	3,800	162,000	6,290	20	215,000
Salt Creek, below salt springs, Blaine Co., Okla.	11-16-59	4.0	1,700	578	52,100	103	3,200	82,600	6,540	80	159,000
Spring in Kiser Gulch, Harmon Co., Okla.	6-21-59	....	1,480	2,000	120,000	38	3,720	190,000	11,900	0	210,000
Estelline Spring, Hall Co., Texas	2-12-59	....	1,460	273	17,100	...	4,230	26,300	4,650	110	61,600
Spring on west side of Salt Creek, Cottle Co., Texas	7-30-58	21	1,210	279	11,800	122	3,810	18,000	4,070	100	45,700
South Fork Wichita River below Salt Springs, King Co., Texas	7-30-58	15	833	178	4,830	121	2,220	7,730	2,710	100	23,000
Rattlesnake Creek below Salt marshes, Stafford Co., Texas	2-16-60	10	96	20	687	244	122	1,050	120	200	1,950

widespread in the Permian rocks in the southwest part of the state. It was not feasible during this investigation to map in detail the depth to salt water over such an extensive area nor was it possible, in the time available, to determine the concentration of salt in the water. In general the salt water as mapped is too highly mineralized for municipal, industrial, or irrigation uses.

The trend of the region underlain by shallow salt water follows the trend of salt-spring areas because the shallow salt water occurs in the red beds of Permian age that contain salt in many places. This is a good indication that much of the salt dissolved in the water, including the water in the salt springs, is dissolved from salt deposits of Permian age.

QUALITY

Except for difference in dissolved solids content the water from all the salt springs sampled is remarkably similar. The water is the sodium chloride type with the chloride concentration ranging from a few hundred parts per million to 190,000 ppm (parts per million) (table 5). The wide range of dissolved solids is due principally to differential mixing of the salt water with fresh water near the springs. (See section on local movement.) A significant feature of the water is that the ratio of sodium to chloride averages about 0.64 with only slight deviations from that ratio whereas the ratio of sodium to chloride in oil-field brines in the region averages about

0.50 (fig. 4). The excess of chloride content over sodium in the oil-field brines is combined with constituents other than sodium, mainly calcium, to form calcium chloride which is not present either in the salt deposits or the spring water except in very small amounts.

The chief mineral constituent dissolved in the spring water is common table salt (halite); therefore, the water is high in both sodium and chloride content. Base exchange in the spring water probably is relatively unimportant because the sodium plus potassium and the chloride approach equivalence. The chloride in oil-field brines may have gone into solution originally as sodium chloride but base exchange has affected the relative ratios resulting in other salts, chiefly calcium chloride.

Following chloride, the natural contaminant of most concern in the water is sulfate (SO_4) which is derived from gypsum ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$) through solution. Those minerals are distributed widely in the rocks of Permian age. They are present in a variety of forms including massive beds, lenses, veins, and isolated crystals or aggregates of crystals. Wherever surface water or ground water comes in contact with the Permian rocks it will dissolve whatever amount of sulfate prevailing conditions will allow.

Gypsum is readily dissolved in pure water to give, at saturation at ordinary room temperature, about 1,500 ppm of sulfate (Hem, 1959). Many of the salt springs contain more sulfate because the solubility of sulfate is considerably greater in sodium chloride brines than it

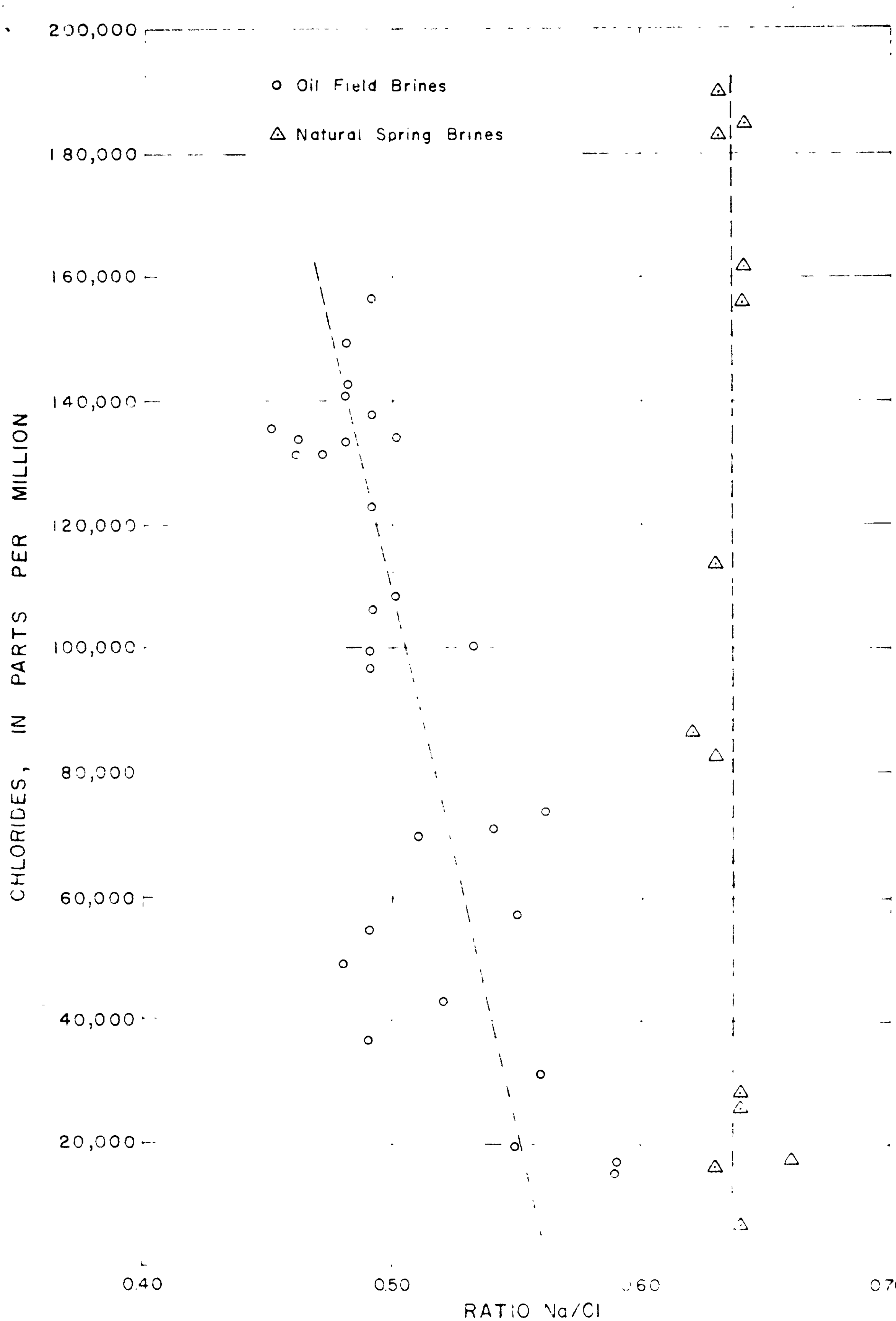


Figure 4.--Comparison of the ratio Na/Cl between oil-field brines and natural spring brines in western Oklahoma and southwestern Kansas.

is in pure water (fig. 5). The sulfate ion once formed is chemically stable in most natural environments.

LOCAL MOVEMENT

The ultimate source of the ground water flowing from the salt springs is precipitation that enters the ground-water reservoir by direct infiltration and by percolation from streams that are above the water table. The ground water remains in motion, moving from higher altitudes in the intake or recharge area to points of lower altitude in the discharge areas. The rate of movement is not known but because of the generally low permeability of many of the rocks it probably does not exceed a few inches per day.

The path that the water takes from the point of intake, downward and through salt-bearing deposits to a spring discharge point is complicated by the nature of the rocks. Most of the salt springs flow from shale that is overlain by dense cavernous beds of gypsum. The shale contains salt in the subsurface and is the major source of salt dissolved in the spring water. In a few places salt found in gypsum and dolomite may contribute to the salinity of some of the springs.

The exact manner by which water moves into the shale is not known but a large part of it probably moves slowly into the shale from overlying gypsum layers. The gypsum contains innumerable solution openings that store and transmit large volumes of water. Ground water in the gypsum is readily recharged through sinkholes and

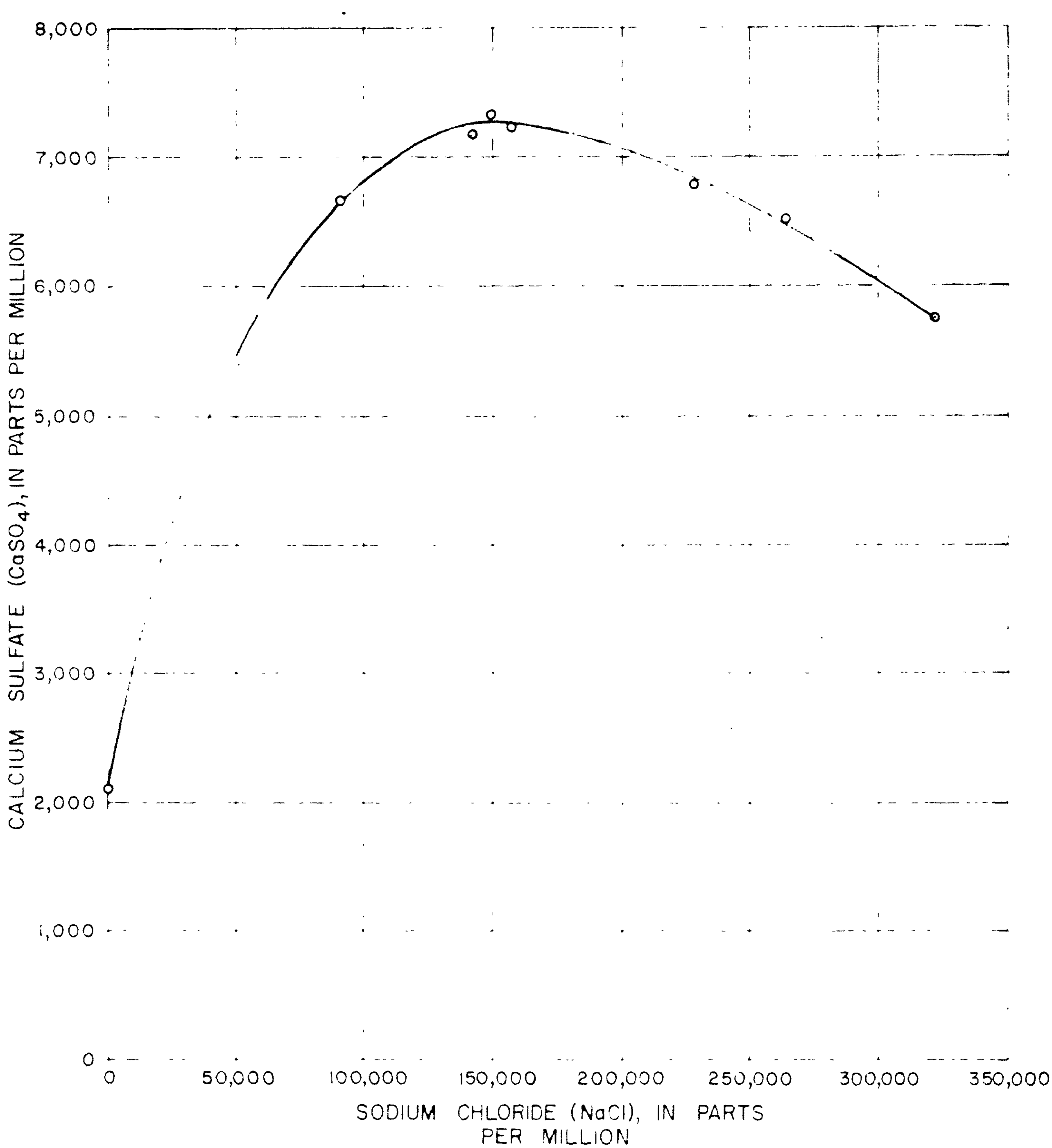


Figure 5.--Solubility of calcium sulfate ($CaSO_4$) in sodium chloride (NaCl) brine. After Seidell, 1940.

enlarged fracture openings that are present wherever the gypsum is at or near land surface. An example of extensive sink development may be observed in an area about 1 mile west of the salt springs in Harmon County, Oklahoma.

Some water seeps into the shales of Permian age from overlying terrace deposits and sand dunes which cover the upland areas near some of the salt-spring areas. The deposits are composed chiefly of unconsolidated sand and gravel. Dune-covered uplands are adjacent to the Great Salt Plain, Big Salt Plain, and the Little Salt Plain in Oklahoma and Estelline Spring in Texas. Terrace deposits cover the upland west of the Salt Creek area in Blaine County, Oklahoma. The unconsolidated deposits are permeable and generally contain and transmit considerable ground water that is replenished from precipitation falling upon their surface.

For the most part the permeability of the salt-bearing shale is low but erratic and water moves through it by devious routes. Openings in the shale are of several types. Spaces between individual grains composing the shale are so diminutive that only very small quantities of water are able to move through them. The shale has a blocky nature in many areas and the small openings outlining the blocks transmit some water. Larger cracks and fracture openings characterize the shale where it has become broken due to slumping. The slumping often accompanies the removal through solution of relatively thick deposits of underlying salt or other soluble material. Voids that were formerly filled with halite may permit the passage of significant amounts of water locally.

Some shallow, relatively fresh ground water enters the shale near some of the springs without coming in contact with salt deposits. Where this water mixes with the brine the chloride concentration in the brine is reduced and consequently the salinity of the spring water is decreased. In any one area the range of the salinity between individual springs may be great as a result of differential dilution. In other words, the saltier springs may be diluted slightly or not at all whereas the flow of the springs of lesser salinity may be made up almost entirely of the fresher water. Such differential dilution is well displayed by the springs at the base of the bluffs bordering the south side of the Big Salt Plain in Woodward County, Oklahoma. The chloride content of individual springs ranges from a few hundred parts per million to almost 200,000 ppm.

Geologic studies and the tritium content of the spring water indicate that the recharge area of individual spring areas is small and local. (See section on tritium dating.) To define spring-recharge areas with accuracy will require additional studies and a drilling program.

TRITIUM DATING

Tritium (T or H^3) is a radioactive isotope of hydrogen with a half-life of 12.4 years. Thus, in a little more than 12 years any given amount of tritium will be halved. Tritium originates chiefly by action of cosmic rays upon the nitrogen atoms of the atmosphere, and recently as a byproduct of hydrogen bombs (Thomas, and White, 1959). Therefore, tritium in a water sample is conclusive proof that the water is meteoric at least in part. Because of its short half-life the tritium content of meteoric water becomes too low to be measurable after the water has been isolated from the atmosphere for more than about 40 years; thus, absence of tritium is not proof of nonmeteoric origin of water because meteoric ground waters are commonly more than 50 years old.

Samples of water were collected from five salt springs and later analyzed for tritium in an attempt to determine the length of time the water has been underground and also to further substantiate its meteoric origin. An age determination of the water is a useful aid in determining the distance that the salt water has migrated underground before coming to the surface. Other factors being equal the greater the distance the salt water migrates the longer it has remained underground. The samples collected were from the Big Salt Plain in Woodward County, Oklahoma, Salton Gulch in Harmon County, Oklahoma, Estelline Spring in Hall County, Texas, Salt Creek in Cottle County, Texas, and the Wichita River in King County, Texas. The analyses data indicate that each spring contains water younger than 20 years. The samples from Cottle and King Counties, Texas, contain considerable amounts of post-1954 water. The results suggest that an appreciable portion of the salt water is very young. This being the case it seems reasonable to assume that most of the water has not migrated from great distances. Such an assumption appears especially valid because the low permeability of most of the rocks will allow water to pass through them only slowly.

