UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

# GEOHYDROLOGY OF THE KEECHI, MOUNT SYLVAN, OAKWOOD, AND PALESTINE SALT DOMES IN THE NORTHEAST TEXAS SALT-DOME BASIN

By Jerry E. Carr, Stephen J. Halasz, and Henry B. Peters

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ABSTRACT

The U.S. Department of Energy is considering the feasibility of using salt domes in the northeast Texas salt-dome basin as repositories for radioactive wastes that may require complete confinement for as much as 250,000 years. Four of fourteen known shallow piercement salt domes within the basin--Keechi, Mount Sylvan, Oakwood, and Palestine Salt Domes--have been selected as candidate domes for further study and possible selection as storage sites.

The salt within these domes has penetrated as much as 20,000 feet of Mesozoic and Cenozoic strata, and presently extends to within 120 to 800 feet of the land surface. The salt penetrates or closely underlies major freshwater and salinewater aquifers within the basin. To provide a safe repository for radioactive wastes within one or more of these domes, a thorough understanding of the geohydrology needs to be obtained, and the hydrologic stability of the domes needs to be established for the expected life of the storage facility.

Dissolution may exist at all four candidate salt domes, possibly through contact with Cretaceous or Tertiary aquifers, or through fault systems in the vicinity of the domes. Strata overlying and surrounding Palestine and Keechi Salt Domes have been arched into steeply-dipping folds that are complexly faulted. Similar conditions exist at Oakwood and Mount Sylvan Domes, except that the Tertiary strata have been only moderately disturbed.

Cap rock, which is generally accepted to be an indication of salt dissolution, is present in varying amounts over all four domes. Salinewater has been reported at the surface at all candidate domes except Oakwood, but only two water wells near the domes yield water containing possible anomalous concentrations of dissolved chloride--one at Keechi and one at Oakwood. Possible subsurface plumes of salinewater, which are indications of instability, exist at all four domes. Additional problems concerning the hydrologic stability of Oakwood and Palestine Salt Domes have resulted from the disposal of oil-field salinewater in the cap rock at the Oakwood Dome and previous solution mining of salt at the Palestine Dome

Additional investigations are needed to determine if a selected dome is hydrologically stable. Needed investigations include: (1) A more complete comparative analysis of the regional and local geohydrologic system; (2) a site-specific drilling and sampling program to analyze the cap rock-aquifer boundary, sediment distribution, hydraulic-parameter variations, hydraulic-head relationships, and hydrochemical patterns; and (3) mass-transport computer modeling of ground-water flow at the domes.

# INTRODUCTION

The U.S. Department of Energy is considering the feasibility of using salt domes in the northeast Texas salt-dome basin (fig. 1) as repositories for radioactive wastes that may require complete confinement for as much as 250,000 years. Salt deposits have been under consideration for radioactive-waste disposal since at least 1957, when the National Academy of Science-National Research Council advisory committee concluded that the burial of solid radioactive wastes in bedded-salt deposits was the best of many methods it had considered (National Academy of Science, 1957). A pilot program conducted by the Oak Ridge National Laboratories, 1963-67, in an abandoned salt mine near Lyons, Kan., demonstrated that radioactive-waste disposal was feasible in bedded salt.

Since the early 1970's, investigations have been expanded to include consideration of domal or diapiric salt deposits, which had not been considered previously because of the anticipated difficulties in demonstrating the tectonic and hydrologic stability of such deposits. However, a study conducted during 1974-75 by the Institute of Environmental Studies at Louisiana State University (Martinez and others, 1975) indicated that the stability of particular domes could be adequately evaluated.

Although 14 shallow (2,000 feet or less from land surface to the top of the salt) piercement salt domes occur within the northeast Texas salt-dome basin (fig. 2), only Keechi, Palestine, Oakwood, and Mount Sylvan Domes were selected for further evaluation. Each of these four candidate domes either penetrates or closely underlies water-bearing formations. Dissolution of the salt could occur where these formations are in contact with the domes, or where faults provide hydraulic continuity between the aquifers and the salt.

## Purpose and Scope of This Report

The purpose of this study is to provide information for evaluating selected salt domes in the northeast Texas salt-dome basin as potential storage sites for radioactive wastes. The specific objectives of the study were: (1) To briefly describe the general geohydrology of the northeast Texas salt-dome basin to provide background information; (2) to describe the geohydrology in the vicinity of the selected salt domes; and (3) to identify the needs for additional studies in the vicinity of the selected domes.

This study was limited primarily to the compilation and interpretation of published data and to the examination of about 800 geophysical logs.

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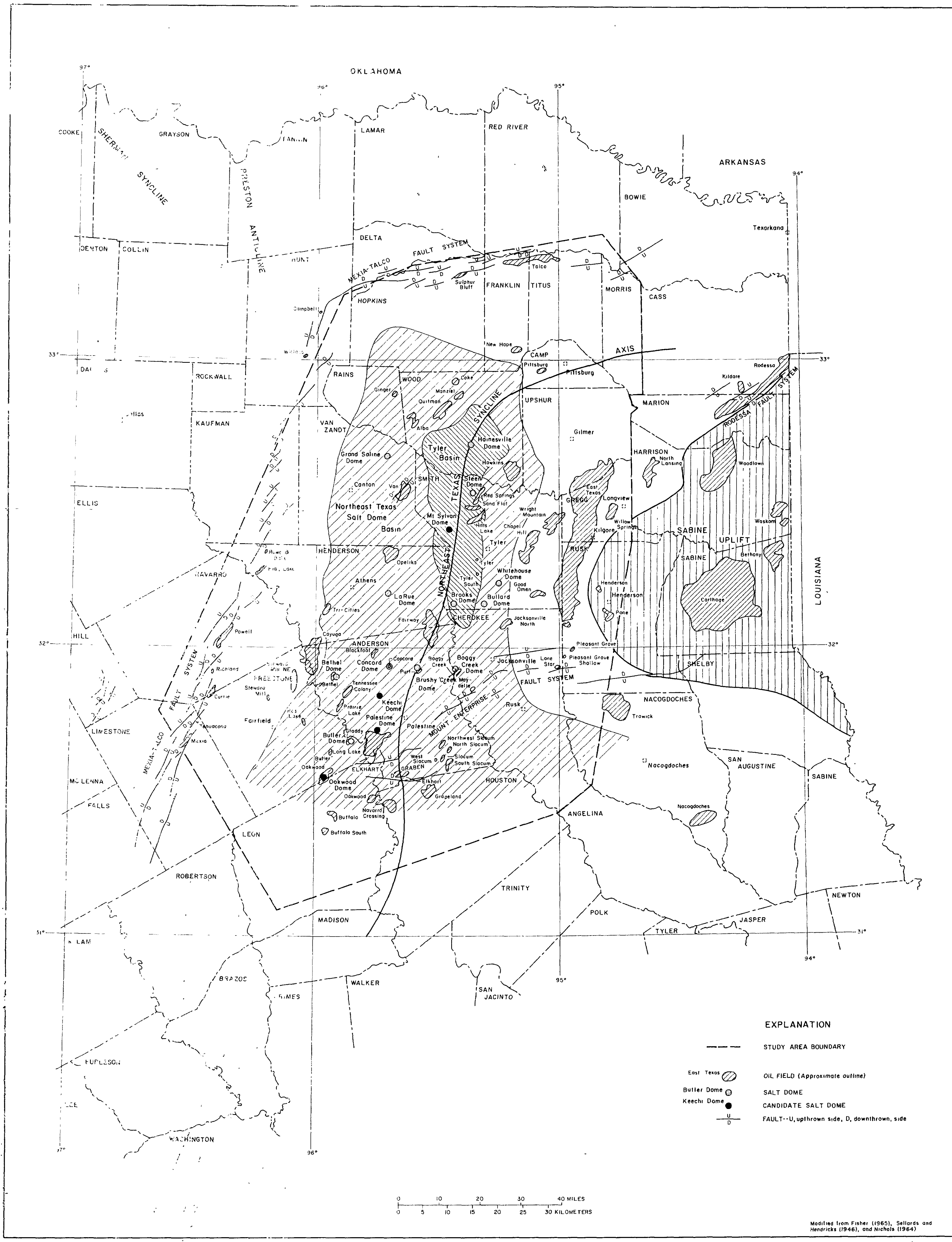


Figure 2. Locations of salt domes, principal structural features, and selected oil fields

## Metric Conversions

The inch-pound units of measurement used in this report may be converted to metric units by using the following conversion factors:

| From | Multiply by | To obtain |
|---|---|---|
| acre-foot | 1233 | cubic meter |
| barrel | 0.1590 | cubic meter |
| barrel per day | 0.1590 | cubic meter per day |
| foot | 0.3048 | meter |
| foot per day | 0.3048 | meter per day |
| foot per mile | 0.189 | meter per kilometer |
| foot per year | 0.3048 | meter per year |
| inch | 25.4 | millimeter |
| mile | 1.609 | kilometer |
| square mile | 2.590 | square kilometer |
| ton | 0.9072 | metric ton |

## DESCRIPTION OF THE SALT-DOME BASIN

The northeast Texas salt-dome basin, referred to in this report as the "basin," occurs within and forms part of the northeast Texas syncline, which is one of three major northward extensions of the Gulf Coast geosyncline. The deepest part of the basin, which is centered in western Smith and southern Wood Counties, is generally known as the Tyler basin.

At least 14 piercement and 11 nonpiercement salt domes occur within the basin (Nichols and others, 1968, p. 1003). The piercement domes are located approximately along the axis of the syncline (fig. 2).

The basin contains a maximum of about 25,000 feet of Mesozoic and Cenozoic deposits that are underlain by basement rocks of Paleozoic age (table 1, fig. 3).[1] Generally, the Mesozoic and Cenozoic strata dip and thicken toward the axis of the syncline; the greatest thicknesses occur in the Tyler basin. The strata in the extreme southern part of the basin dip and thicken toward the Gulf Coast.

The deposits within the syncline reflect numerous sedimentary cycles, and the rock units within each cycle reflect spatial variations in depositional environments. Many units have a general south to north facies change from downdip marine carbonates to updip near-shore clastics. With few exceptions, the depositional patterns indicate an expanding province of deposition.

In general, the sedimentary sequences can be separated into five major periods of deposition. The first four periods consisted primarily of Mesozoic marine deposition with shorter intervals of continental deposition. The last period consisted primarily of Cenozoic continental deposition, with shorter intervals of marine deposition.

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[1] The stratigraphic nomenclature used in this report was determined from several sources and may not follow the usage of the U.S. Geological Survey.

