GEOLOGIC STUDY OF THE INTERIOR SALT DOMES
OF NORTHEAST TEXAS SALT-DOME BASIN
TO INVESTIGATE THEIR SUITABILITY
FOR POSSIBLE STORAGE OF RADIOACTIVE WASTE MATERIAL

May 1976

This report was prepared by Netherland, Sewell & Associates, Inc. under Purchase Order Subcontract 78X-99939V with Union Carbide Corporation, Nuclear Division. The subcontract was administered by Oak Ridge National Laboratory and the Office of Waste Isolation.

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*prepared for the U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
under U.S. GOVERNMENT Contract W-7405 eng 26*

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SUMMARY OF FINDINGS

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The purpose of this study, which focused on the interior salt domes of the Northeast Texas Salt-Dome basin, was (1) to investigate the movement and hydrologic stability of these domes, (2) to identify one or more of these study domes which appear most suitable for further study and consideration, and (3) to outline the additional information needed to more thoroughly evaluate these domes. Our findings are summarized as follows:

LOCATION AND SURROUNDINGS

The interior salt domes of the Northeast Texas Salt-Dome basin are located along the northeast-southwest trending central axis of what is commonly referred to as the East Texas basin or the Tyler basin. The domes are located in an area approximately 60 miles long and 20 miles wide, from 15 miles north of Tyler to 10 miles southwest of Palestine. The terrain is characterized by low, rolling hills and a fertile topsoil utilized for farming and cattle grazing. Rainfall averages 45 to 50 inches per year; the winters are mild and the summers are humid and hot. In addition to the larger population centers such as Tyler (population about 100,000), Palestine (about 15,000), and Athens (about 10,000), small towns and a sizeable rural population are scattered rather evenly throughout the area. The rural population has increased noticeably during the past decade, as residents have moved from the population centers to the open countryside. Many of these residents continue to work in the population centers while living in these rural areas.

STABILITY OF THE DOMES

Kinetic or Movement Stability

Our findings indicate that the growth of the interior salt domes of the Northeast Texas Salt-Dome basin has slowed with geologic time and that, at present, their growth has slowed to a minimum or has halted altogether. Uplifting of the geologic beds above the Wilcox indicates that some growth has occurred during the past 50 million years since Wilcox time; the average rate of uplift during that period is indicated to be approximately 0.006 mm. per year, or an equivalent uplift in a 200,000 year period of approximately 4 feet. The fact that the Northeast Texas Salt-Dome basin is in a geologic period of emergence and erosion (the opposite of sediment deposition, which contributes to the growth of salt domes) suggests that the growth of these domes has halted altogether.

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Hydrologic or Water Dissolution Stability

Our findings indicate that Bullard, Whitehouse, and Keechi domes probably are not subject to significant dissolution of salt at the present time and, for practical purposes, likely can be considered hydrologically stable. However, because good data are limited on the subsurface flow of water around these domes, it is recommended that shallow water wells be drilled and tested to obtain additional data for more thorough evaluation of the indicated hydrologic stability of these domes.

We found no evidence of active salines or salt water springs, etc., near these three domes and our studies of the near-surface geology and the groundwater regime of the areas near these domes indicate conditions which likely would preclude the active dissolution of salt by circulating groundwater at this time. However, caprock found at Bullard and Whitehouse domes indicate that salt dissolution has occurred at some period during the past 50 million years since the Wilcox (the main fresh water aquifer in the area) was deposited. Caprock is found over only a portion of the Keechi dome. If the 150 feet of caprock at Bullard dome and the 100 feet at Whitehouse dome were formed by the dissolution of salt with one percent insoluble, anhydritic impurities during the 50 million years since deposition of the Wilcox, the rate of salt dissolution for these two domes would have averaged 0.0915 and 0.061 mm. per year for this period, or an equivalent salt dissolution during a 200,000 year period of approximately 60 and 40 feet respectively.

The question of using caprock formation as a guide to probable rates of salt dissolution becomes moot if there is no salt dissolution taking place at the study domes. Therefore, the major objective of this study has been to identify those domes where evidence indicates that no significant dissolution of salt is taking place at the present time. While data available to date indicate that Bullard, Whitehouse, and Keechi domes may meet this requirement, these data are not sufficient to confirm this. Thus, as indicated above, it is recommended that shallow water wells be drilled and tested to obtain additional data for more thorough evaluation of the hydrologic conditions surrounding these domes.

ADDITIONAL INFORMATION REQUIRED

A considerable amount of additional information is required to completely evaluate these domes. The purposes for which these additional data are needed together with the general method of obtaining these data may be summarized as follows:

I. To evaluate more thoroughly the salt dissolution or hydrologic stability of the study domes -

(1) Data on subsurface fresh water flow - A series of shallow water wells to be drilled and salinities of water tested to determine if there are any indications that salt dissolution is taking place from these domes and, if so, to serve as the basis of studying salinity patterns and determining quantities of salt being dissolved.

(2) Data on surface runoff water - Samples of runoff water obtained, if possible, and analyzed to determine if there are any indications that salt is being dissolved from these domes and brought to the surface and, if so, to serve as the basis of determining quantities of such salt being dissolved.

(3) Data on caprock and its relation to salt dissolution - Core samples of both caprock and salt to determine the composition and physical characteristics of the caprock and to determine the percent of insoluble impurities in the salt; all to be used in studies to correlate the formation of caprock with the rate of salt dissolution.

II. To examine the evidence of salt dome movement, if any, during recent geologic time -

Study of near-surface alluvium or terrace deposits, if present over or nearby these salt domes, likely would reveal any uplifting or warping by rising salt domes during recent geologic time. We did not observe such deposits on or near Bullard, Whitehouse, or Keechi domes, but a series of shallow boreholes might find such deposits which could be studied.

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III. To define more precisely the size, shape, and configuration of the study domes -

(1) Core-hole data - A series of core holes, carefully located, drilled into the salt dome for more precise measurement of the position of the dome, thickness of caprock, presence of overhangs, and physical characteristics of the caprock and the salt.

(2) Gravity data - A carefully planned program of gravity surveys used in conjunction with core holes, core samples, and other well data relating to the depths and positions of the upper part of a shallow dome would aid in determining the size, shape, and configuration of a dome. Nettleton (1976) describes an approach combining gravity studies with core-hole drilling for purposes of delineating the configuration of a salt dome.

(3) Seismic Data - One or two seismic lines across the salt dome, used in conjunction with gravity data and core-hole data, would aid in delineating the configuration of the dome. As discussed in more detail in the Geophysical Section of this report, we believe there are certain limitations to the use of currently available seismic data for this purpose and such data should be used with caution. It is our belief that the planning, running, and analyzing of both seismic and gravity surveys should be done by professional and experienced geophysicists.

IV. Other Data -

Also, data other than that specified above may be needed on such subjects as (1) the presence of caprock draped over the flanks of some of these domes; (2) the more precise definition of the rates and patterns of subsurface groundwater flow near the domes and throughout the groundwater regime of the basin; (3) the physical reactions taking place at the salt-caprock interface; and (4) other phenomenon associated with water dissolution, caprock formation, domal growth, vertical salt movement, etc.

DOME STABILITIES

The interior salt domes of Northeast Texas are indicated to be rugged, sharp-edged, irregular but generally cylindrical cores of salt, one-to-five miles or more in diameter. The tops of some of these domes come to within 200 to 600 feet of the surface. The base of these domes are attached to the thick Louann (Mother) Salt beds, from which the domes originated. These beds are indicated to be as much as 5,000 feet or more in thickness and are found at depths of 20,000 to 22,000 feet in the deepest portion of the basin.

Geologic studies indicate that these domes grew to their present position at slow, irregular, and generally decreasing rates during past geologic time; the average rate at which the rising domes uplifted overlying geologic beds during the last 50 million years is indicated to be in the range of 0.006 millimeters per year, or an equivalent uplift during a 200,000 year period of approximately 4 feet. These data also indicate that the tops of these domes at the present time probably are not rising at all.

If fresh water sands come in contact with the tops of these domes, circulating fresh groundwater will dissolve salt from the top and upper flanks of the domes. Thus, one of the major objectives of this study was to identify those salt domes where such fresh water zones are not in contact with the core of the dome and where no dissolution of salt is currently taking place. The fresh water zones in the Northeast Texas Salt-Dome basin are depicted on illustrative Exhibit 2. When fresh water dissolves salt from a dome, the one-to-two percent of insoluble anhydritic impurities in the salt are deposited and form hard caprock across the top of the dome. The rate at which the caprock was formed gives an indication of the rate at which salt has been dissolved in the past.

MOVEMENT STABILITY

The investigation of the movement stability of these domes focused on the subjects of (1) the source material or "Mother" salt from which these domes formed, (2) the conditions and causes associated with the formation and growth of these domes, (3) the rates of salt dome movement during various geologic time intervals, and (4) the present status of the domes as relates to any currently indicated movement of the salt stock.

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These subjects were examined by studying (1) the history of sediment deposition in the basin, (2) the Louann or "Mother" Salt and its relationship to the basin and to the initiation and growth of the subject salt domes, (3) the structural and tectonic framework of the basin, and (4) the stratigraphy and indicated "uplift-vs-time" values for the various geologic formations of the basin.

The GEOLOGIC SECTION of this report sets forth the results of studies concerning the structural framework and the stratigraphy of this basin from the Louann Salt, found at a depth of approximately 20,000 to 22,000 feet in the deepest portion of the basin, upward through the Jurassic, the Lower and Upper Cretaceous, and the Tertiary beds. The GEOLOGIC EXHIBITS, G-1 through G-47, reflect the changes in structural configuration and formation thicknesses as a result of the uplifting, deforming, and piercing of these formations by the salt domes.

The times of salt dome growth and the rates at which these domes grew probably are best reflected by "uplift-vs-time" values for the various formations as the upward moving salt stock uplifted these formations. Exhibit 3 indicates the "uplift-vs-time" values for the domes included in this study, together with an average "uplift-vs-time" value for various geologic intervals from Jurassic, through the Lower Cretaceous, the Upper Cretaceous, the Midway-Wilcox portion of the Tertiary, and the beds above the Wilcox. These "uplift-vs-time" values have generally decreased from an indicated average of 0.153 mm. per year for the Upper Jurassic to 0.044 mm. per year for the Lower Cretaceous, 0.020 for the Upper Cretaceous, 0.031 for the Midway-Wilcox portion of the Tertiary, and 0.006 mm. per year for the 50 million year period represented by the beds above the Wilcox.

The Wilcox beds overlying the domes included in this study have been arched-up an average of approximately 1,050 feet during the 50 million years since Wilcox time. This indicates an average uplift rate of approximately 0.006 mm. per year during this 50 million year period, or an equivalent uplift during a 200,000 year period of approximately 4 feet. The general decline in uplift with time indicates that the growth of these domes has declined to a minimum and may have halted altogether. Also, the fact that the Northeast Texas Salt-Dome basin is in a geologic period of emergence and erosion (the opposite of sediment deposition, which contributes to the growth of salt domes) further suggests that the growth of these domes has halted altogether.

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HYDROLOGIC STABILITY

The hydrologic (water dissolution) stability of the subject salt domes was examined by studying (1) the hydrologic or groundwater regime of the basin, (2) the reported salinities of water from shallow water wells, (3) the reported salinities of surface runoff water, and (4) the caprock present over most of the domes of this basin.

Exhibit 2 is an illustrative sketch showing the fresh water zones near the surface in the Northeast Texas Salt-Dome basin. These fresh water zones are fed by rainfall which averages 45 to 50 inches per year for the area. When the fresh water zones come in contact with the salt in the salt domes, the subsurface flowing water will dissolve the salt and carry it away, either downstream through the aquifer, or upward to the surface through porous sediments or along fractures as depicted on the illustrative exhibit. Water that comes to the surface over domes generally is found in saline creeks or salt water springs. Such salines, salt water springs, and salt prairies are found over or near the Steen, Mount Sylvan, and Palestine salt domes. No such salines or springs are found at Bullard, Whitehouse, and Keechi salt domes.

Removal of salt from domes by subsurface water flow is generally indicated by salt water plumes downstream from the dome as reflected by the presence of saline water in shallow water wells, special test wells, or in the outflow of subsurface water into the deeper stream beds or channels in the area. Studies of the available water well data for the area reveal no evidence of salt plumes or other indications that subsurface water flow is currently removing salt from the domes in the study area. As set forth in other sections of this report, it is recommended that shallow water wells be drilled around the Bullard, Whitehouse, and Keechi salt domes and tested to obtain additional data on the subsurface water flow near these domes. Such data would serve as a basis for more thorough evaluation of the indicated hydrologic stability of these domes.

The caprock present over most of the salt domes of this basin provides an indication of the rates at which water dissolved salt from the top of these domes during the past. It is believed that the caprock was formed when salt was dissolved by water, leaving behind a deposit of the insoluble, anhydritic impurities which existed in the salt. These insoluble impurities are believed to constitute approximately one to two percent of the salt found in these salt domes. Thus, the formation of one foot of caprock would have resulted from the dissolution of 100 feet of one percent impurity salt, but would have required the dissolution of only 50 feet of two percent impurity salt.

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Five of the six domes investigated have caprock ranging in maximum thickness from 50 to 300 feet. No caprock has been found at Mount Sylvan dome. Assuming that all the caprock formed during the approximately 50 million years since deposition of the Wilcox sand (the main aquifer in the area), then the maximum rate of salt dissolution for this period would have averaged 0.031 to 0.183 mm. per year, or an equivalent maximum salt dissolution during a 200,000 year period of 20 to 120 feet. If the salt in the Northeast Texas salt domes has more than one percent insoluble impurities from which the caprock was formed, these indicated rates of salt dissolution would be reduced proportionally. In the formation of caprock, it is believed that a large portion of the salt dissolved from the top of the dome is replaced by internal upward movement of salt inside the salt stock, such that the internal core of the dome can be rising to replace the dissolved salt even though the top of the dome is showing no net vertical rise.

The question of caprock and the validity of using its formation in calculating the probable rates of salt dissolution becomes moot if there is no salt dissolution taking place at a particular salt dome. Thus, a major objective of this study has been to identify those salt domes where fresh water zones are not in contact with the core of the dome and/or where geologic and hydrologic data indicate that no dissolution of salt is currently taking place.

Our geologic studies and the available data on the surface and subsurface fresh water regime indicate that probably no dissolution of salt is currently taking place at Bullard, Whitehouse, and Keechi domes and that these domes likely can be considered hydrologically stable. However, as set forth in other sections of this report, it is recommended that shallow water wells be drilled around these domes and tested to obtain additional data for more thorough evaluation of the indicated hydrologic stability of these domes.

In summary, this study indicates that (1) the growth of the subject salt domes has declined to a low minimum and may have halted altogether; (2) there is no evidence that dissolution of salt is currently taking place at Bullard, Whitehouse, and Keechi domes and these domes probably are hydrologically stable; and (3) additional shallow water wells should be drilled to obtain data for more thorough evaluation of the indicated hydrologic stability of Bullard, Whitehouse, and Keechi domes.

GENESIS AND GROWTH OF SALT DOMES

IN THE

NORTHEAST TEXAS SALT-DOME BASIN

SUMMARY

This discussion concerns the conditions and probable causes associated with the formation and growth of salt domes in the Northeast Texas Salt-Dome basin. Such conditions and probable causes are best examined by a careful study of the geology of the basin, including (1) the history of sediment deposition and compaction as reflected in the stratigraphy of the basin; (2) the depth, thickness, and physical characteristics of the Louann (Mother) Salt; and (3) the uplifting and deformation of the various formations by the rising salt stock. Probable rates of dome growth are best derived from geologic data such as "uplift-vs-time" values indicated for the various formations as upward moving salt stock uplifted these formations. Also, analysis of the caprock thickness and the source material from which the caprock was formed affords an indication of the probable rate of vertical movement of the salt in the dome. The geological studies of the Northeast Texas Salt-Dome basin by William A. Huckaba and the detailed studies of the domes by Chas. C. Bankhead, Jr., serve as a basis for examining the formation and growth of the salt domes of this basin.

