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# Hydrogeologic Characterization of the Saline Aquifers, East Texas Basin--Implications to Nuclear Waste Storage in East Texas Salt Domes

by

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## CONTENTS

## FIGURES

## TABLES

# APPENDICES

The raw data displayed in Appendix B were purchased as Proprietary Data under agreement with Petroleum Information Corporation and cannot be shown in the final report. However, interpretations of these data are included in the body of this report. For further information contact the Bureau of Economic Geology.

# ABSTRACT

Ground waters in the deep aquifers (Nacatoch to Travis Peak) range in salinity from 20,000 to over 200,000 mg/l. Based on their isotopic compositions, they were originally recharged as continental meteoric waters. Recharge probably occurred predominantly during Cretaceous time; therefore, the waters are very old. Because the basin has not been uplifted, and faulting of the northern and western sides, there are no extensive recharge or discharge zones. The flanks of domes and radial faults associated with domes may function as localized discharge points. Both the water chemistry and the hydraulic pressures for the aquifers suggest that the basin can be subdivided into two major aquifer systems: (1) the upper Cretaceous aquifers (Woodbine and shallower) which are hydrostatic to subhydrostatic and (2) the deep lower Cretaceous and deeper formations (Glen Rose, Travis Peak, and older units), which are slightly overpressured.

The source of sodium and chloride in the saline waters is considered to be from salt dome dissolution. Most of the dissolution occurred during the Cretaceous. Chlorine-36 analyses suggest that dome solution is not presently occurring. Salinity cross sections across individual domes do not indicate that ongoing solution is an important process.

The major chemical reactions in the saline aquifers are dome dissolution, albitization, and dedolomitization. Albitization and dedolomitization are important only in the deeper formations. The high Na concentrations in the deeper aquifers system results in the alteration of plagioclase to albite and the release of Ca into solution. The increase in Ca concentrations causes a shift in the calcite/dolomite equilibrium. The increase in Mg results from dissolution of dolomite.

The critical hydrologic factors in the utilization of salt domes for disposal of high-level nuclear waste are whether the wastes could leak from a candidate dome and where they would migrate. The following conclusions are applicable to the problem of waste isolation in salt domes.

(1) Salt domes in the East Texas Basin have extensively dissolved. The NaCl in the saline aquifers is primarily from this process. Major dissolution, however, probably occurred in the Cretaceous time. There is little evidence for ongoing salt dome dissolution in the saline aquifers.

(2) If there was a release to a saline aquifer, waste migration would either be along the dome flanks or laterally away from the dome. If there is a permeability conduit along the dome flanks, then contaminants could migrate to the fresh-water aquifers provided an upward hydraulic gradient exists. Calculation of performance assessment scenarios must take into account whether there is potential for upward flow between saline aquifers at repository level and the fresh water aquifers. If an upward flow potential exists, upward leakage along the dome flanks should be used as the worst-case scenario.

# INTRODUCTION

The suitability of salt domes in the East Texas Basin, Texas, for long-term isolation of nuclear wastes is, in part, dependent on the hydrologic stability of the salt domes and the hydrogeologic conditions around the domes. The two prime hydrogeologic issues can be defined as follows: (1) Can salt dissolution breach a dome and permit a repository leak during the life of the repository? and (2) What is the regional aquifer hydrology which determines where radionuclides would migrate (Kreitler, 1979; Fogg and Kreitler, 1981)?

In the studies of the Bureau of Economic Geology on the East Texas Basin much of the emphasis on these two primary issues has been in the shallow fresh ground water aquifers that surround the candidate domes. These shallow aquifers, the Wilcox-Carrizo and Queen City aquifers, represent a major water supply for the region (Fogg and Kreitler, 1982; Fogg, Seni, and Kreitler, 1983). These units have an abundance of data to interpret the physical hydrology and hydrogeochemistry.

The fresh-water aquifers, however, represent only a thin upper layer (maximum thickness of 2,000 ft) to a basin that contains up to 15,000 ft of sedimentary rocks. These deeper formations contain saline waters and constitute another hydrologic system that is separate from the fresh-water aquifers. A potential nuclear waste repository would be located at a depth which would be either transitional between fresh and saline ground-water systems or completely within the saline system. The two issues of dome dissolution and radionuclide migration that have been addressed for the fresh-water aquifers must similarly be addressed for the saline aquifers. This report addresses these problems in the saline aquifers of the East Texas Basin.

This report addresses the general characteristics of deep-basin hydrology. Site-specific studies of candidate domes are not conducted, because of the lack of detailed data surrounding any one dome. The availability of hydraulic and geochemistry data is much more limited than for the fresh-water aquifers. Because the Wilcox-Carrizo, Queen City aquifers are major water suppliers for the region, an extensive data base has been collected by state agencies over the years. In contrast, study of the saline aquifers is dependent on data available from oil and gas wells which are much more limited.

Based on the data from previously analyzed oil field samples and samples collected specifically for this study, the following approach has been taken to address these two prime issues. One is to determine the source of the water by isotopic analyses. The hydrogen and oxygen isotopic values can be used to indicate whether the basinal water originated as oceanic waters or were meteoric waters recharged on the continent. Two is to determine whether the domes are the source of salinity in the saline formations. Salinities in these deep formations range from 20,000 to over 200,000 mg/l. Is the source of this salinity from salt dome dissolution over the history of the basin? Mass-balance approaches can help define where and when the salt was dissolved. Three is to determine the important geochemical reactions that occur in the basin. The chemical composition of these waters varies from Na-Cl type to Na-Ca-Cl type. The three geochemical reactions of salt dissolution, albitization and dedolomitization appear to control the chemical composition. By understanding the evolution of the water chemistry it is possible to delineate major hydrologic systems in the basin. Four is to determine the major hydrologic systems from the pressure data of available drill-stem tests. With the information and interpretations from these sections, preliminary conclusions can be drawn on the hydrologic characteristics of the saline aquifers and whether dome dissolution and radionuclide transport are critical problems in the deep saline aquifers.

## REGIONAL GEOLOGIC SETTING OF EAST TEXAS BASIN

The East Texas Basin is one of three inland Mesozoic salt basins in Texas, Louisiana, and Mississippi that flank the northern Gulf of Mexico (fig. 1). About 5,791 m (19,000 ft) of Mesozoic and Tertiary strata are preserved in the central parts of the East Texas Basin. These rocks overlie metamorphosed Paleozoic Ouachita strata, which are probably a continuation of the Appalachian foldbelt (Lyons, 1957; Wood and Walper, 1974; McGookey, 1975).

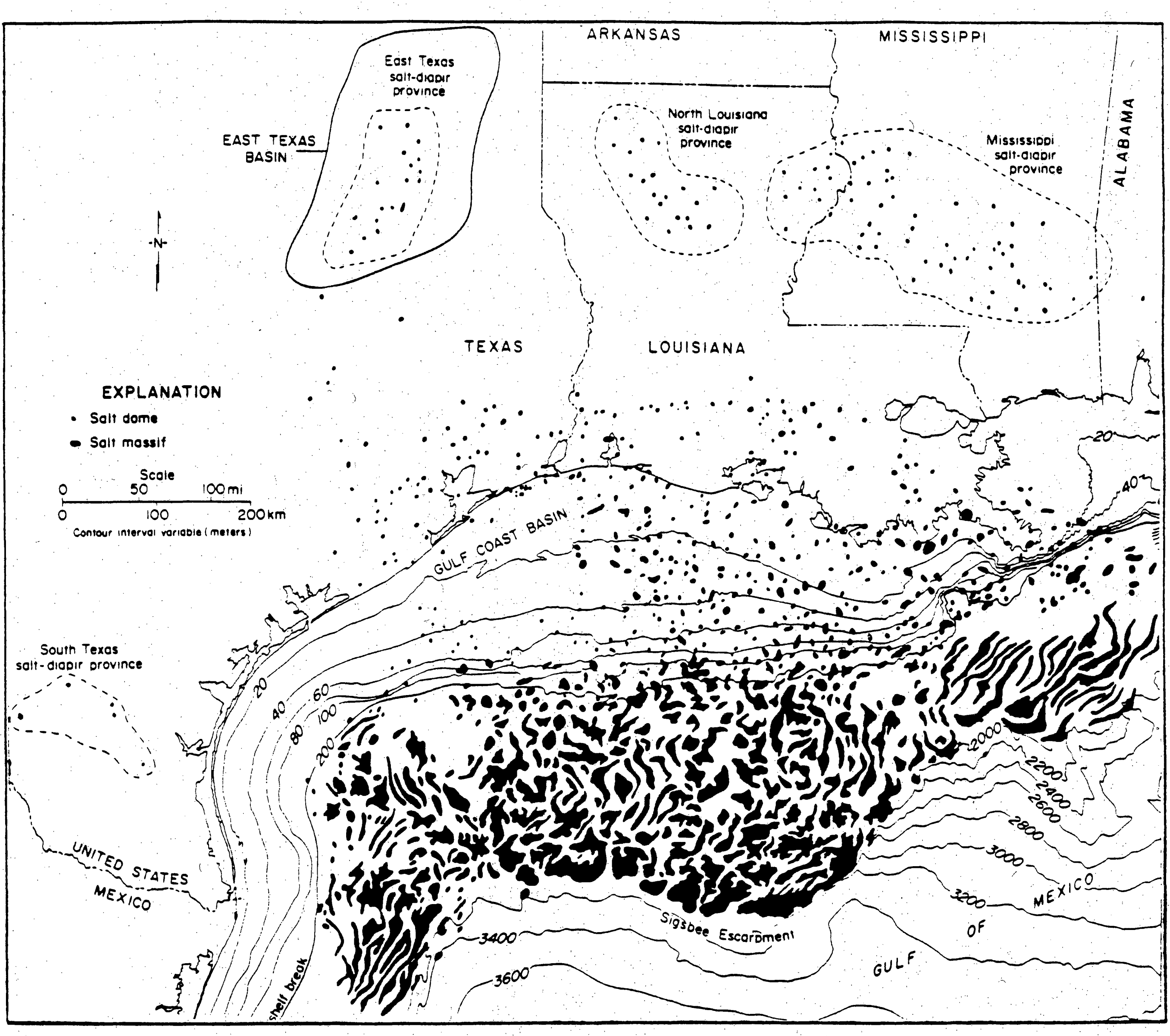

Figure 1. Map showing the East Texas Basin, Gulf Coast Basin, location of inland salt-diapir provinces and salt domes (after Martin, 1978).

The general stratigraphy (fig. 2) and structure of the East Texas Basin (fig. 3) have been summarized in many articles (e.g., Eaton, 1956; Granata, 1963; Bushaw, 1968; Nichols and others, 1968; Kreitler and others, 1980, 1981; Wood and Guevara, 1981; Jackson, 1980; and Jackson and Seni, 1983).

## Basin Stratigraphy

The evolution of this basin is briefly summarized by Jackson and Seni (in press, 1983). The Jurassic Louann Salt was deposited on a planar angular unconformity across Triassic rift fill and Paleozoic basement (fig. 4). The early post-Louann history of the basin was dominated by slow progradation of platform carbonates and minor evaporites during Smackover to Gilmer time. After this phase of carbonate-evaporite deposition, massive progradation of Schuler-Hosston siliciclastics took place in the Late Jurassic-Early Cretaceous. Subsequent sedimentation comprised alternating periods of marine carbonate and siliciclastic accumulation. By Oligocene time subsidence in the East Texas Basin had ceased, and major depocenters shifted to the Gulf of Mexico. Paleocene and Eocene strata crop out in most of the basin, indicating that net erosion charcterized the last 40 million years.

Agagu and others (1980) in a more detailed discussion characterized the basin infilling as six regional depositional sequences and is quoted below.

<u>The Eagle Mills-Louann sequence (Upper Triassic-Middle Jurassic)</u>.--This sequence was initiated by deposition of the undated continental Eagle Mills red beds. The Eagle Mills red beds are composed of red-brown shales, sandstones, and unfossiliferous limestones, which are unconformably overlain by the Werner Formation. Lower sections of the Werner consist of conglomerates and fine- to coarse-grained sandstones that grade upward into finer clastics and evaporites in the upper part of the formation. Halite interbeds in the Werner progressively increase volumetrically toward the top of the formation and are transitional into the conformably overlying Louann Salt (Nichols and others, 1968).

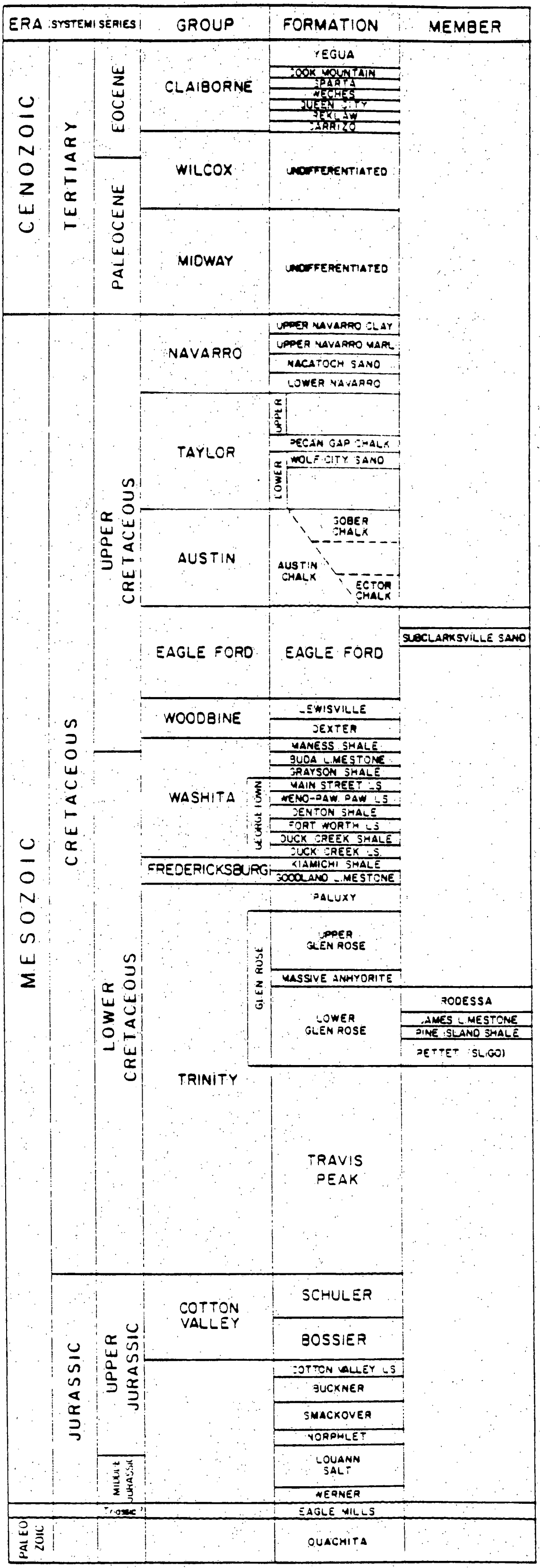

Figure 2. Stratigraphic column of East Texas Basin (from Wood and Guevara, 1978).

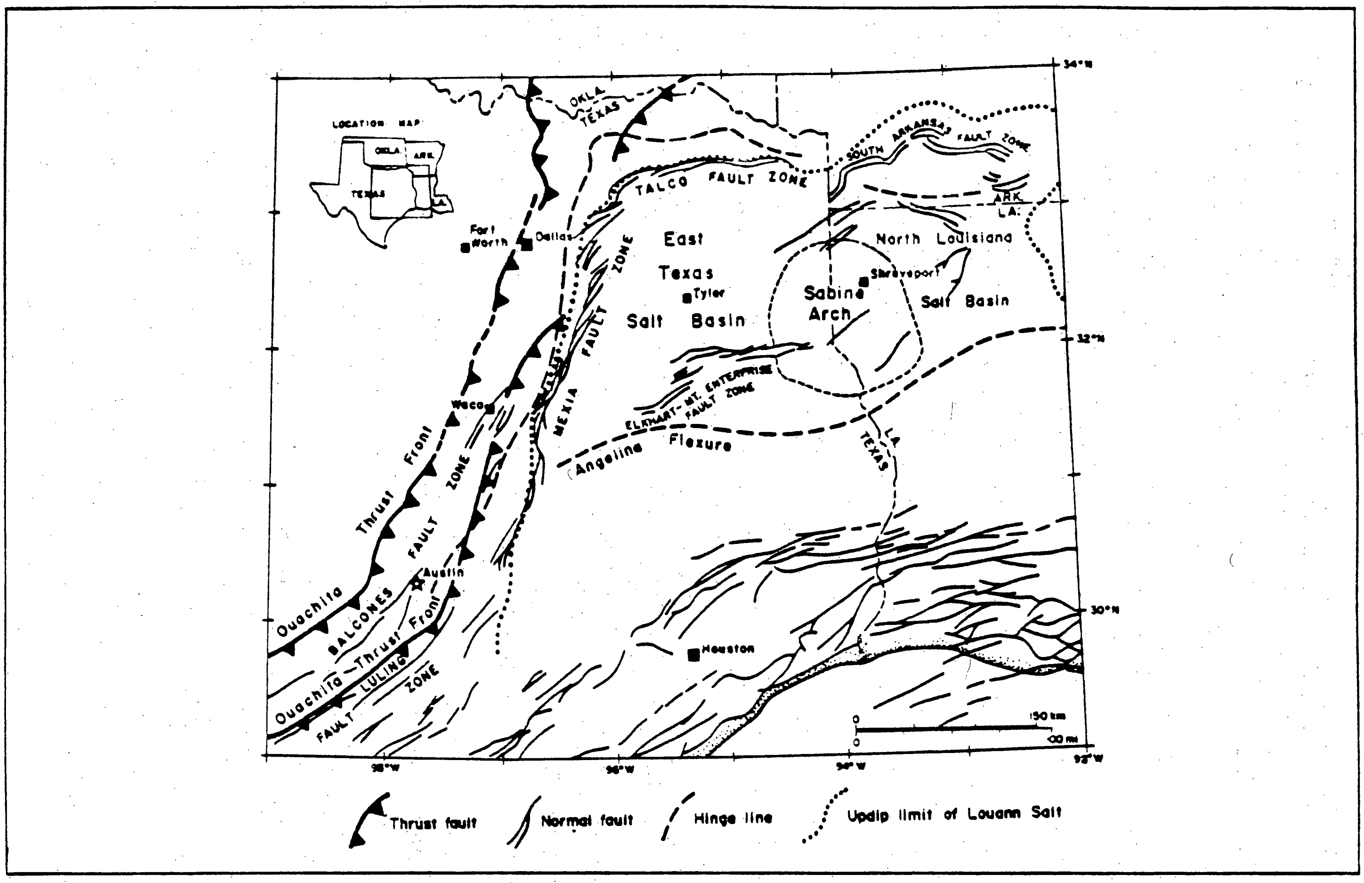

Figure 3. Regional tectonic setting of the East Texas Basin (from Jackson, 1982).

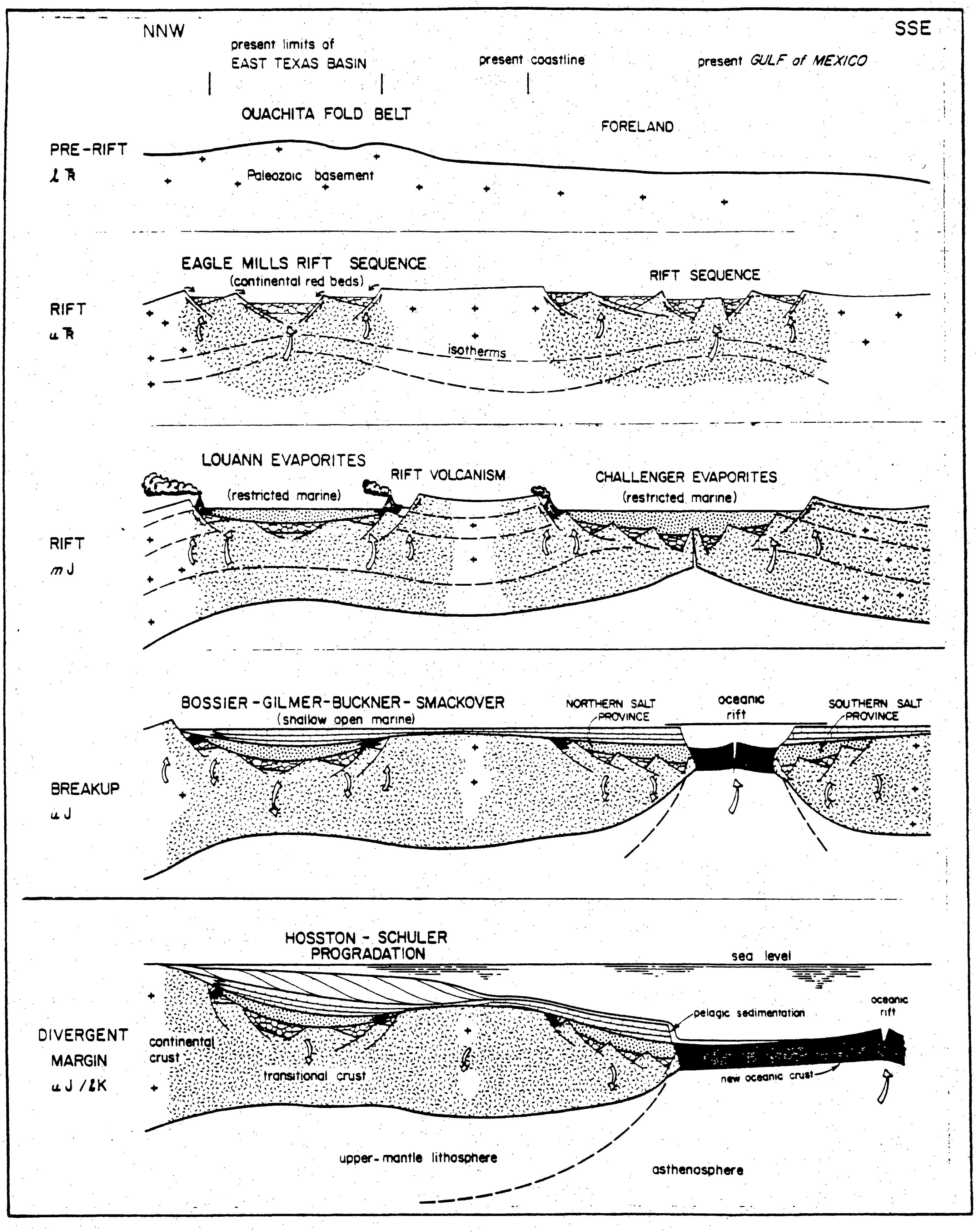

Figure 4a. Schematic northwest-southeast sections showing evolutionary stages in the forming of the East Texas Basin and adjoining Gulf of Mexico (from Jackson and Seni, 1983).

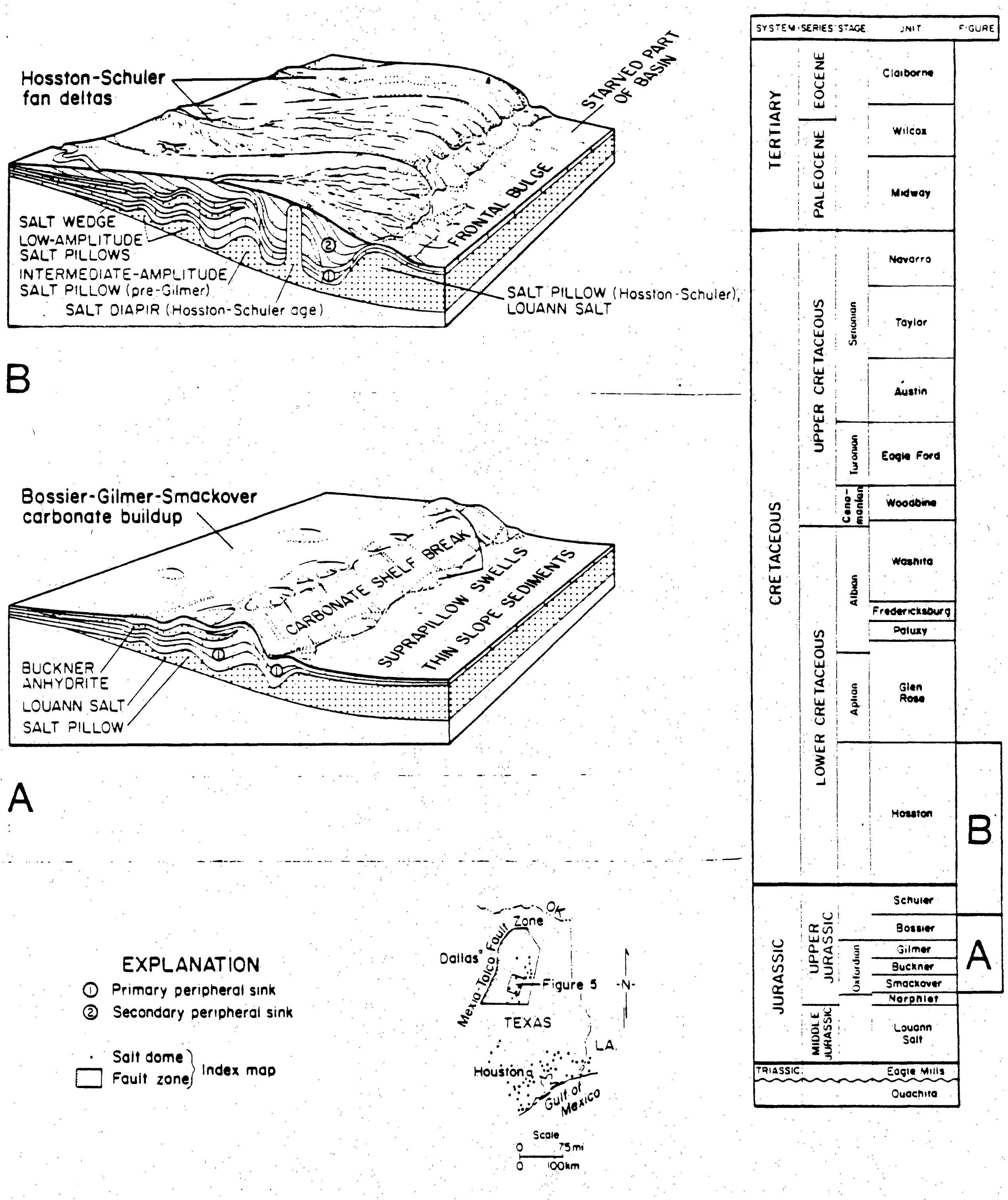

Figure 4b. Schematic block diagram showing relationships between salt flow and sediment accumulation during early period of evolution of the East Texas Basin. A. Initiation of salt flow in Late Jurassic. B. Initiation of Group 1 diapirs in Late Jurassic-Early Cretaceous (after Jackson and Seni, 1983).

The Louann Salt consists of white, gray to blue halite with minor amounts of anhydrite. Upper parts of the formation exhibit some red plastic shales transitional into the conformably overlying Norphlet Formation (Nichols and others, 1968). The partially restricted nature of the East Texas Basin during its initial stages of formation (Wood and Walper, 1974) provided an ideal setting for large-scale evaporitic processes, which have not been repeated in the basin.

Norphlet-Bossier sequence (Upper Jurassic).--The Norphlet Formation consists of sandstones, siltstones, and red shales. The basal part contains halite, anhydrite, and dolomite transitional into the subjacent Louann evaporites (Nichols and others, 1968). The relatively thin Norphlet Formation is conformably overlain by the Smackover Formation, which documents a regressive phase between deposition of the Louann Salt and the Smackover Limestone.

The Smackover Limestone here consists of a basal laminated micrite that grades upward into a pelletal micrite and ultimately into a coated grainstone. The Smackover Limestone is overlain by and is in part correlative with the Buckner Formation, which contains red sandstones in the western and northern margins of the basin and grades basinward into evaporites, shales, dolomites, and limestones (Nichols and others, 1968). The Smackover-Buckner strata document a shoaling sequence from subtidal in the lower Smackover Limestone to supratidal conditions in the Buckner Formation. The Cotton Valley Limestone and Bossier Formation are deeper water, gray, micritic limestones and gray to black shales (Nichols and others, 1968) that onlap the Buckner supratidal facies, an indication of a minor sequence boundary above the Smackover Formation.

Schuler-Glen Rose sequence (Upper Jurassic-Lower Cretaceous).--The Schuler and Travis Peak Formations attest to the high rate of terrigenous clastic influx during Late Jurassic and the Early Cretaceous. They compose a thick sequence (900 m, 3,000 ft) predominantly of sandstones interbedded with dull red and green-gray shales (Nichols and others, 1968). The Schuler-Travis Peak sequence onlaps the subjacent marine units despite its strongly terrigenous character and is probably an example of coastal onlap.

The Glen Rose Group consists of a thick (750 m, 2,500 ft) sequence of shallow marine, micritic, pelletal, oolitic, and shelly limestones interbedded with dark-gray shales and anhydrites (Nichols and others, 1968). The predominantly calcareous units, such as the Pettet, James, and Rodessa Members and much of the Upper Glen Rose Formation, are deeper water facies. Sandy shale units, such as the Pine Island Shale, and evaporites, such as the Massive Anhydrite, were deposited during minor influxes of fine, terrigenous sediment and deposition in supratidal environments, respectively. Terrigenous facies dominate, especially along the north and northwestern flanks of the basin.

Paluxy-Washita sequence (Lower Cretaceous).--The Paluxy Formation consists of interbeds of sandstones and shales, and rare conglomerates lie in the northern half of the East Texas Basin. Basinward, toward the south, the Paluxy gradually changes into dark-gray shales and micritic limestones (Nichols and others, 1968). The volume of terrigenous clastic sediment (up to 135 m, 450 ft) and the high rate of deposition indicate that a major though short-lived phase of fluvial-deltaic clastic influx occurred. Limestone and shales of the Fredericksburg and Washita Groups in East Texas document the Early Cretaceous sea-level high that drowned the Paluxy deltas.

Woodbine-Midway sequence (Upper Cretaceous-Paleocene).--Spasmodic uplift of the marginal areas of the East Texas Basin during Late Cretaceous to Paleocene times, accompanied by possible lowering of relative sea level, resulted in the terrigenous clastic influx marked by the Woodbine and Eagle Ford Groups. The Woodbine Group, composed mainly of fluvial and deltaic sandstone and subordinate shales, marks the peak of clastic sedimentation during this phase. The Eagle Ford Group, consisting primarily of shelf and slope shales and minor sandstones, documents the waning phase of clastic deposition.

The Austin Group initiated the transgressive and submergent phase that terminated in the Paleocene. During this depositional phase, up to 244 m (800 ft) of shelf chalks, shales, and marls were deposited with rare clastic facies that define minor variations in this sequence.

Tertiary Clastics.--The Tertiary stratigraphic sequence in the East Texas Basin is a complex unit mainly composed of fluvio-deltaic sandstones and shales. The Wilcox Group is a thick (up to 900 m, 3,000 ft) unit of fluvial and deltaic sands, clays, lignites, and marls. The Claiborne Group is similar to the Wilcox Group, but it displays some shaly, glauconitic, fossiliferous shelf/embayment units (Reklaw Formation, Weches Formation, and Cook Mountain) that alternate regionally with more sandy fluvial-deltaic units (Carrizo, Queen City, Sparta, and Yegua Formations). The entire Tertiary section constitutes a major regressive phase.

The permeable saline formations in the East Texas Basin are the Nacatoch, Eagle Ford, Woodbine, Paluxy, Glen Rose (including Rodessa and Pettet), Travis Peak (Hosston), and Cotton Valley (Schuler). These formations are considered permeable and are called saline aquifers in the text because they are oil-producing formations and not because aquifer tests were conducted to determine their permeable nature. It is implied that these formations have some permeability because they produce hydrocarbons. A more rigorous site-specific study of a candidate dome will require hydrologic testing of these deep saline aquifers to obtain accurate hydrologic properties. For this reconnaissance study of the East Texas Basin hydrology, it is sufficient to say that these formations have the potential for transmitting water.

## Structural Framework

The structural framework of the East Texas Basin is summarized by Jackson (1982).

A map of the tectonic setting of the East Texas Basin (fig. 3) reveals that the western and northern margins of the basin coincide with other geologic structures varying from Pennsylvanian to Tertiary age. The Pennsylvanian Ouachita fold and thrust belt crops out in Arkansas and Oklahoma and extends to southwest Texas beneath Mesozoic cover (Thomas, 1976). Stratal shortening of Ouachita marine deposits generated northwest-converging folds and thrusts. Early Mesozoic continental rifting of this Paleozoic terrane can be inferred from the confinement of the Triassic Eagle Mills rift clastics to grabens and half grabens parallel to the Ouachita trends (Salvador and Green, 1980). Further subsidence allowed marine incursions that deposited the evaporitic Louann Salt on an eroded post-rift, pre-breakup terrane. The updip limit of the Louann Salt (fig. 4) is also parallel to the Ouachita trends, which indicates that during the Jurassic the Ouachita area was still elevated with respect to the subsiding East Texas Basin. A poorly defined monoclinal hinge line is present updip of the Louann Salt (fig. 3), but is too weak to delineate the western and northern margins of the basin. This part of the basin margin is therefore defined by the Mexia-Talco Fault Zone, a peripheral graben system active from the Jurassic to the Eocene that coincides with the updip limit of the Louann Salt (Jackson, 1982).

The Sabine Arch, a broad structural dome, forms the eastern margin of the basin. The southern margin of the basin is defined by the Angelina Flexure, a hinge line that is generally monoclinal at its ends and anticlinal in the middle. The Elkhart-Mount Enterprise Fault Zone extends from just north of the western end of the Angelina Flexure to the center of the Sabine Arch (fig. 3) (Jackson, 1982).

## History of Salt Movement

Seni and Jackson (1983) described the evolution of salt structures in the East Texas Basin and is summarized as following.

The present distribution and morphology of salt structures in the East Texas Basin are shown in Figure 5. A broad amphitheater of undeformed salt, 2.7 to 4.6 km deep and 225 km long, encircles a heterogenous array of salt structures. In much of the basin center the Louann Salt is absent or so thin as to be seismically unresolvable. The salt masses can be resolved into geometric groups, each of which defines a province (fig. 5) (Jackson and Seni, 1983). (1) An outermost salt wedge consists of apparently undeformed salt ranging from 0 to 340-640 m thick. Its updip pinchout coincides with the Mexia-Talco fault zone, a symmetrical peripheral graben apparently formed by basinward creep of the Louann Salt and the post-Louann section over a décollement zone of salt (Cloos, 1968; Jackson, 1982). (2) Periclinal salt structures with low amplitude/wavelength ratios are called low amplitude salt pillows. These pillows are flanked by

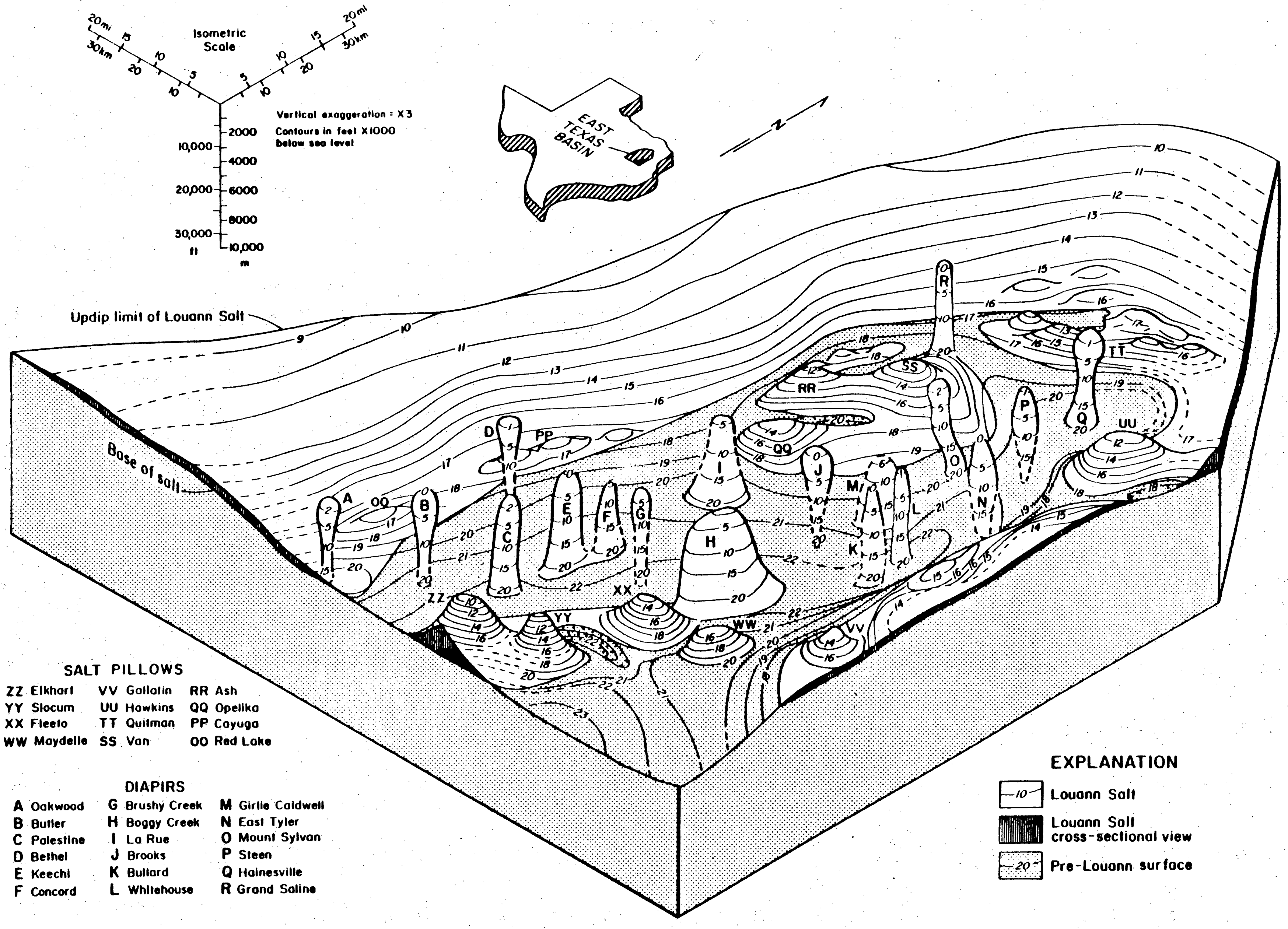

Figure 5. Isometric block diagram of the East Texas Basin showing the three-dimensional configuration of structure contours on top of Louann Salt, or, where salt is absent, on top of basement (from Jackson and Seni, 1983).

synclines of Louann Salt. The Louann Salt was originally at least 550 to 625 m thick before deformation; 600 m is therefore suggested as the approximate minimum thickness of mother salt required to allow formation of salt structures in the East Texas Basin. Overburden thickness was about 500 m throughout provinces 1 through 3 at the start of salt movement. (3) Intermediate-amplitude salt pillows are commonly separated by synclines evacuated of salt and are larger than pillows of province 2. Original thickness of the salt source layer here is estimated as 550 to > 760 meters. (4) The salt diapirs of the diapir province in the basin center are the most mature salt structures. They have all partially "pierced" their overburden and have risen to within 23 m (Steen Dome) to about 2,000 m (Girlie Caldwell Dome) of the present surface.

The earliest record of movement in the Louann Salt is in the overlying shallow-marine interval below the top of the Upper Jurassic Gilmer Limestone. This seismic unit thins over salt anticlines of province 2, indicating the growth of low-amplitude salt pillows in pre-Gilmer time (Jackson and Harris, 1981). The overlying Upper Jurassic marine strata formed an aggrading, slowly prograding, carbonate wedge (Bishop, 1968) that loaded the salt fairly uniformly (fig. 4b).

In Late Jurassic and Early Cretaceous time the Schuler-Travis Peak clastics prograded rapidly across the carbonate platform as coalescing sand-rich deltas. Progradation slowed on crossing the shelf break, but the thick deltas continued to advance as a linear front into the previously starved basn (fig. 4b). Loading of the pre-Schuler substrate by the advancing linear depocenters would have squeezed salt ahead as a frontal bulge to form a salt anticline (cf. Ramberg, 1981, p. 282-286). Increase in sediment supply for progradational rate would bury the frontal anticline, thereby initiating a parallel, but more distal, salt anticline. These anticlines, which may have been formed partly by gravity gliding as well as differential loading, were ridges of source rock from which the salt diapirs grew by budding upward.

The evolution of many of the salt pillows to salt diapirs started by mid-Early Cretaceous time when salt diapirs were growing in three areas around the periphery of the diapir province, starting at about 130 m.y. ago (Seni and Jackson, 1983). At least two areas coincide with the clastic depocenters described above. These early diapirs thus appear to have been localized by loading on the salt-cored anticlines in front of the prograding Schuler-Travis Peak deltas.

By the mid-Cretaceous when maximum sedimentation was taking place in the basin center, a second generation of diapirs evolved, via a pillow stage, from the thick salt layer there. Sites of diapir initiation migrated from the basin center northward along the basin axis.

The diapirs on the northern and western margin of the diapir province had an entirely different origin. In Late Cretaceous time, subsidence of the East Texas Basin had declined exponentially to relatively low rates. Tilting of the basin margins by loading of the basin center would have encouraged basin-edge erosion. Local unconformities exist over Hainesville Dome (Loocke, 1978), and 150 to 200 km$^3$ of salt are calculated to be missing. The precursor salt pillow was breached by erosion; salt withdrawal through extrusion formed an enormous secondary peripheral sink, the largest in the East Texas Basin. Erosional breaching of the faulted crests of salt pillows might also have initiated diapirism of the first and second generations of diapirs, but we have no unequivocal evidence for this hypothesis.

All the east Texas domes have risen very slowly since the end of the Mesozoic (mean net rate = 35 m/m.y.). No effects of salt withdrawal have been transmitted to the surface since the Paleocene; the diapirs are thus inferred to have risen by basal necking in the Tertiary.

## ORIGIN OF WATERS IN THE SALINE AQUIFERS, EAST TEXAS BASIN

### Introduction--Summary

Based on hydrogen and oxygen isotopic data, the saline waters in the East Texas Basin appear to have a continental meteoric origin. If there were oceanic waters originally present, they have been flushed by meteoric water. The presence of meteoric water does not, however, imply that these waters are geologically young. The addition of meteoric water has probably been ongoing since early Cretaceous time.

## Procedures

Fifty water samples were collected and analyzed for $\delta^{18}O$ and $\delta^{2}H$ (fig. 6 and table 1). Analyses were performed by Global Geochemistry Corporation. For $\delta^{18}O$ measurements brine samples were distilled before equilibration with carbon dioxide. Table 1 shows the error based on replication of samples.

Fourteen samples are not included in further analysis of data because these samples were not considered as representative of natural subsurface conditions. This is based on the extremely low Na, Cl, Ca, Br concentrations for their respective depths (table 2). (See p. 89 and tables 2 and 2a for more complete discussion.)

## Definition of Terms

Several terms are used in this paper that are used in various ways in the scientific literature. It is therefore appropriate to define these terms to avoid ambiguity.

Meteoric water: Meteoric waters are surface waters or shallow ground waters. They have not undergone significant isotopic changes of the $\delta^{2}H$ or $\delta^{18}O$ values because of rock-water geochemical reactions. The ratio of $\delta^{2}H$ and $\delta^{18}O$ compositions of waters world-wide plots on a straight line with the equation $\delta^{2}H = 8\delta^{18}O + 10$ (Craig, 1961).

Marine water: Oceanic waters are the ultimate source for nearly all the waters of the hydrosphere. Marine water has a $\delta^{2}H$ and $\delta^{18}O$ composition of approximately $0^{o}/oo$, $0^{o}/oo$, respectively. The isotopic composition of an average ocean water (SMOW--standard mean ocean water) does not plot on the meteoric water line because of a small isotopic fraction that results from the evaporation of sea water. Marine waters with this 0, 0 isotopic composition are expected to be trapped with marine sediments during deposition and burial.

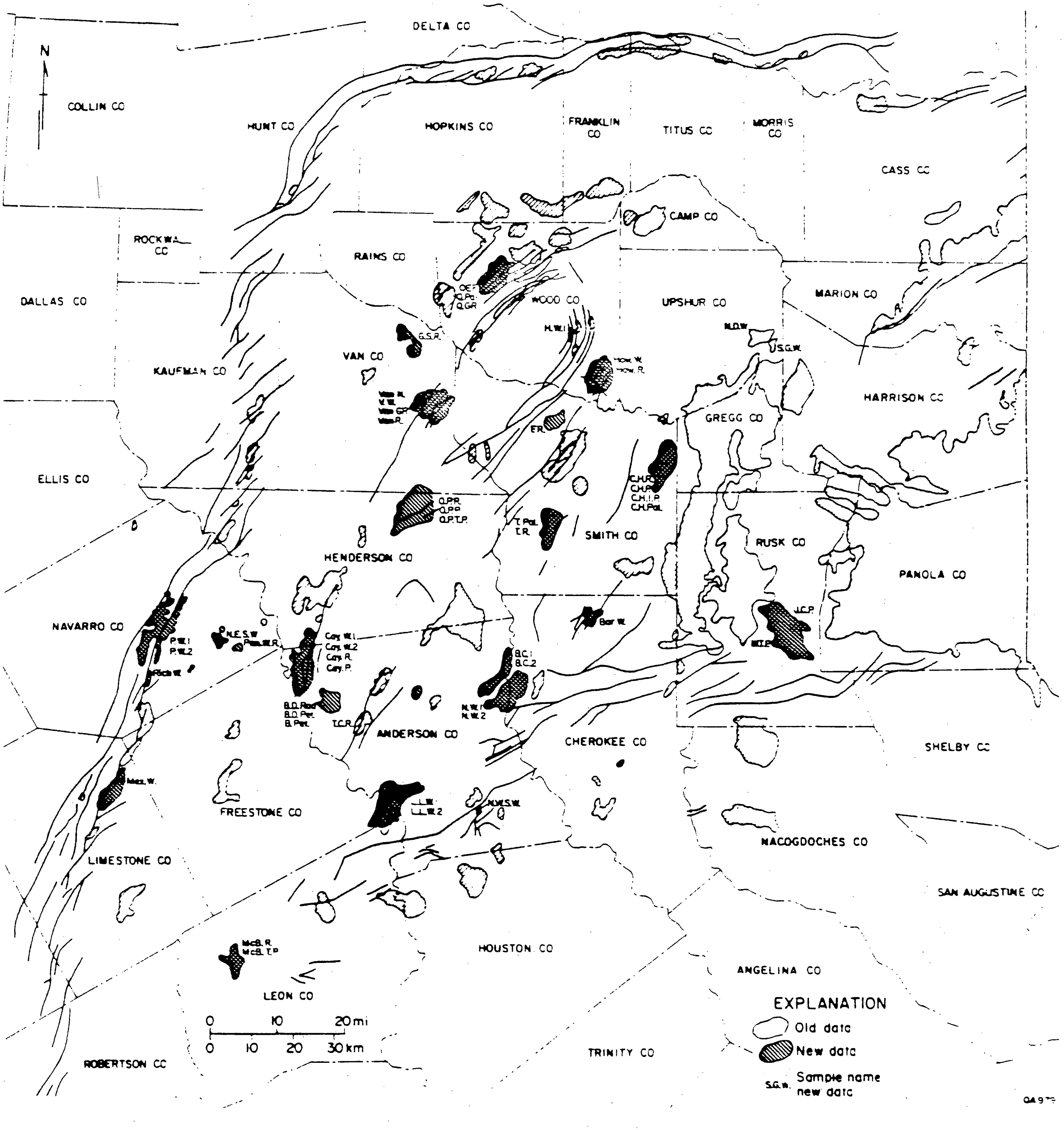

Figure 6. Location map of oil and gas fields where water samples were collected. Map indicates where both analyses from this study and previously published analyses were collected. Data in Table 1 and Appendix A.