SALT SPRINGS

Most of the natural salt pollution in the Arkansas and Red River basins is caused by salt plains, seeps, and springs. The known springs are confined to 13 local areas (fig. 1) and bring sodium-chloride salt to the surface at a total rate estimated by the U.S. Public Health Service to be 8,000 tons per day (table 6). That figure is based on short-term records and undoubtedly will be revised as additional data are collected and compiled. Each of the salt-spring areas contains numerous saline springs and seeps except the Estelline area in Hall County, Texas, where most, if not all, of the salt water flows from one large spring.

The springs are situated in the topographic lows of stream valleys and brine flowing from them saturates the surrounding alluvium. Evaporation from the alluvial surface results in the formation of a thin crust of salt that is dissolved during rainstorms but forms again soon after the rain stops. Where the alluvial plain is narrow the area covered with salt is small and is confined to a narrow strip along each stream bank for a short distance downstream from the springs (fig. 23). Where the alluvial plain is wide and the spring flow is relatively large the salt-incrusted alluvium appears as a flat salt plain. The largest salt plain is the Great Salt Plain in Alfalfa County, Oklahoma, which has an area of about 60 square miles (figs. 7 and 8).

Table 6.--Estimated daily rate that salt (NaCl) and chloride (Cl) is brought to the surface by salt springs in western Oklahoma and adjacent areas in Kansas and Texas.

Source	Location	Tons per day	
		Salt (NaCl)	Chloride (Cl)
Rattlesnake Creek	Stafford County, Kans.	500	300
Great Salt Plain	Alfalfa County, Okla.	3,300	2,000
Big Salt Plain	Woods and Woodward Counties, Okla.	2,600	1,600
Little Salt Plain	Woods and Harper Counties, Okla.	160	100
Salt Creek	Blaine County, Okla.	160	100
Boggy Creek	Beckham County, Okla.	.....	.....
Elm Fork Red River	Harmon County, Okla.	490	300
Lebos Creek	Jackson County, Okla.	Few	Few
Estelline Spring	Hall County, Texas	490	300
North and Middle Pease Rivers	Cottle County, Texas	66	40
Salt Creek	do.	250	150
Middle Wichita River	King County, Texas	80	50
South Wichita River	do.	250	150
	TOTAL	8,300	5,100

All the salt springs studied are restricted to areas underlain by rocks of Permian age and consequently are located within a broad northeastward-trending band that corresponds roughly with the outcrop band of rocks of Permian age. Except for an area in central-western Oklahoma the line of salt springs in the basins of the Arkansas and Red Rivers extends from King County, Texas, to Stafford County, Kansas. The absence of springs in central-western Oklahoma is caused by the deep structural Anadarko Basin. Across much of the basin salt deposits are too deeply buried to be affected appreciably by circulating ground water; consequently, salt springs are absent. Furthermore, the stratigraphic units that contain the upper evaporitic zone grade into clastics (shale, silstone, sandstone, etc.) as the outcrop of these rocks swings around the eastern part of the basin. The clastic rocks are devoid of salt deposits.

Salt springs similar to those studied are present in the Brazos River basin south of the Red River basin in Texas. A study of them is outside the scope of the present investigation and they are not discussed in this report.

Most of the salt springs are small and many of them appear to bubble up from the salt-incrusted alluvial flats where they sometimes coalesce to form small streams that meander over the surface of the plain. The larger springs generally flow from the base of bedrock bluffs that border the stream valleys (fig. 18).

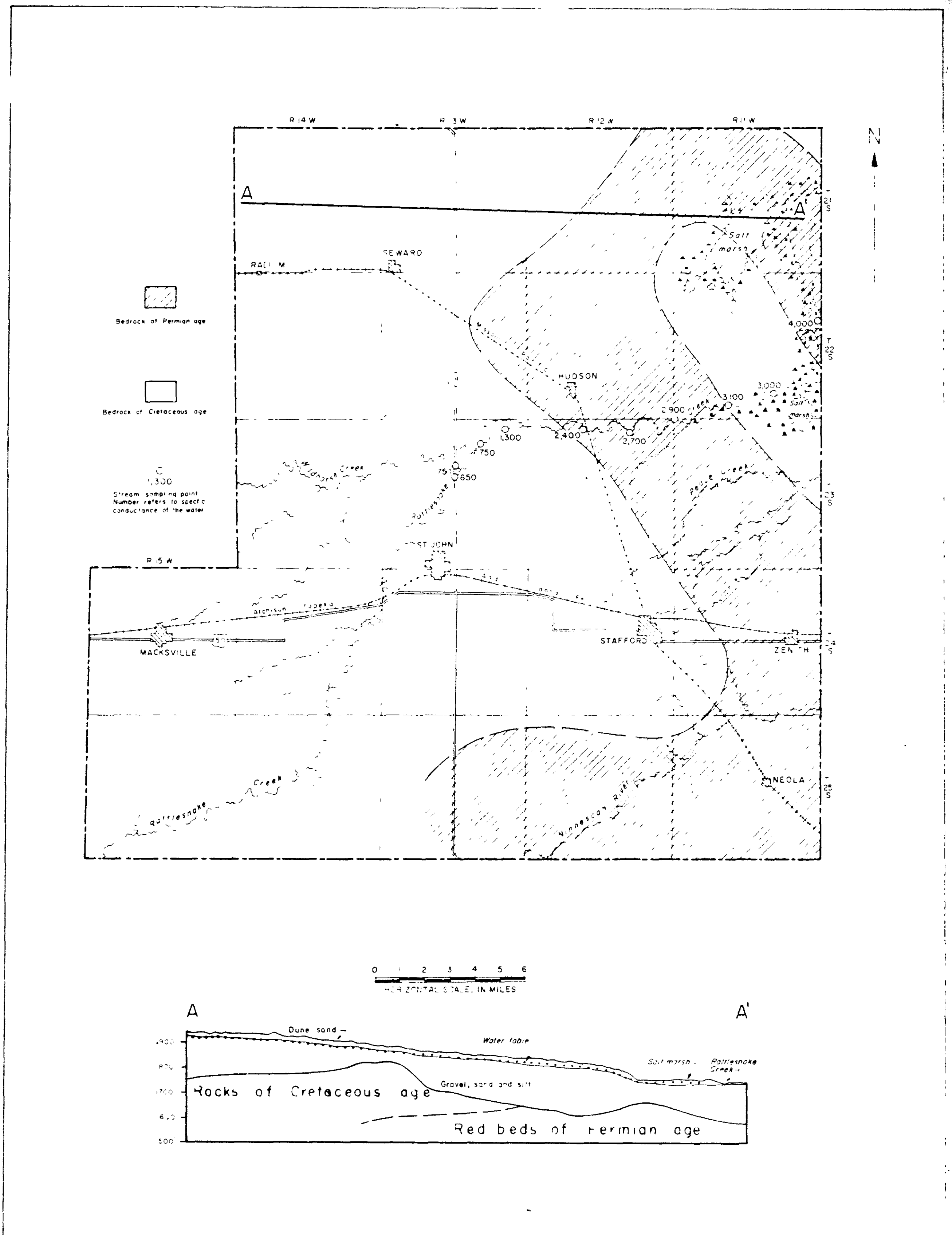
The major salt plains and spring areas are discussed individually in the following section. They are described as they occur geographically from north to south; therefore, those in the Arkansas Basin are described first.

ARKANSAS RIVER BASIN

Rattlesnake Creek

The northernmost area of significant natural salt pollution in the Arkansas River basin is along Rattlesnake Creek in Stafford County, Kansas. Due to the entrance of saline ground water into Rattlesnake Creek the chloride content in the creek is generally less than 50 ppm but where the creek flows out of the county the chloride content often exceeds 1,000 ppm. Chloride is added to the Arkansas River by the creek at an estimated rate of 300 tons per day.

Rattlesnake Creek is a meandering stream that has reached temporary base level. The valley ranges in width from less than one-half to about 2 miles and is bordered by low bluffs of dune sand. Marshland occupies much of the valley and there are two salt marshes near the eastern side of Stafford County (fig. 6). The largest salt marsh covers about 16 square miles in T. 21 S., R. 11 W. The smaller marsh is 6 miles southeast of the larger one. It covers an area of about 1 mile in the southeast corner of T. 22 S., R. 11 W. The small



Modified after ... 1953

Figure 6.--Approximate distribution of bedrock in Stafford County, Kansas, and water conductivity in Rattlesnake Creek on November 19, 1959.

marsh has no natural outlet; however, the flow of Rattlesnake Creek is diverted occasionally through the marsh by means of a dredged ditch. The intermittent overflow from the big marsh passes through a small tributary to Rattlesnake Creek. Evaporation from the marshes tends to concentrate the salinity of the water. A sample of water collected on October 10, 1942, from a drainage ditch on the east side of the big marsh had 4,060 ppm of chloride. A sample collected from the same site on July 10, 1944, contained 5,900 ppm of chloride (Latta, 1950, p. 135).

The Rattlesnake Creek valley is covered with alluvium and the marshes are underlain by marsh deposits. The remainder of Stafford County is covered with dune sand except for areas in the southwest and southeast that are covered by older deposits of unconsolidated gravel, sand, and silt. Beneath the mantle are rocks of Cretaceous and Permian ages. In general the western part is underlain by Cretaceous rocks and the eastern part is underlain by Permian rocks.

Rattlesnake Creek picks up nearly all its dissolved salt load as it traverses the area that is underlain by rocks of Permian age (fig. 6). This indicates that the mineralized water originates from the Permian rocks. Latta (1950), however, states that both the Permian and the Cretaceous rocks contain mineralized water that, when under greater head than the fresher water in the overlying unconsolidated materials, moves upward into them and tends to concentrate at the base of the unconsolidated deposits. Latta states further that a high bedrock ridge trending perpendicular to the direction of movement of ground water forces the mineralized water to the surface in northeastern Stafford County. In either case, the area where the mineralized water comes to the surface is restricted to the northern part of Stafford County but the rocks containing salt water are widespread.

Great Salt Plain

The Great Salt Plain in Alfalfa County, Oklahoma, is a large low-lying, flat, depressionlike alluviated plain that remains covered with a thin crust of salt except during rainy periods (fig. 7). It lies in the valley of Salt Fork Arkansas River into which it drains (fig. 8). A dam constructed across the river just below the plain forms a shallow lake over part of the plains. The plain has an area of about 60 square miles and lies principally in Tps. 26 and 27 N., R. 10 W. The Hennessey shale, which is composed of silty shale and fine-grained sandstone underlies the alluvial sand. The Great Salt Plain basin has probably been formed by a combination of collapse of the Hennessey resulting from the removal of salt and from stream erosion.

No springs are visible either on the plain or around its margin, and no streams flow across it except in wet weather. The alluvium is composed of fine sand and silt which remains saturated with salt water to within inches of the surface. Water collected from a hole dug to a depth of 2 feet in the plain on May 14, 1959, had a chloride

Figure 7.--Great Salt Plain, Alfalfa County, Oklahoma.

Figure 9.--Wind-blown salt in a small hole dug in the Great Salt Plain, Alfalfa County, Oklahoma.

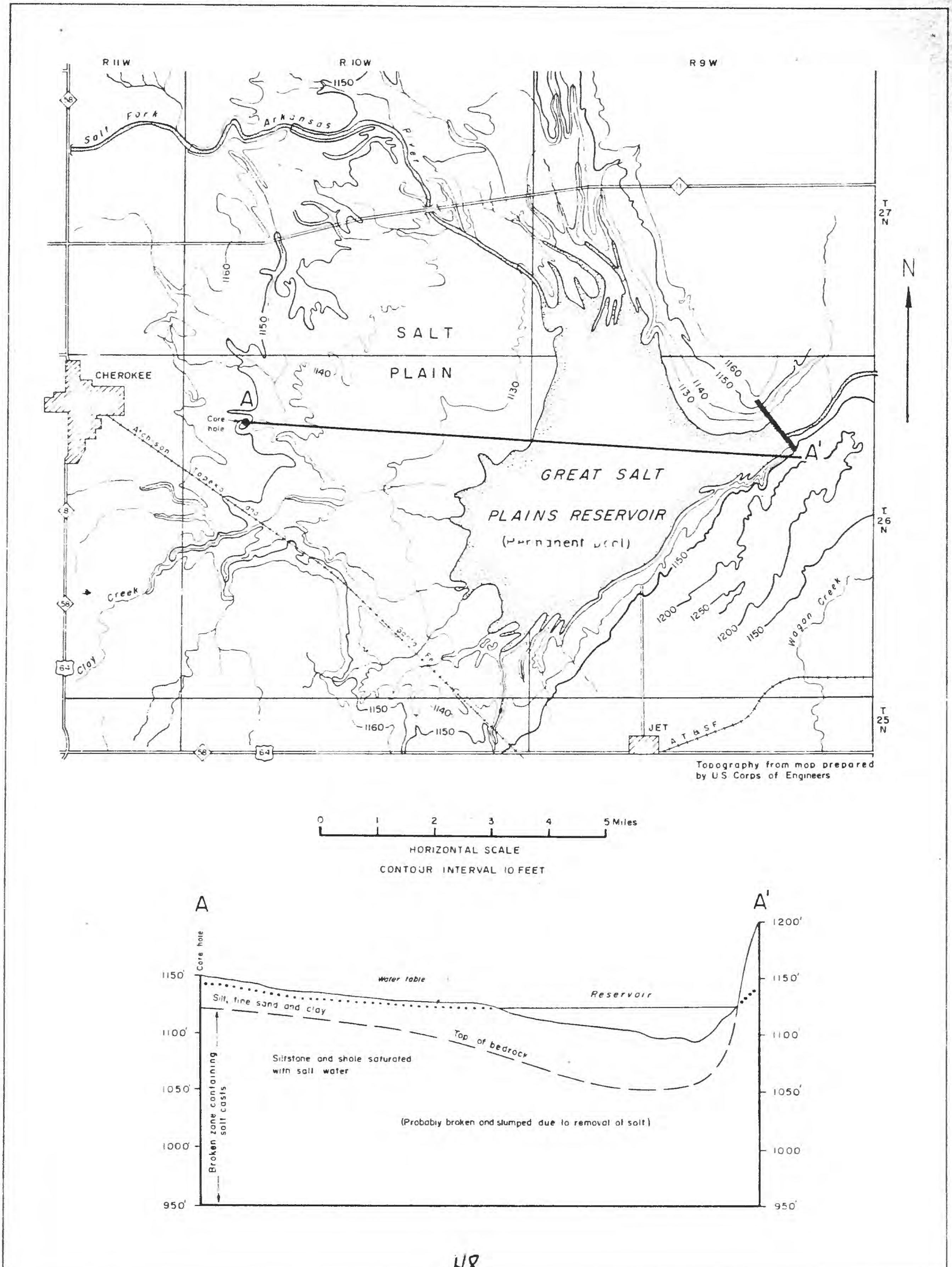


Figure 8.--Map and interpretative cross section of the Great Salt Plain area, Alfalfa County, Oklahoma.

concentration of 114,000 ppm. When the hole was visited about a month later it had filled to within inches of the surface with sand and wind-blown salt (fig. 9). Shallow wells near the plain produce salty water although not as highly mineralized as that underlying the plain. Water from a well in the NE¼SW¼ sec. 30, T. 27 N., R. 10 W., was tested and found to contain 4,100 ppm of chloride and 2,960 ppm of sulfate.

Some of the ground water in surficial deposits of higher elevations probably percolates down to relatively shallow salt-bearing deposits and becomes salt laden. The salty ground water then flows slowly toward the low-lying plain where it seeps from the bedrock into the alluvium. The salt water in the alluvium flows into the Salt Fork Arkansas River carrying with it an estimated 2,000 tons of chloride per day.