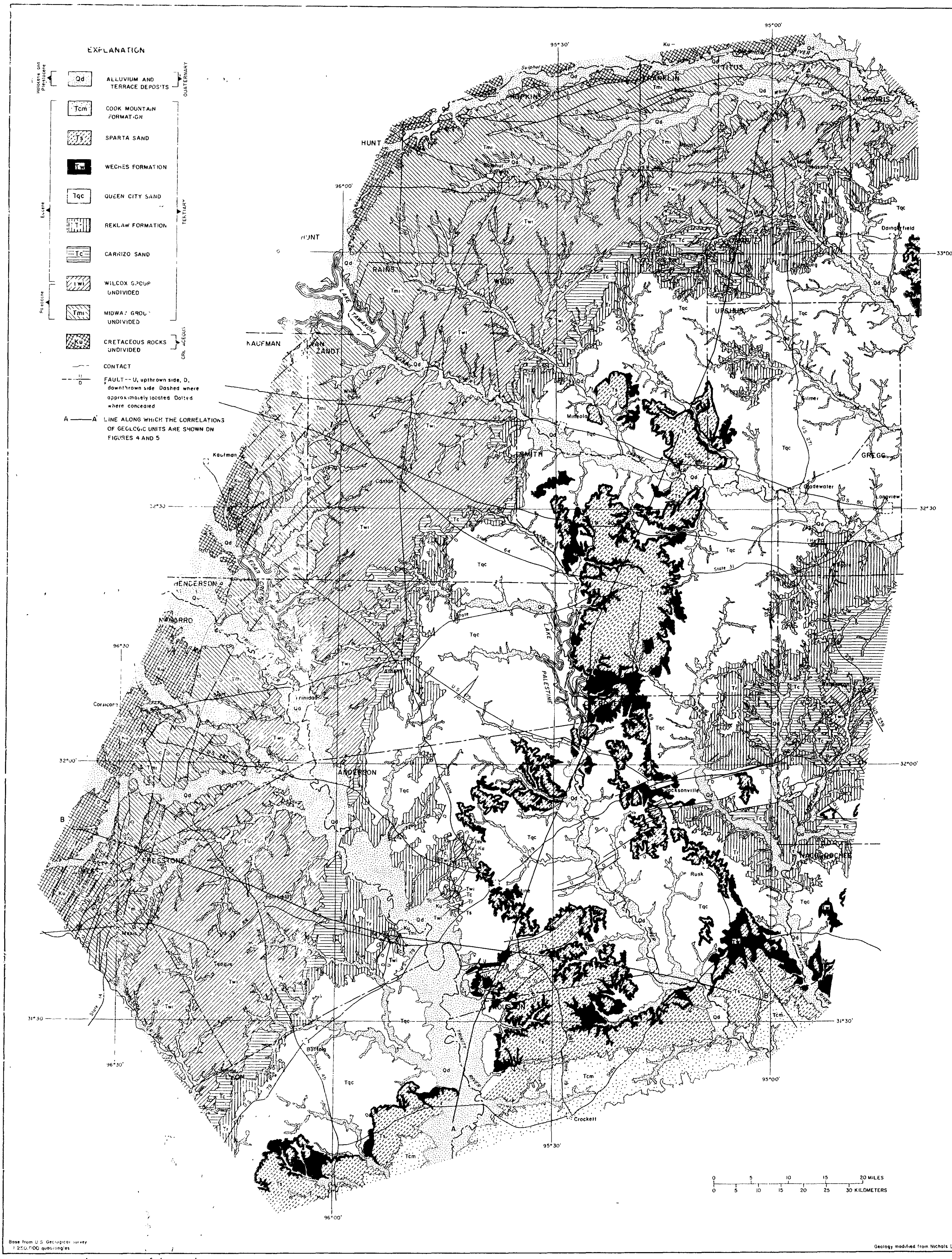


Figure 3-Geologic map of the study area

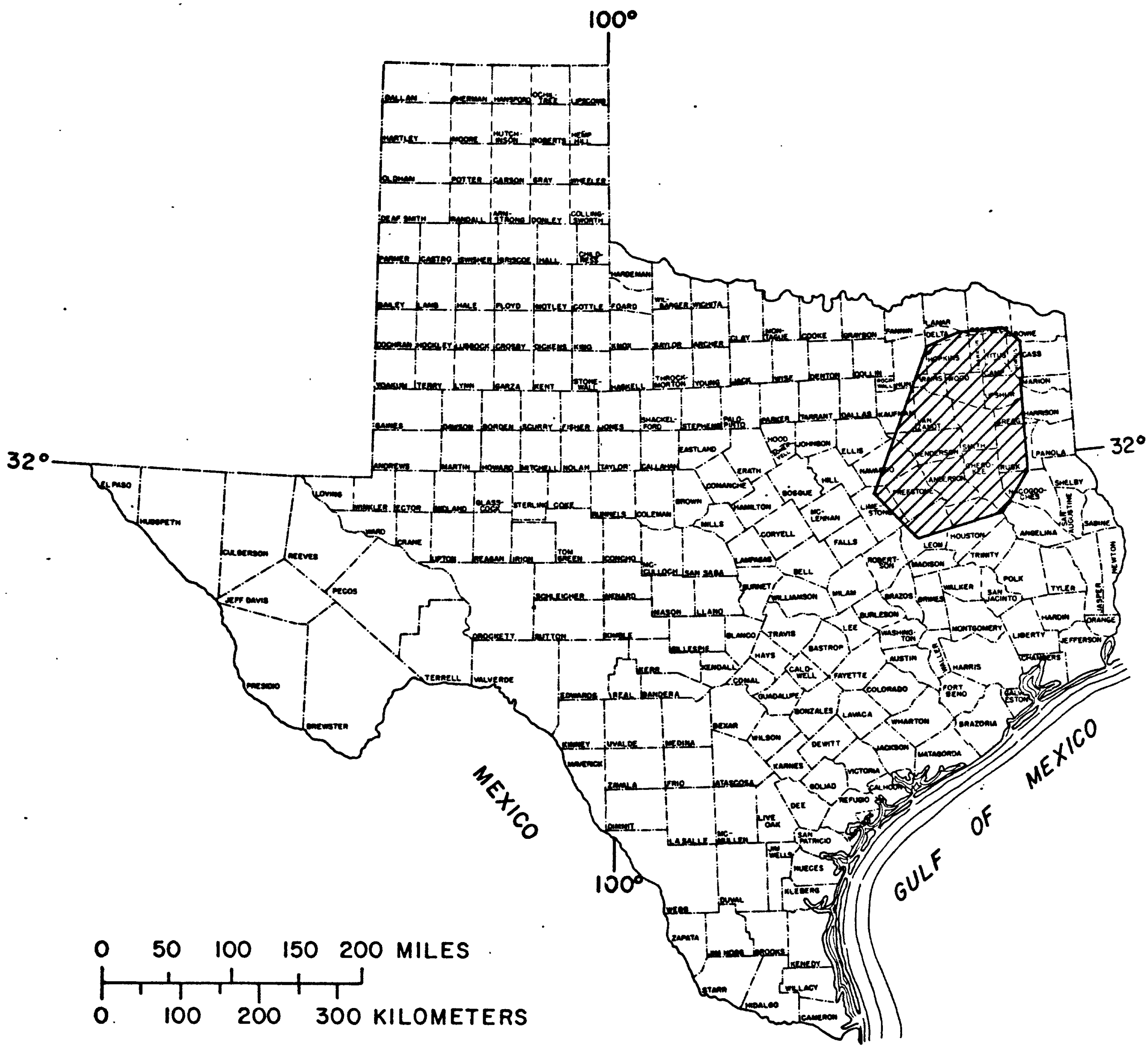


Figure 1.-Location of the study area

Considerable information on the stratigraphy and structure of the northeast Texas area is given by Andrews (1960), Coon (1956), Eaton (1956, 1961), Fisher (1963, 1965), Fisher and McGowen (1967), Forgotson (1956), Guevara and Garcia (1972), Newkirk (1971), and Vernon (1971).

The water-bearing strata of primary concern to this study are those of Late Cretaceous and Cenozoic age. Within the basin, all units of pre-Tertiary age contain very saline water, and in general, all units of Cenozoic age contain fresh to moderately saline water. The stratigraphic and structural relationships of the geohydrologic units are shown on figures 4-5.

The Woodbine Formation is the only major water-bearing unit of Late Cretaceous age, but the Nacatoch Sand of the Navarro Group is a minor aquifer in the northern one-half of the basin. The principal water-bearing unit of Cenozoic age is the Carrizo-Wilcox aquifer. Minor aquifers of Cenozoic age are the Queen City Sand, the Sparta Sand, and the alluvial and terrace deposits.

Other geologic units within the basin are mainly confining units and yield only minor amounts of water, generally within the outcrop areas. A major sequence of confining units, consisting of the Eagle Ford Group, Austin Group, Taylor Group, Navarro Group, and Midway Group, separate the freshwater units from the salinewater aquifers. Two important confining units interlayered with the freshwater units are the Reklaw and Weches Formations. The Reklaw is widespread and has a relatively uniform thickness throughout the basin, whereas the Weches acts as a confining unit primarily within the Tyler basin and in the southernmost part of the basin.

Individual beds within the aquifers, with the exception of the Carrizo Sand, have little lithologic continuity; and because the lithology varies considerably within short distances, so do the hydrologic characteristics. The potentiometric surfaces in the Carrizo-Wilcox aquifer and the Queen City Sand are shown on figures 6 and 7.

## GEOHYDROLOGY OF THE SELECTED SALT DOMES

The four interior salt domes selected for investigation--Keechi, Palestine, Oakwood, and Mount Sylvan--are in the southern one-half of the basin (fig. 2). All four domes have some surface expression, and most are or have been associated with salinewater at the land surface. The potential for dissolution probably exists at each of these domes through contact with Cretaceous or Tertiary waterbearing units or through fault systems in the vicinity of the domes.

Except for the Oakwood Salt Dome, previous studies provide general and specific geologic and hydrologic data for the explicit purpose of evaluating the domes as possible radioactive-waste storage sites. These studies include: Netherland, Sewell, and Associates, Inc. (1976); Martinez and others (1976); Anderson and others (1973); and Law Engineering Testing Co. (1978).

Selected data were collected for each of the four domes within a 5-mile radius of each dome, and the geologic literature for each dome was reviewed. Subsurface data were used to construct geologic or geohydrologic sections. The water-quality data are presented in a separate report (Carr and others, 1980).

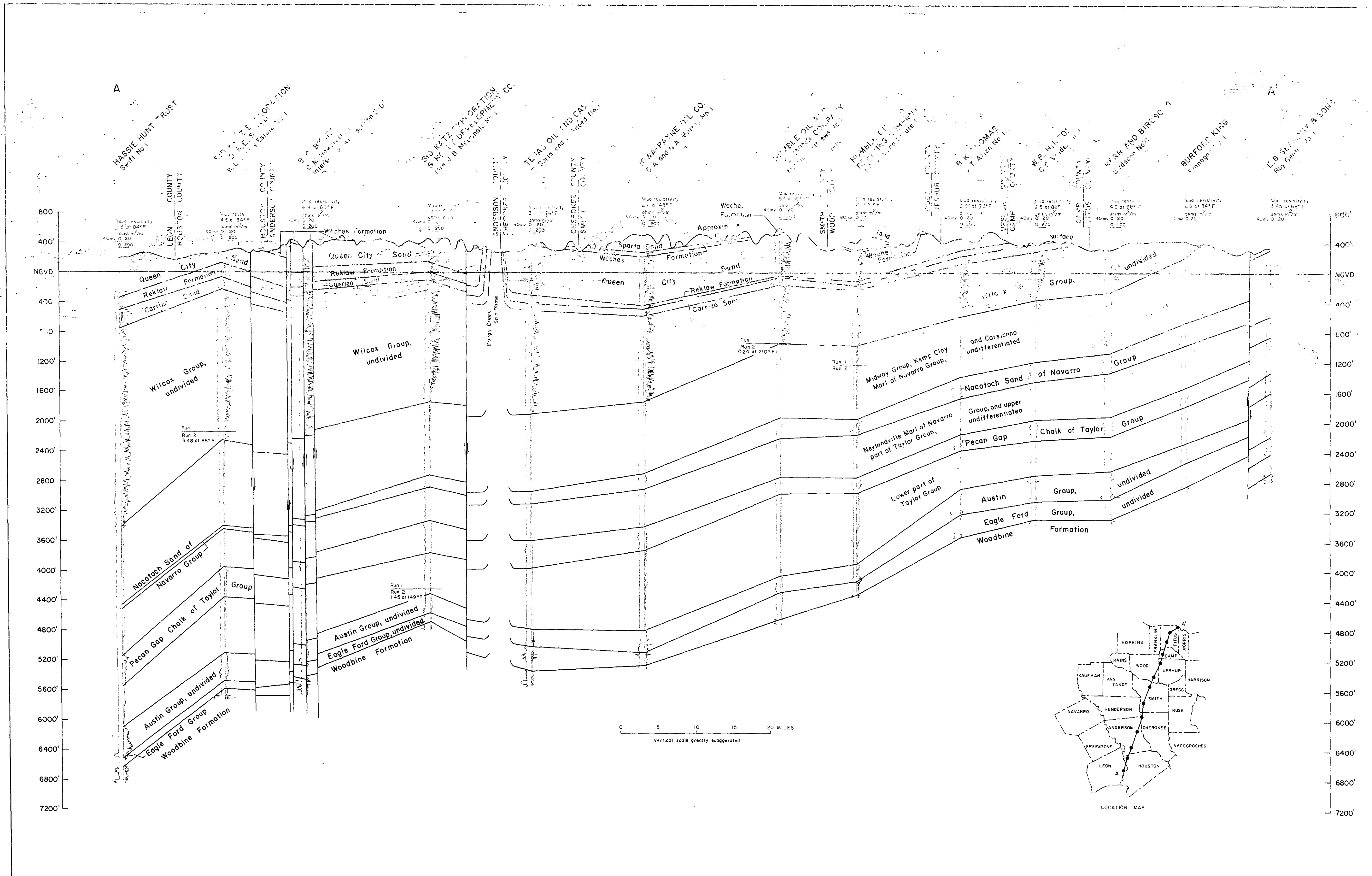

Figure 4.-Geologic section A-A', northeast Texas salt-dome basin

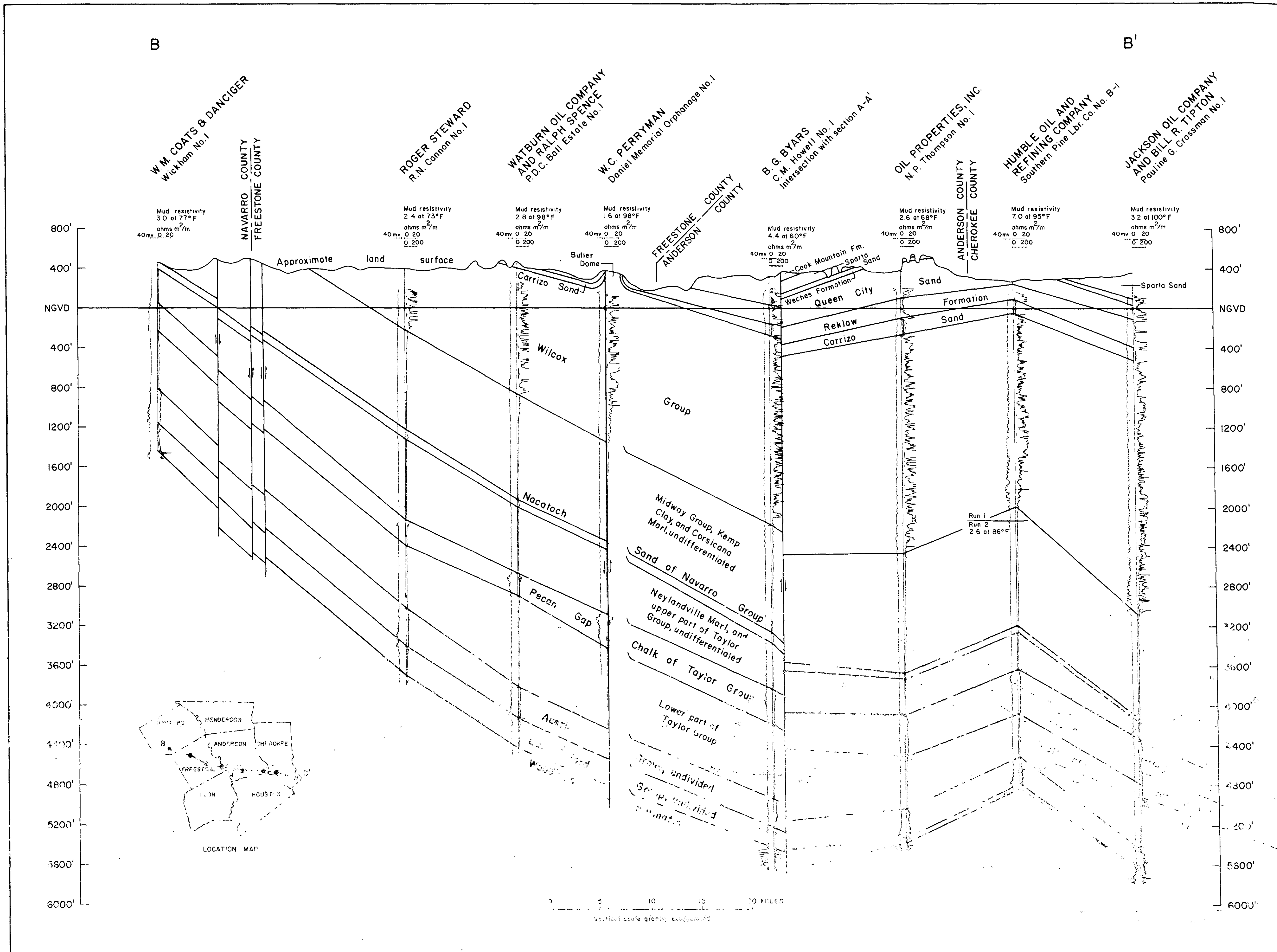


Figure 5.-Geologic section B-B', northeast Texas salt-dome basin.