Table 1. Chemical and isotopic composition of samples collected for this study between February and July, 1982.

| Sample No. | Formation | Depth | Na | K | Ca | Mg | Cl | $SO_4$ | $HCO_3$ | Br | I | Al | Fe | $SiO_2$ | $H_2S$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Van N | Nacatoch | 1,200 | 7,240 | 24 | 300 | 86 | 10,950 | 29 | 439 | 55 | 13 | 0.235 | 6.69 | 22.5 | <1 |
| QEF | Eagle Ford | 4,210 | 23,800 | 81.4 | 1,030 | 203 | 40,400 | <4.5 | 187 | 262 | 29 | <0.2 | 0.145 | 25.7 | <0.1 |
| B.C.1 | Woodbine | 3,600 | 37,900 | 125 | 3,250 | 465 | 65,500 | 120 | 160 | 140 | 42 | <0.2 | 21 | 16 | <0.1 |
| B.C.2 | Woodbine | 3,600 | 38,300 | 122 | 3,070 | 500 | 64,000 | 130 | 170 | 150 | 40 | <0.1 | 17 | 15 | <0.1 |
| C.W.1 | Woodbine | 4,404 | 35,100 | 112 | 3,400 | 530 | 61,200 | 90 | 120 | 150 | 24 | <0.2 | 102 | 27 | <1 |
| N.W.1 | Woodbine | 4,704 | 35,500 | 169 | 3,190 | 543 | 62,100 | 110 | 160 | 150 | 38 | <0.2 | 8.6 | 18 | <1 |
| N.W.2 | Woodbine | 4,704 | 35,700 | 168 | 3,200 | 545 | 62,100 | 90 | 150 | 170 | 39 | <0.2 | 11 | 19 | <1 |
| CAY W.1 | Woodbine | 4,030 | 29,300 | 73 | 1,200 | 210 | 48,200 | 120 | 170 | 73 | 31 | <0.2 | 0.74 | 24 | <1 |
| CAY W.2 | Woodbine | 4,030 | 29,600 | 70 | 1,200 | 210 | 48,500 | 120 | 160 | 64 | 31 | <0.2 | 0.22 | 24 | <1 |
| BAR. W. | Woodbine | 4,259 | 29,400 | 76 | 1,400 | 210 | 49,300 | 270 | 230 | 83 | 35 | <0.2 | 17 | 20 | <1 |
| L.L.W.1 | Woodbine | 5,272 | 36,400 | 83 | 2,400 | 280 | 62,200 | 110 | 170 | 110 | 33 | <0.2 | 1.4 | 26 | <1 |
| L.L.W.2 | Woodbine | 5,272 | 35,600 | 88 | 2,300 | 280 | 58,900 | 110 | 180 | 90 | 34 | <0.2 | 6.4 | 28 | <1 |
| P.W.1 | Woodbine | 3,000 | 4,400 | 24 | 74.5 | 27 | 6,500 | 60 | 350 | 32 | 5 | <0.1 | 0.10 | 30 | <1 |
| P.W.2 | Woodbine | 3,000 | 5,070 | 26 | 86.6 | 28 | 7,700 | 55 | 340 | 38 | 5 | <0.1 | 0.04 | 30 | <1 |
| V.W | Woodbine | 2,900 | 25,100 | 110 | 1,160 | 290 | 43,100 | 60 | 120 | 250 | 27 | <0.2 | 0.38 | 24 | <1 |
| N.W.S.W. | Woodbine | 5,400 | 32,500 | 170 | 2,700 | 460 | 58,100 | 73 | 98 | 280 | 37 | <0.2 | 11 | 35 | <1 |
| N.E.S.W. | Woodbine | 3,390 | 11,200 | 41 | 220 | 70 | 17,900 | 58 | 300 | 25 | 12 | <0.2 | 0.04 | 24 | <1 |
| HAW.W. | Woodbine | 4,531 | 35,200 | 99 | 2,300 | 290 | 59,500 | 250 | 170 | 120 | 33 | <0.2 | 2.7 | 26 | <1 |

Table 1. (cont.)

| Sample No. | Sr | Ba | Ti | Cu | Mn | Zn | Pb | Li | F | B | Br/Cl $\times 10^{-4}$ | $\delta^2H$ | $\delta^{18}O$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Van N | 26.3 | 17.6 | 0.055 | <0.01 | 0.281 | 0.022 | <0.1 | 0.675 | 0.4 | 9.89 | 50.22 | -30 | -3.83 |
| QEF | 224 | 25.7 | <0.05 | 0.022 | 0.913 | <0.02 | <0.2 | 1.08 | 0.6 | 11.6 | 64.9 | -27 | -1.75 |
| B.C.1 | 550 | 3.5 | <0.05 | <0.02 | 2.4 |  | <0.2 | 3.0 | 0.8 | 25 | 21.4 | -33 | 0.03 |
| B.C.2 | 550 | 3.6 | <0.03 | <0.01 | 2.3 |  | <0.1 | 2.5 | 0.6 | 21 | 23 | -31 | 0.00 |
| C.W.1 | 510 | 5.8 | <0.05 | 1.6 | 3.9 |  | <0.2 | 3.4 | 1.3 | 30 | 24.5 | -33,-31 | -1.57 |
| N.W.1 | 620 | 4.3 | <0.05 | <0.02 | 1.8 |  | <0.2 | 3.7 | 0.8 | 34 | 24.2 | -31,-29 | 0.87 |
| N.W.2 | 620 | 4.3 | <0.05 | <0.02 | 1.8 |  | <0.2 | 3.9 | 0.9 | 35 | 27.4 | -31,-30 | 0.63 |
| CAY W.1 | 300 | 2.7 | <0.05 | <0.02 | 0.71 | <0.02 | <0.2 | 2.4 | 0.9 | 19 | 15.1 | -34 | 0.10 |
| CAY W.2 | 300 | 2.5 | <0.05 | <0.02 | 0.39 | <0.02 | <0.2 | 2.4 | 0.9 | 19 | 13.2 | -29 | 0.29 |
| BAR.W. | 340 | 1.7 | <0.05 | <0.02 | 0.74 | <0.02 | <0.2 | 2.6 | 1.1 | 21 | 16.8 | -22 | -0.56 |
| L.L.W.1 | 510 | 3.4 | <0.05 | <0.02 | 1.6 | <0.02 | <0.2 | 3.4 | 0.9 | 19 | 17.7 | -33 | 0.70 |
| L.L.W.2 | 510 | 5.0 | <0.05 | <0.02 | 1.1 | <0.02 | <0.2 | 3.9 | 1.0 | 19 | 15.2 | -29 | 0.78 |
| P.W.1 | 13 | 9.2 | <0.03 | <0.01 | 0.06 | 0.02 | <0.1 | 0.54 | 1.2 | 22 | 49 | -28 | -3.81 |
| P.W.2 | 15 | 8.8 | <0.03 | <0.01 | 0.06 | <0.01 | <0.1 | 0.56 | 1.0 | 23 | 49 | -29 | -3.70 |
| V.W | 280 | 4.3 | <0.05 | <0.02 | 0.77 | <0.02 | <0.2 | 2.1 | 0.7 | 18 | 58 | -32 | -1.30 |
| N.W.S.W. | 660 | 8.8 | <0.05 | <0.02 | 2.0 | <0.02 | <0.2 | 5.5 | 0.7 | 29 | 48.2 | -30 | 1.16 |
| N.E.S.W. | 54 | 6.8 | <0.05 | <0.02 | 0.08 | <0.02 | <0.2 | 1.0 | 1.2 | 23 | 14 | -29 | -2.03 |
| HAW.W. | 430 | 2.6 | <0.05 | <0.02 | 1.4 | <0.02 | <0.2 | 3.4 | 1.0 | 20 | 20.2 | -29 | 0.17 |

Table 1. (cont.)

| Sample No. | Formation | Depth | Na | K | Ca | Mg | Cl | $SO_4$ | $HCO_3$ | Br | I | Al | Fe | $SiO_2$ | $H_2S$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEX. W | Woodbine | 3,100 | 12,270 | 44 | 570 | 142 | 20,300 | <6 | 263 | 124 | 19 | 0.236 | 0.041 | 22.2 | <1 |
| RICH. W | Woodbine | 3,300 | 5,285 | 22 | 94 | 29 | 8,280 | <6 | 350 | 39 | 7 | 0.246 | 0.047 | 24.8 | <1 |
| S.G.W. | Woodbine | 3,800 | 19,100 | 76 | 1,620 | 235 | 33,200 | <6 | 150 | 155 | 37 | 0.475 | 8.37 | 41.2 | <1 |
| N.D.W | Woodbine | 3,700 | 21,800 | 69 | 835 | 215 | 36,200 | <6 | 280 | 233 | 32 | 0.470 | 0.109 | 24.7 | <1 |
| C.H. Pal. | Paluxy | 5,600 | 28,700 | 67.4 | 1,680 | 256 | 48,000 | 800 | 164 | 173 | 33 | <0.2 | 0.239 | 23.4 | <0.1 |
| Q. Pal. | Paluxy | 6,230 | 39,000 | 159 | 9,540 | 936 | 81,300 | 389 | 54 | 1,160 | 24 | 0.436 | 6.46 | 23.0 | <0.1 |
| QGR | Glen Rose | 7,320 | 50,200 | 147 | 11,700 | 1,008 | 103,500 | 286 | 53 | 470 | 44 | 0.452 | 32.3 | 28.6 | <0.1 |
| B.D.ROD. | Rodessa | 10,100 | 70,900 | 2,350 | 31,500 | 1,800 | 169,000 | 15 | 43 | 1,700 | 40 | <0.2 | 110 | 36 | <0.1 |
| HAW.R. | Rodessa | 8,300 | 27,300 | 540 | 24,100 | 1,300 | 90,300 | 85 | 51 | 710 | 34 | 0.50 | 160 | 12 | <1 |
| T.C.R. | Rodessa | 9,000 | 42,490 | 250 | 14,160 | 1,540 | 87,900 | 132 | 31 | 597 | 40 | 0.599 | 113 | 26.0 | <1 |
| McB.R. | Rodessa | 8,790 | 50,600 | 1,200 | 13,300 | 712 | 101,000 | 269 | 83 | 460 | 47 | 0.578 | 1.60 | 51.5 | <1 |
| PAN.W.R. | Rodessa | 6,460 | 65,900 | 390 | 24,350 | 2,674 | 147,000 | 225 | 18 | 1,800 | 35 | 0.721 | 27.3 | 20.7 | <1 |
| C.H.R | Rodessa | 7,680 | 53,800 | 318 | 28,000 | 2,140 | 127,000 | 160 | 23 | 1,200 | 32 | 0.986 | 52.2 | 72.0 | <0.1 |
| G.S.R | Rodessa | 8,200 | 68,200 | 736 | 20,000 | 2,014 | 165,000 | 83 | 0 | 2,290 | 31 | 1.05 | 184 | 48.4 | <0.1 |

Table 1. (cont.)

| Sample No. | Sr | Ba | Ti | Cu | Mn | Zn | Pb | Li | F | B | Br/Cl $x10^{-4}$ | $\delta^2H$ | $\delta^{18}O$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MEX. W | 115 | 58.6 | 0.052 | <0.01 | 0.479 | 0.029 | <0.1 | 1.0 | 0.6 | 21.3 | 61.1 | -33 | -2.30 |
| RICH. W. | 17 | 24 | 0.059 | <0.02 | 0.083 | 0.017 | <0.1 | 0.415 | 1.5 | 18.5 | 47 | -40 | -4.15 |
| S.G.W. | 280 | 20 | 0.102 | <0.02 | 1.53 | 0.038 | <0.2 | 1.068 | 6.1 | 18.8 | 46.7 | -26 | -2.03 |
| N.D.W | 336 | 161 | 0.105 | <0.02 | 1.88 | 0.030 | <0.2 | 1.30 | 1.2 | 20.9 | 64.4 | -31 | -2.13 |
| C.H. Pal. | 158 | 5.10 | <0.05 | 0.084 | 0.891 | 0.028 | <0.2 | 1.97 | 0.9 | 30.9 | 36.0 | -26 | 1.67 |
| Q. Pal. | 526 | 2.57 | 0.068 | 0.037 | 3.59 | 0.142 | <0.2 | 6.53 | 1.4 | 42.6 | 142.7 | -24,-25 | 0.43 |
| Q GR | 636 | 1.15 | 0.08 | 0.033 | 0.589 | 0.097 | <0.2 | 6.52 | 2.4 | 58.4 | 45.4 | -26 | 2.82 |
| B.D.ROD. | 3,000 | 53 | <0.05 | <0.02 | 26 |  | <0.2 | 75 | 6.4 | 51 | 100.6 | -31 | 2.83 |
| HAW.R. | 1,700 | 36 | <0.05 | <0.02 | 61 | 23 | <0.2 | 25 | 1.4 | 13 | 78.6 | -32 | -2.24 |
| T.C.R. | 980 | 6 | 0.136 | 0.163 | 1.07 | 0.068 | <0.2 | 19.5 | 7.5 | 67.4 | 67.9 | -23 | 7.11 |
| McB.R. | 903 | 1.76 | 0.392 | <0.02 | 0.180 | 0.045 | <0.2 | 70.3 | 7.5 | 149 | 45.5 | -27 | 8.95 |
| PAN.W.R | 1,270 | 2.19 | 0.150 | <0.02 | 0.452 | 0.423 | <0.2 | 15.1 | 5.4 | 45.9 | 122.4 | -24 | 1.56 |
| C.H.R | 1,174 | 3.87 | 0.152 | 0.077 | 1.92 | 2.14 | <0.4 | 16.1 | 4.2 | 72.0 | 94.5 | -11 | 5.88 |
| G.S.R | 1,700 | 8.46 | 0.197 | 0.111 | 8.77 | 7.34 | <0.4 | 19.3 | 2.0 | 48.4 | 138.8 | -18 | 2.60 |

Table 1. (cont.)

| Sample No. | Formation | Depth | Na | K | Ca | Mg | Cl | $SO_4$ | $HCO_3$ | Br | I | Al | Fe | $SiO_2$ | $H_2S$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VAN.R. | Rodessa | 5,220 | 23,400 | 130 | 7,530 | 890 | 50,000 | 18 | 130 | 600 | 12 | 0.587 | 589 | 9.6 | <1 |
| B.Pet. | Pettet | 9,500-10,500 | 69,900 | 2,000 | 25,800 | 1,690 | 154,000 | 70 | 39 | 1,400 | 50 | <0.2 | 49 | 34 | <0.1 |
| JCP | Pettet | 7,200 | 46,400 | 773 | 13,100 | 749 | 99,600 | 82 | 30 | 746 | 23 | 0.503 | 315 | 17.8 | <0.1 |
| McB. T.P | Travis Peak | 11,200 | 56,700 | 3,340 | 12,700 | 452 | 108,000 | 214 | 20 | 801 | 56 | 0.545 | 37.2 | 78.6 | <1 |
| OP.T.P | Travis Peak | 10,000 | 52,800 | 2,580 | 17,800 | 1,230 | 111,000 | 89 | 23 | 1,540 | 22 | 0.625 | 132 | 47.4 | <1 |
| MTP | Travis Peak | 7,300 | 60,600 | 1,730 | 18,100 | 1,200 | 133,000 | 217 | 27 | 1,230 | 22 | 0.783 | 118 | 32.9 | <0.1 |

Table 1. (cont.)

| Sample No. | Sr | Ba | Ti | Cu | Mn | Zn | Pb | Li | F | B | Br/Cl $\times 10^{-4}$ | $\delta^2H$ | $\delta^{18}O$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VAN.R. | 306 | 39 | 0.127 | <0.02 | 5.71 | 0.040 | <0.2 | 4.04 | 0.4 | 29.2 | 120 | -35 | -2.04 |
| B.Pet. | 2,100 | 33 | <0.05 | <0.02 | 9.0 |  | <0.2 | 52 | 4.5 | 58 | 90.9 | -34 | 4.48 |
| JCP | 840 | 7.79 | 0.093 | 0.061 | 6.26 | 0.037 | <0.2 | 24.4 | 1.0 | 44.2 | 74.9 | -22 | 1.49 |
| McB. T.P | 976 | 11.4 | 0.129 | <0.02 | 3.31 | 0.046 | <0.2 | 35.8 | 214 | 37.2 | 74.2 | -24 | 3.17 |
| OP.T.P | 1,140 | 12.7 | 0.151 | <0.02 | 8.86 | 4.93 | <0.2 | 22.4 | 89 | 132 | 138 | -21 | 0.63 |
| MTP | 1,180 | 12.8 | 0.125 | 0.060 | 11.1 | 7.93 | 0.713 | 48.6 | 0.8 | 61.4 | 92.5 | -19 | 2.73 |

Table 2. Chemical analyses of deleted data.

| Sample No. | Formation | Depth | Na | K | Ca | Mg | Cl | $SO_4$ | $HCO_3$ | Br | I | Al | Fe | $SiO_2$ | $H_2S$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H.W.I | Woodbine | 9,776 | 67 | 1.1 | 45 | 1.9 | 126 | 3 | 52 | 7.5 | 3.8 | <0.1 | 41 | 7.7 | <1 |
| T.Pal. | Paluxy | 7,500 | 8,000 | 7,210 | 1,130 | 151 | 21,800 | <4.5 | 69 | 32 | 10 | <0.1 | 103 | 16.5 | <0.1 |
| Van GR | Glen Rose | 7,230 | 4,400 | 24 | 74.5 | 27 | 6,500 | 60 | 350 | 32 | 5 | <0.1 | 0.10 | 30 | <1 |
| CAY.R | Rodessa | 7,460 | 11.2 | 0.89 | 4.45 | 0.79 | 24 | <6 | 14 | 1.4 | 1.8 | 0.256 | 0.765 | 1.40 | <1 |
| OP.R | Rodessa | 8,630 | 705 | 112 | 586 | 25 | 2,220 | 7 | 72 | 25 | 4 | 0.165 | 158 | 2.6 | <1 |
| T.R. | Rodessa | 9,600 | 15,000 | 47.2 | 2,810 | 288 | 29,600 | <4.5 | 109 | 106 | 20 | 0.237 | 115 | 13.0 | <0.1 |
| F.R. | Rodessa | 10,660 | 5,600 | 397 | 3,510 | 1,060 | 19,500 | 286 | 0 | 42 | 1.8 | 0.274 | 1,180 | 3.6 | <0.1 |
| VAN.R. | Rodessa | 5,220 | 23,400 | 130 | 7,530 | 890 | 50,000 | 18 | 130 | 600 | 12 | 0.587 | 589 | 9.6 | <1 |
| B.Pet. | Pettet | ≈ 9,500-10,500 | 69,900 | 2,000 | 25,800 | 1,690 | 154,000 | 70 | 39 | 1,400 | 50 | <0.2 | 49 | 34 | <0.1 |
| B.D.Pet. | Pettet | 10,300 | 1,650 | 48 | 610 | 48 | 4,760 | 1 | 24 | 49 | 2.4 | <0.1 | 190 | 4.6 | 3.4 |
| CAY.P. | Pettet | 7,550 | 56 | 1.02 | 6.5 | 10.2 | 92 | <6 | 39 | 2.5 | 2 | 0.252 | 0.158 | <1 | <1 |
| OP.P. | Pettet | 8,900 | 25 | 1.6 | 27.5 | 1.15 | 72.7 | <6 | 24 | <0.5 | 1 | 0.268 | 0.036 | <1 | <1 |
| CH.P. | Pettet | 8,000 | 137 | 2.15 | 41.6 | 3.00 | 327 | <4.5 | 22 | 2.1 | 0.9 | <0.1 | 0.372 | 0.777 | <0.1 |
| CH.T.P | Travis Peak | 8,350 | 36,100 | 649 | 15,800 | 942 | 90,200 | 77 | 3 | 895 | 13 | 0.571 | 170 | 14.9 | <0.1 |

Table 2. (cont.)

| Sample No. | Sr | Ba | Ti | Cu | Mn | Zn | Pb | Li | F | B | Br/Cl $\times 10^{-4}$ | $\delta^2H$ | $\delta^{18}O$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| H.W.1 | 3.2 | 0.30 | <0.025 | <0.01 | 1.1 |  | <0.1 | <0.01 | 0.1 | 1.4 | 595.2 | -30,-32 | 0.38 |
| T.Pal. | 63.4 | 0.727 | <0.025 | 0.020 | 2.39 | 0.027 | <0.1 | 0.539 | 0.4 | 5.86 | 14.7 | -32 | 0.05 |
| Van GR | 13 | 9.2 | <0.03 | <0.01 | 0.06 | 0.02 | <0.1 | 0.54 | 1.2 | 22 | 49 | -36 | 1.43 |
| CAY.R | 0.26 | 0.04 | 0.056 | <0.01 | 0.270 | 0.014 | <0.1 | 0.019 | 0.2 | 1.25 | 583 | -26 | 2.48 |
| OP.R. | 19.6 | 3.8 | 0.038 | <0.01 | 1.45 | 0.024 | <0.1 | 0.327 | <0.2 | <1 | 112 | -24 | -0.30 |
| T.R. | 188 | 2.39 | <0.05 | 0.030 | 1.78 | 0.034 | <0.2 | 2.01 | 1.0 | 14.2 | 35.8 | -34 | 0.22 |
| F.R. | 29.2 | 4.98 | 0.04 | 0.026 | 25.8 | 0.066 | 0.105 | 1.55 | 1.7 | 5.15 | 21.5 | -31 | 4.30 |
| VAN.R. | 306 | 39 | 0.127 | <0.02 | 5.71 | 0.040 | <0.2 | 4.04 | 0.4 | 29.2 | 120 | -35 | -2.04 |
| B.Pet. | 2,100 | 33 | <0.05 | <0.02 | 9.0 |  | <0.2 | 52 | 4.5 | 58 | 90.9 | -34 | 4.48 |
| B.D.Pet. | 47 | 45 | <0.03 | <0.01 | 1.7 |  | <0.1 | 0.88 | 0.2 | 7.8 | 102 | -43 | 0.10 |
| CAY.P. | 0.76 | 0.105 | 0.05 | <0.01 | 0.357 | 0.016 | <0.1 | 0.01 | <0.2 | <1 | 271 | -15 | -0.09 |
| OP.P. | 0.7 | 0.081 | 0.054 | <0.01 | 0.198 | 0.014 | <0.1 | 0.024 | <0.2 | <1 | 70 | -24,-25 | 1.98 |
| CH.P. | 2.47 | 0.282 | <0.025 | 0.01 | 0.511 | <0.01 | <0.1 | 0.042 | <0.2 | 1.15 | 70 | -17 | 1.54 |
| CH.T.P | 945 | 8.78 | 0.101 | 0.059 | 13.3 | 4.19 | <0.2 | 15.2 | 1.6 | 33.2 | 99.2 | -14 | -3.72 |

Table 2a. Type of Well and Collection Points for Deleted Data

| Name | Type | Collection Point |
|---|---|---|
| HWI | oil | separator |
| T. Pal | oil | storage tank |
| Van GR | oil | well head |
| Cay, R | gas | storage tank |
| Op. R | oil | storage tank |
| T.R | gas | separator |
| F.R | oil | separator |
| B.D Det | gas | separator |
| Cay, P | gas | storage |
| OP.P | gas | storage |
| CH.P | oil | storage |
| CH.T.D. | gas | storage |

Continental meteoric water: Continental meteoric waters are those waters that result from atmospheric precipitation on the continents. Generally they are on the meteoric water line but are isotopically depleted in $\delta^2$H and $\delta^{18}$O relative to sea water and follow the meteoric water line, as defined by the equation $\delta^2H = 8\delta^{18}O + 10$.

## Isotopic Trends

Three isotopic trends are observed: $\delta^{18}$O vs. $\delta^2$H (fig. 7), $\delta^{18}$O vs. depth (fig. 8), $\delta^{18}$O vs. Cl (fig. 9).

### $\delta^{18}$O versus $\delta^2$H (fig. 7)

$\delta^{18}$O and $\delta^2$H values range from -6°/oo ($\delta^{18}$O) and -20°/oo ($\delta^2$H) to +6°/oo($\delta^{18}$O) and -15°/oo ($\delta^2$H). The trend approaches the meteoric water line at the same $\delta^{18}$O value expected for meteoric water in East Texas. $\delta^{18}$O of ground water samples from the Wilcox around Oakwood dome was -4.9.

### $\delta^{18}$O versus depth (fig. 8)

The $\delta^{18}$O values increase with depth. The $\delta^{18}$O values from shallow waters are approximately the same as the $\delta^{18}$O values of meteoric water in the region ($\delta^{18}O \simeq -5$°/oo). The $\delta^{18}$O values increase to +9°/oo. This trend is consistent for all formations sampled.

### $\delta^{18}$O versus chlorinity (fig. 9)

The $\delta^{18}$O values increase with increasing chlorinity.

## Discussion of Isotopic Values

The saline waters in the Nacatoch, Eagle Ford, Woodbine, Paluxy, Glen Rose, Rodessa, Pettet, and Travis Peak Formations all appear to have a continental meteoric water origin. The basin has been flushed of any original oceanic waters and has been replaced by meteoric water.

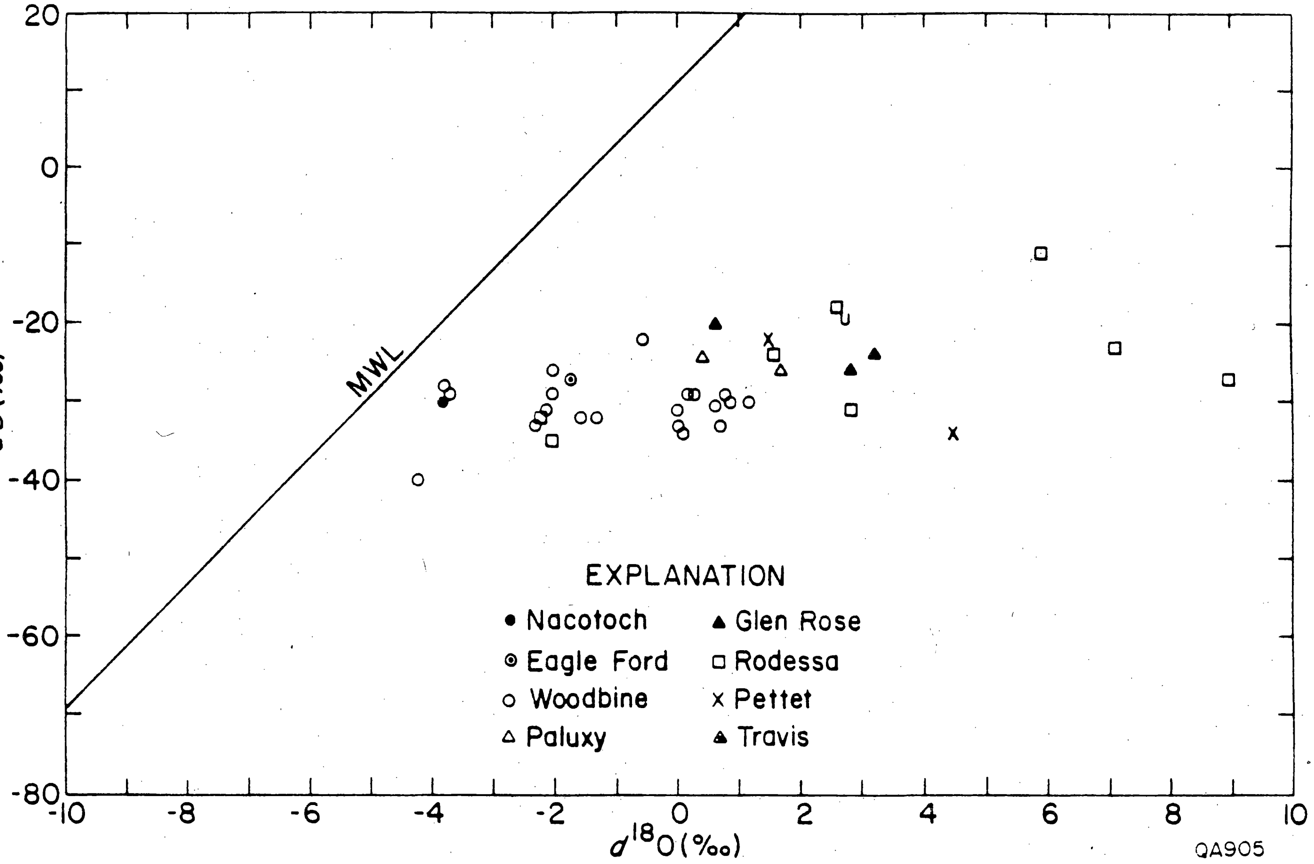

Figure 7. Hydrogen and oxygen isotopic composition of saline waters, East Texas Basin. Table 1 includes isotopic values.

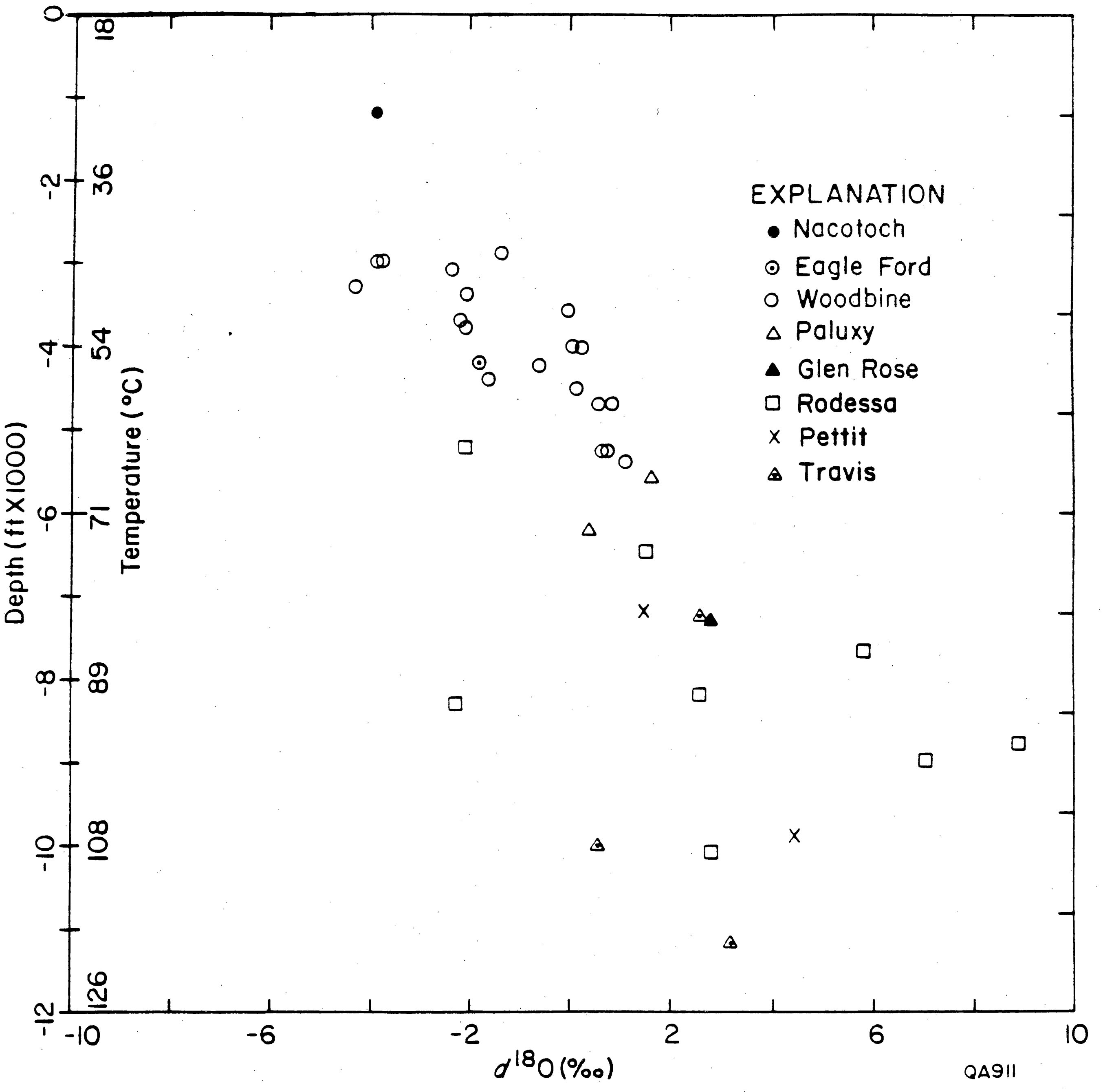

Figure 8. $\delta^{18}O$ values of saline waters, East Texas Basin versus depth (temperature). Note enrichment in $\delta^{18}O$ with increased depth (temperature). (Temperature based on average geothermal gradient of 0.9°C per 100 ft.) Isotopic analyses in Table 1.

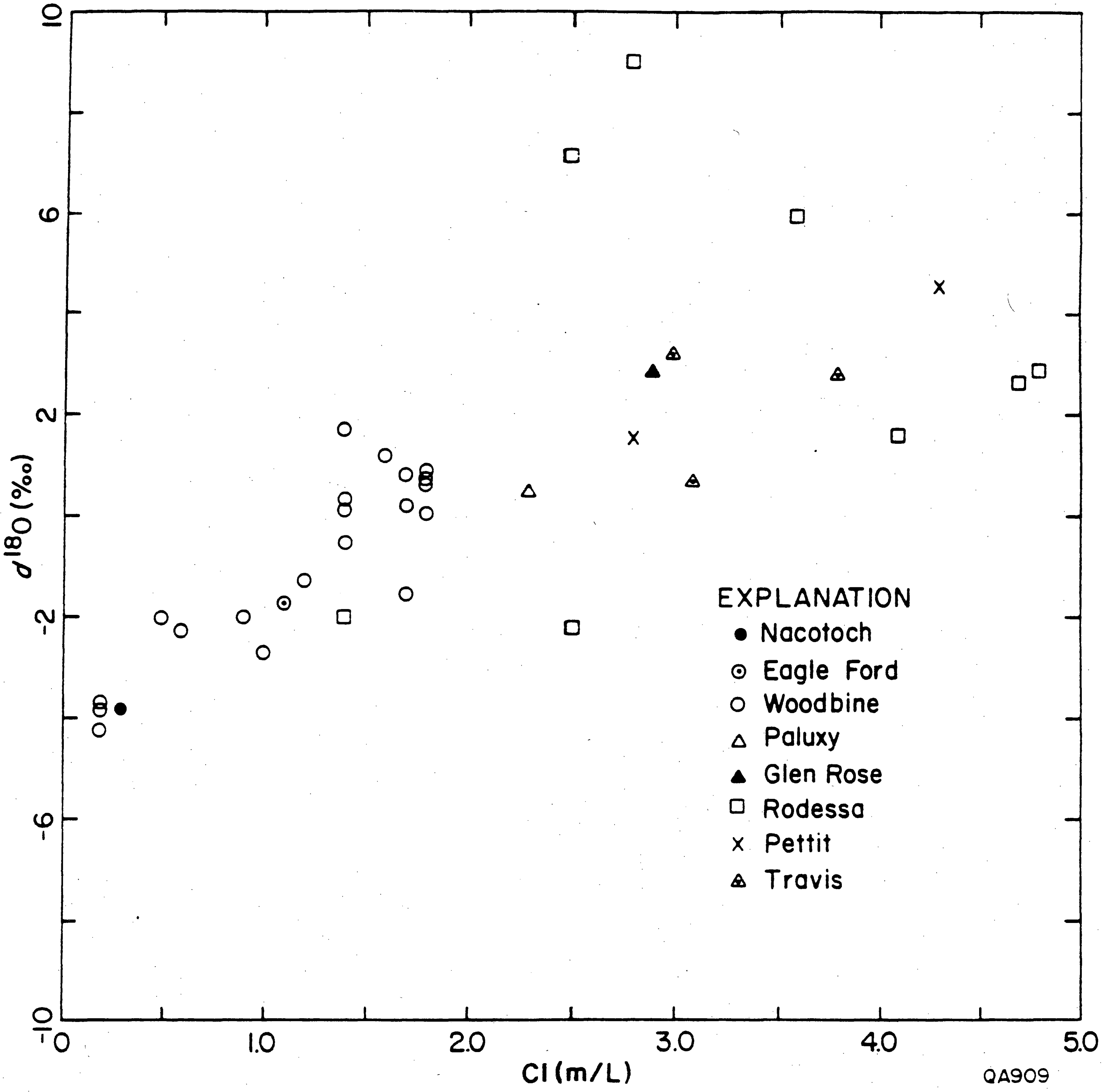

Figure 9. $\delta^{18}O$ values of saline waters versus chlorinity. Data in Table 1.

The presence of meteoric water does not, however, imply that these waters are geologically young. The flushing process was probably predominant in Cretaceous time.

These conclusions are based on the following lines of evidence. The scattergram of $\delta^{18}O$ versus $\delta^{2}H$ (fig. 7) trends back to the original isotopic composition of the meteoric water before the waters equilibrated with the sediments in the basin. With increasing depths (and temperatures) the waters reequilibrate with the oxygen in the carbonate minerals causing an enrichment of $^{18}O$ in the waters (a reaction documented by Clayton, 1959, 1961). The $\delta^{2}H$ values range between -20 to $-30^{o}$/oo, the approximate hydrogen isotope composition of meteoric water for this region. Land and Prezbindowski (1981) found that the $\delta^{2}H$ of meteoric waters in Central Texas ranged from -20 to $-30^{o}$/oo. Knauth and others (1980) found meteoric water in northern Louisiana (≃ 150 km east of East Texas Basin) with a $\delta^{2}H$ value of $-30^{o}$/oo. A slight enrichment of $\delta^{2}H$ with increased $\delta^{18}O$ could be interpreted for the East Texas Basin data. Because of the minimal isotopic variation in the $\delta^{2}H$ values, regardless of enrichment of the $\delta^{18}O$, the initial $\delta^{2}H$ composition of the basinal waters was approximately $-20^{o}$/oo to $-30^{o}$/oo. In contrast marine waters have a $\delta$ value of approximately $0^{o}$/oo. The hydrogen data, therefore, suggest that the deep basin water originated as a continental meteoric water rather than an oceanic water entrapped during sedimentation and burial.

Clayton and others (1966) observed similar relationships for the Illinois, Michigan, and Alberta sedimentary basins. Isotopic data for each basin trended back to the isotopic composition of surface water and shallow ground water of the area. An enrichment of $\delta^{18}O$ with depth (temperature) was also observed for each basin, as was observed in the East Texas Basin (fig. 8). They attributed this enrichment with increased temperature to a shift in isotopic equilibria for the temperature dependent isotopic reaction between calcite and water. Clayton (1959, 1961) presents the experimental data that documents this isotopic reaction.

Salinity increases as $\delta^{18}O$ values become enriched. This relationship appears coincidental rather than resulting from any mutual dependent geochemical reactions. Clayton and others (1966) also observed an increase in $\delta^{18}O$ with salinity but offered no explanation for this relationship. This increased salinity with depth and oxygen isotope composition will be discussed under Source of NaCl.

Degen and others (1964) suggested that the oxygen isotope shift resulted from mixing of meteoric waters with marine waters. The isotopic data for the East Texas Basin do not agree with this interpretation. The $\delta^{2}H$ remains constant over the range of $\delta^{18}O$ values. If mixing was the mechanism, then there should be an isotopic shift in $\delta^{2}H$ as well as $\delta^{18}O$.

The isotopic shift observed by Clayton and others (1965) for the Alberta, Illinois, and Michigan basins is approximately 0.2 $^{o}/oo$ ($\delta^{18}O$)/°C. The isotopic shift for the waters in the East Texas Basin is 0.16$^{o}/oo$ ($\delta^{18}O$/°C, similar to the range observed by Clayton (table 3). For the $\delta^{18}O$ values for the different basins, the initial meteoric waters for the East Texas Basin are isotopically heavier than the other basins and have $\delta^{18}O$ values in the deep basin for similar temperature ranges which are also more enriched. This enriched isotopic range is consistent with the proximal position of the East Texas Basin to the coast in comparison to the other basins. If Degen and others' (1964) mixing model is correct, then the slope of the isotopic shift per temperature rise would not remain constant for all the basins. In contrast the $\delta^{18}O$ of the deep basin waters (the initial sea water end members) should remain constant for all basins, which it doesn't. A model requiring mixing of continental meteoric and original oceanic waters is not considered realistic for the East Texas Basin.

The presence of meteoric water through the basin does not infer that the flushing is recent or is occurring at a rapid hydrologic rate. The timing of fluid movement in the basin is interesting but not resolvable at this point. A brief review of geologic history of the basin points to hydrogeologic complexity. During Travis Peak time (Early Cretaceous) thick alluvial fan delta sediments were deposited. These rocks may have been flushed by continental meteoric waters and never contained oceanic waters. From Glen Rose to Nacatoch time (Cretaceous) the major rock units were marine and therefore contained marine waters. During this time the continental waters in the underlying Travis Peak may have been replaced by waters with a marine origin. From the Tertiary to present the basin was being infilled by

Table 3. Oxygen Isotope and Temperature Ranges of Waters from Four Interior Sedimentary Basins

| Basin | Temperature Range (°C) | $\delta^{18}O$ Range (o/oo) | $\delta^{18}O$ (o/oo)/°C |
|---|---|---|---|
| Alberta[1] | 30-95 (65°) | -8, +4 (12) | 0.18 |
| Illinois[1] | 10-60 (50°) | -8, +2 (10) | 0.2 |
| Michigan[1] | 10-60 (50°) | -9, +3 (12) | 0.24 |
| East Texas[2] | 45-108 (63°) | -5, +5 (10) | 0.16 |

[1] from Clayton and others (1965)

[2] from this study

primarily continental terrigenous sediments that were subaerially exposed. Minor marine sandstones and shales were deposited during Tertiary time but are considered insignificant in the overall character of the basin.

Incorporation of meteoric water into the different formations of the East Texas Basin may have occurred at different times in the geologic history of the basin. The isotopic data does not indicate when the water was added, just that it had a continental meteoric origin.

## SOURCE OF NaCl IN THE DEEP-BASIN BRINE AQUIFERS, EAST TEXAS BASIN

### Introduction--Summary

The source of dissolved sodium and chlorides in saline to brine concentrations in deep-basinal formations is enigmatic, primarily because of (1) the high solubility of halite, (2) the multiple sources (evaporites, ocean water) or methods in which brines can be concentrated (ultra-filtration), (3) the lack of a distinguishing tracer that could separate different chloride sources, and (4) our generally poor understanding of hydrologic and geochemical processes in the deep subsurface. Researchers have suggested that the elevated NaCl concentrations have resulted from at least 5 sources or mechanisms: (1) "connate waters" (original sea water) (White, 1965), (2) ultra-filtration (reverse osmosis, e.g., the trapping of dissolved species on the high pressure side of a semipermeable membrane (Graf et al., 1965; Hanshaw and Coplen, 1973), (3) drainage of bittern brine pockets entrapped in the original bedded Louann salt (Carpenter, 1978), (4) brine leaking up from an unknown or external source (Land and Prezbindowski, 1981), or (5) dissolution of halite as either bedded or domal salt (Bassett and Bentley, 1982).

This study has concluded that the source of dissolved NaCl in the saline aquifers of the East Texas Basin is the result of (5) dissolution of halite as domal salt. This conclusion is based on two different approaches: (1) a comparison of the halite that has been lost (original volume of Louann Salt minus present volume in basin) with the dissolved NaCl in the aquifers and (2) a comparison of the amount of halite that was dissolved to accumulate the volume of cap rock in salt domes with the dissolved NaCl in the deep-basin aquifers. Both approaches indicate that more halite is missing than can be accounted for by present dissolved NaCl. All the NaCl that is presently in solution can, therefore, result from dissolution of halite.

This approach does not prove that dome dissolution is the major contributor of NaCl, but does demonstrate that dome salt is a feasible source for the basin's salinity. Previous studies on the origin of saline waters have not been able to document a salt source (occult salt) or mechanism for concentrating NaCl to brine concentrations.

## Dissolved NaCl in Deep-Basin Aquifers

The total volume of dissolved salt in the saline part of the East Texas Basin is estimated at 298 $km^3$ (table 4). This estimate is based on the sum of the average salinity times the average porosity of individual volumes of the Woodbine, Paluxy, Glen Rose, and Travis Peak formations, the units considered as the important saline aquifers in the basin.

## Salt Loss

1. Approach 1. Original salt volume versus present salt volume

Comparison of the halite still in the basin (domal, anticlinal, and wedge halite) with estimated original Louann salt indicates that approximately 40 percent of the original halite is missing (6000 $km^3$). Salt loss is predominantly from the diapirs. Approximately 70 percent of the salt originally in the diapir province is calculated to be missing. Salt was lost by both surface extrusion and subaerial erosion, and subsurface dissolution of salt at diapir crests and flanks.

A. Present Volume of Salt

Present volume of salt in the East Texas Basin (table 5) was calculated by planimetry of a hand-drawn salt isopach map. Four sources of data were used to construct the isopach map.

(1) 740 km of regional and local depth-converted seismic lines;

Table 4

| Saline Aquifer | Average Salinity (mg/L)[1] | Volume of Formation (km$^3$)[2] | Average Porosity (%)[3] | Volume Dissolved Salt (km$^3$)[4] |
|---|---|---|---|---|
| WOODBINE | 67,500 | 4,600 | 25.0 | 35.2 |
| PALUXY | 70,000 | 3,300 | 12.0 | 12.7 |
| GLEN ROSE | 165,000 | 15,000 | 8.5 | 95.3 |
| TRAVIS PEAK | 200,000 | 24,500 | 7.0 | 155.0 |
| | | | | 298.2 |

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[1] Determined from resistivity curves and Schlumberger charts.

[2] Determined from isopach maps for individual formations.

[3] Determined from sonic and density logs.

[4] Density of halite = 2.1 gm/cm$^3$

1 km$^3$ halite = 2.16 x $10^{15}$gm

Table 5

| Salt Structure Province | Area ($km^2$) | Present Volume ($km^3$) | Original Volume ($km^3$) | Volume Loss ($km^3$) | Percent Volume Loss | Original Maximum Thickness (m) | Techniques |
|---|---|---|---|---|---|---|---|
| Salt Wedge (Western Area) | 7,810 | 2,110 | 2,360 | 250 | 11 | 340-640 | A Centripetal rate of thickness increase |
| Salt Pillow (Western Area) | 4,070 | 2,260 | 2,700 | 440 | 16 | 640-750 | A Centripetal rate of thickness increase |
| | | | 2,620 | 360 | 14 | 620-730 | C Wavelength theory |
| Salt Diapir (1/2 total) | 2,520 | 950 | 3,200 | 2,250 | 70 | 1,784 | Mean |
| | | | 2,840 | 1,890 | 67 | 1,500 | A Centripetal rate of thickness increase |
| | | | 2,920 | 1,970 | 67 | 1,570 | $B_1$ Sediment thickening around Hainesville Dome |
| | | | 3,560 | 2,610 | 73 | 2,070 | $B_2$ Sediment thinning around Hainesville Dome |
| | | | 4,660 | 3,710 | 80 | 1,580-1,850 range<br>1,850 best | C Wavelength theory |
| | | | 3,380 | 2,430 | 72 | 1,290-3,060 range<br>1,930 mean | D Dome diameter theory |
| TOTAL (for 1/2 basin) | 14,400 | 5,120 | 8,450 | 3,130 | 37 | 1,500-2,070 range | |

Conversion of volume to mass

Density salt = 2,100 $kg/m^3$

(2) Basinwide residual-gravity map;

(3) Salt structure maps of all 15 shallow diapirs from gravity models; and

(4) 4,600 geophysical logs.

There are four salt provinces in the East Texas Basin: (1) salt wedge; (2) low-amplitude salt pillow; (3) intermediate-amplitude salt pillow; and (4) salt diapir (Jackson and Seni, 1983). For the present study, provinces 2 and 3 are combined. Present salt volume, original salt volume, and original maximum salt thickness were calculated for each province. The distribution of regional seismic coverage restricted calculations of salt volume and thickness to the western half of the basin in the wedge and pillow provinces. Therefore, to facilitate comparisons, the area and volume of the diapir province were reduced by one-half. In areas of the diapir province where the salt is too thin for its upper and lower contacts to be resolved it is likely to have a finite thickness of up to one-quarter wavelength of the seismic impulse; at about 6 km depth this is approximately 80 m thickness. Using this upper estimate of present thickness conservative estimates of salt loss can be determined. Volumes and areas in table 5 should be doubled to obtain values for the entire basin.

### B. Original Volume of Salt (table 5)

The five techniques employed for calculation of the original maximum thickness and original volume of Louann Salt in different provinces of the East Texas Basin are:

(1) Centripetal rate of salt thickness increase

(2) Original volume of salt pillow determined by sediment thickening during diapirism;

(3) Original volume of salt pillow determined by sediment thinning during pillow growth;

(4) Wavelength of present and Jurassic salt ridges; and

(5) Dome diameter.

Centripetal Rate of Thickness Increase--This technique was applied to salt wedge, salt pillow, and salt diapir provinces. Present salt thickness and geometry were calculated from regional seismic control (Jackson and Seni, 1983). Original maximum salt thickness was determined by a straight-line extrapolation of present average rate of increase of the salt thickness in the wedge province to the axis of the diapir province (table 5). Seismic data shows no evidence of post-depositional thickness changes in the wedge province. But if the wedge had thinned uniformly by dissolution or flow, the processes would leave little trace. The extrapolation technique, therefore, yields conservative thickness estimates. Using the centripetal method of calculation, calculated original volumes of salt for the western salt wedge, western salt pillow and western half of the salt diapir province were 2,360 km$^3$, 2,200 km$^3$, and 3,200 km$^3$, respectively. This technique is advantageous because it is applicable to all provinces and can be used in conjunction with other techniques that are appropriate only for the pillow or diapir provinces.

Hainesville Pillow Reconstruction--This technique is applicable to the original salt volume and thickness in the Hainesville dome region. Hainesville Dome was selected for analysis because seismic data are available down to Louann Salt. Present geometry of Hainesville stock and surrounding strata was determined from a 25 km-long Exxon seismic line (Loocke, 1978) and from 153 logs for three-dimensional control. All thickness variations in strata surrounding the dome are inferred to be salt-induced and synsedimentary because of the absence of basement structure and the inability of structural distortion to account for the magnitude of observed thickness variations (Seni and Jackson, in press).

Sediment Thickening During Diapirism at Hainesville Dome--The shallower seismic-stratigraphic units thicken progressively toward Hainesville Dome. The volume of strata thicker than regional norms defines the salt withdrawal basin. This volume, termed the collapse volume, is the volume of salt evacuated from the collapsing pillow during deposition of the overlying units. If the collapse volume equals the present diapir volume, salt loss was zero. The collapse volume minus the volume of salt in the present diapir indicates the amount of salt lost from the Hainesville structure. In the case of Hainesville Dome, 67 percent of the original volume has been lost. Next Hainesville dome is assumed to be representative of other domes in the basin in terms of its salt budget. The original volume of salt in the whole diapir province can be calculated by analogy (1):

$$(1) \quad \begin{array}{l}\text{Original volume of salt}\\ \text{in diapir province}\end{array} = \frac{\text{Present salt volume}}{\text{1-fractional volume loss}}$$

This approach estimates that the original volume of salt in the entire diapir province was 5,840 $km^3$ and the original maximum thickness was 1,570 m (table 5).

Sediment Thinning During Pillow Growth at Hainesville Dome--The deeper units surrounding Hainesville dome thin progressively toward the dome as a result of syndepositional uplift of the original Hainesville pillow below them. The amount of thinning along each seismic-stratigraphic unit defines the vertical component of growth of the pillow during deposition of that unit. This thinning can be quantified in the vertical section as the rise area, which is the area lost due to thinning. The area of the pillow in the vertical section is equivalent to the rise area of units deposited during pillow growth. Assuming axial symmetry, the volume of the pillow is derived from the geometry of a right circular cone and frustum of a cone. Subtracting the present volume of Hainesville salt stock from the volume of the reconstructed Hainesville salt pillow yields volume of salt lost. Using equation (1), the original salt volume in the entire diapir province is estimated at 7,120 $km^3$ with a maximum original thickness of 2,070 m (table 5).

Wavelength of Present and Jurassic Salt Ridges--Ramberg (1981) showed experimentally and theoretically that the wavelength of buoyant salt ridges (salt pillows) is a function of the thickness of the initial buoyant source layer and the density contrast and the viscosity contrast betwen source layer and overburden (Ramberg, 1981, Table 7.5). In the pillow province these Jurassic ridges evolved into salt pillows by segmentation of salt ridges. In the diapir province Jurassic ridges evolved into diapirs. The mean wavelength between 10 salt pillows in the western half of the East Texas Basin is 7 km (standard deviation = 2 km). Using Ramberg's table 7.5, for systems with a buoyant source layer and overburden, a density difference ($P_o$-$P_s$/$P_o$) of 0.1, and viscosity contrast of 3,800 yields original salt thickness of 640 to 750 ma.

The location and orientation of ancestral Jurassic salt ridges on the diapir province was inferred from linear dome families, structural mapping of salt-withdrawal basins, and distribution of salt pillows. The mean wavelength of the seven mapped Jurassic salt ridges within the diapir province is 18 km (standard deviation = 4 km). Using Ramberg's table 7.5, this wavelength yields original maximum salt volumes and thickness of 9,320 km$^3$ and 1,850 m in the entire diapir province.

Dome Diameter--Parker and McDowell (1955) showed empirically with model domes and Ramberg (1981) confirmed theoretically that dome diameter equals the thickness of the salt source layer. Salt structure contours from twelve East Texas diapirs were used to define the minimum dome diameter. The maximum diameter of the dome is controlled by lateral spreading at the level of the salt overhang. As overhang diameter is dependent on other variables as well as source layer thickness, it was ignored. Diameters of conical diapirs were also not calculated, for such structures are immature. Mean dome diameter yields original salt thickness of 1,930 m and original volume of 6,760 km$^3$ in the entire diapir province.

The different techniques for calculating original salt thickness all indicate salt loss in the salt wedge, salt pillow, and salt diapir province with the greatest loss in the diapir province. More than 6,000 km$^3$ of salt in the total basin are calculated to have been lost. This is approximately 20 times more NaCl than presently is in solution. This mass balance calculation indicates that all NaCl in solution in the saline aquifers can easily be accommodated by dome dissolution.

Salt loss from the original Louann Salt can occur, however, by two different mechanisms, (1) subsurface salt dissolution and (2) salt dome extrusion and subaerial erosion. For example, Loocke (1978) and Seni and Jackson (1983) deduced that the majority of the salt loss on Hainesville salt dome occurred by surface extrusion. This surface dissolution and erosion would not contribute to the NaCl load in the subsurface waters. Another technique for calculating salt loss by ground-water dissolution is by calculating the volume of salt that had to be dissolved to leave the anhydrite cap rock residuum present on many East Texas domes.

2. Approach 2. Cap Rock

The volume of halite dissolved by subsurface ground water can be estimated by calculating the amount of diapir halite that had to be dissolved to account for the anhydrite and calcite cap rock that presently occurs on top and on the flanks of the diapirs. Using this approach, a minimum of 790 $km^3$ of salt has been dissolved (table 6). Approximately 2.5 times more salt has been dissovlved than presently occurs in solution.

Cap rocks on top and on the flanks of salt domes result from the dissolution of salt diapirs, leaving a residuum of anhydrite. Later diagenesis of anhydrite (or gypsum) by sulfate-reducing bacteria and oxidation of organics yield calcite and pyrite (Kreitler and Dutton, 1983). By knowing the total volume of cap rock and the original $CaSO_4$ percent in the diapir salt, the amount of salt that had to be dissolved can be calculated. The following assumptions were used.

(1) The Louann Salt in the East Texas Basin originally contained 98% NaCl and 2% $CaSO_4$. (This figure represents a mean from Balk, 1944; Kreitler and Muehlberger, 1981; and Dix and Jackson, 1982).

(2) That all anhydrite in the cap rocks formed by residual accumulation during dissolution of dome salt.

(3) There was no removal of cap rock by dissolution or erosion.

(4) No significant volume changes occurred in cap rock during diagenesis from pure anhydrite to the present mixture of anhydrite, calcite, and gypsum.

Cap-rock volumes were calculated for 15 shallow domes in the East Texas Basin (table 6) using gravity models (Exploration Techniques, 1979) and geophysical logs. The total cap-rock volume is approximately 16 $km^3$. If the original diapir salt contained 2% $CaSO_4$, then 774 $km^3$ of halite have been dissolved. This estimate is considered a minimum because the cap rock on the dome flanks (which is also a dissolution residuum) was not accounted for.

Approach 2 also indicates that all NaCl presently in solution can be accounted for by salt dome dissolution.

Table 6

| Salt Domes | Cap Rock Volume ($km^3$) |
|---|---|
| BETHEL | 1.2 |
| BOGGY CREEK | 3.4 |
| BROOKS | 1.4 |
| BRUSHY CREEK | 0.1 |
| BULLARD | 0.2 |
| BUTLER | 0.0* |
| EAST TYLER | 1.8 |
| GRAND SALINE | 0.3 |
| HAINESVILLE | 0.6 |
| KEECHI | 2.1 |
| MOUNT SYLVAN | 0.5 |
| PALESTINE | 0.1 |
| OAKWOOD | 2.4 |
| STEEN | 1.0 |
| WHITEHOUSE | 0.7 |
|  | 15.8 $km^3$ ≈ 774 $km^3$ halite |

* True cap-rock material is absent. "Fake caprock" over Butler Dome consists of calcite cementec sandstone.

## Timing of Salt Dissolution

Evidence presented in the previous section of this report suggests that the dissolved NaCl in the saline aquifers of the East Texas Basin is the result of salt dome dissolution. This is an important conclusion in the context of the suitability of salt domes for nuclear waste isolation because it indicates that there has been extensive salt loss over the geologic history of the domes. The next critical question is a question of timing. Is dome dissolution presently occurring and, if not, when did it occur? Interpretation of available data suggests that large-scale dome dissolution by deep basin waters is not presently occurring and much of the dissolution occurred early in the history of the basin. This conclusion is based on three different lines of investigation: (1) salinity (NaCl) distribution around salt domes in the Woodbine Formation, (2) $Cl^{36}$ age dating and (3) timing of rim syncline and cap-rock formation.

### Salinity of Woodbine Waters Around Salt Domes, East Texas Basin

Water salinities were calculated for the Woodbine Formation in local cross sections across salt domes (fig. 10) and in regional cross sections through the East Texas Basin (figs. 11-18) to determine if there were consistently higher salinities around the domes. The Woodbine was chosen because its relatively high transmissivity and shallow depth would presumably cause the highest dissolution rates of the saline aquifers. No consistent pattern of increased salinity was found near the domes. High salinities were evident near seven domes--Bethel, Brushy Creek, Bullard, Grand Saline, Hainesville, La Rue, and Palestine, but not seven others--Boggy Creek, Butler, Keechi, Steen, Whitehouse, Oakwood, and Mt. Sylvan. Often salinities increased away from the dome. Areas where no domes are present also exhibit high, erratic salinities (fig. 11-18). Variability in calculated salinity may stem from errors in method. Figure 20 indicates errors of approximately ±20,000 ppm.