An exploratory core hole was drilled to a depth of 204 feet in the NW cor. sec. 8, T. 26 N., R. 10 W., without finding salt (fig. 8). The hole passed through 28 feet of alluvial silt and fine sand before entering bedrock. Bedrock consisted mainly of red gypsiferous clay-shale and siltstone of the Hennessey shale. Between the depths of 50 and 180 feet the rock contained many salt casts, some of which measured more than 1 inch across. As a result of the removal of salt by ground water the strata containing the salt casts are characterized by zones that are severely fractured and broken. These strata, being in the Hennessey shale, are within the lower part of salt-zone A, and contain salt in other nearby areas where it is being dissolved slowly by ground water. It is this salt-laden ground water that is feeding the Great Salt Plain. Additional drilling is needed to substantiate the occurrence of shallow salt nearby, but plate 3 indicates that patches of shallow salt in zone A are within 70 feet of the surface in eastern Woods County. Similar patches of salt occur in Alfalfa County.

Big Salt Plain

The alluvial plain of the Cimarron River in parts of T. 27 N., Rs. 19 and 20 W., becomes covered with salt during dry periods and is termed the Big Salt Plain (fig. 10). During the summer the salt-incrusted area may extend for 8 miles or more along the river and range in width from less than half a mile to 2 miles. The widest part of the plain is near the confluence of Buffalo Creek and the Cimarron River. The south side of the plain is bounded by cliffs that rise almost vertically for about 100 feet. The cliffs on the north side are not nearly so steep and are about half a mile from the plain. For the most part the cliffs are capped by the Blaine gypsum and are underlain by the Flowerpot shale (fig. 11). The floor of the plain is almost flat except for a few meandering channels which are dry most of the time.

Small amounts of salt have been produced commercially from the salt plain for many years. Shallow depressions or ponds excavated in the surface of the plain are allowed to fill with brine. When the ponds are full the inflow is diverted and evaporation concentrates the water until the salt precipitates. When a layer of salt several

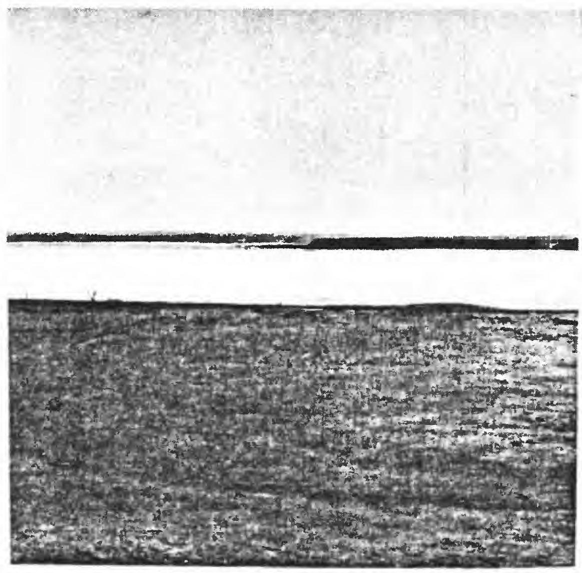


Figure 10.--Big Salt Plain in the Cimarron River valley between Woods and Woodward Counties, Oklahoma.

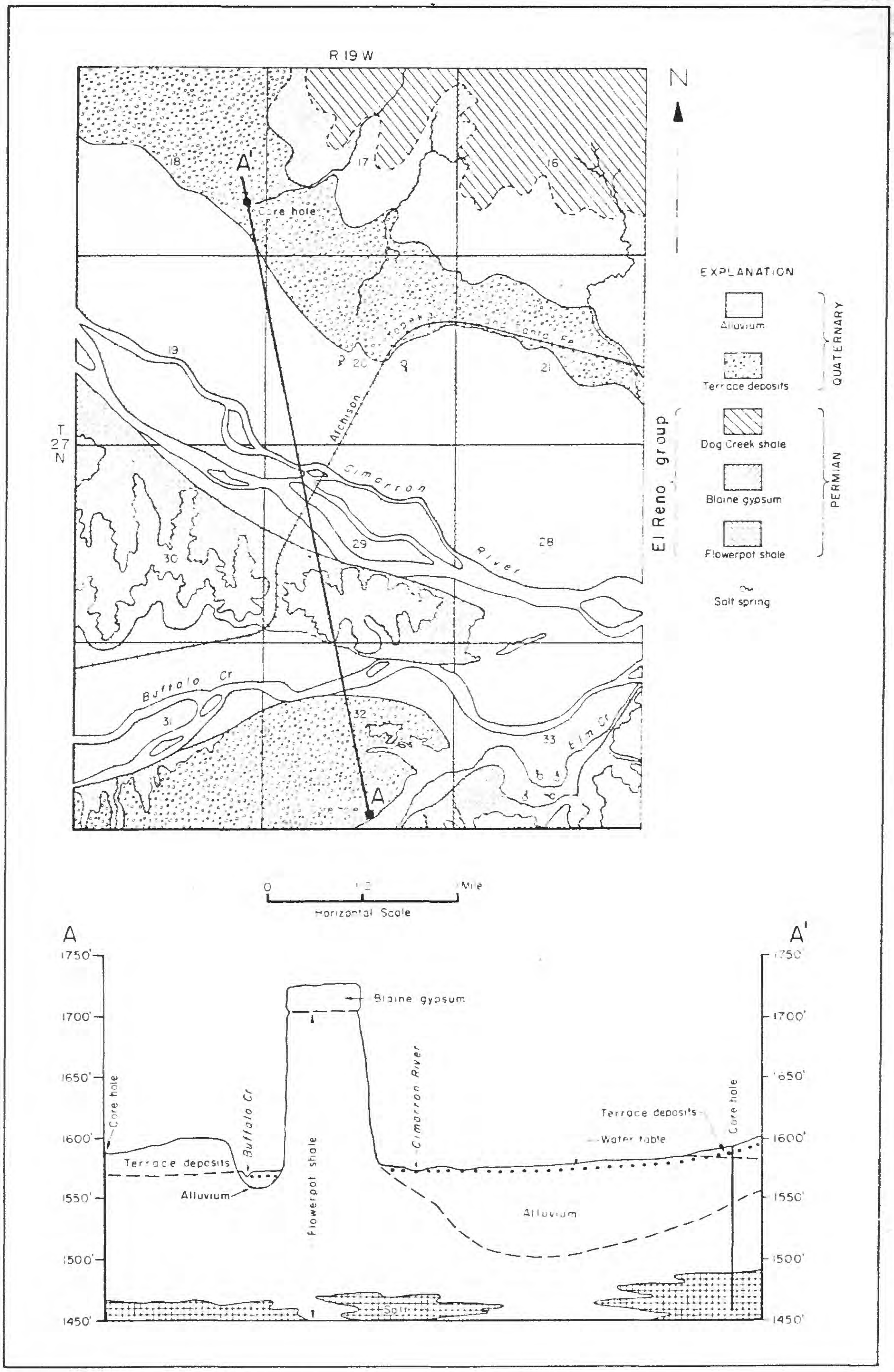


Figure 11.--Geologic map and interpretative cross section of the Big Salt Plain area, Woods and Woodward Counties, Oklahoma.

inches thick has formed on the bottom of the pond it is scraped out and dried. The salt is then ready for market. Most of it is purchased for use by livestock and in water softeners, although some of it is used locally by farmers and ranchers to kill weeds.

Salt springs are visible on the north and south margins of the plain, and along the banks of Buffalo Creek. A few seeps were observed bubbling up through alluvial sand on the surface of the plain. The U.S. Public Health Service estimates that the springs in the area contribute chloride to the Cimarron River at a rate of 1,600 tons per day. The visible salt springs do not account for the total salt load contributed to the river in the salt-plain area. An appreciable amount of salt is added by salt water seeping from the bedrock directly into the overlying alluvial sand and does not appear at the surface before it enters the river.

In 1960, the U.S. Corps of Engineers drilled a series of core holes on both sides of the plain. Several of the holes found salt and most of them found salt water. The water level in a hole in the SE$\frac{1}{4}$ sec. 24, T. 29 N., R. 19 W., was 7 feet in June 1960. At a depth of 53 feet the chlorides were less than 10,000 ppm but increased sharply with depth. A hole in the SW$\frac{1}{4}$ sec. 33, T. 27 N., R. 19 W., was reported to have found brine that flowed at land surface.

The tritium in a water sample collected at a spring flowing from the Flowerpot shale on the south side of the plain indicated that the age of the water is less than 20 years. This is very young for ground water and suggests that the water has not migrated very far. Because water generally moves through shale at a slow rate the water likely would be considerably older than 20 years had it migrated over great distances.

It is concluded that circulating ground water continually dissolves salt from the Flowerpot shale in close proximity to the salt plain. Precipitation falling in the upland areas surrounding the plain readily recharges the ground water in the cavernous Blaine gypsum. Much of this ground water is discharged through springs near the base of the gypsum where it is exposed in stream cuts. A small part of the water in the Blaine seeps slowly downward through the underlying jointed and fractured salt-bearing Flowerpot shale where it becomes saturated with salt. The water returns to the surface at low elevations in the valley of the Cimarron River, driven by pressure exerted by the relatively high ground-water head in upland areas. The salty water seeps from the bedrock and saturates the alluvium; from there it enters the river.

Little Salt Plain

The Little Salt Plain is like the Big Salt Plain in many respects. It appears as a salt-incrusted patch of alluvium in the Cimarron River valley. The upper end of the plain is about 2 miles south of the Kansas border. The maximum width of the plain is nearly 1 mile and the length, depending on the dryness of the weather and the stream flow, varies between 2 and 3 miles. The bordering cliffs are considerably more subdued than those at the Big Salt Plain.

Bedrock is obscured on the north side by dune sand but on the south side are many exposures of the Blaine gypsum. Near the center on the south side of the plain several feet of the Flowerpot shale are exposed. Salty zones were observed in the outcropping shale a few feet below the base of the overlying Blaine gypsum, indicating that ground water in the Flowerpot shale is probably salty.

No salt springs have been observed at the Little Salt Plain. The salt water seeps from the Flowerpot shale into the alluvium beneath the land surface. The rate at which chloride is added to the Cimarron River at the plain is estimated to be 100 tons per day. Because of the similarity, the discussion of the Big Salt Plain applies generally to the Little Salt Plain.

It is likely that salt water moves toward the river from both sides. The dune sand and terrace deposits on the north side and the gypsum on the south side could be the source of ground water that percolates down to the salt-bearing strata and thence into the alluvium. Residents in the vicinity report that a well drilled several years ago about 5 miles north of the plain produced "strong" brine from a depth of 60 feet. This indicates that some ground water, dissolving shallow salt deposits north of the plain, moves southward to the Little Salt Plain.

Turkey Creek

Turkey Creek, a tributary to the Cimarron River, picks up an undetermined quantity of chloride from a flat alluvial covered basin in Twps. 21 and 22 N., R. 8 W., in western Garfield County, Oklahoma (fig. 12). The area is referred to locally as the Drummond Flat. It is an abandoned lake bed of Pleistocene (?) age and is roughly 6 miles long by 4 miles wide. Turkey Creek flows southward into the basin in sec. 28, T. 22 N., R. 8 W., but about midway it changes course abruptly to the northeastward and leaves the basin in sec. 27 of the same township. All drainage from the lake enters Turkey Creek. On May 17, 1961, the chlorides in the creek where it enters the lake was 77 ppm and where it leaves the lake the chloride content was 570 ppm. Although it had rained a short time before and streamflow was relatively high a small amount of salt was visible along the banks of Dry Salt Creek in the south-central part of the basin.

The Quality of Water Branch, U.S. Geological Survey, collected water samples intermittently from 1951 to 1959 from Turkey Creek below Drummond Flat. The chlorides during that period ranged from a few to 2,790 ppm.

The source of the salt water has not been determined but it probably moves into the lake deposits from the underlying Permian rocks and thence to the surface in the low-lying basinal depression. Local residents report that salt water underlies the central portion of the basin at depth of less than 5 feet.

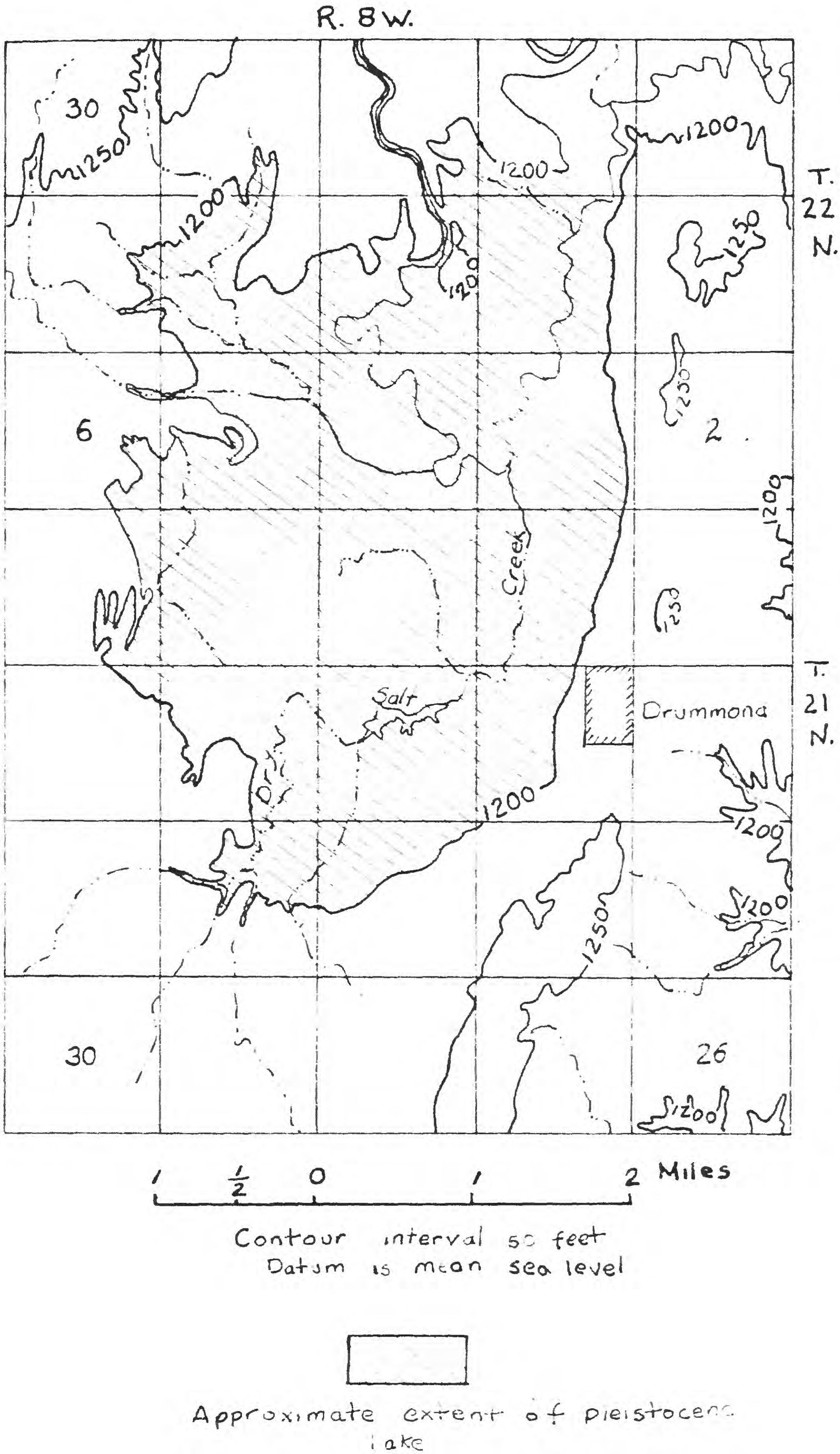


Figure 12.--Map of the Drummond Flat area in Western Garfield County, Oklahoma.

