EVALUATING THE POTENTIAL OF EAST TEXAS SALT DOMES FOR ISOLATION OF NUCLEAR WASTE

Annual Report

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INTRODUCTION

Since January 1978, the Bureau of Economic Geology has been evaluating the potential for using a salt dome in the East Texas Basin as a repository for nuclear waste isolation. This report is a brief summation of work accomplished within Year I.

Using the dome selection criteria of Brunton and others (1977), Kreitler and others (1978) selected Oakwood, Keechi, and Palestine salt domes as possible sites for a nuclear waste repository. The problem of depositing nuclear wastes into an East Texas salt dome contains two critical questions: (1) Are the domes still growing (tectonic stability)? (2) Are the domes dissolving, and what is the rate of dissolution (hydrologic stability)? These two questions are being asked on a dome-specific and a regional scale. The long-term suitability of a dome cannot be ascertained until it is placed in a regional context. This necessitates regional as well as site-specific studies.

The approach includes three subprograms: (1) subsurface geology, (2) hydrogeology, and (3) surficial geology and remote sensing. The subsurface geology program investigates dome size and shape, the geology immediately around the dome, and the infilling of the East Texas Basin over geologic time and how this basin filling affected the growth of the domes. The surficial geology and remote sensing program addresses the problem of potential dome growth during the Quaternary. Typical questions which are examined in this program are whether Pleistocene terraces have been uplifted or warped; whether there has been any fault movement in the Pleistocene; and whether there are any movements reflected in lineation patterns around domes anomalous to regional patterns or indicated by drainage networks. The hydrogeology program evaluates the hydrologic stability of the domes with the following objectives. What are the rates and directions of regional ground-water flow? What are the ages of these ground waters? How does ground water flow around a salt dome? What are the rates of salt solution? Does the caprock prevent salt dissolution?

This document represents a progress report and is not a final statement on the Bureau of Economic Geology's position on the suitability of salt domes in East Texas Basin for waste isolation. The observations and ideas presented in this document therefore represent a status report and may be subject to change as more information and concepts are developed.

SUBSURFACE GEOLOGY

Regional Studies

Regional subsurface studies of East Texas have been undertaken to delineate the structure and stratigraphy of the basin and to determine the relationship between salt-dome growth and basin evolution. The purpose of these studies is to understand the regional factors influencing dome stability.

The area of study covers approximately 16,800 square miles (43,570 square kilometers) and extends from the Mexia-Talco fault zone in the north and west, to the Sabine Uplift in the east, and to the vicinity of the Angelina flexure in the south. It includes all of Freestone, Anderson, Cherokee, Henderson, Smith, Van Zandt, Rains, Wood, Hopkins, Franklin, Titus, Camp, and Upshur Counties; western Morris, Gregg, Rusk, Nacogdoches, and Angelina Counties; northern Leon, Houston, and Trinity Counties; and eastern Limestone, Navarro, Kaufman, and Hunt Counties.

The study is based mainly on the correlation of electric-log stratigraphic markers in both the Mesozoic and Tertiary sections. A total of about 1,500 well logs and scout cards are the main sources of information. Logs from wells which are generally about 5 miles apart have been received for most of the study area. Construction and correlation of well-log cross sections for the regional studies started in mid-May 1978. Logs received have been catalogued and are being utilized in the construction of 50 cross sections (vertical scale 1" = 200'). Nineteen are in a generally NE-SW direction (about parallel to the axis of the basin) and average approximately 130 miles in length. Thirty-one are in a NW-SE direction (nearly perpendicular to the basin axis) and average about 90 miles in length. To date, 26 cross sections have been constructed, 8 along the basin and 18 across the basin. Stratigraphic markers have been correlated on 19 of these sections. Correlation tables are being prepared, showing the elevation of the stratigraphic markers and the thickness of the various stratigraphic intervals. These values will be plotted and contoured on well-location base maps at a scale of 1:250,000. The correlation of stratigraphic well-log markers will provide the data for the construction of structural, isopach, and facies maps of selected stratigraphic units--which are critical in the evaluation of the growth history and stability of the domes in this region.