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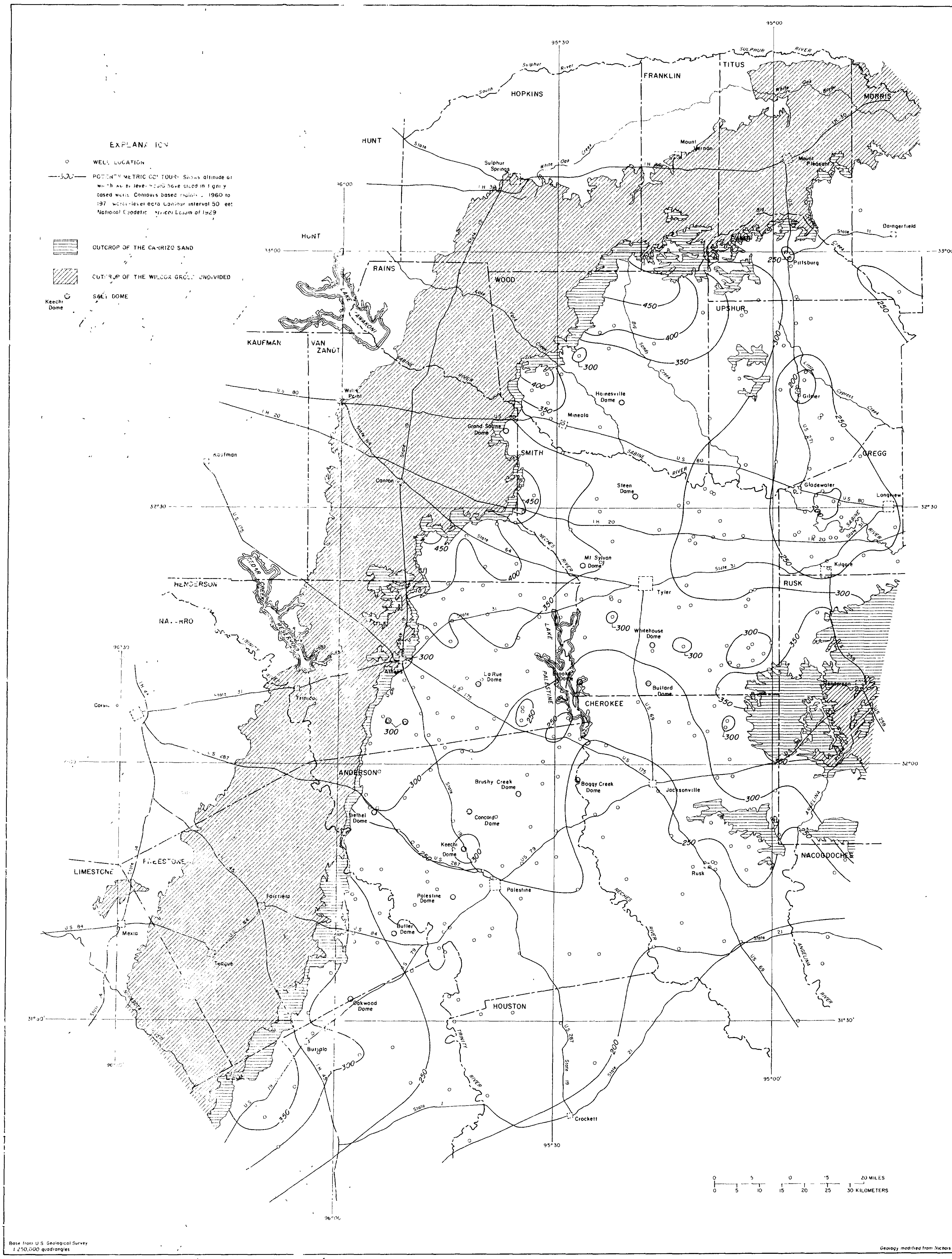


Figure 6.-Potentiometric surface of the Carrizo-Wilcox aquifer

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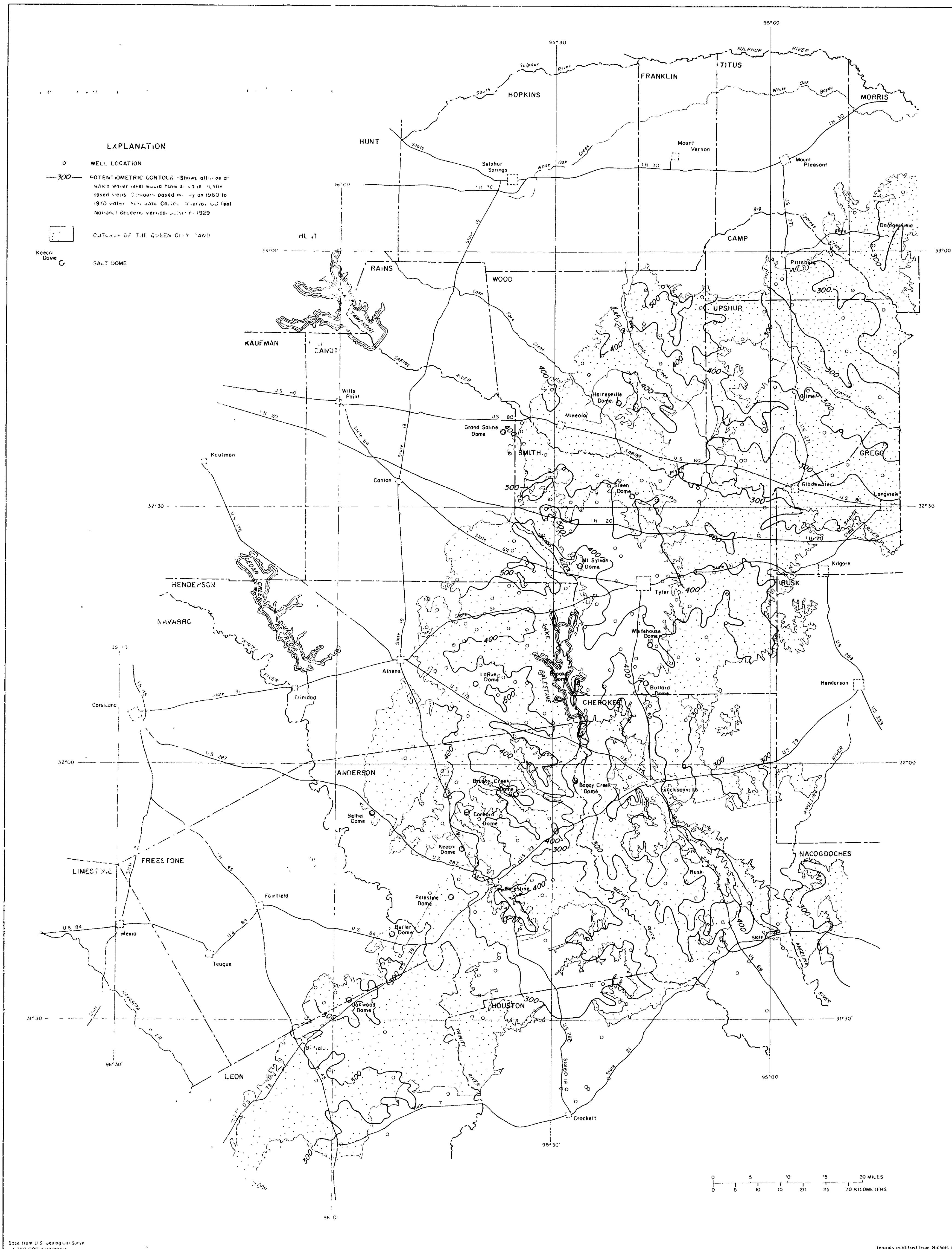


Figure 7. Potentiometric surface of the Queen City Sand

TABLE 1.--Stratigraphic column for the northeast Texas salt-dome basin

| ERATHEM | SYSTEM | SERIES | STRATIGRAPHIC UNIT | |
|---|---|---|---|---|
| CENOZOIC | QUATERNARY | HOLOCENE AND PLEISTOCENE | ALLUVIUM AND TERRACE DEPOSITS | |
| CENOZOIC | TERTIARY | EOCENE | CLAIBORNE GROUP | COOK MOUNTAIN FM. |
| | | | | SPARTA SAND |
| | | | | WECHES FORMATION |
| | | | | QUEEN CITY SAND |
| | | | | REKLAW FORMATION |
| | | | | CARRIZO SAND |
| | | EOCENE / PALEOCENE | WILCOX GROUP | UNDIFFERENTIATED |
| | | PALEOCENE | MIDWAY GROUP | WILLS POINT FORMATION |
| | | | | KINCAID FORMATION |
| MESOZOIC | CRETACEOUS | GULFIAN | NAVARRO GROUP | KEMP CLAY |
| | | | | CORSICANA MARL |
| | | | | NACATOCH SAND |
| | | | | NEYLANDVILLE MARL |
| | | | | MARLBROOK MARL |
| | | | TAYLOR GROUP | PECAN GAP CHALK |
| | | | | WOLFE CITY SAND |
| | | | | OZAN FORMATION |
| | | | AUSTIN GROUP | GOBER CHALK |
| | | | | EQUIVALENT OF TOKIO FORMATION |
| | | | EAGLE FORD GROUP | SUB-CLARKSVILLE SAND[1] |
| | | | | COKER SAND[1] |
| | | | | HARRIS SAND[1] |
| | | | WOODBINE FM. | LEWISVILLE MEMBER |
| | | | | DEXTER MEMBER |
| | | COMANCHEAN | WASHITA GROUP | MANESS SHALE[2] |
| | | | | BUDA LIMESTONE |
| | | | | GRAYSON MARL |
| | | | GEORGETOWN LIMESTONE | MAIN STREET LS. |
| | | | | WENO LS. AND PAW PAW FORMATION |
| | | | | DENTON CLAY |
| | | | | FORT WORTH LS. |
| | | | | DUCK CREEK LS. |
| | | | FREDERICKSBURG GROUP | KIAMICHI FORMATION |
| | | | | GOODLAND LIMESTONE OR EDWARDS LIMESTONE |

| ERATHEM | SYSTEM | SERIES | STRATIGRAPHIC UNIT | | |
|---|---|---|---|---|---|
| MESOZOIC | CRETACEOUS | COMANCHEAN | TRINITY GROUP | PALUXY SAND | |
| | | | | GLEN ROSE LIMESTONE | |
| | | | | | FERRY LAKE ANHYDRITE |
| | | | | | RODESSA FORMATION |
| | | | | | JAMES LIMESTONE |
| | | | | | PINE ISLAND SHALE |
| | | | | | PETTET LIMESTONE |
| | | | | TRAVIS PEAK FORMATION | |
| | JURASSIC | UPPER JURASSIC | COTTON VALLEY GROUP | SCHULER FORMATION | |
| | | | | BOSSIER FORMATION | |
| | | | BUCKNER FORMATION | | |
| | | | SMACKOVER FORMATION | | |
| | | | NORPHLET FORMATION | | |
| | | MIDDLE JURASSIC | LOUANN SALT | | |
| | | | WERNER FORMATION | | |
| ? | ** | | EAGLE MILLS FORMATION | | |
| PALEOZOIC | | | Complexly folded and faulted formations of the Ouachita facies ranging in age from Ordovician (Mazarn Shale) to Pennsylvanian (Atoka Formation) have been penetrated in the subsurface equivalent in northeast Texas. Schist of unknown age (possibly Early Cambrian or Precambrian) is overthrust westward and northwestward along the eastern and southern margins of the Paleozoic Fold Belt and probably represents the oldest lithology penetrated to date (1960). | | |

**pre-Werner - post Atoka (Pennsylvanian) red beds.

[1]Of informal subsurface usage.
[2]Of local usage.

Modified from Nichols (1964)

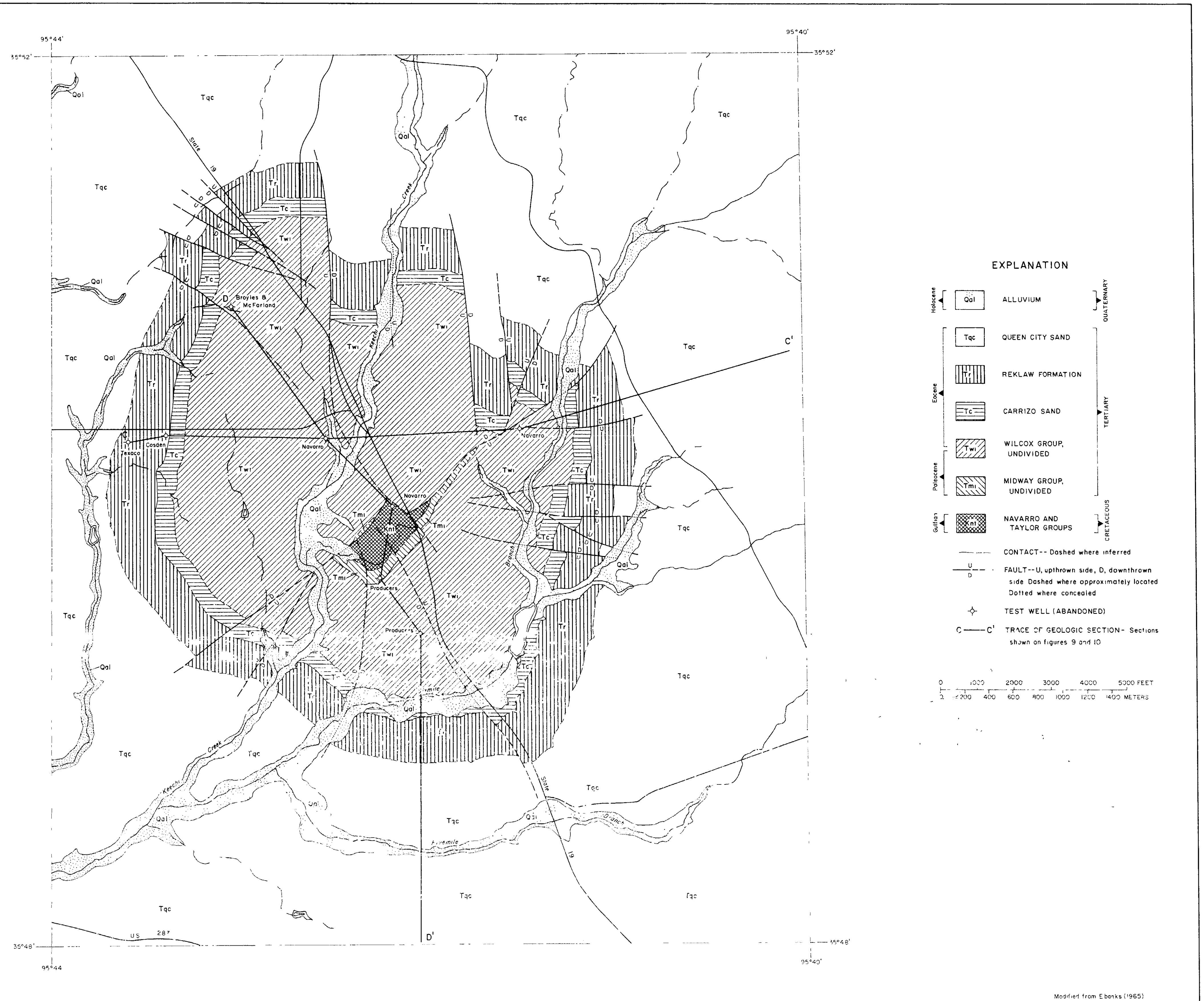


Figure 8 -Geologic map of Keechi Salt-Dome area

Estimates of water quality used in the construction of the geologic sections were made from electrical-log resistivities. The method used is described by Turcan (1966) and by Whitman (1965). In general, water-quality samples taken from wells completed in limited vertical sections were correlated with the corresponding interval on resistivity logs from the same well. Data used for correlation were made available by the Layne-Texas Co., Houston, Tex.