Salt Creek

(Blaine County, Oklahoma)

Salt springs in north-central Blaine County, Oklahoma, are near the head of two small tributaries of Salt Creek in the east-central part of T. 18 N., R. 12 W (fig. 13). The streams head at the base of a steep eastward-facing escarpment that is capped by the Dog Creek shale and the Blaine gypsum and is underlain by the Flowerpot shale. Stream erosion has cut short, narrow, steep-sided canyons into the face of the escarpment. Water in the extreme upper reaches of the two streams is fresh and originates from surface runoff and wet-weather springs. A short distance downstream salt water seeping from the Flowerpot shale raises the chloride content in the creek from a few parts per million to 10,000 ppm or more depending upon the volume of fresh water flowing from higher elevations. Farther downstream the stream gradient lessens and the valley floor is covered with a thin layer of alluvial sand. Salty stream water saturates the alluvium and evaporation from the alluvial surface concentrates the salt causing it to precipitate. The result is that the alluvial plain becomes veneered with a crust of salt. Chloride is brought to the surface in the area at an estimated rate of 100 tons per day.

In parts of Blaine County both the Blaine gypsum and the Flowerpot shale contain salt in the subsurface. A core hole in the southwest part of Blaine County in the NW$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 36, T. 14 N., R. 13 W., penetrated salt in the Blaine gypsum at a depth of 460 feet

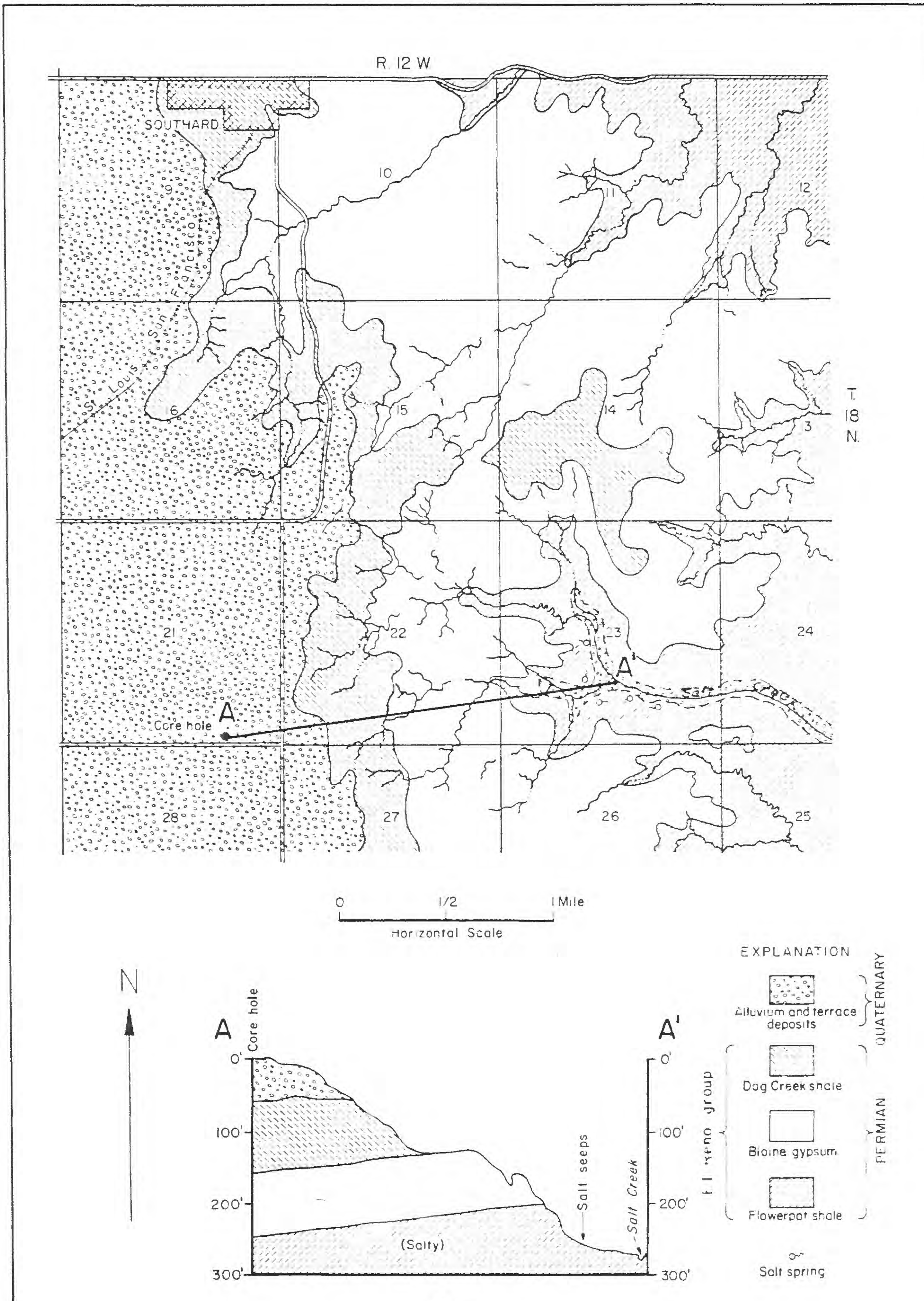


Figure 13.--Geologic map and interpretative cross section of the Salt Creek salt spring area, Blaine County, Oklahoma.

(elev., 1,106 feet). Considerably more salt was found beneath the Blaine in the underlying Flowerpot shale. An exploratory hole cored about 1 mile west of the salt-spring area in the SE¼SE¼ sec. 21, T. 18 N., R. 12 W., extended to a depth of 296 feet (fig. 13). The hole penetrated 52 feet into the Flowerpot shale but did not find salt. Salt is believed to be in the Flowerpot shale in the area but is probably at a lower depth. The broken vuggy appearance of the cores taken from the Flowerpot shale probably results from the removal of salt through solution.

The upland west of the spring area is covered with terrace deposits consisting of permeable unconsolidated sand and gravel. Precipitation falling on the land surface is readily absorbed by the terrace deposits thereby recharging the local water-bearing rocks. Much of the ground water is discharged along the face of the escarpment to the east through fresh-water springs. Some of the ground water circulates deeper and dissolves halite from the underlying Flowerpot shale. The salt water then circulates upward and discharges in the bed and along the banks of Salt Creek. The recharge area feeding the springs has not been determined but probably is not extensive.

RED RIVER BASIN

Boggy Creek

The salt springs in Beckham County, Oklahoma, are located 2½ miles south of Carter in the valley of Boggy Creek, a tributary to North Fork Red River (fig. 14). Salt water issues from the base of

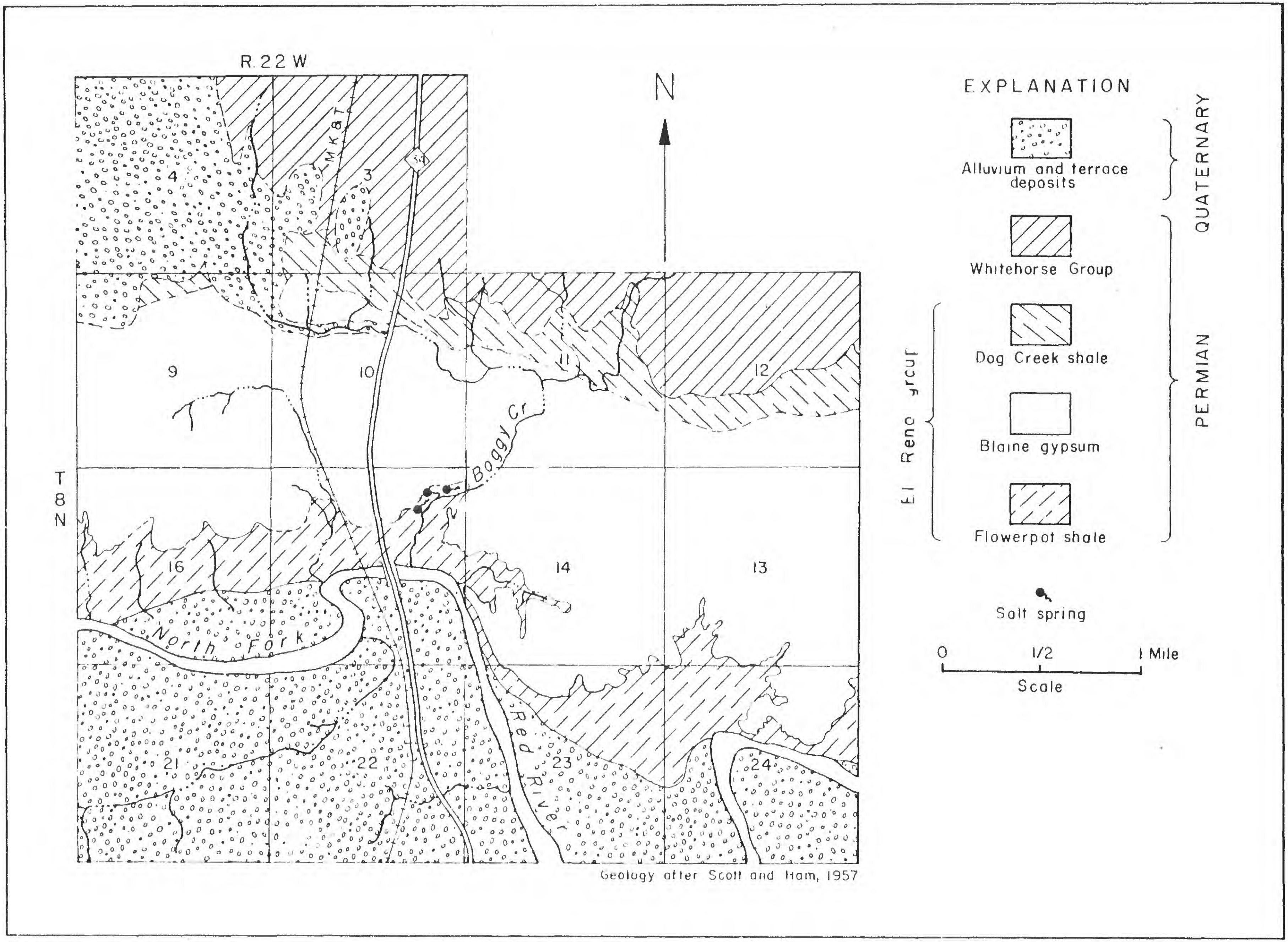


Figure 14.--Geologic map of the Boggy Creek salt plain area, Beckham County, Oklahoma.

the Blaine gypsum and saturates the sandy alluvium along the west and north sides of the creek for a distance of several hundred feet. Evaporation from the surface of the alluvial plain results in the formation of a thin salt crust. The salt-incrusted plain attains a maximum width of 400 or 500 feet. Salt springs were observed bubbling up from the plain's surface in several places. Salt crystals that form around the springs may attain a thickness of 3 or 4 inches (fig. 15). The discharge from these springs forms small streams that meander over the surface of the plain and empty into Boggy Creek. On August 1, 1960, the water in one of the larger springs had a chloride content of 64,000 ppm. On the same date the chloride content in the creek about 1 mile below the salt plain near its confluence with North Fork Red River was 1,650 ppm. The rate that salt is brought to the surface by the springs is unknown but probably does not exceed a few tons per day.

The source of the salt dissolved in the spring water is judged to be halite deposits in the Flowerpot shale. Salty zones in the Flowerpot shale crop out on the west side of Boggy Creek (fig. 16). The salt probably is dissolved by ground water and brought to the surface by water that has evaporated leaving a salt residue on the rock surface.

The spring-recharge area is unknown but may be small. Shallow deposits of salt are reported a few miles north of the area but salt is not known to be nearer the surface than about 500 to 600 feet near the spring area. If shallow salt is not present near the springs the

Figure 15.--Salt crystals around salt springs on the Boggy Creek salt plain, Beckham County, Oklahoma.

Figure 16.--Salty zone in the Flowerpot shale on the west side of Boggy Creek, Beckham County, Oklahoma.

the recharge area may extend for a considerable distance. However, shallow salt deposits are likely to occur nearby but this can be proven only by drilling. Because most of the salt seeps and springs are on the west and north sides of the plain it is likely that the salt water moves from those directions.

Elm Fork Red River

The salt springs in Harmon County, Oklahoma, are confined to three small canyons on the south side of Elm Fork Red River (fig. 17). The canyons are known locally as Kiser Gulch (SW$\frac{1}{4}$ sec. 11, T. 6 N., R. 26 W.), Robinson's Gulch (NE$\frac{1}{4}$ sec. 10, T. 6 N., R. 26 W.), and Salton Gulch (SE$\frac{1}{4}$ sec. 4, T. 6 N., R. 26 W). The canyons are eroded 200 feet below the upland surface through the Dog Creek shale and the Blaine gypsum and into the Flowerpot shale. The lower 100 feet of the canyons appear as inner canyons with nearly vertical walls. Salt springs bubble up through the narrow strip of alluvial sand and silt that covers the canyon floors. A few springs were observed issuing from the Flowerpot shale at the base of the canyon walls. The largest spring flows from a thin gypsum bed in the Flowerpot shale near the head of Salton Gulch.

Salt is being produced on a small scale in Salton Gulch by solar evaporation (fig. 18). Salt was produced in Kiser Gulch by heating the brine artificially but the process was not economical and the operation was abandoned.

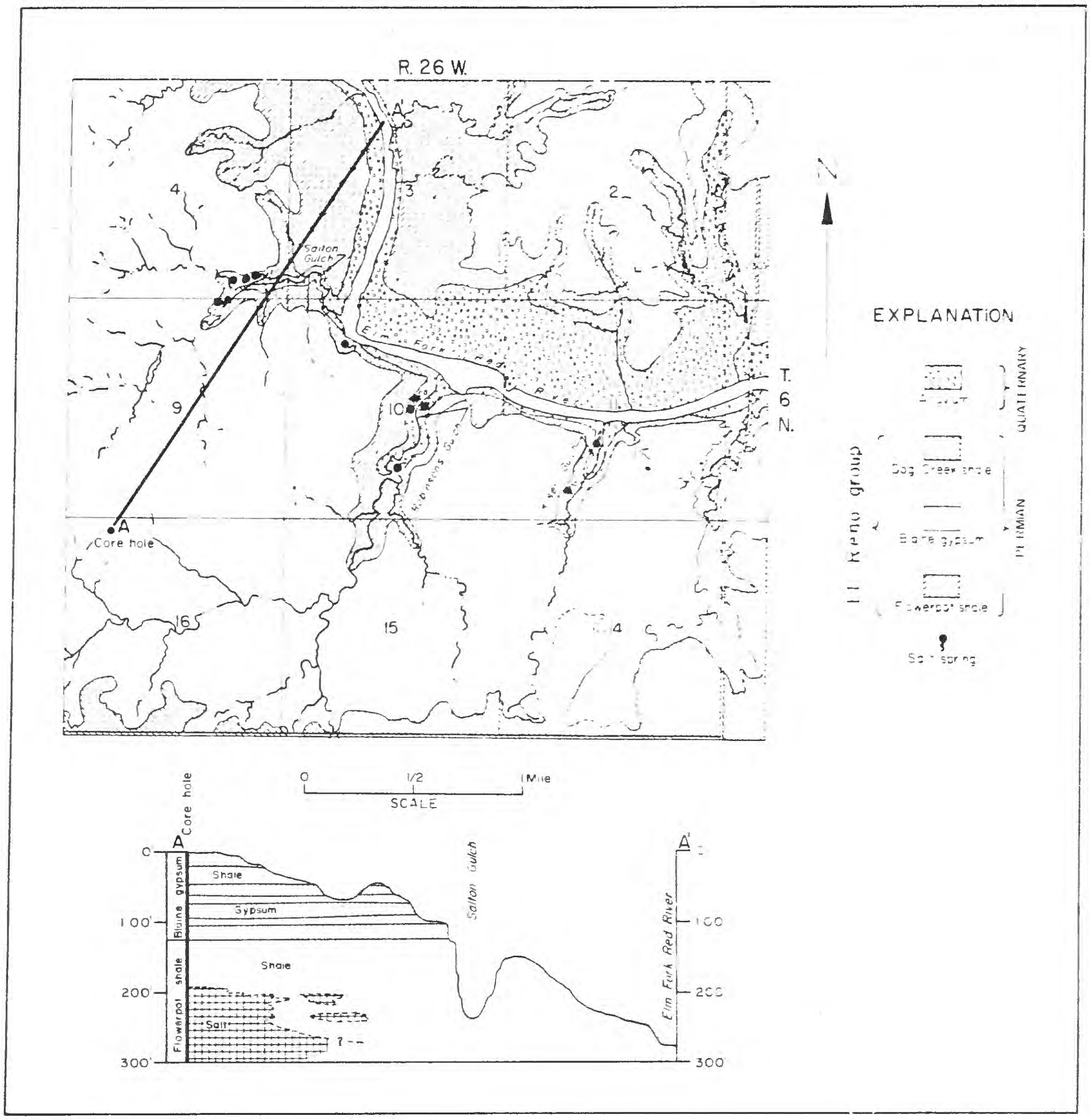


Figure 17.--Geologic map and interpretative cross section of the Harmon County salt-spring area, Oklahoma.

