PRELIMINARY REPORT ON THE INVESTIGATION OF SALT SPRINGS AND SEEPS IN A PORTION OF THE PERMIAN BASIN IN TEXAS

By

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INTRODUCTION

The Permian Basin (fig. 1) comprises a large area in the southern midcontinent region and includes major portions of Texas, New Mexico, Oklahoma, and Kansas. Within this basin brine springs and seeps discharge more than 20,000 tons per day of sodium chloride (common table salt). This brine contaminates many streams greatly impairing the utility of their waters. The water in some streams is of such poor quality it cannot be used for municipal and industrial purposes and for irrigation. Nor is the problem limited to the Permian Basin. The contaminated streams leaving the Permian Basin bring salty water to downstream areas of Arkansas and Louisiana, as well as to other parts of Texas, New Mexico, Oklahoma, and Kansas. In no comparable area of the interior United States are natural sources of salt water so widespread or deleterious to the fresh water supply of so large a segment of the nation's population and industry.

The Brazos River traverses the eastern part of the Permian Basin, and is potentially one of the principal sources of water in Texas. It carries an average daily load of 1,650 tons of sodium chloride (common table salt) into Possum Kingdom Reservoir, about 110 miles west of Dallas. More than 85 percent of this salt is contributed by the Salt Fork Brazos River, and more than one-half originates from Springs and seeps in Croton and Salt Croton Creeks, tributaries to the Salt Fork Brazos River. The undesirably high chloride content of the water impounded in Possum Kingdom Reservoir limits the utility of this water, although it is used for irrigation and by some industries.

Understanding of the origin and hydrology of the natural brine is fundamental to consideration of engineering measures to control the flow of salt water to streams, or to general plans to

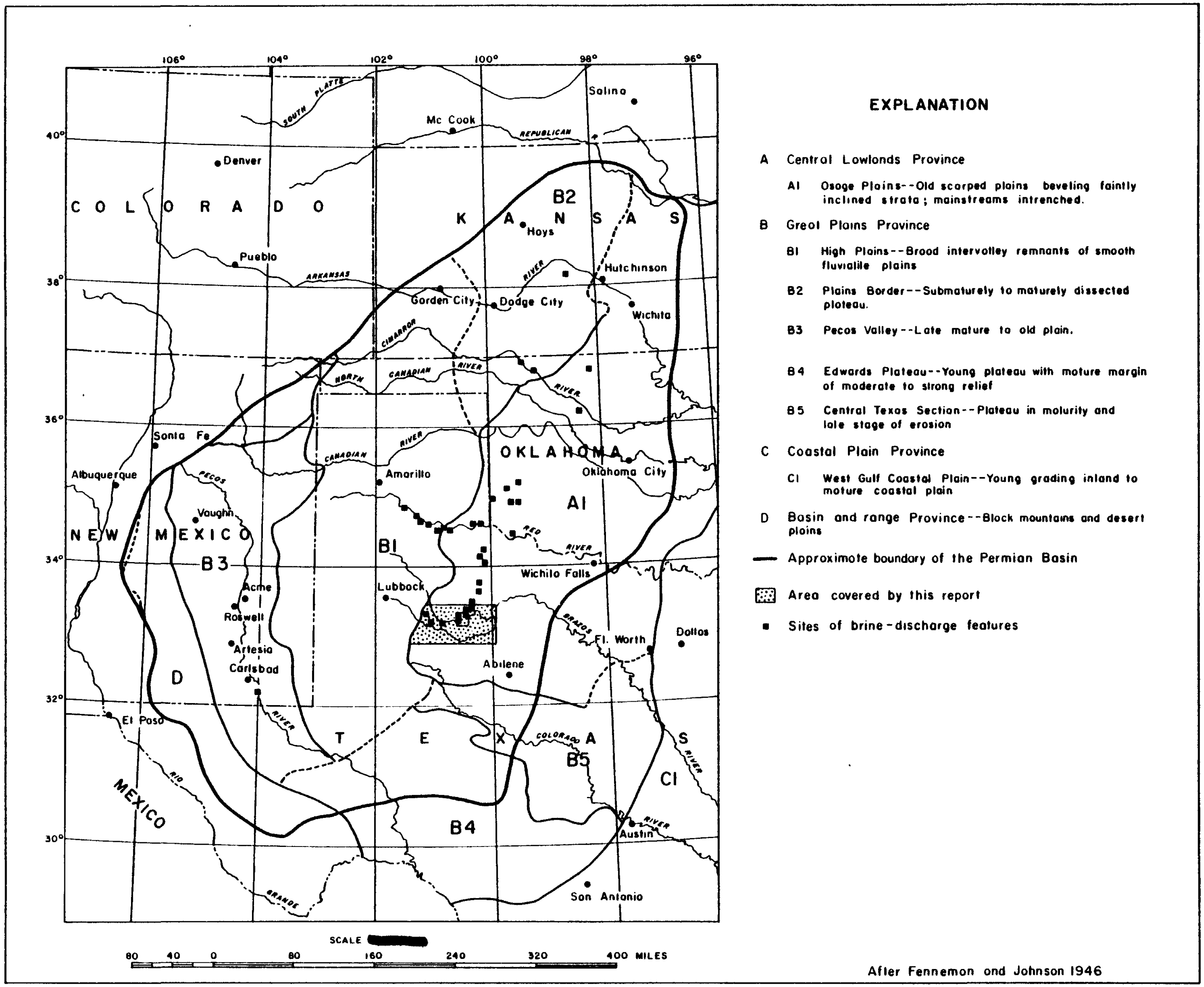

FIGURE 1.- Map of the Permian Basin showing physiographic divisions, sites of brine discharge, and the area covered by this report

alleviate the situation in any way that includes altering the brine-discharge system.

