OKLAHOMA GEOLOGICAL SURVEY

Robert H. Dott, Director

Mineral Report No. 11

GEOLOGY OF OKLAHOMA GROUND WATER SUPPLIES

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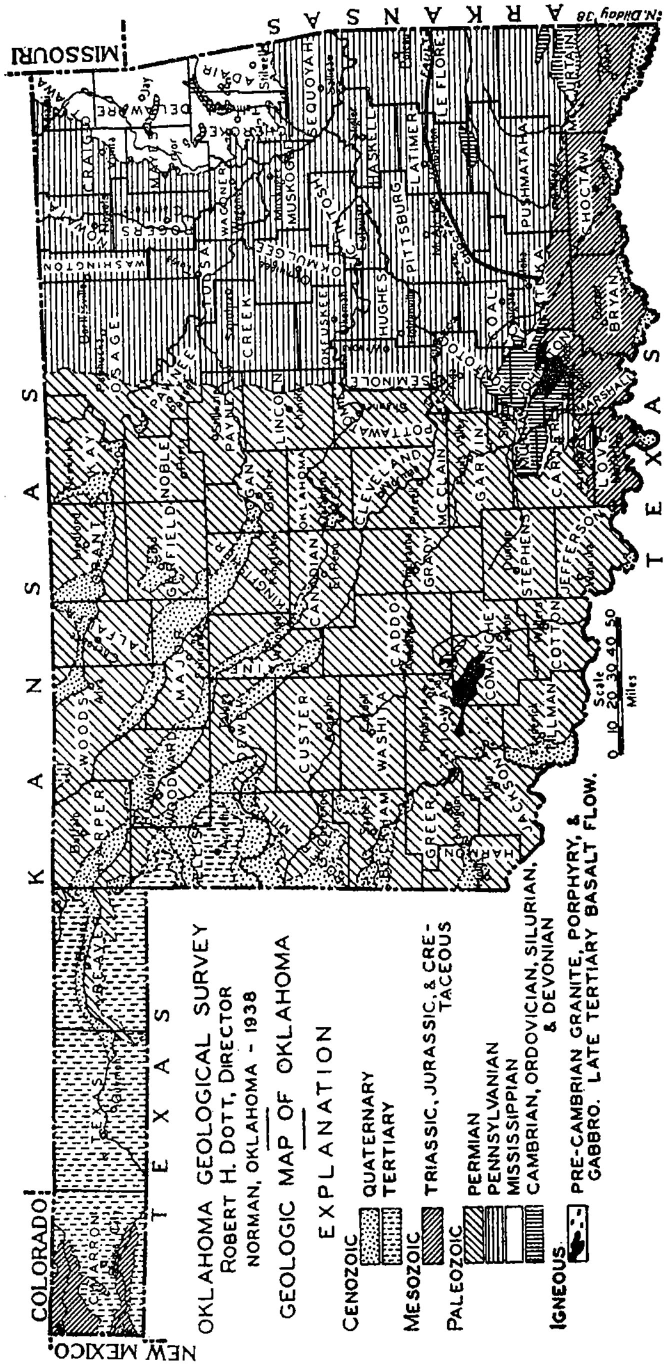
FOREWORD

Data on the chemical quality of Oklahoma water supplies, principally those used by municipalities of the State, have been compiled by Dr. O.M. Smith, head, Department of Chemistry, Oklahoma Agricultural and Mechanical College, in co-operation with the State Department of Public Health. These data consist of about 1,800 analyses of water samples, made by the Department of Health, the Department of Chemistry of the Agricultural and Mechanical College, commercial water-treating concerns, and others. The Oklahoma Geological Survey was requested to prepare a discussion of the geological conditions relating to the occurrence and quality of ground waters in different parts of the state.

The complete report, including tabulations of analyses, is to be published by the Engineering Experiment Station, Oklahoma Agricultural and Mechanical College, Stillwater. The discussion of the geology of ground waters of Oklahoma, however, is given here because of the many inquiries that come to the Oklahoma Geological Survey for information relating to ground-water supplies.

The summary discussion of quality of water in different aquifers is based on the study of the tabulations of analyses, and gives a general idea of the type of water that may be obtained in different parts of the state. It is regrettable that very few data are available on quantities of water that may be obtained from different water-bearing formations.



GEOLOGY OF OKLAHOMA GROUND WATER SUPPLIES

Introduction

Water is a natural, homogeneous, inorganic substance, having a definite chemical composition and is crystalline in solid state. Hence it answers all the requirements of the definition of a mineral. Ground water is present in the pore spaces of rocks or rock material, hence its occurrence is a geological phenomenon, and the conditions controlling its movements are a part of the science of geology.

All forms of life, including man, require water in their physiology. Man consumes water directly, assimilates additional quantities through eating vegetables, meat, milk, and other organic foods;and uses large quantities for sanitation, agriculture, industry, and in other ways.

All water used directly by man for physiological needs, sanitation, agriculture, or industry, falls to the earth as rain or snow, regardless of whether its immediate source is a river, lake, or well. This is known as meteoric water. Rain water is nearly pure, and contains only the substances picked from the air. In many sections of Oklahoma, rain water is collected in cisterns and is used for domestic needs.

After meteoric water reaches the surface of the earth, a portion of it runs off into drainage channels, and may be impounded in reservoirs.Part evaporates and part sinks into the soil to become soil moisture and is used by plants. When the soil is thoroughly saturated, and plant requirements have been met, further additions of water to the soil will penetrate to the zone of saturation,and become ground water. Ground water may return to the surface as springs, or drain into the streams, and it may be recovered from wells.

Depending on geological conditions, ground water is defined as "free" or "confined".

Free water is not under pressure, and will not rise in the well above the level at which it is first encountered. The top of the zone of saturation is called the water table, and conforms roughly to the topography of the land surface, so that depths to water in a given area are approximately the same. The water table, however, is somewhat deeper below the hills than below the valleys. The level at which the water table stands, and therefore the level of the water in wells, depends largely on the rainfall.

The quantity of free water in the zone of saturation depends on the thickness of the water-bearing formation below the water table. The character of the materials determines the rate at which water can be discharged from a well; and the amount of water that is annually recharged or replenished to the formation is a measure of safe yield.

Springs are commonly related to free water and issue where the contact between the permeable aquifer and an underlying layer of impermeable material has been exposed by erosion. Because the water in the aquifer cannot move down into the impermeable layer, it tends to move laterally to the outcrop and therefore to drain the aquifer.

In Oklahoma, the formations that contain free water are the valley alluvium, the terrace deposits adjacent to major streams, the sand dune areas, and the sand and gravel deposits underlying the High Plains in Cimarron, Texas, Beaver, and part of Ellis Counties.