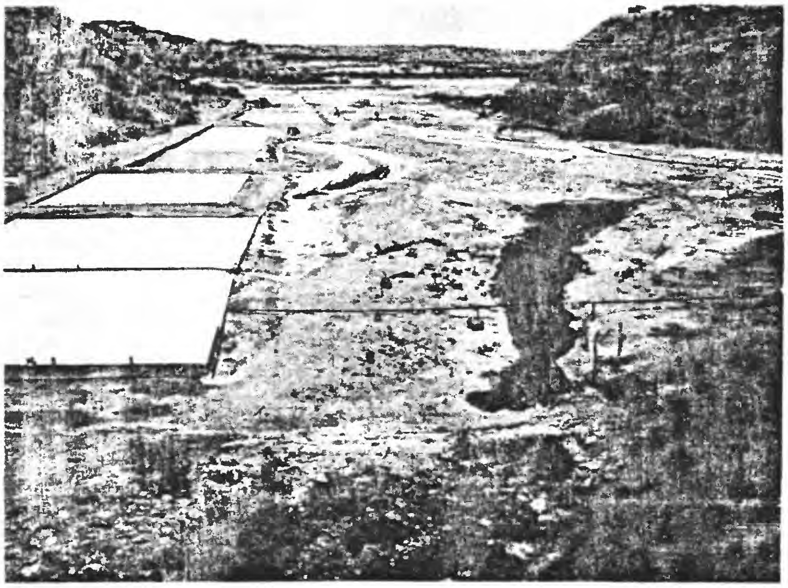


Figure 18.--Vats used in the production of salt by solar evaporation in Salton Gulch in northern Harmon County, Oklahoma. The spring in the right-hand side of the photograph had a chloride concentration of nearly 184,000 parts per million (ppm) in 1958.

The Flowerpot shale contains salty zones in places along the canyon walls. The salt probably is brought to the surface by ground water slowly moving laterally through zones in the shale that are slightly more permeable than the surrounding rock.

Chloride content in the springs sampled ranged up to 190,000 ppm. Chlorides are brought to the surface by springs in the three canyons at an estimated rate of 300 tons per day. Bloesch (1942) reported finding salt springs on the south bank of the river upstream from the canyons. The chloride load contributed by those springs was too small to measure when they were visited during the summer of 1958.

An exploratory core hole drilled about 1 mile southwest of Salton Gulch in sec. 16, T. 6 N., R. 26 W., penetrated a 3-foot shale zone at a depth of about 200 feet that contained salt crystals and solution voids. The upper few inches of the zone contains cubic-shaped voids that were formerly occupied by salt crystals. Several inches lower the voids are partially filled with salt. The lower part of the zone contains cubic crystals of salt but does not contain solution voids. At a depth of about 204 feet halite is interbedded with the shale. The empty and partially filled vugs suggest strongly that the salt is being removed through solution by ground water along the top of the salt-bearing beds. These beds doubtless are the source of the salt found in the springs in the canyons on the south side of Elm Fork Red River.

Local ground-water recharge is indicated by the tritium content of a water sample collected at a spring in Salton Guch. The analysis suggests that the age of the water is less than 20 years. If the water had traveled a great distance before coming to the surface, its age would be greater than that shown by the tritium.

The surface-drainage area tributary to the three canyons is less than 20 square miles. If the ground-water divide approximates the drainage divide, the ground-water basin too must be small. The massive beds of gypsum underlying the upland areas adjacent to the canyons contain numerous solution openings which are conducive to ground-water recharge. About $1\frac{1}{2}$ miles west of Salton Gulch numerous sinkholes have developed in an area covering nearly 2 square miles. Such openings favor a high rate of ground-water recharge, some of which must percolate through the underlying salt-bearing shale before returning to the surface.

Lebos Creek

Small salt seeps occur irregularly along Lebos Creek and its tributaries about 4 miles south of Eldorado in Jackson County, Oklahoma (fig. 19). No springs have been observed but during periods of dry weather a thin crust of salt and gypsum forms on sand bars and on the sandy alluvium along both sides of the creek. Some salt water apparently seeps directly from bedrock into the alluvium and does not appear at the surface before it enters the creek. The total flow of the seeps in the area probably does not exceed a few gallons per minute. The chloride content in a tributary to Lebos Creek in the $NE\frac{1}{4}$ sec. 6, T. 2 S., R. 23 W., was 10,500 ppm on September 23, 1958. The flow of the tributary at that time was only a trickle. The chloride in the water probably was concentrated somewhat by evaporation.

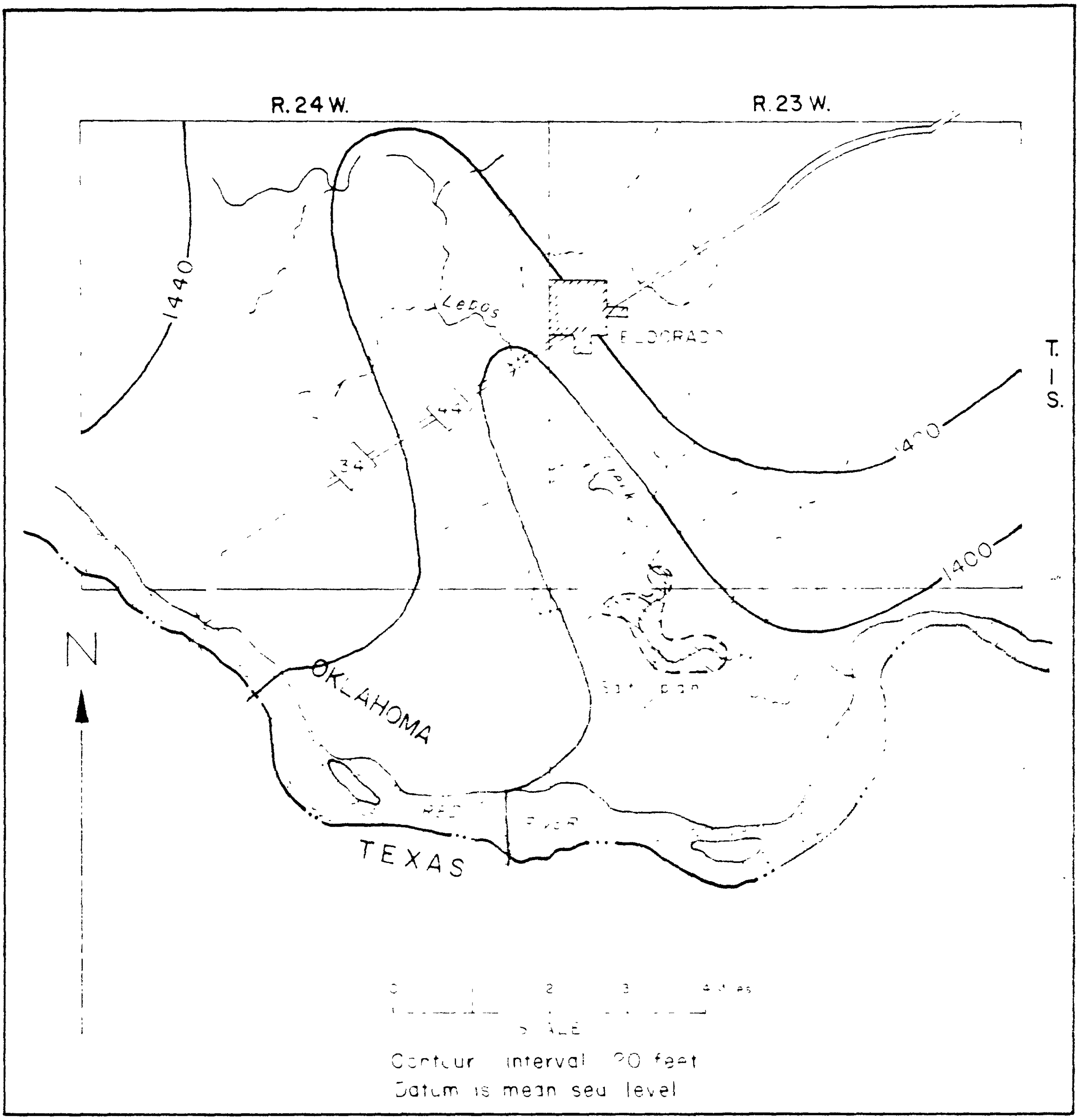


Figure 19.--Map of southern Jackson County, Oklahoma, showing the location of a small salt plain and the altitude of the water table in February 1954.

The topography in the area is rolling to flat and the slope from the uplands to the creek is gentle. The stream has cut through the Dog Creek shale which consists of red gypsiferous shale into the Blaine gypsum which consists of gypsum and gypsiferous shale.

The chloride in the water is dissolved from shallow beds of halite. Because shallow ground water occurs at higher elevation west and northwest of the springs and because surface drainage is southeastward, it is believed that the salty ground water causing the salt seeps moves from the northwest toward the seep area. The map (pl. 3) shows that halite is within 100 feet of the surface a few miles upstream in the northern part of T. 1 N., R. 24 W. This salt is in the lower part of the Dog Creek shale or the upper part of the Blaine gypsum. A well about 1 mile west of the salt-seep area in the NE$\frac{1}{4}$ sec. 1, T. 2 S., R. 24 W., found salt water at a depth of 86 feet. Salt water in the southwest corner of sec. 12 in the same township is 118 feet below the surface. Several other wells in the area found salt or salt water less than 200 feet below land surface.

Estelline Spring

In contrast to most salt-spring areas, which are characterized by numerous small springs and seeps most of the salt water in the Estelline area is brought to the surface through one relatively large spring. The spring is on the south edge of the alluvial plain of Prairie Dog Town Fork Red River about three-fourths of a mile east of the town of Estelline in Hall County, Texas (fig. 20). The flat

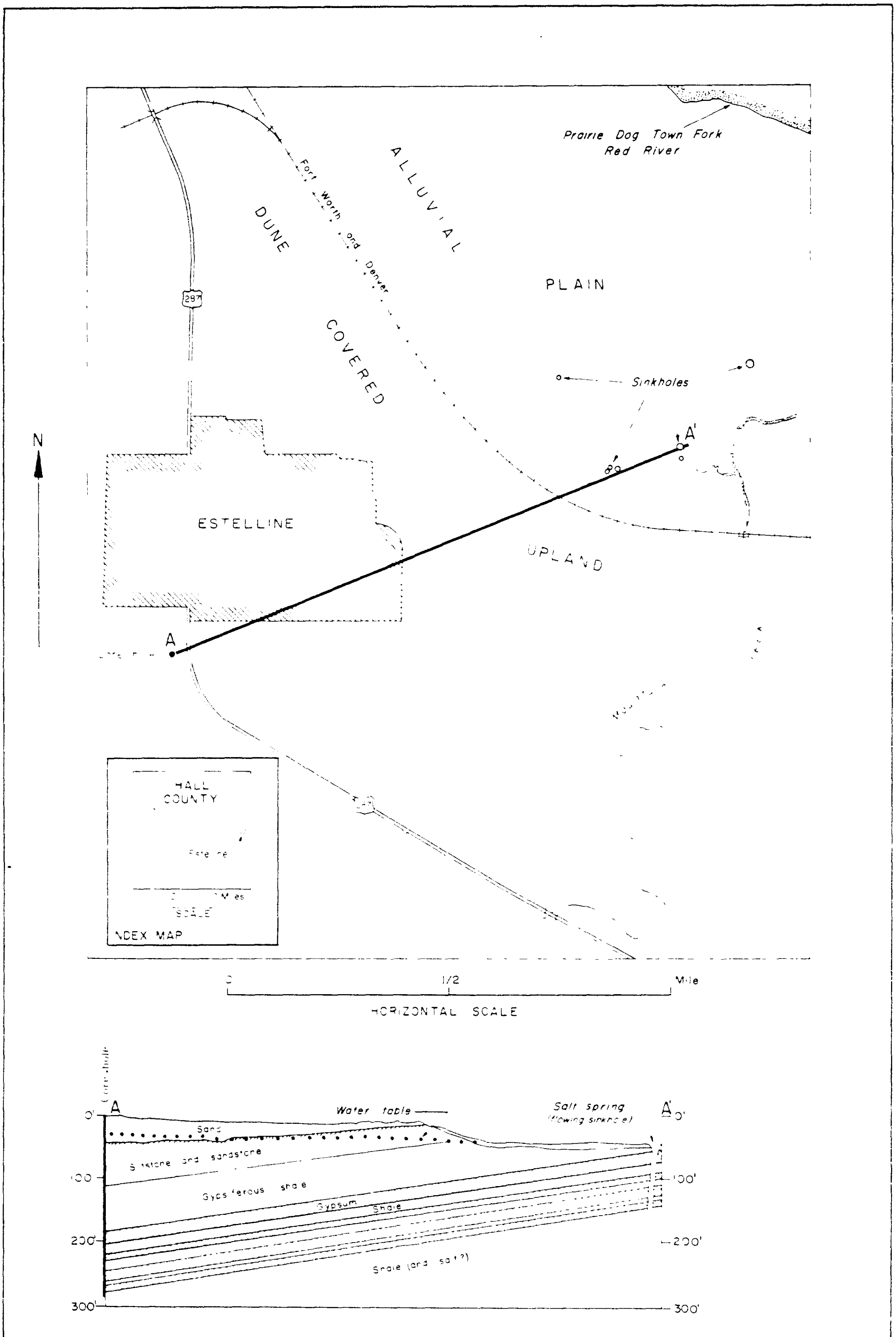


Figure 20.--Map and interpretative cross section of the Estelline Spring area, Hall County, Texas.

alluvial plain of the river in the vicinity is about 1 mile wide. The river is typically braided and the water courses are continually shifting from place to place on the plain. Land surface rises gradually away from the river. Bedrock south of the river is obscured in most places but at the edge of the alluvial plain immediately south of the spring gypsiferous Dog Creek shale crops out from beneath sand dunes. Gypsiferous shale and gypsum in the Whitehorse (?) group crop out in an extensive area north of the river.

Salt water at the spring site flows up through a deep sinkhole at a rate of 4 cubic feet per second (1,800 gallons per minute). The chloride content of the spring water averages about 28,000 ppm. Using that figure the rate that chloride is discharged into the river is about 300 tons per day.