Previous investigations of natural brine features have been directed toward describing the local details of individual problem areas. Thus the occurrence of brine features has been described strictly in terms of the local environment. The origin and discharge of brine have been ascribed invariably to local sources and to local hydraulic controls. The case for local origin of the brine has been stated by Ward and Leonard (1961). According to their hypothesis brines evolve in the circulation of ground water in local hydraulic systems which feature the following conditions: (a) halite deposits or halite-bearing rocks at relatively shallow depth; (b) ground water that circulates to the halite-bearing zones; and (c) a local topographically low area where the water can emerge as a mineral spring.

An alternate hypothesis (Greenman and Stevens, 1963) is that the salt springs originate as outcrops of a regional body of brine and that the primary factors determining their distribution are regional hydrologic controls, such as physiography, geology, and climate. The precise location of springs, the nature and amount of discharge, as well as their salinity, depend on secondary hydrologic factors, such as local geologic conditions, local topography that governs the movement of the overlying fresh water, and the hydrologic environment in the vicinity of the springs, which determines the amount of mixing of the brine and the fresh water at each locality. In general, the brine is a water body separate and distinct from the overlying fresh water. The salinity of individual springs is determined by the amount of mixing of the brine with the fresh water--not by solution of salt-bearing materials in local hydraulic systems. The geographic zone in which all of the brine springs and seeps occur is determined by regional topographic and perhaps climatic conditions. If the regional hypothesis is true, remedial measures must take into account a set of hydraulic and hydrologic circumstances that is fundamentally different from that postulated previously.

PURPOSE

In 1963 the Geological Survey began an investigation of part of the eastern Permian Basin in order to test the regional hypothesis of origin of the salt springs and seeps. The broad purpose of the work is to determine the origin of the salt springs and the factors that control their discharge and salinity. The work has been concentrated in the headwaters area of the Brazos River basin and has included test drilling to check the hydraulics of the spring discharges, to determine the salinity of the water and the degree of separation of the fresh water and the brine, and to observe, if possible, directions and rates of movement of fresh water and brine. This paper is a preliminary report of findings with suggestions about how these findings bear on the regional hypothesis.

LOCATION AND EXTENT OF AREA

The area selected for study is that part of the Brazos River basin upstream from the confluence of the Double Mountain Fork and the Salt Fork and east of the escarpment of the High Plains in Texas (fig. 1). This progress report concerns principally the drainage basins of Salt Croton Creek, Croton Creek, and Duck Creek, tributaries to the Salt Fork Brazos River, shown on figure 2. This area was designated the "Croton Creek - Salt Croton Creek area" in a previous report (Baker and others, 1964). The entire area of concern appears on the Lubbock, Big Spring, and Wichita Falls sheets of the map of the United States, scale of 1:250,000, prepared by the Army Map Service. The Croton Creek - Salt Croton Creek area appears on the following U.S. Geological Survey 7½-minute topographic quadrangle maps: Bob Creek, Gilpin, Girard, Jayton, Lovers Resort, Pursley House, Seven Diamond L. Canyon, and Southerland Canyon.

PREVIOUS WORK

Many publications describe various aspects and features of the geology and hydrology, but only a handfull deal directly with the problem of natural brine (Latta, 1950, H. R. Blank, 1955, Mason and Johnson, 1955, McMillion, 1958, Ward, 1961, and Baker, Hughes, and Yost, 1964). Currently the Corps of Engineers and the Public Health Service are making detailed studies of problem areas in the Arkansas and Red River basins aimed at improving and controlling water quality in these streams (U.S. Army Engineer District, Tulsa, 1965).

METHODS OF INVESTIGATIONS

Twenty-six test holes, ranging in depth from 30 to 625 feet, were the primary source of information on geologic and hydrologic conditions, on water quality, and on the position of the brine-fresh water interface. As shown on figure 2, they centered around Short Croton Creek Salt Flat with some to the west in Duck Creek, which is free of brine contamination, and some to the northeast