Confined water occurs in stratified, generally consolidated, permeable rock strata that are overlain and underlain by impermeable strata, and dip or slope away from their outcrops. Meteroic water

enters the aquifer at the outcrop, and sinks down in the same manner as in the case of free water. It then flows by gravity down the dip away from the outcrop, somewhat like water passing through a conduit or pipe, except that it is actually going through many small conduits of irregular size and shape, made by the openings between the mineral fragments of the rock.

As more water is added at the outcrop, its weight creates pressure on the water at depth in the formation, and accelerates movement. When the aquifer is penetrated by a well, the water will rise to a height a little lower than the outcrop or intake area. If the mouth of the well is lower than the intake area, the well will flow at the surface. Such a well is commonly called "artesian", although technically the term "artesian" applies to all wells in which the water rises substantially above the level where it is first encountered. A flowing well, therefore, is only a special kind of artesian well. The water is said to be under artesian pressure, or to occur under artesian conditions.

Artesian springs may occur where a fault or fissure intercepts a confined aquifer at depth, and the surface of the ground is lower than the intake area of the aquifer. Like a well, the fissure provides an opening up which water may rise under the impetus of artesian pressure.

The greatest part of the area of Oklahoma is underlain by consolidated rock formations that contain confined water, under artesian conditions, which they yield to wells in greater or lesser amounts, depending on the character of the materials. Except in a few areas, as at Sulphur and Lawton, artesian water in Oklahoma will not rise to the surface in wells.

Water-Bearing Formations

Properties of Water-Bearing Rocks. The water-bearing properties of the most important aquifers in Oklahoma are summarized in following pages. Their importances is due principally to the relative abundance of the water they contain, partly to their location, and to the chemical character of the water they yield.

Good aquifers are rock formations that have high porosity, high permeability, considerable thickness, and large intake areas. The porosity of a rock is the pore space, or openings between the mineral grains, and its permeability is its capacity for transmitting water under pressure. Porosity and permeability are not synonymous. Some clays have high porosity but will transmit very little water, whereas gravels and sands, perhaps with lower porosity, will transmit water freely. If a rock is porous, its permeability depends on its coarseness, the uniformity of the size of the grains in it, and the extent to which the pore spaces have been filled with cementing material.

Gravel and coarse, well-sorted sand make the best aquifers, but coarse-grained sandstone and thick limestone containing cracks, crevices, joints, and solution openings are almost as good. Shale is ordinarily too impervious to yield much water to wells, but if it is much jointed and cracked it will yield moderate supplies of water.

The intake area of an aquifer is approximately equal to the outcrop area of the formation. It is the area where the formation is exposed at the surface so that meteoric water can seep downward into it.

The value of a formation as an aquifer is greater if it is thick because a thick formation, obviously, has greater reservoir capacity than a thin one. Also, a thick formation generally has a wider outcrop at the surface, and therefore, a larger intake area. The width of outcrop, however, depends also on the angle of dip of the formation, being less where dip is steep than where it is gentle, if the thickness is the same. If the land surface

is rough in the outcrop area, the actual area may be greater than on flat surfaces, but a larger part of the precipitation may go into the streams as direct run-off because of the steep slopes, and so the effectiveness of the intake area may be no greater than on a flat surface.

Mineral content. Most of the rocks of the earth's surface contain soluble mineral salts in greater or lesser amounts, and these are dissolved by the waters that pass over or through the rocks. Thus both surface and ground waters become mineralized, and may contain some of the common salts. Among these are calcium and magnesium bicarbonate, calcium and magnesium sulfate, bicarbonate of soda, sodium sulfate (glaubers salt), and sodium chloride (common salt).

Calcium carbonate is the principal constituent of limestone, and also occurs in many sandstones and shales. Therefore, the analyses of waters from limestone areas, such as the Arbuckle and Ozark Mountains, show relatively high concentrations of this compound, in the form of calcium bicarbonate. Such waters are hard and produce a white scale in tea kettles, water heaters, and boilers.

In general, the waters from sandstones in Oklahoma are soft, containing relatively little calcium bicarbonate but higher concentrations of sodium bicarbonate and sulfate. The sandstones of western Oklahoma are more highly impregnated with soluble salts at shallow depths than are those in eastern Oklahoma. Consequently, the waters from these regions are more highly mineralized.

The shales of eastern Oklahoma contain only small amounts of soluble salts, whereas most of the red shales of western Oklahoma contain considerable quantities of gypsum (calcium sulfate) and common salt (sodium chloride).

The degree of mineralization of the water is proportional to the quantity of soluble salts in the rocks and the length of time that the water is in contact with them. It may also depend on the perviousness of the rocks and the rapidity of the circulation through them, because in time the soluble salts may be largely removed where the circulation is good. In the same area, ground water will contain more mineral matter than surface water because of its greater opportunity for dissolving the salts. During heavy rains, when large volumes of water rapidly run off the surface into the streams, the surface water contains relatively less dissolved mineral matter than during low stages when the stream flow is maintained chiefly by ground-water inflow. During protracted droughts, when evaporation may be high, the mineral matter in surface water may become highly concentrated.

The character of the surface waters reflects the mineralogical nature of the rocks over which they flow. The surface waters containing the smallest amounts of dissolved solids are those of the sandstone and shale area of east-central and southeastern Oklahoma. The surface waters containing the largest amounts of dissolved solids are the waters from limestones areas, which generally are high in calcium bicarbonate, and those from the redbeds area of western Oklahoma, which generally contain more or less dissolved gypsum and salt.

Part of the ground water found in the alluvium, or valley fill, especially in a band close to the stream, is supplied by underflow from the stream and is similar in chemical character to the water of the stream, although it may differ somewhat in the degree of concentration. As with surface water, the concentration of minerals in the ground water in alluvium is rather closely related to the amount of rainfall, tending to increase in time of drought. The same is true, but to a lesser extent, of ground water in other formations.

In general the water from a deep aquifer is more highly mineralized than that from a shallow aquifer, and the water in the same aquifer is more

highly mineralized where the aquifer is deep beneath the surface than at shallow depths near the outcrop. Thus some sandstones that contain potable water at depths down to 1,000 feet yield only highly mineralized, saline waters from greater depths.

Methods of Investigation

The identification of the geological formations from which the different samples of water had come is based on the study of several lines of evidence. Tables of chemical analyses of the water from the different wells, expressed in hypothetical combinations, were furnished by Dr. O. M. Smith, Head, Department of Chemistry, Oklahoma Agricultural and Mechanical College, together with data on the locations and depths of the wells. The geological formation cropping out at the surface in the vicinity of each well was determined from published geological maps, and the thickness of this and other geological formations in the area were obtained from geological reports. Reports of the Oklahoma Geological Survey and the United States Geological Survey, publications of the American Association of Petroleum Geologists, and other sources, were drawn on freely.