Their studies reflect the uplift of the various sediments in the Jurassic, the Early and Late Cretaceous, and the Tertiary. It is noted that their studies indicate generally decreasing "uplift-vs-time" values from the Jurassic, through the Early Cretaceous, the Late Cretaceous, the Midway and Wilcox Groups, and the post-Wilcox beds. These decreasing "uplift-vs-time" values suggest that the rate of growth for the domes in the Northeast Texas Salt-Dome basin has decreased with time. Just as sinking of the basin and rapid deposition of sediments appear to contribute to increased rate of domal growth, it is likely that during period of regional emergence and erosion, as is the case in the Northeast Texas Salt-Dome basin at the present time, the growth of these salt domes has been reduced to a minimum or halted altogether. Any domal growth during Late Cenozoic time should be reflected by the uplifting or warping of any alluvium or terrace deposits found over or near these domes. Additional study of such alluvium or terrace deposits may be warranted.

Dr. William R. Muehlberger, Ph.D.

GENESIS AND GROWTH OF SALT DOMES
IN THE
NORTHEAST TEXAS SALT-DOME BASIN

Dr. William R. Muehlberger, Ph.D.

The conditions and probable causes associated with the genesis and growth of salt domes include (1) differential deposition of sediments, resulting in uneven loading which causes the salt to move out from under the heavier load; (2) basin tilt of salt and sediments along basin edges, causing up-dip "pull-apart" structures and down-dip creep and broad folding; (3) buoyancy resulting from density differences between "light" salt and overlying "heavy" compacted clastic or carbonate sediments which produce an unstable condition in which the salt tends to rise where local stress minima are produced; and (4) other factors such as horizontal compression, compaction, etc.

Salt found in thick beds buried under heavy sediments and existing under conditions indicated above tends to move from under the heavier portions of the overburden and form swells and pillows from which the "light" salt emerges and commences its diapiric upward movement. The diapir moves essentially as a cylinder of salt, commonly referred to as a salt plug or stock. Most such stocks are one to two miles in diameter. Salt in the rising stock is fed by lateral flow of salt from the underlying salt bed through the base of the salt stock and then vertically upward into the dome. Martinez, Kupfer, et al. (1975) describe the stages of salt movement usually associated with the genesis and growth of salt domes.

Interpretations concerning the rates of salt dome growth range from (1) a continuous, constant slow uplift; (2) a series of spasmodic, non-uniform uplifts; to (3) a single, violent uplift. Martinez, et al. (1975) categorize the three types as continuous, pulsating, and single-pulse. Nearly all workers subscribe to the pulsating category in which uplift is spasmodic and non-uniform but relatively slow. The uplift of salt in spines of smaller diameter than the main salt mass (Muehlberger, 1960; Kupfer, 1974) can result in the center of the salt stock shifting laterally as it moves upward. The rate of salt dome growth is increased by rapid deposition of sediments in a relatively rapid sinking basin such as the present Gulf Coastal area and is diminished, and perhaps halted altogether, during periods of non-deposition or regional emergence such as exists in the Northeast Texas area.

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The rate at which the top of a salt dome rises is derived from the deformed shapes of geologic time markers by the moving salt stock. This uplift is reflected in the structure and stratigraphy of the beds overlying the dome and by the size of the rim syncline at various stratigraphic levels adjacent to the salt dome. Calculation of "uplift-vs-time" values for various geologic intervals indicates that salt dome growth rates varied during different periods of geologic time and, in general, shows a decreasing rate through time as the centers of rapid sedimentation moved southward toward the Gulf Coast. The thickness of caprock overlying many domes also gives an indication of the amount of vertical salt movement inasmuch as the caprock is believed to be the accumulation of the relatively insoluble anhydrite as the salt is dissolved from the top and/or flanks of the dome. If the anhydrite-to-salt ratio in the salt dome is the same as in sea water, then each foot of caprock (anhydrite) represents about 30 feet of dissolved salt dome. If the ratios vary, as they do across an evaporite basin, then the proportions will change and the estimate of removed salt dome will be wrong by an undetermined amount. Present knowledge of the salt/anhydrite content in Northeast Texas domes suggests, however, that the normal sea water assumption is reasonable.

Upward growth of a salt dome may be halted by (1) depletion of replacement salt at the base of the dome; (2) resistance encountered in the overlying sediments, including resistance by drag between the salt stock and surrounding sediments; (3) the neutralization of the buoyancy effect as the salt core penetrates shallower sediments that have not been compacted into high density beds; or (4) the dome encounters a fresh-water regime which, as it dissolves the top of the emerging dome, develops a caprock which, upon growing down to the base of the moving ground-water zone, will both seal off further dissolution and by its own massive structure will offer further resistance to the upward growth of the dome.

The Louann Salt, found at an approximate depth of 20,000 to 22,000 feet in the deepest portion of the Northeast Texas Salt-Dome basin, serves as the source material for the formation and growth of the salt domes in this basin. The history of sediment deposition in the Jurassic and Early Cretaceous indicates that deltaic sedimentation, with accompanying uneven loading, existed in the early life of this basin. Basin tilting resulted in down-dip creep of the sediments and salt. As the basin sank and the thickness of the overlying sediments increased, compaction increased the density of these sediments beyond the density of the "light" salt, at which point the "light" salt underlying the heavy compacted sediments established an unstable buoyancy condition between the salt and the overlying sediments. The initiation of salt dome growth in the basin was probably caused when this instability reached a critical level by continuing differential or deltaic sedimentation and regional tilt.

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The accompanying geologic studies by William A. Huckaba and Chas. C. Bankhead, Jr., indicate uplift of the rising salt domes in the Jurassic, the Early and Late Cretaceous, and the Tertiary. Their studies indicate generally decreasing "uplift-vs-time" values for the successive geologic units listed: Jurassic through the Early Cretaceous, the Late Cretaceous, the Midway and Wilcox Groups, and the post-Wilcox beds. These decreasing "uplift-vs-time" values suggest that the rate of growth for the domes of the Northeast Texas Salt-Dome basin decreased with time. Their studies also indicate that the rates of domal uplift have not been uniform even though the trend has continued to reflect decreasing uplift with time. Just as higher rates of uplift accompanied the rapid deposition of sediments into the sinking basin, slower sedimentation rates resulted in slower uplift rates, and it is likely that during periods of regional emergence and erosion, as is the case in the Northeast Texas Salt-Dome basin at the present time, these uplift rates for the domes of this basin have been slowed to a minimum or halted altogether.

A thorough geologic study of the stream (modern and ancient) deposits found over and near the salt domes of this basin should indicate whether or not uplift resulting from dome growth has continued during Late Cenozoic time. This study will require the drilling of shallow boreholes from which samples can be obtained for an analysis of whether the stream profile over the dome has been changed and whether movements of the dome affected the erosion, transportation, and sedimentation regime of the stream. A brief study of available maps shows no readily identifiable anomalies in drainage patterns that can be ascribed to recent domal uplift.

REGIONAL GEOLOGY
OF THE
NORTHEAST TEXAS SALT-DOME BASIN

SUMMARY

This regional study is part of an investigation of the tectonic and hydrologic stability of certain salt domes of the Northeast Texas Salt-Dome basin. It concerns the subsurface geologic framework and stratigraphy of the basin, the relationship of the Louann or "Mother" Salt to the basin, as well as the genesis and growth of the salt domes located in this basin.

The Northeast Texas Salt-Dome basin is an embayment within the broad Gulf Coast basin. Prior to Jurassic time, the area had a complex geologic history that ended with deposition of thick Triassic red-beds, block faulting, and beveling by erosion. As the basin sank, it became the repository of a thick section of Jurassic, Cretaceous, and Tertiary sediments. It is theorized that salt beds of the Louann Formation near the base of this sequence became unstable early in the cycle of deposition. Movements of the salt and the overlying sediments created ridges, domes, and troughs that continued to develop as younger deposits accumulated in the sinking basin.

During, or prior to, Early Cretaceous time, the salt in the central part of the basin became buried deeply enough to initiate growth of piercement salt domes in the troughs. A few of the piercement domes ceased growing as diapiric features during the Cretaceous, but most of them rose to within a few hundred feet of the present surface. Our findings indicate no significant upward movement of the "top-of-salt" of the shallow domes of this basin at the present time. There are indications of some interior salt movement, confined primarily to replacement of the salt being leached out by upwelling groundwater around and over some, but not all, of the domes.

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TABLE OF CONTENTS

<u>GEOLOGICAL DISCUSSION</u>	<u>Page No.</u>
INTRODUCTION	G- 1
STRATIGRAPHY	G- 3
PRE-JURASSIC	G- 3
JURASSIC	G- 3
LOWER CRETACEOUS	G- 4
UPPER CRETACEOUS	G- 5
POST-CRETACEOUS	G- 6
STRUCTURE	G- 8
HISTORICAL GEOLOGY	G- 9
SALT MOVEMENT	G-11
TYPES OF MOVEMENT	G-11
TIMES OF MOVEMENT	G-12
RATES OF MOVEMENT	G-12
ALLUVIUM OR TERRACE DEPOSITS	G-14
AS INDICATORS OF POSSIBLE RECENT MOVEMENT	
HYDROLOGY OF SALT DOMES	G-15
DISSOLUTION BY WATER	G-15
CAPROCK AND DISSOLUTION	G-15
GROUNDWATER AND DISSOLUTION	G-16
CURRENT RATES OF DISSOLUTION	G-17
GEOPHYSICAL ASPECTS	G-19

REGIONAL GEOLOGY
OF THE
NORTHEAST TEXAS SALT-DOME BASIN

William A. Huckaba

INTRODUCTION

This study investigates the subsurface geologic framework and stratigraphy of the Northeast Texas Salt-Dome basin, the Louann or "Mother" Salt as it relates to the basin, the genesis and growth of the salt domes located in this basin, and the present tectonic and hydrologic stability of certain of these salt domes.

The Northeast Texas Salt-Dome basin (also known as the East Texas basin, the Tyler basin, and the Henderson embayment) occupies a large portion of northeastern Texas. Salt domes occur along the deep, central part of the basin; and this study concentrates on the areas of Anderson, Cherokee, Henderson, Smith, Van Zandt, and Wood Counties, where these salt domes are located.

Low, rolling hills characterize the topography of most of the study area. Elevations range from 200 feet to 700 feet above sea level. Major drainage of the area is to the southeast by the Sabine, Neches, and Trinity Rivers. Natural vegetation is mostly oak and pine forests on the sandy hills in the central part of the basin, whereas irregular, grassy plains characterize the clay soils that occur in the northern and western parts of the region. Population centers in the area include Tyler (about 100,000), Palestine (about 15,000), Athens (about 10,000), and Jacksonville (about 10,000). Small towns and a sizeable rural population are scattered rather evenly throughout the area.

Records of approximately 1,600 exploratory wells and 400 development wells were acquired and processed to provide data for subsurface studies of the basin. Structure maps of key horizons and isopachous maps of numerous stratigraphic intervals were constructed to determine the present configuration of the basin and its history of development. The maps considered most significant are presented in this report.

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An extensive search of the literature was made to obtain additional geological and geophysical information about the study area; the literature on salt domes in general was also researched. The accompanying bibliography lists some of the articles that were reviewed.

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STRATIGRAPHY

Exhibit G-1 shows the surface geologic map and stratigraphic column of the Northeast Texas Salt-Dome basin. Exhibit G-2 shows the subsurface stratigraphic column and Exhibit G-3 shows the regional relationships of the basin deposits along a west-to-east cross-section.

PRE-JURASSIC

Rocks older than Jurassic have not been penetrated by drilling in the study area. Therefore, opinions regarding the older rocks are drawn from information outside the area and are somewhat speculative.

Basement, Paleozoic, and Triassic rocks which underlie the basin probably have been subjected to geologic environments considerably different from those which have prevailed since the basin began to form. Studies by Vernon (1971) indicate the "floor" of the basin probably includes a sequence of marine Paleozoic sediments that culminated with the deposition of Permian red-beds. There is evidence that a thick section of Triassic red-beds (Eagle Mills Formation) covered the area at one time and that portions of these deposits may be preserved in down-thrown fault blocks under the basin.

JURASSIC DEPOSITS

Oldest known deposits that accumulated after the Northeast Texas basin began to form are the basal clastics and the anhydrite of the Werner Formation of Jurassic age.

The thick salt beds of the Louann Formation rest conformably on the Werner. These deposits extend across southern and eastern Texas, southern Arkansas, Louisiana, southern Mississippi, and southwestern Alabama. Folding, flowage, and diapirism have distorted the Louann Salt beds, making it difficult to estimate original thicknesses of the formation. Speculative estimates of maximum original thickness range upward to more than 5,000 feet of salt. It seems likely that the Northeast Texas basin sank more rapidly than the adjacent shelf areas under the Louann sea and was the site of greater salt accumulation. Withdrawal of the sea at the close of Louann time may have subjected the salt deposits to subaerial erosion in the northern part of the basin.

In Late Jurassic, the conglomerates, red-beds, and anhydritic clastics of the Norphlet Formation were laid down over the Louann. An

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incursion of the sea restored open marine condition in the basin, and the thick carbonates of the Smackover Formation were deposited conformably over the Norphlet. At the close of Smackover time, carbonate banks restricted marine circulation and the lagoonal evaporites of the Bucker Formation accumulated in the northern and western part of the basin. Re-incursion of the open sea across the basin resulted in deposition of the Cotton Valley Lime, the Bossier shales, and the Schuler sands of the Cotton valley Group. These units interfinger and, in general, thicken southward. To the north and west, all of the Upper Jurassic formations grade into undifferentiated continental clastics.

Detailed discussions of Jurassic stratigraphy in the Gulf Coast have been presented by Newkirk (1971), Nichols, et al (1968, 1964), Eaton (1961), Andrews (1960), and others.

Limited well data and seismic records (Becker, 1974) indicate that local deformation of the Louann Salt and overlying deposits within the Northeast Texas basin began in the Late Jurassic. The isopachous map of the interval from the top of the Cotton Valley to the top of the Louann Salt (Exhibit G-4) depicts the pattern of early thinning and thickening within the basin.

LOWER CRETACEOUS

The Lower Cretaceous is represented in the basin by a series of formations laid down by alternating regressions and transgressions of the seas. The near-shore and non-marine clastic deposition of the Late Jurassic continued, without apparent interruption, into the Cretaceous and is represented in the basin by the Travis Peak Formation. A return to marine sedimentation brought a varied succession of deposits as follows: the carbonates of the Sligo Formation; the Pine Island shale; the James Lime; the carbonates and clastics of the Rodessa Formation; the Massive Anhydrite; and the Upper Glen Rose carbonates and clastics. As the seas then receded, carbonates gave way to non-marine clastics, culminating with deposition of the Paluxy sands, shales, and red-beds. The final marine incursion of the Lower Cretaceous resulted in deposition of the series of limestones and shales of the Fredericksburg and Washita Groups.

More extensive descriptions of the Lower Cretaceous section can be found in published articles by Rainwater (1971), Nichols, et al (1968, 1964), Forgotsen (1956), and others.

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Isopachous maps of intervals below the Massive Anhydrite (Exhibit G-5), above the Massive Anhydrite (Exhibit G-6), and within the Washita-Fredericksburg (Exhibit G-7) show the pronounced local thickening and thinning imposed on the Lower Cretaceous deposits by contemporaneous growth of the troughs and ridges in the study area. Diapiric growth of salt domes in the troughs began before the end of the Lower Cretaceous.

Individual Lower Cretaceous rock units vary in thickness, but are uniform in lithology, with only a few facies changes attributed to local structures such as the James limestone development at Fairway field of Henderson County (Fox, 1963).

Prior to Late Cretaceous time, there were significant changes in the shapes of the Gulf Coast basins. A pronounced unconformity between the Upper Cretaceous and successively older Lower Cretaceous units is found northeast of the study area in Texas and southwestern Arkansas. Within the study area, this unconformity, if present, is not regionally pronounced. On local positive structures and on the Sabine uplift to the east, the contact between Upper and Lower Cretaceous deposits has been truncated by later uplift and erosion.