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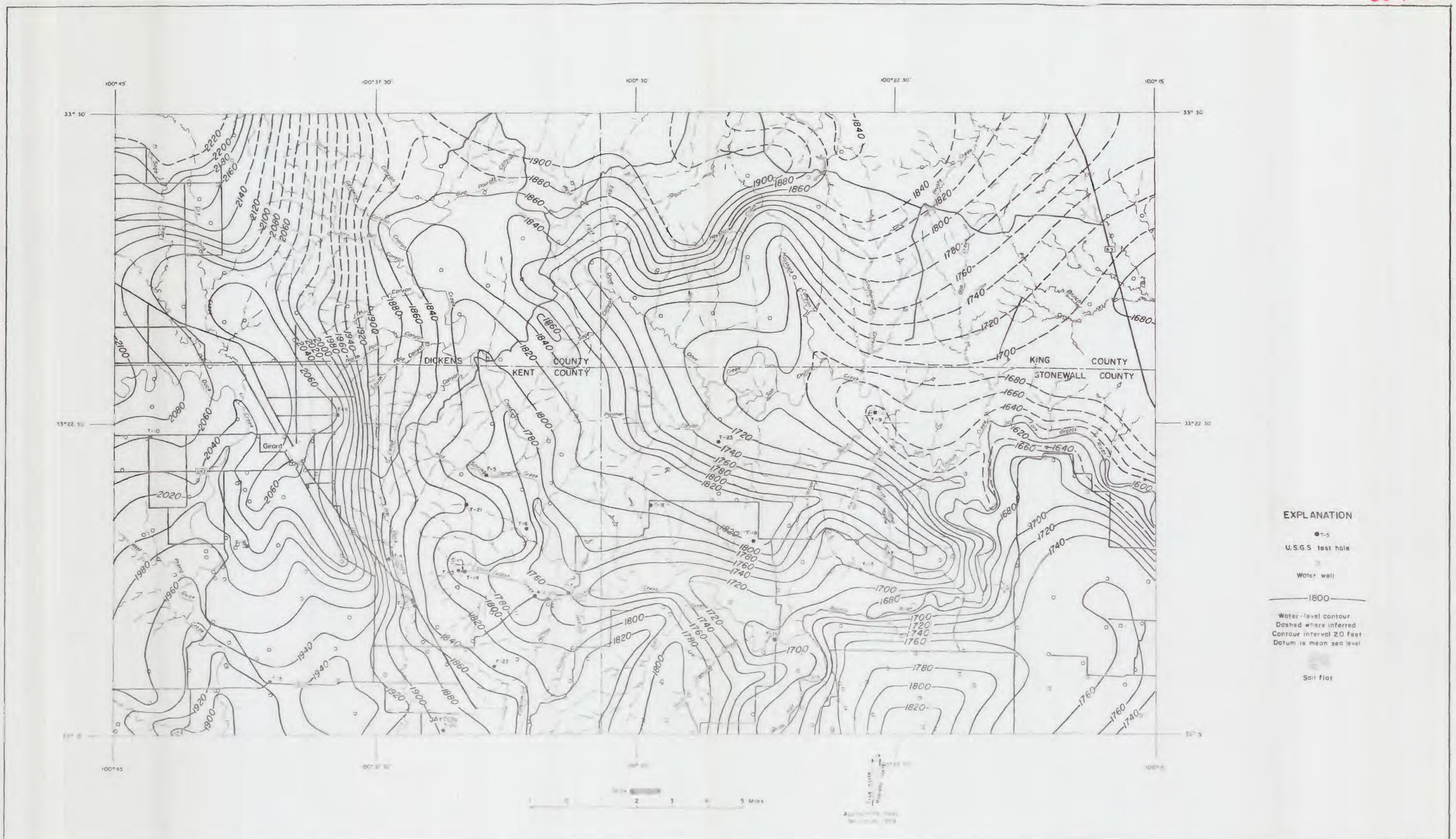

Figure 2.—Map of the Croton Creek–Salt Croton Creek area showing the locations of well and contours on the water table

in Dove Creek, which contains prominent brine features. Samples of water were collected using modified oil well straddle packers and pneumatic straddle packers to isolate the interval sampled. Selected samples of this water were analyzed for chemical, radiochemical, and minor metal constituents and for content of certain isotopes. During the drilling, samples of drill cuttings were collected at intervals of 5 feet and at each change in formation from the land surface downward to the bottom of the hole. The specific conductance of the drilling mud was monitored during drilling to determine at what interval brine or halite was encountered by the bit. Cores were taken, and selected sections were analyzed in the laboratory to determine the physical and hydrologic properties of representative sections of the rocks penetrated and to provide data necessary for positive correlation and semi-quantitative interpretation of geophysical logs. In addition, more than three-fourths of the existing wells in the Croton Creek - Salt Croton Creek area were inventoried and the depth to water was measured. Samples of water were collected from selected wells, springs, and streams for chemical analysis.

Information on subsurface conditions in the vicinity of Dove Creek Salt Flat is obtained from a dam-site investigation and salt-water study made for the Brazos River Authority by Mason-Johnson and Associates, Dallas, Texas.

Finally, geophysical techniques (well-logging) in the bore holes were used extensively to provide positive stratigraphic correlation between test holes, to locate the position of the brine-fresh water interface both inside and outside the boreholes, and to determine the horizons at which to set straddle packers during sampling. The geophysical testing was done as a part of a research project, "Borehole geophysics as applied to geohydrology," under the leadership of W. S. Keys. The results of the borehole geophysical studies to date, the techniques used, and the principles of the applied techniques necessary for an understanding of the interpretations will be described in a report by Keys.

RESULTS OF THE EXPLORATION

Results of the test-drilling and field work reveal several significant facts. First, the data indicate the presence of two distinct bodies of ground water: shallow "fresh" water and a deeper brine. A relatively sharp interface separates the two. Brine movement, though affected locally by the head or thickness of overlying fresh water, has a circulation pattern of its own, independent of local recharge.

SHALLOW FRESH GROUND WATER

A shallow body of relatively fresh ground water underlies the area. This water is called "fresh," but it contains 2,000 to 5,000 ppm (parts per million) of total dissolved solids. The water serves many purposes and is fresh relative to the underlying brine. The density exceeds 1.000 g/ml (grams per milliliter) only slightly, and is considered to be 1.

Figure 2 shows contours on the water table, derived from water level measurements in about 300 wells, and certain of the test holes. The contours show a range in altitude from 2,220 feet above sea level in the northwest corner of the area to about 1,600 feet along the Salt Fork of the Brazos River near the southeast corner. In a broad sense the water table slopes from west to east and in detail slopes from high ridges or mounds beneath the inter-fluves to low troughs along the perennial streams. Thus the water table is a modified image of the land surface; and the shallow ground water itself discharges from high places to the lower intervening stream valleys.

Preponderant evidence indicates that, relative to the brine, the chemical composition of the fresh water is everywhere about the same, both in total dissolved solids and in the relative abundance of various constituents. The water is predominantly of the calcium-sulfate type, presumably owing to solution of gypsum at shallow depth. Halite has been encountered in this area in test holes and has been reported in local wells, but it always occurs in brine-saturated rocks. As the brine is saturated with sodium chloride, it is in equilibrium with the associated halite. Under these conditions the existing deposits of halite are not susceptible to solution and are an improbable source of the brine.