The sink was created by collapse of beds into solution cavities developed in underlying massive gypsum layers in the Blaine. The sink is in the shape of a funnel with the mouth at land surface. The wide sloping part corresponds to that portion in alluvium and the neck corresponds to that portion developed in bedrock. The diameter at land surface is estimated to be 150 feet and the least diameter observable beneath the water is estimated to be 20 feet. Divers report that they are able to swim to a depth of 125 feet, below which the opening narrows to 4 feet or less.

Other sinks are visible on the alluvial plain nearby but do not flow because they are choked at the bottom with silt and clay. Some of the sinks stand full of water and the water in one, 400 feet southwest of the spring, had a chloride content of 4,000 ppm on February 10,

1959. That content is greater than that in the river but less than that in the spring and indicates that some salt water seeps upward through the rock debris filling the lower part of the sink. The standing water porbably is diluted either by rainfall or more likely by seepage of shallow fresh-ground water from the alluvium.

A core hole was drilled 1½ miles southwest of the spring to a total depth of 280 feet without penetrating salt beds (fig. 20). The shale interbedded with gypsum and anhydrite from a depth of 206 feet to the bottom of the hole had a salty taste. These beds probably are in the Blaine gypsum or its equivalent. It is not known if the salt in the shale is due to salt water migrating through the shale from some other source or whether it is halite dispersed in the shale as a primary constituent. The sink forming the spring extends through part or possibly all the beds penetrated by the core hole.

The ground-water head in the surrounding uplands is great enough to force water through the bedrock and then to the surface through the sinkhole. The source of the salt in the spring water may be salt in the shales penetrated but a more likely source is salt in underlying beds in the Flowerpot shale nearby. Regional studies indicate that salt-bearing deposits in salt-zone A are at higher elevations under the uplands both north and south of the river than they are near the river (pl. 3). Therefore, the salt in the water possibly may result from the solution of halite in rocks underlying the uplands a few miles from the spring.

Residents in the area report that a low earthern dike was constructed around the spring several years ago to create a swimming pool by deepening the water around the sinkhole. They also report that the spring stopped flowing when the water rose a foot above its former level, therefore the project was abandoned. No investigation was made to see whether or not the salt water broke out elsewhere in the area. The water could have entered the river easily through other sinks or solution passages in the underlying beds of gypsum.

Prairie Dog Town Fork
West of Estelline

Natural salt pollution occurring along the Prairie Dog Town Fork Red River west of Estelline, Texas, has not been studied by the writer. The main area or areas of pollution are thought to be in Briscoe and Armstrong Counties, Texas (fig. 1). Water samples collected periodically from the river indicate that chloride is added to the river west of Estelline at a rate of about 200 tons per day, but this figure will probably be revised as additional data are collected. The source of the salt has not been determined but probably is salt seeps or springs issuing from Permian rocks.

North and Middle Forks of the Pease River

Salt seeps are located in the river bed of the North and Middle Forks of the Pease River in north-central Cottle County, Texas. The river has cut its valley about 100 feet below the dissected upland surface into gypsiferous silty shale, gypsum, and dolomite in the Dog Creek shale and possibly the upper part of the Blaine gypsum. The valley floor is flat, is a quarter of a mile or more wide, and is covered with alluvial sand. Salt water seeps from bedrock at the base of the steep bluffs that commonly parallel the alluvial plain. A few seeps were observed issuing from bedrock a few feet above the river bed. In a few places where no springs or seeps are visible the alluvium becomes crusted over with salt indicating that in the near vicinity, salt water is seeping from bedrock into the alluvium beneath the land surface.

The river water upstream from the seeps is of relatively good chemical quality, but the flow isintermittent. The flow downstream from the springs is intermittent also but is of poor quality due to mixing with the spring water. The total chloride contributed by the springs is estimated to be in excess of 40 tons per day.

Conditions are favorable locally for ground-water recharge. The exposed gypsum contains solution openings and is fractured, therefore, it is capable of absorbing and transmitting appreciable quantities of ground water. The shale generally has low permeability but because it is fractured in many places it can absorb some precipitation. Some of the ground water that infiltrates locally percolates down to shallow salt deposits. The water dissolves as much salt as prevailing conditions allow and returns to the surface as salt springs at low points in the river valleys. The salt-bearing rocks are in the Blaine gypsum or Dog Creek shale and are equivalent, at least in part, to the rocks in the spring area along Salt Creek near the central part of Cottle County.

Salt Creek

(Cottle County, Texas)

Salt springs and seeps are scattered along Salt Creek in central Cottle County, Texas, from its junction with the North Wichita River to a point $2\frac{1}{2}$ miles upstream (fig. 21). The creek is eroded 100 feet below the gently undulating uplands through red beds in the Dog Creek shale and Blaine gypsum interval. A few salt springs occur along the south side of the North Wichita River for a distance of 3 miles below the Salt Creek junction, and a few occur above the junction. The chloride content in springs along the creek range from about 5,000 to 25,000 ppm, and the content in the springs along the North Wichita River range from about 300 to 5,000 ppm. The springs along the river tend generally to be progressively fresher in a downstream direction. Chlorides are brought to the surface by springs in the area at a rate estimated to be 150 tons per day.

All the springs observed flow from thin-bedded, blocky, gray dolomite beds having an average thickness of 13 feet. The dolomite is underlain and overlain by silty blocky gypsiferous shale. The shale above the dolomite contains numerous salt casts and in places is salty on the outcrop. The rocks throughout the Salt Creek vicinity exhibit complicated slump structure indicating that underlying

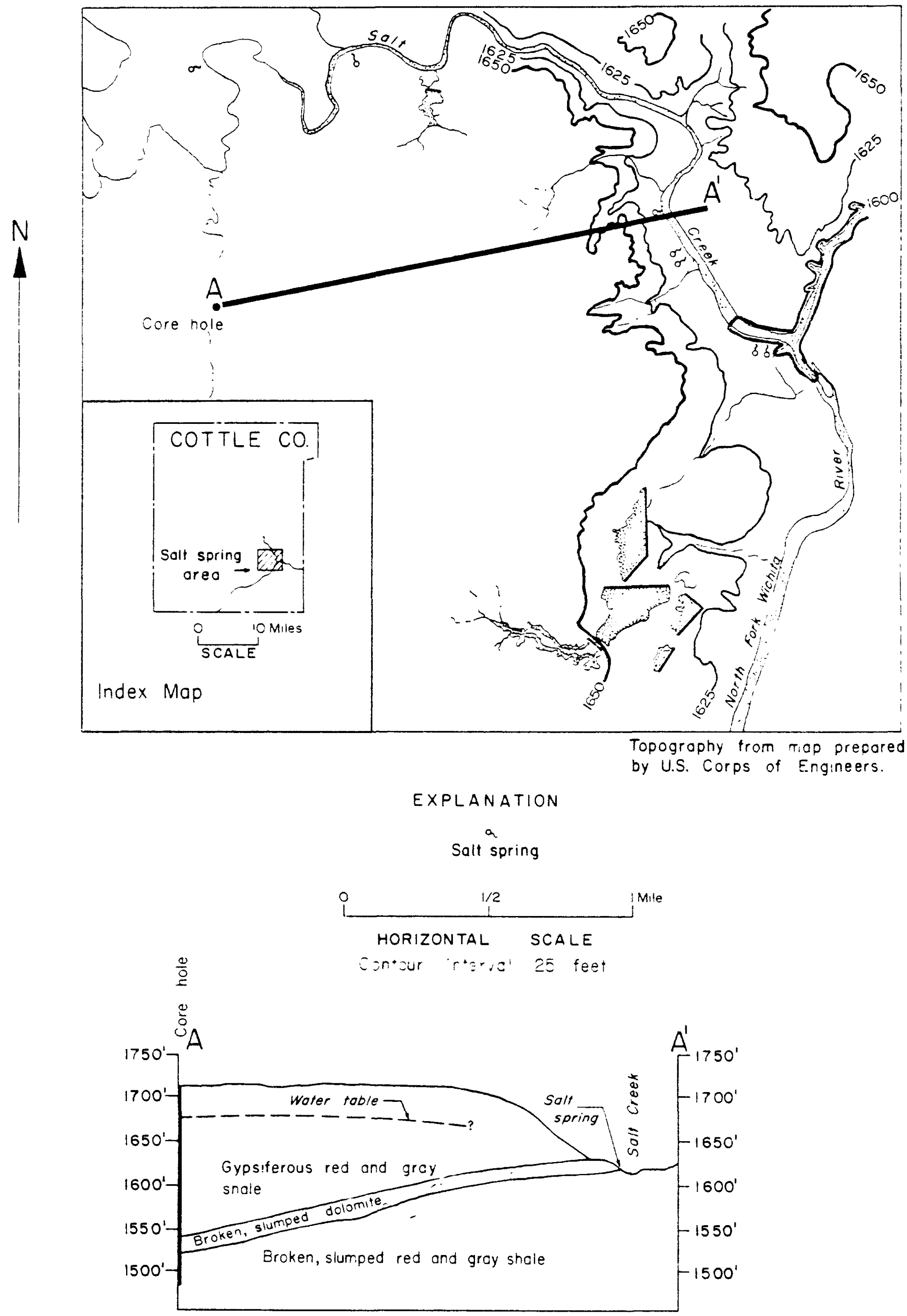


Figure 21.--Map and interpretative cross section of the Salt Creek salt-spring area, Cottle County, Texas.

materials, probably salt and gypsum, have been removed through solution. Solutioning is indicated also by sinkholes in the area. The dolomites from which the springs issue are severely slumped and broken. At places they are several feet above the water level in the creek and at other places they plunge beneath the creek only to reappear a short distance away.

The dolomite bed from which the major springs issue was found at a depth of 172 feet in a core hole drilled $1\frac{1}{2}$ miles southwest of the principal spring area (fig. 21). The shale beneath the dolomite is vuggy and slumped as it would if it contained salt which had been removed by solution. If this is correct,it is likely that the shale horizon contains salt elsewhere in the vicinity and that it is the source of salt in the spring water.

The elevation of the dolomite at the largest spring on Salt Creek is 1,620 feet and the elevation of the dolomite in the core hole is estimated to be 1,550 feet. This suggests a local westward dip of almost 50 feet per mile which may reflect slumping and local structure rather than regional dip. It is postulated that the salt-spring area has been elevated and that subsequent erosion has exposed part of the salt-bearing beds. The action of surface water has dissolved the salt from the outcrop and ground water percolating toward the stream has removed much or all the shallow salt from the subsurface for some distance back from the springs. The removal of salt by ground water has resulted in differential collapse of the overlying rock strata.

The salt springs are evidence that such removal is continuing. The upland southwest of the salt-spring area is covered with 30 feet or more of unconsolidated sand and silt. Precipitation falling on those deposits is readily absorbed and retained long enough to allow some water to enter the underlying fractured shale and dolomite and cavernous gypsum. As the ground water circulates deeper it dissolves salt from the rocks and returns to the surface along Salt Creek. The water table in the unconsolidated rocks is high enough to force water to the surface along the creek, but whether or not that ground water is hydraulically connected to the spring water is conjectural. Local residents report that salt water is relatively shallow throughout the Salt Creek area. Water flows readily through the dolomite because it is thin bedded and broken thereby affording relatively easy passage for water compared to the relatively impervious overlying and underlying shaly beds. Local ground-water recharge is indicated by the tritium analysis of a water sample from a salt spring on the southwest side of Salt Creek. The analysis indicates that the spring water is made up of a considerable amount of post-1954 water.

Middle Fork Wichita River

Salt seeps occur along a 6-mile stretch of the Middle Fork of the Wichita River in the northeast corner of King County, Texas. In this area the river has excavated a valley about half a mile wide and 100 feet deep through the lower part of the Dog Creek shale and into the Blaine gypsum. The valley floor is flat and is covered with alluvial sand over which the river meanders. The salt seeps are scattered widely and are ill defined. In a few places seeps were observed emerging from gypsiferous shale at the base of the vertical cliffs that commonly define the margin of the alluvial plain. The seeps are easiest to locate in dry weather because of the tell-tale crust of salt that is left on the sand. Analyses data of the water from a few of the seeps show chloride content ranged between 10,000 and 25,000 ppm. The amount of chloride reaching the river in the area is estimated to be 40 tons per day.

It is presumed that the salt in the seeps is dissolved from halite deposits in the Dog Creek shale or the Blaine gypsum under the uplands on either side of the river. The salt probably is discontinuous and lenticular. Its distribution can be defined only by a drilling program.

Broken shale, gypsum, and dolomite underlying the uplands probably receive enough recharge locally to maintain the flow of the salt springs and seeps. The direction of ground-water flow is unknown but may reflect the slope of the land surface. If so, the ground water moves in a downstream direction and from points of higher elevation bordering the valley to points of lower elevation in the river valley.

South Fork Wichita River

Small salt springs and seeps occur irregularly along about a 2-mile stretch of the South Wichita River from about 4 miles to 6 miles east of Guthrie in King County, Texas (fig. 22). The river

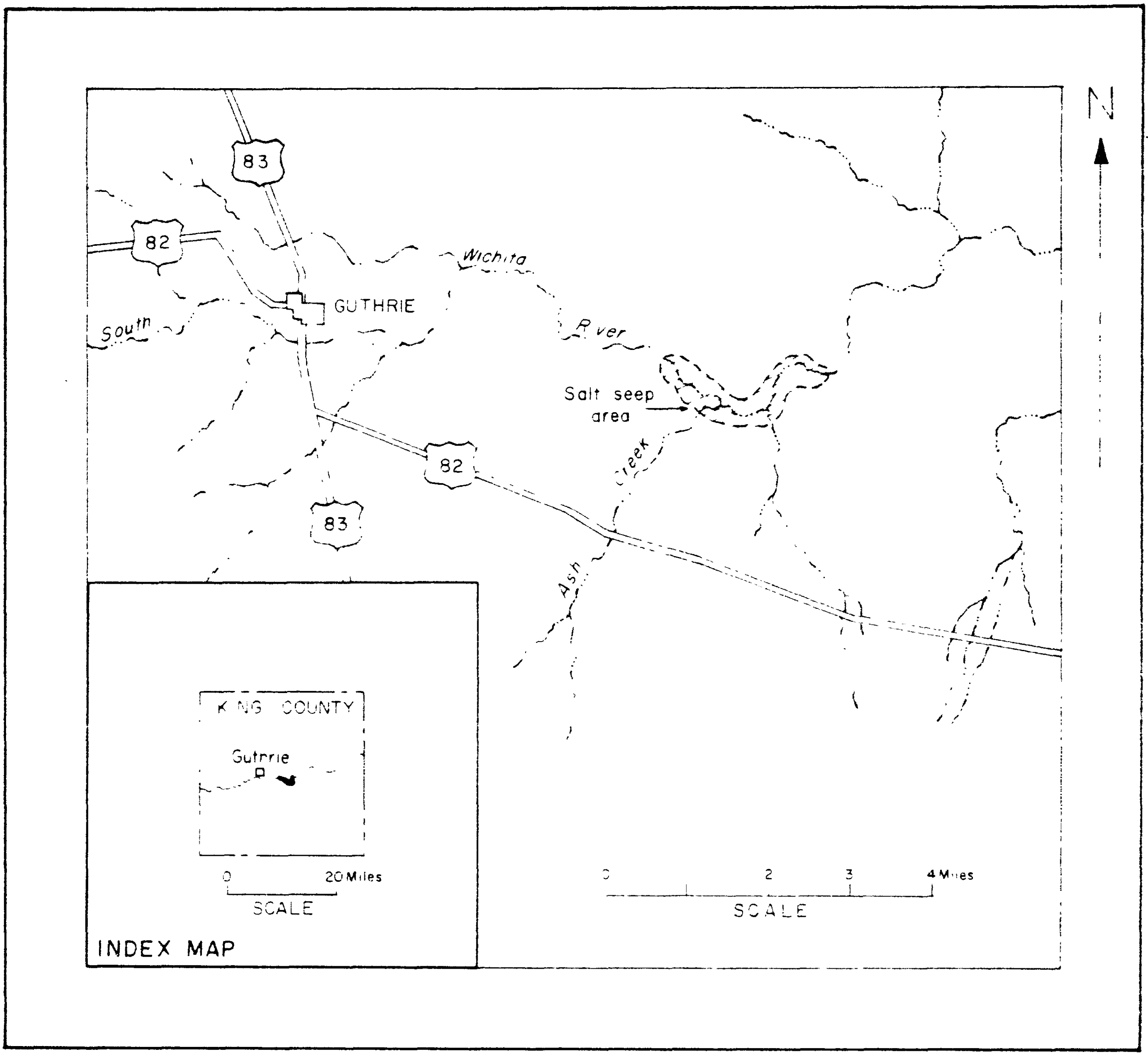


Figure 22.--Sketch map showing the salt-seep area on the South Wichita River, King County, Texas.

has eroded a narrow steep-walled canyon into the Dog Creek shale and Blaine gypsum that consist of massive gypsum beds, gypsiferous shales and dense, fractured dolomites. The salt springs emerge at the base of the cliffs near the river's edge. During dry periods the thin strip of alluvial sand paralleling the river becomes crusted over with salt (fig. 23). The chloride content of the springs examined ranged between 10,000 and 25,000 ppm. It is estimated that the springs bring about 100 to 150 tons of chloride salts to the surface daily.