## Keechi Salt Dome

Keechi Dome is in the central part of Anderson County, approximately 7 miles northwest of Palestine. The dome is near the divide between the Neches and Trinity River drainage systems, and drainage is to the Trinity River system. The dome area is drained by three streams: Keechi Creek, Sixmile Branch, and Fivemile Branch. Keechi Creek was referred to as "Salt Fork of Keechi Creek" by Powers (1926, p. 36).

In general, the topography is gently rolling, and a ring of low hills surrounds the dome; however, the dome has no conspicuous topographic expression. Altitudes within the area range from a maximum of about 645 feet above NGVD (National Geodetic Vertical Datum of 1929) in the southeast part to a low of about 290 feet above NGVD where Keechi Creek flows out of the southwest part of the area. Altitudes near the center of the dome range from about 340 feet to about 400 feet above NGVD.

The discovery well--Producers Oil Co. No. 1 Barrett and Greenwood--was drilled in 1916. According to Powers (1926, p. 43) this well penetrated a salt overhang between depths of 2,162 and 2,822 feet and penetrated the main salt body at 3,091 feet. Prior to 1926, five wells had been drilled on the Keechi Dome, but only the discovery well penetrated salt. From 1926 to 1930, eight more wells were drilled for oil, but all were dry and abandoned. Six of these eight wells penetrated anhydrite cap rock, from 16 to 120 feet thick, and penetrated salt (Lahee, 1933, p. 77). Netherland, Sewell, and Associates, Inc. (1976, p. 629) report that a total of 14 wells have been drilled at Keechi Dome, either to cap rock or salt, or to test the flanks of the dome. Although a show of heavy oil was found in the first well drilled on this dome, no other oil and gas indications have been reported and there is no present economic use of the dome.

### Geology

The strata overlying and surrounding the dome have been arched into steeply-dipping folds that have been complexly faulted. Cretaceous strata of the Taylor and Navarro Groups, which crop out on the south-central part of the dome (fig. 8), have been upthrown about 4,200 feet. Increasingly younger Tertiary strata surround this Cretaceous outcrop. According to Netherland, Sewell, and Associates, Inc. (1976, p. G-33), uplift reflected in beds above the Wilcox Group is indicated to be on the order of 2,000 feet.

The center of the dome is overlain mainly by the Wilcox Group. The dips are from 25 to 75 degrees near the dome, but are only about 2 degrees within 1.5 miles from the center of the dome. The faults are assumed to be normal faults, and the pattern of faulting is virtually radial. Ebanks (1965, p. 67)

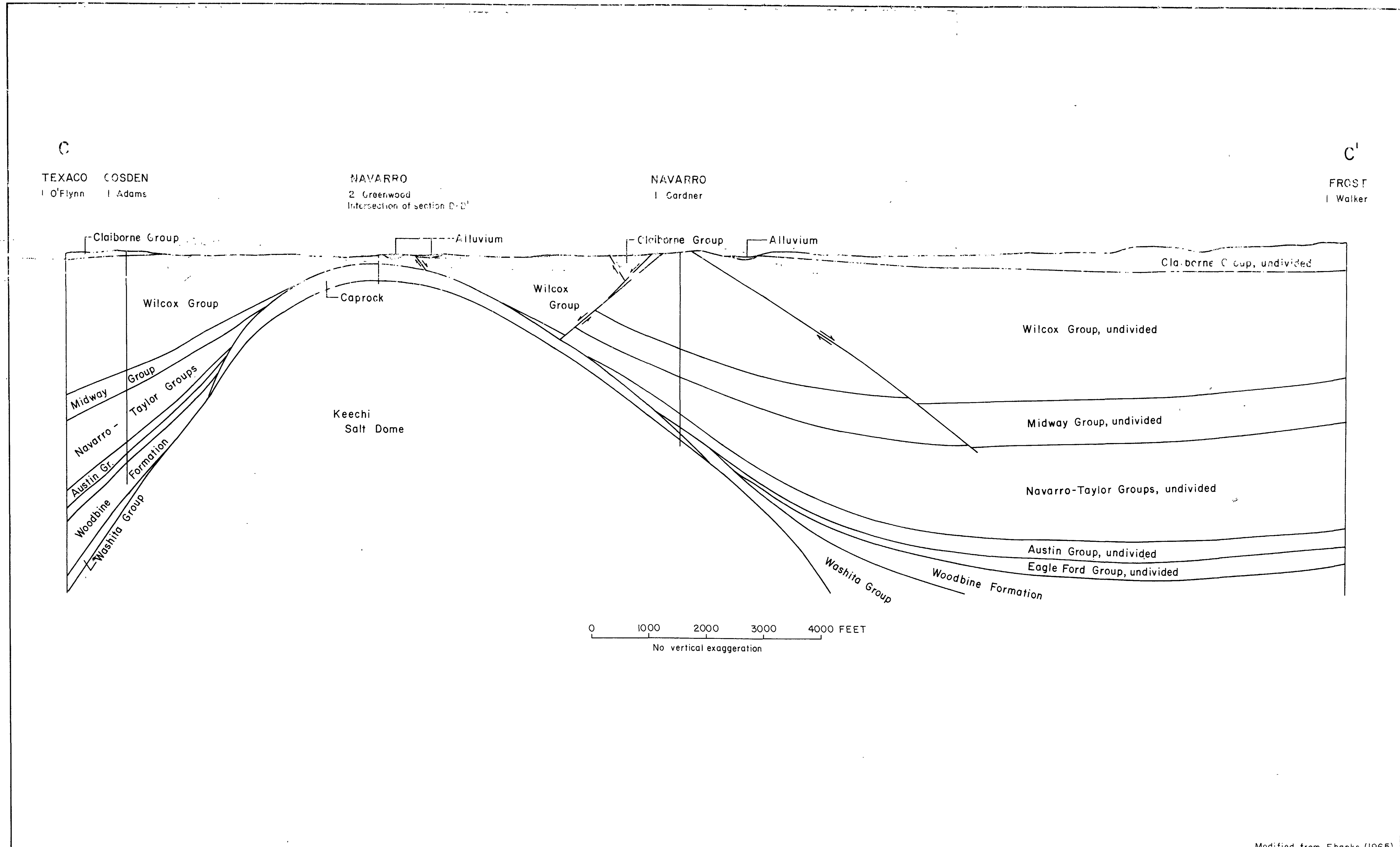


Figure 9.-Geologic section C-C', Keechi Salt Dome

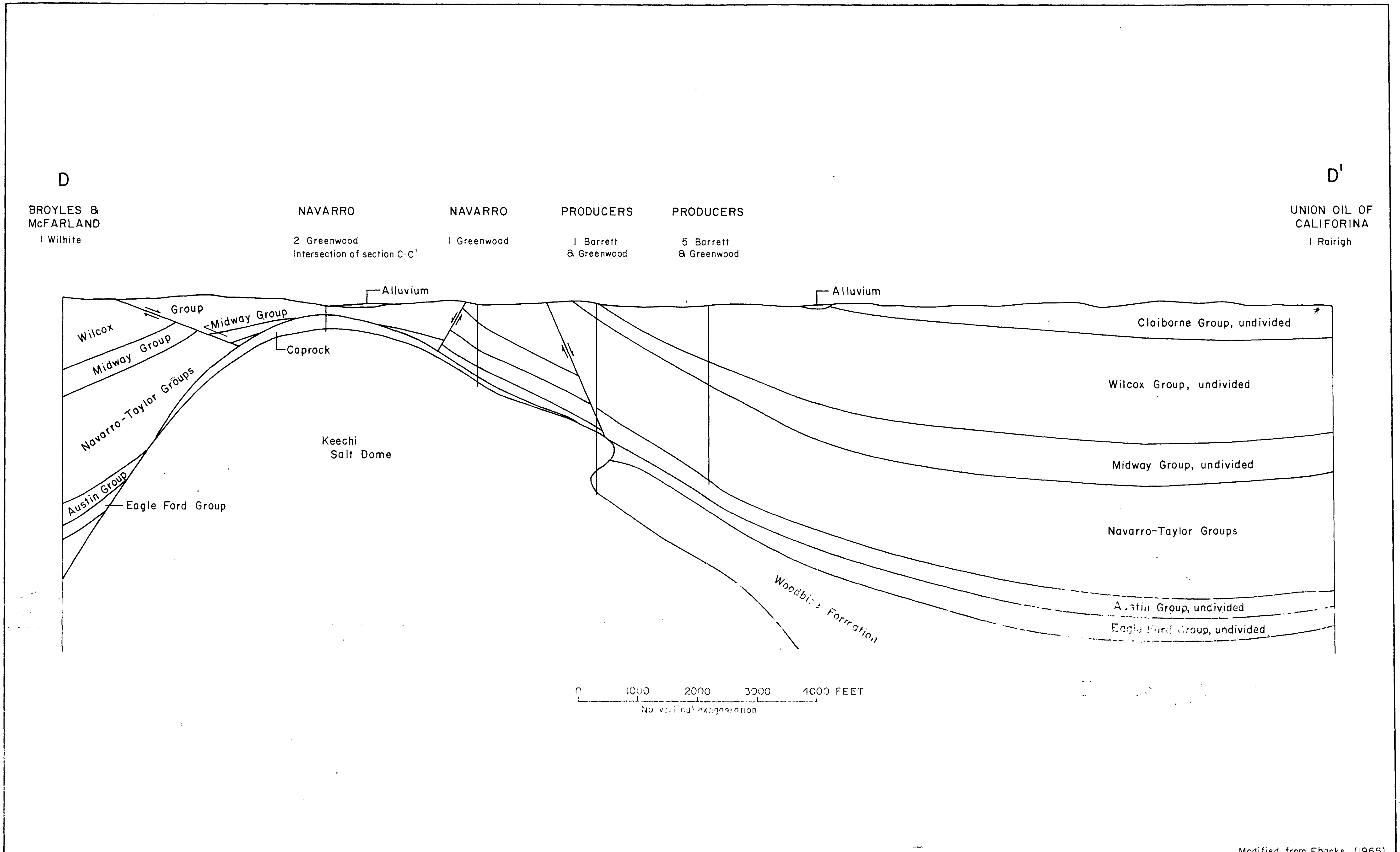


Figure 10.-Geologic section D-D', Keechi Salt Dome

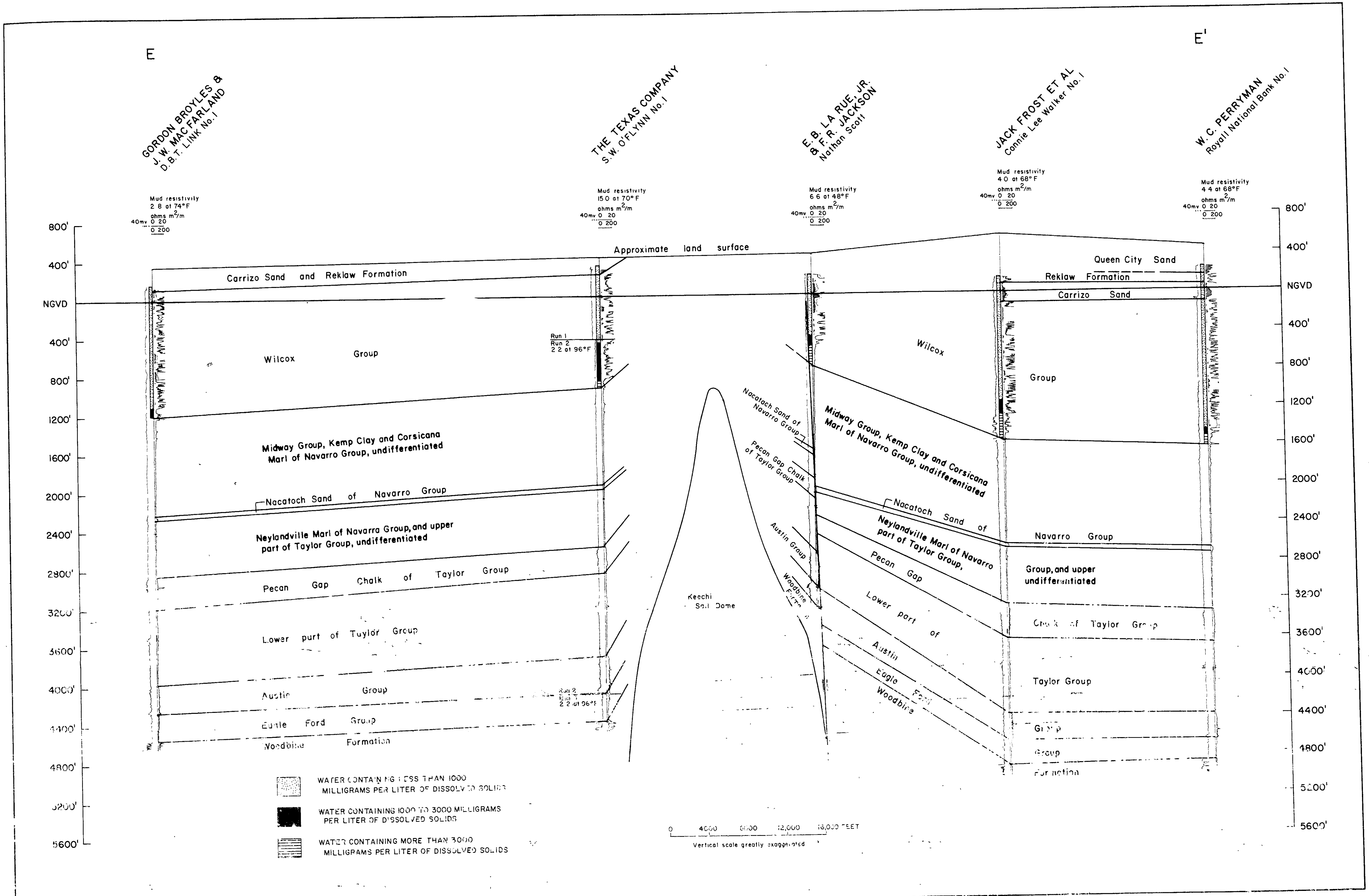


Figure 11.-Geohydrologic section E-E', Keechi Salt Dome

reports that the Link Fault that crosses the entire dome from the northeast to the southwest probably has the largest amount of throw, which is about 1,500 feet in reference to the base of the Wilcox. In reference to the base of the Reklaw, Ebanks reports that the Keechi and Wilhite Faults have the largest throws, which are estimated at about 300 feet for the Keechi and 275 feet for the Wilhite. These two parallel step faults, which are on the north one-half of the dome, trend in a northerly direction.