UPPER CRETACEOUS

Upper Cretaceous sedimentation in northeast Texas began with deposition of the non-marine and near-shore marine sands and shales of the Woodbine Group. The Woodbine is overlain conformably by the marine shales of the Eagle Ford Group.

After the close of Eagle Ford time, regional uplift in the Upper Gulf Coast and growth of local structures resulted in erosion and truncation, in some areas, of deposits down to and including the Travis Peak. The first positive growth of the Sabine uplift occurred at this time and, within the study area, several salt domes grew diapirically and developed salt overhangs.

Above the Eagle Ford, the Upper Cretaceous in the basin is characterized by a series of marine deposits that are predominantly chalks, shales, and marls. These are the Austin Group, the Taylor Group (including the Pecan Gap), and the Navarro Group (including the Nacatoch).

The Upper Cretaceous units of the basin have been described in greater detail by Steli, et al (1972), Holcomb (1971), Nichols, et al (1968, 1964), and Eaton (1956).

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Thickness patterns of the Upper Cretaceous sediments (Exhibits G-8, G-9, and G-10) are similar to those of the Jurassic and Lower Cretaceous in being related to the ridges and troughs, except in areas where diapiric salt domes stopped growing. Around LaRue and Concord salt domes, both of which ceased to penetrate overlying strata near the end of Early Cretaceous time, the troughs stopped sinking and became broad, ridge-like areas of uplift and thinning.

POST-CRETACEOUS

At the close of Late Cretaceous time, marine conditions prevailed over the Northeast Texas basin. At the start of the Tertiary, the marine shales of the Midway Group were deposited. The contact between the Midway and the underlying Navarro is believed to be unconformable, but the similarity of the shales of these two groups makes precise determination of the contact difficult. At the top of the Midway, the contact with the overlying sands of the Wilcox Group is gradational and marks a transition from marine to continental sedimentation. The Wilcox is the most important fresh-water aquifer in the study area. Also, it contains the largest commercial deposits of lignite in East Texas. Outcrops of the Wilcox cross the northwest part of the study area and are also exposed around many of the piercement salt domes (Exhibit G-11).

Youngest Tertiary beds in the study area are the Claiborne Group of non-marine and marine formations. This group rests unconformably on the Wilcox and is exposed at the surface in the central part of the basin (Exhibit G-1). Formations of the group are the Carrizo, Reklaw, Queen City, Weches, and Sparta. The Weches "greensand" is a glauconitic deposit which is the source of East Texas iron ore. Sparta sands cap the hills in the central part of the basin and, immediately south of the study area, are overlain by the Crockett and Yegua Formations of the Claiborne Group. It is possible that at one time some of the Crockett beds extended as far north as the study area. The seas never encroached beyond South Texas after Crockett time, and the only post-Crockett sedimentation in northeast Texas has been in the form of local lacustrine deposits, terrace deposits, and alluvium along the stream channels.

Considerable detailed information about the Tertiary of the area can be found in articles by White (1973), Guyton (1972), Lofton and Adams (1971), Nichols, et al (1968), Fisher (1965, 1963), Dillard (1963), Eaton (1956), Meyer (1939), Eckel (1938), Wendlandt and Knebel (1929), and others.

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Thickness variations in Tertiary deposits follow the pattern of the older rocks. Marked thinning occurred around and over the active salt domes, as illustrated by Exhibit G-11.

STRUCTURE

Major structural features adjacent to the present Northeast Texas basin are the Mexia-Talco fault system to the west and north, the Sabine Uplift to the east, and the Elkhart-Mount Enterprise fault system to the south. This framework encompasses a basin of approximately 100 miles in diameter, with the center of the basin being located near the City of Tyler. Thus, the basin is also referred to as the Tyler basin.

The structural shape of the basin in pre-Jurassic rocks can be only inferred because of the lack of deep test wells and the difficulty of obtaining reliable seismic reflections from formations below the Louann Salt. It is probably a relatively smooth, elongated bowl below the Jurassic evaporites. The Mexia-Talco fault zone may be related to basement structural movements on the west and north flanks of the basin. Growth of the Sabine Uplift has raised the east flank of the basin, and a low-relief shelf area appears to have existed periodically across the south margin of the basin.

Within the basin, the post-Louann sediments feature a series of northeast-southwest trending ridges and troughs. Broad, deep-seated salt domes are associated with the ridges whereas the shallow and intermediate depth piercement salt domes are located in the troughs (Exhibits G-12, G-13, G-14, G-15, and G-16. Up-to-the-trough normal faults (not shown on the structure maps) are present on the flanks of most of the ridges. Many of these faults are reported to die out upward and downward from their levels of major displacement in the Cretaceous. Local radial faults are generally associated with the salt domes and central grabens have developed over some of the deep uplifts.

Some of the publications that deal with the regional and local structures of the basin are Newkirk (1971), Flawn (1964, 1961), Bornhauser (1958), Coon (1956), Eaton (1952), and Branson (1950).

HISTORICAL GEOLOGY
(BASIN FORMATION, THE LOUANN SALT, AND RELATED SALT DOMES)

This study indicates that the Northeast Texas Salt-Dome basin began to take shape during the Early or Middle Jurassic. Prior to that time, the area had undergone orogenic processes having little relationship to later events and had been beveled by erosion.

As the Gulf Coast area began to subside, the Northeast Texas basin area sank at a somewhat faster rate and became the site of some of the thicker evaporite and sedimentary deposits of the Gulf Coast interior. Among these deposits are the thick salt beds of the Louann Formation which rest conformably on the Werner of Jurassic age. The Louann Salt beds extend across southern and eastern Texas, southern Arkansas, Louisiana, southern Mississippi, and southwestern Alabama. Folding, flowage, and diapirism have distorted the Louann Salt beds, making it difficult to estimate original thicknesses of the formation; however, evidence indicates original thickness ranges upward to more than 5,000 feet of salt. The depth of the Louann Salt at the deepest portion of the Northeast Texas basin is estimated to be approximately 22,000 feet below the present surface.

As the basin sank, the tilted sedimentary sections on the flanks tended to slide toward the central axis with the Louann Salt acting as the detachment surface. Wrinkles parallel to the flanks of the basin developed in the sediments and the salt flowed from the troughs into the cores of the ridges, or pillows, and broad domes. Salt movement at this stage was probably more in the nature of the adjustment to differential loading of a relatively incompetent unit. It is doubtful that depth-of-burial and subsurface temperatures had reached a point at this time sufficient to cause plastic flow of the salt. Some of the ridges rose enough in Late Jurassic time for the sediments to be subjected to severe thinning, erosion, and faulting. The absence of Smackover and younger deposits over some of the ridges and broad domes indicates exposure of salt at the surface may have occurred on the crests of some of these features. However, it is doubtful that salt movement was truly diapiric in these early structures.

Uplift of the flanks of the troughs repeated, on a smaller scale, the unstable conditions on the flanks of the basin. Sliding of overlying sediments toward the trough axes threw up small ridges and domes. Because of their location in the deepest parts of the basin, these domes were the first to achieve the overburden and temperature necessary to initiate plastic flow of the salt and piercement of overlying deposits. Some of the domes, such as LaRue and Hainesville, became diapiric prior to the end of Early Cretaceous time.

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Growth of the piercement salt domes appears to have been episodic, with greatest vertical movement taking place during periods of maximum sinking and sedimentation in the basin. During periods of non-deposition or erosion, the near-surface salt spires were probably subjected to leaching by circulating groundwater and, in some instances, spread out to form overhangs in the less dense muds of the surrounding formations. Formation of caprock and consolidation of overlying sediments appears to have inhibited the diapiric movement of salt in some domes and caused abrupt changes in salt-stock configuration in others. Some domes that ceased to be piercement features became areas of broad uplift similar to the ridges and deep-seated domes. Such continued uplift makes it doubtful that diapiric movement ceased as a result of the exhaustion of the salt source at the base of these domes.

The last major movement of salt in the shallow domes appears to have occurred in the Tertiary. Uplift and thinning of Midway, Wilcox, and Claiborne deposits is evident around and over these domes. Uplift of overlying sediments since the Eocene has probably been relatively slight. The formation of caprock indicates that circulating groundwater has risen through the Wilcox and other sands around some of these domes and slowly leached away the uppermost parts of the rising salt spires.

SALT MOVEMENT

The causes for salt movement and diapiric intrusion of salt through overlying sediments are generally postulated to be: (1) differential sedimentation resulting in uneven loading, thereby causing the salt to move; (2) basin tilt of salt and sediments along basin edges causing down-dip creep; (3) buoyancy resulting from density differences; and (4) other factors such as compaction, heat, etc.

Comprehensive studies of salt movement and the growth of salt domes have been published by Martinez, et al (1975), Anderson, et al (1973), Muehlberger and Clabaugh (1968), Gussow (1968), Mattox, et al (1968), Ode (1968), Sannemann (1968), Andrews (1960), Trusheim (1960), Atwater and Forman (1959), Jones (1959), Bornhouser (1958), Handin and Hager (1958), Nettleton (1955, 1943, 1934), Parker and McDowell (1955), and Hanna (1934).

The rate of salt movement in piercement domes is not uniform. Domes in the Northeast Texas basin appear to have grown more rapidly in their early stages and during period of rapid sedimentation. During periods of emergence and erosion in the basin, the domes probably grew very slowly or became stable.

Uplift and thinning of sedimentary layers around salt domes indicate relative "uplift-vs-time" values at various times but do not reflect the amount of salt that has moved upward through these layers and has been dissolved. The thickness of anhydrite caprock over a dome is an indication that dissolution and movement of the salt in the dome have occurred. Calculations can be made of amounts of salt that has been dissolved and of average rates of movement on the basis of caprock thickness. Such calculations assume all of the caprock came from the salt, that all of it has been preserved, and that formation of the caprock began at some selected geologic time. The average growth rate calculated does not necessarily represent salt movement at present or at specific times in the past.

TYPES OF MOVEMENT

Solid rocks of all types, including salt, can be deformed. The variables affecting deformation are composition, pressure, temperature, and time. Types of deformation include fracturing, plastic flow (as solids), and fluid flow (as viscous liquids). Salt can be deformed at low pressure and temperature by the gliding of portions of the salt across other portions along internal fractures. Thus, differential pressures in a buried salt mass

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will generate movement of salt into low pressure areas to form pillows under more competent beds that have been arched up or fractured.

At a temperature of approximately 300° C., solid salt becomes plastic and will flow without fracturing. This plasticity permits acceleration of salt movement into a local area of low pressure such as a diapiric stock. A normal subsurface temperature gradient requires burial of salt to a depth of approximately 25,000 feet to achieve a temperature of 300° C. Inasmuch as there is evidence that diapiric growth has occurred in some areas before the base of the salt reached 25,000 feet, it would become necessary to invoke an abnormally high temperature gradient if heat were considered to be the controlling factor initiating piercement growth of domes as theorized by Gussow (1968). Thus, other factors such as differential sedimentation and compaction, basin tilt and down-dip creep, and density differences may be involved in the initiation of such piercement growth of these domes.

TIMES OF MOVEMENT

There is considerable evidence that piercement and growth of salt stocks tend to be episodic (Halbouty and Hardin, 1951). Growth seems to be greatest during periods of rapid accumulation of sediments and rapid sinking of the basin. If the basin becomes stable and sedimentation is slow or gives way to erosion, as currently is the case in the Northeast Texas Salt-Dome basin, piercement activity slows down or stops altogether. Capping of domes by the formation of thick caprock or by consolidation of overlying beds may stop diapiric growth temporarily or even permanently. When salt breaks through such a crust, it frequently rises as a smaller diameter spire that is asymmetrical to the older upward axis of movement. Below unconformities in the Northeast Texas basin, the piercement domes commonly have shoulders or overhangs of salt that are overlain by caprock.

RATES OF MOVEMENT

Our findings indicate that the net vertical movement of salt domes in the Northeast Texas Salt-Dome basin, as reflected by the stratigraphic studies for this basin and the "uplift-vs-time" values, to be considerably lower than the rate of salt movement in salt domes as discussed by others. Trushlem (1960) and Sannemann (1968) indicate a constant rate of salt flow in the range of 0.300 mm. per year during both the pillow stage and diapiric stage of salt dome growth. Trushlem also cites measurements by Lotze of recent changes in surface levels over salt stocks that give a

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relative rise of 1 to 2 mm. per year and geologic studies by Teichmuller that indicate a post-diapiric rise of a salt stock, over the past 20,000 years, of about 2 mm. per year. Ewing and Ewing (1962) calculated the rate of distortion of the sea floor over salt domes of the Sigsbee Knolls in the Gulf of Mexico to be about 1 mm. per year. They state that the relative rate of rise of the dome is probably somewhat larger, but also point out that differential compaction of sediments could account for some of the relative vertical displacement.

This investigation has been concerned with the net vertical movement of domal salt. Measurements of thinning and uplift of adjacent and overlying sediments are considered to indicate only the relative changes in the position of the top of the salt. Differential compaction of sediments tends to exaggerate these changes, whereas dissolution of rising salt by circulating groundwater is not reflected by uplift, causing measurements of relative change in adjacent sediments to indicate less than actual salt movement.

The maximum relief of salt in the Northeast Texas basin is about 22,000 feet. Net vertical movement of salt since the beginning of post-salt sedimentation (149 million years) has averaged about 0.045 mm. per year. Calculations of rates of uplift and thinning reflected by regional study indicate the net rate of vertical salt movement was greatest during Late Jurassic time and has generally declined since, as shown on Exhibit 3. As shown on this exhibit, the estimated average net rates of uplift are indicated to be 0.153 mm. per year in the Late Jurassic, 0.044 mm. per year in the Early Cretaceous, 0.020 mm. per year in the Late Cretaceous, 0.031 mm. per year during the Midway-Wilcox portion of the Tertiary, and 0.006 mm. per year during the post-Wilcox time.

In addition, the LaRue dome in Henderson County is an intermediate depth dome that stopped diapiric growth near the end of Early Cretaceous time, but continued to arch up the overlying deposits during the Late Cretaceous and Tertiary. Net vertical movement of the LaRue salt to the end of the Early Cretaceous was at an average rate of about 0.090 mm. per year. After that time, movement slowed considerably, being at a rate of about 0.014 mm. per year during Late Cretaceous time and 0.005 mm. per year average during Tertiary time.

The significance of these measurements is the evidence that the rate of growth of Northeast Texas salt domes has generally declined throughout geologic time and that, during periods of regional emergence and erosion (such as the present), growth of domes is retarded and likely is stopped altogether.

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ALLUVIUM OR TERRACE DEPOSITS AS INDICATORS OF POSSIBLE RECENT MOVEMENT

The most likely method of detecting any salt dome movement during recent geologic time of less than one million years would be the thorough study of the alluvium or terrace deposits, found in or near the stream beds which traverse or skirt the salt domes of the Northeast Texas Salt-Dome basin, in the manner as outlined by Martinez and Kolb in their salt-dome report dated June 30, 1975. There are indications that limited amounts of such deposits may exist near the Mount Sylvan, Palestine, and Steen domes. Such deposits are not indicated to be present over or near the Bullard, Keechi, and Whitehouse domes. Solution salt mining and surface quarrying have taken place on the Palestine and Steen domes. The findings from extensive studies of the alluvium or terrace deposits around these two domes likely would be distorted by such solution salt mining and surface quarrying and would make questionable any indications of uplift that might be detected in such studies. The Mount Sylvan dome also may have alluvium or terrace deposits suitable for more thorough investigation. Even though present data do not indicate alluvium or terrace deposits over or near the Bullard, Keechi, or Whitehouse domes, future borehole drilling and careful study of shallow deposits could reveal the presence of such deposits. If any program is undertaken in the future which would require the drilling of shallow holes over or near either of these domes, we believe provisions should be made for studying the shallow deposits to determine their suitability for analysis of recent uplift.