In instances where well data were inadequate, the aquifers were identified by comparing water analyses with those of similar waters whose geological source was better known. From this work it developed that some formations contain water of such definite chemical character that correlation of the formations can be made on the basis of the chemical analyses of the water they yield.

Two major difficulties were encountered. In the first place, basic geological information in the form of accurate, detailed geologic maps, and detailed measurements and descriptions of exposed formations, is available for only a few parts of the state. Second, the well data accompanying the analyses are very meager. Few drillers' logs are available. Even depths and accurate locations for many of the wells are lacking, so that it is impossible to determine with certainty in what formations these wells started or finished. Even if the formation in which a well stopped can be fairly well identified, there is often the possibility that the water sample analyzed came from a formation above the botton of the well, or was a mixture of water from two or more aquifers. Some of the deficiencies in the data on wells however, were made up from the records of the State Mineral Survey.1/

Principal Aquifers in Oklahoma

The more important water-bearing formations in Oklahoma are listed in stratigraphic succession, oldest first. Their position with respect to other formations is shown in Table 2.

Arbuckle limestone (Ordovician age). The Arbuckle limestone is extensively exposed in the Arbuckle and Wichita Mountains, and beds of the same age crop out in northeastern Oklahoma and adjacent parts of Arkansas and Missouri. The Arbuckle limestone is correlated with the so-called "siliceous lime" of the oil fields, an oil-producing formation in western Kansas and some parts of Oklahoma. It contains some fractures and solution channels and some sandy zones. It yields water in and adjacent to the mountain areas, through springs and wells, and not uncommonly through flowing wells.

In general the water is hard, being relatively high in calcium and magnesium bicarbonates, and low in sodium sulfates and chlorides. Four analyses of water from flowing wells which produce water from a zone in the Arbuckle limestone, near Lawton, Comanche County, however, show quite the reverse, being low in calcium and magnesium bicarbonate, and high in sodium sulfate and chloride. Because of the unusual chemical character of this water, it is believed that the meteoric waters fell on the granite

1/ WPA project 65-65-538, sponsored and directed by the Oklahoma Geological Survey, 1936-1937.

cropping out in the Wichita Mountains to the west, and there dissolved sodium bicarbonate which, in turn, prevented the solution of calcium bicarbonate after the water reached the limestone.

Samples of water from the Arbuckle limestone, taken from several wells 600 to 1500 feet deep in northeastern Oklahoma, are highly mineralized. One sample of water from Claremore, Rogers County, shows 36,823 parts per million of total solids. A possible explanation is that the "connate" water (theoretically "fossil" sea water) which the rocks contained when they were deposited has not been diluted by meteoric waters.

Boone limestone (Mississippian age). The Boone limestone, also known as Boone chert, crops out over most of the Ozark area in northeastern Oklahoma. It has an average thickness of about 300 feet, contains many fractures, fissures, and cavities, and therefore has a high reservoir capacity. It crops out in an area of relatively high rainfall for Oklahoma, with a good vegetative cover, and so acquires and contains a large volume of ground water. It is underlain by the impervious Chattanooga shale, and many springs issue at this contact. The Boone supplies many of the wells and springs in and adjacent to the outcrop area. The water is moderately soft.

The Boone limestone is correlated with the so-called "Mississippi lime" of northern Oklahoma and Kansas.

Minor aquifers in the Pennsylvanian. Westward and southward from the outcrop of the Boone limestone, much of the bed rock of northeastern Oklahoma is shale in which little ground water is to be had, but interbedded with the shales are many beds of sandstone. Where these sandstones are thick and coarse and not too tightly cemented, they may furnish moderately large and satisfactory water supplies. Little information regarding the ground water potentialities of these sandstones is available, however, because large municipal and industrial supplies seem not to have been developed in them, either because they are inadequate to meet such large demands, or because other sources -- such as surface streams -- are more easily available.

Nelagoney-Vamoosa formation (Pennsylvanian age). The Nelagoney-Vamoosa formation crops out in a band from northeastern Osage County, extending southwestward through eastern Pawnee, western Creek and Okfuskee, and central Seminole Counties. This formation consists of coarse-grained sandstone and conglomerate, with some interbedded shale, and ranges from 250 to 600 feet in thickness. Its waters are utilized in the counties through which it crops out, and also in Lincoln and Pottawatomie Counties, to the west of the outcrop.

The quality of the water from the Nelagoney-Vamoosa varies somewhat from north to south, and also, in common with water from most horizons, down the dip to the westward. Waters from Creek County show moderate concentrations of calcium and magnesium bicarbonates and sodium sulfate with smaller amounts of sodium bicarbonate and magnesium sulfate. In Lincoln County, to the west and at greater depths, the total solids are higher and considerable calcium and sodium sulfates are present, but sodium bicarbonate is negligible. In Seminole and Pottawatomie Counties, the total solids are about the same as in Creek County, calcium and magnesium bicarbonates and sodium sulfate are relatively low and the sodium bicarbonate is high. Water from the Nelagoney-Vamoosa is extensively used by oil companies in drilling operations in Creek, Seminole, and Pottawatomie Counties.

Clear Fork-Wichita formation (Permian age). The Clear Fork-Wichita formation is exposed in southern and southwestern Oklahoma, from Carter County to northern Kiowa, eastern Greer and Jackson Counties, and south to Red River. It consists pf red shale and sandstones, the latter being important aquifers in most of the area.

Waters from the Clear Fork-Wichita are very low in calcium sulfate, but contain large amounts of sodium bicarbonates, sulfates, and chlorides.

On the Geologic Map of Oklahoma 2/, the Clear Fork-Wichita in Stephens and Carter Counties is divided into three units. Waters from the lower unit, which is a calcareous sandstone, are distinguished by high concentrations of sodium bicarbonate.

The middle and upper parts of the Clear Fork-Wichita are approximately equivalent to the Garber sandstone and Hennessey shale of central Oklahoma.

Garber sandstone (Permian age). The so-called Garber sandstone, including sandstones belonging to the underlying Wellington and perhaps Stillwater formations, is the most important aquifer in central Oklahoma, and water from these beds is utilized in Garfield, Logan, Oklahoma, and Cleveland Counties, but to the greatest extent in the latter two. Waters from the "Garber" are high in total solids, but are generally soft, and are characterized by the relatively high concentrations of sodium bicarbonate and sodium sulfate.

At Norman, three zones can be distinguished in the "Garber": (1) 75 to 250 feet below the top of the Garber sandstone, the water is high in sodium sulfate and chloride. (2) 350 to 450 feet below the top, the sodium bicarbonate is greater than the sodium sulfate. (3) About 500 feet below the top, the water contains less sodium bicarbonate than sulfate.