Domal Studies

The subsurface geology of 16 shallow (< 4,000 feet deep) domes in the East Texas Basin is being evaluated to determine the geometry of each dome and to develop a framework for hydrogeologic studies. The study is undertaken to analyze the growth history of each dome and to evaluate the present tectonic stability of the domes. The 16 domes are Oakwood, Keechi, Palestine, Butler, Bethel, Brushy Creek, Boggy Creek, Brooks, Bullard, Whitehouse, Mount Sylvan, Steen, East Tyler, Hainesville, Grand Saline, and Marquez (fig. 1). The Oakwood, Keechi, and Palestine domes have been selected for more detailed studies (Kreitler and others, 1978).

Work Completed

Cross sections have been constructed through each dome with the exception of Marquez and Grand Saline Domes. Subsurface stratigraphic units have tentatively been correlated for each cross section.

Maps of Brushy Creek, Bethel, Butler, and Oakwood Domes showing depth to the dome from available logs and a single contour on top of the dome were completed. Isochore data and the elevation of stratigraphic markers have been plotted on domal base maps for Keechi, Palestine, Oakwood, Bethel, Brushy Creek, Butler, and Boggy Creek Domes. Outcrop patterns of the various strata contoured were transferred onto domal base maps from surface geology presented on the Geologic Atlas of Texas Sheets, and on maps by Ebanks (1965) and Hightower (1958).

Conclusions

Preliminary conclusions regarding the dome geometry and surrounding subsurface geology of Keechi, Palestine, and Oakwood Domes have been made from available well-log data. The shallowest known depth to each dome is presented in table 1.

Table 1. Shallowest known depth to dome.

Dome	Depth from ground	Well
Keechi	125	Navarro #2 Greenwood
Palestine	120	Brine well discussed by Powers (1926)
Oakwood	878	Texas Company #1 Settlemyre (McBee #D1 Settlemyre)

The youngest unit believed to be in contact with each dome is shown in table 2.

Table 2. Youngest probable lithostratigraphic unit in contact with the dome.

Dome	Youngest probable strata in contact with dome	Data source
Keechi	Wilcox Group	Navarro #2 Greenwood
Palestine	Eocene sediments or Recent alluvium	Powers (1926)
Oakwood	Wilcox Group	Shell (McBee) #1 Tinsley

Of the three aforementioned domes, Oakwood and Keechi have overhangs. The #1 Barrett and Greenwood on the southern flank of Keechi Dome penetrates salt from a depth of 2,162 feet to 2,822 feet and repenetrates salt at a 3,091-foot depth. Wells around Oakwood Dome indicate an overhang on all sides of the dome as shown by Nance (1962).

The structure of beds around Keechi and Palestine Domes is similar in that the strata have been steeply uplifted and thin along the flanks of both domes. At Keechi and Palestine Domes, Cretaceous strata have been identified in outcrop over the dome, and numerous surface faults have been mapped. The strata around Oakwood Dome, however, appear to be relatively undeformed, and no Cretaceous outcrops have been identified at the surface over the dome. Cross sections through the dome show little, if any, thinning of strata near the dome, nor do beds appear to steepen considerably around the dome flanks. A summary of the findings for the three domes follows.

Oakwood Dome

The Oakwood Dome, located at the Leon-Freestone county line, was selected for further studies because of its size and depth to salt. Since the sands of the Wilcox Group appear to be in contact with the dome (fig. 2), there is a potential for salt dissolution by ground water. Most of the available well data from the Oakwood Dome area is from the eastern domal margin where oil has been produced from the Woodbine Formation and the Georgetown Group beneath the dome overhang (Nance, 1962). Cumulative crude oil production from sediments near the dome was 2,110,106 barrels on January 1, 1978 (Texas Railroad Commission, 1978). Repository siting within such a large dome must avoid the production area.