HYDROLOGY OF SALT DOMES

Martinez, et al (1975) outlined the various parameters useful in defining hydrologically stable domes and hydrologically unstable domes. The hydrologically stable domes may be characterized by the following conditions: "(1) Dome is encased by clay strata, clay gouge and sands containing highly saline, non-circulating waters; (2) Circulating water in overlying aquifers is not contaminated by salt; (3) Salt licks are absent at the surface; (4) Caprock is not present; and (5) Dome is proven to be tectonically stable." Of the six domes studied in detail and included in this report, Bullard, Keechi, and Whitehouse appear to be the more hydrologically stable domes.

DISSOLUTION BY WATER

Salt can be dissolved and removed from salt domes by waters that come in contact with the salt. Salt that reaches the surface can be washed away by seas and streams. Subsurface flowing water can carry the salt away, either downstream through the aquifer, or upward to the surface through porous sediments or along fractures. Dormant subsurface water can remove salt from the dome by diffusion (Horton, 1944), but this process seems insignificant relative to the other methods of dissolution.

It appears likely that some of the near-surface salt domes lose large quantities of salt by solution at certain stages. An active dome near the floor of a sea that is receiving sediments is in contact with a thick section of deposits that contain excessive water. As the increasing overburden pressure compacts the deposits, the excess water is expelled upward and the upturned beds and fractures associated with salt domes would provide favorable avenues for escape. Similarly, a sinking basin of non-marine sedimentation would provide an environment favorable for dissolution by circulating fresh water.

In an emergent basin, being subjected to erosion, surface and near-surface sediments tend to consolidate and commonly form hard limestones, sandstones, and impermeable shales. Such a condition could greatly restrict, and in some instances cut off, the amount of flowing water available for dissolution of a near-surface dome.

CAPROCK AND DISSOLUTION

The formation of caprock over salt domes is generally accepted as being a residual accumulation of grains of anhydrite, present as an im-

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purity in the salt, that were deposited as salt was dissolved and carried away by upwelling groundwater. Limestone sometimes forms over the anhydrite, probably by combination of calcium from the anhydrite with carbon dioxide from the groundwater. As salt is dissolved, either the salt stock moves upward to prevent formation of a void at the top or, in some domes, the overburden collapses creating a faulted and brecciated sink above the dome. Inasmuch as the top portion of the caprock is often hard and impermeable, upward escape of water over the dome must be by way of fissures created by uplift or collapse. The thickness of caprock has been used as a guide to rough estimates of the rates of dissolution of salt from the tops of domes and, because the stock moves up to replace dissolved salt, as a clue to rates of diapiric movement. The amount of anhydrite in the salt domes of Northeast Texas is probably between one and two percent (Balk, 1949). Thus, each foot of caprock would indicate a maximum upward movement of salt on the order of 100 feet.

Caprock data are sparse for domes in the Northeast Texas basin. Based on the data which are available, five of the six domes investigated in detail have caprock ranging in maximum thickness from 50 feet to 300 feet. No caprock has been found at Mount Sylvan. Assuming all of the caprock over domes in the basin has formed during the approximately 50 million years since deposition of the Wilcox sands (the main aquifer in the area), then the maximum rate of salt movement in these domes due to dissolution would be from 0.031 to 0.183 mm. per year. Addition of these rates to the average net rate indicated by uplift (0.006 mm. per year) during the period of approximately 50 million years since deposition of the Wilcox gives maximum total rates of vertical salt movement ranging from 0.037 to 0.189 mm. per year for this period, or an equivalent maximum vertical salt movement during a 200,000 year period of approximately 24 to 124 feet. However, it is to be noted that by far the greatest portion of this vertical salt movement is indicated to result in caprock formation by dissolution and very little, if any, is indicated to result in a net vertical rise in the top of the dome. If the salt in the Northeast Texas salt domes is more than 1 percent insoluble anhydritic impurities, from which caprock is formed, the indicated rates of vertical salt movement outlined above would be reduced proportionally. There are indications that these insoluble impurities may be as high as 2 or 3 percent and, therefore, the indicated rates may be only one-half or one-third those shown.

GROUNDWATER AND DISSOLUTION

Indirect surface and subsurface evidence indicates that dissolution of some of the shallow salt domes in the Northeast Texas basin is

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occurring at the present time; for other domes, there is evidence indicating that no dissolution is taking place.

In the study area, surface salines are present over the Grand Saline, Steen, Brooks, Palestine, and Butler salt domes. Most of these salines are small and the amount of salt being brought to the surface does not seem large except, possibly, at Grand Saline. Salt has been precipitated along the dry creek bed at the downstream edge of Palestine dome; however, the small artificial lake over the center of the dome contains water fresh enough to support fish.

A 10-month study by the U.S. Geological Survey (White, 1973) of the brine content of creek water downstream from Grand Saline dome found an average salt (sodium chloride) load of about 65 tons per day. Sources of some of this salt are underground and solution mining operations (past and present) at Grand Saline. For all of the creek salt to be derived by natural dissolution of the dome (radius 4,000 feet) would require a dome growth rate of 2.1 mm. per year. In contrast, reliable data give an average caprock thickness of 28 feet at Grand Saline dome (Peters and Dugan, 1948), which would indicate vertical salt movement at a rate of 0.017 mm. per year, or an equivalent vertical salt movement during a 200,000 year period of 11.2 feet.

CURRENT RATES OF DISSOLUTION

The presence of large salines and active salt water springs over the domes are an indication that there is very little restriction on vertical flow of groundwater from the salt to the surface. Therefore, the rate of dissolution from such domes is probably high. The presence of small salines and minor salt springs over domes indicates significant restrictions in the system, either at the aquifer-salt contact or over the dome, and the dissolution rate is modest. Domes in this category include Steen, Mount Sylvan, and Palestine. Domes which have slight or no indications of dissolved salt at the surface and/or a small head of groundwater probably have a high degree of hydrologic stability. Domes having these characteristics include Keechi, Whitehouse, and Bullard.

Measurements of salt volumes in solution of surface runoff water over a dome or of water produced from test wells over a dome would indicate the current rate of salt dissolution and, therefore, the hydrologic stability of the dome.

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Subsurface water flow is known to dissolve salt from some domes. Martinez, et al (1975) have described subsurface plumes of salt water in association with domes. Roach (1943) presents convincing evidence of subsurface removal of salt by groundwater at the Jennings dome in South Louisiana where residual anhydrite is found in sands abutting the dome. White (1965) suggests dissolution of salt by subsurface water flow has occurred in several Gulf Coast domes.

Removal of salt from domes by subsurface water flow is not evident in the study area. Transported caprock material has not been detected in sands adjacent to the domes and groundwater studies (Dillard, 1963; Guyton, 1972; White, 1973) do not indicate the domes have significantly affected the water salinity patterns in the area.

The Grand Saline dome is in the area of Wilcox outcrops on the west flank of the basin. There are 22 Wilcox water wells within a five-mile radius of the dome. Many of the wells were drilled for municipal and industrial use and the others are used for rural domestic supply. All except two of these wells produce fresh water. A shallow domestic well located four miles north of the dome produces moderately saline water from a depth of 55 feet. This well is updip from the dome and there are several fresh-water wells between it and the dome. It is very unlikely that the dome is the source of contamination in this well. A shallow domestic well located almost five miles south of the Grand Saline dome produces slightly saline water from a depth of 44 feet. Wells closer to the dome produce fresh water, so the source of contamination is probably a local one, such as surface brine from the nearby Van oil field. Heavy withdrawal of water from the Wilcox by wells near the Grand Saline dome has lowered the water level to as much as 168 feet below ground surface during dry seasons. However, there is no indication that normal upwelling of water to the salt marsh over the dome has been interrupted or reversed.

The City of Tyler in Smith County produces water from several Wilcox wells. Dissolved solids in the water of most of the wells is less than 240 parts per million. Water from one well, located east of the other wells and about one and one-half miles southwest of the East Tyler dome, has a dissolved solids content of 700 parts per million. The higher salinity in this well may indicate dissolution of salt from the dome, but the amount is too small to be of any significance as far as dome growth is concerned.

If salt water plumes are associated with the domes in the study area, they have not been encountered by water wells. Pressure drawdown particularly from concentrations of municipal and industrial water wells, should tend to divert plumes, if present, into wells located near salt domes.

GEOPHYSICAL ASPECTS

While this investigation did not authorize the acquisition and interpretation of raw geophysical data for the Northeast Texas Salt-Dome basin, it was possible to obtain, at nominal cost, some seismic and gravity information on the basin in general and on certain specific domes. All of these data have been incorporated into our studies of the regional geology of the basin and into descriptions of domes selected for detailed study.

A considerable amount of additional geophysical information for the basin is available for purchase or lease from various sources. This information consists of (1) single-fold seismic records with station location maps, (2) CDP (common-depth-point) seismic records with line location maps, and (3) maps showing gravity readings for survey stations.

Consideration has been given to more comprehensive use of geophysical data for the purpose of defining the shape, size, and configuration of salt domes as well as the depth, thickness, and other characteristics of the caprock overlying some of these domes. While we believe it is practical to use geophysical data for these purposes, we believe the use of these data, particularly currently available seismic data, has definite limitations and should be used with caution.

Because of the steeply dipping and ruptured formations usually surrounding these domes, good seismic records can be obtained only from a carefully designed program (shot-hole and geophone spacing, etc.) by geophysicists experienced in dealing with these types of conditions. Seismic data currently available originally had oil and gas exploration as its objective, and much of it was directed toward study of deeper beds, which often results in poor records on the shallower horizons. Thus, we believe most of the currently available seismic records which were obtained by oil companies should be viewed with considerable caution as far as salt dome studies are concerned.

Exhibits G-17 through G-20 show areas in the Northeast Texas basin for which single-fold seismic records are currently available and can be acquired. The density of lines is too great in most of the areas to permit individual shot-points to be shown on these exhibits. Large scale shot-point maps can be obtained of areas of interest. Cost of this type seismic coverage averages about \$40 per shot-point (\$150 per mile). New single-fold surveying would cost about \$800 per mile. Single-fold records in Northeast Texas sometimes yield good shallow records, if spacing is properly planned, but are often unreliable for interpretation of deep intervals because of low signal strength and multiple reflections. Thus, these

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records have some definite limitations in their use for defining the shape, size, and configuration of the salt domes under study.

Exhibits G-17 through G-20 also show CDP seismic lines available for the Northeast Texas basin. These continuous profiles usually cost \$600 per mile, with a minimum purchase of ten miles of coverage. New CDP surveying costs about \$2,500 per mile. CDP seismic lines are usually designed to obtain maximum resolution of deep reflective horizons and generally yield poor shallow records and, when designed in this fashion, must be used with caution if applied to shallow salt dome analysis.

Concerning gravity surveys, as a result of our discussion with Nettleton (personal communication May 24, 1976), it is our understanding that gravity surveys used in conjunction with other subsurface geologic information may afford a reliable and reasonably inexpensive method of defining the shape, size, and configuration of salt domes.

We have obtained and have in our files location plats showing stations in the basin for which gravity readings are currently available and can be purchased at a cost of approximately \$1.50 per station. Field surveying of new gravity stations for a particular area would cost about \$30.00 per station. The cost of analysis of gravity data of a particular area would depend on the amount of data to be processed and the degree of sophistication of the analytical method. Gravity surveys should include enough stations to detail the dome and also give a reliable picture of the regional gravity configuration. Subsurface data on depths to the upper part of a shallow dome, from wells and core-holes, greatly improve the probability that a model interpretation of a salt dome from gravity data will be accurate (Nettleton, 1971, p. 61-63). Considerable effort should be made to obtain accurate density data on all the rocks involved in the gravity analysis. A computer program of the type described by Nettleton (1976) combined with a comprehensive core-hole program, would be an effective method of delineating the configuration of a particular salt dome. The total cost of the gravity survey and analysis portion of such a study would probably exceed \$25,000.

In considering the vertical continuity of a salt dome, Nettleton has advised us (personal communication May 24, 1976) that seismic shot-points directly over shallow domes have resulted in records showing a deep reflection, believed to be the base of the salt, below a long interval of no reflections. Such records would indicate the salt of a dome to have vertical continuity. Interruptions of vertical continuity, such as salt overhangs or major departures of the salt stock from a vertical direction, should be reflected on such seismic records.

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To obtain new geophysical data, particularly seismic records, involves considerable cost and we recommend that the planning and running of such surveys be done by professional and experienced geophysicists. The cost of obtaining and analyzing geophysical data for a particular project will vary considerably depending on miles of lines involved, complexity of geology, quality of records, and objectives of the study. Such geophysical analysis of a Northeast Texas salt dome, including acquisition of data, would probably cost in excess of \$100,000.

GEOLOGY OF CERTAIN DOMES
OF THE
NORTHEAST TEXAS SALT-DOME BASIN

SUMMARY

Six domes of the Northeast Texas Salt-Dome basin have been studied for the purpose of examining their tectonic and hydrologic stabilities. These domes include Bullard, Keechi, Mount Sylvan, Palestine, Steen, and Whitehouse located in Smith and Anderson Counties, Texas.

These studies included an investigation of (1) the depth, size, and configuration of the salt mass, (2) the uplifting and warping of the sedimentary beds as the salt mass moved upward, (3) the position and thickness of the caprock associated with most of these domes, (4) the fresh water zones in the area and the hydrologic stability of the domes, and (5) the potential of the area for oil and gas development. A detailed description of findings and maps and cross-sections are presented for each of the domes. A field trip was made to the location of each of these domes to observe the surface geology, terrain, drainage patterns, and land use.

Based on these studies, the Bullard, Whitehouse, and Keechi domes appear to have the highest degree of hydrologic stability and, therefore, are the most suitable for further examination. However, additional data are needed to delineate more accurately the configuration of the salt mass, to examine the caprock, and to evaluate more completely the hydrologic stability of the domes.

A brief review of other domes in the Northeast Texas Salt-Dome basin is also included as part of this presentation.

Chas. C. Bankhead, Jr.

AAPG Certified Petroleum Geologist 257

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TABLE OF CONTENTS

<u>GEOLOGICAL DISCUSSION</u>	<u>Page No.</u>
INTRODUCTION	G-22
BULLARD DOME	G-26
KEECHI DOME	G-29
MOUNT SYLVAN DOME	G-35
PALESTINE DOME	G-38
STEEN DOME	G-41
WHITEHOUSE DOME	G-44
GENERAL REVIEW OF SALT DOMES OF THE NORTHEAST TEXAS BASIN	G-47
TABULATION OF KEY WELLS	G-50

GEOLOGY OF CERTAIN DOMES
OF THE
NORTHEAST TEXAS SALT-DOME BASIN

Chas. C. Bankhead, Jr.

INTRODUCTION

The seven interior salt domes in the Northeast Texas Salt-Dome basin selected for study included Brooks, Bullard, Keechi, Mount Sylvan, Palestine, Steen, and Whitehouse. They are all piercement domes and are near the surface; all have some gravity delineation and some subsurface control to show the general configuration of the salt mass. In all cases, there are no indications that significant oil or gas accumulations are present nor are they being utilized for storage of oil and gas products.

A field trip was made to ascertain that the surface conditions do not prohibit access to the salt mass. All domes are readily accessible by road, except Brooks. The Brooks dome, in the southwest corner of Smith County, has been converted into a resort area known as Emerald Bay. An arm of Lake Palestine on the Neches River covers the dome area; the shore line of the lake is dotted with marinas, lake houses, and a country club with a golf course. Accordingly, the Brooks dome investigation was suspended.

Palestine, Steen and Mount Sylvan have small salines. In the past, solution process mining operations at Palestine and Steen produced considerable quantities of salt. At Palestine, the solution mining of salt from below the caprock caused segments of the caprock to collapse, which resulted in surface cave-ins. At both Palestine and Steen domes, the location of most of the salt solution wells is not known.

GENERAL

Data for each of the six domes were collected within a five-mile radius of the apex of the salt mass. All available well logs and scout cards were assembled, catalogued, and the well locations spotted on a base map. Topographic maps were obtained and the domal uplifts depicted thereon. Aerial photographic mosaics were acquired, and the dome areas on the photos were examined. These mosaics are maintained on file. All

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domes have some surface expression of the salt intrusion, both geologically and geographically, and most have or have had salines. A comprehensive review of all available literature regarding the six domes and the Northeast Texas Salt-Dome basin was made.