Hennessey Shale (Permian age). Overlying the Garber sandstone is the Hennessey shale, equivalent to the upper part of the Clear Fork-Wichita. It yields water over a considerable area, principally from sandstone members. Water from the Hennessey shale contains relatively large amounts of calcium, magnesium, and sodium sulfates, and sodium chloride.

2/ H. D. Miser, "Geologic Map of Oklahoma," U. S. Geol. Survey, 1926.

Whitehorse sandstone (Permian age). The Whitehorse formation is the most important aquifer in west-central Oklahoma. The Whitehorse is comprised of two members. The Marlow or lower member consists of sandstone and shale, with considerable gypsum (calcium sulfate) disseminated through it. The upper member, known as the Rush Springs sandstone, is largely sandstone, and is the more important aquifer of the two, both because of its thickness and the quantity and quality of the water it contains. The Whitehorse formation has an average thickness of about 350 feet, with the Marlow member 100 feet and the Rush Springs sandstone 250 feet thick.

The chemical character of the waters from the two members is distinct. Water from the Marlow is high in calcium, magnesium, and sodium sulfates, but is free from magnesium bicarbonate, whereas Rush Springs water is practically free from calcium sulfate and contains slightly more sodium sulfate and somewhat more sodium and magnesium bi-carbonate than the Marlow water. Both waters contain sodium chloride.

Quartermaster formation (Permian Age). The Quartermaster formation is exposed in western Washita, northern Beckham, and Roger Mills Counties. It consists of soft, red, rather fine-grained sandstone and shale, and is about 300 feet thick. Water from the Quartermaster formation is relatively high in calcium and magnesium bi-carbonate, with some sodium bicarbonate, sulfate, and chloride. The Quartermaster formation is especially important as an aquifer, although its yield is rather small, because other formation in the area yield less water of poor quality; high in calcium and magnesium sulfate, and in total solids.

Trinity sand (Cretaceous age). The Trinity sand crops out in southeastern Oklahoma from Love, Carter, and Marshall Counties, through southern Atoka, Pushmataha, northern Choctaw, and southern McCurtain Counties. Between the northern limit of its outcrop and Red River, the Trinity yields moderately large

supplies of water that is soft but contains high concentrations of sodium bicarbonate.

Ogallala formation (Tertiary age). The Ogallala formation underlies the high plains of the Oklahoma Panhandle, and supplies nearly all the water consumed in that area of low rainfall. The formation consists of calcareous sands, gravels, and sandy clays, has an average thickness of 300 feet, and a maximum thickness of 600 feet. Some of the water from the Ogallala is being utilized for irrigation. Depths to water in the Ogallala range from about 50 to 300 feet in Cimarron County, 70 to 250 feet in Texas County, and 50 to 250 feet in Beaver County.

The water is very hard, but is relatively low in sulfates and chlorides. Total dissolved solids are much lower than in most waters from bed rock formations farther east.

Terrace Deposits (Pleistocene age). Deposits of sand and silt underlie high level terraces along many of the larger stream valleys. In general, the terraces represent older, higher stages of the rivers that have since cut their channels deeper and developed new flood plains. The terrace deposits in Roger Mills and Ellis Counties may represent remnants of the High Plains.

The terrace deposits are generally more or less permeable, and therefore readily absorb water directly from rainfall and from the run-off from adjacent uplands. The quality of the waters from these deposits generally is good, and they are, consequently, of great value in areas where other water supplies are inadequate or of inferior quality.

These deposits were originally alluvium, and may contain mineral salts brought down by the waters of the streams that deposited them. The chemical character of water in terrade deposits may be influenced unfavorably by the character of the rocks in adjacent areas. In western Oklahoma, terrace deposits are surrounded by Permian redbeds, and if soluble minerals such as gypsum or salt are present in these rocks, waters that flow over them later to collect in the terrace deposits is likely to be highly mineralized.

Alluvium (Recent age). Alluvium is the deposit built up by the present streams in their valleys or "bottoms". Alluvium resembles terrace deposits in being loosely consolidated and, where coarse, capable of yielding large volumes of water. The chemical character is similar, too. Because of this similarity, considerable difficulty was encountered in differentiating waters from terrace deposits from those of alluvium.

Water is fed into alluvium by underflow from the stream itself, by rain water that falls upon it, and by run-off from adjacent uplands. Insofar as the supply comes by underflow, the quality of water resembles that of the stream water, and is determined by the character of the rocks cropping out in the drainage basin. Flood waters tend to flush out salts previously deposited by evaporation, and dilute the water in wells in alluvium. A direct correlation between rainfall and total solids was noted in the analyses of samples of water obtained from the alluvium of North Fork of Red River at Erick, Beckham County (Table 1).

Stratigraphy of Oklahoma

The following tables show the principal geologic formations exposed in different parts of Oklahoma, arranged in stratigraphic order, with the oldest at the bottom. Formations from which water samples were analyzed are indicated by an (*), but the intervening formations are listed in order to show the complete sequence.

A generalized geologic map of Oklahoma is given on the inside front cover, but the reader is referred to the Geologic Map of Oklahoma for details of distribution of the individual formations.

TABLE 1. Annual Rainfall and Concentration of Total Solids in Water from Alluvium, Erick, Beckham County, Oklahoma

Year	Total Precipitation (inches)	Average Total Solids in Water p.p.m.	Date of Analyses	Number of Analyses
1927	19.51			
1928	28.14			
1929	24.18	482 450	4/4/29 12/16/29	1 1
1930	27.81			
1931	20.92			
1932	23.45			
1933	13.78	569	3/31/33	4**
1934	11.52*	678 678 855	5/5/34 5/5/34 November, '34	1 1 1

* Interpolated
** Several wells

TABLE 2. Water Bearing Formations in Oklahoma

Age	Southern Oklahoma	Oklahoma Generally	Panhandle	Water Bearing Properties
Surface water				See Note 1
Quaternary	Alluvium* Terrace Deposits*	Alluvium* Terrace Deposits*	Alluvium* Terrace Deposits	See Note 2
Tertiary	Absent		Ogallala fm*	See Note 3
Cretaceous	Woodbine ss.*		Dakota ss.	See Note 4
	Washita group* Trinity sand*		Purgatoire fm. Absent	See Note 5 See Note 6
Jurassic	Absent		Morrison fm.*	See Note 7
Triassic	Absent		Exeter ss.* Dockum fm.	See Note 7

1. Surface streams and reservoirs are the most important source of water in Oklahoma, and supply larger cities. Quality depends on rainfall and mineral character of the rocks in the watershed. It ranges from very dilute, in sections of Eastern Oklahoma underlain by sandstones and shale that contain few soluble salts, to waters unfit for human use because of concentration of calcium sulfate and sodium chloride, in some streams of southwestern Oklahoma. Surface water that crosses areas of limestone outcrops, as in the Arbuckle and Ozark Mountains, contains considerable calcium bi-carbonate.