It is probable that the brine originated at least in part from deposit of halite that existed in the fresh-water zone sometime in the geologic past. If so, the deposits have been largely dissolved away, because no traces of them were found. The chemical composition of the fresh water varies somewhat, but no systematic differences in composition either areally or with depth indicate any progressive gradation from fresh water into brine. Furthermore, there is no significant change in the chemical composition or concentration of the fresh water along approximate flow paths.

THE BRINE-FRESH WATER INTERFACE

A thin zone of transition, whose position can be approximately represented by a surface, lies between the fresh water and the underlying brine. This zone of transition will be referred to as the "interface." The position and shape of the interface in the Croton Creek - Salt Croton Creek area are shown by contours in figure 3. The contours are based upon the position of the change from fresh to salt water as found in the test drilling and upon the inferred position of this change obtained through interpretation of geophysical logs of 110 stratigraphic test holes drilled in previous years. The electric logs of the stratigraphic test holes were obtained through the courtesy of the Continental Oil Company and the Skelly Oil Company. Interpretation of these logs and of the geophysical data obtained from the U.S. Geological Survey test holes were made by W. S. Keys and E. R. Bullard. These interpretations are preliminary.

At some places, the interface occurs within a dense shale or layer of anhydrite, but at others, it occurs within a pervious silt or sandstone. In detail, the configuration of the interface is partly controlled by stratigraphy, but in general it transects lithologic units and is not related to stratigraphy or structure (fig. 4). The Permian rocks dip southwest at a uniform rate of about 25 feet per mile but the interface, although very irregular, has a general slope to the southeast.

Figure 5 shows the shift on the single point resistivity log and neutron epithermal neutron and neutron gamma logs indicating the position of the interface in test hole T-18. This illustration is taken from a report to be published by Keys.

The detailed configuration of the interface is closely related to the thickness of the overlying body of fresh water. Comparison of the map of the interface (fig. 3) and the map showing the thickness of fresh water (fig. 6) indicates that the depth of the interface below land surface is greatest where the thickness of fresh water overlying the brine is greatest. Conversely, in the valleys where the thickness of fresh water is the smallest, the depth of the interface below land surface is generally least. Although the data are insufficient to show a relation with all the local topographic highs and lows, the configuration of the interface in general resembles an inverted and much subdued image of the topography.

The interface constitutes a hydraulic boundary separating the brine and fresh water into two systems of water flow.

THE BRINE

Very salty water, or brine, was encountered in all the test holes. It has been encountered in many of the ranch and stock wells throughout the area that have been deepened in attempts to increase their yields, and it's presence is inferred from electric logs in oil company stratigraphic test holes. All available data indicate that this water underlies the entire area, and discharges in the salt springs and seeps. The total dissolved solids content of the brine averages about 250,000 ppm, although the content is less where diluted with fresh water, or contaminated by drilling mud or mud infiltrate. In contrast to the overlying fresh water, the brine is predominantly of the sodium-chloride type. The density of water having a total dissolved solids content of 250,000 ppm is about 1.2 g/ml. This has been confirmed by density measurements of water samples, both in the field and in the laboratory.

Movement of Brine

Because the bodies of brine and fresh water are in hydraulic continuity, their pressures near the interface are very nearly equal. Therefore, in a well screened just below the interface, the brine would rise approximately to the water table, if the brine had the same density as the fresh water. However, because the brine has a density of 1.2, it would rise in such a well to a level somewhat below that of the water table. Neglecting head differences due to vertical components of flow, the height to which the brine would rise above the interface, is the thickness of the fresh-water zone multiplied by the ratio of the density of fresh water to that of the brine. By adding this height to the altitude of the interface at representative points we can obtain the piezometric surface of the brine.

Figure 7 shows the computed form and position of the piezometric surface of the brine system. In general, the movement of the brine is down gradient at about right angles to the piezometric contour lines. In detail the movement of brine is more complex than is indicated on figure 7. However, no greater detail can be derived from the available data. The piezometric surface of the brine is highest in the northwestern part of the report area and movement of the brine is generally eastward toward Croton Creek and Dove Creek. Movement of brine from the piezometric high between Dove Creek and Croton Creek is down gradient toward each creek.