The data from the well logs and scout cards were compiled in tabular form, and each well within the five-mile radius of the salt mass was assigned a key number. This key number was tabbed on all information regarding the particular well, including the work map and all other maps used in the study.

Utilizing the subsurface information from the wells drilled in the area of interest, cross-sections and subsurface maps were prepared to permit a comprehensive analysis of the structural, tectonic, and stratigraphic conditions. Not all work maps and cross-sections are included in this report, but are available for review. It was decided that the following maps and cross-sections would present the best illustration of surface and subsurface conditions in the vicinity of the domes:

Maps

A. Structure map on the top of the salt

All subsurface information regarding caprock and salt was reviewed, analyzed, and incorporated when considered reliable. A set of gravity interpretations, showing for each dome the possible configuration of the salt mass upward from the approximate top of the Louann (Mother) Salt, was acquired and studied. Some of the shapes were unique; but in general, the subsurface control which was available down to only approximately 5,000 feet subsea essentially confirmed the gravity interpretation of the salt masses. The subsurface maps of the salt utilized all available subsurface data and the shapes derived by gravity were adjusted to conform with definite subsurface information. In all cases, the configurations below 5,000 feet were based upon gravity data.

B. Structure map on a basal Wilcox marker

The surface and near-surface geology was reviewed and an identifiable marker near the base of the Wilcox sands was selected as the contour horizon for this structural map. Accordingly, the cross-sections will show that this marker is also the top of the Midway shales, although the selected marker is not always the true lithologic top of the Midway.

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C. Structure map on the base of the Austin Chalk

The Austin Chalk rests unconformably on top of the older sediments and is a good recognizable marker on both the electrical logs and the sample logs. Before this map was made, a Woodbine sand map was prepared inasmuch as this horizon afforded the maximum amount of subsurface information. In the absence of electrical or sample logs, the scout cards generally gave the top of the Woodbine. This marker was used even though it was recognized that there is some discrepancy between the top of the Woodbine Formation (which could be a shale in some cases) and the top of the Woodbine sand. A structure map of the Woodbine within the five-mile radius was prepared for each of the domes and greatly assisted in the interpretation of the structure at the base of the Austin Chalk.

D. Topographical map

The United States Geological Survey topographic map was used in all cases to show the configuration around each of the domal uplifts. This map depicts the drainage area, the surface expression of the collapsed domal areas, the hills surrounding the domal area, and other surface conditions.

Cross-Sections

Cross-sections, designed to traverse the apex of the salt dome at approximately right angles, show the salient surface topographical features of the dome.

A number of preliminary cross-sections were prepared for each dome, basically through diagnostic wells, in order to determine the subsurface structural configuration of the formations. Based upon this approach, the regional dip, local anomalies, rim synclines, stratigraphic thickening and thinning, possible faulting and eventual abutment at the salt, caprock, or the surface could be determined. It was recognized that some of the thinning could be attributed either to faulting, domal uplift, or unconformities. After the structure maps and the preliminary cross-sections had been coordinated, two diagrammatic cross-sections were prepared for the report. These cross-sections show the configuration of the salt plug in an axial direction of approximately north-south, with a second cross-section at right angles to depict the other dimension. Each cross-section, starting at the surface, shows the geological conditions determined by this investigation, as well as those reported by eminent geologists who have published their findings. For presentation purposes, there is a 2-to-1 expansion of

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the vertical scale compared to the horizontal scale. The near-surface enlargement has been further expanded to 20-to-1 to permit better visual observation of surface and near-surface conditions and the exposure of the various subsurface strata at the surface. These cross-sections depict the abutment of formations against the salt and/or caprock, the thinning occasioned by the various salt movements, and any unconformities which may have occurred. The drag or uplift of the formations by the salt as it moved upward can be discerned on these diagrammatic cross-sections.

In some cases, faulting is definitely evident in the uplift of formations which have been displaced some several thousand feet, as in the case of Keechi where Cretaceous beds on the south side of a large fault are in contact with Wilcox beds on the north side of the fault. Faulting is probably present in a radial pattern around all of the domes. However, no faulting is shown on either the maps or the cross-sections in this report unless definite data were available to confirm such faulting.

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BULLARD DOME

DISCOVERY

The Bullard salt dome, located in southern Smith County, Texas, approximately ten miles south of the City of Tyler, was first detected by seismic surveys made in 1927 and was confirmed later that year by the drilling of a shallow well to the salt (Renick, 1928). Since discovery, four additional wells have been drilled on the west flank of the dome, and one well has been drilled near the east flank.

GEOGRAPHY

Rolling terrain characterizes the Bullard dome area, and the topographic expression of the domal uplift is very subtle (Exhibit G-22). The dome is situated high on the east slope of the divide between the Neches River and West Mud Creek. Drainage in the vicinity of the dome is to the northeast. The domal area is traversed by State Highway 344 and partially traversed by U.S. Highway 69. There are several rural homes in the general area of the dome, and the surface is being used for cattle grazing and small farms.

SURFACE GEOLOGY

The Bullard dome is overlain by outcrops of Queen City sands. Renick (1928) reports steep dips over the dome in the Queen City (Mount Selman). The hills north, west, and southwest of the dome are capped by Weches greensand. According to Wendlandt and Knebel (1929), there is a slight rim syncline on the northwest side of the dome. Exhibit G-23 shows the rim syncline reflected by the Basal Wilcox horizon.

SUBSURFACE GEOLOGY

The salt dome at Bullard, as interpreted from well and gravity data, is a broad, circular stock that tapers upward above 6,000 feet sub-sea to a relatively small pinnacle (Exhibit G-22). Between 1,000 feet and 5,000 feet subsea, there is a salt overhang on the west flank of the dome. The crest of the salt is slightly above sea level, has a diameter of less than 2,000 feet, and is overlain by about 150 feet of anhydritic caprock. The diagrammatic cross-sections (Exhibit G-25) show the subsurface interpretation of the relationship of the salt stock to the adjacent sediments. Of particular interest is the unconformity at the base of the Austin Chalk which truncates all of the Woodbine and part of the Washita-Fredericksburg

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near the west-flank overhang. Hanna (1934) indicates caprock to be present between the Austin Chalk and the salt overhang, but Judson (1929) does not identify the lithology of this 143-foot interval.

The steep dips and rim syncline imposed on adjacent sedimentary units by the intrusive salt are shown on the structure maps of the Basal Wilcox horizon and the base of the Austin Chalk (Exhibits G-23 and G-24).

STABILITY OF DOME

There has been some arching-up of overlying Eocene beds by the salt at Bullard dome. Uplift, reflected in beds above the Wilcox, is indicated to be on the order of 500 feet. This would indicate an "uplift-vs-time" value of approximately 0.003 mm. per year for this 50 million year period, or an equivalent uplift in a 200,000 year period of approximately 2 feet. Thus, the amount of net salt movement indicated by such "uplift-vs-time" value is considered to be of minor significance.

At Bullard dome, the caprock thickness of approximately 150 feet indicates dissolution of salt has occurred during the 50 million years since Wilcox time. Based on this thickness of caprock and assuming the interior core of the dome moved vertically to replace the salt dissolved in the process of caprock formation, the rate of vertical salt movement was 0.091 mm. per year for this 50 million year period, or an equivalent vertical movement during a 200,000 year period of approximately 60 feet. At present, Wilcox sands abut the top of the dome, and water flowing through this aquifer may be dissolving salt from the stock; however, the dense caprock and overlying marine shales of the Reklaw would tend to prevent escape of such Wilcox water to the surface over the dome or into the Queen City sands. One Queen City water well on the east (downslope) side of the dome indicates this aquifer to be uncontaminated by salt from the dome.

Water well data are lacking to establish subsurface water salinities downstream from Bullard dome in the Wilcox sand. To determine whether or not salt is currently being dissolved by subsurface water movement, it is felt that a number of test wells need to be drilled over and around this dome and sample analysis run to determine the salinity of such subsurface water in an effort to determine the quantity, if any, of salt being dissolved. Such drilling could also serve to confirm the shape, size, and configuration of the salt core of the Bullard dome.

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OIL AND GAS POTENTIAL

Drilling for oil and gas at Bullard dome has been unsuccessful to date. Portions of the dome remain untested, but the results of exploration of Northeast Texas shallow piercement domes have been discouraging in general, and the prospects of finding oil and gas on or near the Bullard dome are not favorable.

KEECHI DOME

DISCOVERY

The Keechi dome is located in the central part of Anderson County, Texas, approximately seven miles northwest of the City of Palestine and about six miles northeast of the Palestine dome. The Palestine-Athens State Highway 19 traverses the dome almost centrally. The discovery well, Producers Oil Company No. 1 Barrett and Greenwood (Key No. 50), was drilled in 1916. It encountered a salt overhang between 2,162 feet and 2,822 feet and the main salt mass at 3,091 feet. Thirteen additional wells have been drilled at Keechi, either to the caprock or salt, or to test the flanks of the dome.

GEOGRAPHY

Keechi dome is located on the upper west flank of the divide between the Neches River and Trinity River drainage systems. The topographic map, Exhibit G-26, shows the configuration of the intricate character of the terrain. Salt Fork of Keechi Creek, which drains the western part of the dome area, flows through the central core of the dome. Keechi Creek and its headward portion, called Spring Creek or Wagoner Branch, receives the drainage from the northeastern and eastern part of the dome and flows in a semicircle around the eastern side of the dome. Southwest of the dome, Keechi Creek is joined by the Salt Fork. The center of the dome occupies the area between Salt Fork and the two tributaries.

Elevations in the vicinity of the dome range from about 290 feet in the valley where Keechi Creek flows to the southwest to over 600 feet in the southeastern portion of the area. Over the dome, the elevation range is about 290 feet to 410 feet. In general, the topography is gently rolling, with a ring of hills surrounding the center of the dome. The topography is more extensively discussed by Powers (1926), Eubanks (1965), and others.

Reference to the topographic map, Exhibit G-26, will indicate that the apex of the Keechi dome is expressed as a low valley and is almost completely surrounded by a rim of interior low hills with elevations on the order of 400 feet. The countryside is broken up into rural homesites, small farms, and fenced cattle-grazing lands. The area lies on the Palestine-Athens highway and has been a natural choice for Palestine residents to expand into the countryside.

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LOCATION AND SHAPE OF THE DOME

The general configuration of the salt mass indicates that Keechi dome originally had its center of rise somewhat south of the present apex. The salt pierced the overlying beds, with the caprock apparently starting to form during Austin Chalk time in Middle Upper Cretaceous. The Woodbine sand may well have been the aquifer which leached the rising salt and thereby formed the original caprock. Near the close of Cretaceous time, this caprock probably was uplifted along with beds of Cretaceous age, resulting in both the Midway and Pecan Gap Formations being exposed at the surface on the upthrown side of a large fault where they are in contact with the Wilcox Formation.

The salt mass is elliptical in shape with the long axis trending north-south. It becomes more egg-shaped above 5,000 feet and has an overhang on the south end at about 2,000 feet. It is capped on the north and central portion with material variously described as gyp, hard rock, and cap. The caprock is probably a composition of gypsum and anhydrite and reaches a maximum thickness of 300 feet in the Navarro-Greenwood No. 2 well (Key Well No. 51), near the apex of the salt mass (Exhibit G-26).

The mapping of the salt and caprock was controlled by subsurface data, augmented by gravity data. No definite subsurface control was available below 3,500 feet, although deeper wells which did not encounter salt aided in establishing the configuration. Data are not available on the depth to the Louann Salt, but regional control suggests that it is in the order of 20,000 feet.

The accompanying tabulation shows the wells which found caprock and/or salt, as depicted on Exhibits G-29 and G-30.

SURFACE GEOLOGY

Keechi dome has a central fault of considerable magnitude which brings Cretaceous Pecan Gap on the south in contact with Wilcox beds on the north. Strata overlying and surrounding the salt core have been arched into a steeply-dipping, probably highly-faulted quaquaversal fold. Data are not available to show the fault pattern, but it is assumed that faults are normal and form a radial pattern.

State Highway 19, traversing the dome in a northwest-southeast direction, almost bisects the domal uplift. The surface expression of the central fault can be observed from the surface. In a west-east direction

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KEECHI SALT DOME

ANDERSON COUNTY, TEXAS

DEPTHS TO CAPROCK AND SALT

<u>Key No.</u>	<u>Well</u>	<u>Caprock (Feet)</u>	<u>Salt (Feet)</u>
51	Navarro-Greenwood #2	350 (+215)	435 (-85)
50	Navarro-Greenwood #1	1,263 (-883)	1,363 (-983)
49	Navarro-Greenwood #3		1,361 (-977)
53	Navarro-Barrett #1	2,162 (-1,777)	
		Out of Salt 2,822 (-2,437)	Into Salt 3,166 (-2,781)
37	Navarro-Greenwood #4		2,460 (-2,038)
48	Allison Gardner #1 Sun Oil Company	3,192 (-2,774)	3,230 (-2,812)
33	E. B. Larue and F. R. Jackson - Jernigan #1	3,553 (-3,067)	3,695 (-3,209)

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over the central portion of the dome, the caprock is covered by the Wilcox sands; in a north-south direction, the Wilcox abuts against the central fault on the downthrown side, while the Cretaceous and Midway are present on the upthrown side in a semi-circular manner. The Wilcox covers the entire domal uplift with the exception of the Cretaceous and Midway outcrop. The Cretaceous and Midway exposures appear to be an expression of uplift by the salt and caprock on the southeast side of the dome, with the downthrown side of the fault partially resulting from collapse of the central domal material.

SUBSURFACE GEOLOGY

Regional studies indicate that the depth to the top of the Louann Salt in the vicinity of the Keechi Dome is at least 20,000 feet. Gravity data depict a slightly elliptical configuration at 15,000 feet with a diameter of 23,500 feet in an east-west direction and 29,000 feet in a north-south direction. The interpretation of gravity data was compared with subsurface information and the two interpretations are remarkably similar.

Drilling around the periphery of the dome has disclosed a complete geological section from the Wilcox to the Pettet, with all formations thinning in a domeward direction.

The salt apparently rose in a uniform manner during Early Cretaceous time. The cross-sections, Exhibit G-29, illustrate a later movement, probably coincidental with the formation of caprock, at Austin Chalk time. This shoulder at about 4,000 feet subsea is coincidental with what appears to be an erosional surface at the base of the Austin Chalk. The caprock apparently does not cover the entire salt stock; and, as is shown on Exhibit G-30, it reaches a thickness of some 300 feet. The caprock is confined to the northern portion of the salt dome and drapes over the salt mass down to 3,500 feet subsea in the north and 2,500 feet subsea in the south. It appears that a portion of the caprock on this dome had been formed at Woodbine time when the Woodbine sands were near surface and groundwater started leaching the salt. Thereafter, as the salt continued to move upward, it appears that it carried this portion of the caprock with it.

STABILITY OF DOME

Some leaching of salt by groundwater may be taking place at Keechi dome. There are no known salines at the present time, but Powers (1926) reports salty patches occur in summer along Salt Fork Creek and that several water wells have found salty water. There are five water

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wells near Keechi, but four produce from zones that outcrop before reaching the dome. One well, located near the west flank of the dome, produces fresh water from the Wilcox sands. Based on the report by Powers (1926) of salty patches along Salt Fork Creek, it appears that fresh water from the Wilcox occasionally leaches salt from the dome and carries the dissolved salt to the surface.