Only one well, Roxana #1 Marshall, has been drilled near the dome center. According to Renick (1928), Judson (1929), Nance (1962), Hawkins and Jirik (1966), and Halbouty (1967), anhydrite caprock was reached at a depth of 703 feet in that well.

Williams (1928), however, reported that the same well never reached the dome. Assuming the depth to the dome in Roxana #1 Marshall is questionable, the shallowest known depth to the salt dome is 878 feet in Texas Company #1 Settlemyre (McBee #D1 Settlemyre).

Despite the relatively large size of Oakwood Dome, the available well control indicates comparatively little structural deformation around the dome. Unlike some other smaller East Texas domes, such as Palestine, Keechi, and Butler, no Cretaceous beds have been brought to the surface during domal growth. According to the Palestine Geologic Atlas Sheet and Stenzel (1938), the Eocene Queen City Formation is the only unit exposed at the surface over Oakwood Dome. Ed Collins (1978, personal communication, The University of Texas at Austin, Bureau of Economic Geology) has identified one possible Reklaw outcrop in a creek bank over the dome. A gamma-ray-lateral resistivity log for McBee #1 Storms on the west side of the dome suggests that Wilcox may crop out in the area. Renick (1928, p. 537) reported there are "pronounced dips" in the Queen City, Reklaw (Cane River greensand), and Carrizo on all sides of Oakwood Dome. Stenzel (1938) also observed steep dips in Queen City beds near the dome.

Cross sections constructed through Oakwood Dome show little, if any, stratigraphic thinning near the dome flanks (figs. 3 and 4). On the northeast and northwest sides of the dome, no uplift of surrounding strata can be seen in cross section. In fact, beds appear to dip toward the dome, contrary to the above-cited references.

Keechi Dome

Keechi Dome is a piercement salt dome located approximately 7 miles northwest of Palestine, Texas, in central Anderson County. Sediments as old as the Upper Cretaceous Pecan Gap are exposed over the dome crest (Ebanks, 1965). Ebanks (1965) constructed west-east and northwest-south cross sections through Keechi Dome as well as a contour map on top of the salt to a subsea depth of 4,000 feet (fig. 5). His contours are in agreement with the Bureau analysis of the well data. The only discrepancies in salt elevation values between Ebanks' map and our calculations are for Navarro #4 Greenwood and LaRue and Jackson #1 Jernigan. These values should be -2,026 feet and -3,209 feet, respectively. Such a change would not alter the contours on Ebanks' map, as he has apparently mislabeled salt elevation values for these two wells. Additional well data added by us to Ebanks' map also has not altered his contouring.

There is disagreement among previous authors identifying the lithostratigraphic units immediately over the domal apex. Powers (1926) shows Upper Cretaceous Navarro sediments directly over the dome and Midway and Wilcox strata above. Netherland, Sewell and Associates (1976) indicate Midway beds sheathing most or all of the upper dome with Wilcox sediments at the surface. Work by Ebanks (1965) and the BEG (figs. 6 and 7) indicates that the Wilcox Group directly overlies the caprock. Evidence for this is a bed of lignite which is recorded in a sample log of Navarro #2 Greenwood. The lignite lies directly beneath a sand and above a 50-foot thick limestone. Both Netherland, Sewell and Associates (1976) and the BEG interpret the limestone as part of the caprock. A questionable hypothesis is that the limestone is Upper Cretaceous.

Palestine Dome

Palestine Dome, located 5 miles west of the town of Palestine, Texas, in central Anderson County is a piercement salt dome which has uplifted geologic units as old as Cretaceous around it. A north-south domal cross section is shown in figure 7, and an east-west cross section across the southern flank is shown in figure 8.