2. Alluvium is material deposited by streams on their present bottoms, and consists of clay, silt, sand, and gravel locally. Terrace deposits are old alluvium representing older and higher stages of present streams, and in extreme western Oklahoma may represent remnants of the High Plains.

Terrace and alluvial deposits generally are loosely consolidated, and able to absorb large volumes of water that falls as rain and snow. Alluvium is partly fed by underflow from the stream. Both deposits are of great importance, especially in western Oklahoma, in areas where water from other sources are inadequate or inferior. Quality of water in alluvium, and to a lesser extent in terrace deposits is influenced by the character of rocks exposed in the drainage basin.

3. Ogallala formation, underlying the High Plains, chiefly in the Panhandle counties, consists of clay, sand, and gravel, and freely yields water that is hard, but relatively low in sulfates, chlorides, and total solids.

4. Woodbine formation supplies some water in southern Bryan and Choctaw Counties. Many springs issue from Dakota sandstone in Cimarron County, and it yields water to farm wells in the same area.

5. Washita group: alternating shale and limestone. Yields hard water in southeastern Oklahoma.

6. Trinity sand, an important aquifer in southern Oklahoma, yields soft water.

7. Wells near Kenton, Cimarron County, from Morrison and Exeter.

TABLE 2 A. Permian Aquifers

Age	Southern and Southwestern	South Central	West Central	Northern and Northwestern	Water bearing properties
PERMIAN	*Quartermaster	Quartermaster fm.*		Quartermaster fm	See note 8
	*Cloud Chief	Cloud Chief gypsum*		Cloud Chief gyp.	See note 9
	*Rush Springs *Marlow member	Rush Springs ss* Marlow member*		Whitehorse formation*	See note 10
	*Dog Creek sh. *Blaine gypsum *Duncan ss.	Chickasha-Duncan*	El Reno*: Dog Cr. sh.* Blaine gypsum* Flower Pot sh.	El Reno*: Dog Creek sh. Blaine gypsum Flower Pot sh	See note 11
	*Clear Fork-Wichita	Hennessey sh.* Garber ss.*	Hennessey sh.* Garber ss.*	Hennessey sh.* Garber ss.*	See note 12
		Wellington fm*	Iconium sh.* Fallis ss.*	Wellington fm*	See note 13
	*Stratford sh.	Asher ss.* Konawa ss.*	Asher ss.* Konawa ss.*	Stillwater fm.*	See note 14

8. Quartermaster present in Washita, Beckham and Roger Mills Counties. Water is relatively high in calcium bi-carbonate, magnesium bi-carbonate, with sodium bi-carbonate, sodium sulfate and sodium chloride.

9. Cloud Chief is a gypsum and shale formation; water is high in calcium sulfate and contains considerable magnesium sulfate and sodium sulfate.

10. Whitehorse formation is important over a large area of western Oklahoma. Rush Springs member is the more important, both as to quantity and quality of water.

11. Chickasha-Duncan formation, in Grady and Stephens Counties, is mostly sandstone. It is thought to be equivalent to the El Reno group, which consists of shale and gypsum.

Chickasha-Duncan waters contain moderate amounts of calcium sulfate and considerable magnesium sulfate, sodium sulfate and chloride. Waters from the Blaine gypsum are high in calcium sulfate, magnesium sulfate, and contain considerable sodium sulfate and sodium chloride.

12. Clear Fork-Wichita formation consists of alternating sandstone and shale. In Garvin, Stephens and Carter Counties, waters from lower part contain higher concentration of sodium bi-carbonate.

Garber sandstone is important in central Oklahoma, especially in Cleveland and Oklahoma Counties. The water is usually soft, and is characterized by relatively high concentrations of sodium bi-carbonate and sodium sulfate.

Hennessey shale yields water, principally from sandstone members, in parts of central Oklahoma. The water is relatively high in calcium, magnesium, and sodium sulfate and sodium chloride.

13. Wellington formation is alternating shale and sandstone. Water contains considerable calcium and sodium sulfate; locally it is high in sodium chloride.

14. Konawa and Asher formations mostly coarse sandstone. Stillwater is alternating shale, sandstone and limestone.

TABLE 2 B. Pennsylvanian Aquifers

Age		South-Central	East-Central	Northern	Water bearing properties
PENNSYLVANIAN	Virgil Group	Vanoss fm.*	Vanoss fm.*	(Wabaunsee fm.* (Pawhuska ls.	See note 15
		Ada fm.		Elgin ss.*	See note 16
		Vamoosa fm.*	Vamoosa fm.*	Nelagoney fm.*	See note 17
	Missouri Group	Ochelata fm.	Ochelata fm.	Ochelata fm.*	See note 18
		Absent	(Avant ls. (Chanute sh.	Avant ls. Chanute sh.*	
		Belle City fm.	Dewey ls.	Dewey ls.	
		Francis fm.*	(Nellie Bly fm. (Hogshooter ls. (Coffeyville fm*	(Nellie Bly fm.* (Hogshooter ls. (Coffeyville fm.*	See note 19
		Seminole ss.	Seminole ss.*	Seminole ss.	See note 20

(Continued)