As discussed above, the caprock situation at Keechi dome is uncertain. The caprock is confined to the northern portion of the dome, and it appears that this may have been formed at Woodbine time and subsequently lifted by the rising dome. However, if it is assumed that the entire 300 feet of caprock was formed during the 50 million years since Wilcox time and that the interior core of the dome moved vertically to replace the salt dissolved in the process of such caprock formation, the maximum rate of vertical salt movement was 0.183 mm. per year for this 50 million year period, or an equivalent vertical movement during a 200,000 year period of approximately 120 feet. Also, if the salt in Keechi dome has more than 1 percent insoluble anhydritic impurities, from which the caprock was formed, the indicated rate of vertical salt movement would be reduced proportionately. There are indications that these insoluble impurities may be as high as 2 or 3 percent; and, if so, the indicated maximum rate of vertical movement of salt during a 200,000 year period would be reduced to 60 and 40 feet, respectively.

Data are not available to indicate whether or not any subsurface dissolution of salt is occurring at the present time, and it is recommended that additional studies be undertaken to establish the extent of salt dissolution by subsurface water. Such studies should include the drilling of shallow water wells and the analysis of water samples from these wells. Runoff water from the surface drainage system should also be gathered and analyzed to assist in determining the quantity of salt, if any, which is being dissolved from this dome.

There has been arching-up of overlying Eocene beds by the salt at Keechi dome. Uplift, reflected in beds above the Wilcox, is indicated to be in the order of 2,000 feet. This would indicate an "uplift-vs-time" value of approximately 0.012 mm. per year for this 50 million year period, or an equivalent uplift in a 200,000 year period of approximately 8 feet. The "uplift-vs-time" values for Keechi dome have shown a general decline from Jurassic time, through Early and Late Cretaceous time, and through the Tertiary time such that the rate of uplift at the present time is believed to be very slight, if not halted altogether.

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OIL AND GAS POTENTIAL

It appears that Keechi dome is not an attractive hydrocarbon exploratory target. With the exception of a heavy oil show in the Woodbine in the first well drilled on this dome, no other oil and gas indications have been reported. It would thus appear that any potential horizons would be in beds deeper than those of Woodbine age and would necessitate exploration at considerable distance from the salt mass. Accordingly, such operations would not interfere with access and use of the core of this salt dome.

WORK NEEDED TO ACCURATELY DELINEATE THE SALT

Keechi dome is similar to the other interior domes investigated in this study in that the more subsurface information that is available, the more complex the configuration of the caprock and salt is revealed to be. Core-hole drilling is believed to be the most accurate tool in defining the salt and its contact with the caprock. Thus, a program including core-hole drilling, gravity surveys, and possibly one or two seismic lines should define the dome. One seismic line traversing the long axis of the dome and the other at right angles thereto would be desirable in setting the pattern for the core drilling.

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MOUNT SYLVAN DOME

DISCOVERY

The Mount Sylvan dome is located in the western part of Smith County, Texas, some eight miles west-northwest of the City of Tyler. It is approximately four miles south-southeast of the town of Mount Sylvan, immediately east of the Neches River, and is traversed in a northwest-southeast direction by State Highway 724.

Olfenbittel and LeGrand drilled a 400-foot well in 1920 near the edge of the dome on the Lola V. Reese and George P. Werner 127-acre tract in the Benjamin Kuykendall Survey. It is reported that this well encountered salt water at 250 feet; the salt water was still present when the well was abandoned at 400 feet; and a spring of flowing salt water could be found some 300 feet from the well (Wendlandt and Knebel, 1929).

Humble Oil & Refining Company completed its Lola V. Reese No. 1 well in 1931 at a total depth of 1,208 feet in salt. The top of the anhydrite was encountered at 650 feet; streaks of anhydrite, salt, and sand from 650 feet to 1,050 feet; and rock salt from 1,050 feet to 1,208 feet (Wendlandt and Knebel, 1929-31). No additional data are available on either of these wells.

Some eight wells have been drilled near the crest or on the flank of the salt plug, and numerous wells have been drilled within a five-mile radius of the apex. Oil and gas production has been established in scattered locations some four to five miles away from the apex of the dome. However, no hydrocarbon shows have been encountered near the salt mass.

GEOGRAPHY

The Mount Sylvan dome has a low central area and is surrounded by a rim of hills with a circular drainage; its surface indication is well defined. Black Fork Creek has cut through the northeastern side and drains through the central part of the dome. It has cut through the rim on the south side and flows into the Neches River. Several saline prairies were reported on the southeastern part of the dome (Wendlandt and Knebel, 1936).

Several rural homesites are located on top of and near the Mount Sylvan salt dome. The land is being used for fenced cattle grazing and scattered fields of row crops.

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SURFACE GEOLOGY

The dome is surrounded by a rim of low hills with a valley crossing the dome. The surface formations are Queen City, Weches, and Sparta of the Eocene Claiborne Group, with the southeastern part of the dome covered by alluvium.

The dome is overlain by a blanket of Midway shale, covered by Wilcox formations with Queen City, Weches, and Sparta of the Eocene exposed at the surface. The surface exhibits a strong collapsed area in a west-east direction (Exhibit G-31), where the low hills overlook the central valley. This dome has a small saline prairie and marsh on the southeast which may include minor salt springs.

SUBSURFACE GEOLOGY

Exhibits G-31 and G-32 show the structure on the top of the salt, constructed from subsurface and gravity data. Mount Sylvan dome cants to the southwest with an overhang on the southwest at about 2,000 feet. To date, no caprock has been found at Mount Sylvan dome, and the Midway shale extends over the salt mass, separating the salt mass from the Queen City and Wilcox sands, the groundwater aquifers in this area. Thus, it appears that the groundwater aquifers do not come in contact with the salt of this dome, which probably explains the absence of caprock. However, this leaves unanswered the question concerning the origin of the saline prairies on the southeastern portion of the dome. It is possible that movement of groundwaters through fractures and/or along fault planes may be the source of the salt found in the saline prairies. The few wells drilled above the salt mass or near the flanks of this dome did not disclose any caprock, but the possibility that a caprock is present over the north, west, and central area is not precluded. Exhibit G-35 shows two cross-sections depicting geological sequence of the beds down to the top of the Pettet Formation, based upon information from wells drilled in the vicinity of the dome. Gravity suggests a decreasing taper in a southwesterly direction from a depth of 18,000 feet to 10,000 feet subsea by about the end of Rodessa time. From 10,000 feet to 6,000 feet subsea, the emergent salt appeared to have moved upward, forming a pronounced bulge. Between 6,000 feet and the surface, the salt appears to have moved essentially vertical with an overhang developed to the southwest at about 2,000 feet subsea. This latter movement resulted in the arching up of the Upper Cretaceous beds together with the Midway and Wilcox beds of the Eocene.

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The shape of the salt stock, depicted on the cross-sections and the structure maps, appears to be essentially a near-vertical shaft canted to the southwest, with at least three periods of stabilization suggested, each followed by periods of renewed growth.

STABILITY OF DOME

There has been some arching-up of overlying Eocene beds by the salt at Mount Sylvan dome. Uplift, reflected in beds above the Wilcox, is indicated to be in the order of 500 feet. This would indicate an "uplift-vs-time" value of approximately 0.003 mm. per year for this 50 million year period, or an equivalent uplift in a 200,000 year period of approximately 2 feet. Thus, the amount of net salt movement indicated by such "uplift-vs-time" value is considered to be of minor significance.

Data available at this point do not indicate the presence of any caprock on the Mount Sylvan dome and, from this, it might be speculated that no dissolution of salt has taken place. However, the reported presence of saline prairies on the southeastern portion of the dome would indicate that some dissolution of salt is taking place at the present time. The extent to which salt currently is being leached from the dome cannot be determined from the data currently available. To obtain data to serve as a basis for determining the rate of salt dissolution for this dome would require the drilling of waterwells and the testing of both subsurface groundwater and surface runoff water. However, it is not recommended at this time that such a program be undertaken for the Mount Sylvan dome.

OIL AND GAS POTENTIAL

As indicated in the earlier discussion of this dome, a number of wells have been drilled on or near the flanks of this dome, and numerous wells have been drilled within a five-mile radius of the apex. Although oil and gas production has been established in scattered locations some four to five miles away from the apex of the dome, prospects are not favorable for oil and gas development near this dome.

PALESTINE DOME

DISCOVERY

The Palestine dome is located in Anderson County, Texas, approximately six miles southwest of the City of Palestine, and is the southernmost of the six domes investigated.

It is reported that, during the Civil War, salt was recovered by evaporation of brine from salt water wells producing from this dome. Later, the Palestine Salt and Coal Company started its operations in 1904. Little is known about these brine wells, but they apparently were drilled through the caprock where casing was set and salt removed by circulation of water. Each of these wells apparently continued to operate until the caprock collapsed when it was no longer able to sustain the weight of the overburden. A topographic map of the Palestine salt dome from U.S.G.S. Bulletin 661 shows that nine brine wells were drilled on the north side of the salt mass near the north shore of Duggey's Lake, and seven wells were drilled on the south side of the lake. A lignite mine was operated in 1923, approximately one and one-quarter miles northeast of the dome to supply fuel for the salt works.

Numerous wells have been drilled which have delineated the general configuration and shape of this dome. No hydrocarbons have been found in the immediate vicinity of the dome, but a large oil and gas field is located approximately two miles south of the domal uplift.

GEOGRAPHY

The Palestine dome has a central lake, Duggey's, with an elevation of approximately 250 feet, with a rim of hills encircling the lake. Town Creek drains the area to the southwest into the Trinity River. A salt lick was observed on the western side of Duggey's Lake, and salt marsh deposits have been observed about one-half mile to the east of the Palestine dome.

SURFACE GEOLOGY

The salt plug of the Palestine dome has risen to at least 150 feet above sea level. Hightower (Muehlberger, 1962) presented a well-documented geologic map of the Palestine salt dome area (Figure 4 of the report). He depicts some eight radial faults formed by the intrusion of the salt mass, which brought formations as old as the Buda Limestone of Cre-

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taceous age to the surface. Thus, the surface overlying the salt mass centered by Duggey's Lake presents exposure of formations from Quaternary, Tertiary, and Cretaceous beds. Northwest-southeast and southwest-northeast cross-sections depict the tilted and displaced formations adjacent to the salt plug and caprock. Each graphically depicts the collapsed domal area which is now Duggey's Lake (Exhibit G-39).

SUBSURFACE GEOLOGY

Exhibit G-39 depicts the shape of the salt stock at Palestine dome which has been interpreted from all available well data and gravity information. It appears that the salt grew vertically from some 20,000 feet to approximately 6,000 feet near the close of Lower Cretaceous time. Later movement of the salt mass resulted in the formation of a shoulder, followed by the thinning of the salt from some three miles in diameter to approximately one mile in diameter at its top. The top of the dome extends to approximately 150 feet above sea level and is covered by caprock which probably averages less than 50 feet in thickness. Salt movement has arched up all of the beds, resulting in a thinning of all of the formations from Lower Cretaceous through and including the Tertiary beds.

STABILITY OF DOME

Based on the salt lick on the western side of Duggey's Lake, the salt marsh deposits on the eastern portion of the dome, and the presence of salines around the dome, it appears that dissolution of salt from this dome probably still is in progress. Based on the 50 feet of caprock at Palestine dome and assuming the interior core of the dome moved vertically to replace the salt dissolved in the process of the caprock formation, the rate of vertical salt movement was 0.031 mm. per year for the 50 million year period since Wilcox time, or an equivalent vertical movement during a 200,000 year period of approximately 20 feet.

There has been arching-up of overlying Eocene beds by the salt at Palestine dome. Uplift, reflected in beds above the Wilcox, is indicated to be in the order of 1,700 feet. This would indicate an "uplift-vs-time" value of approximately 0.010 mm. per year for this 50 million year period, or an equivalent uplift in a 200,000 year period of approximately 7 feet. There are indications that alluvium and terrace deposits may be present near the Palestine dome. Extensive borehole drilling and study of such deposits might indicate whether or not there has been any uplift resulting from salt movement during recent time. However, it is not recommended that such study of the alluvium or terrace deposits be under-

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taken at this time because of the presence of active salines around this dome and the uncertainty of the location and present mechanical condition of the salt solution wells used in the early solution mining of salt from this dome.

OIL AND GAS POTENTIAL

A number of shallow test wells drilled on the flank of this dome failed to encounter hydrocarbons, and it is felt that the prospects for commercial accumulations in flank sediments down through and including Upper Cretaceous are not attractive. A large oil and gas field is located approximately two miles to the south of the Palestine dome. Although there have been very few deep tests in the vicinity of this dome, it is not felt that the older objectives offer an attractive target for oil and gas exploration.

STEEN DOME

DISCOVERY

The Steen dome is located in the northern portion of Smith County, Texas, approximately five and one-half miles east of the town of Lindale and fourteen miles north of the City of Tyler; the dome is approximately two and one-half miles south of the Sabine River. It is the northernmost of the six domes investigated.

It is reported that some 3,000 people were engaged in making salt on the Steen dome during the Civil War, and the output was on the order of 120 tons daily, with 20 furnaces making a bushel of salt from every 190 gallons of water (Powers, 1926). The location of the brine wells is not known, and it is unlikely that they can now be found. Furthermore, if found, it would be impossible to ascertain the method of abandonment and the present mechanical condition.

Limestone was quarried on the west side of the dome in rocks believed to be of Wilcox age.

GEOGRAPHY

The Steen dome is traversed by Saline Creek which flows from south to north through a saline marsh and empties into the Sabine River (Exhibit G-40). The marsh area is about a mile long and a half-mile wide. The domal area is surrounded by a ring of low hills which, in turn, are surrounded by an outer ring of higher hills. The area is the site of several rural homes, well-tended grazing lands, cultivated row crops, and commercial rose farms.

SURFACE GEOLOGY

The Steen dome is covered by a blanket of Wilcox beds and there are no exposures of older beds in the vicinity of the domal uplift. There is a definite surface expression of the domal collapse over the central portion of the salt marsh (Exhibit G-43).

SUBSURFACE GEOLOGY

The Steen dome cants to the northeast and grew as an increasingly expanding cylinder to approximately 100 feet above sea level. There appears to have been at least three periods of diapiric movement. Based

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upon gravity, it appears that the salt grew vertically from 18,000 feet to approximately 10,000 feet probably by the close of Rodessa time. Continued movement in a northeasterly direction resulted in an expansion of the salt mass with a definite overhang to the northeast from 10,000 feet to approximately 5,000 feet (Woodbine time). It appears that the Woodbine may have been one of the aquifers that dissolved the salt inasmuch as caprock was reported on the west flank in the Fair Oil Company No. 2 well (Key Well No. 54) at 4,221 feet subsea, or only 16 feet below the top of the Woodbine. From 5,000 feet to approximately 3,000 feet, the salt grew vertically, uplifting the surrounding beds. From this point, the salt again grew vertically and, at the present time, has a caprock averaging approximately 150 feet, extending to a point approximately 250 feet above sea level, as encountered in the Weeks-Pierce well drilled in 1924.

STABILITY OF DOME

It is reported (Powers, 1926) that springs in the central area represented artesian, slightly saline waters from sands of Wilcox age, reaching the surface along joints and faults in rocks overlying the caprock. A sulphur spring is reported on the northeast part of the dome. Caprock across the top of the dome, and probably draped over the sides of the dome to a depth of as much as 5,000 feet, indicate dissolution of salt from the top and the sides of this dome. Based on a caprock thickness of 150 feet and assuming the interior core of the dome has moved vertically to replace the salt dissolved in the process of caprock formation, the rate of vertical salt movement was 0.091 mm. per year for the 50 million year period since Wilcox time, or an equivalent vertical salt movement during a 200,000 year period of approximately 60 feet.

The history of early salt mining by means of brine wells at unknown points on this dome in addition to the quarry mining on the western flank of the dome are considered to be unfavorable factors associated with this dome.

There has been arching-up of overlying Eocene beds by the salt at Steen dome. Uplift, reflected in beds above the Wilcox, is indicated to be in the order of 1,000 feet. This would indicate an "uplift-vs-time" value of approximately 0.006 mm. per year for this 50 million year period, or an equivalent uplift in a 200,000 year period of approximately 4 feet. Thus, the amount of net salt movement indicated by such "uplift-vs-time" value is considered to be insignificant.