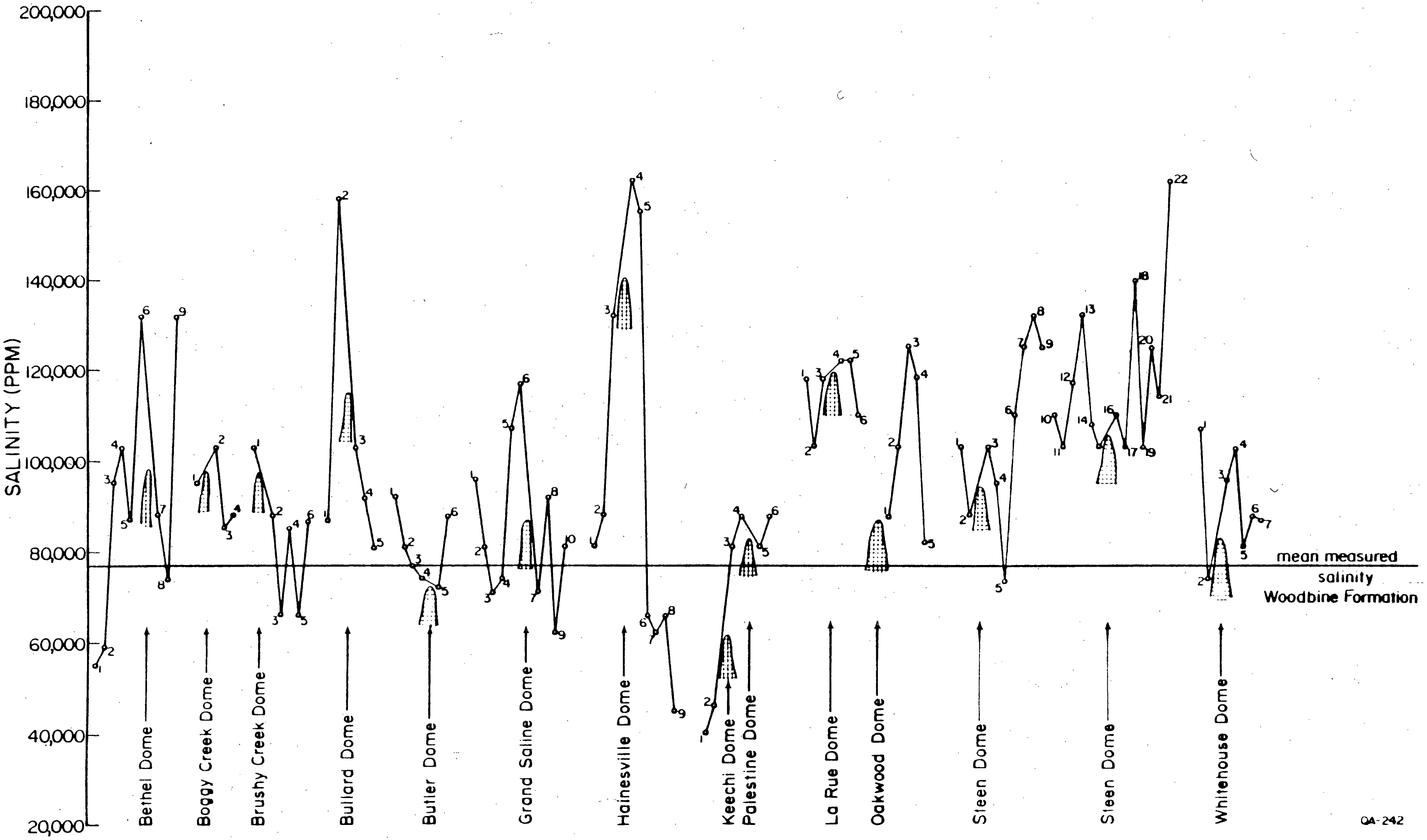


Figure 10. Composite cross section showing distribution of salinity in Woodbine Formation across 14 salt domes. Location of cross sections in Figure 19.

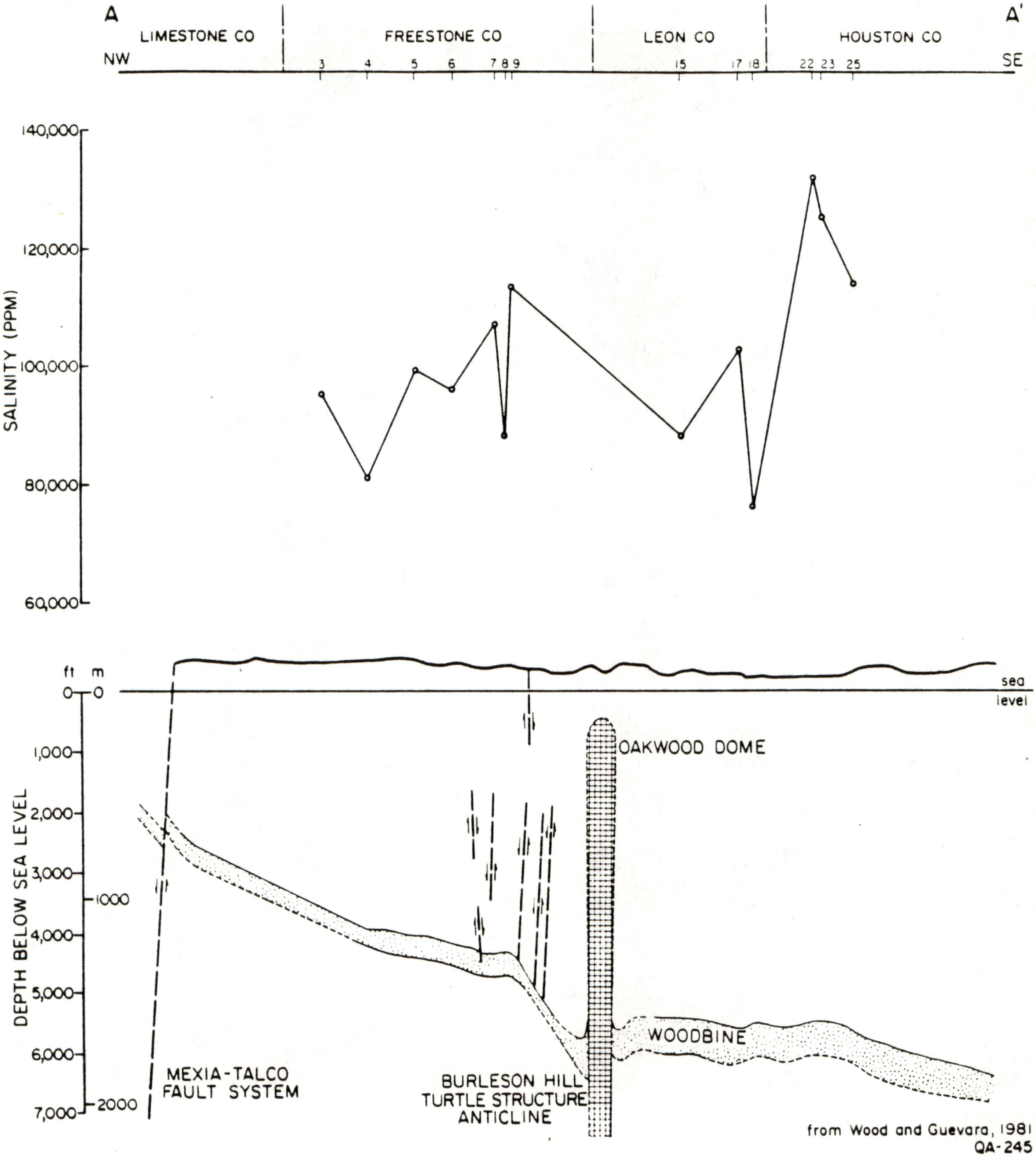
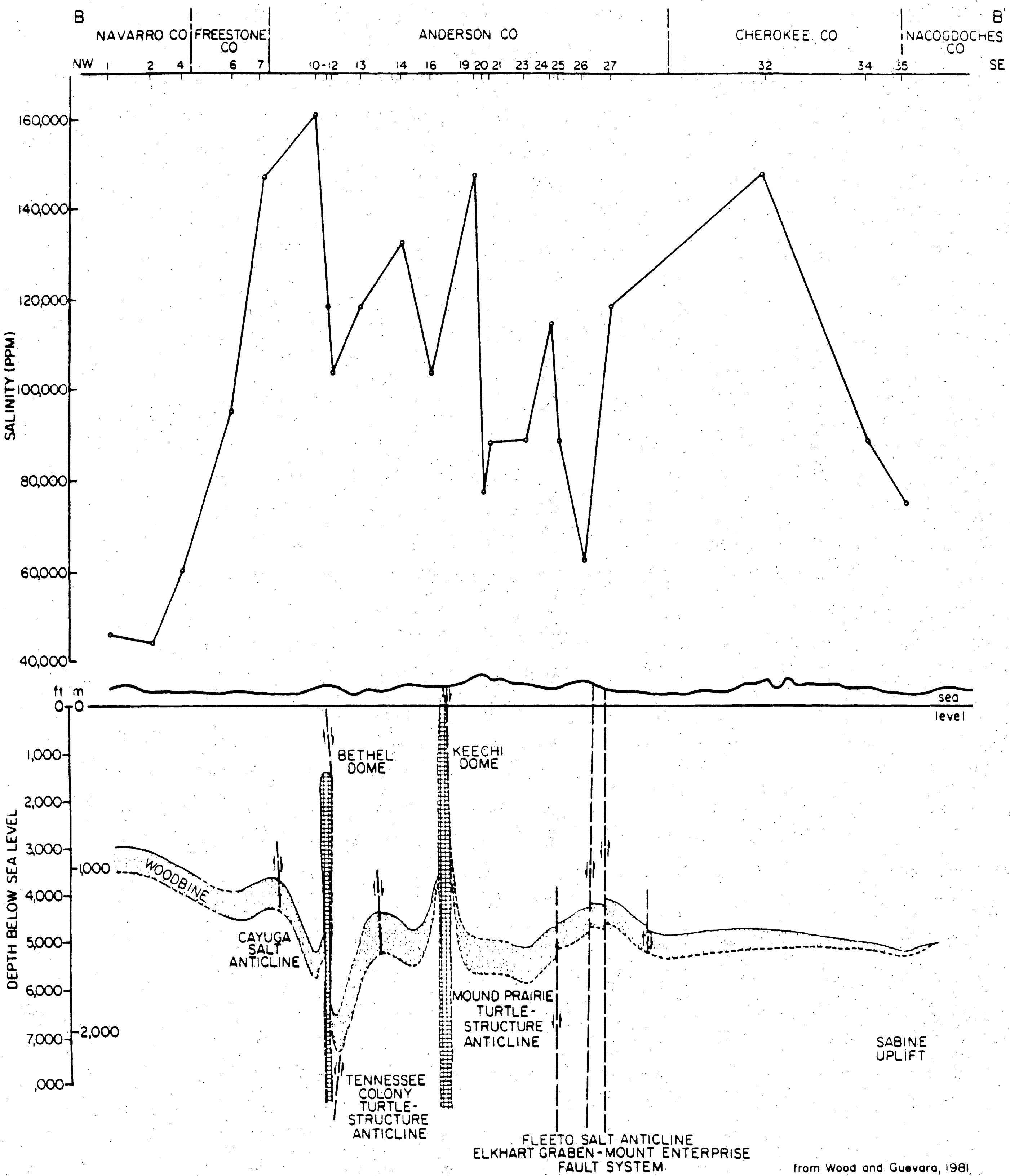


Figure 11. Salinity distribution in Woodbine Formation along cross section AA'. Location of line AA' on Figure 19.



from Wood and Guevara, 1981
QA-244

Figure 12. Salinity distribution in Woodbine Formation along cross section BB'. Location of line BB' on Figure 19.

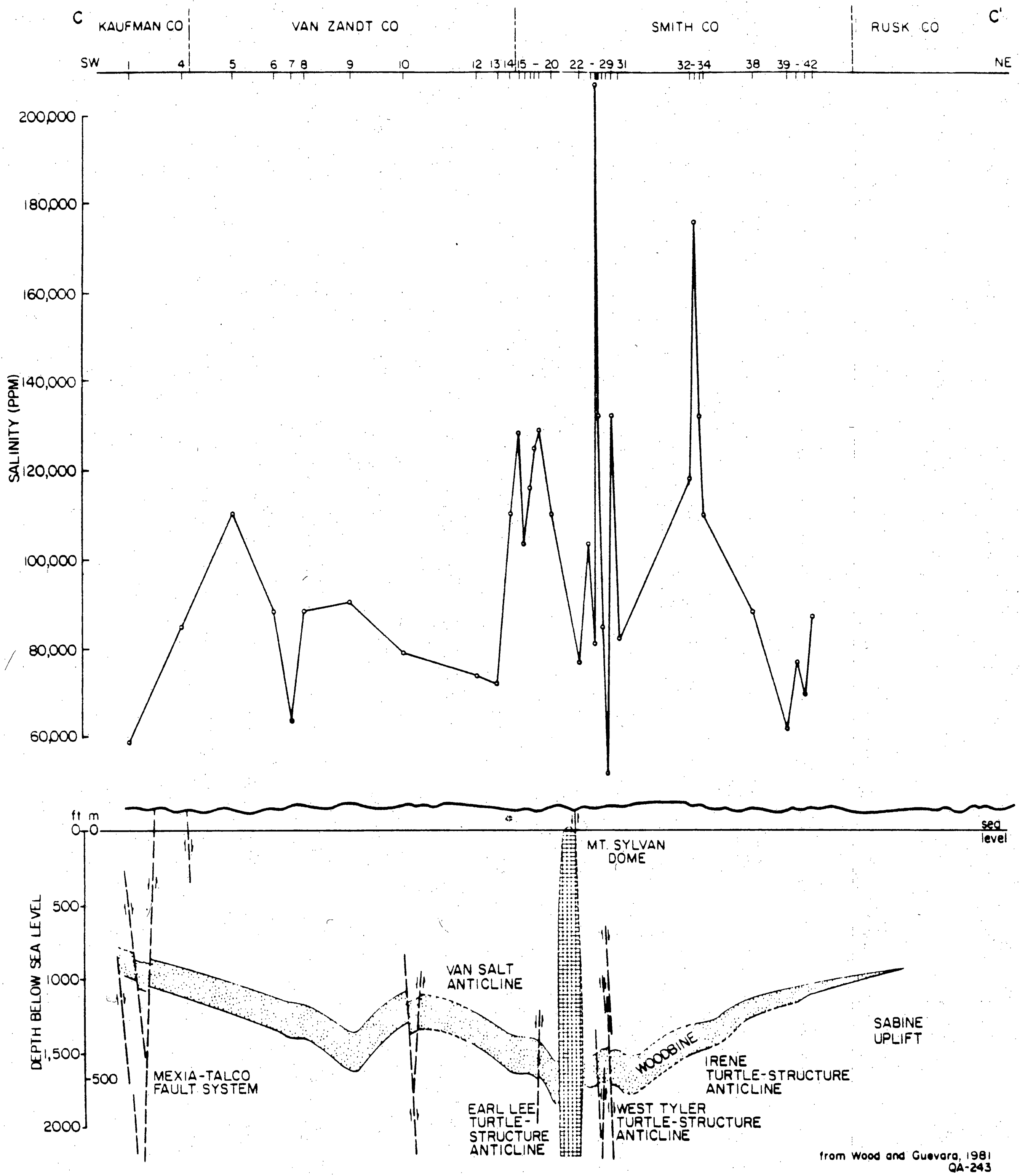


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Figure 13. Salinity distribution in Woodbine Formation along cross section CC'. Location of line CC' on Figure 19.

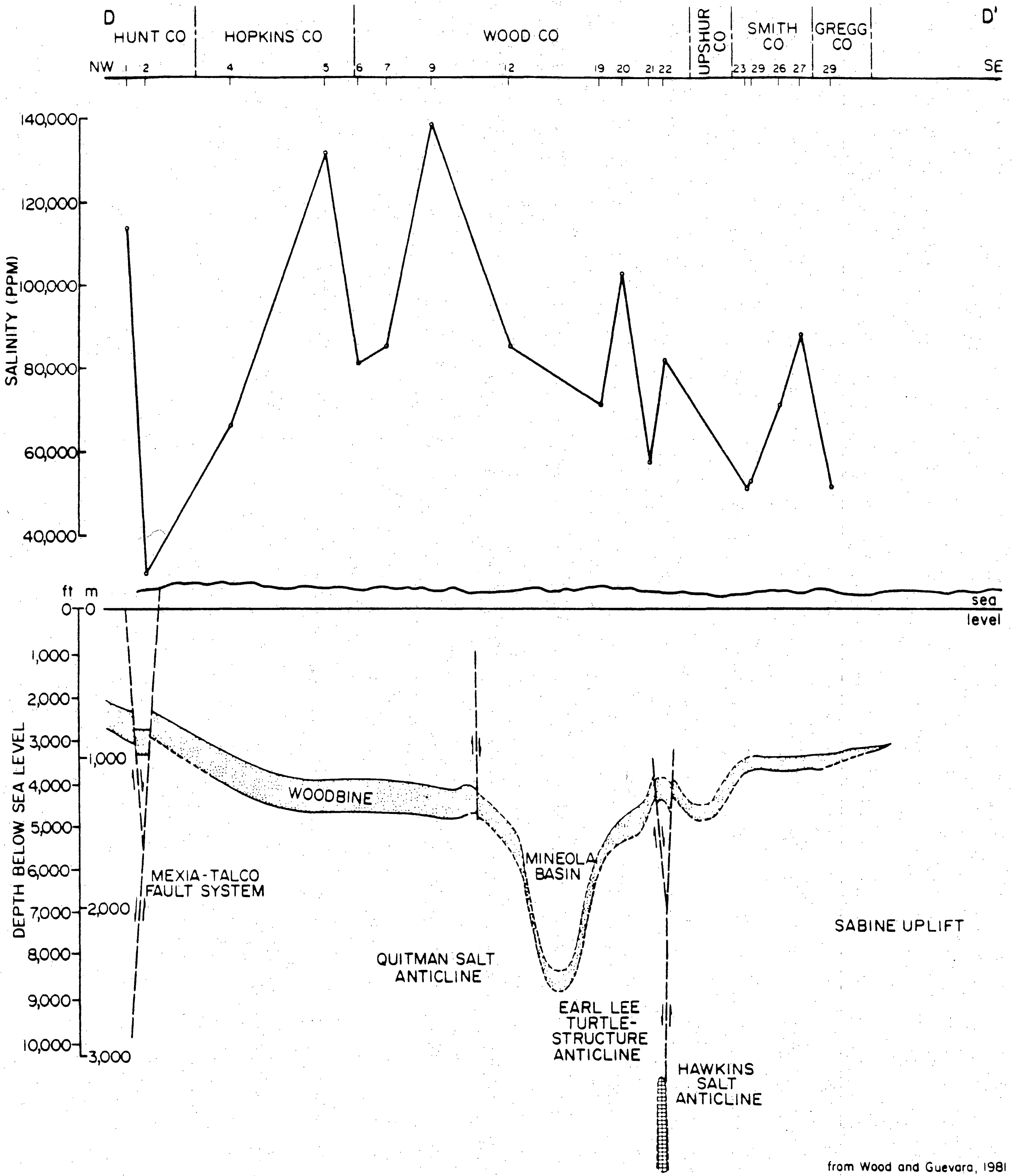

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Figure 14. Salinity distribution in Woodbine Formation along cross section DD'. Location of line DD' on Figure 19.

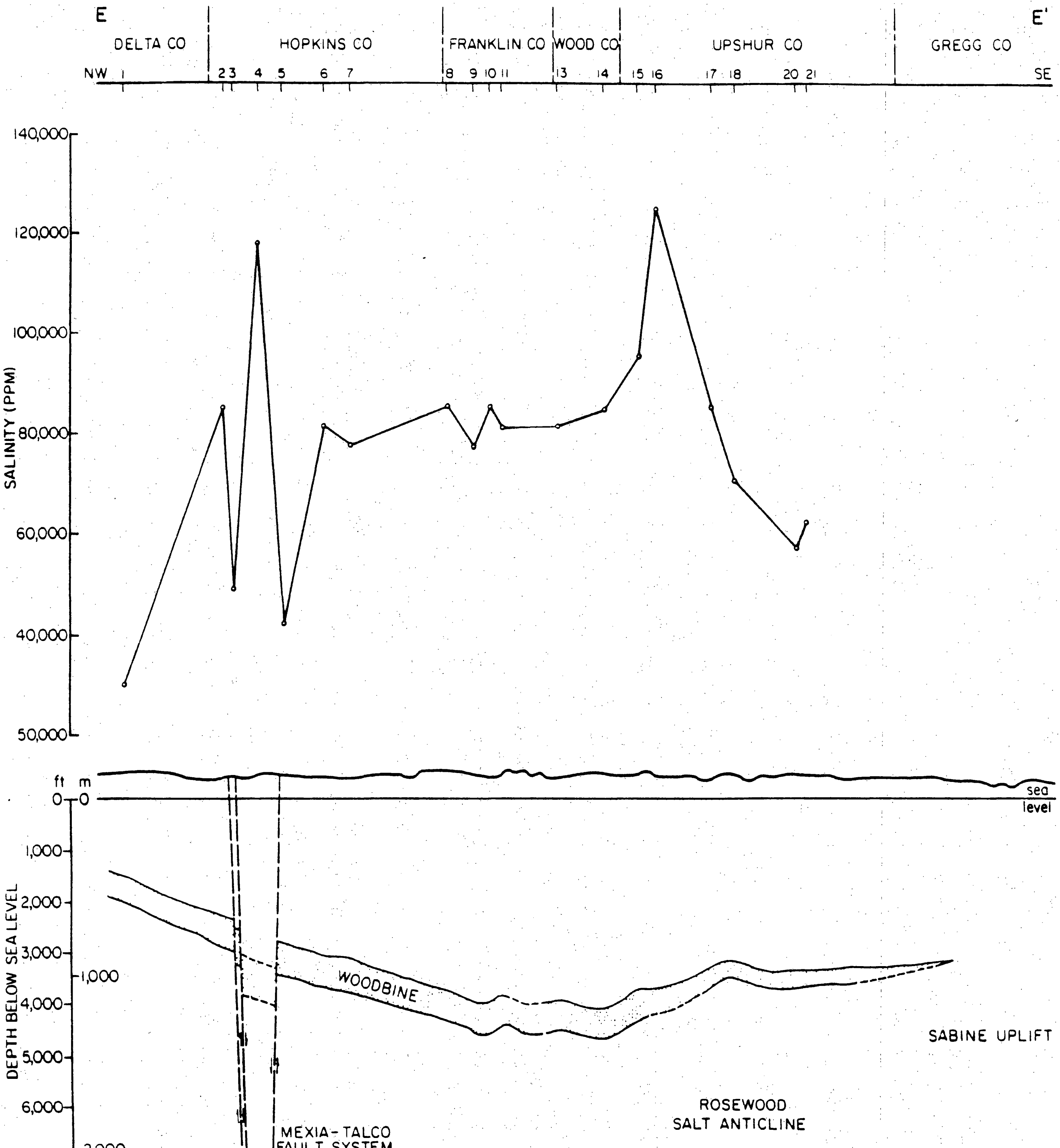

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Figure 15. Salinity distribution along cross section EE'. Location of EE' on Figure 19.

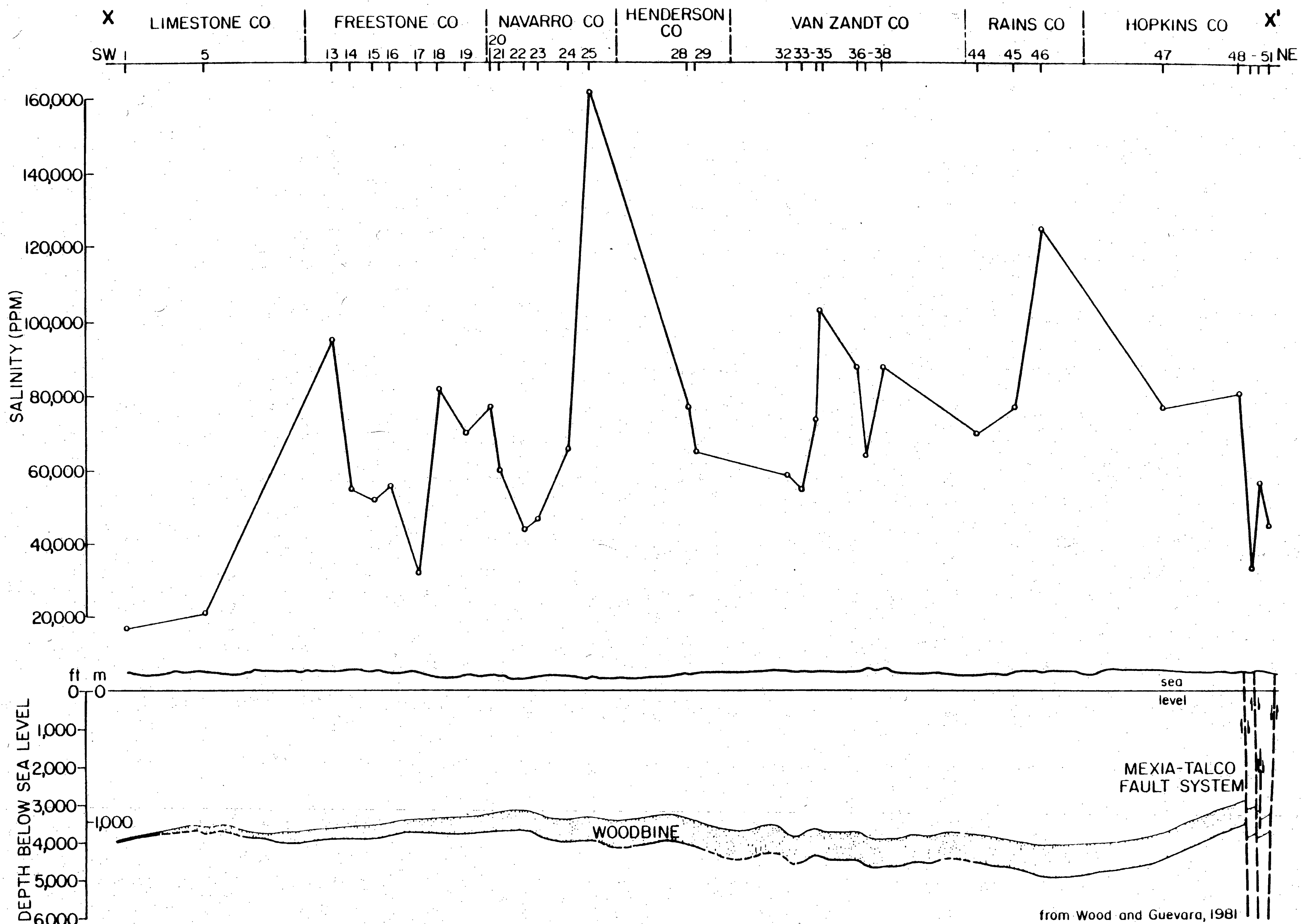

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Figure 16. Salinity distribution in Woodbine Formation along cross section XX'. Location of line XX' on Figure 19.

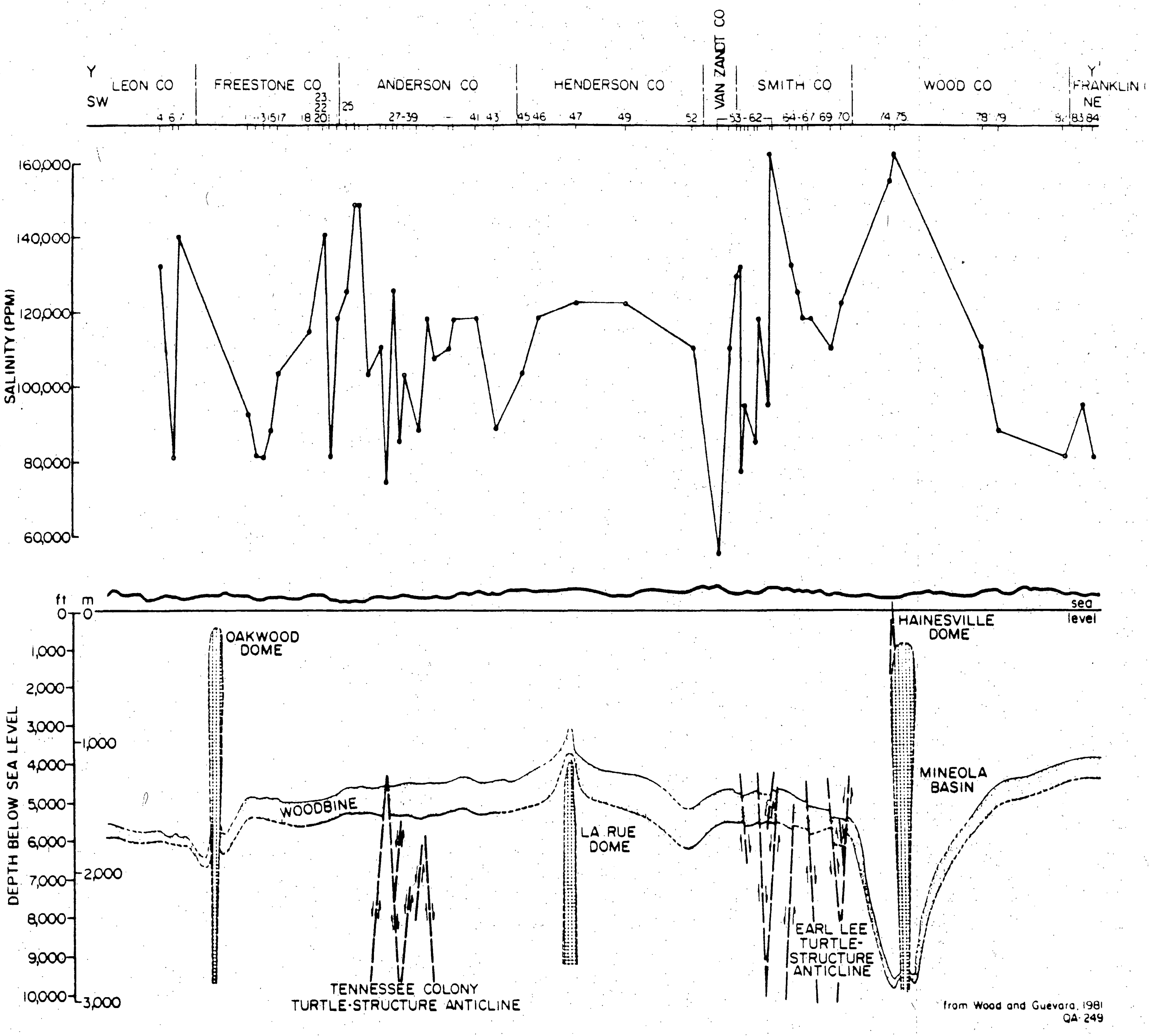

Figure 17. Salinity distribution in Woodbine Formation along cross section YY'. Location of line YY' on Figure 19.

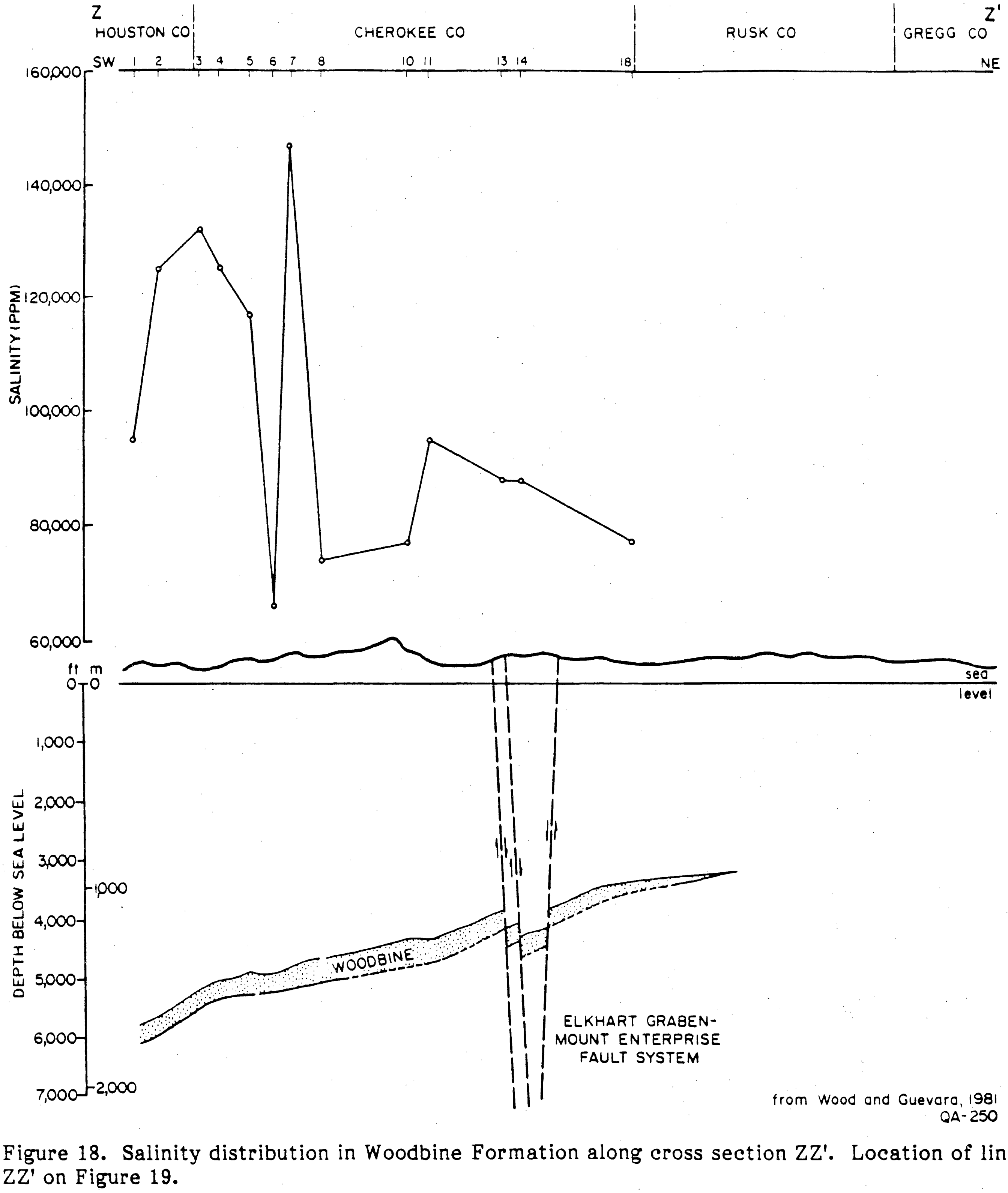

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Figure 18. Salinity distribution in Woodbine Formation along cross section ZZ'. Location of line ZZ' on Figure 19.

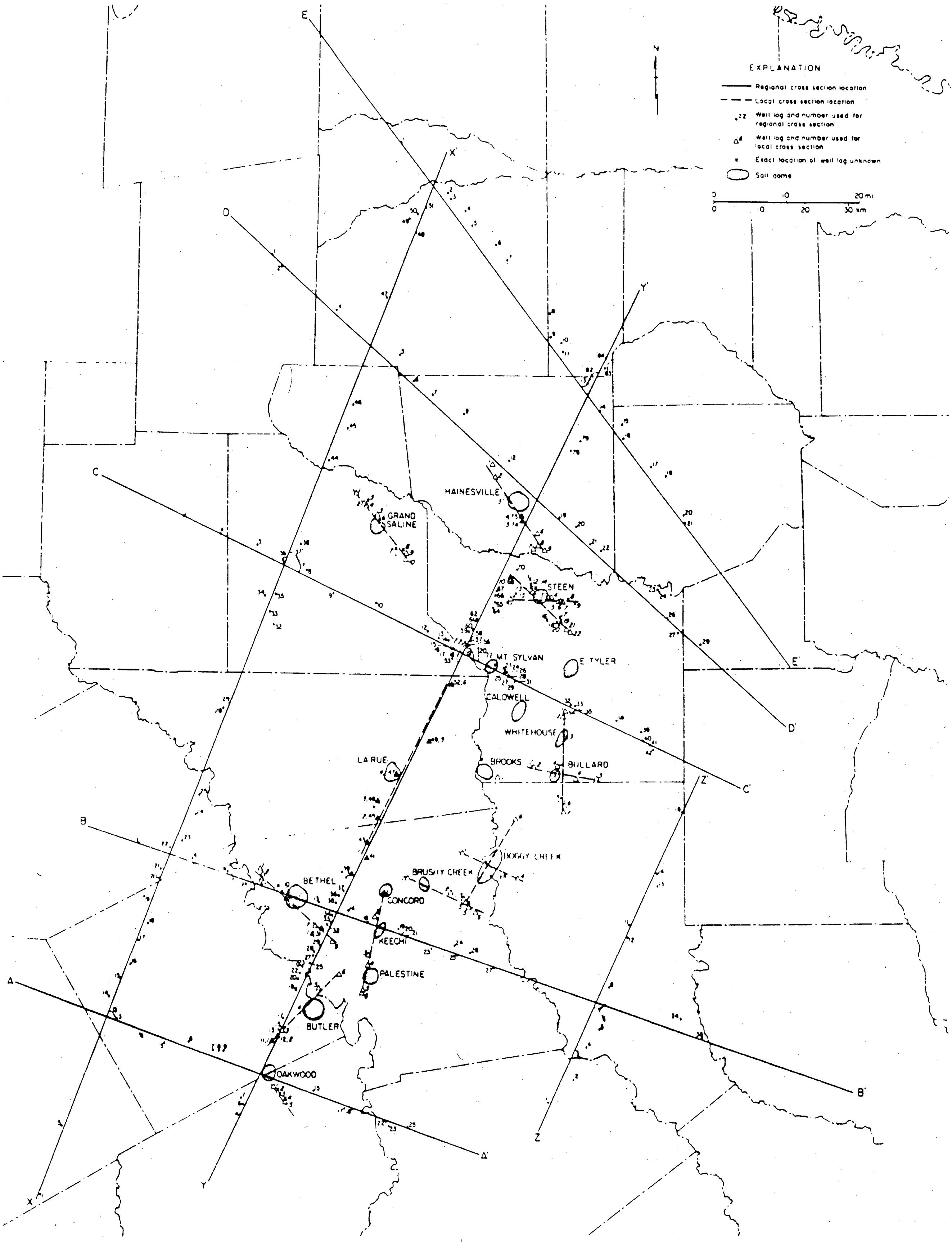

Figure 19. Index map of local (Figure 10) and regional (Figures 11-18) Woodbine salinity cross sections. Regional cross sections are from Wood and Guevara (1981).

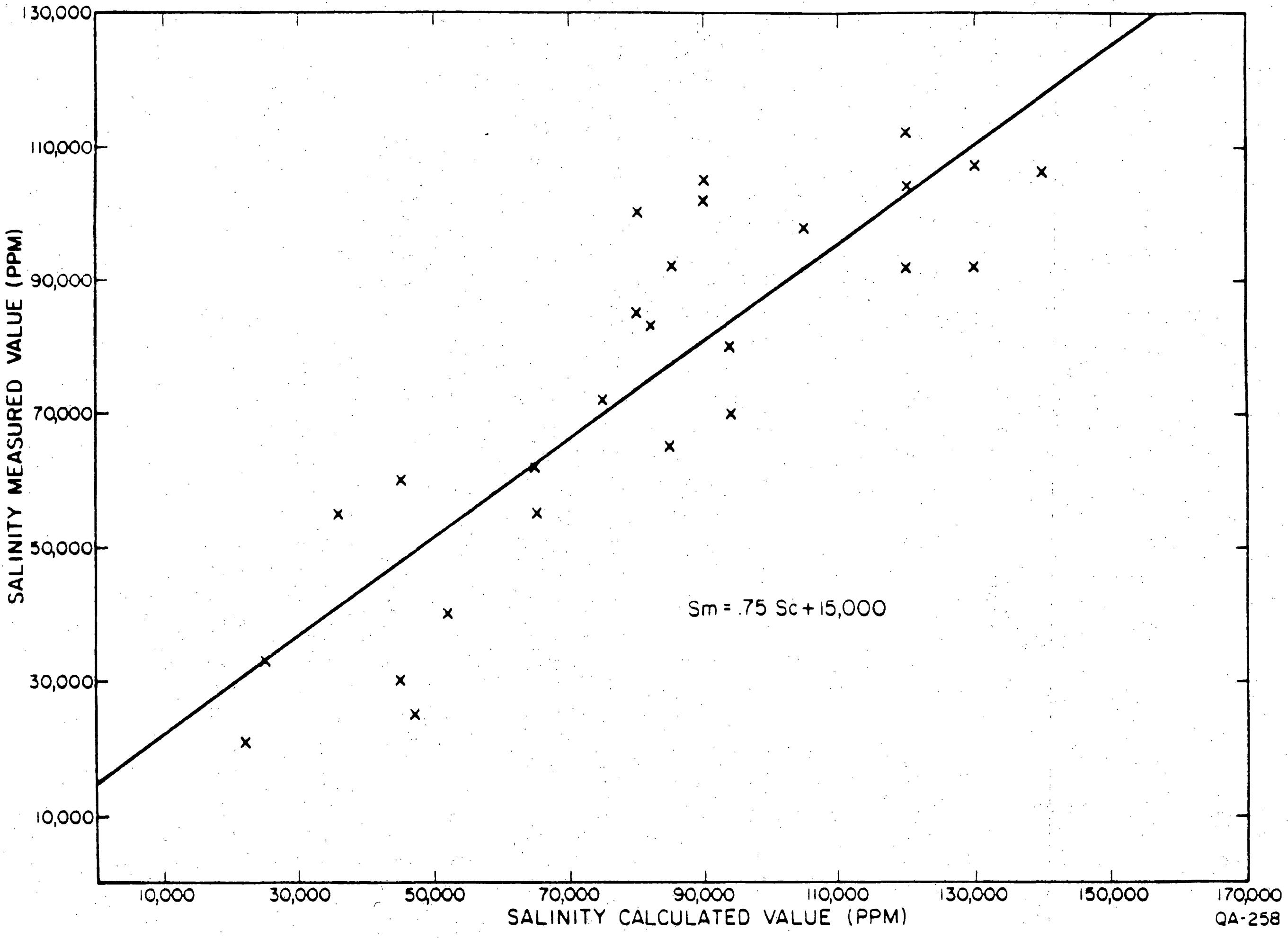

Figure 20. Measured salinity versus calculated salinity.

## Technique for Calculating Water Salinity of Woodbine Formation

Water salinities for the Woodbine Formation along the cross sections (figs. 10-18) were calculated using spontaneous potential logs based on Dresser Atlas (1975, p. 3-4). Twenty-eight chemical analyses of Woodbine Formation waters were then compared to the calculated salinity values from the geophysical logs to correct the calculated values to "true" salinity values. Figure 20 shows measured and calculated salinities and a linear regression line of best fit. The correlation coefficient is .88. The corrected values were used in the cross sections (figs. 10-18).

## Chlorine-36 Age Dating of Salt Dome Dissolution in the East Texas Basin

Based on $^{36}$Cl age dating techniques, the chloride in two brine samples from the East Texas Basin resulted from salt dome dissolution more than approximately 1 million years ago.

Chlorine-36 ($^{36}$Cl) is a radioactive isotope of chlorine with a half-life of $3.01 \times 10^5$ years (Davis and Bentley, 1982). Because of its long half-life, it offers a promising potential for absolute dating of old waters. Measurement of chlorine-36 was made by Harold Bentley (Hydrogeochem, Inc.) on a tandem Van de Graff accelerator at the University of Rochester Nuclear Structure Laboratory, Rochester, New York. Analyses are given as the ratio of $^{36}$Cl nuclei to the total number of chlorine nuclei $\times 10^{-15}$.

Chlorine-36 has two sources in a ground-water system, (1) an atmospheric and soil surface source and a subsurface production by natural subsurface neutron flux (Bentley, 1978). Because of the interaction of these two sources of $^{36}$Cl, the $^{36}$Cl dating technique has both advantages and disadvantages for dating saline waters in deep sedimentary basins. If atmospheric chloride is the only source of chloride in aquifers, the maximum age a water can be dated at is 1,000,000 years old (Davis and Bentley, 1982). As the activity of $^{36}$Cl of groundwater chloride declines because of radioactive decay, there is also an increase in $^{36}$Cl by subsurface neutron bombardment. The two sources reach equal concentrations in the age range of 800,000 to 1.2 million years old (fig. 21). Waters with low $^{36}$Cl/Cl ratios can only be assigned ages of 1 million

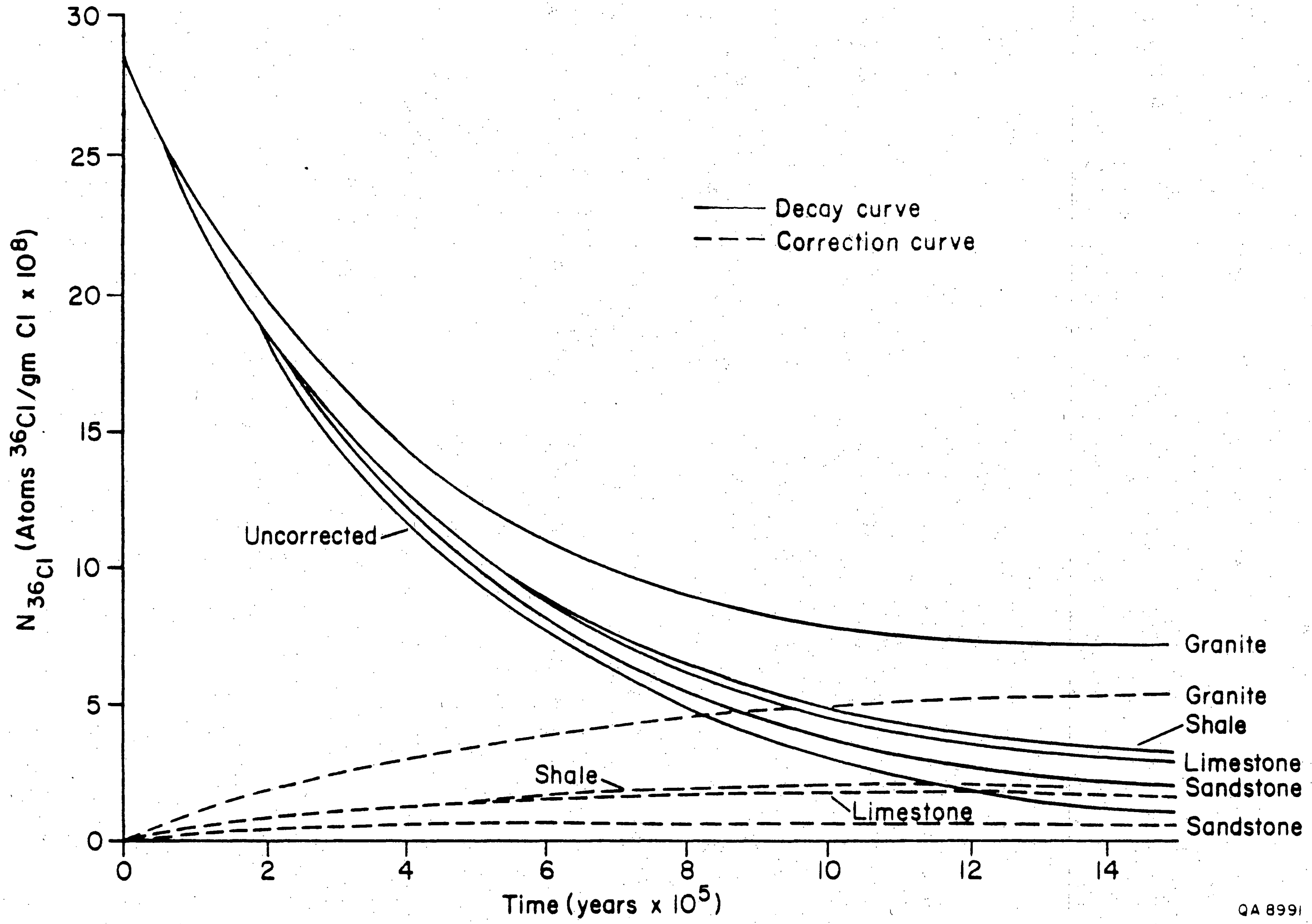

Figure 21. Decay curve of representative $^{36}$Cl ground-water samples from different aquifers. The curves rising with time represent the subsurface contribution to $^{36}$Cl as a function of aquifer type. The decay curves assume an initial concentration of 2.8 x $10^9$ atoms $^{36}$Cl/gm Cl (atmospheric component) and 1 x $10^8$ atoms $^{36}$Cl/gm Cl (soil surface component) (from Bentley, 1978).

years or greater. $^{36}$Cl dating of saline waters is further complicated because the atmospheric chloride is swamped by dead chloride from a nonatmospheric source making absolute dating of the water even more tenuous.

Because of the buildup of $^{36}$Cl by subsurface neutron flux and the massive addition of dome salt by salt dissolution, the ages of the waters in the saline aquifers of the East Texas Basin cannot be determined. However, minimum ages of dome dissolution can be estimated. Louann salt (i.e., dome salt) should have no $^{36}$Cl because of its Jurassic age. There also should be no buildup of $^{36}$Cl in halite by subsurface neutron bombardment, because the dome shields itself from neutron bombardment (Davis and Bentley, 1982). Two halite samples, one from the Kleer Mine, Grand Saline salt dome, East Texas Basin and the other from Permian Clear Fork Formation, Palo Duro Basin, West Texas, have $^{36}$Cl/gm Cl ratios of 0 ± 2 and 1 ± 2, respectively. In contrast, two brine water samples from the Pettet Formation flanking the Bethel salt dome and from the Woodbine Formation flanking the Boggy Creek salt dome have $^{36}$Cl/gm Cl ratios of 22 and 6, respectively (table 17); these values are considered to be in the range expected for a secular equilibrium caused by neutron bombardment (Bentley, personal communication, 1982). Based on Table 7 and Figure 21 the salt dome dissolution that resulted in these brines occurred at least one million years ago.

In contrast two samples were analyzed for $^{36}$Cl from a shallow fresh-water Carrizo aquifer flanking the Oakwood Dome. The $^{36}$Cl was measured to determine if the Cl in the shallow low TDS ground water was from dome dissolution. The $^{36}$Cl values were 230 $^{36}$Cl/Cl and 280 $^{36}$Cl/Cl, typical of young waters with an atmospheric source and not of Jurassic halite. No salt dome dissolution was evident from these specific wells sampled for this study.

## Geologic Evidence for Early Dissolution

Salinity typically increases with depth in many sedimentary basins. This is true for the Michigan, Illinois, Alberta (Graf and others, 1966), Palo Duro (Bassett and Bentley, 1983), and San Juan Basins (Berry, 1968) as well as the East Texas Basin (fig. 22). The cause for the continual increase is as enigmatic as is the original source of chloride. The following

## Table 7. $^{36}$Cl in Halite and Water Samples

| Sample Name | Location | Cl (mg/L) | $^{36}$Cl/Cl (X $10^{15}$) |
|---|---|---|---|
| halite | Clear Fork Formation<br>Palo Duro Basin,<br>West Texas | -- | 1 ± 2 |
| halite | Kleer Mine, Grand Saline<br>Salt Dome, East Texas Basin | -- | 0 ± 2 |
| Bethel | Pettit Formation<br>Bethel Dome | 154,000 | 22 |
| Boggy Creek | Woodbine Formation<br>Boggy Creek Dome | 65,000 | 6 |
| OK-102 | Carrizo Formation<br>Oakwood Dome | 39 | 230 |
| TOH-5 | Carrizo Formation<br>Oakwood Dome | 130 | 280 |

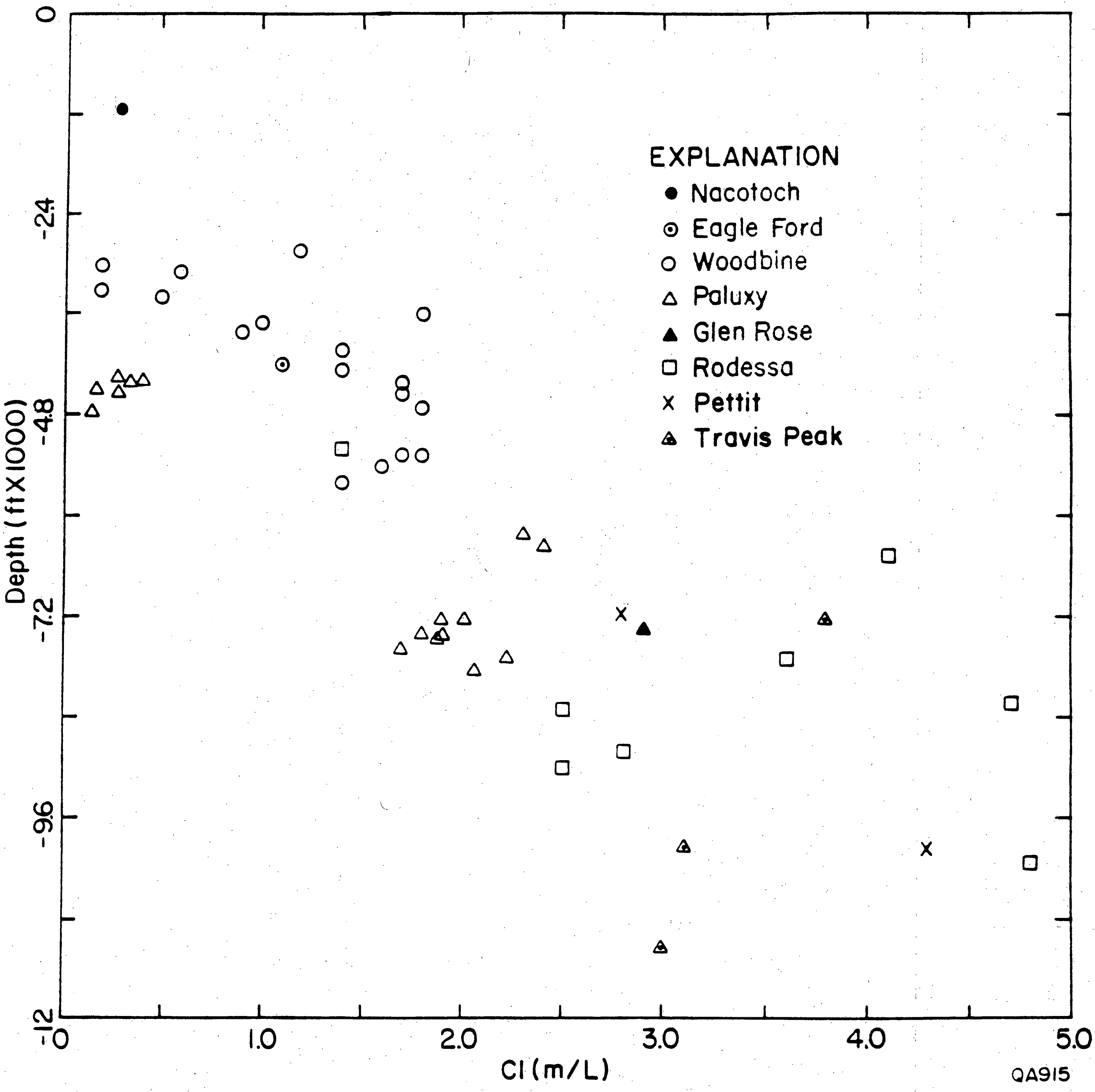

Figure 22. Cl (m/L) vs. depth, note increase in Cl with depth. Chemical analyses in Table 1.

hypotheses have been offered as mechanisms to explain this phenomenon. (1) Mixing of shallow, lower salinity waters with a deeper saline source (Carpenter, 1978; Land and Prezbindowski, 1981), (2) As water moves deeper it increases salinity by dissolving evaporites or other Cl sources, (3) If there is a general upward flow component, salinities in the deep basin are increased by ultra-filtration through shale membranes (Graf and others, 1965; Hitchon and Freedman, 1969).