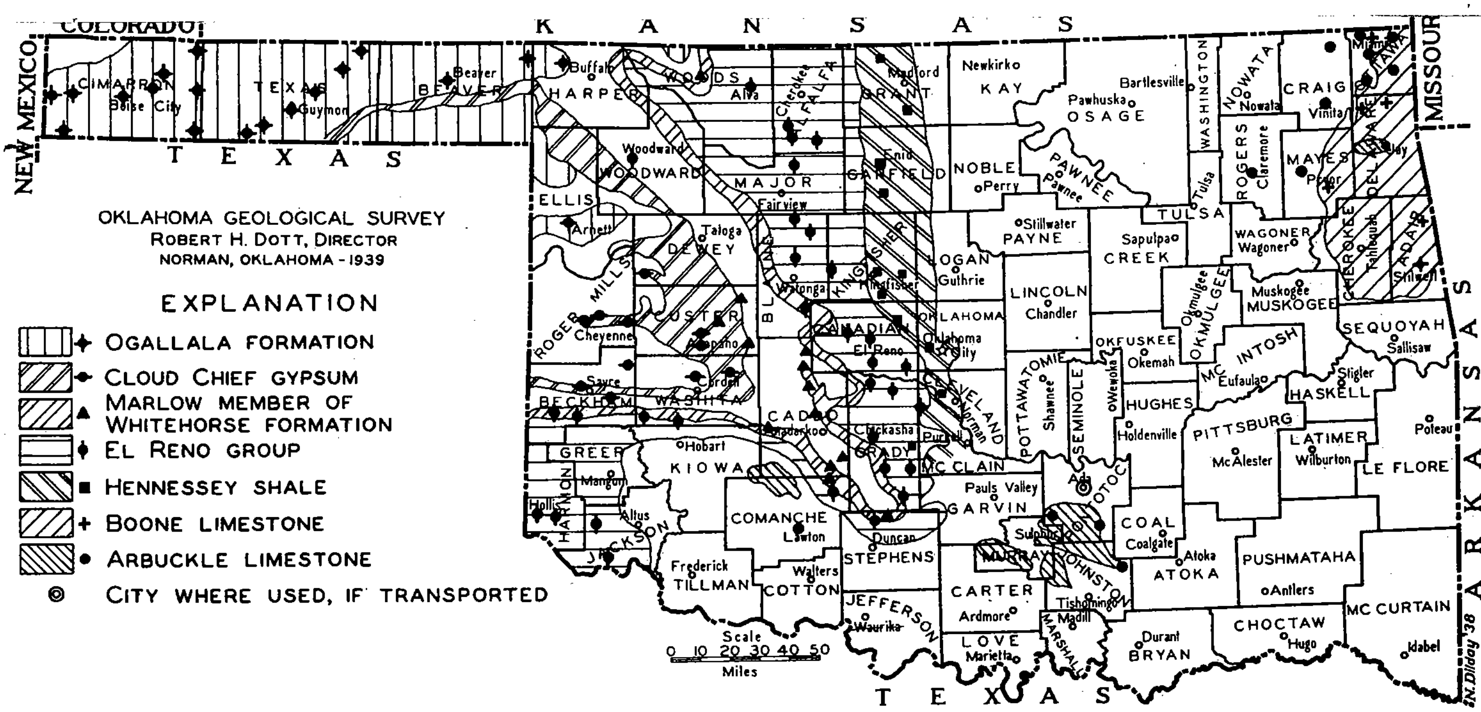
24. Boone limestone yields soft water in Ozark area. Springs issue at base, at contact with Chattanooga shale.

25. Simpson group yields water on flanks of Ozarks and Arbuckle Mountains, where it is often mineralized, notably at Sulphur.

26. Arbuckle limestone yields water on flanks of Wichita, Arbuckle and Ozark Mountains, often with artesian flow. Water ordinarily of good quality, though hard, but locally highly mineralized at depth.

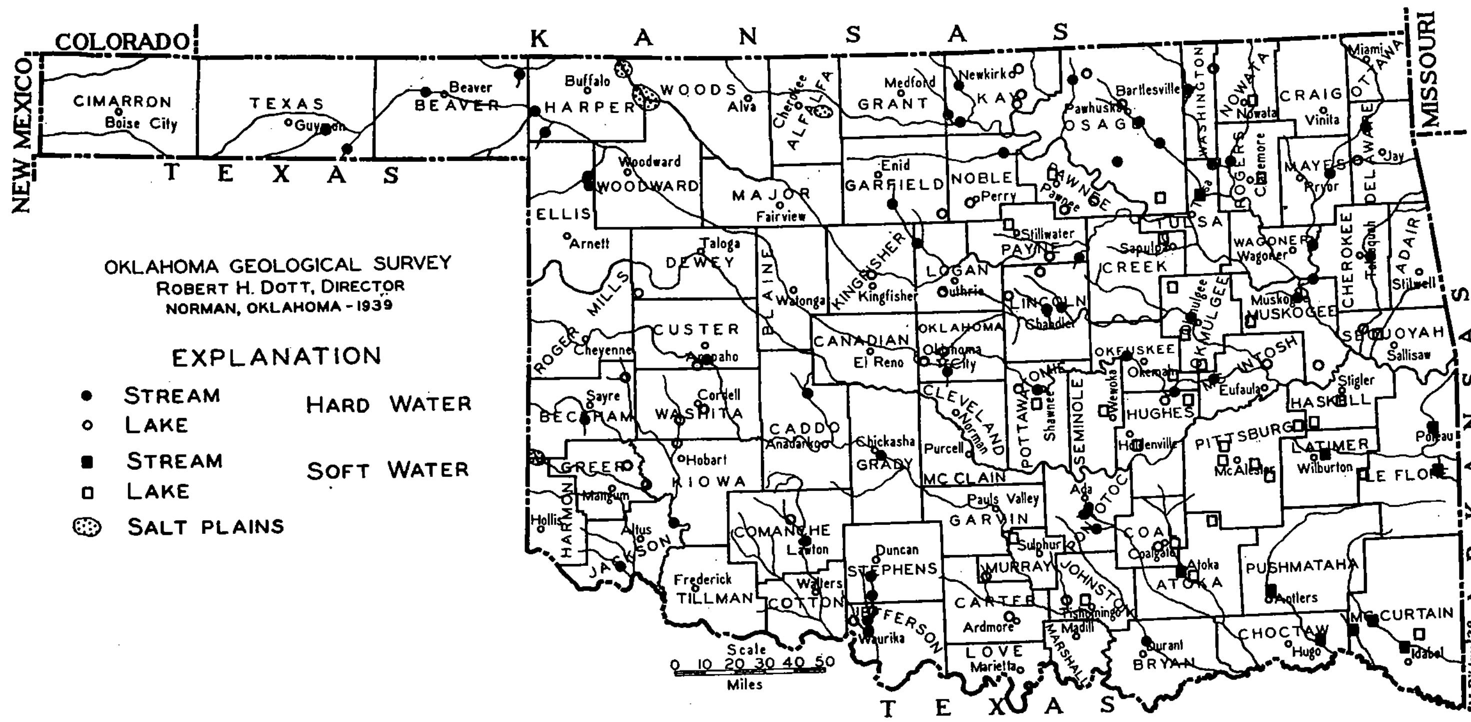
TABLE 2 D. Cambrian and Ordovician Aquifers

Age	Southwestern Oklahoma	South Central Oklahoma	Northeastern Oklahoma	Water bearing properties
Ordovician	Absent	Sylvan shale	Absent	
	Viola limestone	Viola limestone	Fernvale limestone Fite limestone	
	Simpson group	Simpson group*	Tyner formation Burgen sandstone*	See note 25
	Arbuckle limestone*	Arbuckle limestone*	Cotter dolomite*	See note 26
Cambrian	Honey Creek limestone Reagan sandstone		Absent	
Pre-Cambrian	Granite	Granite	Granite	