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OIL AND GAS POTENTIAL

Numerous wells have been drilled over and around the flanks of this dome, but only one well on the eastern flank encountered hydrocarbons in commercial quantities. This well produced from the Rodessa Formation but was offset by dry holes. The deeper formations near the dome have not been tested; but based upon the drilling to date, the prospects for finding hydrocarbons on and around the Steen dome are not considered favorable.

WHITEHOUSE DOME

DISCOVERY

Whitehouse salt dome is located in south-central Smith County, Texas, about five miles south of the City of Tyler. Seismic surveys made in 1927 indicated the presence of the dome and, in early 1928, a well drilled near the center of the dome encountered anhydritic caprock at shallow depths (Renick, 1928). Later in 1928, a flank well penetrated the salt (Judson, 1929). Subsequent drilling and gravity data have delineated the general shape of the dome.

GEOGRAPHY

Low ridges mark the east, north, and south flanks of Whitehouse dome (Exhibit G-44). Over the central portion of the dome, the ground slopes to the west and is drained by two small tributaries of the creek that skirts the west flank of the dome.

SURFACE GEOLOGY

Queen City sands are exposed over the center and west flank of Whitehouse dome. The Queen City is overlain by the resistant Weches greensands, which form the partially encircling ridges on the other flanks. Sparta sands cap the Weches to the northeast, east, and southeast.

Wendlandt and Knebel (1929) report that the outcrops dip away from the dome into rim synclines and that slumping due to salt dissolution is indicated by outcrop of Weches greensand over the top of the dome at a lower level than on the adjacent rim.

SUBSURFACE GEOLOGY

Exhibit G-44 shows the configuration of the salt stock at Whitehouse dome as interpreted from well data and available gravity data. The shallow part of the salt tapers up to a narrow crest at about 115 feet above sea level and is overlain by approximately 100 feet of caprock (Exhibit G-47). Between 3,000 and 8,000 feet subsea, the stock widens and an overhang has developed on the north flank. Above the overhang, the Woodbine and Lower Cretaceous beds are truncated by a local unconformity at the base of the Austin Chalk. Thinning in the Woodbine and Washita-Fredericksburg indicates the bulge developed at the close of Early Cretaceous and continued to arch up the overlying beds at the start of Late

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Cretaceous time. The emergent dome area was beveled by erosion prior to deposition of the Austin Chalk. During Late Cretaceous time, the salt continued to arch up the overlying sediments. It eventually broke through the overburden, in the area south of the overhang, either late in the Cretaceous or early in the Tertiary. Exhibits G-45 and G-46 show the rim syncline and steeply, upturned structure around the dome in Lower Eocene and Upper Cretaceous horizons.

STABILITY OF DOME

The relatively small amount of arching up of beds above the Wilcox over the Whitehouse dome, compared to older formations, indicates the amount of uplift by salt movement has been minor since Eocene time. Uplift, reflected in beds above the Wilcox, is indicated to be in the order of 600 feet. This would indicate an "uplift-vs-time" value of approximately 0.004 mm. per year for this 50 million year period, or an equivalent uplift in a 200,000 year period of approximately 3 feet. The "uplift-vs-time" values for the Whitehouse dome have shown a general decline from Jurassic time, through Early and Late Cretaceous time, and through the Tertiary time such that the rate of uplift at the present time is believed to be very slight, if not halted altogether.

Caprock thickness and the reported collapse of the Weches over the dome indicate dissolution of salt has occurred at Whitehouse dome during the period since Wilcox time (approximately 50 million years). Based on a caprock thickness of 100 feet and assuming the interior core of the dome moved vertically to replace the salt dissolved in the process of caprock formation, the rate of vertical salt movement was 0.061 mm. per year for this 50 million year period, or an equivalent vertical salt movement during a 200,000 year period of approximately 40 feet.

However, groundwater data indicate the likelihood that little or no dissolution of salt is taking place at present. The level of fresh groundwater was measured at 312 feet above sea level in a Wilcox water well on the south edge of the dome on March 19, 1962. This level is about 100 feet below the ground surface in the vicinity of the dome and in the creek bed to the west. Fresh groundwater level in a Wilcox water well west of the creek was found to be at 312 feet above sea level on January 4, 1960, and March 19, 1962. Queen City water wells on the north and east flanks of the dome had a water level of 405 feet above sea level in the mid-1950's. Fresh water flowing through the Queen City probably never comes in contact with the salt at Whitehouse. Wilcox water does not come to the surface at Whitehouse; and, if salt is being dissolved and carried

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away underground in this formation, it is not apparent in the nearby water wells. The drilling of additional water wells in the vicinity of this dome would aid in verifying whether or not salt is being dissolved by subsurface water.

OIL AND GAS POTENTIAL

Shallow drilling at Whitehouse dome has failed to encounter hydrocarbons and the prospects are poor for oil and gas traps in the Tertiary and Upper Cretaceous. Older objectives have not been tested near the dome, but the results of the few deep tests of shallow piercement domes in the basin have not indicated such features to be favorable exploration targets.

GENERAL REVIEW OF SALT DOMES

OF THE

NORTHEAST TEXAS BASIN

There are 14 shallow salt domes (including the six discussed in detail in this report) and three intermediate depth piercement salt domes in the study area covered by this report. There are also several deep salt-cored domes in the area that may or may not be diapiric structures. Brief descriptions of these domes follow:

BETHEL - Shallow dome, located in west-central Anderson County. Salt overhangs on west and east flanks are underlain by oil and gas reservoirs. References: Krusekopf (1968, 1964, 1959); Fisher (1965); Love (1957); Hanna (1934); Judson (1929); Wendlandt (1929); Renick (1928).

BOGGY CREEK - Large, elongate, northeast-southwest trending shallow dome located in northeastern Anderson County and northwestern Cherokee County. Oil production on southeast flank. References: Fisher (1965); Cawthon (1964); Herald (1951); Hanna (1934); McLellan (1932); Judson (1929); Wendlandt (1929); Renick (1928).

BROOKS - This shallow dome, located in southwestern Smith County, is now overlain at the surface by an arm of the Lake Palestine reservoir and by a resort development. References: Fisher (1965); Wendlandt (1929); Powers (1926).

BRUSHY CREEK - Intermediate depth dome located in northeastern Anderson County. Top of salt is at 3,570 feet and oil production is from a Woodbine reservoir over the dome at about 3,300 feet. References: Fisher (1965); Wendlandt (1929).

BULLARD - See detailed description in this report.

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BUTLER - Shallow dome in northern Freestone County. Upturned surface formations form "race track" over dome. In use for storage of LPG in solution cavity. References: Halbouty (1967); Fisher (1965); Wendlandt (1929); Powers (1926).

CHAPEL HILL - Deep-seated salt feature located in eastern Smith County. Produces oil and gas from the Paluxy, Rodessa, Pettet, and Travis Peak. References: Herald (1951).

CONCORD - Intermediate depth dome in north-central Anderson County. Top of salt at 6,000 feet. Oil production from Woodbine on southeastern flank of dome. References: Fisher (1965).

EAST TYLER - Shallow dome in central Smith County, on east edge of City of Tyler. Solution cavity in salt used for LPG storage. A small thrust fault is exposed in Eocene outcrops near the southwest flank of this dome (McCallum, 1961). Water wells are discussed in the section of this report that deals with hydrologic stability of salt domes. References: Halbouty (1967); Fisher (1965); Judson (1929); Wendlandt (1929); Renick (1928).

GRAND SALINE - Shallow dome in northeastern Van Zandt County. Used for solution mining and bulk mining of salt. See section of this report on hydrologic stability of domes for groundwater data. References: White (1973); Muehlberger (1968, 1962); Fisher (1965); Balk (1949); Peters (1948); Hanna (1934); Wendlandt (1929); Powers (1926).

HAINESVILLE - Shallow dome in central Wood County. Gas production from reservoir under salt overhang on southwest flank. Solution cavity in salt used for LPG storage. References: Halbouty (1967); Fisher (1965); Krusekopf (1959); Eaton (1952); Wendlandt (1929); Renick (1928).

HAWKINS - Broad, circular, deep-seated dome located in southeastern Wood County. Highly faulted. Dome produces oil from the Woodbine sand and gas from the Rodessa Formation. References: Herald (1951); Wendlandt (1946).

KEECHI - See detailed description in this report.

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LA RUE - Intermediate depth dome located in central Henderson County. Top of salt at 4,450 feet. Growth rates discussed in the section of this report on stability of salt domes. References: Fisher (1965); Bornhauser (1958); Wendlandt (1929); Renick (1928).

MOUNT SYLVAN - See detailed description in this report.

OAKWOOD - Shallow dome located on line between Freestone and Leon Counties. Oil production from Woodbine under salt overhang on north, east, and southeast flanks. References: Fisher (1965); Nance (1964); Judson (1929); Wendlandt (1929); Renick (1928).

OPELIKA - Deep domal feature located in northern Henderson County. Produces oil and gas from Glen Rose, Rodessa, James, Pettet, and Travis Peak. References: Brogdon (1968); Herald (1951).

PALESTINE - See detailed description in this report.

QUITMAN - Deep-seated dome located in western Wood County. Produces oil from the Sub-Clarksville, Eagle Ford, Woodbine, Paluxy, and Lower Glen Rose. References: Miron (1964); Bornhauser (1958); Herald (1951); Scott (1948).

SLOCUM - Deep domal feature in southeastern Anderson County. Highly faulted. Produces oil from Sub-Clarksville and Woodbine. References: Read (1959).

STEEN - See detailed description in this report.

VAN - Deep-seated dome in eastern Van Zandt County. Produces oil from the Woodbine. Faulted. References: Herald (1951); Liddle (1936).

WHITEHOUSE - See detailed description in this report.

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INDEX OF WELLS SHOWN ON BASE MAP OF THE SIX DOMES STUDIED

BULLARD DOME

<u>Key No.</u>	<u>Operator</u>	<u>Well Name, Number</u>
9	Perryman	#1 Chesley
10	Fair-Rhodes Unit	#1A Dykes
11	Humble	#1 Clements
12	Fair Oil	#1 Richburg
13	Fair	#1 Clements
16	Purnell & Coleman	#1 May Epsy
19	Purnell & Coleman	#1 Terry Graham
20	Williams	#1 Tomlin
21	Gulf	#3 McCammond
22	Gulf	#2 McCammond
23	Gulf	#1 McCammond
24	Halbert Drlg Co.	#1 Ray
24A	Gulf	#1 Morgan
25	U.S. Smelting	#1 Johnson
26	Arcadia Refining	#1 Carlton (Brown)
28	Voight	#1 Hawthorne
29	Voight	#1 Pace
30	Voight	#1 Cawthorn
31	Pruett & Pope	#1 Cawthorn
32	Voight	#1 Long
33	Sklar	#1 Looney
38A	Humble	#1 Tomlin
39	Lake-Talbert	#1 Phillips
39A	Humble	#1 Fall
41A	Humble	#1 Nyman
44	Ivey	#1 Dennis
44A	Rowe & Peveto	#1 Walker
45	Hughey	#1 Boyles
46	Ellison	#1 Williams
47	Manziel	#1 Douglas
48	Humble	#1 Walker
48A	Hamon	#1 Murphy
50	Ellison	#1 Douglas

NETHERLAND, SEWELL & ASSOCIATES, INC.

INDEX OF WELLS SHOWN ON BASE MAP OF THE SIX DOMES STUDIED

KEECHI DOME

Key Nos.	Operator	Well Name, Number
1	Delta	#1 Ward
2	Pan-Am	#1 Seymour
21	Humble	#1 Horwitz
23	Humble	#1 Valentine
29	Fair Oil Co.	#1 Quick
30	Byrd & Hunt	#1 Dosser
31	Humble Oil & Ref. Co.	#1 Rooney Est.
33	E.B.LaRue-F. R. Jackson	#1 Jernigan
34	L. W. Storms	#1 Broyles
35	Broyles & McFarlane	#2 Wilhite
36	Broyles & McFarlane	#1 Wilhite
37	Navarro	#4 Greenwood
38	LaRue & Jackson	#1 Nathan Scott
42	Lamar Hunt	#1 R. C. Fort
46	Texas Company	#1 O'Flynn
47	Geiselman	#1 O'Flynn
48	Sun Oil Company	#1 Allison Gardner
49	Navarro	#3 Greenwood
50	Navarro	#1 Greenwood
51	Navarro	#2 Greenwood
52	Broyles & McFarlane	#1 Butler
53	Navarro	#1 Barrett
53A	Producers	#5 Barrett
56	Hughey et al	#1 Gardner
57	Union of Texas	#1 Shroyer
58	Halbouty	#1 Gardner
59	Kohibush-Halbouty	#1 Gardner
60	Huggins	#1 Cone & Cone
61	Byars	#1 Pessoney
62	Tipton	#1 Chotinar
63	Union of Calif.	#1 Raisigh
64	Epperson	#1 Shelton

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INDEX OF WELLS SHOWN ON BASE MAP OF THE SIX DOMES STUDIED

MOUNT SYLVAN DOME

<u>Key Nos.</u>	<u>Operator</u>	<u>Well Name, Number</u>
3	Humble	#1 Gary
4	Harry Owens	#1 Wilkinson
5	Powell	#1 Gary
10	Charles Halstead	#1 Talbert
12	Ellis	#1 Talbert
15	Halstead	#1 Cade (Jodie Newton)
17	Delta	#1 Gary
21	Gist	#1 Smith
23	Sinclair	#1 Curtis
24	J. K. Wadley	#1 Adams
27	Standard Oil of Texas	#1 A. M. Steele
28	Gulf Oil Corp.	#1 D. M. Jackson
30	J. Trantham & J. G. Voight	#1 D. M. Jackson
31	G. C. Clark	#1 D. M. Jackson
32	D. D. Feldman Oil & Gas	#1 Geo. P. Verner Est.
33	Damson Exploration	#1 Sibyl Verner McGinney
34	D. D. Feldman or Damson Expl.	#1A Mary Puckett
35	B. G. Byars et al	#1 Verner Estate
54	Peyton McKnight, Jr.	#1 Beard
55	Peyton McKnight, Jr.	#1 Bundy
58	Carter-Jones Drilling Co.	#1 Katherine Hanjeian
60	Standard Oil Company	#1 Pauline E. Glasco
61	Humble Oil & Ref. Co.	#1 E. A. Humble et al
62	E. A. Carter & B. A. Kaemmerer	
66	Delta Drilling Co.	#1 O. M. Boun
67	M. K. Marr	#1 E. M. McFarland

NETHERLAND, SEWELL & ASSOCIATES, INC.

INDEX OF WELLS SHOWN ON BASE MAP OF THE SIX DOMES STUDIED

PALESTINE DOME

<u>Key Nos.</u>	<u>Operator</u>	<u>Well Name, Number</u>
1	Hughey	#1 Huffman
3	Devon-Leduc	#1 Barrett
4	Union Oil Co. of Calif.	#1 Raisigh
6	Miller & Walker	#1 Coble
7	Pure Oil	#1 City of Palestine Waterworks
9	Avery	#1 Henry
10	Carlson & Heller	#1 Bernard
11	Johnson & Berry	#1 Armstrong
12	Roper-Humphrey	#1 Berry
13	Roper	#1 Kaemmerer
14	Lacy, Inc.	#1 Hanks
15	Kahn	#1 Conyers
16	Thompson	#2 Texas Co.
17	Thompson	#1 Texas Co.
B	Texas Co.	#1 J. J. Briggan
C	Texas Co.	#1 Forrest L. Long
18	Thompson	#3 Texas Co.
19	Thompson	#1 Carter-Gregg
20	Lacy	#1 Abbott
21	Morrow	#1 Watkins
22	F. H. E. Oil Co.	#2 Moody Est.
23	Anco Gas	#1 Hinderf
25	Locke	#3 Tidewater
26	Hughey & Cone	#1 Cern & Shaw

NETHERLAND, SEWELL & ASSOCIATES, INC.