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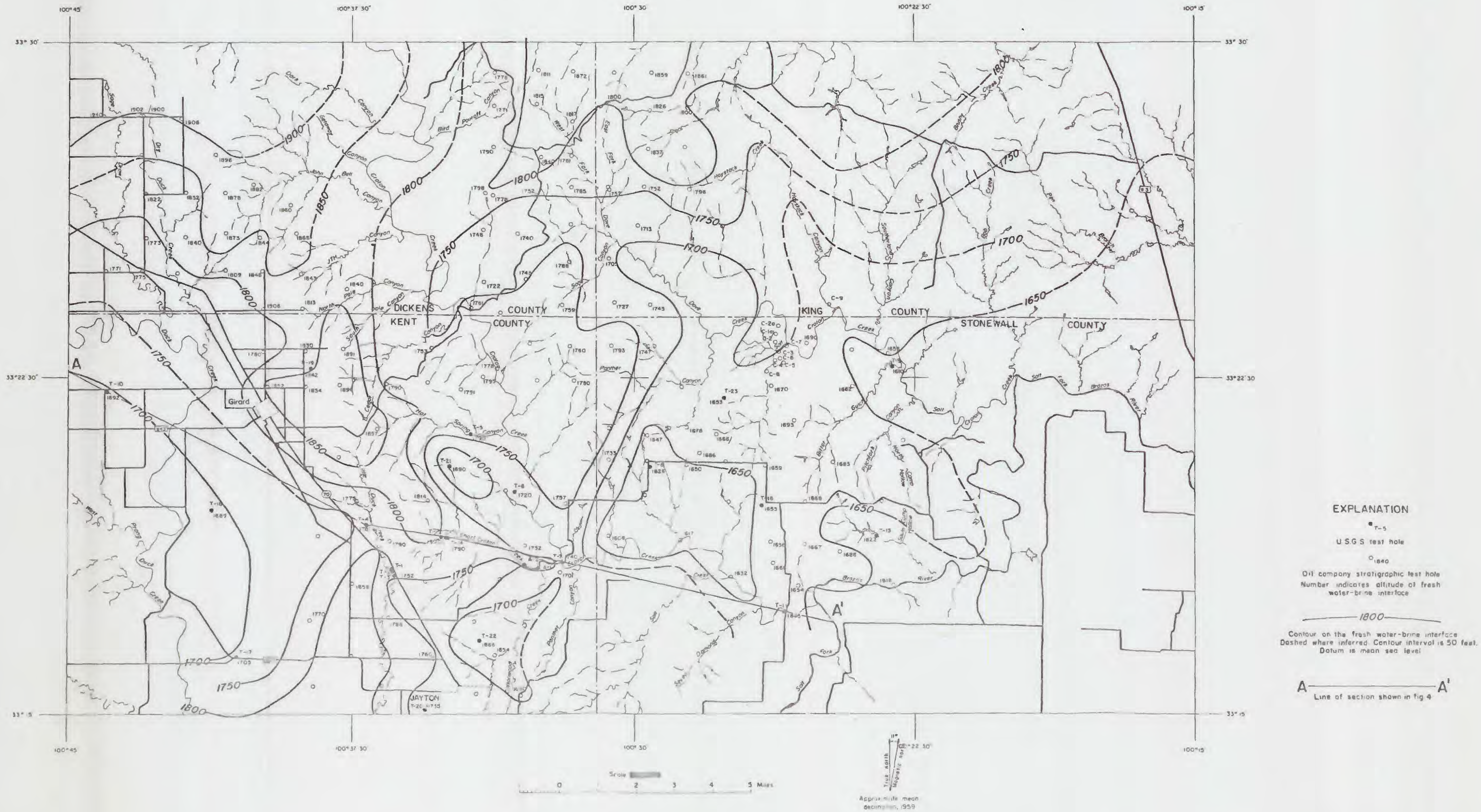

Figure 3.–Map of the Croton Creek–Salt Croton Creek area showing the location of test holes and contours on the fresh water-brine interface

Figure 4.-East-west section through the Croton Creek-Salt Croton Creek area showing geologic and hydrologic relations