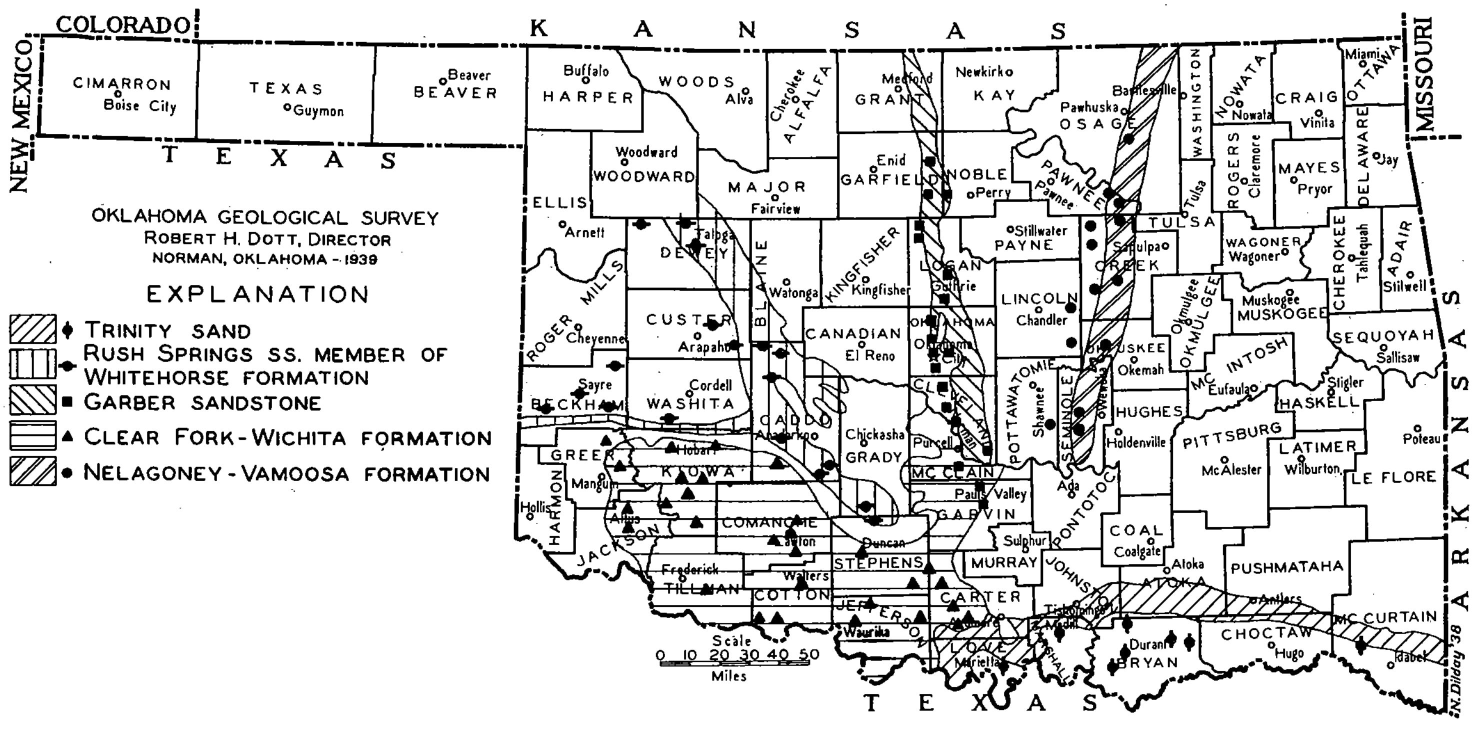
This map shows the areas in Oklahoma supplied by water from different formations, with outcrops and locations of wells and springs on which chemical analyses are available. The outcrops are shown by patterns, wells and springs by symbols. These waters are high in calcium carbonate and sulfate.

28

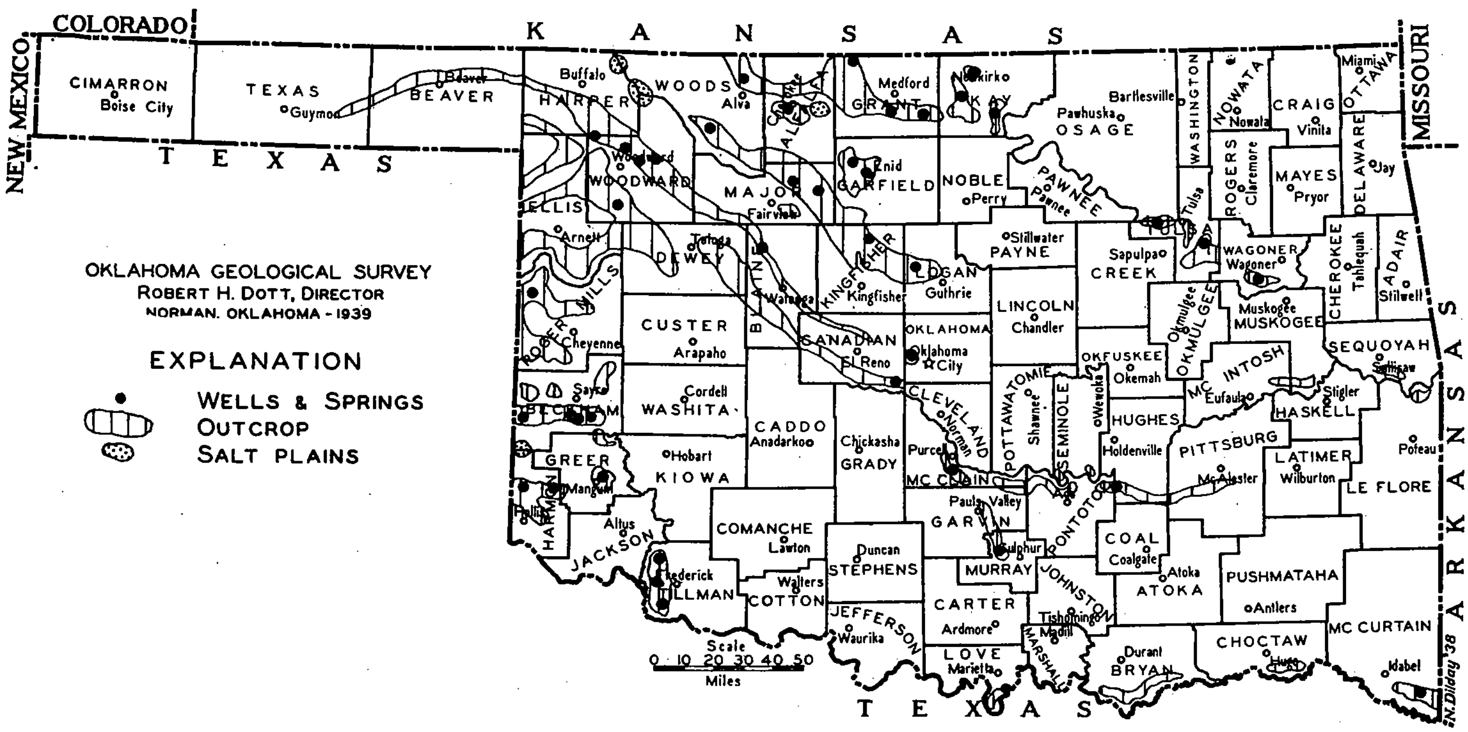


Locations of supplies of surface water. Waters containing over 100 p. p. m. total hardness are classified as hard, and those under 100 p. p. m. as soft.