A core hole was drilled about 1 mile south of the river, 4.2 miles east and 1.3 miles south of Guthrie, to a depth of 289.6 feet. Salt was found in the hole in dolomite between the depths of 246.3 feet and 248.5 feet. Thin discontinuous stringers of salt probably occur beneath the uplands throughout the area. Inasmuch as the majority of the salt springs are on the north bank of the river more salt may be on that side than on the south side. Thicker and more extensive salt deposits occur west of the salt-spring area (pl 3). A relationship between that salt and the salt springs has not been established.

Broken dolomite and weathered gypsum crop out on upland surfaces in many places. Both rock types are capable of absorbing appreciable quantities of precipitation; thus, conditions for ground-water recharge are favorable. Conditions conducive to recharge are indicated by the occurrence of sinkholes in the area.

Figure 23.--Salt-incrusted alluvium along the south bank of the South Wichita River in central King County, Texas.

All the water wells in the town of Guthrie are reported to produce brackish water unfit to drink. The slope of the land surface suggests that part of that water moves eastward toward the Wichita River to help maintain the flow of the salt springs. It is concluded that the salt content in the spring water is dissolved from salt deposits by ground water migrating toward the river from the north, south, and west.

SUMMARY AND RECOMMENDATIONS

Halite (NaCl) underlies a vast region in the Arkansas and Red River basins in southwestern Kansas, western Oklahoma, and northwestern Texas including the Texas Panhandle. In several places the halite is within 200 feet or less of land surface. Where the salt is shallow and geologic conditions are favorable, water circulates beneath the ground to the salt-bearing beds and dissolves large quantities of salt. At places, in the topographic lows, some of the salt water emerges at the surface to form salt springs or plains. The flow of these springs is small but because the water is highly mineralized it has a pronounced effect on the quality of water in the streams. Salt springs and plains bring more than 8,000 tons of sodium chloride to the surface daily in the two rivers.

Reconnaissance studies of the geology around some of the springs indicate that local structure may have some influence on the occurrence of the springs. The surface and subsurface geology of the areas should be mapped in detail to determine the importance of local structure and lithology. The areas mapped should include the major areas of recharge for the springs.

Additional studies and careful planning are necessary to devise the best means possible to eliminate or appreciably alleviate the natural salt pollution. One or more pilot projects may be feasible to test the practicability of remedial measures that are suggested or selected. The recharge area of each spring locality should be determined accurately and the direction of movement of the water toward the spring should be established. It would be desirable to establish the relationship between the various springs within a spring area. The variability of spring flow and the variability of the chloride content of the spring water should be determined and the variance related to natural phenomena such as seasonal and short-term precipitation patterns and streamflow.

The success of remedial measures will depend on accurate knowledge and understanding of hydrologic features of pollution sources. That information can be obtained only by conducting intensive and detailed hydrologic and geologic studies of spring areas.

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UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SUPPLEMENT

GEOLOGY AND GROUND-WATER FEATURES OF SALT SPRINGS IN NORTHERN HARMON COUNTY, OKLAHOMA

By Porter E. Ward

Prepared in cooperation with the

U.S. Public Health Service

Administrative report

For U.S. Government use only

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GEOLOGY AND GROUND-WATER FEATURES OF SALT SPRINGS IN NORTHERN HARMON COUNTY, OKLAHOMA

By Porter E. Ward

ABSTRACT

The source of the salt dissolved in the salt springs in Harmon County, Oklahoma, is halite in the Flowerpot shale of Permian age. The halite was found to range from 30 to 197 feet below the land surface in the spring area. Ground water enters cavernous gypsum in the overlying Blaine gypsum west and south of the salt springs. Part of the water is discharged from fresh-water springs and part percolates into the Flowerpot shale, circulating deep enough to dissolve halite. Water in the Flowerpot shale thereby becomes salty and is discharged at favorable topographic lows forming salt springs.

INTRODUCTION

PURPOSE AND SCOPE

This investigation supplements the administrative report by Porter E. Ward entitled, "Geology and ground-water features of salt springs, seeps, and plains in the Arkansas and Red River basins of western Oklahoma and adjacent parts of Kansas and Texas."

The present study was made to define, in more detail than was possible in the regional administrative report, the geologic setting and the circulation of ground water at the salt-spring area in northwestern Harmon County, Oklahoma.

LOCATION AND EXTENT OF THE AREA

The salt-spring area described in this report is along Elm Fork Red River in northwestern Harmon, County, Oklahoma (fig. 1). The largest salt springs issue in three small canyons in the northeastern part of T. 6 N., R. 26 W (fig. 2). The canyons are eroded into rocks of Permian age. The rims of the canyons are cut through massive gypsum of the Blaine gypsum and the lower parts of the canyons are encised into red gypsiferous shale of the Flowerpot shale (Ward, 1961, fig. 17). The salt springs that flow from the Flowerpot shale in the bottom of the canyons are estimated to bring 300 tons of chloride to the surface daily. Smaller salt springs and seeps are along the banks of Elm Fork upstream and downstream from the canyons for a distance of about 2 miles, and along Bull and Elm Creeks.

METHODS OF INVESTIGATION

Most of the fieldwork upon which this report is based was done during the summer of 1961. Eight test holes were drilled under contract with cable-tool drilling rigs to obtain geologic and ground-water data. The core hole in section 16 was drilled by the Corps of Engineers during October and November 1960. To supplement the test-hole data, altitudes were obtained of the water level in stock

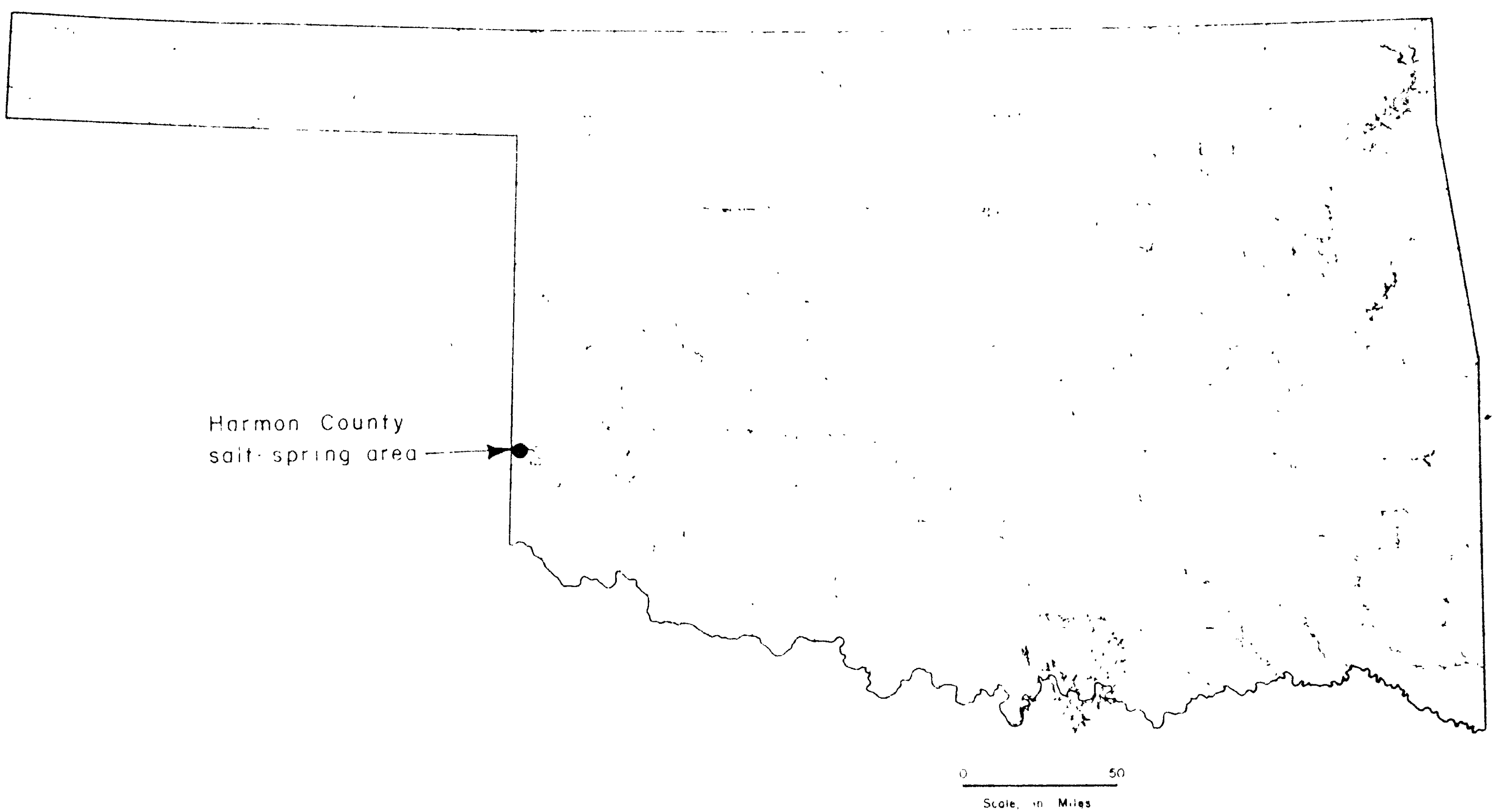

Figure 1 -- Map of Oklahoma showing the location of the Harmon County salt-spring area

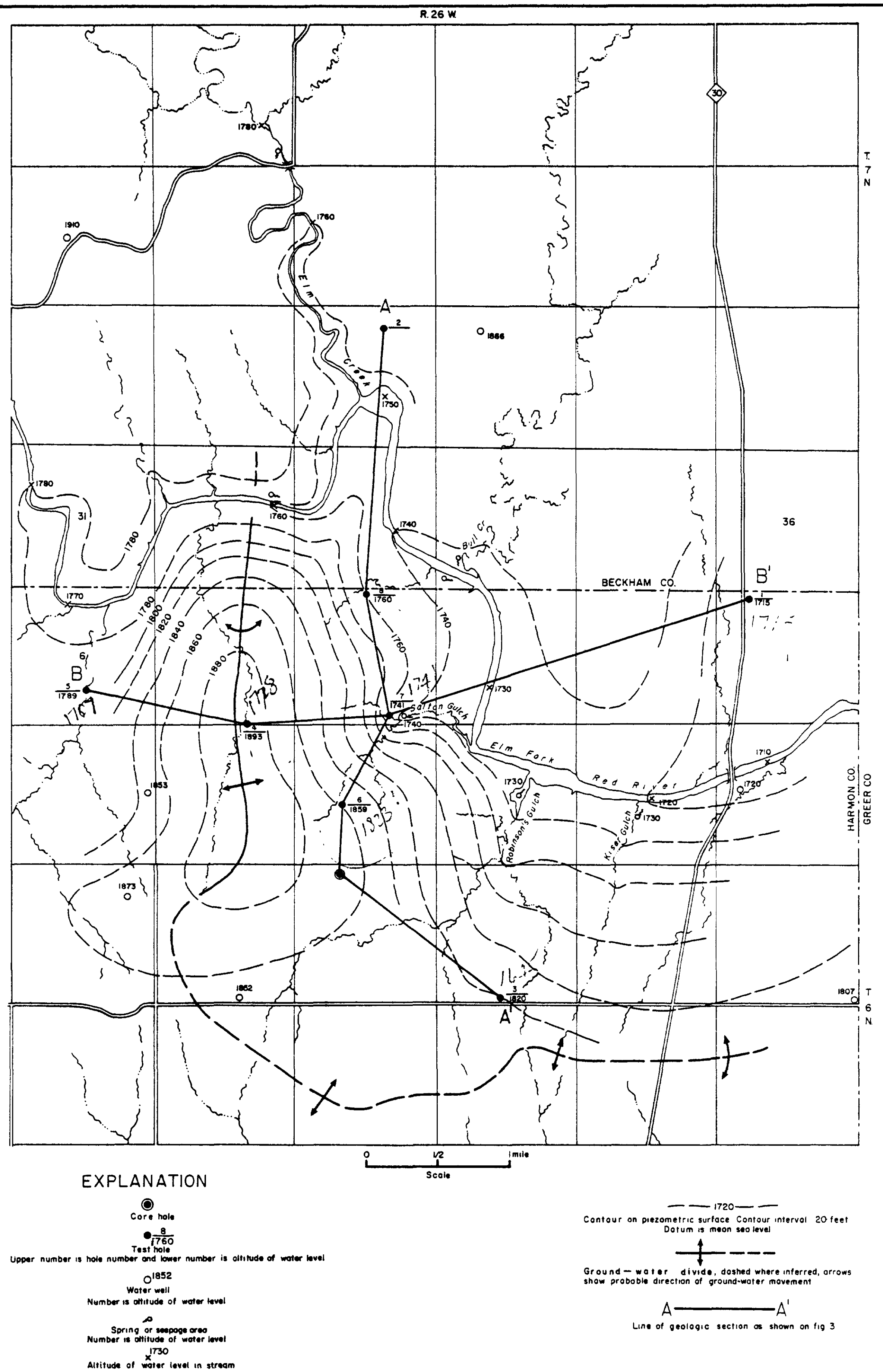

Figure 2.- Map of the Harmon County, Okla. salt-spring area showing the location of wells, core holes, and test holes and the altitude of the piezometric surface.

and domestic wells in the area. Stream altitudes were taken from the U.S. Geological Survey topographic map (Erick, S. W., Oklahoma, advanced print, 1959). Water samples were analyzed for chloride content by the Quality of Water Branch, U.S. Geological Survey.

GEOLOGY AND ITS RELATION TO GROUND WATER

PERMIAN ROCKS

Bedrock in the entire area is of Permian age (Ward, 1961, fig. 17). The formations exposed are, in ascending order, the Flowerpot shale, Blaine gypsum, and Dog Creek shale. The Dog Creek shale is not important to the present study and was not penetrated by any test holes, therefore it is not discussed in this report.

Flowerpot shale

The Flowerpot shale in the area consists principally of red and gray gypsiferous shale containing halite in the subsurface. None of the test holes penetrated the entire thickness of the Flowerpot but test-hole 2 started about 20 feet below the top of the formation and remained in it to the bottom of the hole, a depth of 220 feet (fig. 3).