Little information is available directly over the top of Palestine Dome to indicate the impact of uplift on the geology in this locality. Since no logs are available for the solution-mining wells drilled into the Palestine Dome, the only information available about the subsurface geology over the dome crest is from

Powers (1926). He reports that the caprock is a "hard, gray limestone" with sand and shale overlying it. The surface geology over the dome crest is presently hidden by Duggey's Lake, as it was when Powers published his report. Quaternary deposits surround much of the lake shoreline (Hightower, 1958). Powers (1926) suggested that the sediments overlying the dome crest are either Recent alluvium or subsided Eocene deposits.

If the sediments are younger than Cretaceous, they must be preserved in a graben over the dome since Hightower (1958) has clearly identified Cretaceous outcrops on the north, east, and south margins of Duggey's Lake. A graben could have resulted from dome dissolution by ground waters with consequent collapse of overburden materials, or the graben could be solely a result of domal growth. Parker and McDowell (1951) have used weak barite muds and commercial asphalt to model salt-dome growth. They found that a central graben formed over domes with either a thick or thin sediment overburden.

Powers (1926) also describes a "water sand" which occurs between the caprock and salt in all brine wells except those on the east side of the dome. In a well on the west side of Duggey's Lake, this "water sand" is 194.5 feet thick. Such a large thickness of sand leaves the suspicion that the caprock limestone Powers refers to is actually a Cretaceous or an Eocene deposit.

HYDROGEOLOGY

A prime concern is to determine the hydrologic stability of salt domes in the East Texas Basin. The regional patterns of ground-water flow, the flow rates of ground water in the fresh-water aquifers, and the patterns of ground-water flow around a dome are the major problems being addressed. These problems are being studied by means of both regional and site-specific studies.

Regional Hydrology

A study of the regional circulation of ground water in the East Texas Basin is needed to define (1) the rates of ground-water movement, (2) the interactions of ground waters of one aquifer with another,(3) the manner in which salt diapirs disturb normal hydrologic flow, and (4) the potential for radionuclide transport to the biosphere. The proposal for the first year of this program stated that "a regional study of the hydrology of the East Texas area requires an integration of the geologic framework, potentiometric surface elevations and hydrochemical facies evolution to resolve these four goals."

Work within the first year of the program maintained an integrated approach and accomplished the following objectives:

1. Potentiometric surfaces for the Carrizo-Wilcox and Queen City aquifers were constructed.
2. Percent-sand, net-sand, and structure contour maps of the Wilcox aquifer have been integrated with the potentiometric surface of the Wilcox.

Work was initiated in which water chemistry data are evaluated for validity, plotted on scatter plots for ionic statistical correlations, and plotted on map view to determine ground-water chemistry evolution.

Primary conclusions from Year I regional hydrologic studies follow. The aquifer of prime concern for the dissolution of salt domes is the Wilcox aquifer because it (1) covers the entire basin, (2) is in contact with many of the salt domes, (3) contains fresh ground water that will permit dome solution, and (4) has relatively rapid rates of circulation. The second aquifer of major concern is the Queen City. It is also fresh-water bearing, but is not as geographically extensive, and is in direct contact with fewer domes.

Wilcox Aquifer

In the East Texas Basin, the Wilcox Group contains structures, textures, and compositions identified with deltaic and fluvial sediments. The distribution of thick sands is predominantly dip oriented with major thick sands in the center and along the southern edge of the basin (fig. 9). Greater volumes and greater rates of ground-water flow are expected in the dip-oriented thick sand sections than in higher percentage mud areas.

The outcrop partly encircles western, northern, and eastern inland portions of the basin. The Wilcox Group has been warped as is shown by the structure map on top of the Wilcox unit (fig. 10). This warping has caused a structural high trending northwest across the middle of the basin, which has given the Wilcox aquifer an increased dip to the south and reversed the dip north of a structural divide where the Wilcox aquifer now dips to the northeast.

The potentiometric surface of the Wilcox aquifer (fig. 11) indicates two sub-basins of ground-water flow. Ground water is recharged at the outcrop and flows down the structural dip. South of the structural divide, ground-water flow is to the south into the center of the basin. Discharge appears to be into the rivers crossing the basin. North of the structural divide ground-water flow is to the northeast, probably discharging into rivers which transect that section of the basin.