Geologic sections of the dome by Ebanks (1965) are shown on figures 9 and 10. Additional structural movement is indicated on the northeast side of the dome where the LaRue Jr., and Jackson, No. 1 Nathan Scott well shows about 500 feet of the Taylor Group to be missing (fig. 11).

The salt mass is elliptical, with the long axis trending north. The salt mass becomes more egg-shaped above a depth of 5,000 feet and has an overhang on the south end at a depth of about 2,000 feet. As described by Ebanks (1965, p. 61) the overhang extends outward below the Austin Group and into the Eagle Ford Group (fig. 10). The shallowest known point on the salt is at the Navarro Oil Co., No. 2 Greenwood well at the southern edge of the J. D. Smullen survey. At this location, the salt is at a depth of 435 feet below land surface.

Cap rock drapes over the salt to an altitude of 3,500 feet below NGVD in the northern part and 2,500 feet below NGVD in the central part. The cap rock, which probably consists of gypsum and anhydrite, has a maximum thickness of 300 feet near the apex of the dome.

## Hydrology

The major water-bearing units at Keechi Dome are the Woodbine Formation, Wilcox Group, and Carrizo Sand. The general thicknesses of these units about 2 miles from the dome are: Woodbine Formation, 700 feet; Wilcox Group, 1,400 feet; and Carrizo Sand, 200 feet. The thicknesses generally decrease toward the dome.

Regional ground-water flow in the Carrizo-Wilcox aquifer is generally to the south-southeast. The regional hydraulic gradient for the Carrizo-Wilcox in this area ranges from about 2 to 4 feet per mile. Reasonable upper limits for the rate of regional ground-water flow within the Carrizo-Wilcox aquifer is about 18 feet per year with these gradients. Few water-level data indicate that recharge to the Carrizo-Wilcox aquifer, and probably to other aquifers cropping out at the dome, occur at the dome.

Water levels in wells completed in the Carrizo-Wilcox aquifer generally range from 70 to 200 feet below land surface. However, the regional potentiometric surface (fig. 6) is at or near land surface along some stream channels near the dome. Water levels in the Queen City Sand generally are shallower, ranging from 10 to 50 feet below land surface.

Although freshwater aquifers at Keechi Dome seem to be isolated from the dome by strata of the Midway Group, some evidence indicates that salinewater occurs at the land surface and plumes of salinewater occur in the subsurface. Small salt licks, which occurred during the summer at a few semibarren patches along Keechi Creek, were reported by Powers (1926, p. 36). In addition, Powers (1926, p. 38) indicated that springs were not conspicuous at the dome, although they are present along Keechi Creek. Powers also reported that although mineralized springs were not noted, several dug wells produced salinewater.

The pattern of maximum salinity in the basal sand of the Wilcox Group near the Keechi Dome indicates a possible plume of salinewater east of the dome. Water-quality data are not available to confirm this plume because only one chemical analysis is available for the Wilcox in the vicinity of the dome. The source of this possible plume is also questionable because it extends slightly up the hydraulic gradient. The salinity pattern could be more a function of flushing of salinewater from the structural low in this area or from invasion of the Wilcox by salinewaters from deeper units rather than from recent dissolution of the dome.

## Mount Sylvan Salt Dome

Mount Sylvan Dome is in the western part of Smith County about 8 miles west-northwest of Tyler. The dome is in the Neches River drainage system and is drained by Prairie Creek, which traverses the central part of the dome before it flows into the Neches River, and by Black Fork Creek, which crosses the northeast side of the dome before flowing into Prairie Creek. The dome has a low central area, which has an altitude of about 365 feet above NGVD, surrounded by a rim of low hills that have a maximum altitude of about 500 feet above NGVD. According to Wendlandt and Knebel (1929, p. 1362), the rim, which is pronounced on nearly all sides of the dome, is underlain by the Weches Formation except where the Weches has been eroded. The rim has been cut through on the northeast side by Black Fork Creek and on the south side by Prairie Creek.

The Mount Sylvan Dome was recommended for seismograph exploration by E. A. Wendlandt on June 8, 1927. A seismograph crew of the Humble Oil and Refining Co. verified the existence of the dome on June 15, 1927 (Wendlandt and Knebel, 1929, p. 1362). Humble Oil and Refining Co. completed its No. 1 Lola V. Reese well in 1931 at a total depth of 1,208 feet in salt. The top of anhydrite was found at a depth of 650 feet; streaks of anhydrite, salt, and sand from 650 to 1,050 feet; and rock salt from 1,050 to 1,208 feet (Wendlandt and Knebel, 1936, p. 1041).

According to Netherland, Sewell, and Associates, Inc. (1976, p. G-35), eight wells have been drilled near the crest or on the flank of the salt dome, and numerous wells have been drilled within a 5-mile radius of the apex. Significant oil and gas production has been established in scattered locations approximately 4 to 5 miles from the apex of the dome; however, no hydrocarbons have been found near the salt mass.

### Geology

Detailed surface geologic mapping of Mount Sylvan Dome is not available. However, the general geology of the area is shown on figure 3. The strata immediately overlying and surrounding the dome have been folded, but the surface

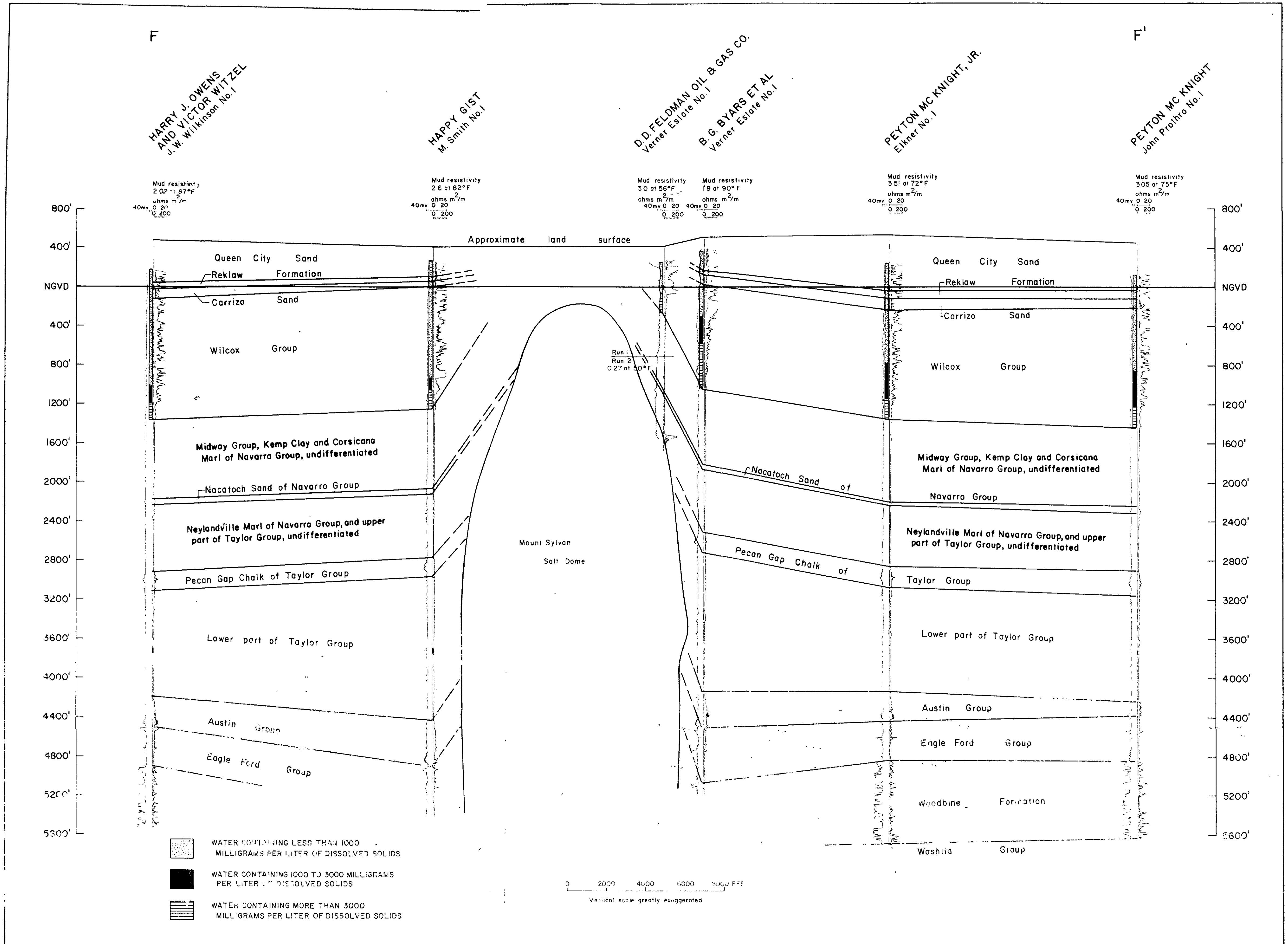


Figure 12.-Geohydrologic section F-F', Mount Sylvan Salt Dome

sediments show no pronounced structural disturbance as a result of growth of the dome. Although there is probably some slumping over the central part of the dome, the character of the exposed material is such that it is impossible to determine the exact amount (Wendlandt and Knebel, 1929, p. 1366). The surface formations over the dome, which are mostly Eocene deposits of the Claiborne Group, include the Queen City Sand, Weches Formation, and Sparta Sand. Holocene alluvium associated with Prairie and Black Fork Creeks occurs on the flood plains that vary in width from about 0.25 to 0.75 mile over the dome.

No faults are shown on the Geologic Atlas of Texas - Tyler Sheet (University of Texas Bureau of Economic Geology, 1965); however, according to Wendlandt and Knebel (1929, p. 1368), a small amount of faulting was noticed at a few places. Folding and faulting associated with dome growth probably significantly affects the Midway Group and older units. Netherland, Sewell, and Associates, Inc. (1976, p. G-37) report that uplift indicated by beds above the Wilcox is on the order of 500 feet. As described by Wendlandt and Knebel (1929, p. 1368), the lower Claiborne beds show a smaller amount of movement than is evident in the Wilcox Group. The Claiborne beds dip gently away from the uplifted rim and into the northeast Texas (fig. 12) syncline.

The salt stock extends to within about 380 feet of land surface. The shape of the stock is interpreted to be cylindrical with a noticeable increase in diameter between altitudes of 10,000 to 6,000 feet below NGVD. Above this level, the dome tapers upward into an overhang to the southwest between altitudes of 0 to 3,000 feet below NGVD. Although not shown on figure 12 because of the position of the geohydrologic section, Netherland, Sewell, and Associates, Inc. (1976, exhibits G-31 and G-35) indicate that at 0 NGVD the dome is about 1 mile in diameter. A small overhang is also indicated on the southeast side of the dome at a depth of about 3,100 to 3,734 feet.

Cap-rock distribution has not been defined at the dome; however, data from at least two wells have indicated its presence. The Humble Oil and Refining Co. No. 1 Lola V. Reese in 1931 penetrated cap rock at a depth of 650 feet, and the Gulf Oil Co. No. 1 C. M. Jackson penetrated cap rock at a depth of about about 700 feet.

## Hydrology

The major water-bearing units at Mount Sylvan Dome and their general thicknesses about 3 miles from the dome are: Woodbine Formation, 900 feet; Wilcox Group, 1,200 feet; Carrizo Sand, 110 feet; and Queen City Sand, 450 feet. Regional ground-water flow in the Carrizo-Wilcox aquifer is generally to the southeast under the natural hydraulic gradient of about 4.5 feet per mile. The upper limit of the rate of regional ground-water flow in the Wilcox Group is estimated to be about 22 feet per year under this gradient. The regional potentiometric surface of the Carrizo-Wilcox aquifer is at or near land surface in some stream channels around the dome.