Halite (common table salt) occurs commonly in the Flowerpot both disseminated in the shale and in lenticular beds. Three holes (test-holes 6 and 7, and the core hole) penetrated bedded salt and all the holes penetrated salty shale (table 1). Bedded salt (halite) was found at altitudes of 1,720, 1,725, and 1,764 feet above mean sea level and the depth below land surface was 30, 149, and 197 feet.

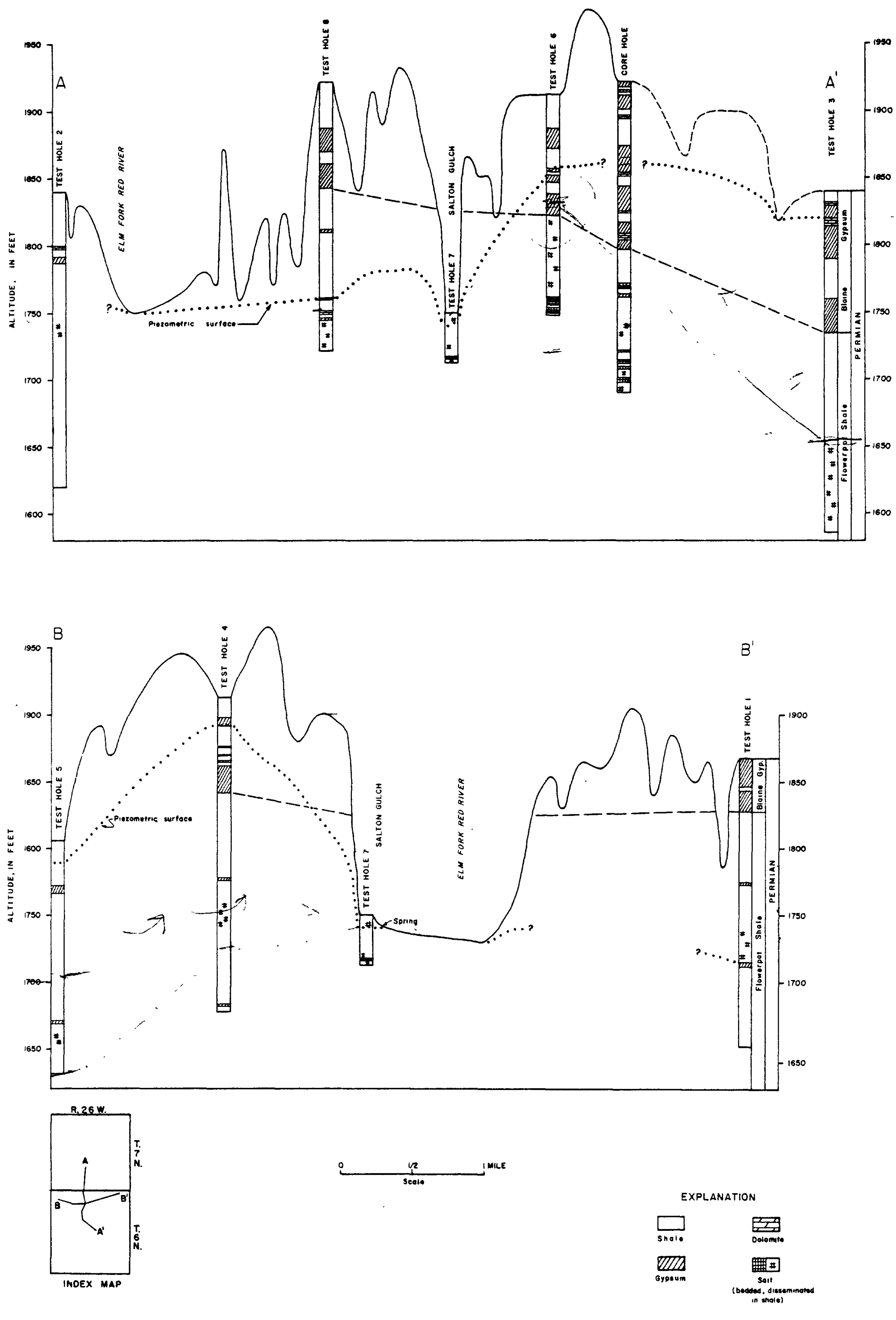

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Figure 3.--Geologic sections of the Harmon County, Okla. salt-spring area.

Table 1.--Test-hole data

(All figures are in feet. Altitude is height above mean sea level. Depth refers to land surface.)

Test hole			Fresh water		Salt water		Halite		Salty shale		Altitude of the top of the Flowerpot shale
No.	Altitude	Depth	Depth	Altitude	Depth	Altitude	Depth	Altitude	Depth	Altitude	
1	1,868	215	None	.....	163	1,715	None	.....	130	1,738	1,828
2	1,840	220	do.	.....	None[a]	.....	do.	.....	100	1,740	.....
3	1,840	255	20	1,820	195	1,645	do.	.....	195	1,645	1,735
4	1,913	235	20	1,893	185	1,728	do.	.....	155	1,758	1,843
5	1,807	175	18	1,789	100[b]	1,707	do.	.....	145	1,662	.....
6	1,913	170	54	1,859	90[c]	1,823	149	1,764	90	1,823	1,853
7	1,750	37	None	.....	9	1,741	30	1,720	9[d]	1,741	.....
8	1,923	200	do.	.....	171[e]	1,752	None	.....	150	1,773	1,843
Core hole	1,922	226	.....[f]	.....	.....	.....	197	1,725	180	1,742	1,799

[a] A small amount of water was indicated at a depth of 80 to 100 feet.

[b] Salt water rose from a depth of 175 to 100 feet.

[c] Owing to a small amount of fresh water leaking around the casing from the Blaine an accurate salt-water level was not obtained.

[d] Owing to caving and the abundance of salt water an accurate depth that salty shale was penetrated was not obtained.

[e] Salt water rose from a depth of 194 to 171 feet. [f] Owing to caving ground-water data were not obtained.

The 30-foot depth is in Salton Gulch where the surface altitude is 1,750 feet.

Salt water was found in the Flowerpot in all holes except test-hole 2 (table 1). It is not known whether salt water was present in the core hole because it caved. The salt water in test-holes 5 and 8 was under artesian pressure. In test-hole 5 salt water rose from a depth of 175 to 100 feet, and in test-hole 8 salt water rose from 194 to 171 feet.

The water of lowest mineral content found in the Flowerpot contained 152 ppm of chloride at a depth of 54 feet in test-hole 5 (table 2). At a depth of 170 feet in the same hole the water had 54,000 ppm of chloride. The chloride content rose sharply at a depth of about 160 to 170 feet; the water to that depth was relatively fresh and below that depth the water was noticeably saltier. Most likely the two waters mixed during drilling and bailing operations, therefore the chloride content of the water at depths below 160 feet probably is greater than that shown in table 2.

The Flowerpot, in some areas, contains a small amount of water between its contact with the overlying Blaine and the bottom of the test holes, suggesting that the two formations are connected hydraulically. The Flowerpot, although low in permeability, is capable of collecting and transmitting small quantities of water, particularly through small cracks and fractures. The shale is characterized by numerous intersecting selenite veins, many of which are paper thin. Cores taken from the Flowerpot in the core hole when handled after drying parted along the veins into irregular

Table 2.--Chloride content of water in the test holes

Test-hole number	Depth sampled (feet)	Chloride (ppm)	Geologic formation
1	180	10,250	Flowerpot
1	215	23,500	Do.
3	35	135	Blaine
3	180	4,400	Flowerpot
3	230	8,250[a]	Do.
4	220	67,500[a]	Do.
5	18	40	Blaine
5	35	35	Do.
5	54	152	Flowerpot
5	70	230	Do.
5	170	54,000[a]	Do.
6	150	12,800[a]	Do.
7	18	131,000	Do.
8	194	165,000	Do.

[a] Salt water probably was diluted by fresh water leaking around the well casing from an upper zone.

blocks. Space at the contact of the selenite with the shale is wide enough in places to allow the passage of water. Openings in the shale occur at random, consequently, the overall permeability probably differs considerably within short distances. No particular zone or zones were found that appeared to be either consistently high or low in permeability.

Blaine Gypsum

The Blaine gypsum consists mainly of beds of massive gypsum separated by red, gypsiferous shale. In places, the gypsum beds are underlain by thin, impure dolomite. All the holes penetrating the Blaine started into it at land surface, therefore the entire thickness is not represented in any of the holes. The core hole penetrated 123 feet of the Blaine, including all but the upper few feet of the formation. It consisted of 75 feet of gypsum, 10 feet of dolomite, and 38 feet of gypsiferous shale.

In the area investigated, the solvent action of water has dissolved numerous sinkholes, solution channels, and caves in the Blaine. The diameter of the sinkholes range from several hundred feet to less than a foot. The deepest sink observed was about 90 feet deep and is in the NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 6, T. 6 N., R. 26 W. The most intensive areas of sink development are west of the major salt springs in secs. 5, 6, 7, and 8, T. 6 N., R. 26 W., and in secs. 11, 12, 14, 23, and 24, T. 6 N., R. 27 W. Sinkholes in the Blaine are most common adjacent to surface drainage lines. The courses of main streams in the area, particularly Elm Fork and Elm Creek, have sharp angles that may have been controlled originally by jointing in the Blaine. As the streams lowered the local base level, percolating water accelerated the formation of caves and sinks in the gypsum. Some of the sinks are so small that they probably were developed by the enlargement of the intersection of two sets of joints or fractures rather than by cave collapse. In areas where the Blaine is covered, it is composed generally of dense anhydrite of low permeability that has been affected little by the solvent action of water.

Sinks and enlarged fractures in the exposed surface of the Blaine have resulted in a terrain that locally is highly favorable for ground-water recharge from precipitation. Part of the water in the Blaine percolates downward into the underlying Flowerpot shale where it becomes salty by dissolving halite.

STRUCTURE

The Permian rocks have a regional dip of about 14 feet per mile toward the south-southwest (J. E. Barclay, written communication). Because of local structural features, however, the dip of the rocks in the area studied deviates from the regional dip. Although these features are small, they may exert some influence over the occurrence of salt springs.

The top of the Flowerpot shale is generally higher west of the salt springs than at the springs. The altitude of the Flowerpot near the head of Salton Gulch in the SW$\frac{1}{4}$ sec. 4, T. 6 N., R. 26 W., is 1,826 feet. In test-hole 4, a mile west, and in test-hole 8, a little less than a mile north of Salton Gulch, the altitude is

1,843 feet. In test-hole 6, about two-thirds of a mile southwest of the gulch, the altitude of the Flowerpot is 1,853 feet. The altitude decreases west and south from test-holes 4, 6, and 8 indicating a small structural ridge that arches around the western side of Salton Gulch. Test-hole data indicate that salty shale in the Flowerpot is at a relatively high altitude in the general vicinity of the structural ridge. Also, water levels are at a relatively high altitude in the same general area.

Before structure can be related to ground-water movement, additional studies will have to be made. If structural movement is responsible for salt and salty shale being at a relatively high altitude around the salt springs, the assumption can be made that structure affects the amount of salt discharged from springs in the area. The salt in the Flowerpot appears to be at the same horizon as in many localities in western Oklahoma where salt springs do not occur. Therefore, stratigraphy alone does not account for the occurrence of salt springs.

GROUND-WATER MOVEMENT AND THE WATER-TABLE MAP

The water-table map (fig. 2) is based on data from test holes, water wells, and the altitude of water in Elm Fork and Elm Creek. In all cases the altitude indicates the elevation of the piezometric surface regardless of the quality of the water. The water level in test-hole 1 may have risen to a higher level in time than that shown on the map, but because of road construction the hole was filled after standing for 2 days and the water level could no longer be measured.

The map (fig. 2) shows that ground water in the area is moving toward the river from both sides. The steep ground-water gradient toward the river from the west and south, coincides with the side of the river on which the major salt springs are located. The greatest difference found between the altitude of water in the test holes and the altitude of the salt springs is 163 feet between test-hole 4 (altitude, 1,893 feet) and springs in Salton Gulch (altitude, 1,730 feet). This is a piezometric gradient of about 150 feet per mile. Because of low permeability the head loss between points of ground-water intake and ground-water discharge at the springs probably is great. The piezometric high in secs. 5, 8, and 17, T. 6 N., R. 26 W., represents a north-south trending ground-water divide about a mile west of Salton Gulch. Although data are insufficient to define accurately the divide south of the major salt springs, the divide west of Salton Gulch probably swings eastward, parallel to the river and coincides with the surface-water divide. The divide probably is about 2 miles south of the river in most places.

Data on the piezometric surface on the north side of the river are sparse. The altitude shown and the occurrence of small springs on the north side of the river indicate that water is moving toward the river from the uplands. Most salt water enters the river from the south and west but salt-water seeps have been observed on the north bank in the NE$\frac{1}{4}$ sec. 32, T. 7 N., R. 26 W., and along Elm and Bull Creeks. If the ground-water divide approximates the surface divide, the ground-water area draining toward the river is greater on the north side of the river than on the south side.

The major salt springs are associated with steep ground-water gradients and the occurrence of shallow halite and halite-bearing shale. In test-hole 6 halite was found at an altitude higher than the floor of nearby Salton Gulch where a large salt spring emerges. In test-holes 4, 6, 7, and 8 salty shale was found at an altitude higher than the canyon bottom. The largest salt springs apparently are on the south and southwest side of Elm Fork because subsurface salt is most accessible to circulating ground waters and the ground-water flow pattern is most favorable (Ward and Leonard, 1961).

There may be several reasons why a lesser amount of salt water enters from the north side than from the south. Much of the salt north of the river could have been removed through solution previously or the Flowerpot may contain a smaller amount of salt in that area. The Blaine is so severely dissected by erosion north of the river that it cannot retain ground water long enough for much of it to be absorbed by the underlying Flowerpot shale; hence, only small quantities of water are available to dissolve salt from the Flowerpot. The ground-water gradient north of the river and east of Bull Creek may be considerably less than at other places in the area. If this is true, it would help explain the small amount of salt seeping into streams in that area.

SUMMARY

Salt-water springs flowing into Elm Fork Red River in northern Harmon County issue from the Flowerpot shale of Permain age. The salt in the spring water is dissolved from halite that was found in the Flowerpot at depths ranging from 30 to 197 feet below land surface. Ground water enters gypsum in the overlying Blaine gypsum

in uplands west and south of the salt springs, especially in sinkhole areas. A large part of the water is discharged from freshwater springs, such as are in SW¼ sec. 15, T. 6 N., R. 26 W., but a small part moves downward from the cavernous gypsum into the underlying Flowerpot shale. This water moves through joints and fractures in the shale circulating deep enough to dissolve halite. The salt water circulates to the surface at topographic lows in local canyons, forming the salt springs. Less salt appears on the north side of Elm Fork partly because the gypsum is so severely dissected that most of the ground water is discharged at the surface without circulating deep enough to pass through the salt-bearing shale.

The overall permeability of the Flowerpot shale is low and ground-water gradients are steep. The greatest piezometric gradient found was about 150 feet per mile between test-hole 4 and the springs in Salton Gulch. Because of low permeability the head loss between points of ground-water intake and ground-water discharge at the springs probably is great.

Local structure appears to exert some control over the occurrence of salt springs in the area, but conclusions cannot be made owing to the small amount of data.

The contributing area for the salt springs on the south and west sides of the river appears to extend no farther than about 2 miles. The drainage area north of the river has not been defined in detail but because only a small amount of salt enters the river from that side its importance is small.

References

Ward, P. E., 1961, Geology and ground-water features of salt springs, seeps, and plains in the Arkansas and Red River basins of western Oklahoma and adjacent parts of Kansas and Texas: U.S. Geological Survey administrative report.

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