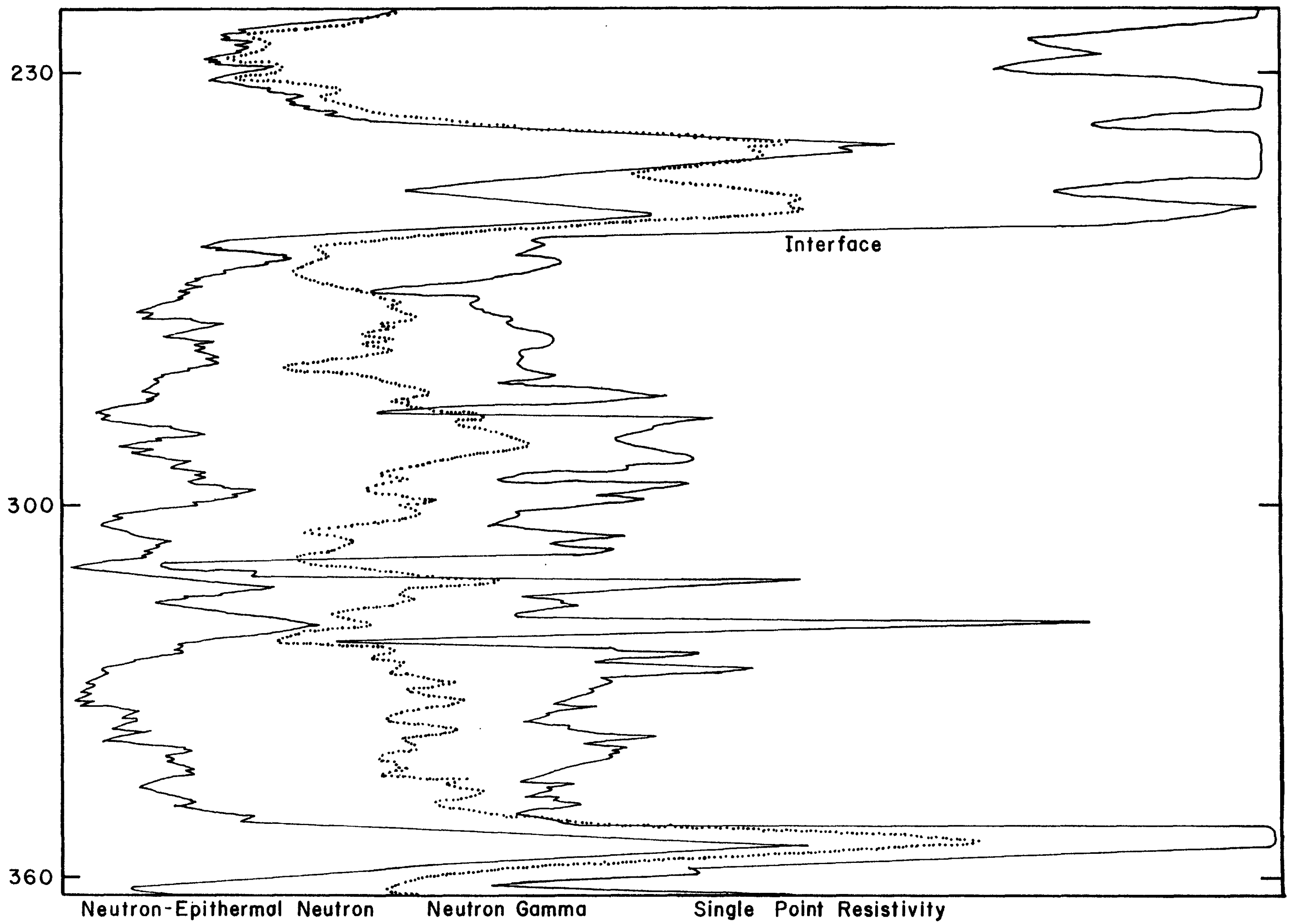

FIGURE 5. - LOCATION OF THE BRINE-FRESH WATER INTERFACE FROM GEOPHYSICAL LOGS T-18

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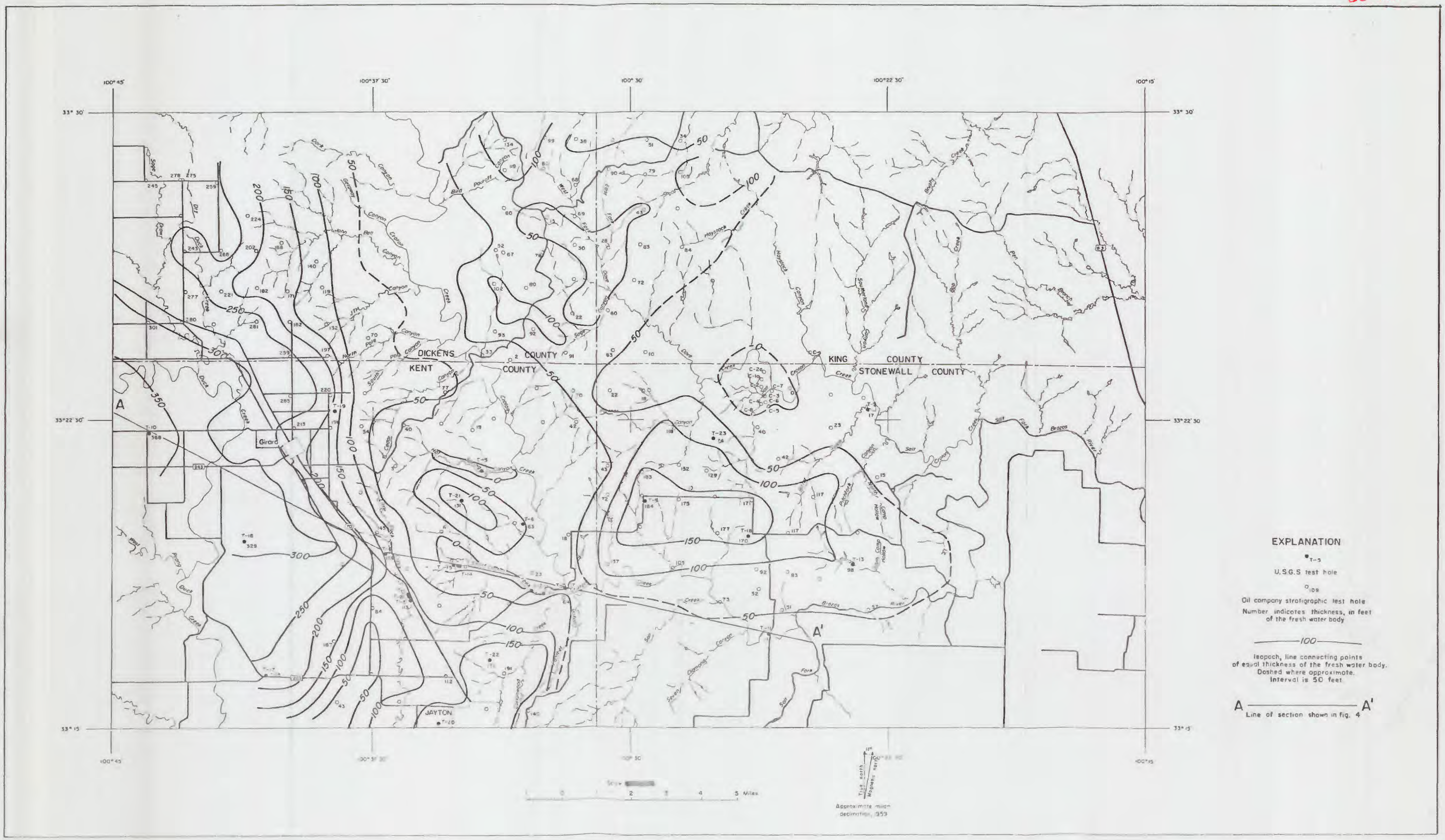

Figure 6.—Map of the Croton Creek–Salt Croton Creek area showing thickness of the fresh water body