The hypothesis that best explains the increased salinity with depth in the East Texas Basin is that most of the dissolution of salt in the basin occurred early in the history of the basin and those Jurasic or Cretaceous waters are still present in the formations. Jurassic formations contain Jurassic and Cretaceous waters and Cretaceous formations contain Cretaceous waters. If we accept the previous argument that the NaCl in solution in the East Texas Basin results from dome dissolution, we may be able to determine when in the history of the basin the NaCl was added to the ground water by understanding when the domes were dissolved.

Kreitler and Dutton (1983) concluded that the formation of the 600 ft thick cap rock on Oakwood Dome in the East Texas Basin occurred during Late Jurassic and Early Cretaceous time. They argued that the evidence for large-scale salt dissolution was evident in the rim synclines surrounding a dome. At Oakwood Dome the only significant rim synclines are in Upper Jurassic and Lower Cretaceous formations; therefore, major dome dissolution and subsequent initial cap rock should have formed in this time period.

At Oakwood Dome 50 $km^3$ of salt was dissolved to form the cap rock. The dissolution of 50 $km^3$ of salt represents a major geologic event. The Oakwood salt stock contains approximately 5 $km^3$ of halite. Ten diapir volumes of halite had to pass through Oakwood dome to be able to accumulate the present volume of caprock. This volume of lost salt should be evident in the salt withdrawal basins surrounding a dome. In Cretaceous (Glen Rose and later) and Tertiary times only 13 $km^3$ of salt withdrawal from rim synclines occurred. Therefore a majority of the dome dissolution probably occurred pre-Glen Rose time (table 8a,b).

Table 8a. Volume of salt dissolved from Oakwood dome to form its cap rock

| | |
|---|---|
| Cap-rock thickness (anhydrite and calcite) | 140 m |
| Cap-rock radius | 1,500 m |
| Cap-rock volume | $9.9 \times 10^8$ m$^3$ |
| Anhydrite content of Oakwood salt dome | 2% |
| Amount of salt dissolved | 50 km$^3$<br>(11.7 miles$^3$) |

Table 8b. Timing and volumes of rim synclines surrounding Oakwood dome. Volume of rim syncline is considered as equivalent to the volume of salt that flowed into the dome and was lost by dissolution.

| Stratigraphic Interval | Rim Syncline Volume (km$^3$) |
|---|---|
| Top Cotton Valley to Top of Travis Peak[1] | significant |
| Top James to Top Glen Rose[2] | no closure |
| Paluxy[2] | no closure |
| Top Kiamichi to Top Buda[2] | 9.7 |
| Woodbine[2] | no closure |
| Base Austin Chalk to Top Pecan Gap[2] | 3.5 |
| Top Pecan Gap to Top Midway[2] | no closure |

[1] from seismic data

[2] from electric log data

A similar approach is applicable for the other domes in the East Texas Basin. The occurrence of a rim syncline (peripheral sink) in a formation indicates that there was salt flow either 1) intrusion of the diapir into overlying formations, 2) flow of salt within the diapir and salt loss by extrusion out of the diapir crest, or 3) flow of salt into the dome and salt loss by dissolution of the diapir by ground water. Conversely, if there are no rim synclines, then there was no major salt loss--either by dome dissolution or dome extrusion. Seni and Jackson (in press) determined that most East Texas salt domes grew fastest during Early Cretaceous (fig. 23). Their conclusions are based on the presence and rate of sediment accumulation in rim synclines. Therefore, most dome dissolution also occurred during that time. In contrast to most of the domes, Hainesville and Bethel salt domes did most of their growing in late Cretaceous. The dissolved NaCl in the Woodbine and younger formations may result from the dissolution of these domes in this later time period. Based on this line of reasoning much of the salt dome dissolution and addition of NaCl to the ground waters may have occurred early in the history of the basin. The waters in the deeper formations therefore are also very old (Jurassic and Cretaceous) and may be static. This hypothesis of greater growth and greater diapir dissolution early in the infilling of the basin explains the relationship of increasing salinity with depth that is observed in the East Texas Basin (fig. 22).

The trend of enrichment of $\delta^{18}O$ with increasing salinity (fig. 9) may be circumstantial. The $\delta^{18}O$ enrichment of the waters is more logically explained by increased burial and greater temperatures. These waters that have become enriched in $^{18}O$ were also emplaced in an earlier time where greater amounts of dome dissolution were occurring. This would explain a correlation of enrichment of $\delta^{18}O$ with increased salinities.

## WATER CHEMISTRY

### Introduction--Summary

The waters in the saline deep basin aquifers appear to have a meteoric continental origin. They were recharged predominantly during Cretaceous times. The dissolved NaCl in the

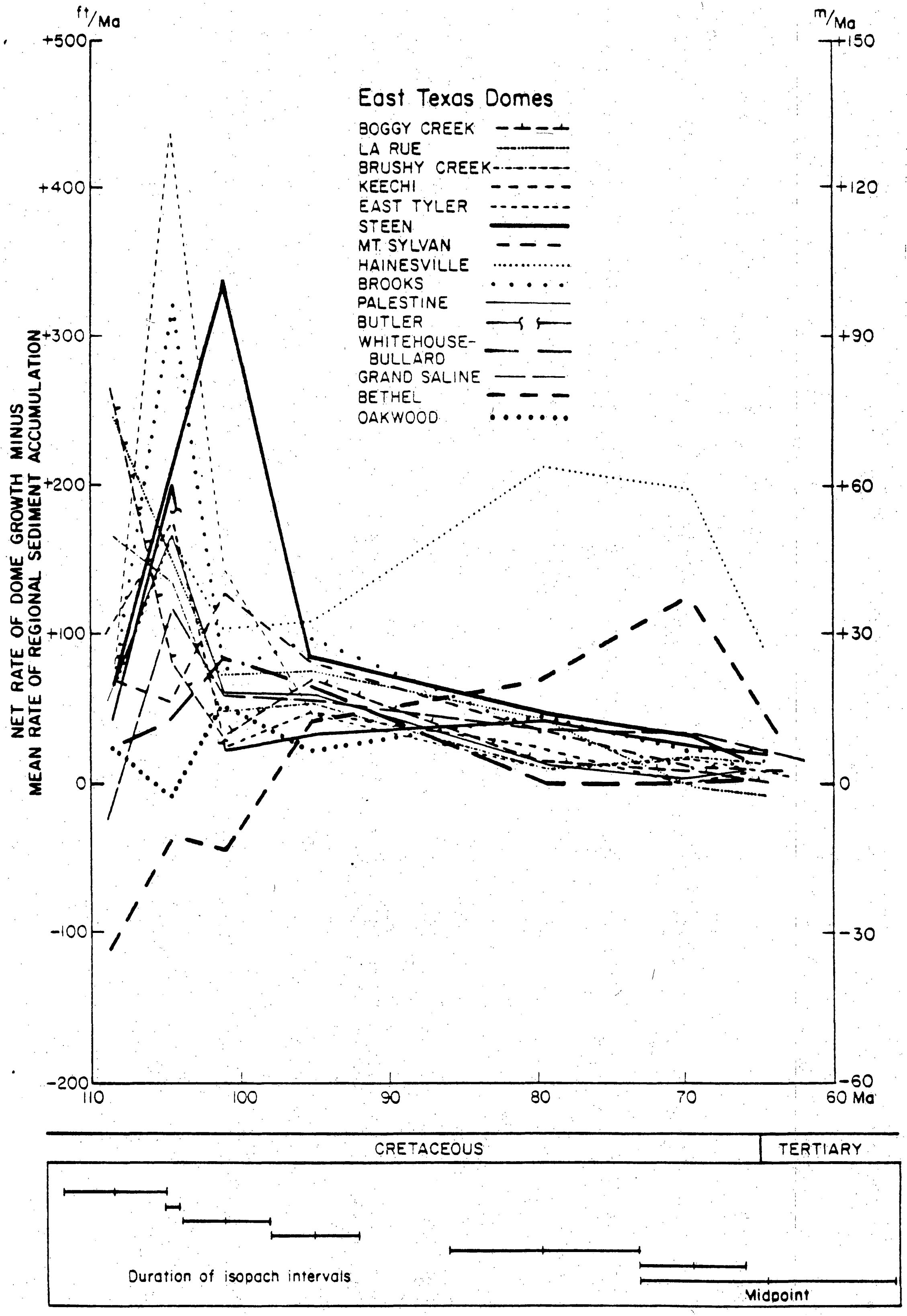

Figure 23. Net rate of dome growth for 16 East Texas domes (calculated by rate of sediment accumulation in peripheral sinks minus mean rate of sediment accumulation) from 112 to 56 ma. Most domes grew fastest during the Early Cretaceous (from Jackson and Seni, in press).

aquifers is predominantly from salt dome solution. The presence of calcium, magnesium, potassium, strontium, and bromide in the basinal waters appears to result primarily from the interaction of the NaCl waters with the rock matrix. The high calcium concentrations may result from albitization of plagioclase. The potassium may result from either albitization or dissolution of potassic feldspars. High magnesium concentrations result from dedolomitization. The bromide may result from Br depletion of halite.

Based on the water chemistry there appear to be two major aquifer systems. The Woodbine and shallower Cretaceous formations are dominated by Na-Cl type waters. Glen Rose and deeper formations are dominated by Na-Ca-Cl type waters. The Na-Ca-Cl type waters have evolved from Na-Cl waters.

## Chemical Analysis of Deep-Basin Brines

### New Data

Fifty water samples were collected and analyzed for $HCO_3$, $SO_4$, F, Cl, Br, I, $H_2S$, Na, K, Mg, Ca, Sr, Ba, Fe, B, $SiO_2$, Al, Ti, Cu, Mn, Zn, Pb, Li (table 1). These samples were collected and analyzed to verify the trends observed in the data base containing the 813 analyses (Appendix A) and to collect data on species not analyzed in the earlier data set. The earlier data set only includes analyses for Na, Ca, Mg, Cl, $SO_4$, pH, and alkalinity.

#### Sample Collection and Methods of Analysis

Samples were collected as close to the well head as possible. For Woodbine samples the oil-water ratio was sufficiently high to allow sample collection at the well head for all but two samples. Deeper samples were generally collected from a separator or storage tank since water production was low. Oil wells were sampled in preference to gas wells to avoid condensate water contamination from produced gas, but, generally, even gas wells yielded reliable formation water samples.

Samples were initially filtered through a funnel filled with pyrex glass wool to remove oil and large particulate matter. The water was then filtered through a 0.45 micron filter using nitrogen pressure to minimize atmospheric contamination. At each sampling site the following samples were collected in sequence from one gallon of sample water: (1) 125 ml preserved with 5 ml CdAc for $H_2S$ analysis; (2) one liter, unacidified, for individually analyzed ions; (3) one liter, unacidified, for storage at the Mineral Studies Lab; (4) 500 ml, unacidified, for isotopic analysis; (5) 250 ml, acidified with 10 ml 6N HCl for ICP analysis of cations; and (6) 25 ml, diluted with 100 ml distilled water, for $SiO_2$ analysis.

All chemical analyses were performed by Mineral Studies Lab, Bureau of Economic Geology, University of Texas at Austin. Bicarbonate analyses were done in the laboratory rather than at the well head or on pressurized samples collected downhole and their concentration should only be considered approximate.

### Deleted Data

Twelve analyses have not been included in the data base of brine water chemistry because the analyses (except CH.T.P.) indicated abnormally low concentrations of Na, Cl, Ca, Mg, Br, I, Sr, and B (table 2). Sample (CH.T.P.) had a hydrogen and oxygen composition that was unrealistic in that it plotted above the meteoric water line (table 2). Eleven of these twelve samples were not collected at the well head but from storage tanks or separators where water from another source may have been mixed with the formation water (table 2a).

### Previously Published Data

Eight hundred thirteen previously published chemical analyses were collected from Hawkins and others (1964) and University of Oklahoma (1980) and are listed in Appendix A. Most samples were collected before 1964. One-hundred-eighteen analyses had cation/anion balances greater than ± 5% and were therefore considered inaccurate and therefore excluded. Bicarbonate and pH analyses should also be considered as approximate because the alkalinity and pH measurements were probably made in the laboratory (and not in the field) at an unknown time after collection.

### Comparison of New Analyses to Previously Published Analyses

A comparison of the chemical composition of the recently collected waters (table 1) to chemical composition of previously published analyses (Appendix A) for the same field and similar depths shows that the analyses are similar (table 9). Two conclusions can be drawn from this observation: (1) the old analyses are correct and (2) secondary recovery operations (such as water flooding) have not altered the water chemistry of the recently collected samples.

## Geochemical Trends

Several geochemical trends are evident from both the recently collected samples and from the previously published analyses. The trends observed on individual plots are similar for both data sets; therefore, only those plots with the recent data are shown in this section. A few identical plots using the older, larger data set are included to show the agreement.

The following scattergram plots of the water samples collected for this study also include 20 samples from the older data base from the Paluxy Formation. Only two wells in the Paluxy were sampled for this study. The water chemistry in the Paluxy appears critical in understanding the geochemical evolution of water types between the shallower saline Nacatoch, Eagle Ford, and Woodbine Formations and the deeper Glen Rose and Travis Peak Formations. Twenty Paluxy analyses from the older data set are included in some of the scattergrams (figs. 24, 26, 28, 33, 36, 39, 40) to provide a more complete data base.

Each scattergram includes data for the formations studied. The geochemical trends are not as evident if the data are plotted solely by formation. The different sampled formations are indicated by different symbols so that ionic concentrations for each formation are identified.

In the scattergrams concentrations (either as moles (or millimoles) per liter or milligrams/liter) are used instead of activities because of the problem of calculating correct activity coefficients for varying ionic strengths (up to 250,000 ppm).

Table 9. Comparison of previously published analyses to chemical analyses from this study.

| Sample No. | Formation | Depth | Sample Type | Temp. | pH | Na | K | Ca | Mg | $HCO_3$ | $SO_4$ | Cl | $NO_3$ | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Quitman | Eagle Ford | old 4,250 | | | | 31,415 | | 1,474 | 205 | 137 | 21 | 51,287 | | |
| | | new 4,210 | | | | 23,800 | | 1,030 | 203 | 187 | < 4 | 40,400 | | |
| Boggy Creek | Woodbine | old 3,634 | | | | 37,615 | | 3,451 | 582 | 329 | 184 | 65,499 | | |
| | | new 3,600 | | | | 37,900 | | 3,250 | 465 | 160 | 120 | 65,500 | | |
| Neches | Woodbine | old 4,742 | | | | 35,582 | | 3,520 | 586 | 274 | 180 | 62,520 | | |
| | | new 4,704 | | | | 35,700 | | 3,200 | 545 | 150 | 90 | 62,100 | | |
| Cayuga | Woodbine | old 4,049 | | | | 29,833 | | 1,620 | 350 | 348 | 118 | 49,600 | | |
| | | new 4,030 | | | | 29,600 | | 1,200 | 210 | 160 | 120 | 48,500 | | |
| Long Lake | Woodbine | old 5,250 | | | | 36,432 | | 2,806 | 474 | 376 | 119 | 62,232 | | |
| | | new 5,272 | | | | 36,400 | | 2,400 | 280 | 170 | 110 | 62,200 | | |
| Powell | Woodbine | old 3,000 | | | | 3,964 | | 62 | 26 | 1,393 | --- | 5,462 | | |
| | | new 3,000 | | | | 4,400 | | 74.5 | 27 | 350 | 60 | 6,500 | | |
| Van | Woodbine | old 2,912 | | | | 27,491 | | 825 | 368 | 536 | 11 | 44,600 | | |
| | | new 2,900 | | | | 25,100 | | 1,160 | 290 | 120 | 60 | 43,100 | | |
| Slocum-NW | Woodbine | old 5,686 | | | | 32,910 | | 3,000 | 430 | 260 | 190 | 57,000 | | |
| | | new 5,400 | | | | 32,500 | | 2,700 | 460 | 98 | 73 | 58,100 | | |
| Hawkins | Woodbine | old 4,650 | | | | 35,668 | | 2,850 | 530 | 406 | 206 | 61,200 | | |
| | | new 4,531 | | | | 35,200 | | 2,300 | 290 | 170 | 250 | 59,500 | | |
| Mexia | Woodbine | old 3,065 | | | | 11,818 | | 561 | 179 | 290 | 4 | 19,573 | | |
| | | new 3,100 | | | | 12,270 | | 570 | 142 | 263 | < 6 | 20,300 | | |
| Richland | Woodbine | old 2,985 | | | | 5,654 | | 124 | 37 | 683 | 0 | 8,652 | | |
| | | new 3,300 | | | | 5,285 | | 94 | 29 | 350 | < 6 | 8,280 | | |
| Quitman | Paluxy | old 6,211 | | | | 39,627 | | 9,731 | 1,388 | 96 | 460 | 82,009 | | |
| | | new 6,230 | | | | 39,000 | | 9,540 | 936 | 54 | 389 | 81,300 | | |

### $Na^+$ versus $Cl^-$ (figs. 24 and 25)

$Na^+$ increases directly with Cl for all samples analyzed. Based on the slope of the line, there are two subsets of data. Up to Cl concentrations of 2 m/l, the slope of Na/Cl is ≃ 1. These data included Nacatoch, Eagle Ford and Woodbine Formations. Above a Cl concentration of 2 m/l, the slope drops to 0.6. These data include Paluxy, Glen Rose, Pettet and Travis Peak Formations.

### $Ca^{++}$ versus $Cl^-$ (figs. 26 and 27)

$Ca^{++}$ concentrations remain low up to $Cl^-$ concentrations of approximately 2 m/l Cl, then Ca concentration increases up to 0.8 m/l in figure 26--to 1.1 m/l in Figure 27. Different trends for Ca versus Cl occur in the same formations as for Na versus Cl. High Ca concentrations begin in the Paluxy Formation.

### $(Na^+ + 2\ Ca^{++})$ versus $Cl^-$ (fig. 28)

A scattergram of $(Na^+ + 2Ca^{++})$ versus $Cl^-$ shows a slope of 1. Two Ca are added to the Na to determine whether the 0.6 slope observed for Na/Cl plot (figs. 24 and 25) was caused by an exchange of Na for Ca. The Ca concentrations are multiplied by 2 to maintain charge balance. If Ca is exchanging for Na, then 2 Na will be lost from the brine. The addition of Ca and depletion of Na relative to Cl appear to be related to the same geochemical reaction.

### $K^+$ versus $Cl^-$ (fig. 29)

The scattergram of K versus Cl shows two different trends. For Cl concentrations less than 2 m/l, Cl increases independently of K. For Cl concentrations greater than 2 m/l, K concentrations increase significantly. This is a similar pattern as observed for Ca versus Cl.

### $Br^-$ versus $Cl^-$ (fig. 30)

The scattergram of Br versus Cl shows two different trends. For Cl concentrations less than 2 m/l Cl and in Nacatoch, Eagle Ford or Woodbine Formations Cl increases independently of Br. For Cl concentrations greater than 2 m/l, Br increases proportionally with Cl at a slope

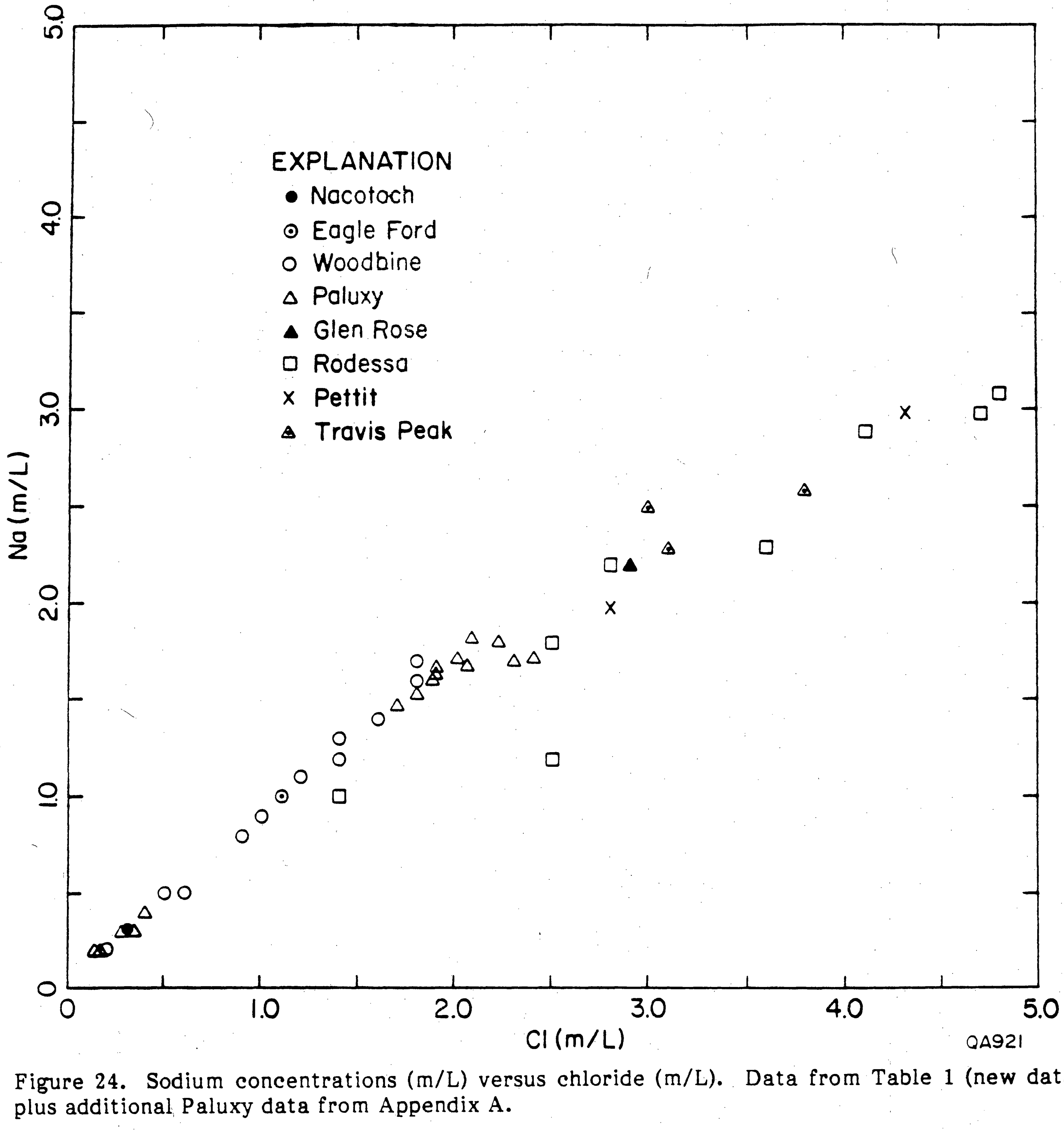

Figure 24. Sodium concentrations (m/L) versus chloride (m/L). Data from Table 1 (new data) plus additional Paluxy data from Appendix A.

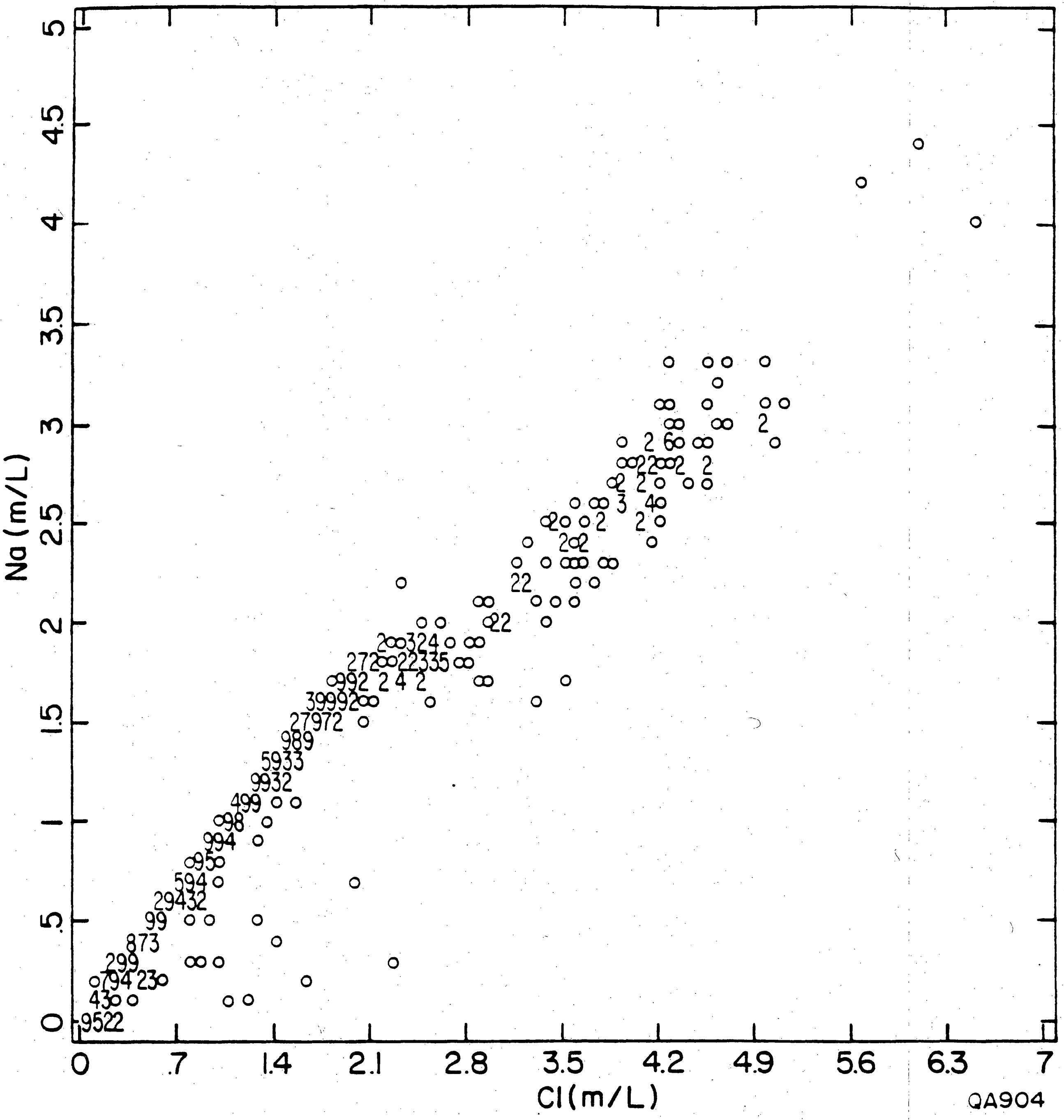

Figure 25. Sodium concentrations (m/L) versus chloride (m/L). Data from Appendix A (previously published data).

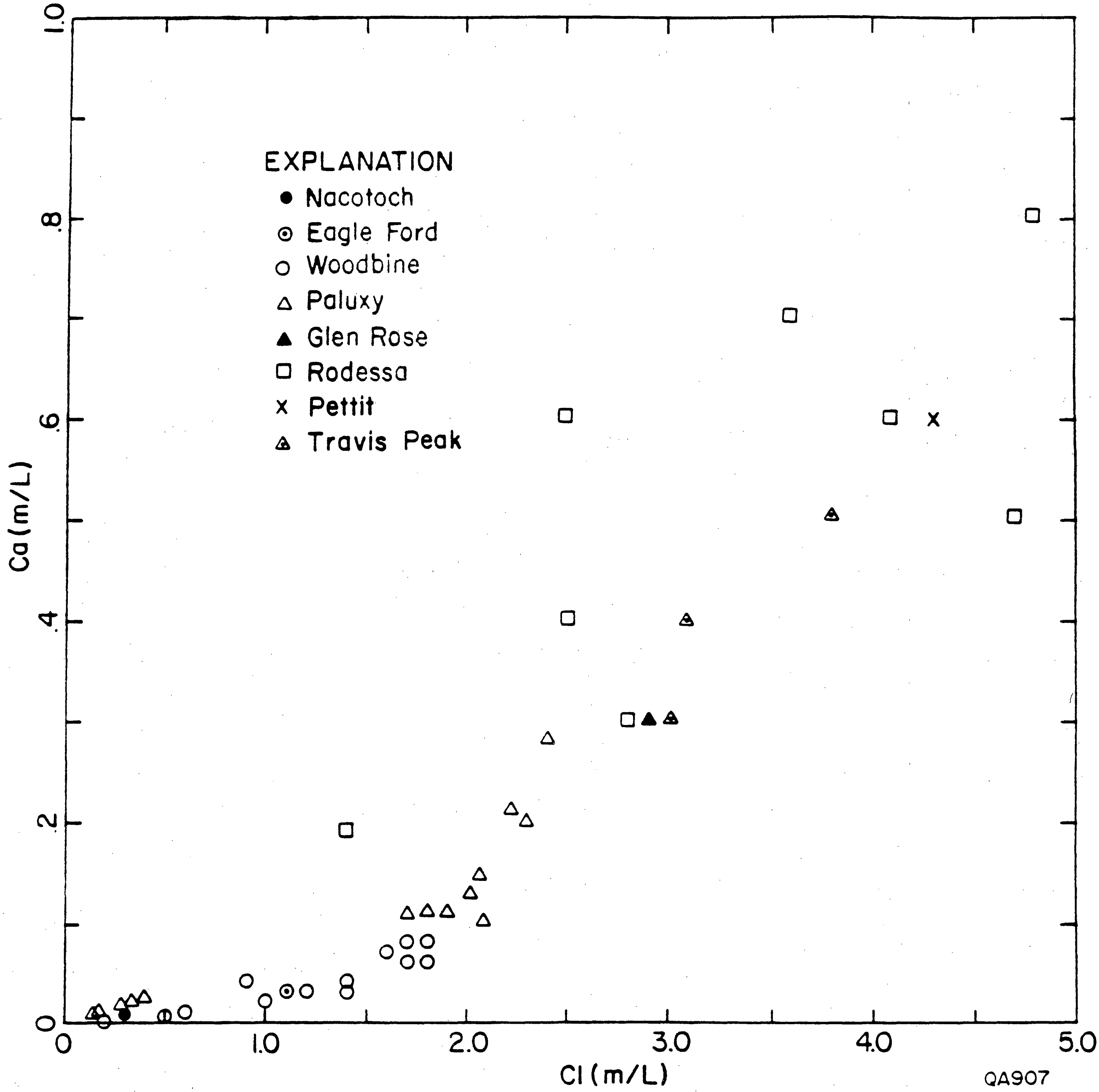

Figure 26. Calcium concentrations (m/L) versus chloride (m/L). Data from Table 1 (new data) plus additional Paluxy data from Appendix A.

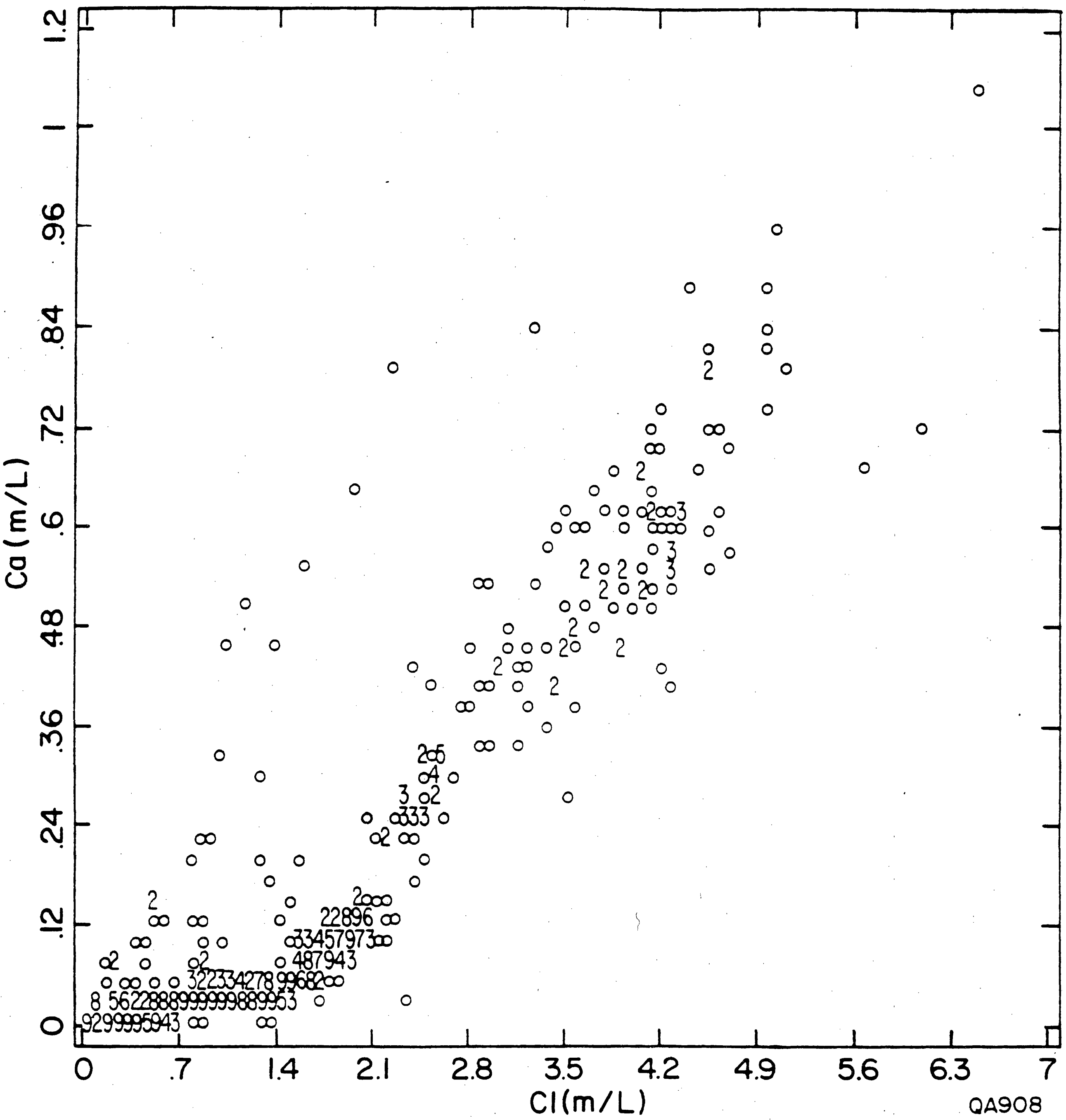

Figure 27. Calcium concentrations (m/L) versus chloride (m/L). Data from Appendix A.

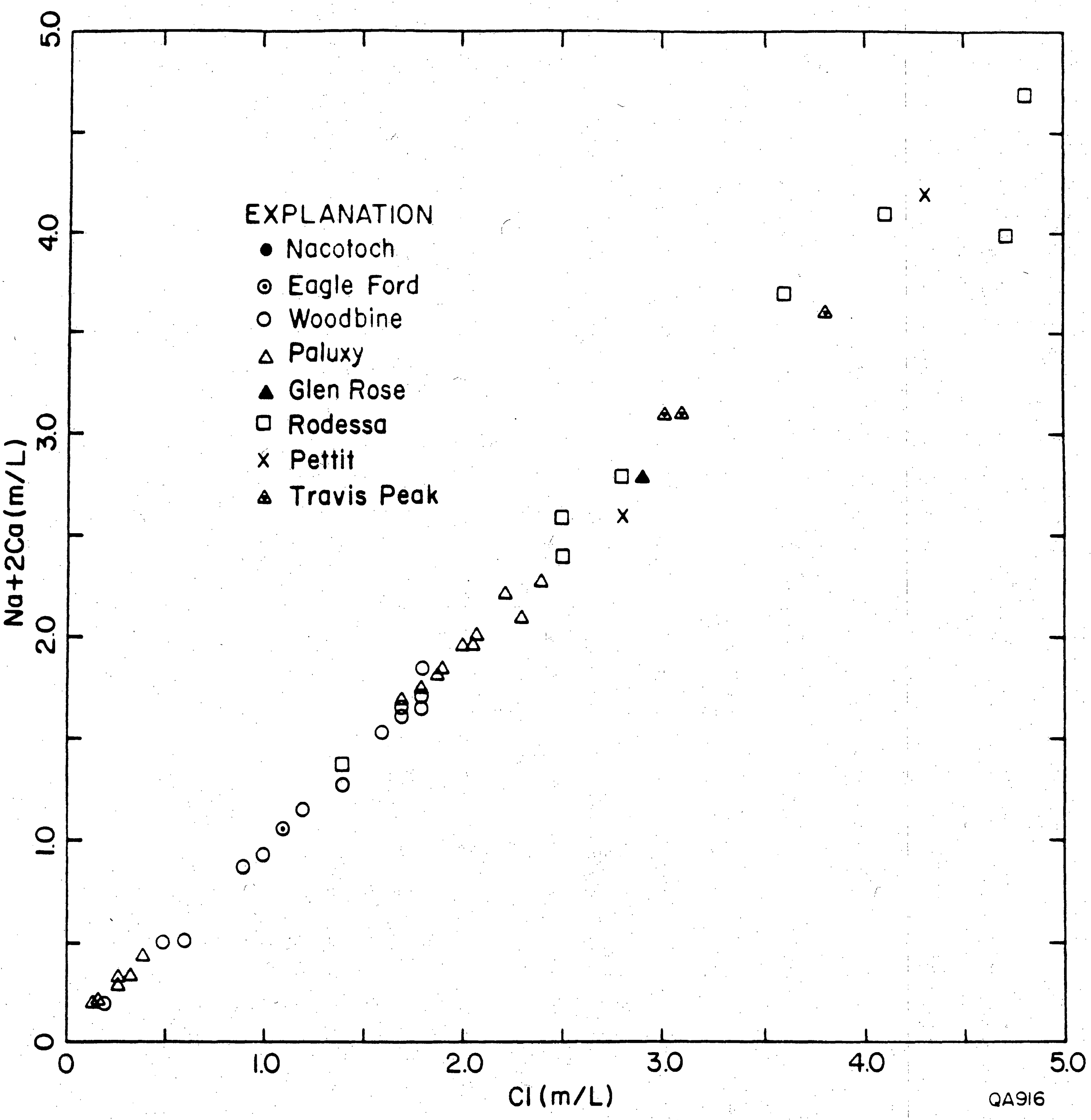

Figure 28. (Na$^+$ + 2 Ca$^{++}$) concentrations (m/L) versus chloride (m/L). Data from Table 1 plus additional Paluxy data from Appendix A.

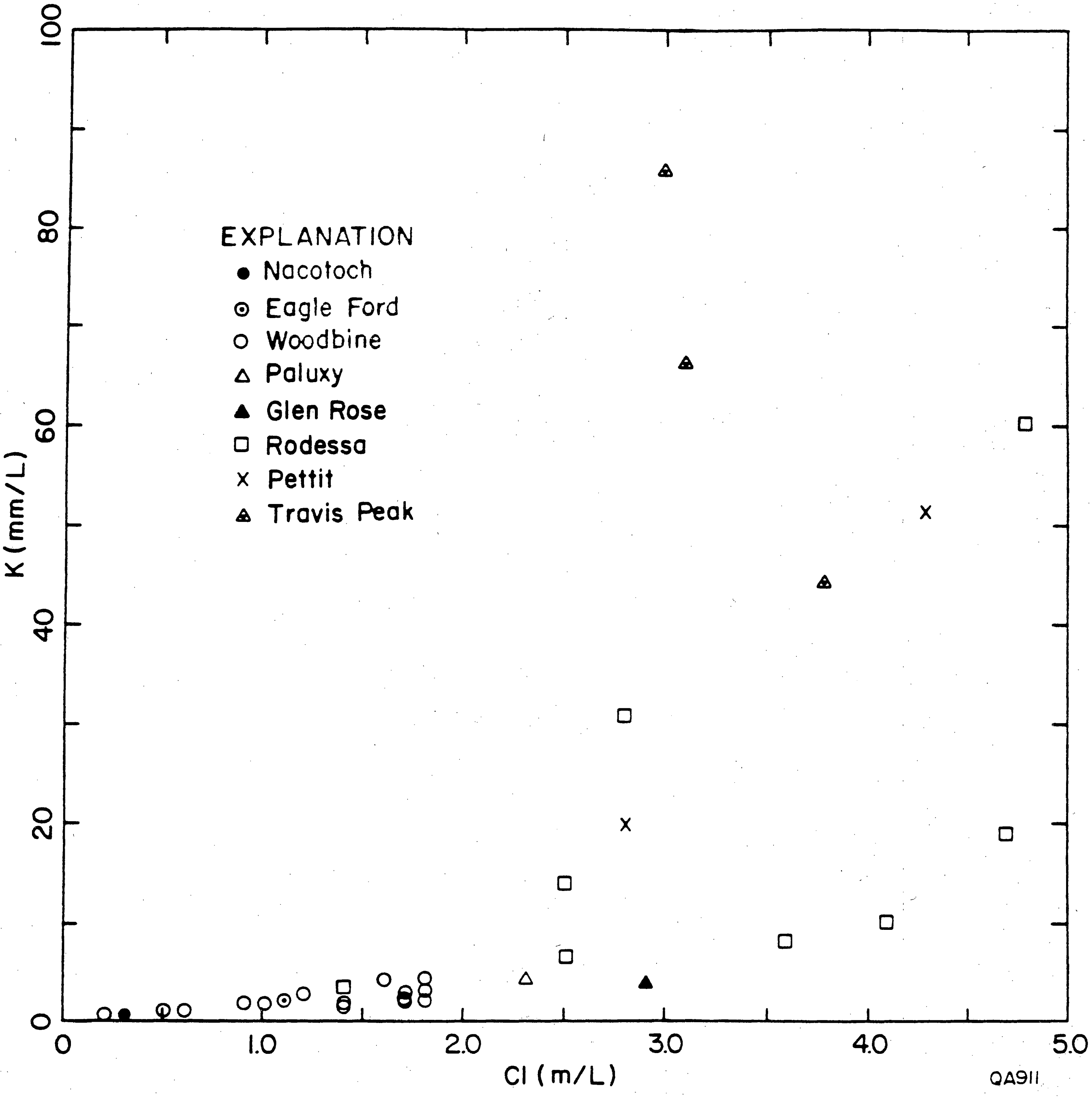

Figure 29. Potassium concentrations (mm/L) versus chloride (m/L). Data from Table 1.

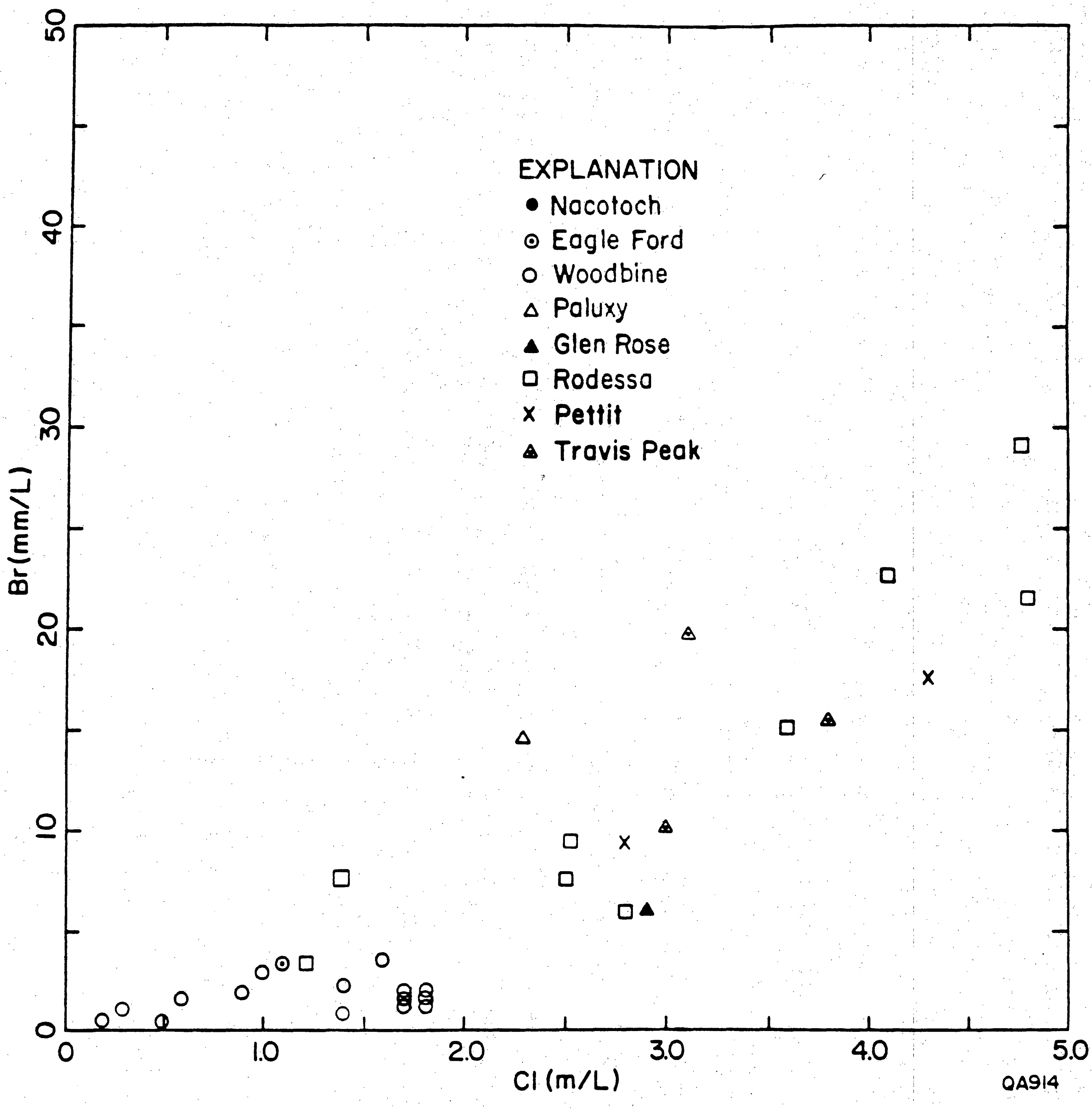

Figure 30. Bromide concentrations (mm/L) versus chloride (m/L). Data from Table 1.

of .006. The Br concentration increases at approximately the chlorinity value where Ca and K also increase significantly.

$Sr^{++}$ versus $Cl^{-}$ (fig. 31)

The scattergram of Sr versus Cl shows a continual increase of Sr with greater Cl concentrations. In contrast to the scattergrams of Ca versus Cl, K versus Cl, and Br versus Cl (figs. 26, 29, 30), Sr is increasing proportionately to Cl in the shallower formations.

$Mg^{++}$ versus $Ca^{++}$ (fig. 32)

The scattergram of Mg versus Ca shows a continual increase of Mg with increasing Ca concentrations. The slope of calcium versus magnesium for the Woodbine, Nacatoch, and Eagle Ford Formations appears greater than for Paluxy, Glen Rose, Rodessa, Pettet, and Travis Peak Formations.

$Br^{-}$ versus $I^{-}$ (fig. 33)

The scattergram of Br versus I shows no correlation between species. Br concentrations increase independent of I concentrations.

$Li^{+}$ versus $Cl^{-}$ (fig. 34)

For Cl concentrations less than approximately 50,000, Cl increases independent of Li. For Cl concentrations greater than 50,000, Li concentrations increase significantly. The Li concentrations increase at approximately the chlorinity value where Ca, K, and Br increase significantly.

$Cl^{-}$ versus Depth (fig. 22)

The scattergram of Cl versus Depth shows a continual increase of Cl with increasing depth. There is a greater scatter of data for the deeper formations (Paluxy, Glen Rose, Pettet, and Travis Peak).

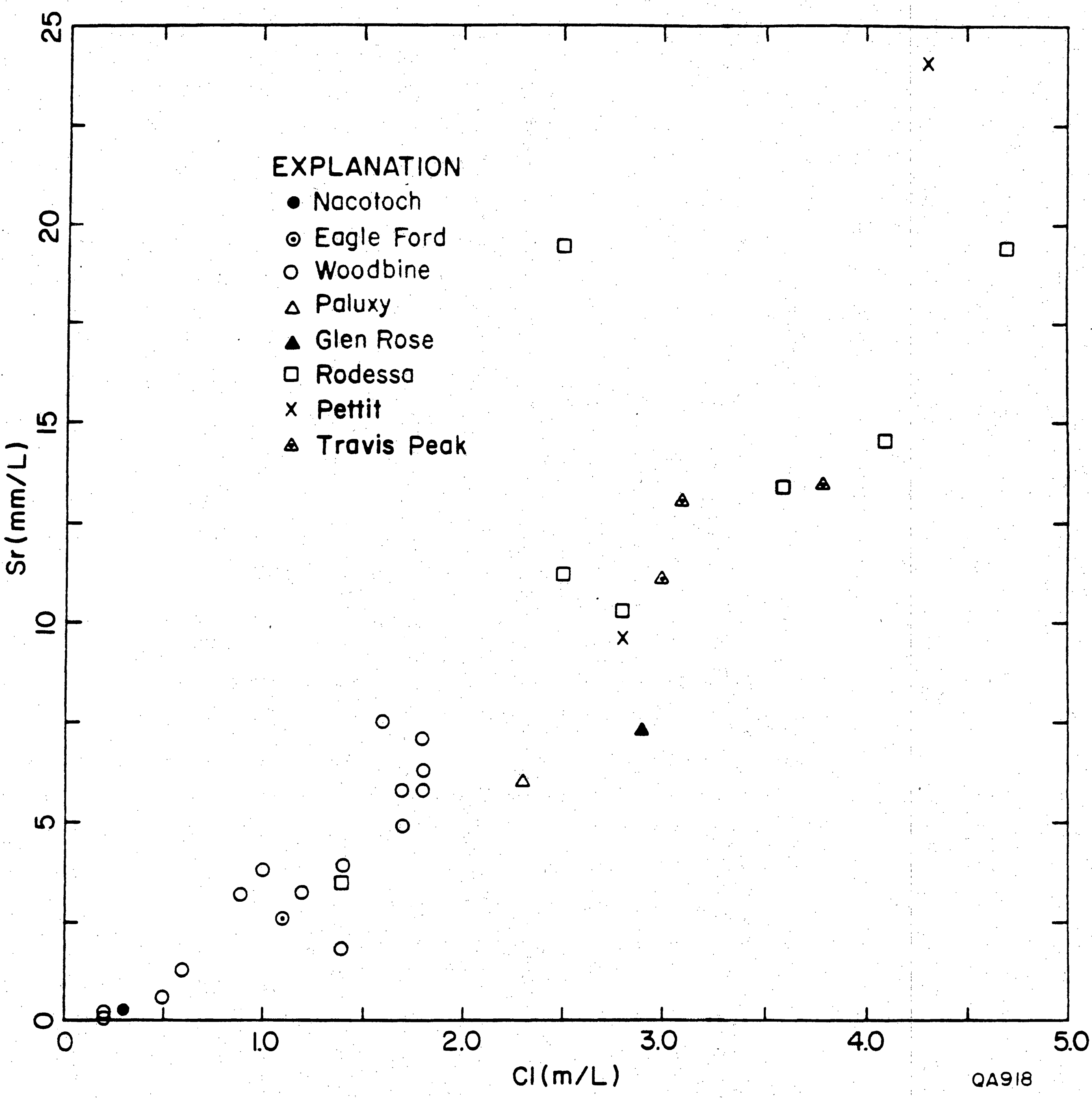

Figure 31. Strontium concentrations (mm/L) versus chloride concentrations (m/L). Data from Table 1.