Freshwater aquifers at Mount Sylvan Dome seem to be isolated from the dome by the underlying Midway Group. However, saline anomalies have been observed at the surface and are indicated by subsurface data. Nearly the entire eastern

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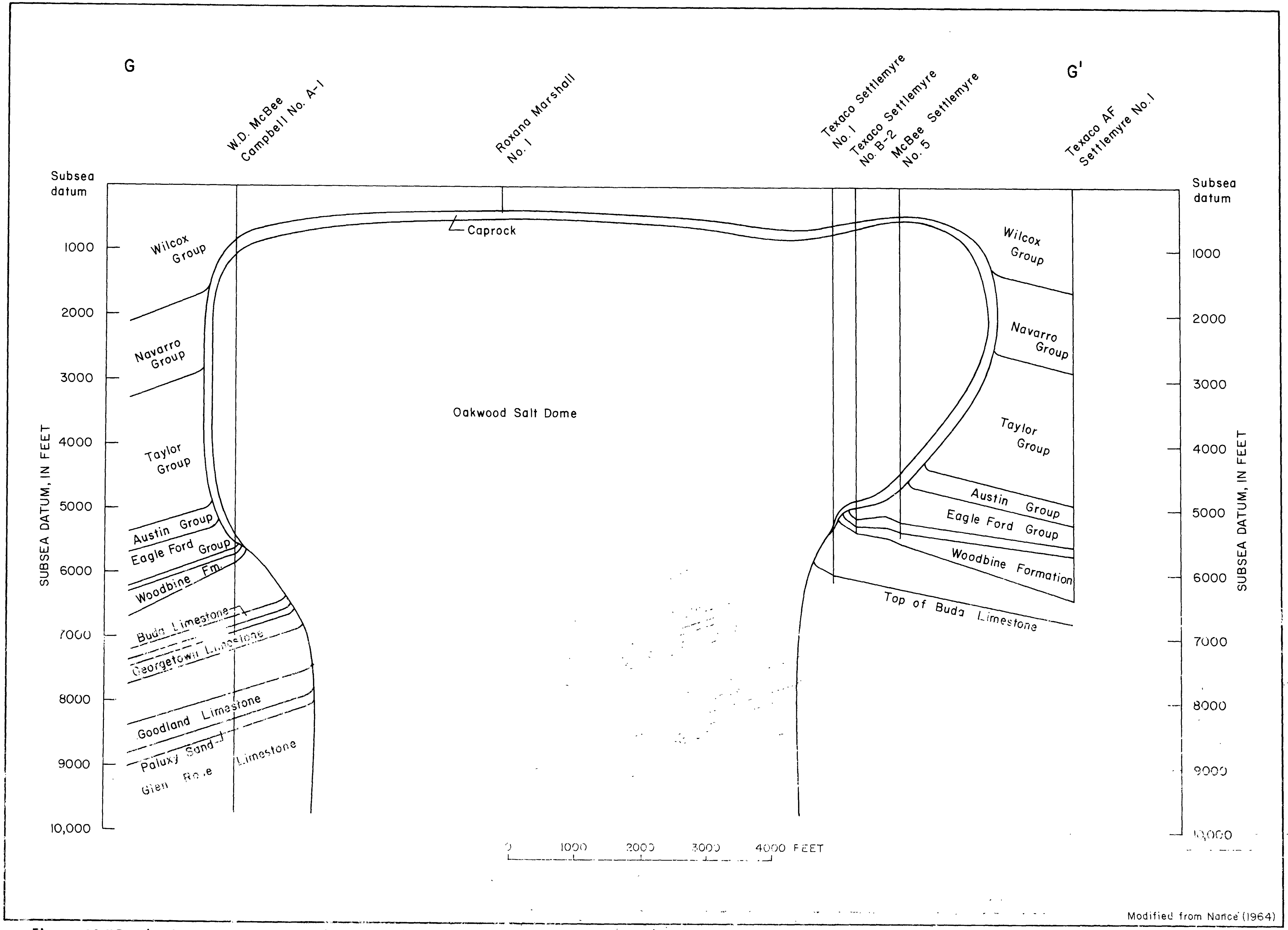


Figure 13.-Geologic section G-G', Oakwood Salt Dome

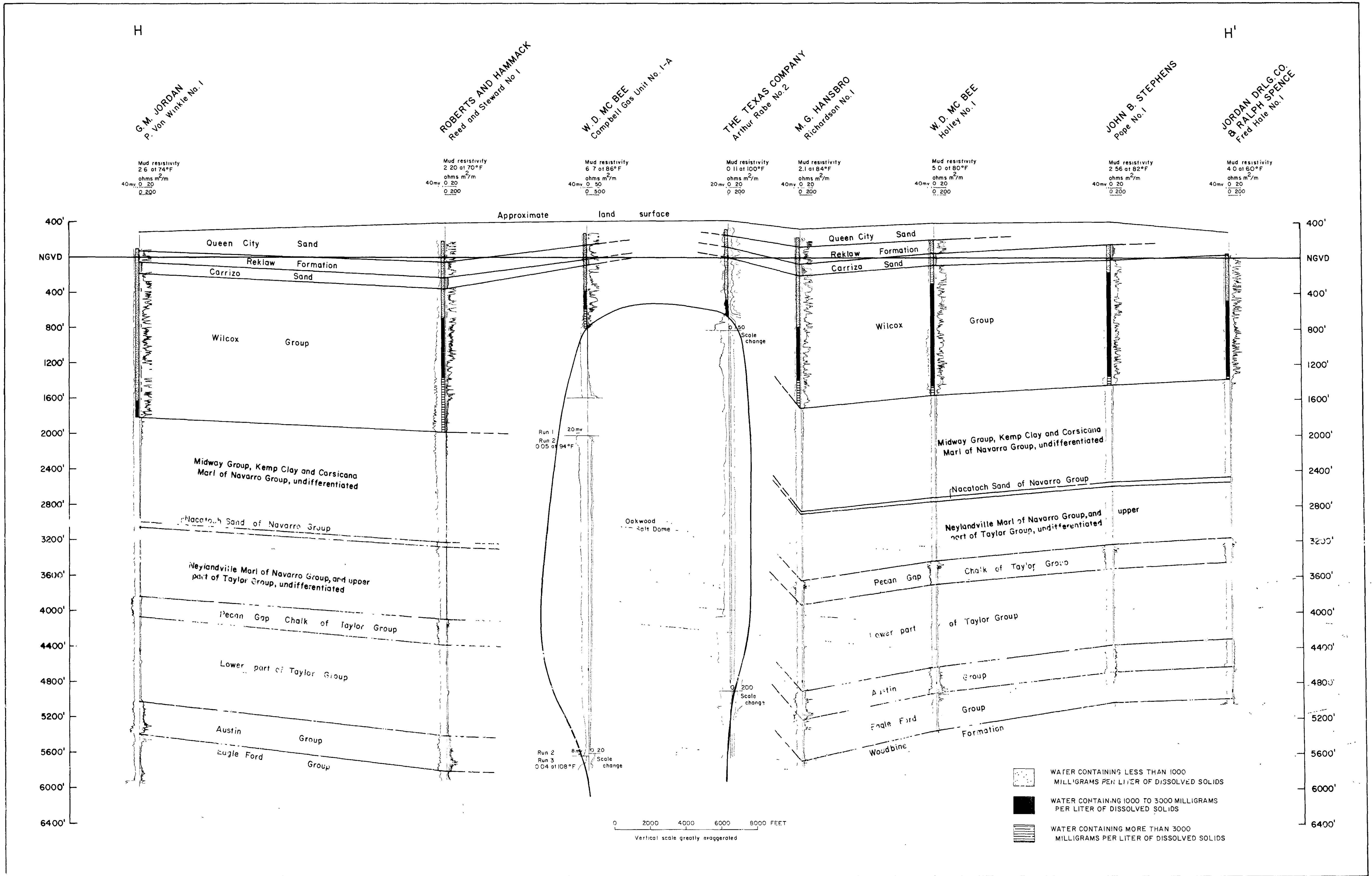


Figure 14.-Geohydrologic section H-H', Oakwood Salt Dome

part of the area overlying the salt mass is swampy wooded bottomland (Wendlandt and Knebel, 1929, p. 1362). Several saline prairies of considerable size occur in the southeastern part of the area, and a salinewater spring occurs on the south side of the dome.

About 300 feet from the salinewater spring, a well drilled in 1910 in the north-central part of the Benjamin Kuykendall survey yielded salinewater at a depth of 250 feet. The well was still yielding salinewater when it was abandoned at a depth of 400 feet (Wendlandt and Knebel, 1929, p. 1364). In addition, a probable plume of salinewater, as determined from geophysical logs, occurs downgradient from the dome in the basal sands of the Wilcox.

## Oakwood Salt Dome

Oakwood Salt Dome is on the Freestone-Leon County line, approximately 2 miles northwest of the town of Keechi. The dome is within the Trinity River drainage system. Locally, surface drainage of the area is by Upper Keechi Creek and its major tributary, Buffalo Creek. In general, the topography is gently rolling. A topographic high, which has radial drainage and a maximum altitude of about 507 feet above NGVD occurs about 2 miles north-northeast of the salt core. However, the area over the salt core is occupied by an inconspicuous depression that is drained by a tributary of Alligator Creek. The land-surface altitude over the salt-core area ranges from about 310 to 450 feet above NGVD.

The presence of a structure in the area was indicated by surface mapping and seismograph exploration by Sun Oil Co. in 1927. The salt dome was proved by drilling of the Roxana Petroleum Co. No. 1 Marshall well, which entered the anhydrite cap at a depth of 703 feet. Later extensive geophysical work in the area by Texaco, Inc., led to the discovery of oil, but seven test wells were drilled on or near the dome before production was established. In 1958, the discovery well, Texaco No. 1 Arther Rabe located in the T. J. Teal survey, produced 142 barrels of oil per day from the Woodbine Formation. The well was perforated at a depth of 5,745 to 5,755 feet (Nance, 1964, p. 45). Gardner (1960, p. 157) reported that the well penetrated 4,100 feet of salt overhang before the producing sand was encountered.

According to Enright (1963, p. 212), the Oakwood Dome had 24 wells by 1963, and was producing more oil daily (800 barrels per day) than any other east Texas dome. In the first 5 years, the Oakwood field produced 1.5 million barrels of oil. However, Enright indicated that encroaching water threatened all wells within the field and that steady declines in daily oil production were occurring in all wells. Cumulative production at the Oakwood field through 1977 was about 2.11 million barrels. However, according to the Texas Railroad Commission, production has decreased substantially, and from February through July of 1978, only two wells were still producing.

### Geology

The strata overlying and surrounding Oakwood Dome are folded (figs. 13-14), but the surface sediments show no pronounced structural disturbances. The Queen City Sand crops out over most of the dome area, and there is a possibility that the Reklaw Formation crops out in some of the stream channels on the dome. Although no surface faults have been mapped in the dome area, more detailed mapping would probably reveal minor faulting. Radial faults in the Woodbine Formation have been mapped in the subsurface around the dome (Nance, 1964).

Oakwood Dome is cylindrical and has a diameter of about 2 miles above an altitude of 3,000 feet below NGVD. Salt extends to within about 800 feet of the land surface at an altitude of about 500 feet below NGVD. A salt overhang about 1,000 to 2,500 feet wide and about 4,000 feet thick is present around the dome (figs. 13 and 14). The overhang extends outward primarily into rocks of the Navarro Group, Taylor Group, Austin Group, and Eagle Ford Group. A cap rock consisting of 80 to 150 feet of anhydrite sand is present on top of the dome. In addition, the sides of the dome are covered by a zone of massive anhydrite and lime gouge, ranging from 100 to 200 feet in thickness. As shown on figure 14, Cretaceous units abut the gouge zone and dip steeply away from the dome. The dip of these Cretaceous units flattens substantially within 4,000 feet of the dome. The gouge zone is believed to occur along the entire side of the salt stock, ending under the overhang.

## Hydrology

The major water-bearing units and general thicknesses of these units near Oakwood Dome are: Woodbine Formation, 600 feet; Wilcox Group, 1,550 feet; Carrizo Sand, 150 feet; and Queen City Sand, 250 feet. Regional ground-water flow in the Carrizo-Wilcox aquifer is generally to the southeast. The natural regional hydraulic gradient for the Carrizo-Wilcox in this area is about 3.5 feet per mile. The upper limit of the rate of regional ground-water flow in the Wilcox Group is estimated to be about 15 feet per year. The regional potentiometric surface of the Carrizo-Wilcox aquifer is at or near land surface in some of the stream channels in the vicinity of the dome.

Oakwood Salt Dome is in contact with the water-bearing sands of the Wilcox Group, and therefore has more potential for salt dissolution from circulatory ground water than either Keechi or Palestine Salt Domes. However, as the dome area is less faulted, the cap rock and gouge over the dome may have formed a better protective layer than at the other two domes. No salinewater has been noted at the surface at Oakwood Dome, but marshes occur on the southeast side of the dome near the junction of Alligator and Buffalo Creeks. Probable plumes of salinewater that extend down the hydraulic gradient from the dome have been identified in the basal sands of the Wilcox.

Additional problems may be encountered in determining the stability of Oakwood Dome as related to cap-rock integrity and to the sources of salinewater around the dome. According to the Texas Railroad Commission, at least two wells have been used to dispose of salinewater from oil fields by gravity feed into the cap rock of the dome, and at least two wells have been used to inject salinewater back into the Woodbine Formation. The two cap rock wells are the Carter-Jones Drilling Co., Inc., No. 2 P. W. Coleman and the W. R. Hughey, No. 1 M. Pickard. The No. 2 P. W. Coleman was operational from 1964 to 1969 when it was plugged. This well was used to dispose of salinewater into the cap rock at depths of 1,271 to 1,280 feet. The No. 1 M. Pickard has been operational since 1969, and is used to dispose of salinewater into the cap rock at depths of 1,260 to 1,268 feet.