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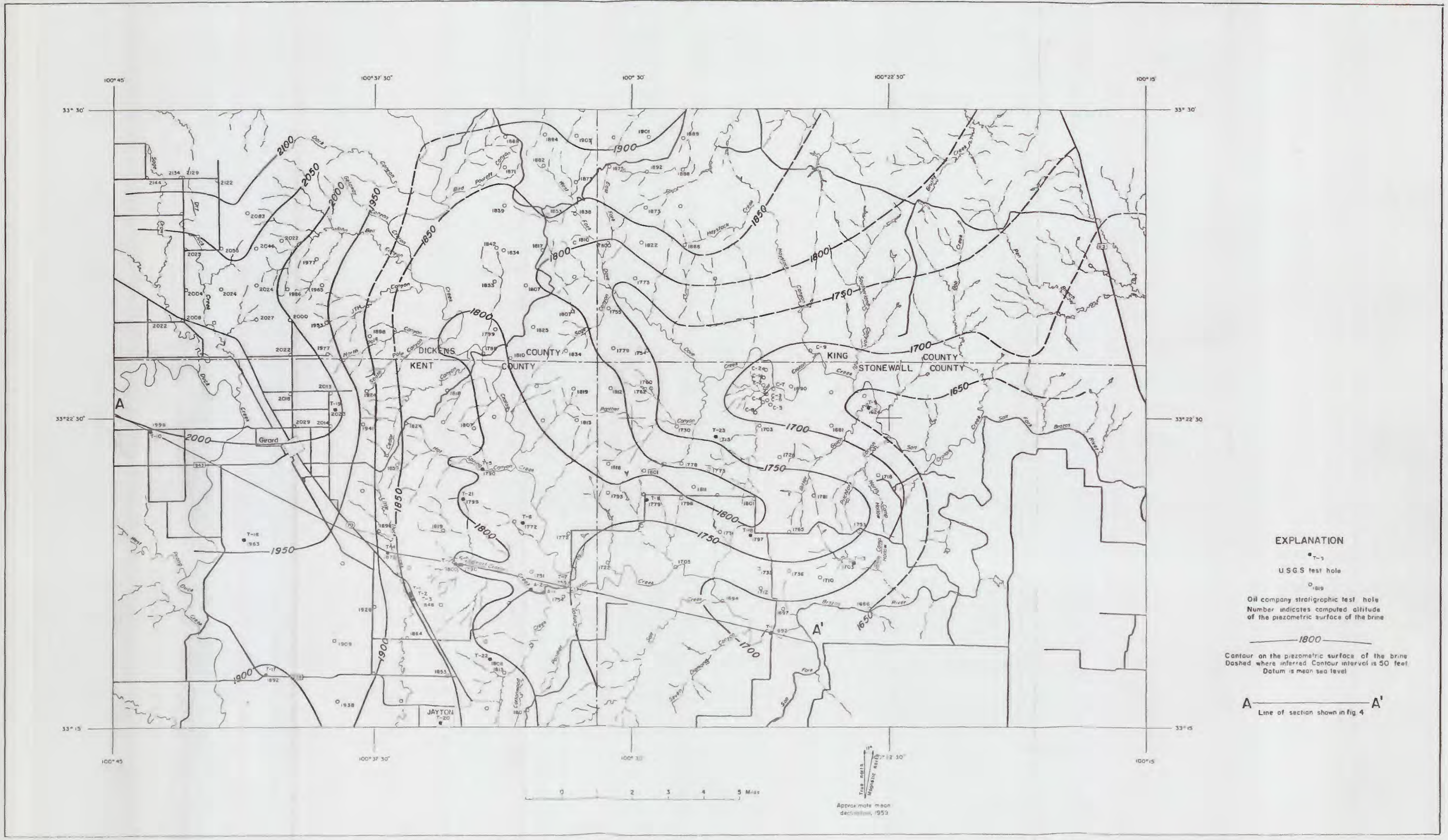

Figure 7.–Map of the Croton Creek–Salt Croton Creek area showing contours on the piezometric surface of the brine

The rate of movement of the brine is proportional to the hydraulic gradient and to the permeability of the rocks through which it moves. The hydraulic gradient is locally fairly high, but the permeability of the rocks is very low. The computed rate of movement of brine ranges from a few hundredths of a foot to more than 2 feet per year. Permeabilities are determined from laboratory tests on selected pieces of rock core. Owing to joints and fractures the overall formational permeability may exceed substantially the intergranular permeability of the rock samples. Hence the actual rate may exceed considerably the computed rate.

Discharge of Brine

Seeps and springs at the salt flats on Hot Springs, Short Croton, Dove, and Haystack Creeks are the principal points of brine discharge. Discharge at the salt flats on Hot Springs and Short Croton Creek is facilitated by fractures and solution openings in a bed of gypsum that crops out at the margins of these salt flats. Analyses of water from springs issuing from this gypsum indicate that the water is probably a mixture of about two parts fresh water and one part brine. The gypsum lies in the lower part of the fresh-water body, and intersects the interface about 1/2 mile west of well T-15 (see fig. 4). Below the interface the bed consists of anhydrite. Above the interface anhydrite has probably been partly or completely altered to gypsum by reaction with fresh water. Probably the geometry of the solution openings controls the movement of water through this bed and facilitates mixing of fresh water and brine during movement up the dip, but down the hydraulic gradient, to salt flats. Test drilling at Dove Creek Salt Flat by Mason and Johnson (1955) indicates that in the vicinity of this salt flat similar conditions exist and the flow of water is further influenced by fractured shale.

The low trough on the piezometric surface downstream from the salt flats on Croton Creek and Salt Croton Creek indicates that brine is discharging in this area, although there is little direct evidence of discharge. Discharge in this area probably is very small, owing to the extremely low permeability of the rocks, and probably is distributed over a considerable length of the stream. Furthermore the brine enters alluvium in the stream bed and because the stream is intermittent and evaporation is rapid, water evaporates and salt is deposited on the surface of the stream bed. Discharge of brine in the reach downstream from the salt flats cannot be separated from, and is effectively masked by, the relatively large discharge of brine from the salt flats. During periods of runoff, of course, the salt is flushed from the stream bed. Thus, concentration of brine discharge at each brine feature and the exact location of brine features within the zone of transition between the High Plains and the Osage Plains, is controlled by secondary factors. Local geology determines the distribution of permeability in the rocks. Local topography governs the movement of fresh water, the geographic distribution of the thickness of the fresh-water body, and the localities where the brine is sufficiently close to land surface for discharge to occur.