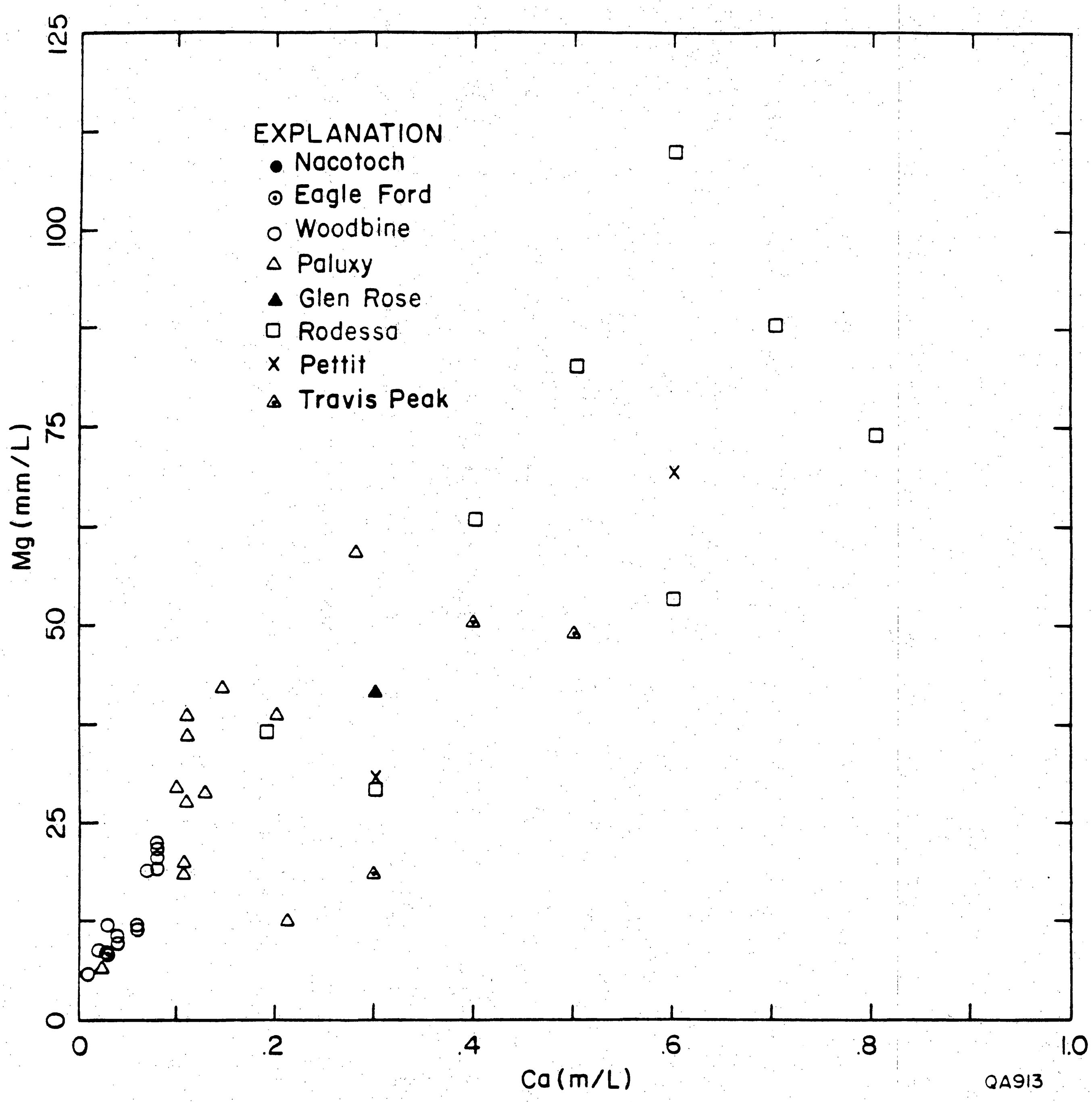

Figure 32. Magnesium concentrations (mm/L) versus calcium (m/L). Data from Table 1 plus additional Paluxy data from Appendix A.

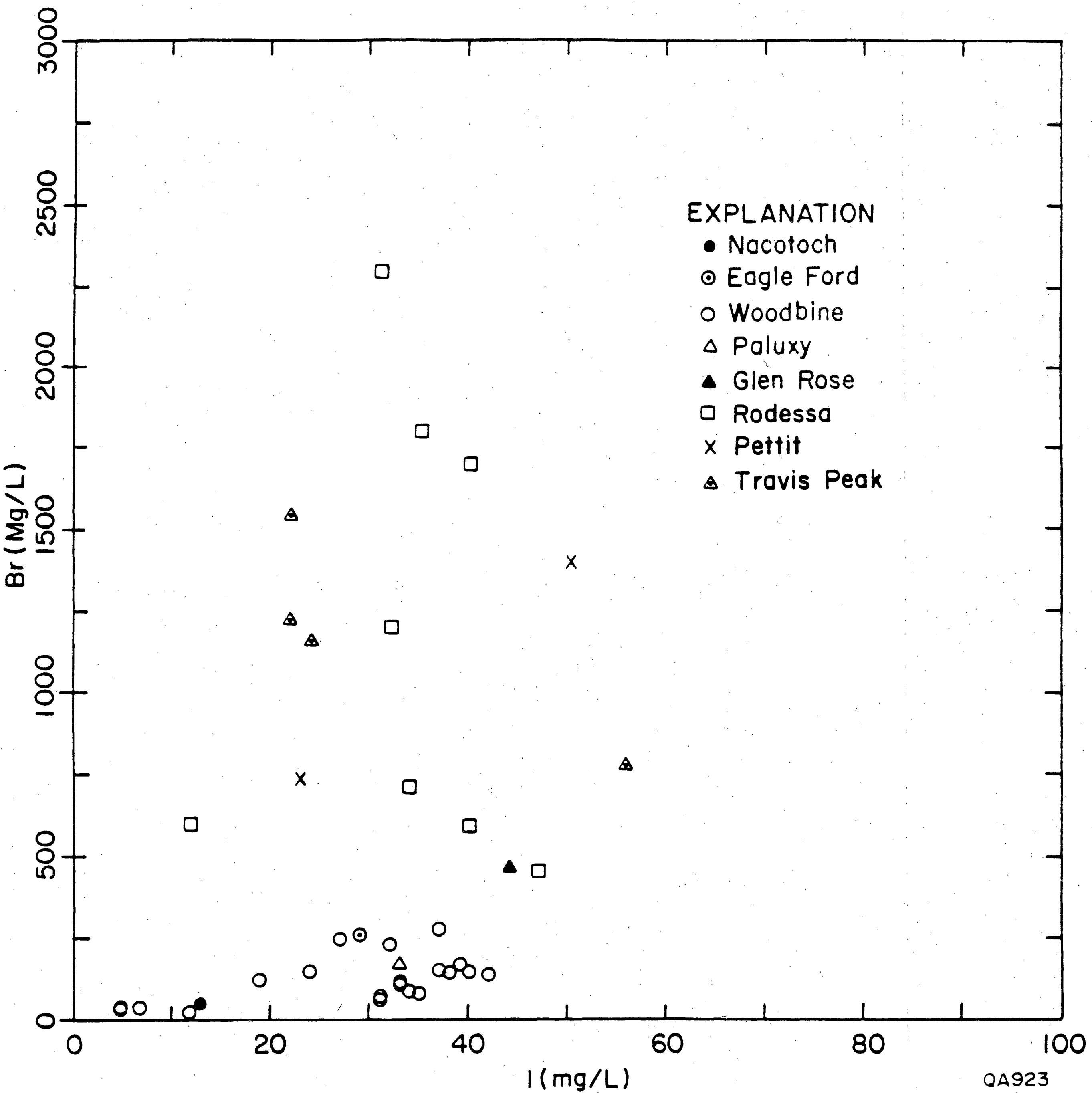

Figure 33. Bromide concentrations (mg/L) versus iodide concentrations (mg/L). Data from Table 1.

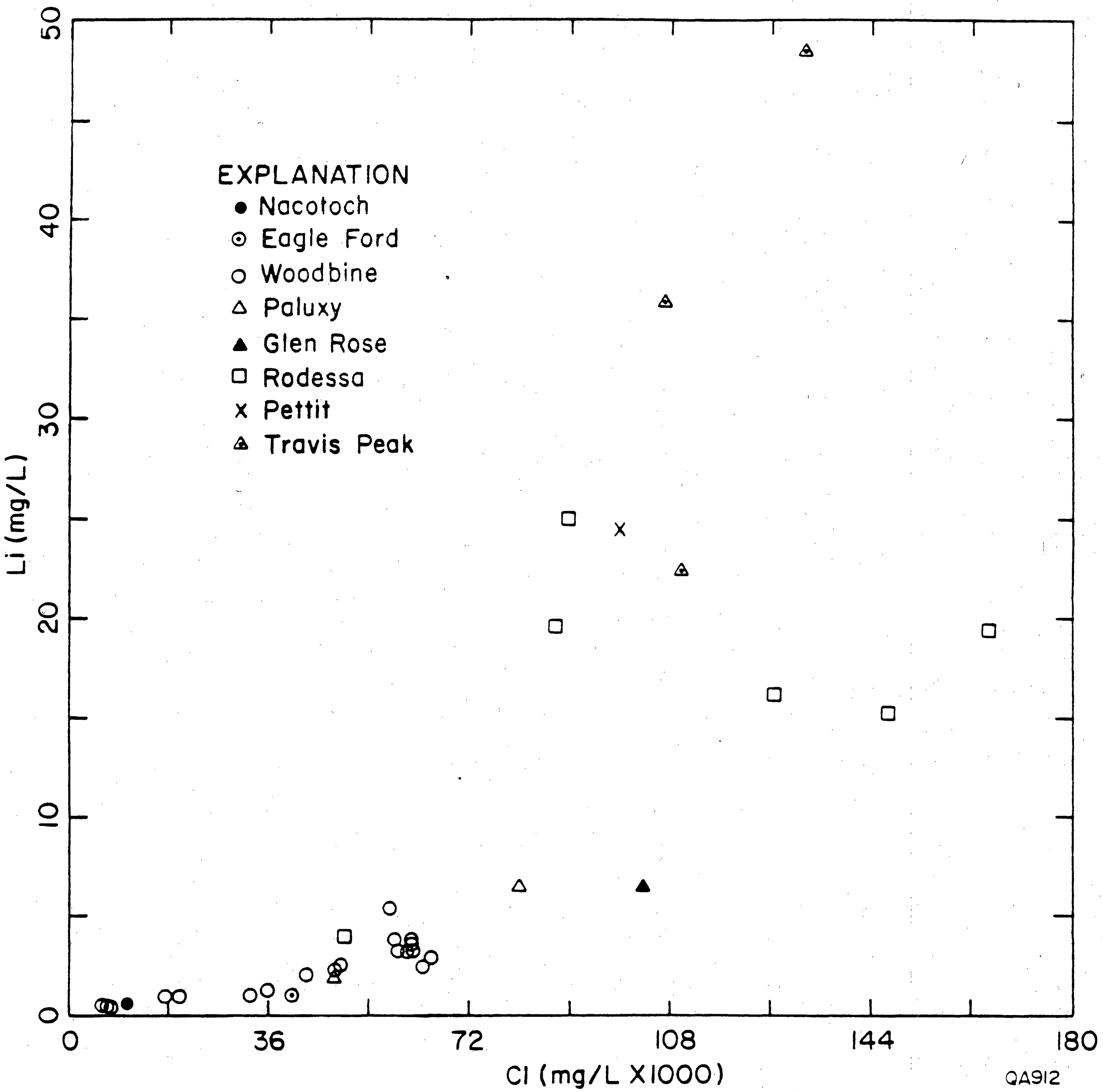

Figure 34. Lithium concentrations (mg/L) versus chloride concentrations (mg/L x 1000). Data from Table 1.

### $Ca^{++}$ versus Depth (figs. 35 and 36)

The scattergram of Ca versus Depth shows two different trends. For samples shallower than 6,000 ft, Ca concentration stays relatively low. In contrast to the shallow sampling depths, the Ca concentrations for the deeper sample are significantly higher and show a wide scatter. This change in trends at approximately 6,000 ft is also coincident with the 0.2 molar Cl concentrations observed to be important on the Ca versus Cl (fig. 26), K versus Cl (fig. 29), and Br versus Cl (fig. 30) graphs.

### $Br^-$ versus Depth (fig. 37)

The scattergram of $Br^-$ versus Depth shows two different geochemical trends which are similar to the trends observed for Ca versus Depth. At shallow depths Br concentrations are low and consistent. At depths greater than 6,000 ft, Br concentrations are greater and have a wider scatter.

## Discussion of Water Chemistry

The ionic solutes in the deep-basin brines result initially from the dissolution of salt domes by meteoric ground water. The previous discussion on the hydrogren and oxygen isotopic composition of the waters indicates that all waters sampled are of a meteoric origin. The mass balance calculations of original Louann Salt versus the amount of remaining domal salt indicate that dome dissolution through the geological history of the basin can easily accommodate for all the Na and Cl presently in solution. Additional geochemical reactions between the water and the rock matrix result in the addition or loss of ionic species in the water.

If dome dissolution appears to be the only important reaction affecting the Na concentrations in the basin, then the Na/Cl molar ratio should be approximately 1. This appears to be true for the shallower formations, Woodbine, Eagle Ford, and Nacatoch (figs. 24, 25). The concentrations of Ca, K, and Br conversely are small indicating minimal water-rock interactions (figs. 26, 29, and 30).

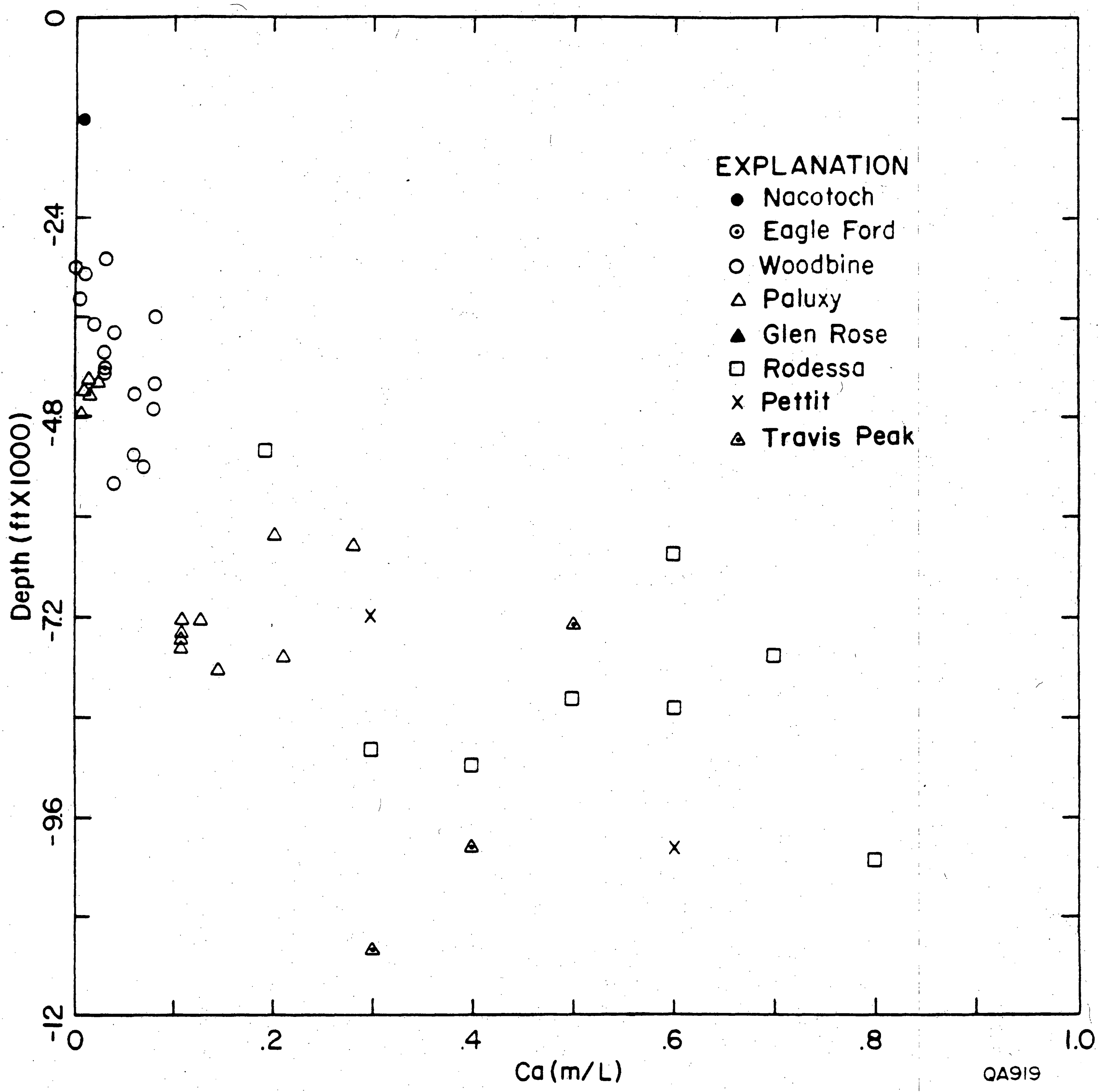

Figure 35. Calcium concentrations (m/L) versus depth. Data from Table 1 plus additional Paluxy data from Appendix A.

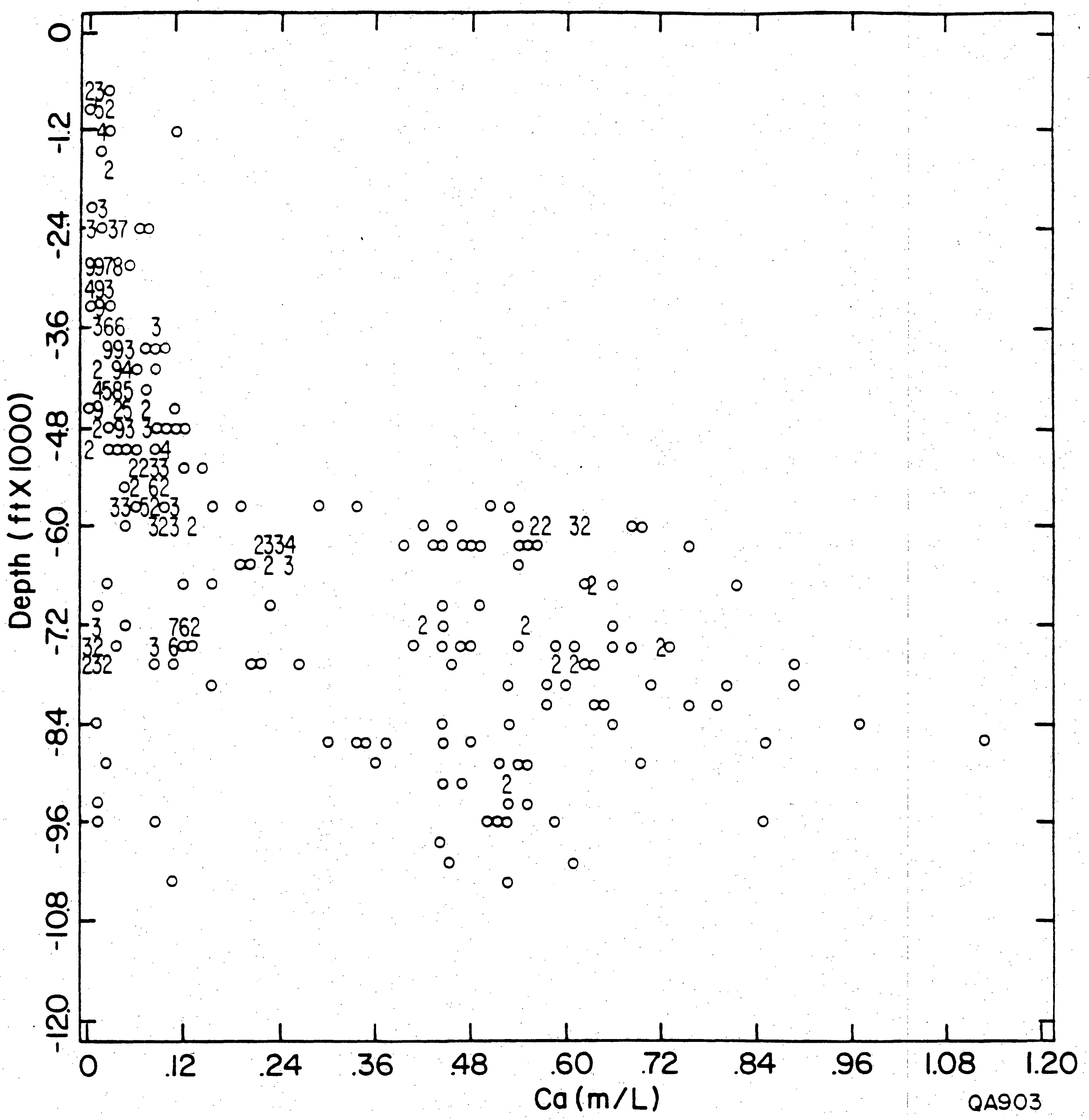

Figure 36. Calcium concentrations (m/L) versus depth. Data from Appendix A.

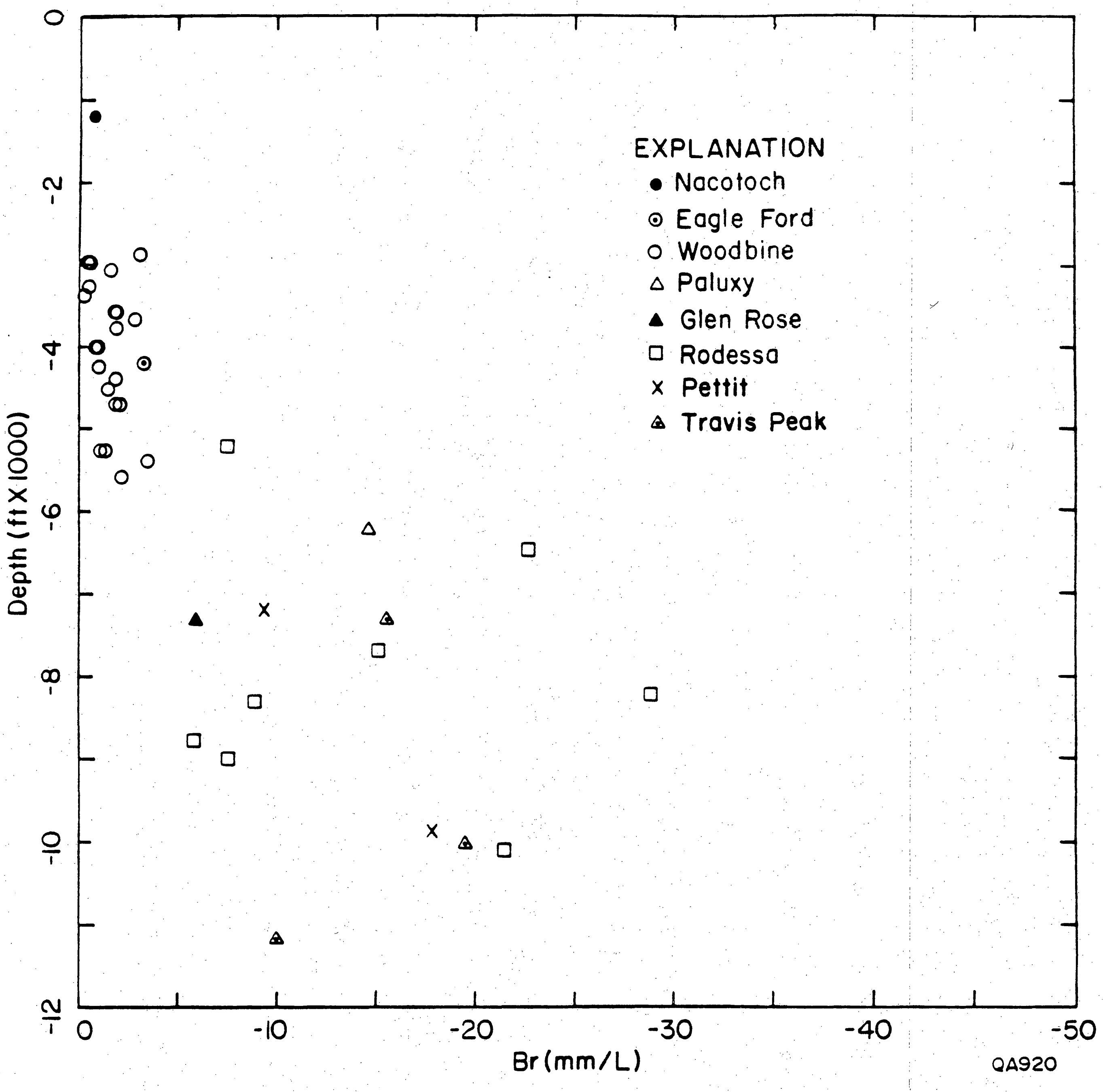

Figure 37. Bromide concentration (m/L) versus depth. Data from Table 1.

The chemical composition of waters in the deeper formations, in contrast, indicates several geochemical reactions have occurred or are presently occurring. The slope of Na to Cl for the deep brines is approximately 0.7 (figs. 24 and 25). Either halite dissolution was not the mechanism contributing to the Na-Cl load or Na has been lost from the brines. The first hypothesis is not considered realistic since a lower concentration brine from which the deeper waters have appeared to evolve, have approximately a 1:1 Na-Cl ratio. Secondly, the waters are continental meteoric in origin and not marine.

The increase in calcium (figs. 26, 27) and loss of Na (figs. 24, 25) are attributed to albitization. In this reaction sodium in solution is exchanged for calcium in the plagioclase. Land and Prezbindowski (1982) defined the equation (1) as follows.

Equation (1) plagioclase + halite + water = Na-Ca-Cl brine + albite

By adding the calcium (2 Ca, for charge balance purposes) to the Na concentrations, there is a close 1:1 molar ratio between Na + Ca/Cl (fig. 28). This 1:1 slope argues that there has been an exchange process that has caused the depletion of Na and the increase of Ca. This 1:1 slope also argues against the solution of anhydrite and subsequent reduction of the sulfate. If sulfate reduction was a dominant reaction, then the Na:Cl molar ratio should remain constant at 1 and not decrease to the observed 0.7 value. The lack of $H_2S$ in the deep-basin brines (table 1) may also argue against sulfate reduction. Wescott (1983) observed that the most common secondary porosity in the Schuler Sandstone (the major sandstone directly beneath the Travis Peak) resulted from feldspar dissolution. Many of the feldspars had been albitized (Dunay, 1981). Garbarini (1979) also observed extensive albitization in the Hosston (Travis Peak) in Mississippi.

Potassium concentrations also increase significantly in the deeper formations. This increase in K could be attributed to either the dissolution of K-feldspars or the alteration of K-feldspars to albite (equation 2), a similar reaction to the albitization of plagioclase.

Equation (2) K-feldspar + halite + water = Na-K-Cl brine + albite

In Dunay's study of the Cotton Valley, minimal dissolution of K-feldspar was observed.

The mechanism which initiates the albitization of potassic and calcic feldspars may be the ionic strength of the brine and/or temperature. The sharp increase in both Ca and K starts at 2 molar Cl solutions. The approximate temperature is 70°C (based on a depth of 6,000 ft and an average geothermal gradient of 1.6°F (.9°C)/100 ft for the region. This temperature is lower than the 120°C suggested by Boles (1979) and Milliken and others (1981) for the albitization threshold temperature. Though the sharp increase in concentrations occurs at 2 molar solution and 70°C, the albitization reaction may be occurring at shallower depths and in less concentrated solutions. Plots of Na/Cl versus depth (fig. 38) and Na/Cl versus Cl (fig. 39) show that the shift of the Na/Cl ratio toward lower values starts in the shallower aquifers with the lower TDS values. This shift may also result from exchange reactions other than albitization such as cation exchange on clays.

Magnesium concentrations increase linearly with calcium (fig. 32). The Mg probably results from dedolomitization. With the increase in calcium in solution from the albitization reaction, the waters become undersaturated with respect to dolomite and dolomite solution should occur until equilibrium is reestablished, by the following equation.

Equation (3) $Ca + CaMg(CO_3)_2 = Mg + 2CaCO_3$

These waters are considered to be in equilibrium concurrently with calcite and dolomite, as evidenced by the relationship between the Ca/Mg ratio and temperature (fig. 40). With an increase in temperature, the calcite/dolomite equilibrium shifts toward dolomite, that is, dolomite becomes more stable (Land and Prezbindowski, 1981; Stoessel and Moore, 1983; Land, 1981). This shift in equilibrium should be observed in the Ca/Mg ratio with increasing temperatures. A linear increase in the ratio with increasing temperature is observed (fig. 40). Molar concentrations of calcium and magnesium are used in Figure 40 instead of the activity values, based on the arguments of Land and Prezbindowski (1981) that the ratio of concentrations is comparable to the activity ratios. The Ca/Mg ratio follows the calcite/dolomite equilibrium curve of Stoessel and Moore (1983) based on Robie et al. (1979) indicating that the waters are in equilibrium with calcite and dolomite.

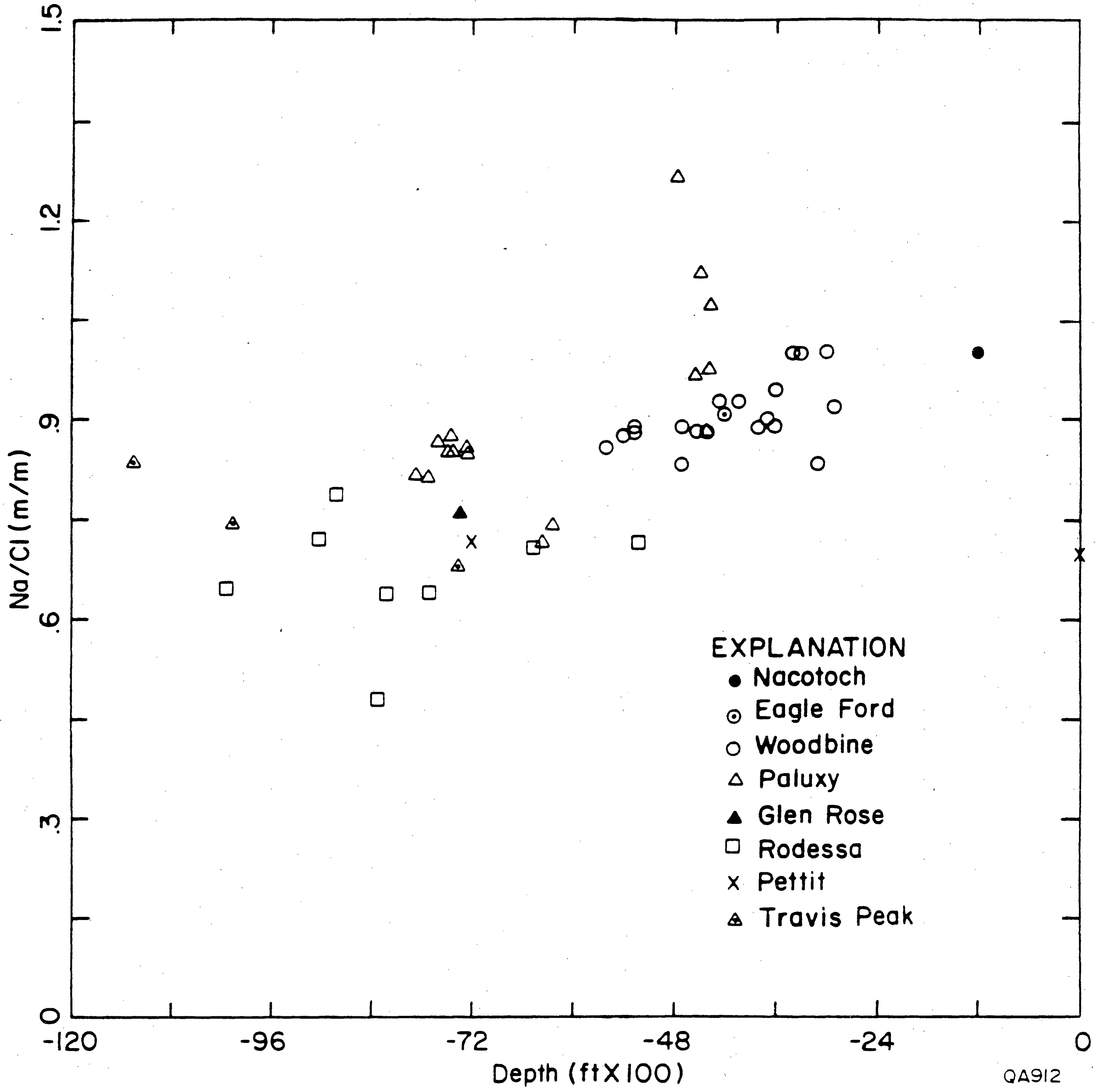

Figure 38. Na/Cl molar ratio versus depth. Data from Table 1 plus additional Paluxy data from Appendix A.

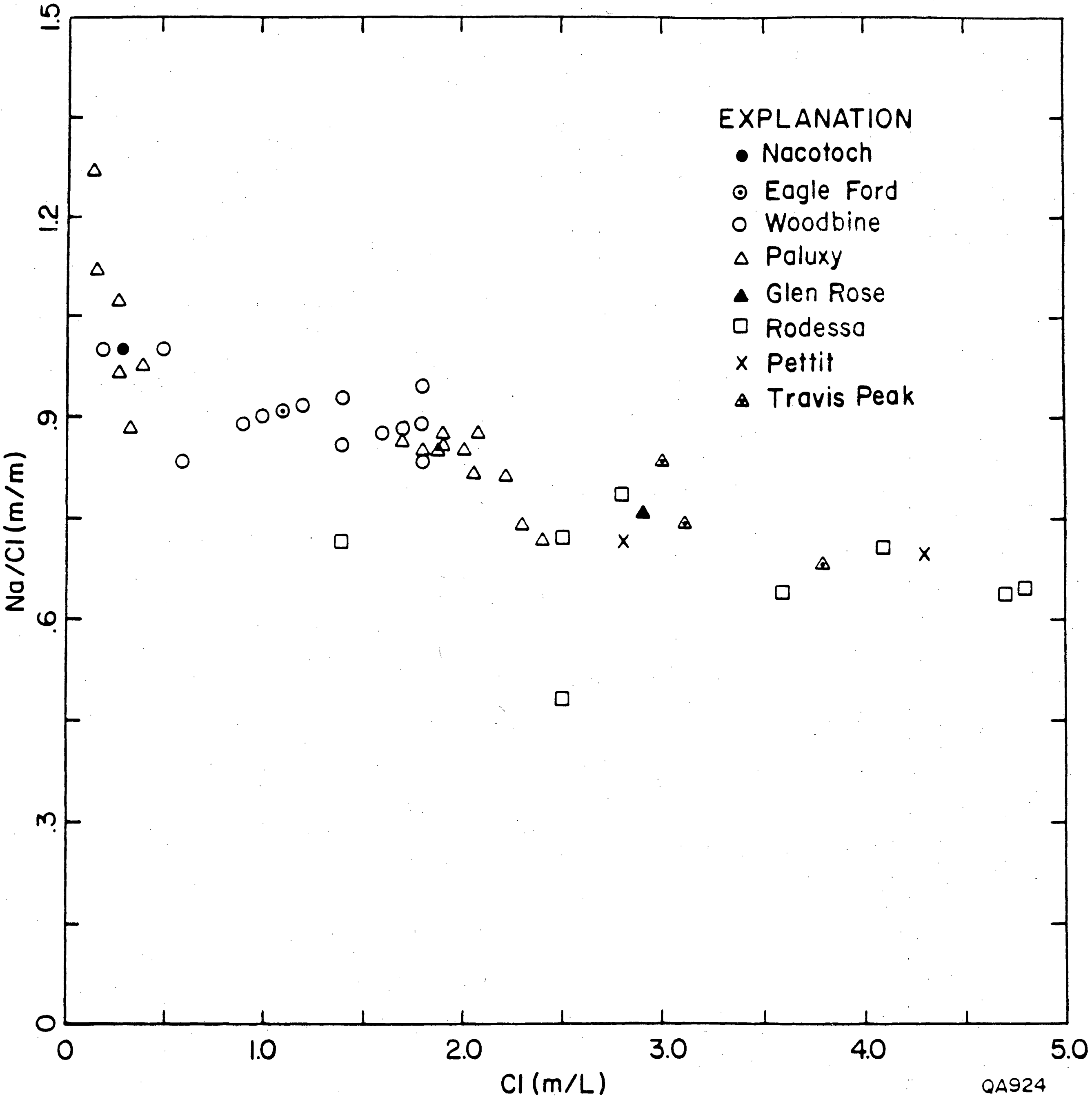

Figure 39. Na/Cl molar ratio versus chloride concentrations (m/L). Data from Table 1 plus additional Paluxy data from Appendix A.

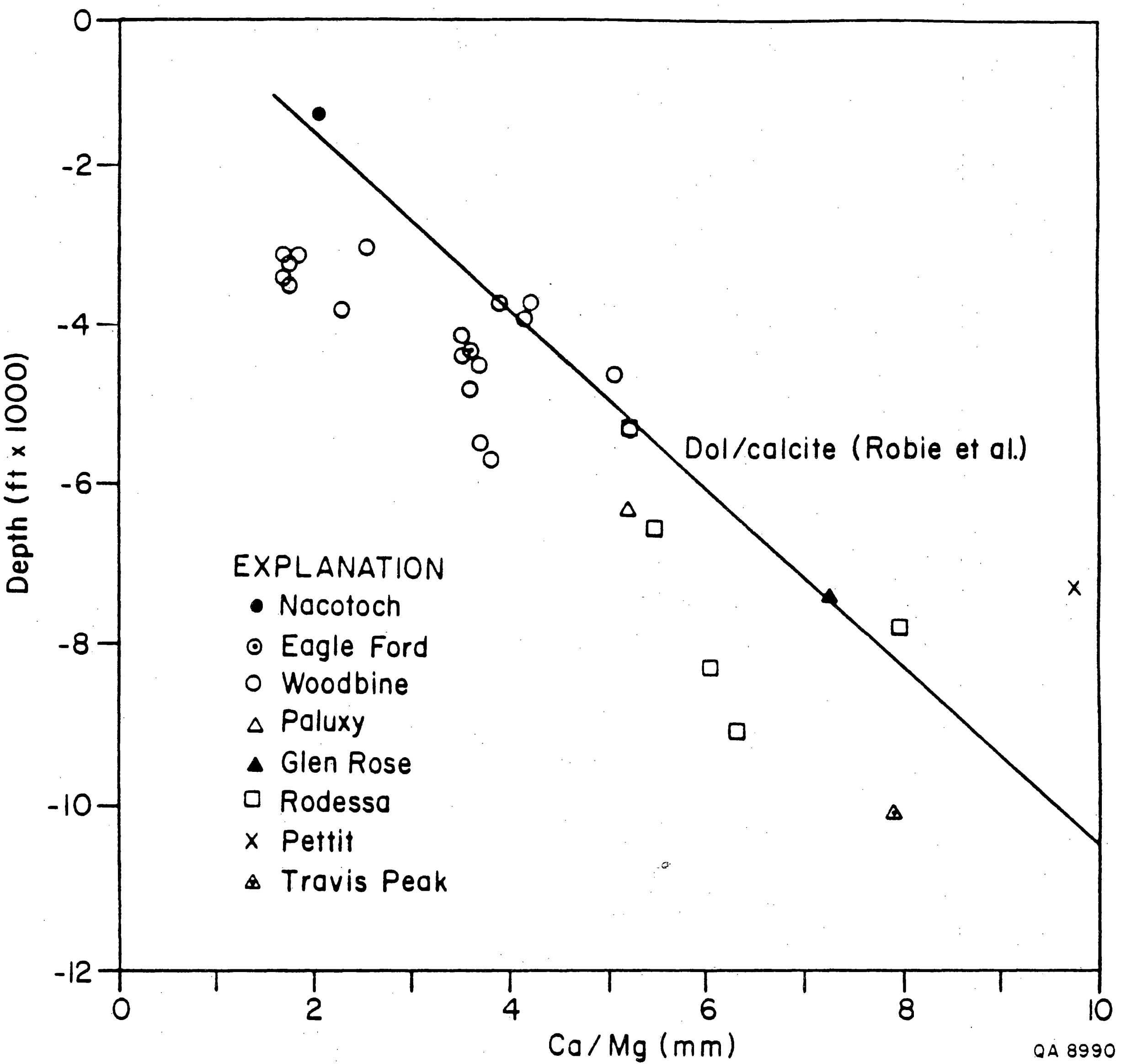

Figure 40. Ca/Mg molar ratio versus depth (Temperature). Data follows calcite/dolomite equilibrium line calculated by Stoessel and Moore (1983) from data of Robie et al (1978). Data from Table 1.

The Br composition of the deep basinal saline waters (figs. 30, 37) also appears to subdivide into two groups: low Br concentrations for Nacatoch, Eagle Ford and Woodbine Formations and significantly higher concentrations for the deeper units. The source of Br in saline deep-basinal water has been enigmatic. Carpenter (1978) suggested that the bromide results from residual brine squeezed out of the Louann Salt. Land and Prezbindowski (1981) suggest that the high Br concentrations result from a solution-reprecipitation of the halite which depletes the halite in Br and conversely enriches the solution in Br. If there is total solution of halite, then the Br/Cl ratio in the water will be the same in the original salt. If there has been solution/reprecipitation, then the Br content will be greater than in the original halite. This second hypothesis is considered a reasonable explanation for the Br in the East Texas brines.

Carpenter's residual Louann brine concept is considered unacceptable for the following reason. The amount of residual brine-pocket fluid needed for the observed Br concentrations through the Glen Rose and Travis Peak Formations is too large. If the Br in solution in the deep formation came from brine pockets squeezed out of the Louann Salt during deep burial, then the volume of the bittern brine can be estimated by (1) knowing the Br in the Glen Rose and Travis Peak Formations and by estimating the Br content in a late stage evaporite fluid. The brine content in the deep formations (Glen Rose and below) is estimated at 3 x $10^{15}$ g of Br. Assuming the Br concentration in a late-stage evaporation brine is 5,000 mg/l based on approximate Br content during K-salt precipitation (Carpenter, 1978), then the estimated volume of the residual brines is 600 $km^3$. This 600 $km^3$ constitutes 10 percent of the volume of the original salt dome province or a porosity of 10 percent. The salt thickness is estimated at 1,500 m. Maintaining this 10 percent porosity during the accumulation of 1,500 m of halite is considered unrealistic.

The solution-reprecipitation mechanism is preferred for the following reasons. The Br concentration of the halite from Oakwood salt dome (East Texas) averages 45 ppm, which is slightly depleted from 65 to 75 ppm Br expected for "first cycle" halite (Holser, 1979). Dix and

Jackson (1981) interpret this depletion as the result of solution and reprecipitation. The Br in the original Louannn Salt may have been much higher. Kreitler and Muehlberger (1981) noted that Grand Saline salt dome had undergone very little dissolution and the geochemistry of these salts might approximate the chemical composition of the original Louann Salt. In Grand Saline, Br concentrations ranged from 100 to 300. If the bromide in the halite at Grand Saline represents original Br concentrations of the Louann Salt, then the halite in Oakwood Dome, and possibly the halite in other domes have undergone a significant depletion of bromide.

Kumar and Hoda (1978) observed Br concentrations in brine pools and brine springs in the Weeks Island and Belle Island salt domes mines that ranged from 1,100 to 13,500 mg/l with a mean of 6,200. Chloride concentrations ranged from 194,000 to 276,000 mg/l. These waters should represent brines that have equilibrated with the mineralogy of the salt stock and may therefore be analogous to formation waters that have equilibrated with the salt stock on its exterior. Their data indicate that high Br concentrations can result from basinal water reacting with a salt dome. Kumar and Hoda's (1978) Br/Cl molar ratio of .09 is higher than Br/Cl molar ratio (.007) observed in the Glen Rose and Travis Peak brines from this study. East Texas deep-basin brines, however, would be the product of both halite dissolution as well as equilibrating with a Br-enriched halite and therefore have Br/Cl ratios lower than observed in pools and springs observed in the mines.

Carpenter and Trout (1978) suggested that Br and I in saline ground water may result from the decomposition of organic material. Figure 33 shows no correlation between Br and I. If iodine is coming from organic decomposition (a reasonable idea), then the Br is not.

The deep-basinal brines also are high in Sr. There are at least two possible sources for the Sr in solution. (1) Disseminated anhydrite in salt dome halite has a strontium content of approximately 1,500 mg/kg (Kreitler and Dutton, 1983). The dissolution of salt dome halite should result in the dissolution of some anhydrite and release of strontium. (2) Albitization of plagioclase may release Sr as well as Ca. Smith (1975) measured Sr concentrations in feldspars up to 5,000 ppm.

A plot of Sr versus Cl (fig. 31) shows a continual increase of Sr with Cl which is in contrast to the Ca versus Cl, K versus Cl and Br versus Cl plots (figs. 26, 29, and 30). This indicates that a geochemical reaction envisioned for brines albitizing Sr-bearing plagioclase in the Paluxy, Glen Rose and Travis Peak is not the sole cause of Sr in solution.

The chemical composition of the saline waters in the Glen Rose (Pettet and Rodessa are part of Glen Rose) and Travis Peak is significantly different than the chemical composition of the waters in the Nacatoch, Eagle Ford and Woodbine Formations. Chemical composition of waters in the Paluxy appears transitional between these deeper and shallower formations. Figures 35, 36, and 37 show an abrupt increase in Ca and Br concentrations at a depth of approximately 6,000 feet. This depth is the general depth of the Paluxy and top of Glen Rose. This depth is also coincident with 2 molar Cl concentration (figure 26) which appears to be an important concentration for initiating albitization and other rock-water reactions.

This break in chemical composition at ≈ 6,000 feet also coincides with the fluid pressure/depth relationships. Shallower than 6,000 ft, the basin pressures are hydrostatic to subhydrostatic. Below 6,000 ft, the pore fluid pressures are slightly overpressured. (A more detailed discussion of basin pressure is in a later section.)

The Na-Ca-Cl waters initially were Na-Cl waters. The addition of Ca, Mg, Sr, and other trace elements had to have occurred after the addition of 2 moles of NaCl. If these waters started as a Na-Ca-Cl water, they should trend to a 0,0 position rather than the 2 mole position (fig. 26).

The transition of a Na-Cl water to a Na-Ca-Cl water implies but does not prove hydrologic continuity between the Na-Cl waters and the Na-Ca-Cl waters. Kreitler and others (1978) in a study of Gulf Coast aquifers and Fogg and Kreitler (1982) in a study of the Carrizo-Wilcox aquifer in East Texas used the continual change in water chemistry as a tool for identifying flow paths. This probably is not a continuous flow system from the shallow saline aquifers to the deeper aquifers in the East Texas basin. The fact that the Na-Ca-Cl waters evolved from a Na-Cl water only indicates that the deeper waters and the shallower saline waters are following the same geochemical evolution and the deeper waters have evolved significantly further.

The chemical composition of the Paluxy waters appears transitional between the shallower Na-Cl waters and the deeper Na-Ca-Cl waters (figs. 24 and 26). This may result from two processes. (1) The Paluxy waters may be in the appropriate temperature and salinity environment such that a Na-Ca-Cl water results, or (2) the chemical composition of these waters may result from the mixing of the two different water types. Leakage may be occurring from the slightly overpressured Glen Rose into the Paluxy.

This subdivision of chemical composition into Na-Cl waters and Na-Ca-Cl waters appears to be independent of lithology within each major group. The Na-Ca-Cl waters occur in both sandstones (Travis Peak) and limestones (Glen Rose Group). The change in chemical compositions may be related to three factors. (1) The two molar NaCl concentration may be a threshold value to cause major rock water reactions; (2) The temperatures at 6,000 feet may be sufficient to initiate the rock-water reactions; (3) The waters in the deeper formations may be much older and have thus permitted greater rock-water interaction.

The interpretation of rock/water geochemical reactions is based only on the chemical analysis of the waters. Minimal petrographic analyses of the different formations are available. This represents a major limitation of the study. If reactions such as albitization of feldspars or dedolomitization have occurred, then they should be evident in the rock record.

## Water Chemistry Proximal to Salt Structures

The previous discussion identified the major chemical composition trends in the saline aquifers. Study of the water chemistry from oil and gas fields close to salt domes might indicate anomalous hydrologic or geochemical processes because of the presence of the dome. Anomalous chemical composition might indicate ongoing dome dissolution or leakage from deeper or shallower formations.

Sixteen water samples of the 38 samples listed in table 1 are near or overlying salt domes or salt pillows (table 10). Seven of these 16 samples were collected from formations that either laterally abutted a salt structure or were less than 1,000 ft overlying a salt structure. There are only a few producing oil fields on the flanks of the salt domes; therefore, samples from dome flanks are very limited. Most of the oil associated with salt structures are fields overlying salt anticlines. The salt anticlines often are very deep and the fields overlying them are shallow in comparison.

Neither the total 16 samples associated with salt structures nor the 7 samples in closer continuity with the salt dome show consistently anomalous water chemistry in comparison to the general trends observed for all the water chemistry analyses (fig. 41 and 42). The salt domes are presently not affecting the chemical composition of the brines. The conclusion is in agreement with the electric log SP interpretation of the Woodbine.

## HYDRAULIC POTENTIAL DISTRIBUTION, EAST TEXAS BASIN

### Introduction--Summary

The hydraulic potential distribution of the saline aquifers in the East Texas Basin has been evaluated by analysis of drill-stem test data. Based on these data, there appear to be two major hydrologic systems: the Upper Cretaceous aquifers and the Lower Cretaceous-Upper Jurassic Formations. The Lower Cretaceous-Upper Jurassic system may be a closed hydrologic system with some leakage into the overlying Paluxy Formation. In the upper aquifer system the Woodbine Formation has been depressurized because of extensive hydrocarbon production. It is doubtful whether fluid pressures in the Woodbine would return to natural levels in the near future.

### Methods of Analysis

Approximately 300 drill-stem pressure measurements were obtained from the files of Petroleum Information Corporation and scout cards (Appendix B). Final shut-in pressures have

## Table 10. Water Samples from Fields Near Salt Domes and Salt Pillows

| Sample | Depth (ft) | Depth to top of salt (ft) |
|---|---|---|
| VAN N | 1,200 | 12,000 |
| V. W | 2,900 | " |
| VAN GR | 7,230 | " |
| VAN R | 5,220 | " |
| B.C.1 | 3,600 | 3,000 |
| B.C.2 | 3,600 | " |
| N.W.1 | 4,704 | " |
| N.W.2 | 4,704 | " |
| H.W. | 9,776 | < 1,000 |
| C.W. | 4,404 | 5,000 |
| CAY.W1 | 4,030 | 16,000 |
| CAY.W2 | 4,030 | " |
| CAY.R | 7,460 | " |
| CAY.P | 7,550 | " |
| NWSW | 5,400 | 10,000 |
| HAW.W | 4,531 | 12,000 |
| HAW.R | 8,300 | " |
| B.D.ROD | 10,100 | < 1,000 |
| B.D.PET | 10,300 | " |
| OP.R | 8,630 | 14,000 |
| OP.P | 8,900 | " |
| OP.TP | 10,000 | " |
| G.S.R. | 8,200 | 0 |

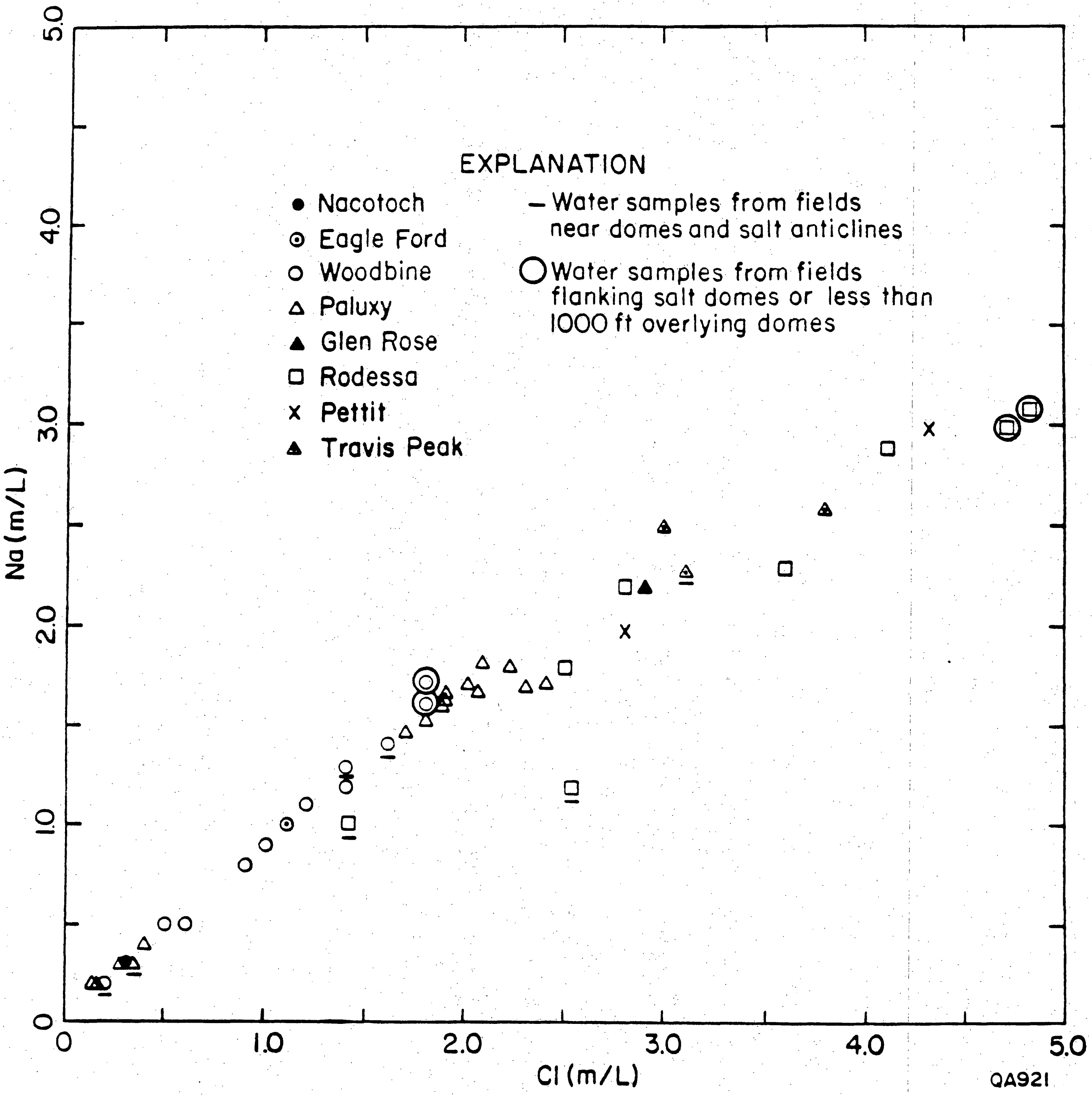

Figure 41. Effect of proximity to salt structures on water chemisty: Ca versus Cl. Data from Table 1.