Queen City Aquifer

The Queen City Formation is a fluvial-deltaic sedimentary unit younger than and overlying the Wilcox Group. The Reklaw Formation behaves as an aquitard between the two units. The Queen City Formation has been extensively eroded. The aquifer is under watertable conditions, and ground-water flow is topographically controlled. Along the southern margin ground-water flow in the Queen City aquifer becomes confined beneath the Weches Formation. The elevation of heads in the Queen City are above the potentiometric surface of the Wilcox aquifer, indicating that there is leakage from the Queen City aquifer into the Wilcox aquifer. This leakage appears to be considerable in certain areas.

Regional Hydrochemistry

The Wilcox aquifer appears to have lower total dissolved solid (TDS) concentrations in the upper half than in the lower half of the aquifer. Characteristically, the lower thin sands are more saline. These conclusions are interpreted from resistivity measurements on electric logs.

Water chemistry analyses from approximately 750 water wells indicate a low-TDS water that is predominantly a sodium-bicarbonate water. The water analyses are predominantly from the upper half of the aquifer. Very little is known about the ionic chemistry of the water in the lower Wilcox aquifer. Sodium and bicarbonate concentrations increase linearly because of the reactions of calcium carbonate dissolution and sodium-calcium cation exchange. Sulfate concentrations decrease with depth because of sulfate reduction. In some areas of the basin there have been significant contaminations of the shallow ground water by sodium-chloride brines, probably from earlier brine dispersal practices in oil field operations. Similar geochemical trends are observed in the Queen City aquifer. The data base, however, is not as large.

Salt Dome Hydrology

A study of the hydrology of specific salt domes in the East Texas Basin is needed to define (1) how salt domes dissolve, and (2) the hydrologic stability of specific domes.

Estimates of Total Dissolved Solids by Electric Log Interpretation

The water chemistry data for the Wilcox aquifer provides good regional control of horizontal chemical variations for the upper half of the aquifer. The chemistry of deep Wilcox ground waters and ground water around the domes is not available. Where water chemistry data were not available, estimates of total dissolved solids (apparent salinity) were made from resistivity curves on electric logs (Kreitler and others, 1978) using a method modified from Turcan (1966).

Salinity measurements around several domes in the East Texas Basin (Oakwood, Butler, Palestine, Bethel, Bullard, Whitehouse, Concord, Steen, Grand Saline, Hainesville, Brooks, Keechi, and Brushy Creek Domes) indicated that increased apparent salinities exist primarily in thin sands in the lower Wilcox strata and not in the shallower thick sands in the middle to upper Wilcox beds. The lower Wilcox unit, which Fisher and McGowen (1967) interpreted as deltaic in origin, represents a transition between the fluvial upper Wilcox and the underlying Midway Group which was deposited in a marine environment. The increased apparent salinities in the thin sands of the lower Wilcox beds may result from one of three mechanisms. First, dome solution may cause the increased salinity. The amount of dome solution would be small because the sands have low permeability and, therefore, the rates of movement are probably slow. Second, the apparent salinity may result from a lack of flushing of original saline formation waters. This would be particularly true if the sands have been isolated from meteoric fresh-water flushing by overlying mud aquitards. Third, the apparent salinity may result from leakage of saline waters from deeper formations. The first and third hypotheses probably are the best since most of the anomalous salinities appear to be downdip from the domes. Detailed hydraulic head measurements and water chemistry analyses in monitored wells will resolve these multiple hypotheses.

Salt Brine Operations at Palestine Salt Dome

The suitability of Palestine salt dome for nuclear waste isolation is in doubt because of the salt brining operation conducted in the dome. Salt was mined from 1900 to 1937 using brine wells. Power (1926) described the following procedure:

"Wells are drilled to the caprock at 120 to 160 feet, casing is set, and then the well is deepened 100 to 250 feet in the salt. Water from a water sand under the caprock flows into the wells, dissolves the salt, and the brine is forced by compressed air to the Plant."