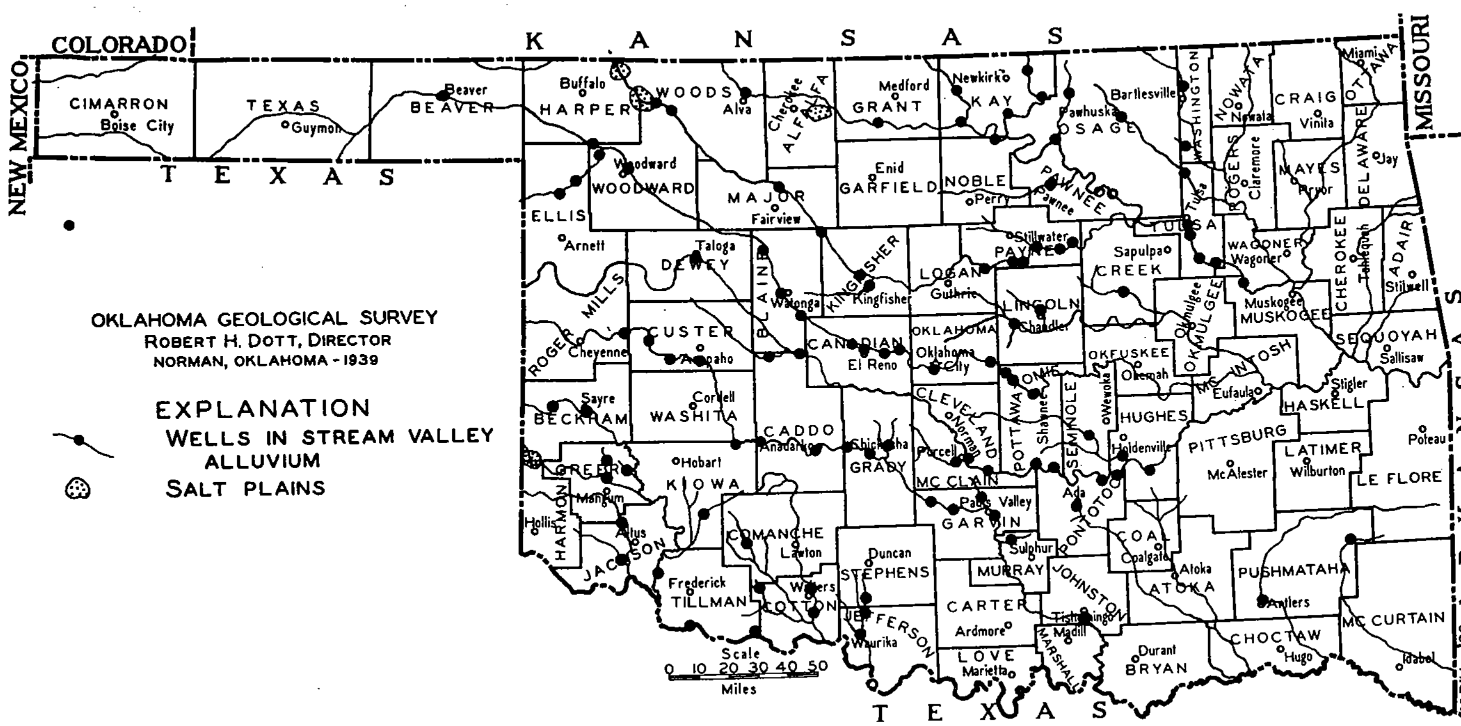
29



Map showing areas of outcrops and wells in formations yielding water high in sodium carbonate and sulfate.



Map showing location of Quaternary terrace deposits and wells yielding water from them.



Map showing locations of samples of water considered from the alluvium.

15. Data on Wabaunsee formation from Payne, Pawnee, Lincoln and Pottawatomie Counties. Soft water, locally high in sodium sulfate and considerable sodium carbonate and chloride. Calcium sulfate present in Pottowatomie County.

16. Data on Elgin sandstone from Creek, Osage and Pawnee Counties. Soft water, locally high in sodium chloride.

17. Nelagoney-Vamoosa formation is an important aquifer in east-central Oklahoma. Water is locally high in calcium sulfate, sodium sulfate and sodium chloride.

18. Data on Ochelata formation from two wells only, in Osage and Washington Counties.

19. Water from Francis formation and equivalents is characterized by relatively high sodium carbonate, sodium sulfate and sodium chloride.

20. Data from three wells only in Seminole sandstone, from Hughes and Okfuskee Counties. Water from Seminole is extensively utilized in Tulsa and vicinity.

(Pennsylvanian Aquifers - Continued)

Age		South-Central	East Central	Northern	Water bearing properties
PENNSYLVANIAN	Des Moines Group	Holdenville sh.*	Holdenville sh. Wewoka fm. Wetumka sh.*	(Memorial sh. (Lenapah ls. (Nowata sh. (Oologah fm. (Labette sh. (Ft. Scott ls.	See note 21
		Calvin ss.* Senora fm. Stuart sh. Thurman ss. Boggy fm.* Savanna fm. McAlester fm.* Hartshorne ss. Upper Atoka fm.	Calvin ss.* Senora fm. Stuart sh. Thurman ss. Boggy fm.* Savanna fm. McAlester fm.* Hartshorne ss. Upper Atoka fm.	Cherokee shale: Calvin ? ss.* Shale Thurman ss.* Boggy fm.* ((Absent ((	See note 22 See note 23
	Bend	Lower Atoka fm. Wapanucka ls. Springer fm.	Lower Atoka Wapanucka ls. Springer fm.	((Absent (	

21. Rocks of upper Des Moines group yield water that is generally soft, but relatively high in sodium carbonate and sodium chloride.

22. Boggy formation yields supplies of fair quality water in eastern Oklahoma.

23. McAlester formation yields soft water, high in sodium carbonate, from sandstone members, in eastern Oklahoma. Some water from shale members in certain areas, where structural movements have produced jointing.

TABLE 2 C. Silurian-Mississippian Aquifers

Age	Southwestern Oklahoma	South Central Oklahoma	Northeastern Oklahoma	Water bearing properties
Mississippian	Absent	Caney shale Absent ? Woodford shale	Chester Group Moorefield shale Boone limestone* Chattanooga shale	See note 24
Devonian	Absent	Frisco limestone Bois d'Arc limestone) Haragan shale)	Sallisaw sandstone Frisco limestone Absent	
Silurian	Absent	Henryhouse shale) Chimney Hill limestone)	St. Clair limestone	

(Continued)