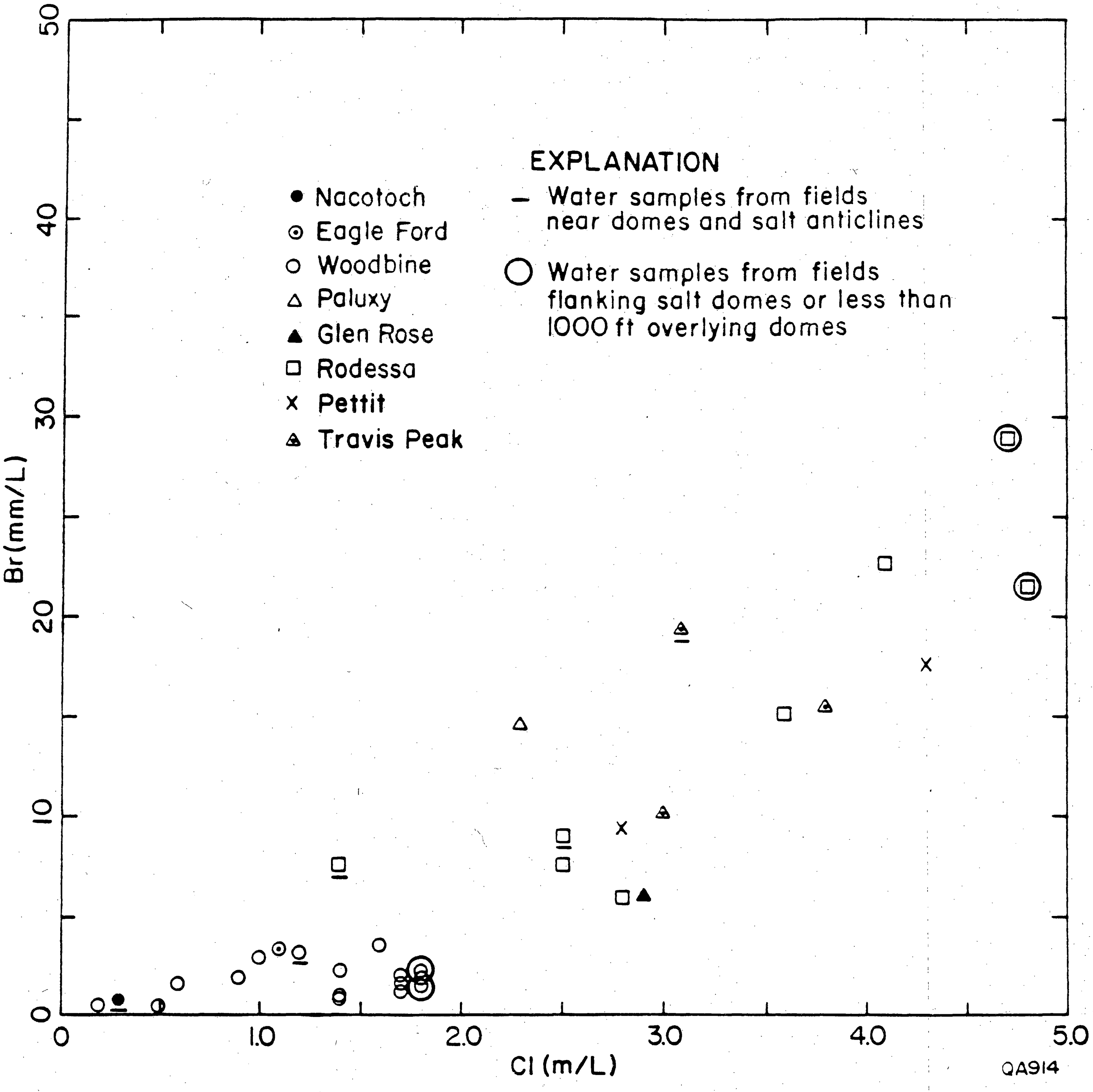

Figure 42. Effect of proximity to salt structures on water chemistry. Br versus Cl. Data from Table 1.

been plotted against depth (fig. 43). The quality of drill-stem test data is always suspect because of the normal difficulties in obtaining good tests. Optimally the test data should include the trace of the test, including an initial shut-in pressure (ISIP) and a final shut-in pressure (FSIP) (Bredehoeft, 1964). Too often, however, only the FSIP is recorded. This is true for the East Texas data. Only 11 out of 300 have both FSIP and ISIP. Fifty-five percent of these tests had FSIP within 10% of the ISIP. No traces of the actual test were available. Without this additional information the accuracy of the FSIP cannot be evaluated. Considering these constraints, it is recognized that the following discussion is based on a less than satisfactory data base.

## Results and Discussion

Two pressure-depth regimes are observed in the East Texas Basin. The Woodbine and shallower formations approach hydrostatic or are subhydrostatic (fig. 43). The lower pressures are the result of hydrocarbon production (Bell and Shepherd, 1951). In contrast, the deeper formations (Glen Rose, Travis Peak, Cotton Valley, Sligo, Buckner, and Smackover) are slightly overpressured (fig. 43) (gradient ≈ .6 psi/ft). Several tests in these deeper zones indicate underpressured conditions that probably have resulted from hydrocarbon production or represent faulty test data.

These two different pressure/depth regimes represent two major aquifer systems: (1) the hydrostatic Upper Cretaceous sandstones and limestones and (2) the slightly overpressured Lower Cretaceous and Upper Jurassic sandstone and limestone formations. The Upper Cretaceous hydrostatic system has better porosity, better permeability and is well interconnected through the basin, in comparison to the deeper formations. Average porosities for Woodbine and Paluxy are 25% and 12%, respectively (table 4). Hydrocarbon production from the Woodbine Formation in the East Texas Field has caused pressure declines in the Woodbine across the entire basin (Bell and Shepherd, 1951; fig. 44).

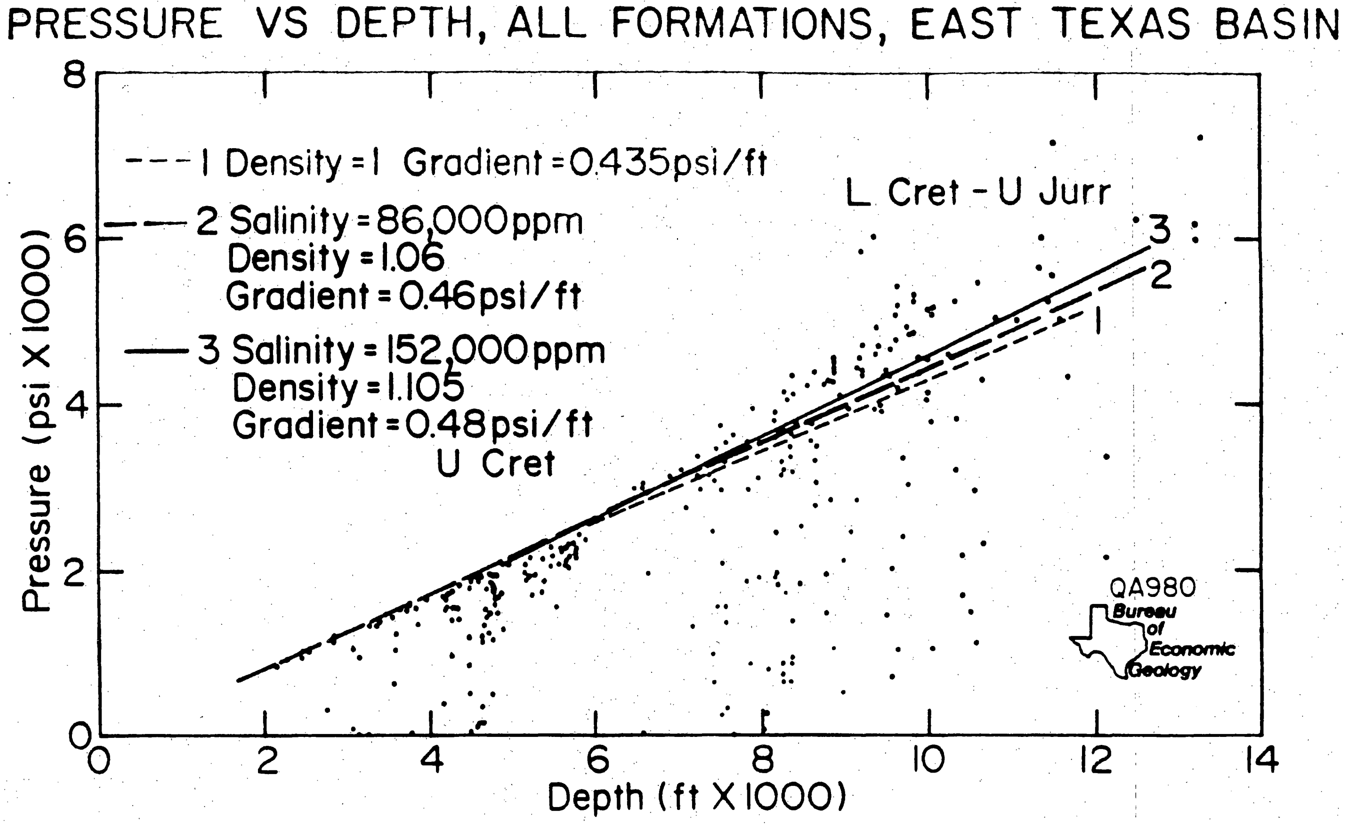

Figure 43. Pressure (psi) versus depth for saline aquifers, East Texas Basin. Data from Appendix B.

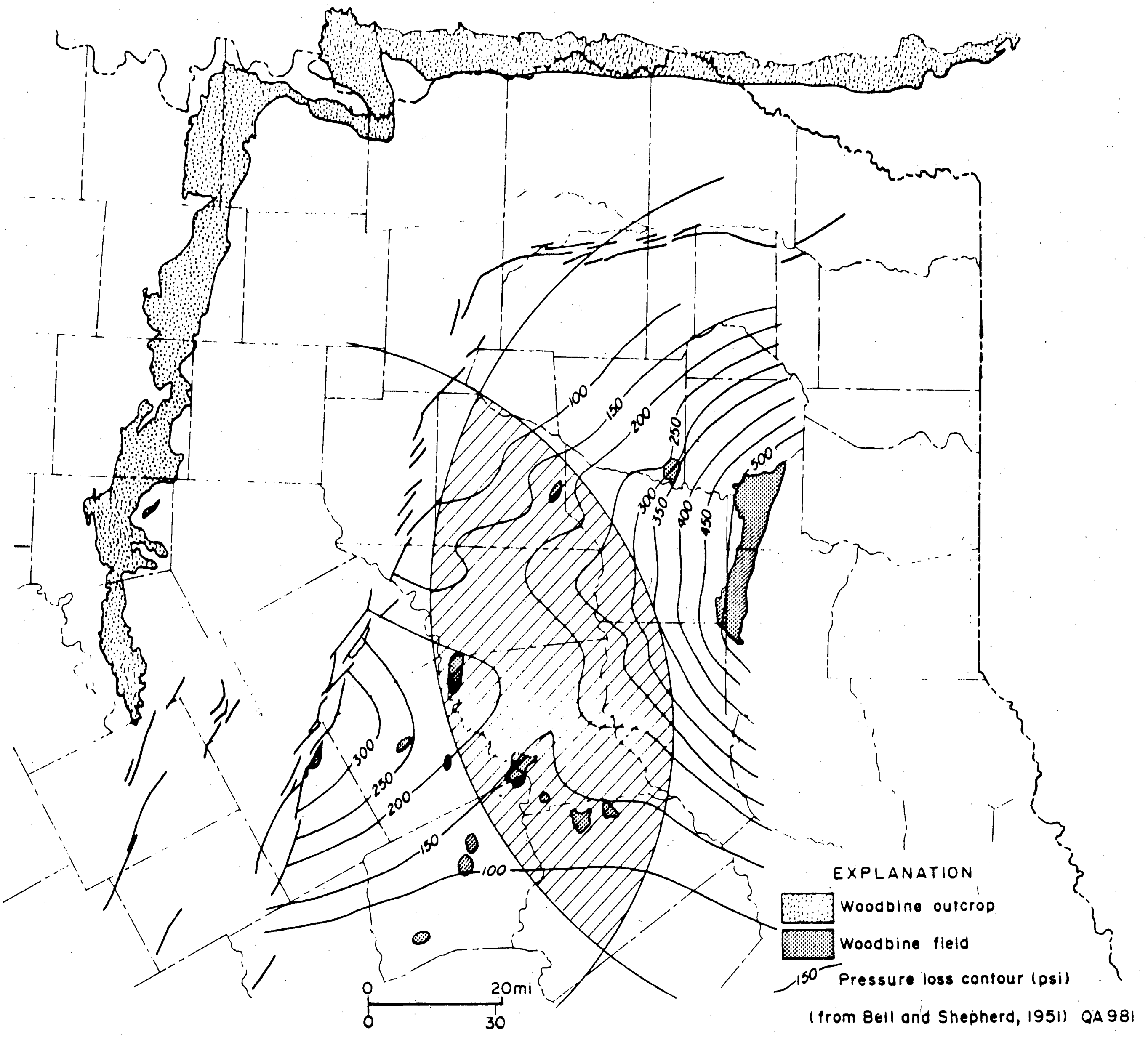

Figure 44. Estimated pressure declines in the Woodbine formation from oil production in East Texas field and the Mexia fold along the Mexia-Talco fault system (from Bell and Shepherd, 1951).

Presumed reasons for such widespread pressure declines are (1) highly permeable, laterally continuous sands; (2) low coefficient of specific storage, approximately 6 x $10^{-6}$ $m^{-1}$ based on values of compressibility for Woodbine core samples (Hall, 1953); (3) lack of lateral recharge owing to barrier boundaries caused by the Mexia-Talco fault zone along the west and north. The Mount Enterprise - Elkhart Graben fault zone along the south, and stratigraphic pinch-out of the Woodbine sand along the east basin margin; and (4) lack of vertical recharge owing to deep burial beneath low-permeability aquitard/aquiclude strata of the Midway and Navarro. The high permeability and low specific storage coefficients give a low diffusivity coefficient (Freeze and Cherry, 1979) which would allow pressure declines to spread a greater distance in a relatively short period of time.

With final depletion and abandonment of oil and gas production in the Woodbine it is doubtful whether fluid pressures would rapidly return to their preproduction levels. A downward vertical hydraulic gradient should remain between overlying fresh-water aquifers and the Woodbine for a long, but undetermined time.

The Lower Cretaceous-Upper Jurassic hydrostratigraphic system has lower porosities, probably lower pemeabilities and less interconnectedness. Average porosities in Glen Rose and Travis Peak are 8.5% and 7.0%, respectively. The overpressuring may result from continued compaction and a minimal leakage of waters into overlying formations. Overpressuring in deep Cretaceous carbonates (Sligo) has been observed in other localities of the Gulf of Mexico (Land and Prezbindowski, 1981). Its origin probably cannot be attributed to shale compaction or shale diagenesis as is the mechanism for the overpressured Tertiary section in the Gulf of Mexico, but may be related to continued compaction and recrystallization of carbonates and sandstones. The process is not understood. This lower hydrostratigraphic system may be a relatively closed system. If this system is an active hydrodynamic system, fluid pressures should have equilibrated to hydrostatic conditions. This interpretation is in agreement with the observation that there is a significantly different water chemistry between deep Lower Cretaceous formations and the Upper Cretaceous formations.

The Paluxy sandstone may be a mixing zone for the Upper Cretaceous hydrologic system and the deeper saline system. The Paluxy Formation was expected to have similar hydrology and geochemistry as the younger Woodbine Formation, because of its similar depositional character (terrigenous sandstone with reasonable interconnectedness) and its similar stratigraphic position (i.e., above the thick Glen Rose carbonates). The depth of the Paluxy pressure data (Appendix B) is where the pressure/depth slope starts rising above brine hydrostatic (fig. 43). The chemical composition of the Paluxy water is variable. Some of the waters are NaCl water, similar to Woodbine, whereas others are Na-Ca-Cl waters and appear intermediary between the chemical composition of Woodbine waters and Travis Peak or Glen Rose waters. The chemistry and hydrology suggest that waters from the Glen Rose and Travis Peak Formations are leaking into the Paluxy.

The data base is inadequate to construct potentiometric surfaces for any of the formations. Bell and Shepherd's (1950) surface is outdated since it was constructed in 1950 and there has been extensive production since then. Without potentiometric surfaces for individual formations or the major aquifer groupings, and without a better understanding of the hydrology, prediction of flow directions or flow velocities is not possible at this time.

## GENERAL HYDRODYNAMICS OF THE SALINE AQUIFERS, EAST TEXAS BASIN

### Introduction

A conclusion of the water chemistry and the pressure-depth discussions of this paper is that the basin has been relatively stagnant over long geologic time. This lack of an active hydrodynamic system is probably controlled by the general hydrologic conditions of the basin. No major tectonic event has uplifted and tilted the basin to establish effective recharge and dicharge zones or steep hydraulic gradients across the basin to facilitate flushing. The East Texas Basin is still largely below sea level. Sedimentary basins such as the Palo Duro, the San

Juan, the Paradox, and the Alberta Basins have all been uplifted by postdepositional tectonic events which have permitted continued flushing of earlier formation waters.

## Recharge to the East Texas Basin

Recharge to the saline formations in the East Texas Basin could be expected where these formations (e.g., Woodbine, Paluxy, Travis Peak (Hosston)) crop out. All the aquifers, however, crop out to the west of both the Balcones and the Mexia-Talco Fault Zones. These faults probably limit the recharge into the basin (Plummer and Sargent, 1931; Parker, 1969; Macpherson, 1982). The hydraulic gradient is either low or reversed, neither situation conducive for basin flushing. The hydraulic heads in the Glen Rose and deeper formations are significantly above land surface because of the slight overpressuring. Ground-water flow from outcrop downdip into the deep basin is not expected because of these high pressures in the saline formation. The Mexia-Talco fault system exhibits greater throw with depth because the faults were active through a broad range of time (Jackson, 1982). Because of the increased displacement with depth, the faults may function as more efficient impermeable barriers at greater depths. The Travis Peak and Glen Rose Formations may be more hydrologically isolated than the shallower Woodbine.

## Discharge from the East Texas Basin

A deep basin must have discharge zones as well as recharge zones for fluid movement to occur. The deep saline formations of the East Texas Basin do not have obvious regional discharge zones. There are no outcrops of Woodbine, Paluxy, Glen Rose or Travis Peak Formations on the eastern or southern sides of the basin, where discharge might occur. The only available avenues for discharge may be along faults or dome flanks located in topographically low areas (Fogg and Kreitler, 1982). The depressuring of the Woodbine formation by oil production has reduced or eliminated the discharge from the Woodbine into shallower aquifers.

## False Cap Rock at Butler Dome, An Example of Deep-Basin Discharge

Deep-basin ground-water discharge may have occurred along the flanks or associated radial faults of Butler Dome, Freestone County, East Texas. A calcite-cemented sandstone identified as "false cap rock" is being quarried from the flanks of Butler Dome. This false cap rock appears to have resulted from the oxidation of hydrocarbons in hot saline waters being discharged up the dome flanks. Saline springs were present over the dome before the depressuring of the Woodbine Formation occurred (DeGolyer, 1919; and Powers, 1920). The springs no longer exist.

Rocks exposed in the East Texas Stone Company's Blue Mountain Quarry on the NNE side of Butler Dome comprise the Eocene-Claiborne Carrizo and Reklaw Formations (fig. 45). Claiborne sediments dip away from the dome's center at a maximum of 25°NE, and are unconformably overlain by Quaternary terrace deposits. The Quaternary deposits reveal no evidence of warping due to dome uplift. A normal fault strikes N10° - 30°E, lateral to the western quarry wall, and dips 70°SE (fig. 46). Claiborne sediments are displaced about 1.5 m. In the quarry on the downthrown side of the fault, Carrizo sandstone is cemented with $CaCO_3$. Typically the Carrizo sandstone in the East Texas Basin is friable. This bell-ringing hard, calcite-cemented Carrizo represents an anomalous case. Sands on the upthrown side of the fault to the west are not cemented with $CaCO_3$. Large ellipsoid calcitic, pyritic concretions are scattered randomly through outcrop (fig. 47). Along the fault plane calcite has precipitated as fracture-filled veins (fig. 48). The fault appears to have been the primary path for fluid movement. At the eastern quarry wall, the calcareous sandstone gradually grades into an uncemented friable sand with only a few patches of $CaCO_3$ cemented sandstone. Some of the sand lenses within the shales and mudstone of the Reklaw Formation are also cemented with $CaCO_3$, but none of the Quaternary sands and gravels have $CaCO_3$ cement. This observation suggests that precipitation of the $CaCO_3$ cement occurred before Quaternary time or that the deeper discharging fluids could not rise any closer to land surface.

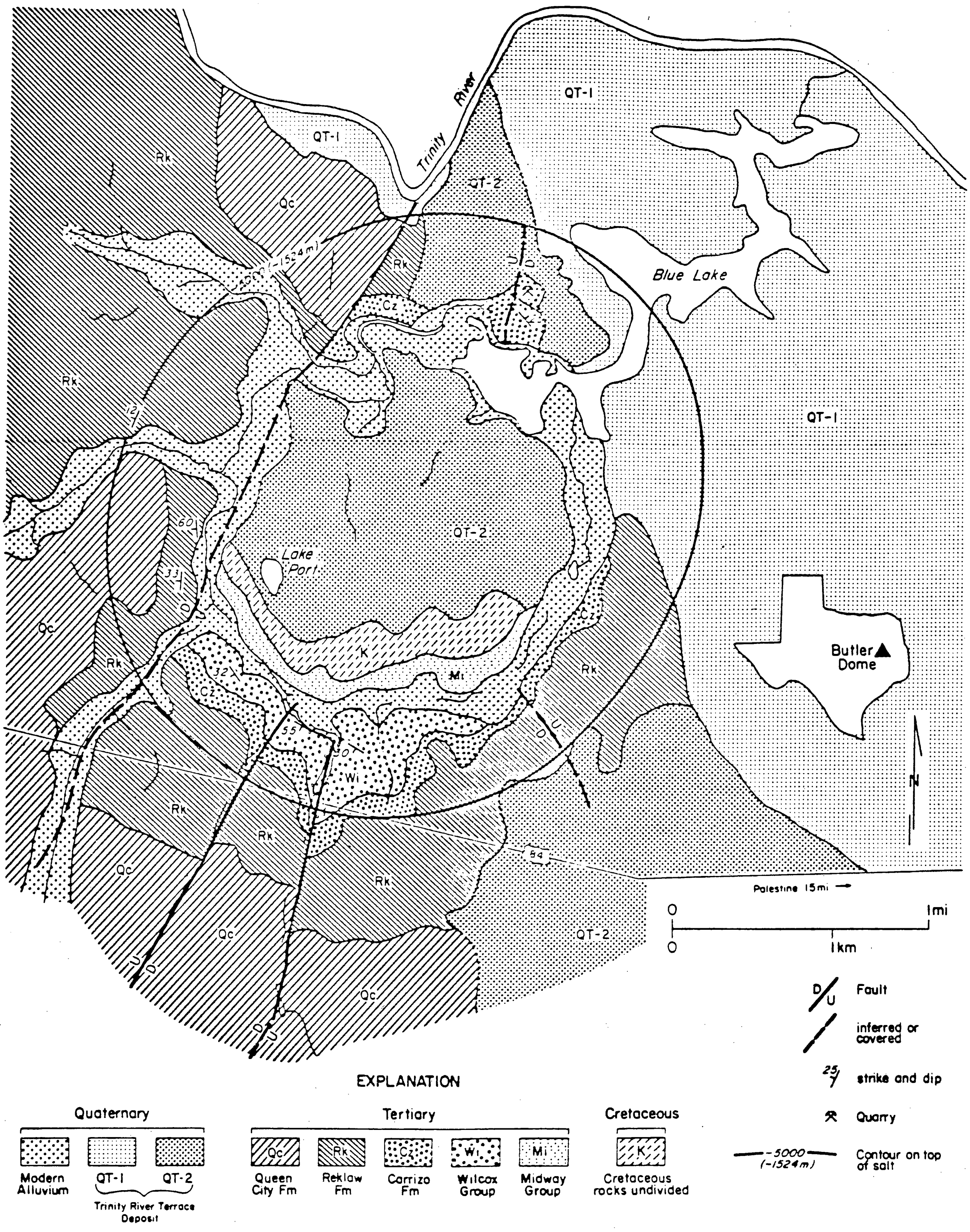

Figure 45. Geologic map of Butler dome, East Texas (modified from Barnes, 1967).

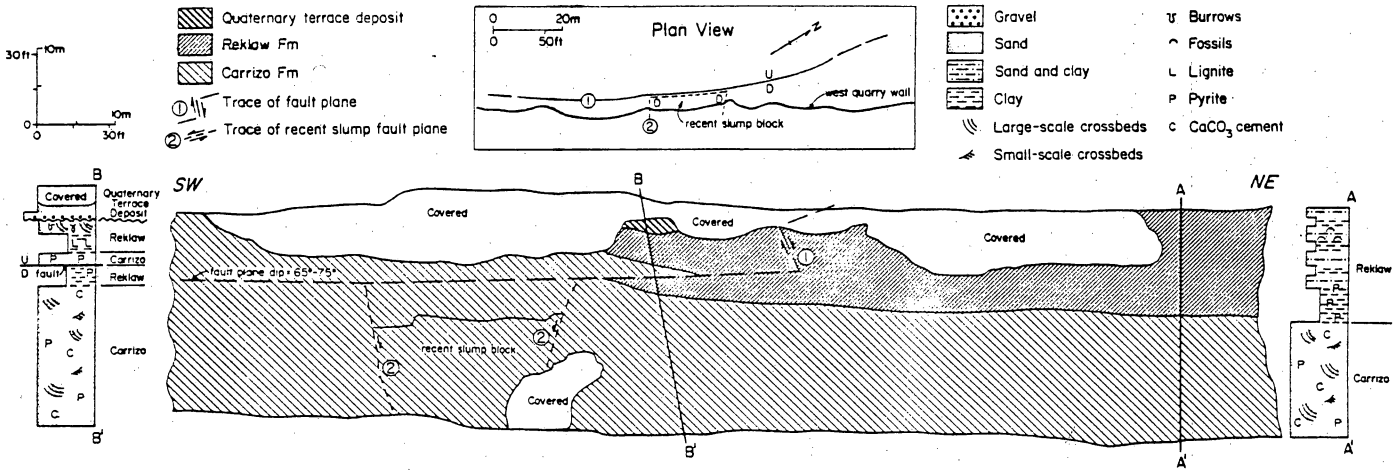

Figure 46. Cross section and map view of fault in Blue Mountain quarry on flank of Butler dome.

Petrographic analyses of these calcareous sandstone samples indicate that the quartz sand grains are cemented with some pyrite and more commonly sparry to prismatic calcite. Little of the original sandstone porosity exists and the cement is commonly poikilotopic (fig. 49). Replacement of the clastic grains by calcite and pyrite is common.

The calcite cement appears to result from oxidation of hydrocarbons by the reaction:

$$CaSO_4 + CH_4 \rightleftarrows H_2S + CaCO_3 + H_2O$$

The $\delta^{13}C$ values of the cements range from -20 to -32 (table 11 and fig. 50), indicative of a hydrocarbon source for the carbon (Feely and Kulp, 1957; Kreitler and Dutton, 1983). The $\delta^{18}O$ values of calcite cements ranged from -8.2 to -9.4%, which is considered to be indicative of calcite precipitation from a hot water. Kreitler and Dutton (1983) observed $\delta^{18}O$ values for Oakwood Dome cap rock in the range of -9 to -11$^{o}$/oo. Similar depleted $\delta^{18}O$ values (-8.6 to -10$^{o}$/oo) were measured for the calite cap rock at Vacherie Dome (Smith and Kolb, 1981). In contrast, the calcite concretions on the uncemented northern side of the fault ranged from -3.4 to -4.1$^{o}$/oo, which is considered to be indicative of calcite precipitation from shallow ground water.

Both DeGolyer (1919) and Powers (1920) observed brine and sulfurous springs over the dome and attributed them to waters rising from great depths. The springs were used intermittently for salt since the Civil War. The springs could not be found in 1980, and it is assumed that depressuring of the Woodbine has stopped spring flow. The combined evidence of saline springs and the presence of the false cap rock at the dome indicate that faults surrounding the dome have functioned as recently as the early 1900's as conduits for deep-basin discharge.

Palestine salt dome, 5 miles to the north of Butler dome, may also have false cap rock associated with its outcrops of Carrizo sandstone which surround the dome and are highly cemented. Petrographic analysis identified a poikilotopic calcite cement similar to the cementation observed at Butler dome.

Table 11. Isotopic composition of calcite-cemented Carrizo Sandstone, Butler Salt Dome.

Calcite-cemented Carrizo sandstone from southern side of fault.

| Sample No. | $\delta^{13}C$% | $\delta^{18}O$% |
|---|---|---|
| 1 | -29.2 | -8.4 |
| 2 | -22.1 | -8.2 |
| 3 | -28.8 | -8.5 |
| 4 | -25.8 | -8.2 |
| 5 | -26.6 | -8.0 |
| 6 | -30.5 | -8.7 |
| 7 | -24.9 | -8.9 |
| 8 | -31.5 | -8.5 |
| 9 | -32.2 | -8.5 |
| 10 | -25.4 | -9.4 |
| 11 | -21.9 | -8.9 |
| 12 | -27.2 | -8.8 |
| 13 | -25.6 | -8.3 |
| 14 | -31.1 | -8.6 |
| 15 | -20.1 | -8.7 |
| 16 | -23.6 | -8.3 |

Calcite-cemented concretion from northern side of fault.

| Sample No. | $\delta^{13}C$% | $\delta^{18}O$% |
|---|---|---|
| C1 | -23.4 | -3.4 |
| C2 | -24.7 | -3.5 |
| C3 | -19.1 | -4.1 |
| C4 | -19.0 | -4.1 |

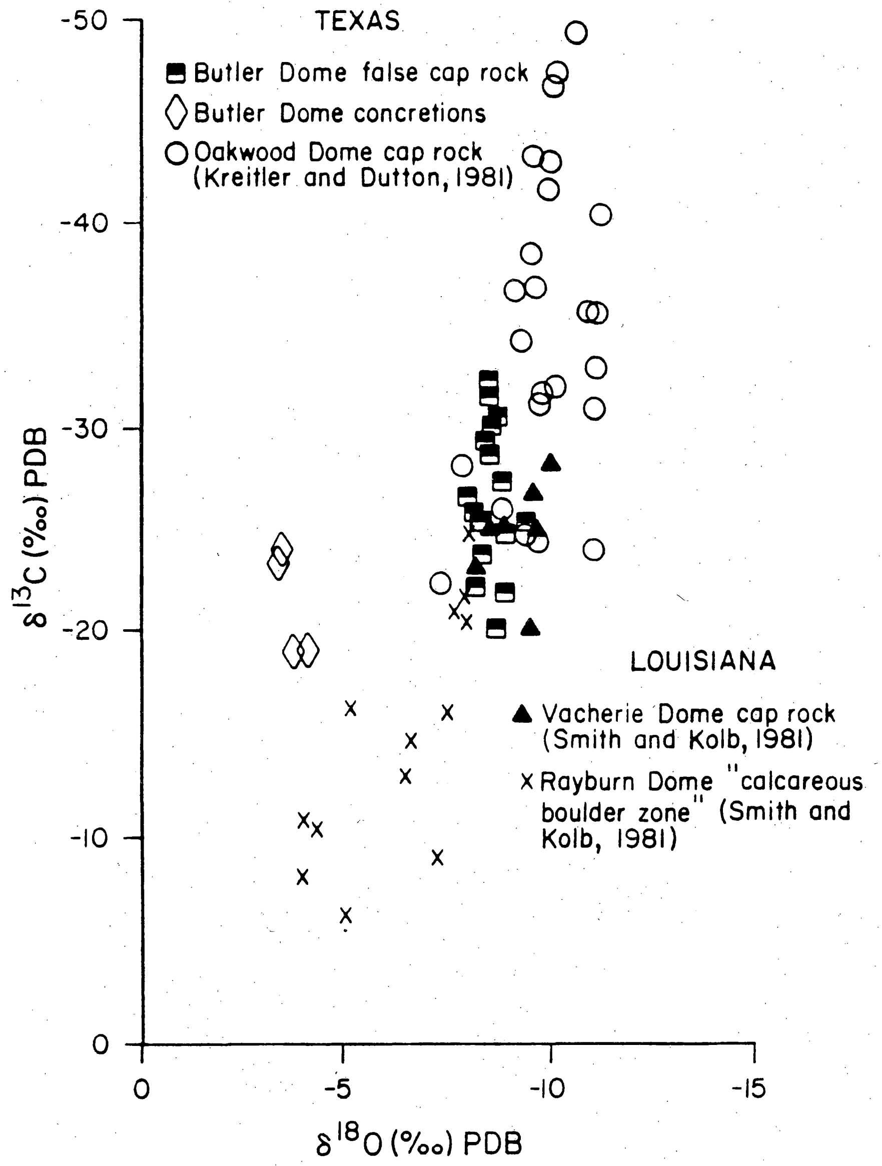

Figure 50. Oxygen ($\delta^{18}O$) and carbon ($\delta^{13}C$) isotopic composition of calcite cements from cemented Carrizo sandstones and calcite concretions from Blue Mountain Quarry (Butler Dome) and other calcites associated with salt domes. Data in Table 11. Location of samples from cemented Carrizo sandstone shown in Figure 51.

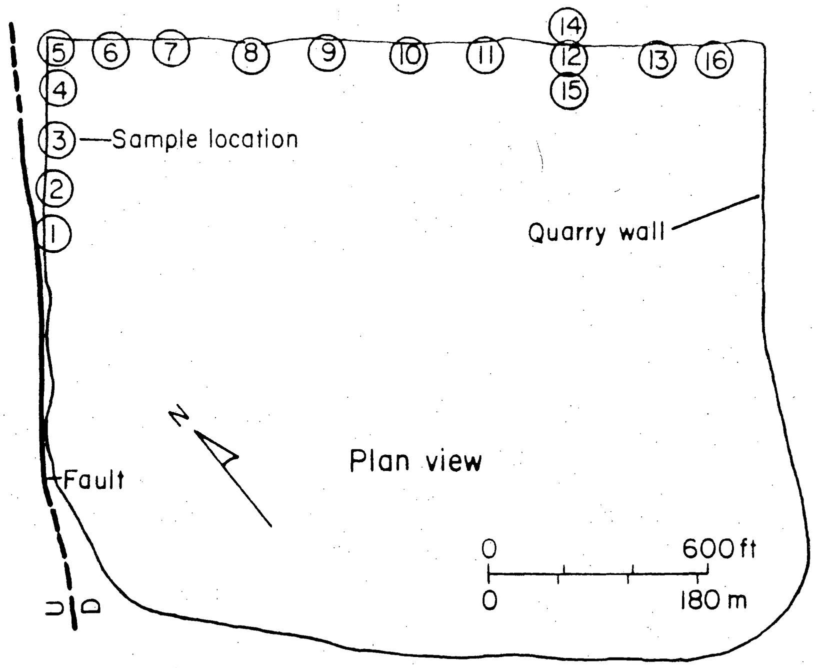

Figure 51. Location of cemented Carrizo Sandstone sampled in Blue Mountain Quarry for carbon and oxygen isotopic analyses.

These are the only domes in the East Texas Basin where false cap rocks have been observed. It is interesting to note that they are located in a low of the Carrizo-Wilcox potentiometric surface. The incision of the Trinity River into the Carrizo has caused this depression in the potentiometric surface (Fogg and Kreitler, 1982). Areas of low hydraulic head in the shallow aquifers could be regional discharge points for the saline aquifers. Only in such areas would the potentials in the shallow fresh-water aquifers be low enough for deep basinal discharge.

## SUMMARY--WASTE ISOLATION IMPLICATIONS

Ground waters in the deep aquifers (Nacatoch to Travis Peak) range in salinity from 20,000 to over 200,000 mg/l. Based on their isotopic compositions, they were originally recharged as continental meteoric waters. Recharge probably occurred predominantly during Cretaceous time; therefore, the waters are very old. The Mexia-Talco fault system on the northern and western sides of the basin probably limit recharge to the basin. Because the basin has not been uplifted and eroded, there are no major discharge zones. The flanks of domes and radial faults associated with domes may function as localized discharge points. Both the water chemistry and the hydraulic pressures for the aquifers indicate two major aquifer systems: (1) the upper Cretaceous aquifers (Woodbine and shallower) which are hydrostatic and (2) the deep lower Cretaceous and deeper formations (Glen Rose, Travis Peak, and older units), which are slightly overpressured.

The source of sodium and chloride in the saline waters is considered to be from salt dome dissolution. Mass-balance equations indicate there has been extensive dissolution of the domes and the amount of dissolution is greater than presently exists in the formations. Most of the dissolution probably occurred during the Cretaceous. The timing of major dissolution has been estimated by determining when salt withdrawal basins surrounding the domes were formed. Chlorine-36 analyses suggest that dome solution is not presently occurring. Salinity cross sections across individual domes do not indicate that ongoing solution is an important process.

The major chemical reactions in the saline aquifers are dome dissolution, albitization, and dedolomitization. Albitization and dedolomitization are important only in the deeper formations. The high Na concentrations in the deeper aquifers system results in the alteration of plagioclase to albite and the release of Ca into solution. The increase in Ca concentrations causes a shift in the calcite/dolomite equilibrium. Dolomite should dissolve resulting in the observed increase in Mg. These conclusions on the dominant chemical reactions are based on the analysis of the water chemistry. Petrographic and geochemical studies of the mineral assemblages are needed to confirm these observations.

The critical factors in the utilization of salt domes for disposal of high-level nuclear waste is whether the wastes could leak from a candidate dome and where they would migrate. Salt domes under investigation in the East Texas, Louisiana, and Mississippi basins are in contact with both fresh and saline aquifers. The potential for dome dissolution and radionuclide migration needs to be considered for both systems. The saline aquifers need to be studied because a potential repository would be located at a depth adjacent to saline rather than freshwater formations. This study has addressed the problems of dome dissolution in the saline aquifers and the general hydrologic characteristics of the saline formations. The following conclusions are applicable to the problem of waste isolation in salt domes.

(1) Salt domes in the East Texas Basin have extensively dissolved. The NaCl in the saline aquifers is primarily from this process. Major dissolution, however, probably occurred in the Cretaceous time. There is little evidence for ongoing salt dome dissolution in the saline aquifers.

(2) If there was a release to a saline aquifer, waste migration would either be along the dome flanks or laterally away from the dome. If there is a permeability conduit along the dome flanks, then contaminants could migrate to the fresh-water aquifers. The migration of saline fluids to the surface is dependent on two factors: (a) Is the hydraulic head in saline aquifer high enough to cause flow at the surface or into shallow aquifers? A potential repository in a salt dome would probably be located at a depth adjacent to the hydrostatic-subhydrostatic aquifer

system. The present depressuring of the Woodbine Formation would probably prevent flow to the surface. (b) Is the hydraulic head in the shallow fresh-water aquifers depressed in the domal area? Upward fluid migration is dependent on the potential in the shallow aquifers as well as the potential in the saline systems. Potentiometric levels in the shallow East Texas aquifers are controlled primarily by topography. The lower the elevation of land surface, the lower will be the level of the potentiometric surface. Salt domes located in regionally topographically low areas (e.g., river valleys) probably have a greater chance for fluid flow up their dome flanks than salt domes located in areas with higher topography. If contaminants migrated laterally into the deep-basin aquifers, they probably would not reach the biosphere. The deep-basinal fluids appear relatively stagnant. The waters are probably very old, and there are no major discharge points from the basin. There is, however, no way to predict flow paths or travel times because there are insufficient data to construct potentiometric maps. Calculation of performance assessment scenarios should use the worst-case scenario of leakage along the flanks of the candidate dome. From this perspective then, a critical unknown is the direction and potential for vertical flow between the Woodbine and shallow Tertiary aquifers, and, in turn, whether cessation of oil and gas production from the Woodbine will reverse the vertical hydraulic gradient from downward to upward within the life of a nuclear waste repository.

(3) The observations and conclusions in this paper are based on information obtained for the East Texas Basin. It is expected that the research approach and general conclusions would be similar for the North Louisiana and Mississippi Basin. Detailed investigations would be needed to confirm the applicability of East Texas Basin results to other basins.

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## Appendix A. Chemical composition of saline waters, East Texas Basin, from previously published data (Hawkins and others, University of Oklahoma, 1980).

East Texas Waste Isolation

Deep Basin Hydrology

| Field | County | Depth | Constituents, Mg/liter |  |  |  |  |  |  | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl |  |  |  |
| NACATOCH (KGNA) |  |  |  |  |  |  |  |  |  |  |  |  |
| Calvert | Robertson | 2,132-2,235 | 340 | 130 | 11,600 | 17 | 1,186 | 8 | 18,100 | 1.024 | .211 | 31,364 |
|  |  | 2,136-2,224 | 300 | 130 | 10,972 | 20 | 1,043 | 30 | 17,200 | 1.023 | .222 | 29,675 |
|  |  | 2,182-2,212 | 200 | 100 | 8,978 | 21 | 1,659 | 35 | 13,500 | 1.020 | .262 | 24,472 |
| Combest | Navarro | 682-730 | 340 | 105 | 6,670 | 3 | 451 | 42 | 10,900 | 1.016 | .354 | 18,508 |
| Edens | Navarro | 800-858 | 250 | 70 | 6,836 | 0 | 290 | 568 | 10,600 | 1.017 | .342 | 18,614 |
| Lone Star (Ponta) | Cherokee | 3,300 | 930 | 230 | 17,738 | - | 606 | 122 | 29,222 | 1.035 | .135 | 48,848 |
| McCrary | Wood | 2,300 | 355 | 97 | 11,320 | - | 208 | 0 | 18,250 | 1.022 | .210 | 30,230 |
| Merigale-Paul | Wood | 2,240-2,245 | 364 | 95 | 11,170 | - | 215 | 0 | 18,025 | 1.022 | .201 | 29,869 |
| Mildred | Navarro | 795-822 | 300 | 100 | 6,400 | 3 | 159 | 43 | 10,600 | 1.016 | .337 | 17,602 |
|  |  | 888-946 | 410 | 30 | 7,300 | 3 | 253 | 27 | 11,900 | 1.017 | .333 | 19,920 |
|  |  | 930-1,010 | 300 | 100 | 6,900 | 0 | 149 | 44 | 11,300 | 1.016 | .347 | 18,793 |
| Pleasant Grove (Shallow) | Rusk | 2,970-2,996 | 600 | 120 | 18,900 | 0 | 201 | 0 | 30,500 | 1.043 | .148 | 50,321 |
|  |  | 2,970-3,000 | 1,302 | 138 | 19,600 | - | 847 | 0 | 32,500 | 1.041 | .128 | 54,387 |
|  |  | 2,970-3,000 | 1,314 | 126 | 19,900 | - | 878 | 0 | 32,600 | 1.042 | .128 | 54,818 |
| Reiter | Freestone | 963-967 | 250 | 100 | 7,295 | 4 | 287 | 23 | 11,800 | 1.017 | .325 | 19,755 |
|  |  | 976-1,027 | 150 | 70 | 4,286 | 0 | 287 | 16 | 6,900 | 1.016 | .547 | 11,709 |
| Reiter, N. | Navarro | 712-758 | 150 | 110 | 6,814 | 4 | 482 | 19 | 10,800 | 1.017 | .320 | 18,375 |
|  |  | 738-744 | 300 | 120 | 7,373 | 3 | 390 | 32 | 12,000 | 1.017 | .315 | 20,215 |
| Rice | Navarro | 594-678 | 160 | 45 | 11,550 | 3 | 180 | 32 | 18,100 | 1.024 | .220 | 30,067 |
|  |  | 628-648 | 920 | 220 | 10,640 | 4 | 448 | 23 | 18,400 | 1.025 | .212 | 30,651 |
| Van | Van Zandt | 1,246 | 275 | 105 | 8,216 | - | 1,159 | 0 | 12,841 | 1.016 | .287 | 22,596 |
| Mildred | Navarro | 800-1,000 | 406 | 51 | 3044 | 101 | - | - | - |  |  | 20,100 |
| Rice | Navarro | 1,200 | 511 | 102 | 6,132 | 204 | - | - | - |  |  | 30,800 |
|  |  | 1,200 | 0 | 72 | 5,110 | 307 | - | - | - |  |  | 30,200 |
| Van | Van Zandt | 825 | 512 | 205 | 819 | 20 | - | - | - |  |  | 23,400 |
| WOLFE CITY (KGWC) |  |  |  |  |  |  |  |  |  |  |  |  |
| Corsicana | Navarro | 986-1,027 | 900 | 270 | 12,100 | 0 | 143 | 50 | 20,900 | 1.027 | .190 | 34,363 |
|  |  | 1,023-1,046 | 900 | 290 | 11,900 | 6 | 165 | 38 | 20,600 | 1.027 | .188 | 33,893 |

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | | | |
| | | | | | WOLFE CITY (KGWC) continued | | | | | | | |
| | | 1,055-1,105 | 900 | 270 | 11,900 | 10 | 159 | 49 | 20,600 | 1.027 | .192 | 33,878 |
| Powell | Navarro | 1,483-1,545 | 700 | 175 | 11,930 | 15 | 555 | 30 | 19,800 | 1.026 | .197 | 33,190 |
| | | 1,604-1,679 | 850 | 230 | 10,646 | 12 | 268 | 48 | 18,400 | 1.026 | .197 | 30,442 |
| | | 1,628-1,687 | 1,000 | 290 | 12,800 | 15 | 159 | 58 | 22,200 | 1.028 | .179 | 36,507 |
| | | | | | TOKIO (KGA) | | | | | | | |
| Marion County Shallow | Marion | 2,300 | 960 | 271 | 11,800 | 7 | 206 | 28 | 20,500 | 1.026 | .193 | 33,765 |
| | | 2,400 | 1,060 | 339 | 15,700 | 0 | 49 | 18 | 27,000 | 1.033 | .153 | 44,166 |
| | | | | | SUB-CLARKSVILLE (EAGLE FORD) (KGEF) | | | | | | | |
| Alba | Wood | 4,275 | 1,236 | 271 | 27,589 | - | 872 | 14 | 44,996 | | | 74,979 |
| | | 4,074-4,105 | 42 | 21 | 4,218 | 42 | - | - | - | | | 80,900 |
| | | 4,057-4,082 | 1,430 | 309 | 28,300 | - | 944 | 32 | 46,492 | | | 77,507 |
| Alba | Wood | 4,110-4,144 | 1,200 | 140 | 18,800 | 0 | 213 | 0 | 40,800 | 1.049 | .103 | 61,153 |
| | | 4,113-4,133 | 1,260 | 338 | 25,335 | - | 1,129 | 30 | 41,600 | 1.050 | .100 | 69,692 |
| | | 4,189-4,240 | 1,800 | 600 | 24,200 | 50 | 128 | 64 | 44,000 | 1.052 | .103 | 70,792 |
| Camp Hill | Anderson | 5,106 | 2,304 | 656 | 31,201 | - | 660 | 331 | 53,494 | 1.063 | .081 | 88,646 |
| | | 5,192 | 2,320 | 474 | 32,043 | - | 403 | 67 | 54,613 | 1.064 | .081 | 89,920 |
| Coke | Wood | 4,053-4,142 | 1,400 | 140 | 25,800 | 0 | 439 | 0 | 42,500 | 1.054 | .103 | 70,279 |
| | | 4,095-4,131 | 1,185 | 484 | 25,700 | 10 | 378 | 0 | 42,900 | 1.053 | .101 | 70,647 |
| Como | Hopkins | 3,970-3,977 | 1,500 | 12 | 29,200 | 0 | 275 | 0 | 47,500 | 1.051 | .106 | 78,487 |
| | | 4,028-4,034 | 1,300 | 250 | 24,200 | 0 | 92 | 181 | 40,100 | 1.051 | .106 | 66,123 |
| Deu Pree | Wood | 4,994-5,014 | 1,700 | 560 | 30,300 | 0 | 537 | - | 51,000 | 1.062 | .087 | 84,097 |
| Grapeland | Houston | 5,873-5,879 | 1,700 | 760 | 28,400 | 1 | 85 | 0 | 48,900 | 1.061 | .086 | 79,845 |
| | | 5,875-5,880 | 1,500 | 200 | 29,600 | 0 | 18 | 0 | 48,900 | 1.060 | .086 | 80,218 |
| | | 5,888-5,892 | 1,700 | 740 | 27,700 | Trace | 18 | 0 | 48,800 | 1.063 | .085 | 78,958 |
| Forest Hill | Wood | 4,479-4,495 | 1,540 | 340 | 30,147 | 17 | 1,013 | 19 | 49,600 | 1.057 | .091 | 82,659 |
| | | 4,350-4,400 | 1,283 | 261 | 28,075 | - | 560 | 41 | 45,980 | 1.055 | .093 | 76,200 |

SUB-CLARKSVILLE (EAGLE FORD) (KGEF) continued

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | | | |
| McCrary | Wood | 4,350-4,418 | 1,367 | 282 | 28,676 | 0 | 298 | 62 | 47,377 | | | 78,217 |
| | | - | 1,310 | 254 | 29,317 | - | 643 | 54 | 47,966 | | | 79,603 |
| | | - | 1,198 | 286 | 28,928 | - | 408 | 18 | 47,304 | | | 78,141 |
| McCrary | Wood | 4,351-4,361 | 1,400 | 200 | 28,000 | 0 | 73 | 994 | 45,400 | 1.059 | .093 | 76,067 |
| | | 4,364-4,374 | 1,200 | 230 | 29,000 | 0 | 653 | Trace | 47,200 | 1.059 | .093 | 78,283 |
| | | 4,371-4,381 | 1,150 | 330 | 27,800 | 3 | 250 | 0 | 45,700 | 1.057 | .094 | 75,230 |
| | | 4,400-4,415 | 1,243 | 241 | 27,880 | - | 610 | 51 | 45,514 | 1.054 | .094 | 75,539 |
| | | 4,408-4,411 | 1,129 | 418 | 30,320 | - | 560 | 16 | 49,626 | | | 82,068 |
| | | - | 1,214 | 262 | 29,528 | - | 442 | 24 | 48,162 | | | 79,632 |
| | | - | 1,350 | 275 | 27,436 | - | 589 | 43 | 48,359 | | | 80,177 |
| | | 4,750-4,800 | 1,470 | 300 | 27,704 | - | 560 | 60 | 45,820 | 1.055 | .092 | 75,914 |
| | | 4,833-4,904 | 1,349 | 281 | 48,157 | 189 | 625 | 36 | 77,436 | | | 128,531 |
| | | - | 82 | 30 | 6,888 | - | 890 | Trace | 10,336 | | | 18,225 |
| Merigale-Paul | Wood | 4,750-4,800 | 1,395 | 305 | 28,766 | - | 444 | 55 | 47,410 | 1.056 | .090 | 78,375 |
| | | 4,755-4,813 | 1,600 | 340 | 31,521 | 12 | 1,025 | 43 | 51,800 | 1.060 | .087 | 86,329 |
| | | 4,766-4,868 | 1,600 | 360 | 33,730 | 13 | 970 | 37 | 55,300 | 1.060 | .087 | 91,997 |
| | | 4,860 | 1,750 | 380 | 32,546 | 14 | 842 | 7 | 53,900 | 1.063 | .085 | 89,425 |
| Manziel | Wood | 4,003-4,042 | 2,000 | 230 | 25,500 | 8 | 378 | 123 | 43,300 | 1.057 | .093 | 71,531 |
| | | 4,039-4,060 | 1,700 | 350 | 29,100 | 24 | 55 | 0 | 48,900 | 1.057 | .090 | 80,105 |
| | | 4,041-4,067 | 1,500 | 500 | 29,400 | 0 | 427 | 370 | 48,900 | 1.060 | .090 | 81,097 |
| Manziel | Wood | 4,041-4,169 | 1,578 | 351 | 29,767 | - | 628 | 0 | 49,350 | | | 81,677 |
| | | 4,045-4,060 | 1,223 | 346 | 30,575 | - | 379 | 0 | 50,099 | 1.060 | .085 | 82,622 |
| Midway Lake | Wood | 4,476-4,550 | 1,700 | 500 | 27,000 | 18 | 726 | - | 45,700 | 1.057 | .093 | 75,626 |
| | | 4,513-4,563 | 1,800 | 450 | 26,500 | 84 | 671 | - | 45,000 | 1.057 | .093 | 74,421 |
| | | 4,534-4,550 | 1,800 | 400 | 28,900 | 8 | 500 | - | 44,300 | 1.058 | .090 | 75,900 |
| Neches | Anderson | 4,584-4,640 | 3,087 | 563 | 33,890 | - | 254 | 1 | 67,000 | 1.078 | .075 | 104,795 |
| | | 4,591-4,595 | 4,300 | 560 | 42,100 | 0 | 298 | 0 | 74,000 | 1.082 | .070 | 121,258 |
| | | 4,665-4,669 | 2,600 | 700 | 35,500 | 0 | 49 | 0 | 61,600 | 1.074 | .074 | 100,449 |
| Pine Mills | Wood | 4,700-4,800 | 1,490 | 302 | 31,418 | - | 799 | 1,000 | 50,750 | 1.060 | .086 | 85,759 |
| | | 4,700-4,800 | 1,421 | 322 | 30,406 | - | 756 | 40 | 49,850 | 1.060 | .087 | 82,795 |
| | | 4,700-4,800 | 1,382 | 312 | 28,612 | - | 780 | 48 | 47,000 | 1.060 | .092 | 78,134 |