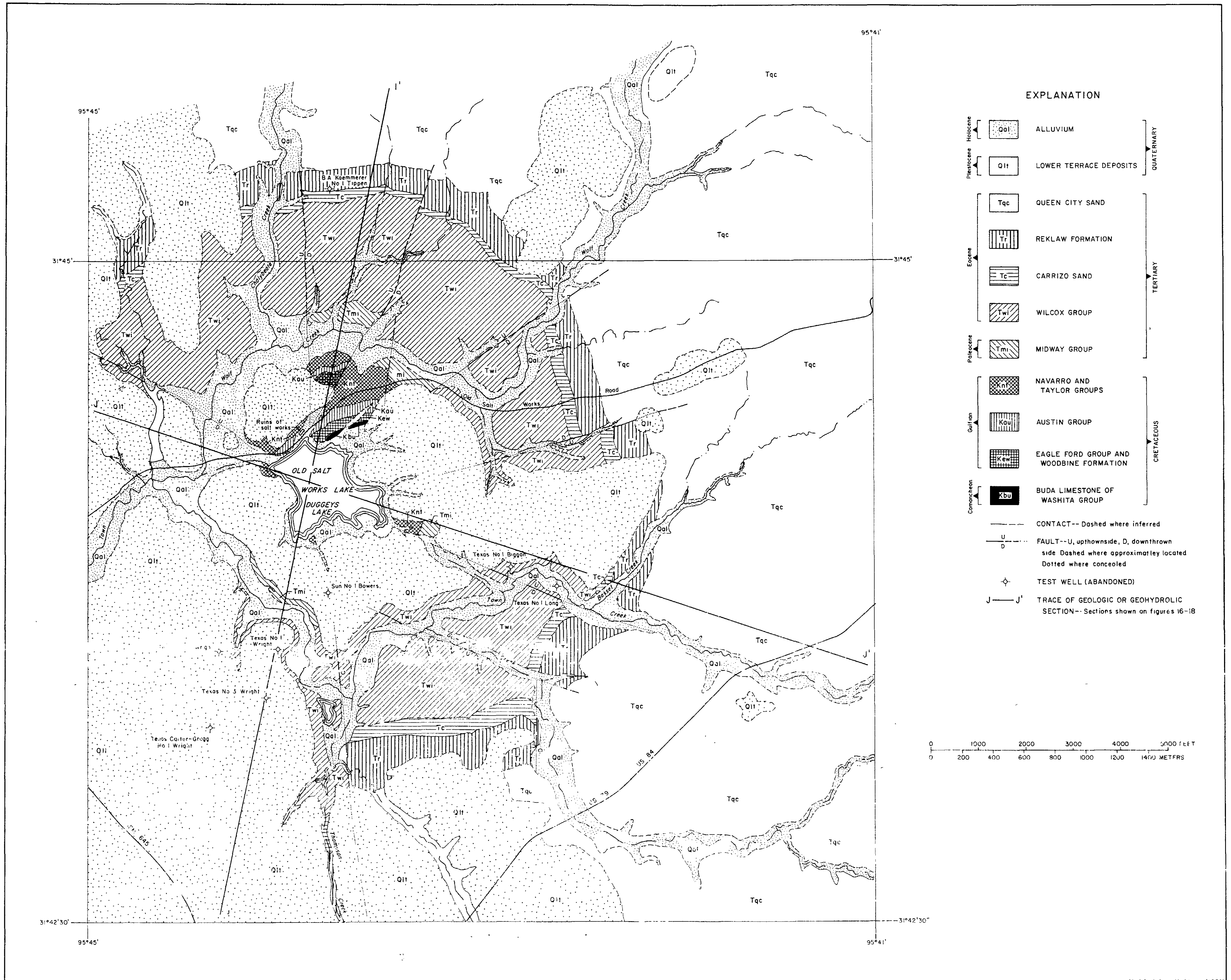


Figure 15.-Geologic map of the Palestine Salt-Dome area

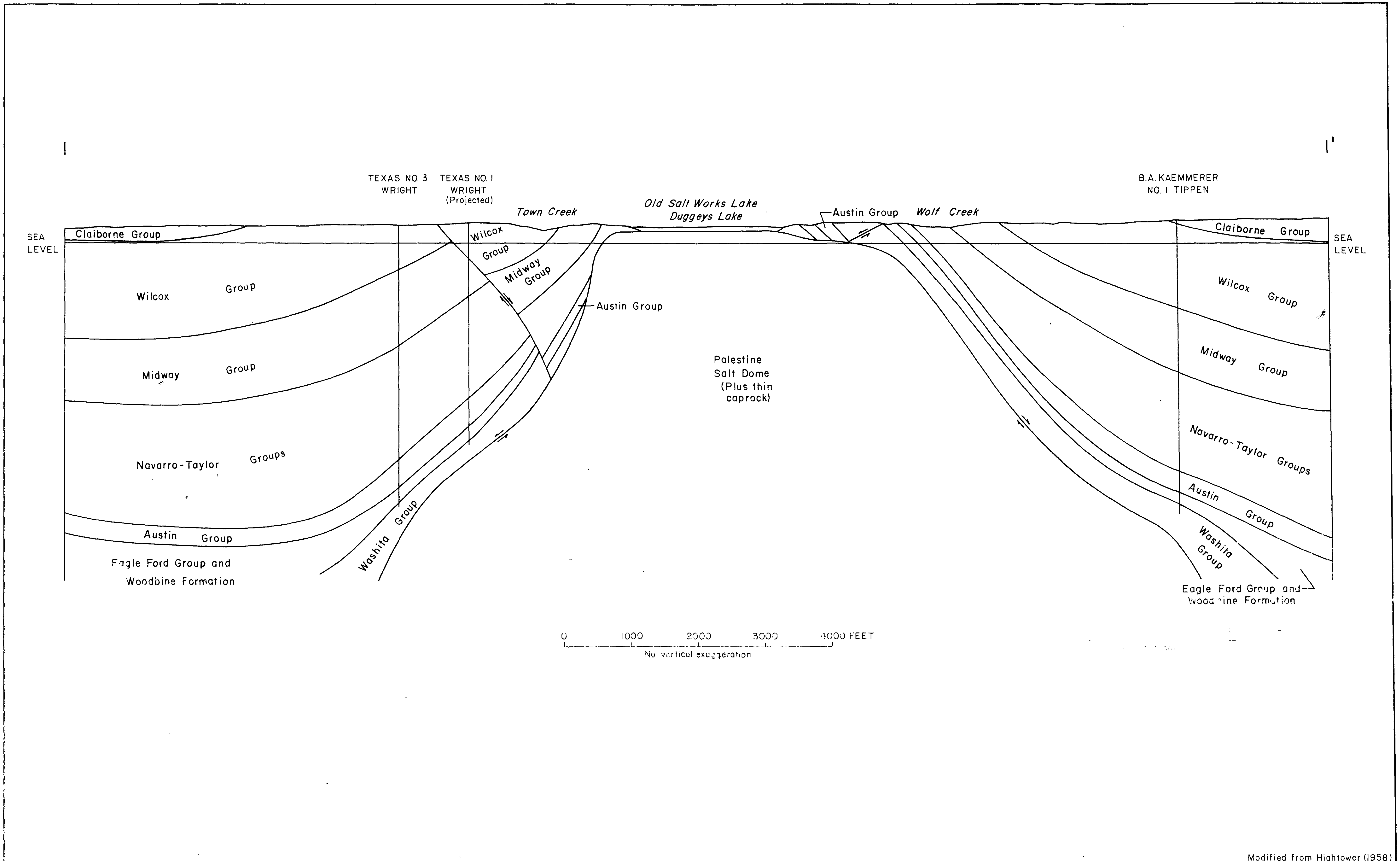


Figure 16.-Geologic section I-I', Palestine Salt Dome

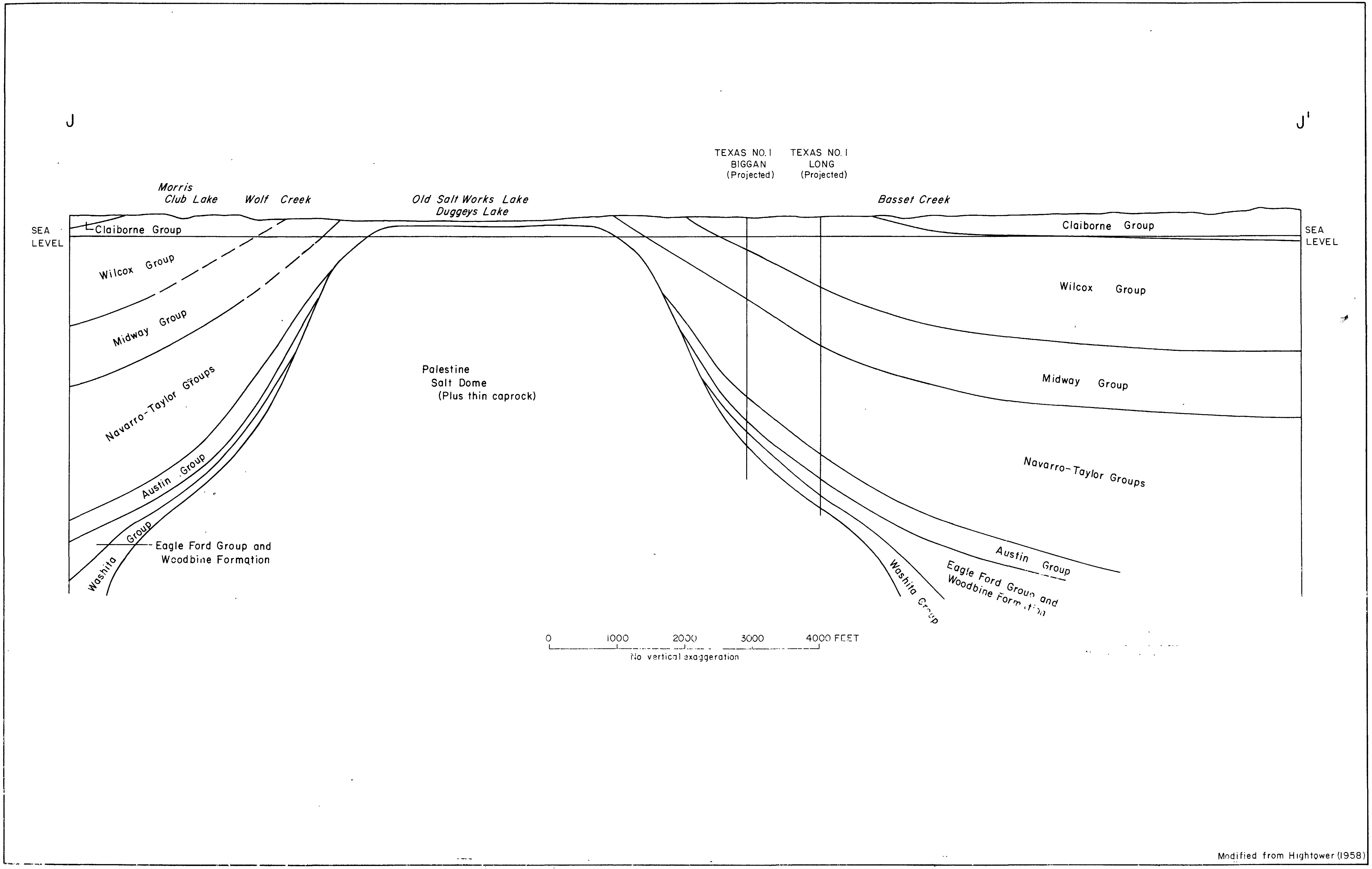


Figure 17.-Geologic section J-J', Palestine Salt Dome

## Palestine Salt Dome

Palestine Salt Dome is in central Anderson County about 6 miles southwest of Palestine and about 6.5 miles south-southwest of Keechi Salt Dome. The dome is in the Trinity River drainage system and is drained by Wolfe and Town Creeks and their tributaries. The channels of Wolfe and Town Creeks form a pronounced angular drainage pattern around the dome. Duggey's Lake (Old Salt Works Lake) occupies a topographic depression at the center of the dome. A survey conducted by the U.S. Geological Survey in 1978 indicated that the maximum depth of the lake is about 5.7 feet. Altitude of the lake surface is about 244 feet above NGVD.

A notable ring of hills with altitudes ranging from 300 to 350 feet above NGVD surrounds the lake. Hopkins (1918, p. 255 and 264) interpreted the central basin of the dome to be a collapse feature due to uplift and removal of the salt from the top of the dome during "recent movement." In addition, he reported that minor stream adjustments occurred during this time that resulted in the reversal of some drainage towards the center of the dome for at least two streams on the southern part of the dome.

Minor amounts of salt were obtained from Palestine Salt Dome as early as the Civil War. From 1904 to 1930, the Palestine Salt and Coal Co. produced brine from brine wells, and by 1916, there were about 16 productive or abandoned brine wells on the dome as shown by Hopkins (1918, p. 260). Nine of these wells were to the northeast of and within 0.3 mile of Duggey's Lake, and seven were to the southwest of and within 0.13 mile of the lake. According to Hopkins (1918, p. 261), the main factor controlling the location of these brine wells was the presence of good cap rock. The cap rock served as a seat for the casing and held up the overlying strata while a large cavity was dissolved out beneath it. The depths of these brine wells were less than 560 feet.

By assuming a daily production of 100 tons of brine per day, Powers (1926) estimated that 500,000 tons of salt were produced from 1904 to 1925, or a bulk sufficient to permit the land surface to subside as much as 0.5 foot over an area of 0.5 square mile. Salt is not now being produced at this dome; however, the effects of past production are still obvious on the dome. Hightower (1958, p. 59) indicated that a few of the brine-well sites could be located by noting sinks at the well locations. No hydrocarbons have been found at this dome.

### Geology

The strata overlying and surrounding Palestine Salt Dome have been arched into steeply dipping folds that are complexly faulted. Powers (1926, p. 53) states that the faulting at Palestine Dome is more complex than that shown at the surface of other domes. Cretaceous strata, which have been upthrust near the center of the dome, crop out mainly north of Duggey's Lake (fig. 15), although several small Cretaceous outcrops occur south of the lake. Cretaceous strata exposed at the surface include rocks of Navarro Group, Taylor Group, Austin Group, Eagle Ford Group, Woodbine Formation, and Buda Limestone of the Washita Group. Geologic sections of the dome by Hightower (1958) are shown on figures 16 and 17.

The Buda Limestone of Cretaceous age crops out on the dome and has a structural relief of nearly 6,500 feet. Increasingly younger Tertiary strata surround the Cretaceous outcrops. The dips are steep, ranging from 45 to 70 degrees near the center of uplift. However, Hightower (1958, p. 61) suggests that these dips are not "true" structural dips but the results of shifting blocks immediately above the intruding salt core. He also states that the true structural dips around the periphery of the dome are approximately 45 to 55 degrees and progressively decrease away from the dome.

The strata in the dome area are intensely faulted in a predominantly radial pattern, and a graben is present in the center of the uplift. Hightower (1958) depicts eight radial faults caused by intrusion of the salt mass. Stratigraphic displacement is greatest near the center of uplift and decreases away from the dome. The Davey Fault, which strikes north from the center of the dome, has the greatest throw, 1,400 feet on the base of the Austin Group, that could be measured (Hightower, 1958, p. 6). Hightower also estimates that throws of the faults range from 100 to 350 feet on the base of the Reklaw Formation. The greatest throw on the Reklaw datum occurs on the Thompson Creek Fault south of the dome.

The salt mass is in the form of a truncated cone. The plan view of the salt mass is symmetrical as shown by Netherland, Sewell, and Associates, Inc. (1976, fig. G-36). The uplift affects an area approximately 4 miles in diameter around the dome. The center of the salt mass lies beneath the east side of Duggey's Lake. Salt within the dome has risen to an altitude of at least 150 feet above NGVD, and the minimum known depth to salt is 120 feet from land surface. According to Hightower (1958, p. 62) rocks older than the uppermost part of the Taylor have been pierced by the salt; he also states that there is no reason to believe that the Tertiary section has been pierced.

Only limited data on cap-rock distribution and thickness are available. Powers (1926, p. 51) indicates that cap rock of gray, hard limestone is found on the dome; the cap rock rapidly increases in thickness from 9 feet at the western shore of Duggey's Lake to 32 feet in the well farthest away to the northeast. Netherland, Sewell, and Associates, Inc. (1976, p. G-39) indicate that cap-rock thickness probably averages less than 50 feet.

## Hydrology

The major water-bearing units at Palestine Salt Dome are the Woodbine Formation, Wilcox Group, and the Carrizo Sand. The general thicknesses of these units about 3 miles from the dome are: Woodbine Formation, 500 feet; Wilcox Group, 1,400 feet; and Carrizo Sand, 150 feet. Although the Queen City Sand crops out over a large part of the area near the dome, only about 100 to 150 feet of the formation is present.