INDEX OF WELLS SHOWN ON BASE MAP OF THE SIX DOMES STUDIED

STEEN DOME

Key Nos.	Operator	Well Name, Number
3	Sohio Producing	#1 Wright
7	John S. Voight	#1 Pool
8	Fleming	#1 Fleming
9	Fleming	#1 Crews
10	Geosearch	#1 Leach
10A	McKnight	#1 Wheelis
11	Sun	#1 Fleming
16	Delta Drilling	#1 Lyons
17	Joe M. Griffith, Jr.	#1 Elizabeth R. Lamb
18	Peyton McKnight	#1 W. A. Stroud
19	J. L. Patton	#1 Mary L. Henderson
19A	Atlantic Refining Co.	#1 Edna Wythe
21	J. L. Patton	#1 W. J. Gardner
22	Winwell 1961 Exploration Co.	#1 M. A. Ward Fuller
23	Sinclair Oil & Gas Co.	#1 M. F. Wells
24	La Coastal Petroleum Corp.	#1 J. M. Mims
26	W. F. Nenny	#1 Brazier
27	Gulf Oil Corp.	#1 Jeff Land
31	Humble Oil & Refining Co.	#1 A. E. Forston et al
33	Humble Oil & Refining Co.	#1 Everett Winters et al
34	Cities Service Oil (Humble)	#1 D. Balfour
36	E. A. Ellison	#1 Julius Mullins
38	Harris R. Fender	#1 Jack B. York
39	Harris R. Fender	#1 Frank (W. G.) Brown
51	John R. Bunn	#1 Ashcraft
52	John R. Bunn	#3 Ashcraft
53	Fair Oil Co.	#1 McDowell
54	Fair Oil Co.	#2 McDowell
55	S. W. Minerals, Inc.	#1 Mrs. L. W. Pierce
55A	Winwell 1963 Exploration Co.	#1 Grace Chastain Unit
56	Gulf Oil Corp.	#1 Mary J. W. Moore
57	Gulf Oil Corp.	#1 W. G. Atwood
58	Lindale Oil Co.	#1 M. W. Winter
59A	Humble Oil & Refining Co.	#1 R. A. Coulter
62	Loyce Phillips	#1 W. B. Duckett Unit #1
63	I. M. Lemon	#1 Hubert Lake et al
64	Sells Petroleum Co.	#1 Oliver Hackett
65	Mrs. I. M. Lemon	#1 Clyde Coulter
67	Mrs. I. M. Lemon	#1 Oliver Hackett Estate
68	I. M. Lemon	#2 Oliver Hackett Estate

NETHERLAND, SEWELL & ASSOCIATES, INC.

INDEX OF WELLS SHOWN ON BASE MAP OF THE SIX DOMES STUDIED

STEEN DOME (Continued)

Key Nos.	Operator	Well Name, Number
69	W. B. Hinton	#1 Coulter-Hitt
70	M. J. Delaney Co.	#1 Oliver Hackett Estate
70A	Humble Oil & Refining Co.	#1 J. P. Gogan
71A	Loyce Phillips	#1 J. P. Gogan Unit
73	Humble Oil & Refining Co.	#1 Minnie Matthews et al
74	Humble Oil & Refining Co.	#1 J. A. Gibson et al
74A	Shell Oil Company	#1 Nat W. Brooks
76	Mrs. I. M. Lemon	#1 C. & O. Matthews
76A	Cities Service Oil Co.	#1 R. C. Wade
77	Peyton McKnight	#1 O. S. Rather
78	Humble Oil & Refining Co.	#1 W. J. Dugger et al
79A	R. W. Fair	#1 A. J. Wells
80	Skelly Oil Company	#1 Bessie Shaw
82	Humble Oil & Refining Co.	#1B Tyler State Park
82C	Humble Oil & Refining Co.	#1C Tyler State Park
83	Humble Oil & Refining Co.	#1 Tyler State Park
84	Billy Mikech	#1 J. L. Crawley
85	Caroline Hunt Sands-L.B.Sands	#1 J. B. McKenzie
86	McCormick Oil & Gas Corp.	#1 Geo. Benson
88	Lyons & Logan	#1 House
88A	Peyton McKnight-M. B. Redman	#1 B. S. Marsh
88C	Lyons Petroleum	#1 Gibson Unit
90	Samedan Oil Corp.	#1 Addie Brown
92	Humble Oil & Refining Co.	#1 Ada Lee
92A	H. L. Hunt	#1 Samuel Miller et al
93	J. E. Kemp	#1 Alice Patterson
94	Delta Drilling Co.	#2 J. M. Christian
95	B. G. Byars	#1 Gentry & Shamburger

NETHERLAND, SEWELL & ASSOCIATES, INC.

INDEX OF WELLS SHOWN ON BASE MAP OF THE SIX DOMES STUDIED

WHITEHOUSE DOME

Key Nos.	Operator	Well Name, Number
1	Phillips	#1 Jackson
2	Phillips	#1 Goss
5	Humble	#2 Sherlock
8	Lone Star	#1 Chilton
9	Delta	#1 Buie
11	Manziel	#1 Lawler
13	Delta Drilling	#1 Ramey
15	Sun-Hunt	#1 Judge
16	Spence	#1 Barron
17	Samedan	#1 Sampson
18	Peyton-McKnight	#1 Story
20	Zephyr	#1 Bergfield
21	McKellar-Champion	#1 Bergfield
22	LeCuno	#1 Neill
24	Mundt	#1 Funderburgh
25	Zephyr	#1 Mundt
26	Zephyr	#1 Murray
27	Rotary	#1 Guinn
31	Delta	#1 Buie
32	Humble	#1 Ellerd
33	Humble (EGU-2)	#1 Hudnall
34	Peveto-Pruitt	#1 Hudnall
37	Marsh-McIlwane	#1 Peveto
39	Humble	#1 Shelton
43	Phillips	#1 Griffith
46	Humble	#1 Hairston
48	Phillips	#1 Craver
48A	Phillips	#1 Halbert
50	Phillips	#3 McMinn
51	Phillips	#1 Massey
58	Phillips	#2 Willingham-Daniels
59	McMinn	#1 Hughes
60	Neil	#1 Hughes
62	Green	#1 Hudnall
62A	Halbert Drlg Co-Casey	#1 Skidmore
62B	Halbert Drlg Co-Casey	#2 Skidmore
63	Acme Oil	#1 Horton
64	Whiteley Drlg.	#1 Edwards Estate
65	Perryman	#1 Chesley
66	Sun Oil Company	#1 Wimberly

NETHERLAND, SEWELL & ASSOCIATES, INC.

INDEX OF WELLS SHOWN ON BASE MAP OF THE SIX DOMES STUDIED

WHITEHOUSE DOME
(Continued)

<u>Key Nos.</u>	<u>Operator</u>	<u>Well Name, Number</u>
67	Humble	#1 Pruett
67A	Humble	#1 Birdsong
67B	Humble	#1 Van Havenberg
68	Voight	#1 Burns
69	Voight	#2 Burns
70	Talbert & Gulley	#1 Simpson
71	Herring Drlg. Co.	#1 Beddingfield
72	Herring Drlg. Co.	#1 Morgan
74	Fair-Rhodes	#1A Dykes
76	Fair Oil	#1 Richburg
77	Fair	#1 Clements
78	Humble	#1 Brelsford
86	U.S. Smelting Co.	#1 Johnson

NORTHWEST

SOUTHEAST

LEGEND

- DIRECTION OF FRESH WATER
- xxxxxx WATER TABLE
- (A) SURFACE RUNOFF ENTERS WILCOX AND OTHER AQUIFERS
- (B) GROUND WATER RETURNS TO SURFACE FLOW IN STREAM VALLEYS
- (C) SALT-WATER SPRINGS FORM WHERE GROUND WATER RISES TO SURFACE OVER SALT DOME
- (D) WECHES FORMS RESISTANT RIDGES IN CENTER OF BASIN
- (E) SPARTA SAND CAPS HIGH HILLS
- (F) MOUNT ENTERPRISE FAULT SYSTEM
- SALTY WATERS IN WILCOX IN DEEPER PART OF BASIN NEAR MOUNT ENTERPRISE FAULT SYSTEM

NORTHEAST TEXAS SALT-DOME BASIN

SKETCH SECTION

SHOWING

FRESH WATER ZONES

NO SCALE

NETHERLAND, SEWELL & ASSOCIATES, INC.
DALLAS, TEXAS MAY, 1976

NETHERLAND, SEWELL & ASSOCIATES, INC.

INDICATED "UPLIFT-VS-TIME" VALUES ⁽¹⁾

CERTAIN DOMES OF NORTHEAST TEXAS SALT-DOME BASIN

INDICATED BY UPLIFT OF ROCK UNITS OF THE STRATIGRAPHIC INTERVAL SHOWN

<u>Stratigraphic Interval</u>	<u>Geologic Age</u> <u>(Million Years)</u>	<u>Interval Time</u> <u>(Million Years)</u>	<u>BULLARD</u>	<u>KEECHI</u>	<u>MT. SYLVAN</u>	<u>PALESTINE</u>	<u>STEEN</u>	<u>WHITEHOUSE</u>	<u>Average</u>
Post-Wilcox	50	50	.003	.012	.003	.010	.006	.004	.006 ⁽²⁾
Wilcox-Midway Groups	65	15	.024	.028	.031	.043	.026	.035	.031
Upper Cretaceous	98	33	.022	.018	.014	.029	.017	.018	.020
Lower Cretaceous	135	37	.049	.038	.054	.026	.049	.047	.044
Upper Jurassic	149	14	?	?	?	?	?	?	.153 ⁽³⁾
Total Time	149	149							

(1) Based on stratigraphic studies of the basin as set forth in this report.

(2) "Uplift-vs-time" value of .006 mm. per year is equivalent to .000019686 feet per year, or approximately 3.9 feet for a 200,000 year period.

(3) Estimated from regional study; uplift associated with growth of salt pillows.

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TABLE OF CONTENTS

<u>GEOLOGICAL EXHIBITS</u>	<u>No.</u>
Surface Geology	G- 1
Subsurface Rock Section	G- 2
Diagrammatic Cross-Section	G- 3
Regional Isopachous Maps	
Top Cotton Valley to Top Louann Salt	G- 4
Base Massive Anhydrite to Top Travis Peak	G- 5
Top Paluxy to Top Massive Anhydrite	G- 6
Top Lower Cretaceous to Top Goodland	G- 7
Base Austin Chalk to Top Lower Cretaceous	G- 8
Top Pecan Gap to Base Austin Chalk	G- 9
Top Nacatoch to Top Pecan Gap	G-10
Top Wilcox to Top Midway	G-11
Regional Structure Maps	
Top Louann Salt	G-12
Top Cotton Valley Lime	G-13
Base Massive Anhydrite	G-14
Base Austin Chalk	G-15
Top Midway	G-16
Portion of Northeast Texas Salt-Dome Basin Showing Available Seismic Data	G-17 - G-20
Dome Maps and Cross-Sections	
Bullard Dome	G-22 - G-25
Keechi Dome	G-26 - G-30
Mount Sylvan Dome	G-31 - G-35
Palestine Dome	G-36 - G-39
Steen Dome	G-40 - G-43
Whitehouse Dome	G-44 - G-47

EXPLANATION OF MAP PATTERNS SURFACE ROCK SECTION

LEGEND

1 STEEN DOME	5 BROOKS DOME
2 MOUNT SYLVAN DOME	6 KEECHI DOME
3 WHITEHOUSE DOME	7 PALESTINE DOME
4 BULLARD DOME	8 BUTLER DOME

NORTHEAST TEXAS SALT-DOME BASIN

SURFACE GEOLOGY
SECTION AND MAP

ADAPTED FROM REPORT OF INVESTIGATIONS
NO. 54, BUREAU OF ECONOMIC GEOLOGY,
UNIVERSITY OF TEXAS, MINERAL RESOURCES,
EAST TEXAS, PLATE II

♦ SALT DOME

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DALLAS, TEXAS MAY, 1976

(Continued from previous page.)

NORTHEAST TEXAS SALT-DOME BASIN

SUBSURFACE ROCK SECTION

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UNIVERSITY OF TEXAS, MINERAL RESOURCES,
EAST TEXAS, PLATE II

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LEGEND

- CDP SEISMIC RECORDS
- SINGLE FOLD SEISMIC RECORDS
- SALT DOME

PORTION OF
NORTHEAST TEXAS SALT-DOME BASIN
SHOWING
AVAILABLE SEISMIC DATA

LEGEND

- CDP SEISMIC RECORDS
- SINGLE FOLD SEISMIC RECORDS
- SALT DOME

PORTION OF
NORTHEAST TEXAS SALT-DOME BASIN

SHOWING

AVAILABLE SEISMIC DATA

PORTION OF
NORTHEAST TEXAS SALT-DOME BASIN
SHOWING
AVAILABLE SEISMIC DATA

LEGEND

- CDP SEISMIC RECORDS
- SINGLE FOLD SEISMIC RECORDS
- SALT DOME

PORTION OF
NORTHEAST TEXAS SALT-DOME BASIN
SHOWING
AVAILABLE SEISMIC DATA

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STRUCTURE MAP ON
TOP OF SALT

TOPOGRAPHICAL MAP
SHOWING DOMAL UPLIFT

NORTHEAST TEXAS SALT-DOME BASIN

STRUCTURE MAP ON TOP OF SALT BULLARD DOME

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NORTHEAST TEXAS SALT-DOME BASIN

CROSS SECTIONS BULLARD DOME

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NORTHEAST TEXAS SALT-DOME BASIN

CROSS SECTIONS

KEECHI DOME

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NORTH-SOUTH CROSS SECTION

STRUCTURE
ON
CAPROCK

THICKNESS
OF
CAPROCK

NORTHEAST TEXAS SALT-DOME BASIN

**SPECIAL CROSS SECTION
WITH CAPROCK MAPS
KEECHI DOME**

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STRUCTURE MAP ON
TOP OF SALT
GRAVITY

STRUCTURE MAP ON
TOP OF SALT
SUBSURFACE COMBINED WITH GRAVITY

TOPOGRAPHICAL MAP
SHOWING DOMAL UPLIFT

NORTHEAST TEXAS SALT-DOME BASIN

STRUCTURE MAPS ON TOP OF SALT MOUNT SYLVAN DOME

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NORTHEAST TEXAS SALT-DOME BASIN

CROSS SECTIONS

MOUNT SYLVAN DOME

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STRUCTURE MAP ON
TOP OF SALT

TOPOGRAPHICAL MAP
SHOWING DOMAL UPLIFT

NORTHEAST TEXAS SALT-DOME BASIN

STRUCTURE MAP ON
TOP OF SALT
PALESTINE DOME

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NORTHEAST TEXAS SALT-DOME BASIN

STRUCTURE MAP ON
BASAL WILCOX HORIZON
PALESTINE DOME

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NORTHEAST TEXAS SALT-DOME BASIN	
CROSS SECTIONS PALESTINE DOME	
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DALLAS, TEXAS	MAY, 1976

STRUCTURE MAP ON
TOP OF SALT
SUBSURFACE COMBINED WITH GRAVITY

M. CARMONA

STRUCTURE MAP ON
TOP OF SALT
GRAVITY

TOPOGRAPHIC MAP
SHOWING DOMAL UPLIFT

NORTHEAST TEXAS SALT-DOME BASIN

STRUCTURE MAPS ON TOP OF SALT STEEN DOME

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NORTHEAST TEXAS SALT-DOME BASIN

CROSS SECTIONS STEEN DOME

1" = 1000'

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STRUCTURE MAP ON
TOP OF SALT

TOPOGRAPHICAL MAP
SHOWING DOMAL UPLIFT

NORTHEAST TEXAS SALT-DOME BASIN

STRUCTURE MAP ON TOP OF SALT WHITEHOUSE DOME

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100

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NORTHEAST TEXAS SALT-DOME BASIN

STRUCTURE MAP ON
BASAL WILCOX HORIZON
WHITEHOUSE DOME

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NORTHEAST TEXAS SALT-DOME BASIN

STRUCTURE MAP ON BASE AUSTIN CHALK WHITEHOUSE DOME

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NORTHEAST TEXAS SALT-DOME BASIN

CROSS SECTIONS

WHITEHOUSE DOME

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