SUB-CLARKSVILLE EAGLE FORD (KGEF) continued

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | | | |
| | | 4,710-4,776 | 1,500 | 230 | 29,300 | 0 | 397 | - | 48,200 | 1.062 | .088 | 79,627 |
| | | 4,797-4,802 | 1,800 | 660 | 27,700 | 0 | 500 | - | 47,500 | 1.058 | .092 | 78,160 |
| Newsome | Camp | 3,850-3,872 | 1,300 | 300 | 25,900 | 0 | 463 | - | 42,900 | 1.054 | .100 | 70,863 |
| | | 3,870-3,875 | 1,400 | 400 | 25,900 | 0 | 366 | 0 | 43,300 | 1.054 | .099 | 71,366 |
| Nolan Edwards | Wood | 4,714-4,744 | 612 | 364 | 27,752 | - | 1,215 | 14 | 44,200 | 1.054 | .099 | 74,157 |
| | | 4,658-4,672 | 1,300 | 330 | 26,852 | 10 | 1,092 | 44 | 44,000 | 1.052 | .098 | 73,618 |
| | | 4,692-4,695 | 1,200 | 300 | 27,216 | 9 | 1,098 | 35 | 44,300 | 1.053 | .097 | 74,149 |
| | | 4,763-4,767 | 1,200 | 320 | 27,448 | 9 | 1,122 | 40 | 44,700 | 1.053 | .098 | 74,830 |
| Pine Mills, E. | Wood | 4,760-4,764 | 2,000 | 740 | 22,100 | 0 | 110 | - | 39,700 | 1.059 | .090 | 64,650 |
| | | 4,782-4,786 | 2,000 | 700 | 18,900 | 0 | 92 | - | 34,700 | 1.059 | .090 | 56,392 |
| Quitman | Wood | 4,018-4,217 | 1,657 | 415 | 32,136 | - | 453 | 24 | 53,414 | | | 88,102 |
| | | - | 2,104 | 638 | 32,867 | - | 382 | 24 | 56,028 | | | 92,046 |
| | | 4,018-4,217 | 2,761 | 239 | 31,692 | - | 764 | 8 | 53,996 | | | 89,461 |
| | | - | 1,604 | 462 | 33,231 | - | 451 | 16 | 55,156 | | | 90,929 |
| | | - | 2,367 | 638 | 31,708 | - | 384 | 0 | 54,866 | | | 90,197 |
| | | - | 2,367 | 558 | 13,590 | - | 344 | 13 | 26,562 | | | 43,435 |
| | | - | 2,367 | 558 | 30,818 | - | 344 | 13 | 53,124 | | | 87,225 |
| | | - | 1,841 | 239 | 27,681 | - | 810 | 13 | 46,156 | | | 76,744 |
| | | - | 1,420 | 383 | 27,888 | - | 843 | 0 | 46,156 | | | 76,718 |
| | | - | 1,841 | 319 | 26,416 | - | 800 | 9 | 44,416 | | | 73,864 |
| | | - | 1,841 | 399 | 27,939 | - | 808 | 9 | 47,028 | | | 78,028 |
| | | - | 1,631 | 399 | 32,552 | - | 390 | 24 | 53,996 | | | 88,993 |
| | | - | 2,630 | 558 | 31,336 | - | 540 | 5 | 54,286 | | | 89,366 |
| Quitman | Wood | - | 2,235 | 638 | 35,963 | - | 497 | 21 | 60,965 | | | 100,321 |
| | | - | 2,104 | 478 | 34,947 | - | 369 | 8 | 58,785 | | | 96,695 |
| | | - | 1,972 | 414 | 32,946 | - | 553 | 22 | 55,156 | | | 90,071 |
| | | - | 2,104 | 478 | 26,567 | - | 762 | 10 | 45,576 | | | 75,467 |
| | | - | 2,630 | 558 | 31,844 | - | 390 | 3 | 55,156 | | | 90,594 |
| | | - | 2,235 | 239 | 8,799 | - | 872 | 6 | 17,708 | | | 29,865 |
| | | - | 2,235 | 239 | 20,282 | - | 872 | 6 | 35,416 | | | 59,056 |
| | | - | 1,631 | 431 | 32,925 | - | 563 | 19 | 54,576 | | | 90,154 |

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | | | |
| | | | | | | SUB-CLARKSVILLE (EAGLE FORD) (KGEF) continued | | | | | | |
| | | - | 1,894 | 415 | 32,605 | - | 434 | 14 | 54,576 | | | 89,941 |
| | | - | 2,498 | 399 | 14,292 | - | 355 | 12 | 27,433 | | | 45,036 |
| | | - | 2,498 | 399 | 32,083 | - | 355 | 12 | 54,866 | | | 90,260 |
| | | - | 2,630 | 399 | 32,145 | - | 394 | 8 | 55,156 | | | 90,747 |
| | | - | 1,525 | 462 | 33,327 | - | 459 | 19 | 55,156 | | | 90,955 |
| | | - | 4,734 | 638 | 32,881 | - | 346 | 100 | 60,672 | | | 99,391 |
| | | - | 1,972 | 399 | 30,671 | - | 474 | 11 | 51,674 | | | 85,222 |
| | | - | 2,761 | 399 | 31,672 | - | 517 | 12 | 54,576 | | | 89,938 |
| | | - | 3,550 | 638 | 32,520 | - | 490 | 10 | 58,060 | | | 95,372 |
| | | - | 2,761 | 399 | 31,099 | - | 459 | 48 | 53,705 | | | 88,484 |
| | | - | 2,498 | 319 | 32,042 | - | 367 | 36 | 54,576 | | | 89,858 |
| | | - | 74 | 21 | 3,185 | 42 | - | - | - | | | 89,000 |
| Quitman | Wood | 4,232-4,252 | 1,474 | 205 | 31,415 | - | 137 | 21 | 51,287 | 1.061 | .083 | 84,539 |
| | | 4,370-4,395 | 891 | 159 | 28,239 | - | 746 | 0 | 45,133 | 1.054 | .093 | 75,168 |
| Reilly Springs | Hopkins | 4,272-4,275 | 1,467 | 230 | 29,788 | 253 | 642 | - | 49,236 | | | 81,838 |
| Shirley-Barbara | Wood | 5,534-5,540 | 1,700 | 540 | 28,300 | 0 | 444 | Trace | 47,900 | 1.058 | .090 | 78,884 |
| | | 5,552-5,556 | 3,400 | 660 | 32,700 | Trace | 603 | - | 58,500 | 1.070 | .080 | 95,863 |
| | | 5,474-5,488 | 2,116 | 194 | 35,100 | 0 | 390 | 47 | 58,150 | 1.067 | .083 | 95,997 |
| | | 5,600 | 2,370 | 389 | 34,500 | 13 | 695 | Trace | 58,060 | 1.069 | .083 | 96,014 |
| Slocum, N. | Anderson | 5,664-5,828* | 532 | 106 | 7,450 | 160 | - | - | - | | | 96,700 |
| Slocum, N. | Anderson | 5,710-5,720 | 1,900 | 900 | 28,300 | 0 | 268 | 302 | 49,200 | 1.065 | .086 | 80,870 |
| Slocum, S. | Anderson | 5,958 | 3,900 | 350 | 27,900 | Trace | 24 | 556 | 50,500 | 1.065 | .081 | 83,230 |
| Trix-Liz | Titus | 2,989-3,006 | 771 | 255 | 18,448 | - | 234 | 1 | 30,450 | 1.036 | .121 | 50,159** |
| Trix-Liz | Titus | 3,003 | 1,052 | 239 | 18,767 | - | 25 | 0 | 31,352 | | | 51,667 |
| | | - | 894 | 255 | 17,555 | - | 167 | 0 | 29,320 | | | 48,224 |
| | | - | 842 | 335 | 17,415 | - | 252 | 0 | 29,175 | | | 48,023 |
| | | - | 1,073 | 344 | 18,966 | 346 | 2,238 | 5 | 37,179 | | | 60,235 |
| Yantis | Wood | 4,172-4,196 | 1,700 | 800 | 31,100 | - | 244 | 123 | 53,200 | 1.059 | .092 | 87,167 |
| | | 4,185-4,195 | 2,400 | 330 | 27,700 | - | 48 | 0 | 47,900 | 1.053 | .102 | 78,378 |
| | | 4,192-4,225 | 2,000 | 16 | 29,400 | 0 | 79 | 0 | 48,900 | 1.053 | .102 | 80,395 |

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*Depth Range

**ppm

| Field | County | Depth | Constituents, Mg/liter |  |  |  |  |  |  | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl |  |  |  |
| COKER SAND (EAGLE FORD) (KGEF) |  |  |  |  |  |  |  |  |  |  |  |  |
| Como | Hopkins | 4,185 | 2,100 | 6 | 26,400 | 0 | 201 | 0 | 44,300 | 1.058 | .092 | 73,007 |
|  |  | 4,185 | 300 | 40 | 27,700 | 55 | 244 | - | 43,300 | 1.056 | .093 | 71,584 |
|  |  | 4,202 | 260 | 50 | 29,900 | 51 | 134 | 193 | 46,500 | 1.055 | .093 | 77,037 |
| MOORINGSPORT LS. (KCGRU) |  |  |  |  |  |  |  |  |  |  |  |  |
| Bethany, NE. | Panola | 3,871-3,877 | 3,034 | 430 | 16,382 | - | - | 1,785 | 30,406 | 1.038 | .132 | 52,037 |
|  |  | 3,900-3,914 | 3,944 | 919 | 14,398 | - | - | 1,753 | 30,406 | 1.037 | .132 | 51,420 |
| GOODLAND LS. (KCF) |  |  |  |  |  |  |  |  |  |  |  |  |
| Longwood | Harrison | 2,360-2,398 | 1,300 | 440 | 15,143 | 0 | 525 | 37 | 26,600 | 1.033 | .154 | 44,045 |
|  |  | 2,369-2,386 | 2,700 | 445 | 15,199 | 0 | 52 | 111 | 29,400 | 1.037 | .142 | 47,907 |
|  |  | 2,385-2,428 | 1,500 | 470 | 15,101 | 0 | 512 | 152 | 26,900 | 1.033 | .152 | 44,635 |
| Panola | Panola | 2,500 | 1,500 | 286 | 14,700 | 0 | 407 | 234 | 25,800 | 1.032 | .158 | 42,927 |
|  |  | 2,500 | 2,200 | 409 | 18,400 | 0 | 447 | 236 | 33,000 | 1.040 | .135 | 54,692 |
|  |  | 2,500 | 1,300 | 46 | 22,400 | Trace | 165 | 469 | 36,500 | 1.038 | .135 | 60,880 |
|  |  | 2,500 | 1,400 | 400 | 21,300 | 6 | 415 | 0 | 36,200 | 1.044 | .121 | 59,715 |
| Waskom | Harrison | 2,400 | 1,050 | 126 | 16,400 | 0 | 482 | 508 | 26,900 | 1.040 | .150 | 45,466 |
|  |  | 2,400 | 1,330 | 76 | 13,300 | 35 | 640 | 0 | 22,700 | 1.030 | .170 | 38,046 |
|  |  | 2,400 | 1,600 | 237 | 13,000 | 0 | 421 | 0 | 23,400 | 1.034 | .170 | 38,658 |
| BUDA LS. (KCW) |  |  |  |  |  |  |  |  |  |  |  |  |
| Deer Creek | Falls | 1,046-1,068 | 300 | 150 | 7,100 | 2 | 268 | 18 | 11,700 | 1.016 | .338 | 19,536 |
| Lott | Falls | 1,211 | 380 | 160 | 6,900 | 28 | 494 | 21 | 11,500 | 1.017 | .328 | 19,455 |
|  |  | 1,230-1,247 | 390 | 160 | 7,200 | 6 | 366 | 20 | 12,000 | 1.017 | .318 | 20,136 |
|  |  | 1,298 | 300 | 160 | 7,100 | 0 | 171 | 18 | 11,900 | 1.017 | .318 | 19,649 |
| FREDERICKSBURG LS. (KCF) |  |  |  |  |  |  |  |  |  |  |  |  |
| Shelbyville, E. | Shelby | 3,600 | 3,326 | 785 | 27,615 | - | 201 | 170 | 50,529 | 1.057 | .085 | 82,626 |

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | | | |
| WOODBINE (KGW) | | | | | | | | | | | | |
| Flagg Lake | Henderson | 3,018-3,024 | 172 | 70 | 8,439 | - | 695 | 2 | 13,120 | 1.018 | .275 | 22,498 |
| | | 3,042-3,056 | 140 | 78 | 8,419 | - | 1,196 | 3 | 12,765 | 1.017 | .280 | 22,601 |
| | | 3,090-3,095 | 280 | 100 | 10,949 | - | 506 | 9 | 17,375 | 1.021 | .266 | 29,219 |
| Good Omen | Smith | 3,950-3,954 | 1,600 | 230 | 25,900 | 0 | 634 | 231 | 43,000 | 1.052 | .099 | 71,595 |
| | | 3,960-3,962 | 1,500 | 315 | 26,200 | 0 | 573 | 201 | 43,500 | 1.052 | .099 | 72,289 |
| Grapeland | Smith | 6,076-6,087 | 4,267 | 594 | 35,454 | - | 153 | 80 | 63,823 | 1.074 | .072 | 104,371 |
| Grimes-Percilla | Smith | 5,880-5,900 | 4,087 | 585 | 38,601 | - | 250 | 104 | 68,259 | 1.076 | .069 | 111,886 |
| Gum Springs | Rusk | 3,649 | 800 | 190 | 16,800 | 0 | 232 | 0 | 27,700 | 1.036 | .150 | 45,722 |
| | | 3,673-3,714 | 800 | 70 | 16,000 | 0 | 256 | 0 | 26,200 | 1.031 | .170 | 43,326 |
| Ham Gossett | Kaufman | 3,401-3,406 | 670 | 75 | 16,500 | 19 | 37 | 0 | 26,900 | 1.034 | .145 | 44,182 |
| | | 3,637-3,644 | 394 | 72 | 18,000 | 1 | 451 | - | 28,400 | 1.034 | .143 | 47,317 |
| | | 3,704-3,710 | 388 | 68 | 17,900 | - | 433 | 29 | 28,000 | 1.037 | .145 | 46,818 |
| | | 3,267-3,271 | 480 | 175 | 14,100 | 0 | 262 | 0 | 23,000 | 1.033 | .172 | 38,017 |
| | | 3,421-3,423 | 240 | 68 | 14,000 | - | 586 | - | 22,200 | 1.028 | .174 | 37,094 |
| | | 3,983-4,030 | 530 | 93 | 14,600 | 22 | 427 | - | 23,400 | 1.040 | .168 | 39,050 |
| | | 5,780-5,785 | 5,900 | 1,984 | 35,400 | 0 | 92 | 948 | 70,000 | 1.084 | .071 | 114,324 |
| Ham Gossett, SE. | Kaufman | 3,252-3,257 | 400 | 24 | 13,600 | 0 | 183 | 0 | 21,600 | 1.028 | .182 | 35,807 |
| | | 3,256-3,265 | 370 | 96 | 13,000 | 0 | 500 | 0 | 20,700 | 1.029 | .185 | 34,666 |
| | | 3,238-3,244 | 593 | 82 | 14,700 | 0 | 531 | - | 23,600 | 1.029 | .175 | 39,506 |
| | | 3,240-3,245 | 237 | 70 | 14,000 | 0 | 488 | Trace | 22,000 | 1.027 | .178 | 36,795 |
| Hawkins | Wood | 4,600-4,650 | 2,850 | 530 | 35,668 | 3 | 406 | 206 | 61,200 | 1.070 | .073 | 100,860 |
| | | 4,790-4,810 | 2,750 | 460 | 35,333 | 0 | 470 | 157 | 60,300 | 1.071 | .073 | 99,470 |
| Hawkins | Wood | 4,818 | 2,750 | 480 | 35,243 | 3 | 290 | 191 | 60,300 | 1.069 | .075 | 99,254 |
| Jacksonville, N. | Cherokee | 4,371-4,372 | 1,740 | 390 | 30,900 | 0 | 537 | 204 | 51,400 | 1.060 | .087 | 85,171 |
| | | 4,383-4,402 | 1,860 | 400 | 31,632 | 0 | 470 | 216 | 52,800 | 1.062 | .085 | 87,378 |
| | | 4,432-4,455 | 1,810 | 400 | 30,550 | 0 | 628 | 16 | 51,100 | 1.060 | .087 | 84,504 |
| Jacksonville, W. | Cherokee | 4,841-4,844 | 1,500 | 640 | 37,289 | 4 | 491 | 181 | 61,600 | 1.073 | .075 | 101,701 |
| | | 4,963-4,968 | 3,200 | 600 | 35,195 | 5 | 519 | 243 | 61,200 | 1.070 | .076 | 100,957 |
| Kerens, S. | Navarro | 3,371-3,419 | 290 | 90 | 10,685 | 8 | 872 | 61 | 16,700 | 1.023 | .226 | 28,698 |
| | | 3,380-3,385 | 245 | 105 | 12,285 | - | 857 | 4 | 19,200 | 1.024 | .196 | 32,696** |

**ppm

|  |  |  | Constituents, Mg/liter |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field | County | Depth | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
| WOODBINE (KGW) continued |  |  |  |  |  |  |  |  |  |  |  |  |
| Lone Star (Ponta) | Cherokee | 3,906-3,932 | 3,500 | 660 | 29,100 | 0 | 31 | 456 | 52,700 | 1.068 | .077 | 86,447 |
|  |  | 3,978-3,980 | 3,500 | 780 | 29,400 | 0 | 37 | 216 | 53,600 | 1.068 | .077 | 87,533 |
| Long Lake | Anderson | 5,190-5,250 | 2,485 | 442 | 35,299 | 0 | 427 | 119 | 59,839 | 1.066 | .074 | 98,611 |
|  |  | 5,190-5,250 | 2,806 | 474 | 36,432 | - | 376 | 119 | 62,232 | 1.073 | .072 | 102,439 |
|  |  | 5,190-5,250 | 2,798 | 474 | 36,460 | 0 | 406 | 139 | 62,232 | 1.073 | .072 | 102,509 |
|  |  | 5,190-5,250 | 3,066 | 493 | 37,245 | 0 | 433 | 135 | 64,005 | 1.075 | .071 | 105,377 |
|  |  | 5,322-5,326 | 3,300 | 570 | 37,637 | 7 | 424 | 121 | 65,200 | 1.075 | .073 | 107,252 |
|  |  | 5,375-5,404 | 3,355 | 530 | 34,814 | - | 138 | 135 | 60,900 | 1.071 | .074 | 99,872 |
| Long Lake, E. | Anderson | 5,320-5,400 | 3,100 | 600 | 37,100 | Trace | 92 | 30 | 64,300 | 1.075 | .073 | 105,222 |
|  |  | 5,340-5,348 | 3,690 | 610 | 37,322 | 10 | 329 | 90 | 65,600 | 1.075 | .073 | 107,641 |
|  |  | 5,340-5,353 | 3,400 | 466 | 40,400 | 18 | 390 | 0 | 62,000 | 1.075 | .073 | 106,656 |
|  |  | 5,402-5,417 | 3,870 | 1,260 | 36,488 | 6 | 332 | 123 | 66,500 | 1.076 | .073 | 108,573 |
|  |  | 5,407-5,424 | 3,830 | 620 | 37,783 | 5 | 421 | 137 | 66,500 | 1.076 | .071 | 109,291 |
| Merigale-Paul | Wood | 5,237-5,488 | 3,100 | 500 | 35,700 | 2 | 110 | 5 | 62,000 | 1.073 | .076 | 101,415 |
| Mexia | Limestone | 2,931-3,012 | 449 | 150 | 10,727 | - | 439 | 8 | 17,517 | 1.021 | .212 | 29,290 |
|  |  | 2,932 | 505 | 172 | 11,311 | - | 439 | 9 | 18,581 | 1.021 | .205 | 31,017 |
|  |  | 2,948-3,060 | 425 | 147 | 10,700 | - | 403 | 7 | 17,446 | 1.020 | .216 | 29,128 |
|  |  | 2,970 | 437 | 137 | 10,684 | - | 445 | 27 | 17,375 | 1.022 | .216 | 29,105 |
|  |  | 2,989-3,060 | 465 | 150 | 10,572 | - | 445 | 7 | 17,304 | 1.020 | .216 | 28,943 |
|  |  | 3,027 | 744 | 170 | 11,499 | - | 284 | 32 | 19,361 | 1.024 | .200 | 32,090 |
|  |  | 3,036 | 485 | 155 | 11,273 | - | 442 | 5 | 18,439 | 1.024 | .205 | 30,799 |
|  |  | 3,042 | 437 | 153 | 10,864 | - | 418 | 6 | 17,730 | 1.022 | .212 | 29,608 |
|  |  | 3,065 | 561 | 179 | 11,818 | - | 290 | 4 | 19,573 | 1.023 | .195 | 32,425 |
| Navarro Crossing | Houston | 5,870-5,875 | 4,100 | 670 | 36,470 | 9 | 281 | 109 | 65,200 | 1.074 | .074 | 106,830 |
|  |  | 5,900 | 4,400 | 680 | 35,813 | 9 | 354 | 115 | 64,700 | 1.075 | .074 | 106,062 |
| Neches | Anderson | 4,723-4,743 | 4,300 | 530 | 36,300 | 0 | 171 | 376 | 64,700 | 1.079 | .074 | 106,377 |
|  |  | 4,732-4,738 | 4,600 | 350 | 35,900 | 0 | 256 | 0 | 64,300 | 1.076 | .075 | 105,406 |
|  |  | 4,749-4,754 | 3,444 | 741 | 36,201 | - | 259 | 1 | 64,000 | 1.075 | .078 | 104,646 |
| New Hope | Franklin | 4,500 | 1,652 | 381 | 30,365 | - | 257 | 4 | 50,704 | 1.058 | .083 | 83,363 |
| Wortham | Freestone | 2,942-2,946 | 270 | 100 | 8,111 | 14 | 616 | 25 | 12,900 | 1.019 | .280 | 22,022 |

WOODBINE (KGW) Continued

| Field | County | Depth | Constituents, Mg/liter |  |  |  |  |  |  | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl |  |  |  |
| Nigger Creek | Limestone | 2,830 | 461 | 149 | 9,666 | - | 317 | 25 | 15,957 | 1.020 | .234 | 26,575 |
|  |  | 2,836 | 453 | 158 | 10,567 | - | 311 | 9 | 17,375 | 1.020 | .216 | 28,873 |
|  |  | 2,849 | 461 | 144 | 9,453 | - | 360 | 7 | 15,602 | 1.020 | .238 | 26,027 |
|  |  | 2,856 | 441 | 156 | 8,063 | - | 299 | 5 | 13,474 | 1.018 | .270 | 22,438 |
| Pine Mills | Wood | 5,200 | 3,600 | 760 | 33,900 | 0 | 98 | 183 | 60,700 | 1.072 | .078 | 99,241 |
|  |  | 5,350-5,400 | 5,742 | 354 | 27,002 | - | 866 | 800 | 51,750 | 1.064 | .085 | 86,514 |
|  |  | 5,270-5,406 | 3,500 | 660 | 32,800 | 0 | 275 | - | 58,500 | 1.067 | .078 | 95,735 |
| Pleasant Grove (Deep) | Rusk | 3,850 | 1,100 | 200 | 18,400 | 0 | 537 | 213 | 30,500 | 1.041 | .127 | 50,950 |
|  |  | 3,852-3,860 | 740 | 120 | 16,700 | 0 | 281 | 180 | 27,100 | 1.034 | .165 | 45,121 |
|  |  | 3,880-3,883 | 1,200 | 300 | 17,500 | 0 | 481 | 0 | 29,800 | 1.043 | .121 | 49,281 |
|  |  | 3,880-3,883 | 1,840 | 70 | 18,500 | - | 201 | 170 | 31,900 | 1.043 | .118 | 52,681 |
|  |  | 3,900 | 1,215 | 154 | 18,400 | 0 | 433 | 267 | 30,500 | 1.041 | .128 | 50,969 |
|  |  | 4,042-4,728 | 920 | 235 | 17,600 | 0 | 79 | 319 | 29,100 | 1.039 | .130 | 48,253 |
| Currie | Navarro | 2,888-2,927 | 65 | 29 | 4,378 | - | 1,403 | 3 | 6,135 | 1.009 | .520 | 12,013 |
|  |  | 2,925-3,000 | 100 | 45 | 5,847 | 6 | 1,183 | 50 | 8,600 | 1.014 | .415 | 15,825 |
|  |  | 2,930-2,957 | 70 | 21 | 3,303 | - | 1,495 | 19 | 4,397 | 1.008 | .680 | 9,305 |
| Richland | Navarro | 2,938-2,949 | 130 | 46 | 5,436 | - | 725 | 33 | 8,300 | 1.014 | .437 | 14,670 |
|  |  | 2,950-2,985 | 137 | 48 | 5,246 | - | 683 | 0 | 8,085 | 1.011 | .440 | 14,199 |
|  |  | 2,950-2,985 | 124 | 37 | 5,654 | - | 683 | 0 | 8,652 | 1.012 | .420 | 15,150 |
| Rowe and Baker | Henderson | 3,137-3,144 | 341 | 124 | 12,475 | - | 604 | - | 19,857 | 1.023 | .192 | 33,401 |
|  |  | 3,137-3,144 | 333 | 126 | 12,474 | - | 586 | 1 | 19,857 | 1.024 | .190 | 33,377 |
|  |  | 3,192-3,193 | 336 | 120 | 11,400 | 14 | 475 | 8 | 18,300 | 1.026 | .209 | 30,639 |
| Rusk | Cherokee | 5,120 | 4,410 | 608 | 34,345 | - | 189 | 165 | 62,304 | 1.072 | .073 | 102,021 |
|  |  | 5,186 | 4,590 | 730 | 33,554 | - | 281 | 171 | 61,700 | 1.071 | .074 | 101,026 |
|  |  | 5,200 | 3,727 | 612 | 37,814 | - | 238 | 116 | 66,486 | 1.074 | .069 | 108,993 |
| Slocum, S. | Anderson | 5,932-5,938 | 3,300 | 800 | 31,000 | 24 | 12 | 325 | 55,800 | 1.075 | .075 | 91,237 |
|  |  | 5,934-5,945 | 3,334 | 778 | 31,400 | - | 67 | 255 | 56,300 | 1.074 | .075 | 92,134 |
|  |  | 5,950-5,952 | 3,800 | 680 | 35,400 | 0 | 268 | 393 | 62,900 | 1.074 | .074 | 103,441 |
|  |  | 5,950 | 3,400 | 990 | 35,800 | 0 | 311 | 215 | 63,800 | 1.076 | .073 | 104,516 |

| Field | County | Depth | Constituents, Mg/liter | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
| WOODBINE (KGW) Continued | | | | | | | | | | | | |
| Slocum, W. | Anderson | 5,675-5,686 | 3,000 | 430 | 32,910 | 0 | 260 | 190 | 57,000 | 1.068 | .081 | 93,790 |
| | | 5,750-5,752 | 3,000 | 525 | 32,900 | 0 | 43 | 0 | 57,600 | 1.067 | .079 | 94,068 |
| | | 5,752-5,755 | 2,700 | 130 | 34,300 | 0 | 274 | 421 | 57,600 | 1.069 | .076 | 95,425 |
| Stegall | Rusk | 3,763-3,766 | 1,344 | 113 | 20,000 | - | 457 | 0 | 33,300 | 1.042 | .128 | 55,214 |
| | | 3,799-3,801 | 1,200 | 330 | 20,900 | - | 366 | 0 | 35,100 | 1.046 | .114 | 57,896 |
| Stewards Mill | Freestone | 4,001-4,006 | 1,300 | 64 | 21,700 | 0 | 183 | 372 | 35,500 | 1.042 | .113 | 59,119 |
| Stone | Cherokee | 3,752-3,753 | 1,220 | 170 | 17,400 | 0 | 146 | 396 | 29,100 | 1.042 | .118 | 48,432 |
| | | 3,752-3,753 | 1,279 | 161 | 19,400 | - | 464 | 188 | 32,300 | 1.043 | .114 | 53,792 |
| | | 3,752-3,770 | 1,300 | 400 | 22,000 | 0 | 409 | 0 | 37,200 | 1.046 | .118 | 61,309 |
| | | 3,752-3,770 | 1,400 | 33 | 22,100 | 0 | 433 | 342 | 36,200 | 1.046 | .114 | 60,508 |
| Trice | Wood | 5,665-5,685 | 700 | 43 | 30,300 | 0 | 177 | 306 | 60,300 | 1.073 | .074 | 91,826 |
| Trix-Liz | Titus | 3,520-3,530 | 468 | 229 | 23,519 | - | 343 | 3 | 37,600 | 1.045 | .122 | 62,162** |
| | | 3,548-3,574 | 1,063 | 331 | 21,776 | - | 102 | 6 | 36,400 | 1.043 | .125 | 59,678** |
| | | 3,608-3,628 | 1,169 | 355 | 22,584 | - | 206 | 1 | 37,850 | 1.045 | .121 | 62,165** |
| | | 3,826-3,836 | 1,222 | 375 | 23,010 | - | 222 | 1 | 38,650 | 1.046 | .101 | 63,480** |
| Van | Van Zandt | 2,855-2,948 | 1,673 | 120 | 24,186 | - | 201 | 105 | 40,423 | 1.048 | .102 | 66,708 |
| | | 2,864-2,867 | 1,475 | 350 | 25,100 | 0 | 73 | 174 | 42,200 | 1.052 | .104 | 69,372 |
| | | 2,874-2,878 | 1,180 | 420 | 22,600 | 181 | 311 | 174 | 37,900 | 1.050 | .103 | 62,585 |
| | | 2,884-2,912 | 825 | 368 | 27,491 | - | 536 | 11 | 44,600 | 1.053 | .101 | 73,831 |
| | | 2,740-2,848 | 1,360 | 437 | 26,200 | 0 | - | 50 | 43,872 | 1.051 | .092 | 71,919 |
| | | 2,760-2,880 | 1,240 | 414 | 25,600 | 0 | - | 14 | 43,247 | 1.050 | .099 | 70,511 |
| | | 2,797-2,938 | 1,191 | 446 | 26,400 | 0 | - | 22 | 41,023 | 1.049 | .095 | 69,082 |
| | | 2,872-2,952 | 1,388 | 445 | 27,800 | 0 | - | 68 | 45,300 | 1.056 | .090 | 75,001 |
| | | 2,897-2,963 | 1,360 | 437 | 27,800 | 0 | - | 67 | 45,120 | 1.053 | .090 | 74,784 |
| | | 2,936-2,941 | 1,142 | 345 | 23,800 | 0 | - | 22 | 37,410 | 1.039 | .107 | 62,719 |
| | | 2,766-2,788 | 1,160 | 384 | 25,700 | 0 | - | 10 | 42,000 | 1.050 | .093 | 69,254 |
| Van | | 2,785-2,814 | 1,080 | 432 | 26,200 | 0 | - | 31 | 43,100 | 1.052 | .095 | 70,843 |
| | | 2,796-2,802 | 1,140 | 444 | 25,900 | 0 | - | 34 | 44,000 | 1.052 | .095 | 71,518 |
| | | 2,826-2,830 | 1,260 | 384 | 26,400 | 0 | - | 23 | 45,400 | 1.052 | .093 | 73,467 |
| | | 2,840-2,843 | 1,120 | 432 | 26,100 | 0 | - | 15 | 44,100 | 1.052 | .093 | 71,767 |
| | | 2,850-2,854 | 1,100 | 444 | 25,700 | 0 | - | 18 | 42,700 | 1.051 | .098 | 69,962 |

**ppm

| Field | County | Depth | Constituents, Mg/liter Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | WOODBINE (KGW) Continued | | | | | | |
| Walter Fair | Kaufman | 4,158-4,165 | 1,200 | 14 | 24,800 | 0 | 43 | - | 40,400 | 1.048 | .105 | 66,457 |
| | | 4,170-4,176 | 1,250 | 331 | 22,200 | 18 | 317 | 0 | 37,200 | 1.048 | .105 | 61,298 |
| | | 4,896-4,932 | 1,410 | 377 | 24,200 | 178 | 214 | 0 | 40,800 | 1.048 | .105 | 67,001 |
| Powell | Navarro | 3,000 | 62 | 26 | 3,964 | - | 1,393 | - | 5,462 | | | 10,941 |
| | | 2,500 | 79 | 35 | 4,606 | - | 1,007 | - | 6,760 | | | 12,525** |
| | | 2,500 | 105 | 41 | 5,603 | - | 1,274 | - | 8,219 | | | 15,287** |
| | | 2,500 | 69 | 29 | 4,371 | - | 993 | - | 6,267 | | | 11,838** |
| | | 2,900 | 217 | 83 | 8,428 | - | 500 | - | 13,333 | | | 22,565** |
| Ham Gossett | Kaufman | 3,254-3,258 | 364 | 116 | 13,481 | - | 492 | 7 | 21,500 | | | 39,960** |
| Hawkins | Wood | 4,898-4,903 | 2,440 | 340 | 35,352 | - | 260 | 145 | 59,700 | | | 96,277** |
| E. Texas | Rusk | 3,650 | 1,300 | 296 | 24,001 | - | 452 | 210 | 39,800 | | | 66,059** |
| | | - | 760 | 284 | 19,259 | 0 | 1,087 | 37 | 31,200 | | | 52,627 |
| | | - | 1,150 | 175 | 19,837 | 0 | 743 | 414 | 32,400 | | | 54,719 |
| | | - | 1,050 | 247 | 20,111 | 0 | 639 | 382 | 32,880 | | | 55,309 |
| | | - | 1,020 | 236 | 18,407 | 0 | 865 | 429 | 30,060 | | | 50,017 |
| | | - | 1,300 | 203 | 22,694 | - | 553 | 338 | 37,320 | | | 62,408 |
| | | - | 950 | 223 | 18,992 | 0 | 744 | 390 | 30,900 | | | 52,199 |
| | | - | 920 | 269 | 17,822 | - | 799 | 367 | 29,160 | | | 49,337 |
| | | - | 1,040 | 288 | 19,349 | - | 805 | 422 | 31,740 | | | 53,644 |
| | | - | 760 | 284 | 19,259 | 0 | 1,087 | 37 | 31,200 | | | 52,627 |
| | | - | 1,150 | 175 | 19,837 | 0 | 743 | 414 | 32,400 | | | 54,719 |
| | Gregg | 3,715 | 1,140 | 297 | 17,951 | 0 | 854 | 420 | 29,760 | | | 50,422 |
| | | - | 1,190 | 302 | 20,443 | 0 | 641 | 240 | 33,960 | | | 56,766 |
| | | - | 1,120 | 276 | 19,300 | 0 | 545 | 311 | 32,000 | | | 53,600 |
| | | - | 1,360 | 216 | 19,694 | 0 | 750 | 199 | 32,820 | | | 55,039 |
| | | - | 1,030 | 297 | 21,100 | 0 | 690 | 454 | 33,000 | | | 55,600 |
| E. Texas | Gregg | - | 1,110 | 229 | 19,795 | - | 806 | 561 | 32,280 | | | 54,781 |
| Newton Branch | Cherokee | 5,148-5,151 | 3,679 | 642 | 35,355 | - | 268 | 149 | 62,628 | | | 102,720 |
| Fort Trinidad | Houston | 8,618-8,641 | 150 | 300 | 4,000 | 150 | - | - | - | | | 71,000 |
| | | - | 628 | 42 | 4,186 | 0 | - | - | - | | | 70,300 |

**ppm

| Field | County | Depth | Constituents, Mg/liter |  |  |  |  |  |  | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl |  |  |  |
| **WOODBINE (KGW) Continued** |  |  |  |  |  |  |  |  |  |  |  |  |
| Navarro Crossing | Houston | - | 3,398 | 531 | 34,942 | - | 247 | 761 | 61,200 |  |  | 100,435 |
|  |  | 5,800 | Trace | 7 | 387 | 0 | 415 | 387 | 376 |  |  | 1,185 |
|  |  | 5,727-5,900 | 5,304 | 194 | 38,739 | 0 | 126 | 1,074 | 67,336 |  |  | 113,440 |
|  |  | 5,771-5,781 | 4,171 | 634 | 35,723 | - | 231 | 118 | 64,092 |  |  | 104,973 |
|  |  | 5,742-5,744 | 7,335 | 705 | 25,097 | - | 7 | 62 | 54,032 |  |  | 87,438 |
|  |  | 5,742-5,744 | 2,891 | 504 | 34,889 | - | 315 | 78 | 58,906 |  |  | 96,783 |
|  |  | 5,742-5,744 | 3,229 | 539 | 34,575 | - | 224 | 128 | 60,366 |  |  | 99,061 |
|  |  | 5,776-5,780 | 3,220 | 582 | 33,893 | 0 | 301 | 98 | 59,400 |  |  | 97,493 |
|  |  | 5,796-5,806 | 3,524 | 504 | 33,941 | 0 | 277 | 132 | 59,780 |  |  | 98,158 |
|  |  | 5,785-5,805 | 4,141 | 567 | 36,575 | 0 | 247 | 118 | 65,141 |  |  | 106,788 |
|  |  | 5,794-5,796 | 3,000 | 485 | 33,307 | 0 | 263 | 120 | 57,836 |  |  | 95,011 |
|  |  | 5,727-5,900 | 5,304 | 194 | 37,674 | - | 126 | 579 | 67,336 |  |  | 112,880 |
|  |  | 5,785-5,805 | 5,831 | 560 | 57,726 | - | 137 | 133 | 31,574 |  |  | 103,995 |
| Buffalo | Leon | 5,941-5,400 | 530 | 159 | 4,243 | 159 | - | - | - |  |  | 85,600 |
| Long Lake | Anderson | 5,272 | 300 | 3 | 4,000 | 500 | - | - | - |  |  | 112,900 |
| Mexia | Limestone | 3,020-3,026 | 528 | 171 | 10,156 | - | 342 | 0 | 16,900 |  |  | 28,162 |
|  |  | - | 154 | 409 | 4,093 | 31 | - | - | - |  |  | 31,600 |
| Slocum, S. | Anderson | 5,934 | 1,074 | 161 | 7,520 | 215 | - | - | - |  |  | 110,000 |
| William Wise | Cherokee | 5,120 | 3,879 | 558 | 35,313 | 0 | 190 | 129 | 62,729 |  |  | 102,798 |
| Neches | Anderson | - | 7,516 | 215 | 5,369 | 215 | - | - | - |  |  | 109,700 |
|  |  | 4,732-4,742 | 3,520 | 586 | 35,582 | 0 | 274 | 180 | 62,520 |  |  | 102,662 |
| Jacksonville, N. | Cherokee | 4,376 | 150 | 1 | 4,000 | 200 | - | - | - |  |  | 87,000 |
| Cayuga | Freestone | 3,800-4,100 | 530 | 0 | 8,474 | 74 | - | - | - |  |  | 85,100 |
| Currie | Navarro | 3,000 | 508 | 102 | 1,523 | 152 | - | - | - |  |  | 19,900 |
| Kerens, S. | Navarro | 3,384 | 409 | 307 | 1,534 | 307 | - | - | - |  |  | 29,700 |
| Powell | Navarro | 3,000 | 303 | 101 | 807 | 101 | - | - | - |  |  | 12,100 |
| Flagg Lake | Henderson | 3,100 | 305 | 183 | 2,032 | 20 | - | - | - |  |  | 23,200 |
|  |  | - | 407 | 204 | 916 | 51 | - | - | - |  |  | 21,600 |
| Big Barnett | Rusk | 3,746-3,751 | 156 | 312 | 3,116 | 208 | - | - | - |  |  | 50,600 |
| Walter Fair | Kaufman | 4,146 | 84 | 420 | 3,150 | 63 | - | - | - |  |  | 69,900 |
| Van | Van Zandt | 3,080 | 150 | 300 | 4,000 | 150 | - | - | - |  |  | 73,600 |

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | | | |
| WOODBINE (KGW) Continued | | | | | | | | | | | | |
| | | 3,080 | 528 | 159 | 4,227 | 85 | - | - | - | | | 79,500 |
| | | 3,080 | 84 | 210 | 4,202 | 42 | - | - | - | | | 74,300 |
| Hawkins | Wood | 5,100 | 160 | 43 | 5,340 | 64 | - | - | - | | | 101,100 |
| Quitman | Wood | 4,351-4,358 | 64 | 21 | 3,183 | 42 | - | - | - | | | 90,100 |
| Wieland | Hunt | 2,800 | 152 | 304 | 709 | 15 | - | - | - | | | 14,100 |
| New Hope | Franklin | 7,300-8,100 | 158 | 42 | 4,225 | 75 | - | - | - | | | 89,100 |
| Talco | Titus | 3,900 | 1,125 | 235 | 21,257 | - | 171 | Trace | 35,400 | | | 58,188 |
| Trix-Liz | Titus | 3,390-3,664 | 1,123 | 357 | 19,035 | 299 | 219 | 0 | 40,455 | | | 61,569 |
| Oakwood | Leon | 6,150 | - | - | - | - | 210 | 160 | 67,000 | | | -ppm |
| | | 6,150 | - | - | - | - | 280 | 10 | 72,000 | | | -ppm |
| Ashby-Ramsey | Hunt | 3,210-3,226 | 83 | 33 | 5,136 | 0 | 796 | 0 | 7,700 | 1.012 | .460 | 13,748 |
| | | 3,227-3,229 | 86 | 40 | 5,006 | 0 | 811 | 22 | 7,500 | 1.012 | .475 | 13,465 |
| Bazette | Navarro | 2,947-2,961 | 190 | 55 | 8,000 | 16 | 702 | 32 | 12,400 | 1.018 | .300 | 21,379 |
| Big Barnett | Rusk | 3,754-3,758 | 2,000 | 440 | 16,660 | 0 | 366 | 230 | 30,100 | 1.040 | .137 | 49,796 |
| | | 3,760-3,766 | 800 | 20 | 18,300 | 0 | 653 | 278 | 29,100 | 1.036 | .140 | 49,151 |
| | | 3,769-3,771 | 1,200 | 175 | 13,700 | 0 | 634 | 458 | 23,000 | 1.040 | .133 | 39,167 |
| Boggy Creek | Anderson | 3,435-3,487 | 3,481 | 580 | 37,278 | - | 279 | 183 | 65,056 | 1.076 | .071 | 106,857 |
| | | 3,547-3,564 | 3,095 | 550 | 36,439 | - | 336 | 195 | 62,950 | 1.072 | .073 | 103,565 |
| | | 3,600-3,634 | 3,451 | 582 | 37,615 | - | 329 | 184 | 65,499 | 1.076 | .070 | 107,660 |
| Buffalo | Leon | 5,642-5,645 | 2,500 | 430 | 30,586 | 9 | 500 | 69 | 52,500 | 1.064 | .089 | 86,585 |
| | | 5,722-5,745 | 1,200 | 260 | 27,164 | 0 | 753 | 42 | 44,300 | 1.050 | .104 | 73,719 |
| | | 5,742-5,747 | 1,700 | 320 | 27,659 | 10 | 787 | 46 | 46,100 | 1.055 | .098 | 76,612 |
| | | 5,742-5,750 | 1,198 | 431 | 30,807 | - | 532 | 92 | 50,500 | 1.061 | .084 | 83,560 |
| Cayuga | Anderson | 3,750-3,800 | 1,412 | 411 | 31,362 | - | 317 | 163 | 51,770 | 1.060 | .085 | 85,435 |
| | | 3,768 | 1,443 | 396 | 30,900 | - | 336 | 157 | 51,061 | 1.061 | .085 | 84,293 |
| | | 4,007-4,014 | 1,580 | 380 | 29,595 | 2 | 250 | 127 | 49,300 | 1.059 | .089 | 81,232 |
| | | 4,009-4,014 | 1,610 | 415 | 30,154 | 3 | 262 | 139 | 50,300 | 1.060 | .087 | 82,880 |
| | | 4,046-4,049 | 1,620 | 350 | 29,833 | 2 | 348 | 118 | 49,600 | 1.059 | .088 | 81,869 |
| Cayuga | Anderson | 4,077 | 1,428 | 305 | 29,900 | - | 158 | 180 | 49,200 | 1.058 | .086 | 81,171 |
| Currie | Navarro | 2,900-2,950 | 256 | 101 | 7,755 | - | 628 | 6 | 12,340 | 1.016 | .285 | 21,086 |
| | | 2,900-2,950 | 250 | 160 | 7,318 | 17 | 653 | 19 | 11,800 | 1.017 | .318 | 20,200 |

|  |  |  | Constituents, Mg/liter |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field | County | Depth | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
| WOODBINE (KGW) Continued |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | 2,958 | 212 | 91 | 7,444 | - | 598 | 4 | 11,772 | 1.015 | .295 | 20,121 |
|  |  | 3,168-3,185 | 276 | 99 | 8,059 | - | 512 | 4 | 12,907 | 1.017 | .280 | 21,857 |
| Dottie Sue | Cherokee | 5,083-5,085 | 800 | 140 | 36,000 | Trace | 171 | 0 | 57,200 | 1.073 | .076 | 94,311 |
| Earl-Lee | Wood | 5,518-5,568 | 3,500 | 640 | 31,500 | 0 | 177 | 263 | 56,300 | 1.071 | .077 | 92,380 |
|  |  | 5,550-5,565 | 3,500 | 640 | 34,100 | 0 | 134 | 373 | 60,300 | 1.073 | .076 | 99,047 |
| East Texas | Upshur | 3,600-3,800 | 1,720 | 85 | 22,100 | - | 495 | 0 | 37,150 | 1.048 | .115 | 61,550 |
|  |  | 3,600-3,800 | 1,140 | 361 | 20,607 | 0 | 596 | 452 | 34,200 | 1.041 | .130 | 57,356 |
| East Texas | Gregg | 3,600-3,800 | 1,260 | 378 | 21,622 | - | 577 | 298 | 36,120 | 1.042 | .153 | 60,255 |
|  |  | 3,600-3,800 | 1,100 | 295 | 22,531 | - | 547 | 204 | 37,080 | 1.045 | .137 | 61,757 |
|  |  | 3,600-3,800 | 1,283 | 340 | 23,228 | - | 603 | 344 | 38,470 | 1.046 | .122 | 64,268 |
| East Texas | Rusk | 3,600-3,800 | 1,300 | 203 | 22,694 | - | 553 | 338 | 37,320 | 1.045 | .133 | 62,408 |
|  |  | 3,600-3,800 | 1,330 | 227 | 23,015 | - | 529 | 383 | 37,920 | 1.047 | .135 | 63,404 |
|  |  | 3,600-3,700 | 1,060 | 279 | 16,900 | 0 | 588 | 311 | 28,200 | 1.034 | .139 | 47,338 |
|  |  | 3,650-3,800 | 1,140 | 297 | 17,951 | 0 | 854 | 420 | 29,760 | 1.038 | .129 | 50,422 |
|  |  | 3,650-3,800 | 1,040 | 288 | 19,349 | - | 805 | 422 | 31,740 | 1.040 | .154 | 53,644 |
|  |  | 3,650-3,800 | 930 | 306 | 19,627 | - | 848 | 198 | 32,160 | 1.038 | .147 | 54,069 |
|  |  | 3,650-3,800 | 1,050 | 247 | 20,111 | 0 | 639 | 382 | 32,880 | 1.040 | .144 | 55,309 |
|  |  | 3,650-3,800 | 1,030 | 297 | 20,100 | 0 | 690 | 454 | 33,000 | 1.039 | .130 | 55,571 |
|  |  | 3,650-3,800 | 1,100 | 303 | 20,100 | 0 | 600 | 334 | 33,200 | 1.040 | .125 | 55,637 |
|  |  | 3,650-3,800 | 960 | 188 | 20,421 | - | 739 | 250 | 33,120 | 1.041 | .120 | 55,678 |
|  |  | 3,650-3,800 | 1,270 | 231 | 20,600 | 5 | 576 | 312 | 34,200 | 1.040 | .133 | 57,189 |
|  |  | 3,650-3,800 | 920 | 109 | 21,343 | 23 | 610 | 416 | 34,200 | 1.041 | .155 | 57,598 |
|  |  | 3,650-3,800 | 1,230 | 273 | 20,793 | - | 706 | 420 | 34,320 | 1.043 | .132 | 57,742 |
|  |  | 3,650-3,800 | 830 | 291 | 21,500 | 0 | 360 | 289 | 35,000 | 1.038 | .135 | 58,270 |
|  |  | 3,650-3,800 | 1,110 | 330 | 20,926 | - | 691 | 147 | 34,680 | 1.042 | .122 | 57,884 |
|  |  | 3,600-3,800 | 1,152 | 307 | 21,960 | - | 586 | 405 | 36,168 | 1.042 | .113 | 60,578 |
|  |  | 3,600-3,800 | 1,082 | 305 | 22,438 | - | 476 | 354 | 36,877 | 1.042 | .112 | 61,532 |
|  |  | 3,600-3,800 | 1,232 | 324 | 24,564 | - | 573 | 352 | 40,423 | 1.047 | .103 | 67,468 |
|  |  | 3,600-3,800 | 1,443 | 146 | 21,000 | - | 482 | 434 | 34,700 | 1.046 | .115 | 58,205 |
|  |  | 3,600-3,800 | 1,302 | 61 | 16,200 | - | 476 | 351 | 26,900 | 1.040 | .131 | 45,290 |

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | | | |
| WOODBINE (KGW) Continued | | | | | | | | | | | | |
| East Texas | Rusk | 3,600-3,800 | 1,262 | 98 | 21,000 | - | 519 | 141 | 34,400 | 1.042 | .125 | 57,420 |
| | | 3,600-3,800 | 1,342 | 158 | 16,800 | - | 409 | 326 | 31,900 | 1.045 | .121 | 50,935 |
| | | 3,600-3,800 | 1,443 | 72 | 21,100 | - | 335 | 49 | 35,000 | 1.046 | .123 | 57,999 |
| | | 3,647-3,668 | 1,162 | 308 | 23,686 | - | 464 | 292 | 39,005 | 1.045 | .106 | 64,917 |
| | | 3,659-3,661 | 1,342 | 307 | 23,731 | - | 500 | 307 | 39,351 | 1.046 | .105 | 65,538 |
| | | 3,700 | 1,400 | 31 | 20,500 | 0 | 768 | 611 | 33,300 | 1.043 | .122 | 56,610 |
| | | 3,700 | 1,300 | 60 | 17,600 | 0 | 506 | 322 | 28,400 | 1.038 | .136 | 48,188 |
| | | 3,700 | 1,300 | 53 | 15,600 | 0 | 353 | 139 | 26,200 | 1.038 | .142 | 43,645 |
| Wieland | Hunt | 2,770 | 97 | 38 | 5,716 | 0 | 659 | 17 | 8,700 | 1.013 | .418 | 15,227 |
| | | 2,772-2,801 | 93 | 5 | 5,700 | 0 | 506 | 0 | 8,700 | 1.015 | .408 | 15,004 |
| Williams-Ham Gossett | Kaufman | 3,228-3,271 | 530 | 21 | 14,600 | 0 | 159 | 0 | 23,400 | 1.030 | .165 | 38,710 |
| William Wise | Cherokee | 5,093-5,135 | 3,960 | 370 | 36,000 | 0 | 256 | 2,457 | 60,600 | 1.074 | .076 | 103,643 |
| | | 5,117-5,120 | 3,980 | 116 | 33,700 | 0 | 67 | 208 | 59,200 | 1.073 | .075 | 97,271 |
| PALUXY (KCPA) | | | | | | | | | | | | |
| Boynton | Smith | 7,456-7,461 | 4,360 | 933 | 36,800 | 0 | 305 | 726 | 66,500 | 1.079 | .070 | 109,624 |
| Coke | Wood | 6,297-6,404 | 8,900 | 680 | 38,800 | 0 | 177 | 497 | 77,100 | 1.088 | .067 | 126,154 |
| | | 6,329-6,333 | 8,750 | 895 | 37,200 | 0 | 111 | 0 | 74,500 | 1.088 | .068 | 121,456 |
| | | 6,370-6,377 | 8,080 | 1,030 | 37,900 | Trace | 183 | 477 | 75,300 | 1.088 | .068 | 122,970 |
| Dalby Springs | Bowie | 4,389-4,390 | 966 | 156 | 9,000 | 0 | 357 | 2,333 | 14,100 | 1.022 | .249 | 26,912 |
| Hitt's Lake | Smith | 7,131-7,248 | 4,450 | 670 | 37,548 | 1 | 311 | 196 | 67,400 | 1.078 | .070 | 110,575 |
| Manziel | Wood | 6,300-6,372 | 7,300 | 738 | 44,000 | - | 34 | 530 | 82,500 | 1.098 | .059 | 135,102 |
| | | 6,347-6,358 | 8,239 | 968 | 35,768 | - | 274 | 476 | 72,047 | 1.083 | .066 | 117,772 |
| | | 6,346-6,358 | 9,500 | 950 | 33,100 | 13 | 79 | 685 | 70,000 | 1.094 | .065 | 114,314 |
| | | 6,367-6,389 | 9,600 | 1,400 | 38,500 | 0 | 189 | 649 | 79,800 | 1.096 | .064 | 130,138 |
| | | 6,375-6,388 | 9,825 | 1,182 | 37,540 | - | 158 | 434 | 78,310 | 1.092 | .061 | 127,449 |
| | | 6,375-6,388 | 9,825 | 1,200 | 38,298 | - | 120 | 438 | 79,540 | 1.094 | .060 | 129,421 |
| Mitchell Creek | Hopkins | 4,466-4,542 | 145 | 15 | 4,900 | 0 | 896 | 96 | 7,300 | 1.012 | .443 | 13,352 |
| | | 4,481-4,524 | 450 | 22 | 4,400 | 0 | 104 | 1,409 | 6,600 | 1.013 | .443 | 12,985 |
| | | 4,500-4,525 | 386 | 38 | 4,970 | - | 364 | 2,300 | 6,560 | 1.010 | .441 | 14,618 |