Regional ground-water flow in the Carrizo-Wilcox aquifer is generally to the southeast. The natural regional hydraulic gradient for the Carrizo-Wilcox in this area ranges from about 0.5 to 1 foot per mile. The upper limit of the rate of regional ground-water flow in the Wilcox Group is estimated to be about 5 feet per year with these gradients.

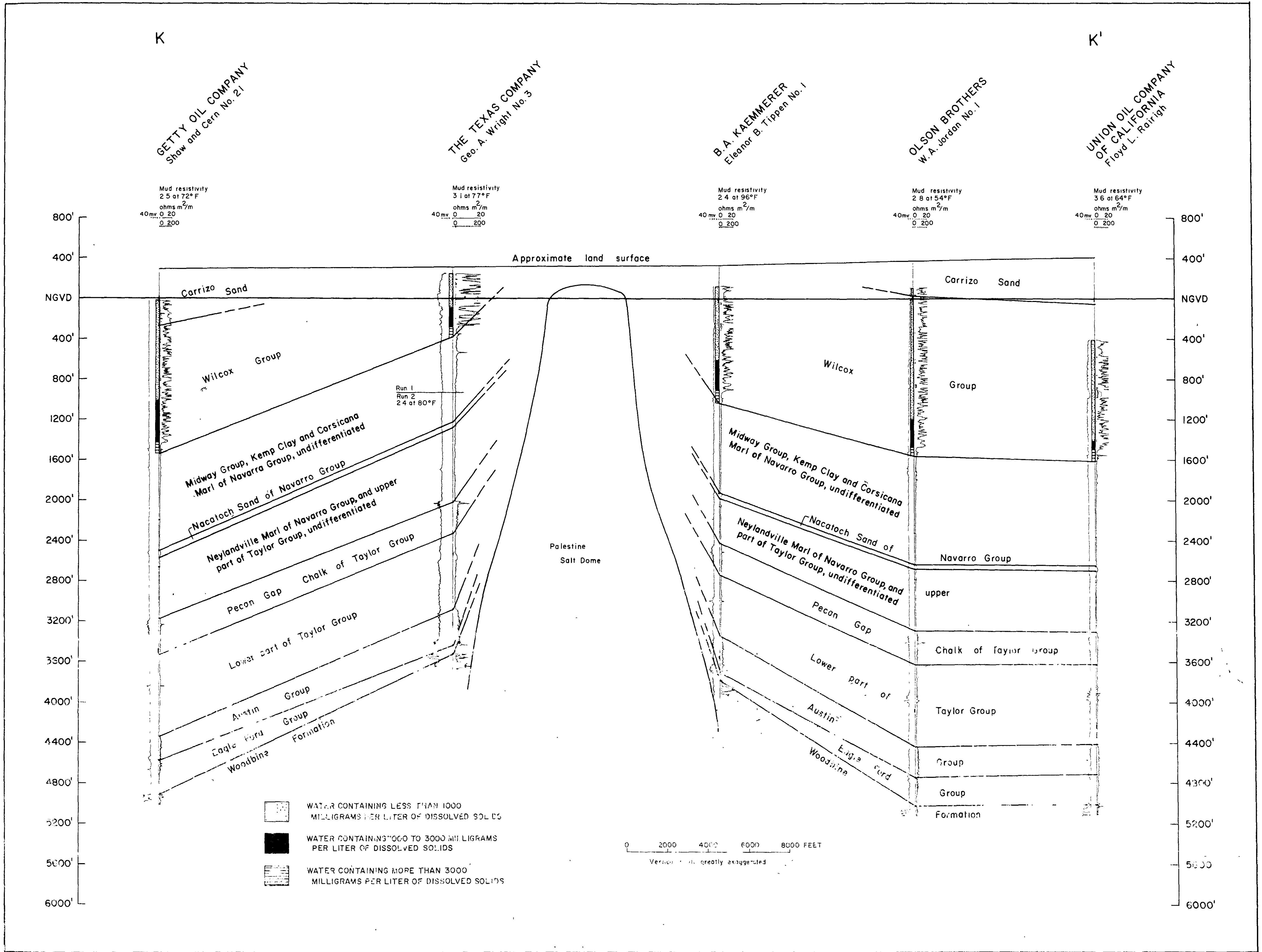


Figure 18.-Geohydrologic section K-K', Palestine Salt Dome

The depth to water in the various formations near the dome is similar to that at Keechi Salt Dome. The regional potentiometric surface of the Carrizo-Wilcox aquifer is at or near land surface in some stream channels near the dome.

Saline anomalies at Palestine Salt Dome are evident from reports of salinewater at the surface and from analyses of geophysical logs, although the freshwater aquifers seem to be isolated from the dome by Cretaceous and Midway strata. A few salt licks were reported by Hopkins (1918, p. 255) in an open valley near the Palestine road crossing of a small branch of a tributary of Wolfe Creek (Little Saline Branch). In March 1978, the authors measured a specific conductance of 960 micromhos per centimeter at 25° Celsius in the water flowing in this tributary. This value was twice that of other tributaries near the dome.

Powers (1926, p. 48) stated that the "Little Saline," on the road to Palestine northeast of the salt works, was the most barren area around the course of the circular drainage. The steep northeast dip in the top of the salt core, as proved by wells east of the salt works, indicates that Little Saline Spring and the other springs issue salinewater that rises from salinewater-bearing sands along their outcrops or along faults or joints and not from the salt core. Many other springs are found along Wolfe and Town Creeks.

Hopkins (1918, p. 256) also reported that "...other interesting features of the dome are the glades which surround it on all sides. These are low areas along stream valleys where no bushes or trees grow, and the principal vegetation is a peculiar swamp grass. The absence of a normal growth of vegetation on these areas suggests that the soil may be slightly saline, owing to the escape of salt-bearing water." Hopkins' map (Hopkins, 1918, p. 260) shows these glade areas to be along Wolfe and Town Creeks. In addition to these areas, a central saline lake previously existed. When visited by Dumble in 1891, Duggey's Lake was a small pool of water in winter only and was surrounded by a broad salt lick (Powers, 1926, p. 47). The present lake was formed by the construction of the railroad embankment in about 1900, which acts as a dam. Hopkins (1918, p. 254) indicated that the salinity of the lake was increasing due to the inflow of salinewater from salt wells and the salt works. Measurements of specific conductance of the lake water in 1978 indicated a uniform value of about 6,400 micromhos.

The possible occurrence of a plume of salinewater is indicated down the hydraulic gradient from the dome. The vertical distribution of salinewater in the Wilcox Group, as shown on figure 18, also tends to confirm the presence of the plume; although salinity anomalies are not indicated by data from water wells in the area. However, most of the water wells in the Wilcox Group in the vicinity of the dome do not extend into the basal salinewater-bearing sands of the Wilcox Group.

Additional problems concerning the hydrologic stability of Palestine Salt Dome have resulted from the solution mining of salt and cap-rock collapse. Presently, the extent and shape of solution cavities at the dome are not known because of the possible coalescense of cavities. Therefore, the future stability of the cap rock and overlying land surface, and thus the hydrologic stability, would be difficult to insure.

## EVALUATION OF HYDROLOGIC STABILITY

Eventual selection of any one of the four candidate domes for radioactive-waste storage would be under the guidelines as set forth by Brunton and others (1977). Although there are many criteria for selection--such as dome geometry, depth to top of salt, and properties of salt within the dome--this study was limited to providing information about the geohydrology and hydrologic stability of the domes by using available data.

The criteria used for indicating probable hydrologic stability of a dome are given by Martinez and others (1975, p. 111) as follows:

1. The dome is encased by clay strata, clay gouge, and sands containing very saline, noncirculating waters.
2. Circulating water in overlying aquifers is not contaminated by salt.
3. Salt licks are absent at the surface.
4. Cap rock is not present.
5. The dome is tectonically stable.

As stated by Martinez and others (1975), hydrologic stability could be expected if all of the stated conditions exist. However, stability could exist even if plumes of salinewater, surface salinewater, and cap rock are present. Piercement-type salt domes deform the strata they penetrate with resulting complex fault patterns, slump blocks, and brecciated zones, which could conceivably form interconnecting zones of vertical permeability. Therefore, the possibility exists that surface salinewater or plumes of salinewater may result from the upward flow of salinewater from deep water-bearing units, as opposed to brines from salt dissolution.

An evalution of these anomalies through comparisons of ion concentrations and ion ratios from chemical analyses of these waters would then be necessary to determine their source in order to judge hydrologic stability of the dome. In addition, although the occurrence of a cap rock is an indication of past salt dissolution, its presence does not preclude present stability, or stability necessary for the length of time required for storage. Moreover, absolute stability for any dome probably does not exist, and hydrologic stability is very likely a relative condition.

A comparison of regional water-quality data with water-quality data in the vicinity of a dome should facilitate the detection of abnormal salinity patterns that may indicate dome dissolution. However, the usefulness of available water-quality data in detecting salinity abnormalities is limited because: (1) The present sampling density in the vicinity of the domes is sparse; (2) the available water-quality analyses typically did not include analyses for certain ions, such as iodide or bromide, which could be useful in determining the source of water in the vicinity of the domes; and (3) the available water-quality analyses typically do not include on-site values of pH and bicarbonate, which would allow development of a more accurate geochemical model of the ground-water system.

The tectonic stability of a dome is a factor that is directly related to the hydrologic stability. This relationship needs to be evaluated before confirmation can be made of a dome's hydrologic stability. However, the limitations of this study restrict consideration of this relationship. A review of published literature indicates that most current investigators explain salt-dome formation through a combination of tectonic and isostatic forces, and postulate dome emplacement as a slow episodic process that decreases nonlinearly with time. An excellent study on salt-dome emplacement and the disturbance of surrounding strata is given by Parker and McDowell (1955).

An analysis by Netherland, Sewell, and Associates, Inc. (1976, p. G-13) indicated that the net average vertical movement of salt since the beginning of post-salt sedimentation is about 0.045 mm per year in the northeast Texas salt-dome basin. Also, they indicate that salt movement was greatest during late Jurassic time, and that movement has generally decreased since then, possibly stopping altogether at the present. Future studies need to address this subject to provide confirmation of this conclusion.

## NEED FOR ADDITIONAL STUDY

Hydrologic stability is a critical element that needs to be established in determining the suitability of a dome as a safe repository for radioactive wastes. Much additional information is required to make this assessment because there is a notable lack of available geologic and hydrologic information on which to base a reliable evaluation of the domes. The evidence of instability, as based on the criteria of Martinez and others (1975, p. 111), is sufficient to necessitate additional studies. To evaluate the hydrologic stability of the candidate domes, the following studies are needed:

1. A more complete regional analysis of the geohydrologic system, including aquifer geometries, stratigraphic and lithologic variations, and hydrochemical patterns, and integration of these data with site-specific data. Regional data will provide background for the interpretation of local data at the dome sites. Although general regional descriptions of the depositional systems and sediment characteristics are available, they are limited in the sense that local variations in depositional patterns near the domes are not defined in relation to the regional pattern. The effects of dome growth could cause variations in depositional patterns near the domes.

2. Site-specific studies of the freshwater- and saltwater-bearing units including: Cap rock-aquifer boundary relationships, spatial-sediment distributions and corresponding hydrologic-parameter variations, hydraulic-head relationships, and hydrochemical patterns. A test-drilling program including water sampling, head measurements, coring, geophysical logging, and aquifer testing is necessary to define these items. In addition, supplementary water samples and water-level or pressure measurements are needed at wells in the vicinity of the domes to help define the potentiometric surfaces and hydrochemical patterns in the aquifers around the domes.

Test holes need to be planned so that head measurements and water samples can be taken in all major water-bearing zones at a given site. This can be accomplished either by multiple sampling in a single test hole or by sampling in multiple test holes drilled to different depths at a single site. Special emphasis needs to be given to sands in the lower part of the Wilcox Group.

Test-site locations for hydrologic testing, in addition to cap-rock testing, need to (as a minimum) include "up" and "down" potentiometric-gradient locations around the domes and at least one location in a mapped plume of salinewater. When and if a primary dome is selected from the candidate domes, a more intensive drilling program would be required for final certification of hydrologic stability. Aquifer tests need to be planned to obtain: (a) Hydrologic parameters for the sediments near the domes, (b) vertical hydraulic-conductivity values to determine interconnection of the aquifers, and (c) hydraulic parameters describing the cap-rock materials and the degree of interconnection between the cap rock and aquifers.

Lithologic and hydrologic conditions at the test sites can be determined from coring and geophysical logging. Geophysical logging needs to include the following logs: Conventional electrical logs with 16-inch short-normal, 64-inch long-normal, 18-foot 8-inch lateral and spontaneous-potential curves; dual induction-lateralog surveys; borehole-compensated acoustic logs; multiarm caliper logs; sidewall neutron-porosity logs; natural-gamma logs; temperature logs; and compensated formation-density (gamma-gamma) logs. Additional logs such as the borehole televiewer-acoustic logs may be helpful in cap-rock test holes.

Water sampling needs to be planned to define the hydrochemical facies distribution around the domes. The program should facilitate detection of saline anomalies and aid in defining ground-water flow around the domes. Sampling sites need to include freshwater and salinewater aquifers, streams, lakes, and salt licks within the probable influence of the dome. In addition, sink holes, such as occur at Palestine Salt Dome need to be sampled. It is important that the hydrogen-ion activity, temperature, bicarbonate concentration, and carbonate concentration be determined immediately at the site when the water samples are collected.

Statistical analysis of water-quality data would be helpful to provide probabilities of the occurrence of significantly larger ion or ion-ratio values. The ion-exchange characteristics and membrane properties of the geologic units need to be determined. The following ions need to be determined for all samples in addition to the constituents of a standard analysis: Iodide, bromide, strontium, lithium, and boron. These ions and ion-ratios, such as chloride/bromide, iodide/chloride, and iodide/bromide, are useful in determining halite leaching and in determining the source of salinewater. Other ionic constituents such as oxygen$^{16}$/oxygen$^{18}$ and carbon$^{14}$ are useful in indicating the age of water from an aquifer. An extensive carbon$^{14}$ sampling program in the basin is desirable to help determine regional ground-water flow patterns and flow patterns at the domes.

3. Computer models of the geohydrologic system need to be constructed for each candidate dome. This would allow a more comprehensive integration of the components of the geohydrologic system and would enhance the understanding of the ground-water flow system and theoretical plume configurations around the domes. Model construction initially needs to include a flow model that could be applied to a mass-transport model. The mass-transport model needs to be capable of simulating ion exchange, variable-fluid densities, and radioactive decay.

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