ORIGIN OF THE SALT SPRINGS

Detailed exploratory work in the Croton Creek - Salt Croton Creek area indicates that a distinct and separate body of brine underlies the entire area. Data from scattered localities and miscellaneous reports suggest that this brine body extends many miles westward beneath the High Plains. It is therefore reasonable to infer that salt springs and seeps are places where this body of brine crops out, or where it is near the surface and is induced to rise hydraulically and to discharge into valley bottoms where the overlying body of fresh water is very thin or absent. Actual points of discharge seem to be controlled by local geology which determines the distribution of permeability within the locality where the brine is near the surface. The varying salinity of the springs and seeps is explained as due to mixing varying amounts of fresh water with the brine at any one place, although this has not been conclusively demonstrated. Thus, the results of exploration to date seem to support the regional hypothesis of the origin of the brine features.

BEARING ON WATER-QUALITY CONTROL METHODS

Various proposals aimed at improving the quality of the stream waters have been advanced by local, state, and federal agencies. Most proposals call for impoundment and storage of the brine, either within its area of discharge or in off-stream evaporation structures. Some proposals suggest disposal of the brine in the deep subsurface through injection wells; collection of the brine and transporting it to the ocean via a pipeline; and collection of the brine and selling it to the oil industry for water-flood operations in oil fields. Evaluation of these proposals involves economic, engineering and water-management considerations as well as hydrologic factors and is beyond the scope of this report.

The work, on which this is a preliminary report, is expected to outline the broad hydrologic system underlying the origin of the springs--a system that must be taken into account in remedial measures. However, within this framework, one or another specific plan may or may not be feasible and effective, depending on the specific geologic and hydrologic conditions at each local site. For example, impoundment of the brine within its area of discharge is an appealing remedial measure because the size of the structure required to impound the brine discharge and surface runoff is small and transportation of the brine is not a problem. However, such impoundment will apply hydraulic head on the brine system. It might work at some places. At others it might simply cause the site of brine discharge to shift to the nearest permeable zone downstream and render the impounding structure ineffective.

Detailed hydrologic studies at the sites of off-stream evaporation reservoirs would be essential to determine whether or not the reservoirs would be water-tight or whether or not leakage of brine would contaminate circulating fresh ground water.

FUTURE WORK

Results of studies in the Croton Creek - Short Croton Creek area support the basic tenets of the regional hypothesis but do not demonstrate conclusively that the brine is a regional feature or that the hydrologic controls that operate in the area are basin wide.

Further work is needed to demonstrate whether or not brine features at Salt Creek, North Croton Creek, McDonald Creek, and a salt spring north of Clairmont are related to the brine system in the Croton Creek - Salt Croton Creek area, and whether the same hydraulic controls pertain throughout the Upper Brazos Basin.

The Salt Fork Brazos River and the Double Mountain Fork Brazos River flow in parallel valleys down the regional topographic slope traversing the same geologic terrain and thus apparently have the same opportunity to acquire a similar salt load. However, 85 percent of the salt load of the Brazos River at Possum Kingdom Reservoir is contributed by the Salt Fork and only 7½ percent each by the Double Mountain Fork and the Clear Fork. A rational explanation of the difference in the salt loads of these streams must be sought.

A regional reconnaissance to extrapolate the results obtained in the Upper Brazos Basin by collection and analysis of well data, primarily from the oil industry, should indicate whether or not the brine is a regional feature and may demonstrate whether or not the primary controls on the occurrence of brine features are regional.

Current studies and work planned for the near future are along the lines indicated in the foregoing paragraphs.

Interpretation of the geochemical and isotope data may shed some light on the geologic origin and hydrologic history of the brine itself. Investigation of conditions at a brine-discharge feature elsewhere in the Permian Basin would be desirable to demonstrate whether or not the regional controls apply elsewhere in the Permian Basin.

REFERENCES

Baker, R. C., Hughes, L. S., and Yost, I. D., 1964, Natural sources of salinity in the Brazos River, Texas: U.S. Geol. Survey, WSP 1669-CC, 81 p., 11 figs., 4 pls.

Blank, H. R., 1955, Sources of salt water entering the Upper Brazos River: Report, Project 99, Texas A & M Foundation, Dept. of Geology, Agricultural and Military College of Texas, 48 p., 10 pls.

Greenman, D. W., and Stevens, P. R., 1963, Program of water resources investigations for the Permian Basin of Texas, New Mexico, Oklahoma, and Kansas: Unpublished planning report for administrative use, U.S. Geol. Survey.

Latta, B. F., 1950, Geology and ground-water sources of Barton and Stafford Counties, Kansas: Kans. Geol. Survey Bull. 88, 228 p., 11 pls., 18 figs.

Mason and Johnson and Associates, 1955, Dove Creek salt study, Stonewall County, Texas: Mason-Johnson and Associates, Dallas, Texas, 17 p., 13 pls., 2 drawings.

McMillion, L. G., 1958, Ground-water geology in the vicinity of Dove and Croton Creeks, Stonewall, Kent, Dickens, and King Counties, Texas, with special reference to salt-water seepage: Texas Board Water Engrs. Bull. 5801, 53 p., 2 pls., 11 figs.

U.S. Army Engineer District, Tulsa, 1965, Survey report on Arkansas - Red River Basins water quality control study, Texas-Oklahoma-Kansas: U.S. Army Corps of Engineers, Tulsa, Oklahoma, Part 1, vol. 1-5.

Ward, P. E., 1963, 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. Geol. Survey open-file report, 94 p., 3 pls., 23 figs.

Ward, P. E., and Leonard, A. R., 1961, Hypothetical circulation of ground water around salt springs in western Oklahoma, Texas, and Kansas: U.S. Geol. Survey Prof. Paper 424-D, p. 150-151.