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | HCO$_3$ | SO$_4$ | Cl | | | |
| PALUXY (KCPA) Continued | | | | | | | | | | | | |
| | | 4,648 | 442 | 85 | 4,898 | - | 457 | 2,249 | 6,656 | 1.010 | .440 | 14,787 |
| Mt. Sylvan | Smith | 7,339-7,352 | 3,400 | 600 | 31,900 | 0 | 177 | 664 | 56,300 | 1.072 | .075 | 93,041 |
| | | 7,404-7,412 | 4,260 | 875 | 35,300 | 148 | 317 | 810 | 63,800 | 1.074 | .074 | 105,362 |
| | | 7,404-7,412 | 3,500 | 640 | 29,700 | 17 | 280 | 621 | 53,200 | 1.070 | .074 | 87,941 |
| Pewitt Ranch | Titus | 4,488-4,539 | 650 | 42 | 6,200 | 0 | 237 | 1,210 | 9,820 | 1.017 | .341 | 18,159 |
| | | 4,512-4,592 | 640 | 20 | 6,100 | 0 | 61 | 874 | 9,930 | 1.017 | .336 | 17,625 |
| | | 4,559-4,572 | 665 | 110 | 6,836 | - | 290 | 2,550 | 10,000 | 1.015 | .280 | 20,451** |
| Quitman | Wood | 6,204-6,310 | 8,525 | 732 | 41,774 | - | 115 | 445 | 81,237 | 1.096 | .059 | 132,828 |
| | | 6,220-6,310 | 9,100 | 720 | 41,565 | - | 84 | 610 | 81,787 | 1.097 | .059 | 133,866 |
| | | 6,222-6,272 | 9,116 | 728 | 42,107 | - | 116 | 580 | 82,654 | 1.098 | .058 | 135,301 |
| | | 6,350-6,372 | 8,986 | 712 | 42,403 | - | 187 | 595 | 82,798 | 1.098 | .058 | 135,681 |
| Sand Flat | Smith | 6,934-7,106 | 4,200 | 440 | 38,700 | 0 | 318 | 355 | 68,000 | 1.079 | .070 | 112,013 |
| | | 7,210-7,239 | 5,150 | 700 | 39,230 | 0 | 180 | 192 | 71,400 | 1.082 | .068 | 116,852 |
| | | 7,540-7,594 | 3,382 | 491 | 38,972 | - | 107 | 600 | 67,000 | 1.080 | .070 | 110,552 |
| Sugar Hill | Titus | 4,377-4,416 | 810 | 64 | 7,000 | 0 | 232 | 62 | 12,200 | 1.022 | .283 | 20,368 |
| Sulphur Bluff | Hopkins | 4,440-4,500 | 385 | 65 | 4,470 | - | 437 | 2,240 | 5,920 | 1.009 | .440 | 13,517 |
| | | 4,483-4,584 | 376 | 10 | 3,800 | 0 | 153 | 354 | 6,200 | 1.014 | .475 | 10,893 |
| | | 4,490-4,561 | 380 | 24 | 4,580 | 0 | 528 | 2,100 | 6,000 | 1.014 | .523 | 13,612 |
| | | 4,500 | 315 | 61 | 5,044 | - | 476 | 2,228 | 6,595 | 1.012 | .400 | 14,719 |
| | | 4,514-4,532 | 384 | 72 | 4,510 | 0 | 444 | 2,230 | 6,000 | 1.012 | .460 | 13,640 |
| Talco | Titus | 4,186-4,342 | 287 | 27 | 6,712 | - | 542 | 2,044 | 9,110 | 1.014 | .345 | 18,722 |
| | | 4,239-4,367 | 600 | 50 | 6,800 | 0 | 353 | 2,302 | 9,800 | 1.019 | .350 | 19,905 |
| Talco | Franklin | 4,252-4,264 | 430 | 87 | 5,849 | - | 479 | 2,200 | 8,080 | 1.013 | .350 | 17,125** |
| Tyler | Smith | 7,678-7,685 | 8,300 | 300 | 41,300 | 0 | 0 | 492 | 78,900 | 1.094 | .061 | 129,292 |
| Walter Fair | Kaufman | 4,960-4,975 | 205 | 80 | 4,800 | Trace | 927 | 295 | 7,300 | 1.017 | .440 | 13,607 |
| | | 4,970-4,976 | 229 | 11 | 4,400 | 0 | 597 | 300 | 6,700 | 1.013 | .440 | 12,237 |
| Birthright | Hopkins | 4,741-4,762 | 270 | 52 | 4,281 | 0 | 555 | 2,316 | 5,200 | 1.012 | .553 | 12,674 |
| | | 4,755-4,759 | 266 | 49 | 4,600 | 0 | 470 | 2,369 | 5,200 | 1.012 | .550 | 12,954 |
| Bud Lee | Smith | 7,564-7,582 | 4,300 | 450 | 33,800 | 0 | 49 | 340 | 60,700 | 1.076 | .074 | 99,639 |
| Mitchell Creek | Hopkins | 4,546-9,340 | 336 | 57 | 4,630 | 0 | 416 | 2,080 | 6,140 | | | 13,700 |
| | | - | 552 | 48 | 5,308 | 0 | 552 | 2,480 | 7,257 | | | 16,012 |

**ppm

| Field | County | Depth | Constituents, Mg/liter |  |  |  |  |  |  | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl |  |  |  |
| PALUXY (KCPA) Continued |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | - | 473 | 1,128 | 4,915 | - | 455 | 1,900 | 7,120 |  |  | 14,994 |
|  |  | - | 500 | 64 | 5,485 | - | 403 | 2,760 | 7,257 |  |  | 16,470 |
|  |  | - | 500 | 48 | 5,619 | - | 413 | 2,760 | 7,403 |  |  | 16,743 |
| Mitchell Creek | Hopkins | - | 473 | 96 | 5,582 | - | 390 | 2,640 | 7,548 |  |  | 16,730 |
|  |  | - | 579 | 80 | 4,917 | - | 394 | 1,840 | 7,257 |  |  | 15,068 |
| Talco | Titus | 4,200-4,230 | 856 | 29 | 6,500 | - | 317 | 1,280 | 7,900 |  |  | 19,932 |
|  |  | - | 61 | 41 | 1,523 | 15 | - | - | - |  |  | 16,600 |
|  |  | - | 81 | 41 | 2,026 | 25 | - | - | - |  |  | 18,400 |
|  |  | - | 41 | 153 | 814 | 8 | - | - | - |  |  | 19,800 |
| Quitman | Wood | 6,293-6,301 | 438 | 164 | 4,383 | 77 | - | - | - |  |  | 153,500 |
|  |  | 4,014-4,032 | 74 | 16 | 3,159 | 42 | - | - | - |  |  | 76,100 |
|  |  | 6,316-6,350 | 438 | 164 | 3,284 | 44 | - | - | - |  |  | 150,200 |
| Chapel Hill | Smith | 5,693 | 155 | 31 | 4,145 | 26 | - | - | - |  |  | 54,600 |
| Shamburger Lake | Smith | 7,394-7,430 | 165 | 50 | 85 | - | 770 | 3 | 120 |  |  | 1,193 |
|  |  | 7,432-7,437 | 4,282 | 481 | 38,389 | - | 221 | 389 | 67,754 |  |  | 111,113 |
|  |  | 7,422-7,500 | 5,076 | 518 | 36,466 | - | 92 | 567 | 66,247 |  |  | 108,966 |
|  |  | - | 4,277 | 945 | 38,183 | - | 184 | 459 | 68,747 |  |  | 112,795 |
|  |  | - | 3,960 | 557 | 38,526 | 0 | 157 | 460 | 67,599 |  |  | 111,258 |
|  |  | - | 4,160 | 630 | 39,662 | 0 | 301 | 510 | 69,800 |  |  | 115,062 |
|  |  | - | 4,140 | 543 | 38,873 | 0 | 144 | 502 | 68,400 |  |  | 112,603 |
| Shamburger Lake | Smith | 6,838-7,670 | 58 | 33 | 6,350 | - | 295 | 319 | 9,540 |  |  | 16,629 |
|  |  | 7,550-7,564 | 413 | 86 | 3,735 | - | 202 | 328 | 6,381 |  |  | 11,143 |
|  |  | 7,486-7,498 | 501 | 50 | 7,215 | - | 536 | 332 | 11,600 |  |  | 20,233 |
|  |  | - | 457 | 45 | 6,753 | 34 | 35 | 610 | 14,136 |  |  | 22,114 |
|  |  | 7,361-7,367 | 665 | 68 | 11,045 | - | 518 | 360 | 17,836 |  |  | 30,491 |
|  |  | - | 349 | 51 | 7,471 | 0 | 588 | 279 | 11,736 |  |  | 20,472 |
|  |  | 7,161-7,167 | 4,018 | 714 | 42,185 | - | 204 | 247 | 73,919 |  |  | 121,308 |
|  |  | - | 305 | 34 | 6,459 | - | 124 | 317 | 10,400 |  |  | 17,760 |
|  |  | 7,336-7,346 | 4,198 | 847 | 36,896 | - | 197 | 349 | 64,801 |  |  | 107,288 |
|  |  | 6,838-6,888 | 284 | 50 | 7,268 | - | 708 | 337 | 11,193 |  |  | 19,837 |
|  |  | 7,336-7,346 | 4,301 | 679 | 36,878 | - | 203 | 257 | 66,202 |  |  | 108,541 |

### PALUXY (KCPA) Continued

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | | | |
| | | 7,328-7,348 | 4,936 | 1,309 | 4,685 | - | 614 | 379 | 19,130 | | | 31,053 |
| | | 7,352-7,362 | 3,290 | 381 | 5,492 | - | 458 | 432 | 14,818 | | | 24,870 |
| | | 7,314-7,326 | 235 | 20 | 5,763 | - | 669 | 365 | 8,698 | | | 15,749 |
| | | - | 705 | 110 | 6,028 | - | 243 | 348 | 10,465 | | | 17,898 |
| | | 7,623-7,670 | 934 | 80 | 14,796 | - | 493 | 299 | 24,205 | | | 40,807 |
| Shamburger Lake | Smith | - | 200 | 23 | 2,540 | - | 515 | 93 | 3,970 | | | 7,342 |
| | | - | 745 | 269 | 12,662 | - | 756 | 841 | 20,564 | | | 35,836 |
| | | - | 104 | 20 | 4,135 | 18 | 780 | 250 | 7,546 | | | 12,885 |
| | | 7,288-7,298 | 438 | 61 | 10,562 | - | 565 | 458 | 16,573 | | | 28,656 |
| | | - | 1,518 | 487 | 23,420 | 186 | 314 | 775 | 38,888 | | | 65,651 |
| | | - | 487 | 63 | 10,200 | - | 571 | 524 | 16,000 | | | 27,840 |
| | | - | 747 | 90 | 11,575 | 61 | 461 | 825 | 21,205 | | | 35,038 |
| | | - | 1,096 | 173 | 16,380 | - | 356 | 484 | 27,137 | | | 45,625 |
| | | - | 1,096 | 185 | 16,790 | - | 401 | 450 | 27,800 | | | 46,723 |
| | | - | 1,078 | 366 | 13,549 | - | 512 | 840 | 22,950 | | | 39,295 |
| | | - | 940 | 48 | 5,162 | - | 119 | 200 | 9,548 | | | 16,017 |
| | | - | 403 | 44 | 3,610 | - | 952 | 300 | 5,640 | | | 10,948 |
| | | - | 0 | 159 | 6,435 | - | 742 | 550 | 9,547 | | | 17,432 |
| | | - | 915 | 134 | 14,176 | - | 437 | 452 | 23,279 | | | 39,392 |
| | | - | 776 | 28 | 3,880 | 195 | 844 | 5 | 7,619 | | | 13,373 |
| | | - | 715 | 72 | 14,000 | - | 505 | 577 | 22,300 | | | 38,169 |
| | | - | 627 | 61 | 12,249 | - | 469 | 340 | 19,653 | | | 33,398 |
| | | 7,590-7,598 | 1,080 | 159 | 14,772 | - | 378 | 468 | 24,580 | | | 41,436 |
| | | - | 812 | 108 | 14,800 | - | 561 | 521 | 23,800 | | | 40,604 |
| | | - | 176 | 28 | 5,950 | - | 804 | 324 | 8,870 | | | 16,151 |
| | | - | 255 | 146 | 5,847 | - | 861 | 36 | 9,364 | | | 16,509 |
| | | - | 906 | 120 | 11,451 | 79 | 789 | 753 | 20,957 | | | 35,129 |
| | | - | 258 | 10 | 6,072 | - | 708 | 420 | 9,078 | | | 16,515 |
| | | - | 1,724 | 235 | 22,381 | - | 402 | 476 | 37,656 | | | 62,875 |
| | | - | 257 | 25 | 5,230 | - | 351 | 298 | 8,160 | | | 14,321 |
| | | 7,263-7,269 | 398 | 97 | 9,297 | - | 546 | 479 | 14,652 | | | 25,469 |

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | | | |
| **PALUXY (KCPA) Continued** | | | | | | | | | | | | |
| | | - | 955 | 182 | 16,241 | 0 | 398 | 630 | 26,565 | | | 44,971 |
| | | 7,263-7,269 | 560 | 58 | 10,981 | 0 | 535 | 459 | 17,441 | | | 30,035 |
| | | - | 882 | 213 | 14,154 | - | 457 | 572 | 23,317 | | | 39,594 |
| | | - | 598 | 80 | 8,646 | 60 | 455 | 669 | 17,808 | | | 28,379 |
| | | - | 157 | 34 | 5,443 | 31 | 902 | 101 | 10,190 | | | 16,897 |
| | | - | 1,124 | 186 | 17,636 | - | 392 | 382 | 29,214 | | | 48,933 |
| Shamburger Lake | Smith | - | 1,740 | 185 | 24,300 | - | 361 | 652 | 40,399 | | | 65,544 |
| | | - | 58 | 33 | 6,350 | - | 295 | 319 | 9,540 | | | 16,628 |
| | | - | 812 | 108 | 14,800 | - | 561 | 521 | 23,800 | | | 40,602 |
| | | 7,317-7,318 | 1,934 | 315 | 22,371 | - | 254 | 519 | 38,279 | | | 63,673 |
| | | - | 1,333 | 134 | 19,687 | 0 | 328 | 610 | 32,458 | | | 54,549 |
| | | - | 869 | 159 | 15,471 | - | 334 | 786 | 25,083 | | | 42,703 |
| Shamburger Lake | Wood | 7,256-7,749 | 353 | 48 | 6,006 | 29 | 11 | 325 | 11,666 | | | 18,452 |
| | | - | 402 | 91 | 9,272 | 52 | 549 | 568 | 14,525 | | | 25,483 |
| | | - | 131 | 38 | 5,283 | 23 | 315 | 320 | 8,116 | | | 14,329 |
| | | - | 552 | 273 | 11,549 | 59 | 0 | 340 | 20,506 | | | 33,319 |
| | | 7,256-7,769 | 350 | 44 | 7,765 | - | 555 | 373 | 12,121 | | | 21,207 |
| | | 7,479-7,489 | 1,501 | 207 | 17,833 | 0 | 155 | 631 | 30,195 | | | 50,522 |
| | | - | 250 | 33 | 4,602 | 27 | 463 | 270 | 7,433 | | | 13,094 |
| | | - | 552 | 121 | 9,303 | 39 | 446 | 450 | 16,233 | | | 27,175 |
| | | - | 301 | 91 | 5,173 | 27 | 244 | 320 | 8,544 | | | 14,719 |
| | | 7,503-7,522 | 199 | 31 | 4,203 | - | 635 | 221 | 6,389 | | | 11,677 |
| | | 7,486-7,498 | 365 | 60 | 6,414 | - | 699 | 1,119 | 10,219 | | | 17,867 |
| | | - | 80 | 10 | 2,055 | 11 | 696 | 180 | 3,952 | | | 7,071 |
| | | - | 602 | 137 | 9,939 | 47 | 244 | 700 | 17,516 | | | 29,286 |
| | | - | 402 | 151 | 9,236 | 29 | 489 | 469 | 14,738 | | | 25,542 |
| | | 7,590-7,598 | 619 | 160 | 12,785 | - | 531 | 28 | 20,948 | | | 35,071 |
| | | - | 1,456 | 324 | 21,114 | 88 | 303 | 750 | 35,671 | | | 59,789 |
| Sand Flat | Smith | 7,220 | 2,161 | 216 | 4,321 | 22 | - | - | - | | | 120,600 |
| Bud Lee | Smith | 7,560 | 4,304 | 523 | 37,634 | - | 244 | 487 | 66,766 | | | 110,071 |
| | | - | 4,161 | 582 | 38,706 | - | 156 | 458 | 68,307 | | | 112,370 |

PALUXY (KCPA) Continued

| Field | County | Depth | Constituents, Mg/liter |  |  |  |  |  |  | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Ca | Mg | Na | Ba-Sr | HCO3 | SO4 | Cl |  |  |  |
|  |  | - | 200 | 200 | 4,000 | 50 | - | - | - |  |  | 48,000 |
| Hitt's Lake | Smith | 7,299-7,305 | 4,444 | 551 | 39,604 | - | 259 | 513 | 70,000 |  |  | 115,371 |
|  |  | 7,219-7,239 | 4,605 | 915 | 39,381 | 193 | 73 | 720 | 67,721 |  |  | 113,730 |
|  |  | 7,203-7,270 | 4,709 | 730 | 34,615 | - | 231 | 221 | 65,532 |  |  | 104,037 |
|  |  | - | 4,143 | 571 | 40,290 | - | 243 | 647 | 70,486 |  |  | 116,375 |
|  |  | 7,294-7,312 | 4,467 | 209 | 39,375 | - | 245 | 649 | 68,605 |  |  | 113,549 |
|  |  | 7,233-7,268 | 4,121 | 685 | 37,809 | 0 | 203 | 628 | 67,158 |  |  | 110,775 |
|  |  | 7,233-7,268 | 3,969 | 450 | 38,388 | - | 295 | 632 | 66,882 |  |  | 110,615 |
| Hitt's Lake | Smith | - | 4,315 | 503 | 37,566 | 0 | 192 | 419 | 66,600 |  |  | 109,595 |
|  |  | 7,294-7,312 | 4,247 | 581 | 38,912 | 0 | 179 | 631 | 68,803 |  |  | 113,535 |
|  |  | - | 4,538 | 661 | 37,322 | - | 191 | 257 | 67,198 |  |  | 110,167 |
|  |  | 7,232.5-7,272.8 | 5,036 | 665 | 42,321 | - | 93 | 840 | 75,429 |  |  | 255,240 |
|  |  | 7,140-7,210 | 4,540 | 765 | 36,670 | 0 | 126 | 207 | 66,741 |  |  | 109,230 |
|  |  | 7,202-7,212 | 4,383 | 724 | 40,240 | - | 238 | 622 | 69,200 |  |  | 115,407 |
|  |  | 7,308-7,318 | 3,963 | 537 | 37,069 | - | 409 | 634 | 65,027 |  |  | 107,639 |
|  |  | - | 4,138 | 576 | 35,303 | - | 201 | 540 | 62,916 |  |  | 103,673 |
|  |  | - | 4,450 | 577 | 37,962 | - | 90 | 450 | 67,703 |  |  | 111,231 |
|  |  | - | 4,519 | 618 | 37,110 | - | 127 | 459 | 66,605 |  |  | 109,438 |
|  |  | - | 4,507 | 579 | 37,424 | - | 170 | 729 | 66,729 |  |  | 110,136 |
|  |  | - | 4,759 | 647 | 35,545 | - | 204 | 227 | 64,821 |  |  | 106,202 |
| Lindale, E. | Smith | 7,841 | 5,840 | 1,020 | 38,741 | 351 | 234 | 560 | 73,000 |  |  | 119,925 |
| Walter Fair | Kaufman | 5,380 | 406 | 152 | 609 | 10 | - | - | - |  |  | 15,600 |
| Quitman | Wood | 6,211-6,352 | 9,731 | 1,388 | 39,627 | - | 96 | 460 | 82,009 |  |  | 133,373 |
|  |  | - | 11,309 | 1,435 | 12,063 | - | 65 | 352 | 42,529 |  |  | 67,801 |
|  |  | - | 11,309 | 1,435 | 39,645 | - | 65 | 352 | 85,058 |  |  | 137,912 |
|  |  | - | 10,651 | 1,356 | 40,998 | - | 129 | 476 | 85,638 |  |  | 139,325 |
|  |  | - | 11,966 | 1,834 | 39,655 | - | 96 | 352 | 87,380 |  |  | 141,335 |
|  |  | - | 10,651 | 1,196 | 40,160 | - | 104 | 444 | 83,896 |  |  | 136,495 |
|  |  | - | 6,443 | 2,073 | 41,192 | - | 67 | 352 | 80,704 |  |  | 130,897 |
|  |  | - | 11,700 | 798 | 40,632 | - | 83 | 460 | 85,348 |  |  | 139,115 |
|  |  | - | 11,572 | 1,595 | 40,407 | - | 96 | 38 | 87,380 |  |  | 141,145 |

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | | | |
| | | | **PALUXY (KCPA) Continued** | | | | | | | | | |
| | | - | 11,966 | 1,750 | 39,599 | - | 102 | 305 | 87,090 | | | 140,875 |
| | | - | 11,046 | 1,435 | 39,576 | - | 104 | 352 | 84,478 | | | 137,065 |
| | | - | 10,257 | 717 | 37,911 | - | 104 | 396 | 78,381 | | | 127,824 |
| | | - | 10,520 | 1,914 | 40,259 | - | 100 | 43 | 86,218 | | | 139,111 |
| | | - | 10,257 | 1,276 | 41,582 | - | 86 | 444 | 85,638 | | | 139,332 |
| | | - | 10,914 | 1,435 | 40,531 | - | 102 | 424 | 85,348 | | | 138,618 |
| | | - | 4,333 | 460 | 25,676 | - | 34 | 0 | 48,742 | | | 79,503 |
| | | - | 11,835 | 1,435 | 39,933 | - | 65 | 360 | 86,509 | | | 140,318 |
| Manziel | Wood | 6,306-6,346 | 9,468 | 1,914 | 39,222 | - | 106 | 444 | 82,444 | | | 133,634 |
| Manziel | Wood | 6,337-6,347 | 9,472 | 1,187 | 39,068 | 0 | 106 | 296 | 80,177 | | | 130,306 |
| | | 6,345-6,357 | 9,541 | 1,059 | 39,143 | - | 99 | 318 | 80,033 | | | 130,192 |
| | | 6,345-6,357 | 8,756 | 1,260 | 38,621 | 0 | 96 | 299 | 78,459 | | | 127,470 |
| | | - | 9,200 | 1,333 | 43,431 | 0 | 107 | 400 | 86,772 | | | 141,242 |
| | | 6,347-6,358 | 8,929 | 1,046 | 38,753 | - | 293 | 516 | 78,077 | | | 127,619 |
| | | | **RODESSA (KCGRL)** | | | | | | | | | |
| Pokey | Limestone | 6,338 | 16,646 | 2,158 | 47,259 | - | 63 | 290 | 108,359 | | | 174,775 |
| McBee | Leon | - | 539 | 43 | 273 | 0 | 0 | Trace | 1,705 | | | 2,602 |
| | | - | 15,200 | 1,290 | 54,100 | 0 | 42 | 287 | 114,000 | | | 185,005 |
| | | 8,703-8,716 | 14,201 | 1,457 | 51,141 | - | 12 | 150 | 108,111 | | | 175,073 |
| | | 8,707-8,720 | 11,652 | 1,331 | 37,461 | - | 67 | 275 | 82,014 | | | 132,799 |
| | | 8,703-8,716 | 12,959 | 1,575 | 50,484 | - | 164 | 280 | 105,062 | | | 170,524 |
| | | 8,762-8,770 | 13,731 | 1,417 | 53,597 | - | 19 | 250 | 110,870 | | | 179,883 |
| | | - | 12,416 | 1,410 | 43,546 | 843 | 200 | 325 | 104,651 | | | 165,026 |
| | | - | 11,640 | 1,816 | 39,548 | - | 302 | 230 | 86,524 | | | 140,060 |
| | | 8,703-8,716 | 12,849 | 1,439 | 45,582 | - | 94 | 314 | 96,924 | | | 157,200 |
| | | - | 212 | 8 | 442 | - | 7 | 0 | 1,080 | | | 1,752 |
| | | - | 251 | 6 | 240 | - | Trace | 0 | 833 | | | 1,330 |
| | | 8,660-8,663 | 16,970 | 1,514 | 39,085 | - | 406 | 337 | 94,218 | | | 152,530 |
| | | 8,650-8,663 | 17,952 | 1,411 | 43,503 | - | 479 | 273 | 102,473 | | | 166,091 |

| Field | County | Depth | Constituents, Mg/liter |  |  |  |  |  |  | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl |  |  |  |
| RODESSA (KCGRL) Continued |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | 8,955-8,979 | 853 | 132 | 8,265 | - | 345 | 579 | 14,018 |  |  | 24,191 |
| Teague, W. | Freestone | 6,702 | 4,915 | 123 | 5,578 | - | 98 | 126 | 18,091 |  |  | 29,302 |
| Tennessee Colony | Anderson | 8,882-9,700 | 11,052 | 553 | 6,631 | 221 | - | - | - |  |  | 152,000 |
| Fairway | Henderson | 9,516-9,540 | 19,860 | 1,442 | 56,113 | - | 32 | 329 | 125,275 |  |  | 204,245 |
|  |  | 9,517-9,523 | 22,127 | 1,922 | 49,003 | - | 0 | 269 | 120,116 |  |  | 193,437 |
|  |  | 9,517-9,523 | 19,042 | 1,971 | 50,359 | - | 79 | 322 | 116,802 |  |  | 188,575 |
|  |  | 9,517-9,523 | 19,164 | 1,976 | 52,593 | - | 114 | 211 | 120,540 |  |  | 194,590 |
|  |  | 9,474-9,485 | 3,085 | 481 | 33,336 | - | 145 | 1,840 | 56,818 |  |  | 95,704 |
| Tyler, S. | Smith | 9,520-9,560 | 1,074 | 85 | 1,891 | - | 74 | 9 | 5,022 |  |  | 9,003 |
| Chapel Hill | Smith | - | 30 | 15 | 3,035 | 76 | - | - | - |  |  | 18,400 |
|  |  | 7,704-7,712 | 22,927 | 2,497 | 60,177 | - | 83 | 247 | 140,399 |  |  | 226,329 |
| Wright Mountain | Smith | 7,586 | 220 | 10 | 4,503 | - | 397 | 7,742 | 1,335 |  |  | 14,274 |
| Hitt's Lake | Smith | 9,305-9,320 | 20,676 | 1,800 | 50,753 | - | Trace | 283 | 119,879 |  |  | 193,390 |
| Lansing, N. | Harrison | 6,957-6,965 | 16,700 | 1,760 | 49,600 | 8 | 102 | 262 | 111,000 |  |  | 179,000 |
|  |  | - | 578 | 25 | 258 | 0 | 62 | 0 | 1,100 |  |  | 1,820 |
|  |  | - | 571 | 17 | 221 | 0 | 37 | 68 | 1,356 |  |  | 2,236 |
|  |  | - | 478 | 46 | 423 | 0 | 48 | 423 | 1,590 |  |  | 2,610 |
|  |  | - | 5,050 | 262 | 13,113 | 0 | 275 | 102 | 29,100 |  |  | 48,502 |
|  |  | - | 630 | 24 | 484 | 0 | 72 | 0 | 1,890 |  |  | 3,100 |
|  |  | - | 475 | 18 | 129 | 0 | 70 | 8 | 1,296 |  |  | 2,193 |
|  |  | - | 14,800 | 1,580 | 41,100 | 0 | 102 | 157 | 94,000 |  |  | 152,000 |
|  |  | - | 14,900 | 1,340 | 40,100 | 25 | 96 | 172 | 92,000 |  |  | 149,000 |
|  |  | - | 15,300 | 1,760 | 42,100 | 0 | 156 | 170 | 97,000 |  |  | 156,500 |
|  |  | - | 15,600 | 1,640 | 43,300 | 14 | 49 | 180 | 99,000 |  |  | 160,000 |
|  |  | - | 19,900 | 365 | 2,940 | 36 | 6 | 113 | 40,800 |  |  | 64,100 |
|  |  | - | 17,800 | 243 | 2,870 | 44 | 30 | 102 | 36,600 |  |  | 57,600 |
|  |  | - | 21,500 | 3,650 | 3,820 | 0 | 12 | 48 | 54,600 |  |  | 83,600 |
|  |  | - | 1,710 | 43 | 501 | 5 | 30 | 16 | 3,900 |  |  | 6,200 |
|  |  | - | 2,960 | 36 | 870 | 0 | 102 | 48 | 6,600 |  |  | 10,600 |
|  |  | - | 2,720 | 24 | 880 | 0 | 180 | 60 | 6,100 |  |  | 10,000 |

|  |  |  | Constituents, Mg/liter |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field | County | Depth | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|  |  |  | RODESSA (KCGRL) Continued |  |  |  |  |  |  |  |  |  |
|  |  | - | 4,100 | 304 | 4,150 | 0 | 120 | 32 | 14,500 |  |  | 23,200 |
|  |  | - | 246 | 7 | 512 | 0 | 36 | 0 | 870 |  |  | 1,670 |
|  |  | - | 3,452 | 377 | 3,180 | 0 | 152 | 47 | 12,000 |  |  | 19,200 |
|  |  | - | 5,400 | 122 | 4,960 | 0 | 146 | 41 | 17,500 |  |  | 28,100 |
|  |  | - | 1,090 | 67 | 895 | 0 | 48 | 0 | 3,480 |  |  | 5,580 |
|  |  | - | 2,600 | 546 | 34,200 | 70 | 113 | 0 | 58,800 |  |  | 96,200 |
|  |  | - | 448 | 18 | 182 | 0 | 30 | 0 | 1,110 |  |  | 1,790 |
|  |  | - | 238 | 8 | 637 | 0 | 132 | 0 | 1,350 |  |  | 2,360 |
|  |  | - | 580 | 58 | 1,580 | 0 | 65 | 0 | 3,600 |  |  | 5,890 |
|  |  | - | 370 | 12 | 86 | 0 | 134 | 4 | 744 |  |  | 1,350 |
|  |  | - | 270 | 4 | 272 | 0 | 95 | 0 | 855 |  |  | 1,500 |
|  |  | - | 226 | 4 | 150 | 0 | 24 | 0 | 630 |  |  | 1,030 |
|  |  | - | 1,600 | 61 | 3,860 | 0 | 85 | 12 | 8,900 |  |  | 14,500 |
| Lansing | Harrison | - | 206 | 2 | 521 | 0 | 43 | 0 | 1,150 |  |  | 1,920 |
|  |  | - | 100 | 36 | 2,470 | 0 | 0 | 8 | 4,080 |  |  | 6,690 |
|  |  | - | 120 | 6 | 270 | 0 | 180 | 0 | 540 |  |  | 1,120 |
|  |  | - | 130 | 46 | 553 | 0 | 30 | 0 | 1,200 |  |  | 1,960 |
|  |  | - | 6,557 | 147 | 2,005 | - | 0 | 101 | 15,086 |  |  | 28,307 |
|  |  | - | 2,210 | 41 | 824 | - | 11 | 38 | 5,279 |  |  | 10,393 |
|  |  | 6,634-6,645 | 6,098 | 608 | 22,725 | - | 98 | 3,781 | 44,756 |  |  | 78,066 |
|  |  | - | 2,681 | 98 | 1,246 | - | 46 | 46 | 6,906 |  |  | 13,694 |
| Quitman | Wood | 8,409-8,425 | 657 | 48 | 1,405 | - | 56 | 21 | 3,484 |  |  | 5,765 |
|  |  | - | 4,997 | 80 | 36,858 | - | 52 | 80 | 65,898 |  |  | 108,095 |
|  |  | - | 22,620 | 2,455 | 56,396 | - | 92 | 420 | 132,252 |  |  | 219,555 |
|  |  | - | 24,722 | 2,711 | 53,054 | - | 10 | 88 | 133,538 |  |  | 214,371 |
|  |  | - | 1,446 | 191 | 6,062 | - | 10 | 27 | 12,483 |  |  | 20,295 |
|  |  | - | 815 | 16 | 2,022 | - | 75 | 0 | 3,193 |  |  | 6,195 |
|  |  | - | 28,798 | 4,306 | 64,806 | - | 6 | 128 | 163,438 |  |  | 261,637 |
|  |  | - | 30,040 | 3,300 | 63,601 | - | 229 | 172 | 160,734 |  |  | 258,309 |
|  |  | - | 12,210 | 183 | 9,768 | 110 | - | - | - |  |  | 335,700 |
|  |  | - | 1,000 | 500 | 5,000 | 350 | - | - | - |  |  | 324,900 |

| | | | Constituents, Mg/liter | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field | County | Depth | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
| | | | | | | RODESSA (KCGRL) Continued | | | | | | |
| Blackfoot | Anderson | 9,030-9,050 | 20,000 | 1,778 | 58,100 | 910 | 251 | 233 | 129,800 | 1.148 | .048 | 210,162 |
| | | 9,034-9,052 | 17,400 | 2,200 | 61,100 | 0 | 0 | 367 | 131,200 | 1.150 | .048 | 212,267 |
| Cayuga, NW. | Henderson | 7,436-7,444 | 22,800 | 1,930 | 59,447 | 5 | 122 | 225 | 137,400 | 1.154 | .046 | 221,924 |
| Cornersville | Franklin | 7,753-7,759 | 32,800 | 2,193 | 62,900 | 368 | 50 | 216 | 161,300 | 1.180 | .046 | 259,459 |
| Fairway | Henderson | 9,565-9,585 | 32,200 | 610 | 34,020 | 0 | 30 | 400 | 111,000 | 1.122 | .049 | 178,260 |
| Haynes | Cass | 6,000-6,003 | 22,920 | 3,200 | 55,800 | 8 | 31 | 104 | 135,800 | 1.152 | .042 | 217,855 |
| | | 6,000-6,004 | 25,800 | 2,440 | 56,800 | 0 | 61 | 327 | 140,000 | 1.161 | .046 | 225,428 |
| | | 6,051-6,064 | 23,200 | 3,100 | 57,400 | Trace | 50 | 100 | 138,500 | 1.159 | .042 | 222,350 |
| | | 6,081-6,083 | 26,300 | 3,400 | 52,600 | 2 | 37 | 89 | 137,700 | 1.157 | .042 | 220,126 |
| Kildare | Cass | 5,591-6,037 | 17,200 | 6,900 | 46,500 | 0 | 0 | 2,305 | 120,500 | 1.142 | .052 | 193,405 |
| LaRue | Henderson | 7,762-7,772 | 22,100 | 2,600 | 59,600 | 6 | 110 | 289 | 138,300 | 1.157 | .047 | 222,999 |
| | | 7,800-8,000 | 20,100 | 3,000 | 59,000 | 12 | 67 | 364 | 134,700 | 1.157 | .047 | 217,231 |
| Malakoff, S. | Henderson | 7,462-7,471 | 17,900 | 2,200 | 52,484 | 5 | 58 | 258 | 118,800 | 1.135 | .048 | 191,700 |
| | | 7,478-7,520 | 18,100 | 3,500 | 49,800 | 5 | 64 | 249 | 118,800 | 1.137 | .049 | 190,513 |
| | | 7,510-7,520 | 16,800 | 1,940 | 52,476 | 4 | 55 | 229 | 116,600 | 1.130 | .049 | 188,100 |
| Mound Prairie | Anderson | 10,046-10,068 | 13,620 | 1,255 | 48,083 | - | 68 | 290 | 101,800 | 1.114 | .050 | 165,116** |
| New Hope | Franklin | 7,302 | 23,233 | 2,306 | 83,181 | - | 71 | 242 | 175,877 | 1.156 | .048 | 284,910 |
| | | 7,364 | 26,800 | 2,970 | 61,486 | - | 40 | 237 | 150,692 | 1.170 | .048 | 242,225 |
| | | 7,364 | 25,004 | 2,691 | 87,773 | - | 62 | 234 | 187,224 | 1.168 | .045 | 302,988 |
| | | 7,350-7,400 | 25,597 | 2,376 | 54,136 | - | 0 | 344 | 135,446 | 1.155 | .047 | 217,899 |
| | | 7,350-7,400 | 24,699 | 2,918 | 61,948 | - | 35 | 287 | 147,501 | 1.166 | .046 | 237,388 |
| Rodessa | Marion | 6,062-6,091 | 20,195 | 2,699 | 62,711 | - | 79 | 310 | 140,063 | 1.152 | .045 | 226,057 |
| | | 6,068-6,090 | 21,157 | 2,839 | 61,332 | - | 67 | 297 | 140,063 | 1.155 | .045 | 225,755 |
| | | 6,077-6,122 | 20,997 | 2,909 | 61,391 | - | 73 | 307 | 140,063 | 1.155 | .045 | 225,740 |
| Rodessa | Cass | 5,986-6,004 | 22,840 | 2,621 | 60,929 | - | - | 279 | 141,836 | 1.155 | .044 | 228,505 |
| | | 5,999-6,025 | 21,478 | 2,455 | 61,672 | - | - | 313 | 140,063 | 1.154 | .044 | 225,981 |
| | | 6,033-6,077 | 23,321 | 2,673 | 60,285 | - | - | 291 | 141,836 | 1.158 | .044 | 228,406 |
| | | 5,981-5,986 | 21,197 | 2,503 | 59,569 | - | 24 | 219 | 136,517 | 1.149 | .046 | 220,029 |
| | | 6,008-6,030 | 21,397 | 2,298 | 62,062 | - | - | 314 | 140,063 | 1.153 | .046 | 226,134 |
| | | 6,024-6,049 | 23,160 | 2,551 | 60,700 | - | - | 292 | 141,836 | 1.157 | .046 | 228,539 |
| Rodessa | Marion | 6,096-6,107 | 15,788 | 3,101 | 65,841 | - | 49 | 299 | 138,290 | 1.155 | .045 | 223,368 |

**ppm

| Field | County | Depth | Constituents, Mg/liter | | | | | | | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | | | |
| | | | | | RODESSA (KCGRL) Continued | | | | | | | |
| Sand Flat | Smith | 9,332-9,342 | 19,744 | 1,735 | 45,669 | - | 107 | 154 | 110,240 | 1.121 | .050 | 177,649 |
| Teague, W. | Freestone | 6,940-6,949 | 16,342 | 1,814 | 50,349 | - | 126 | 464 | 111,600 | 1.123 | .049 | 180,695** |
| Tennessee Colony | Anderson | 8,930-8,971 | 20,600 | 2,060 | 54,259 | 0 | 46 | 267 | 125,900 | 1.141 | .049 | 203,132 |
| | | 8,950-9,004 | 16,800 | 1,480 | 43,556 | 0 | 37 | 248 | 101,000 | 1.116 | .055 | 163,121 |
| | | 9,046-9,058 | 20,100 | 2,153 | 54,700 | 15 | 159 | 269 | 125,900 | 1.143 | .049 | 203,281 |
| Tri-Cities | Henderson | 7,680-7,750 | 10,260 | 6,570 | 51,900 | 0 | 24 | 524 | 117,000 | 1.137 | .049 | 186,278 |
| Winnsboro | Wood | 8,260-8,280 | 28,286 | 2,327 | 53,777 | 0 | 6 | 172 | 140,067 | 1.160 | .047 | 224,635 |
| | | 8,265-8,281 | 25,000 | 3,038 | 49,225 | 0 | 79 | 151 | 129,074 | 1.150 | .044 | 206,567 |
| | | 8,265-8,281 | 20,000 | 1,000 | 67,300 | 0 | 0 | 351 | 141,800 | 1.167 | .046 | 230,451 |
| | | 7,845-7,862 | 32,400 | 2,200 | 86,500 | 36 | 0 | 634 | 161,300 | 1.188 | .044 | 283,034 |
| Kildare | Cass | - | 11,052 | 332 | 3,316 | 67 | - | - | - | | | 168,800 |
| | | 6,032-6,038 | 700 | 100 | 4,000 | 300 | - | - | - | | | 131,000 |
| Douglass | Nacogdoches | 8,210-8,296 | 14,559 | 1,714 | 53,658 | - | 110 | 410 | 113,300 | | | 183,731** |
| Tennessee Colony | Anderson | - | 11,904 | 1,183 | 37,677 | 0 | 82 | 208 | 82,445 | | | 133,533 |
| | | 8,976-9,000 | 17,828 | 1,805 | 49,450 | - | 38 | 184 | 113,100 | | | 182,405** |
| | | - | 7,246 | 729 | 19,122 | 0 | 149 | 104 | 44,325 | | | 71,848 |
| Willow Springs | Gregg | - | 5,400 | 213 | 4,120 | 0 | 12 | 62 | 16,500 | | | 26,300 |
| Willow Springs | Gregg | 6,650 | 1,040 | 103 | 2,720 | 0 | 38 | 12 | 6,300 | | | 10,200 |
| Lansing, N. | Harrison | - | 17,500 | 1,400 | 14,300 | 0 | 314 | 204 | 107,200 | | | 172,300 |
| | | 6,965 | 8,900 | 243 | 7,660 | 0 | 94 | 65 | 28,200 | | | 45,200 |
| | | - | 11,900 | 912 | 6,490 | 0 | 49 | 181 | 33,600 | | | 53,100 |
| | | - | 4,500 | 182 | 11,400 | 0 | 0 | 28 | 26,100 | | | 42,200 |
| | | - | 8,600 | 243 | 10,700 | 28 | 48 | 56 | 32,400 | | | 52,100 |
| | | - | 30,700 | 3,830 | 5,690 | 0 | 6 | 195 | 76,000 | | | 116,400 |
| | | - | 3,050 | 134 | 1,000 | 0 | 348 | 50 | 7,100 | | | 11,700 |
| | | - | 730 | 24 | 268 | 0 | 146 | 16 | 1,680 | | | 2,860 |
| | | | | | JAMES LS. (KCGR) | | | | | | | |
| Fairway | Henderson | 9,819-9,829 | 16,688 | 1,407 | 47,234 | - | 244 | 520 | 106,025 | 1.117 | .049 | 172,118 |
| | | 9,899-10,024 | 17,400 | 1,760 | 46,840 | 0 | 76 | 240 | 108,000 | 1.120 | .049 | 174,316 |

**ppm

| Field | County | Depth | Constituents, Mg/liter |  |  |  |  |  |  | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl |  |  |  |
| JAMES LS. (KCGR) Continued |  |  |  |  |  |  |  |  |  |  |  |  |
|  |  | 10,164-10,285 | 20,700 | 1,880 | 38,930 | 0 | 80 | 240 | 102,000 | 1.148 | .054 | 163,830 |
| Frankston | Henderson | 10,050-10,064 | 23,100 | 1,887 | 56,000 | 10 | 129 | 223 | 132,600 | 1.160 | .046 | 213,939 |
| Tyler, S. | Smith | 9,920-10,000 | 15,300 | 1,500 | 70,900 | 0 | 0 | 835 | 140,100 | 1.158 | .047 | 228,635 |
| PETTET (KCGRL) |  |  |  |  |  |  |  |  |  |  |  |  |
| Tennessee Colony | Anderson | 9,700 | 521 | 48 | 1,417 | 0 | 57 | 9 | 3,216 |  |  | 5,273 |
| Trawick | Nacogdoches | 7,945-8,035 | 18,295 | 1,820 | 60,364 | - | 92 | 265 | 131,000 |  |  | 211,936** |
| Lansing, N. | Harrison | 7,595 | 22,800 | 1,820 | 54,300 | 30 | 378 | 256 | 129,000 |  |  | 209,000 |
|  |  | 7,595 | 7,950 | 420 | 7,860 | 89 | 92 | 109 | 27,300 |  |  | 43,700 |
|  |  | 7,595 | 24,700 | 121 | 14,600 | 0 | 18 | 132 | 66,600 |  |  | 106,000 |
|  |  | 7,595 | 17,800 | 912 | 8,630 | 0 | 0 | 163 | 47,400 |  |  | 74,900 |
| Danville | Gregg | 7,320 | 17,900 | 2,370 | 53,300 | - | 45 | 224 | 114,000 |  |  | 188,036** |
|  |  | 7,320 | 15,300 | 1,570 | 39,000 | - | 50 | 125 | 93,500 |  |  | 149,714** |
|  |  | 7,320 | 14,900 | 1,600 | 27,000 | - | 0 | 45 | 73,600 |  |  | 117,395** |
|  |  | 7,320 | 14,500 | 1,500 | 31,300 | - | 135 | 125 | 79,000 |  |  | 126,697** |
| Tennessee Colony Colony | Anderson | - | 2,023 | 708 | 2,023 | 152 | - | - | - |  |  | 17,800 |
|  |  | 9,654-9,684 | - | - | - | - | - | - | - |  |  | 51,000 |
| Elysian | Harrison | 5,960 | 4,120 | 309 | 7,211 | 82 | - | - | - |  |  | 45,200 |
| Kildare | Cass | - | 348 | 581 | 4,644 | 81 | - | - | - |  |  | 246,400 |
|  |  | 6,618-6,620 | 1,500 | 150 | 5,000 | 350 | - | - | - |  |  | 248,000 |
| Carter-Gragg | Navarro | 6,832-6,842 | 20,500 | 2,070 | 66,076 | 81 | 49 | 213 | 108,100 | 1.127 | .052 | 197,008 |
| Cornersville | Franklin | 8,260-8,282 | 35,800 | 2,123 | 61,900 | 350 | 18 | 138 | 164,900 | 1.185 | .046 | 264,879 |
| Groesbeck | Limestone | 5,604-5,762 | 11,147 | 1,452 | 42,663 | - | 106 | 478 | 89,352 | 1.103 | .057 | 145,198 |
| Henderson | Rusk | 7,262-7,270 | 20,700 | 2,300 | 50,900 | 0 | 0 | 538 | 121,400 | 1.133 | .049 | 195,838 |
| Kildare | Cass | 6,686-6,690 | 30,300 | 2,590 | 57,200 | 0 | 64 | 363 | 149,000 | 1.162 | .046 | 239,517 |
| Longwood | Harrison | 5,626-5,646 | 13,000 | 1,810 | 46,210 | 0 | 110 | 232 | 99,300 | 1.114 | .052 | 160,662 |
| Manziel Brothers | Smith | 8,050-8,060 | 24,200 | 6,600 | 36,400 | 173 | 61 | 297 | 117,900 | 1.136 | .053 | 185,458 |
| New Hope | Franklin | 7,386 | 26,935 | 1,870 | 63,670 | - | 120 | 227 | 151,053 | 1.167 | .045 | 243,875 |
|  |  | 8,072 | 29,476 | 2,524 | 58,982 | - | 52 | 228 | 150,300 | 1.169 | .044 | 241,562 |

| | | | Constituents, Mg/liter | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Field | County | Depth | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
| PETTET (KCGRL) Continued | | | | | | | | | | | | |
| Pittsburgh | Camp | 7,885-8,020 | 26,700 | 1,900 | 55,600 | 0 | 0 | 2,700 | 136,500 | 1.162 | .048 | 223,400 |
| | | 7,970-8,111 | 22,000 | 2,100 | 44,400 | 0 | 0 | 0 | 113,500 | 1.135 | .052 | 182,000 |
| | | 7,838-7,923 | 32,840 | Trace | 56,700 | - | 200 | 285 | 145,000 | 1.157 | .047 | 235,025 |
| | | 7,956 | 29,580 | 2,280 | 58,750 | - | 354 | 220 | 149,200 | 1.160 | .046 | 240,384 |
| Teague, W. | Freestone | 7,340-7,424 | 21,492 | 2,255 | 61,949 | - | 38 | 440 | 140,000 | 1.138 | .042 | 226,174 |
| Waskom | Harrison | 5,820-5,830 | 19,950 | 2,620 | 59,160 | - | 24 | 337 | 133,900 | 1.150 | .046 | 215,991 |
| | | 5,824-5,830 | 18,650 | 2,430 | 62,742 | 0 | 122 | 355 | 136,500 | 1.151 | .046 | 220,799 |
| Woodlawn | Harrison | 6,673-6,786 | 24,000 | 2,150 | 50,900 | 163 | 30 | 304 | 127,000 | 1.148 | .047 | 204,384 |
| | | 6,773-6,786 | 24,700 | 2,540 | 55,565 | 345 | 122 | 298 | 136,500 | 1.155 | .045 | 219,725 |
| | | 6,788-6,796 | 23,600 | 2,320 | 56,613 | 200 | 43 | 263 | 135,600 | 1.152 | .046 | 218,439 |
| TRAVIS PEAK (KCTP) | | | | | | | | | | | | |
| Carthage | Panola | 6,081-6,090 | 19,255 | 1,598 | 77,000 | - | - | 325 | 119,000 | 1.145 | .042 | 217,178 |
| | | 6,094-6,100 | 20,210 | 2,171 | 80,055 | - | - | 254 | 123,645 | 1.151 | .042 | 226,335 |
| | | 6,101-6,108 | 20,609 | 1,930 | 78,865 | - | - | 280 | 121,835 | 1.149 | .042 | 223,519 |
| | | 6,102-6,105 | 20,041 | 1,508 | 79,307 | - | - | 307 | 122,493 | 1.149 | .042 | 223,656 |
| | | 6,103-6,105 | 20,234 | 1,870 | 80,200 | - | - | 302 | 123,900 | 1.151 | .042 | 226,506 |
| | | 6,104-6,108 | 19,426 | 1,809 | 83,500 | - | - | 272 | 128,800 | 1.155 | .042 | 233,807 |
| | | 6,118-6,122 | 19,495 | 1,930 | 77,500 | - | - | 258 | 119,700 | 1.133 | .042 | 218,883 |
| | | 6,133-6,147 | 19,754 | 1,870 | 79,300 | - | - | 304 | 122,500 | 1.149 | .042 | 223,728 |
| Fruitvale | Van Zandt | 8,552-8,570 | 31,300 | 2,850 | 64,549 | 182 | Trace | 171 | 163,100 | 1.183 | .044 | 261,970 |
| | | 7,263-7,269 | 20,900 | 2,000 | 57,600 | 151 | 0 | 246 | 131,500 | 1.154 | .047 | 212,246 |
| | | 7,500-8,000 | 22,500 | 2,110 | 61,137 | 212 | 49 | 282 | 140,000 | 1.157 | .042 | 226,078 |
| Minden | Rusk | 7,461-7,475 | 20,300 | 2,100 | 62,500 | 627 | 0 | 0 | 138,300 | 1.162 | .045 | 223,200 |
| Waskom | Harrison | 6,100-6,200 | 18,328 | 1,866 | 60,622 | 0 | 112 | 335 | 131,025 | 1.141 | .043 | 212,288 |
| | | 6,101-6,170 | 14,800 | 1,930 | 56,700 | 586 | 0 | 320 | 119,000 | 1.134 | .050 | 192,750 |
| | | 6,193-6,239 | 16,700 | 1,840 | 43,100 | 76 | 293 | 237 | 101,000 | 1.116 | .055 | 163,170 |
| | | 6,188-6,194 | 18,100 | 2,040 | 55,300 | 581 | 0 | 230 | 123,000 | 1.137 | .049 | 198,670 |
| | | 6,236-6,246 | 20,750 | 2,210 | 59,561 | 1,069 | 67 | 355 | 134,700 | 1.154 | .046 | 217,643 |
| | | 6,236-6,246 | 20,240 | 1,871 | 64,135 | - | 67 | 273 | 140,067 | 1.158 | .049 | 226,653 |

| Field | County | Depth | Constituents, Mg/liter |  |  |  |  |  |  | Sp. Gr. | Resistivity | Total Solids (mg/liter) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | Ca | Mg | Na | Ba-Sr | $HCO_3$ | $SO_4$ | Cl |  |  |  |
| TRAVIS PEAK (KCTP) Continued |  |  |  |  |  |  |  |  |  |  |  |  |
| McBee | Leon | 10,039-10,204 | 4,058 | 332 | 16,081 | 0 | 119 | 70 | 33,679 |  |  | 55,280 |
| Reka | Navarro | 6,960 | 23,066 | 577 | 8,073 | 231 | - | - | - |  |  | 256,000 |
| Henderson, S. | Rusk | 7,550-7,568 | 22,428 | 2,234 | 65,386 | 145 | 196 | 530 | 146,664 |  |  | 237,590 |
| Henderson | Rusk | 7,475 | 15,390 | 1,440 | 46,685 | - | 25 | 154 | 104,076 |  |  | 168,218 |
| Carthage | Panola | 6,086-6,092 | 197 | 14 | 377 | - | 60 | 4 | 935 |  |  | 2,244 |
|  |  | 6,414 | 19,865 | 1,325 | 70,077 | - | 12 | 237 | 146,387 |  |  | 239,425 |
|  |  | 6,243-6,264 | 27,380 | 2,194 | 68,466 | - | 309 | 943 | 159,453 |  |  | 258,745 |
|  |  | 6,672-6,690 | 22,677 | 1,222 | 67,456 | 1,360 | 29 | 398 | 149,847 |  |  | 244,341 |
| Waskom | Harrison | 6,184-6,195 | 17,380 | 1,128 | 53,828 | - | 27 | 489 | 116,095 |  |  | 190,638 |
| Lansing, N. | Harrison | - | 520 | 55 | 1,743 | - | 400 | 120 | 3,450 |  |  | 6,288 |
|  |  | 7,800 | 21,603 | 1,684 | 62,180 | - | 100 | 392 | 138,656 |  |  | 218,915 |
|  |  | - | 1,377 | 109 | 3,776 | - | 61 | 40 | 8,523 |  |  | 15,238 |
|  |  | - | 3,043 | 72 | 1,946 | - | 414 | 76 | 8,318 |  |  | 16,681 |
| Bethany | Harrison | 6,241-6,265 | 600 | 100 | 3,000 | 200 | - | - | - |  |  | 125,000 |
|  |  | 5,760 | 10,820 | 541 | 5,410 | 325 | - | - | - |  |  | 126,600 |
|  |  | - | 11,421 | 343 | 9,137 | 171 | - | - | - |  |  | 238,100 |
| Fruitvale | Van Zandt | 8,552-8,570 | 39,368 | 2,153 | 81,127 | - | 90 | 260 | 200,774 |  |  | 323,772 |
|  |  | - | 4,734 | 473 | 9,469 | 473 | - | - | - |  |  | 331,300 |
| Manziel | Wood | 8,009-8,915 | 25,640 | 2,790 | 63,268 | - | 179 | 212 | 152,238 |  |  | 246,599 |
|  |  | - | 22,749 | 1,675 | 46,681 | - | 8 | 58 | 117,280 |  |  | 188,783 |
|  |  | 8,886-8,903 | 19,725 | 1,115 | 37,343 | - | 100 | 64 | 95,758 |  |  | 154,307 |
| Bryan's Mill | Cass | 7,915-8,155 | 24,192 | 2,590 | 47,049 | - | 221 | 500 | 122,522 |  |  | 197,254 |
| Linden, E. | Cass | 7,689-7,724 | 22,061 | 2,030 | 46,130 | - | 247 | 1,968 | 114,431 |  |  | 186,866 |

# Appendix B. Pressure/Depth Data from saline formations, East Texas Basin.

Raw data from Petroleum Information, Inc.

East Texas Waste Isolation

Deep Basin Hydrology

The raw data displayed in Appendix B were purchased as Proprietary Data under agreement with Petroleum Information Corporation and cannot be shown in the final report. However, interpretations of these data are included in the body of this report. For further information contact the Bureau of Economic Geology.