The brining operation has resulted in the occurrence of at least 15 collapse features, or sinkholes. Thirteen of the collapse phenomena were mapped by Hightower in 1958. Two additional collapses have occurred since 1958; the most recent significant collapse, which was 36 feet in diameter, was in 1972. The other collapses range from 27 to 105 feet in diameter and from 1.5 to more than 15 feet in depth.

The salt brine operation has disrupted the hydrologic integrity of the caprock/ salt dome interface. Dissolution of this interface by brining may permit greater dissolution from natural ground-water flow over the long-term geologic time. The man-made brine operation may also be analogous to long-term salt solution by fresh ground water over geologic time.

Implications on Hydrologic Stability of Salt Domes

(1) The Wilcox and Queen City aquifers contain low-TDS waters capable of salt dome dissolution. There is, however, little evidence for salt dissolution where the upper half of the Wilcox Group is in contact with domes. The electric-log analysis of salinity around salt domes indicates that the apparent salinity increases in deep thin sands in the Wilcox strata. This increased apparent salinity may result from (1) salt dome solution, (2) lack of flushing of older deeper waters, or (3) leakage from deeper saline aquifers.

(2) The Wilcox aquifer appears to have well-defined recharge-discharge patterns--recharge at the outcrop and discharge to the rivers. In the Texas Coastal Plain, the potentiometric surface of the Wilcox aquifer is higher than the potentiometric surface of the overlying Queen City aquifer. This relationship is caused by the lack of

easy discharge from the Wilcox unit. For ground water to discharge from the Wilcox aquifer into Queen City sands it must be forced through a Reklaw-equivalent aquitard. On the other hand, in the East Texas Basin the relative elevations of the potentiometric surfaces are reversed; the head in the Queen City sands is higher than in the underlying Wilcox aquifer. This relationship indicates effective discharge from the Wilcox aquifer. Discharge to the rivers crossing the basin limits the amount of pressure build-up in the Wilcox Group. An efficient recharge-discharge relationship permits greater rates and volumes of fresh ground-water flow through an aquifer and subsequently would offer a greater potential for salt dome solution and mobilization of nuclear waste than in an aquifer with an inefficient recharge-discharge mechanism.

(3) The geochemical trends evident in the Wilcox and Queen City aquifers characterize both the chemistry today and the evolution of the chemistry as waters moved through the aquifer in the past. In Year II, when hydrologic monitoring of Oakwood Dome is operational, the water chemistry of waters around the dome can be compared to the regional geochemical trends to determine if they are anomalous.

(4) There are serious doubts about the suitability of Palestine salt dome for a repository to isolate nuclear waste because of the abandoned salt brine operations. The random geographic and spatial occurrence of collapse sinks over the dome may prevent the safe construction of the necessary surface installations for a repository. The dissolution of salt between the caprock and dome may permit increased rates of salt dissolution long into future geologic time. However, study of the Palestine salt dome will continue because the effect on dome solution from 30 years of salt brining may be analogous to long-term, geologic time-frame salt dissolution that may be occurring on other domes.

SURFICIAL STUDIES OF QUATERNARY TECTONISM

Reconnaissance surface investigations were conducted over a broad area of East Texas centered upon Palestine, Keechi, and Oakwood Domes to establish the possibility of Quaternary tectonism. The area extended from the Mexia-Talco fault system to the Sabine Uplift, and included the Mount Enterprise fault system. Field procedures involved the examination of terrace deposits and Quaternary topographic surfaces for evidence of tectonic warping or fracturing. These studies were handicapped by the widespread soil and vegetation cover, colluviation of steeper slopes, and effects of erosion. Only in the Trinity River Valley were there extensive exposures of Quaternary sediments whose disposition could be observed intermittently along approximately 40 km of the river course. Field studies, where necessary, were supported by the study of subsurface data and the examination of aerial photographs in the immediate vicinity of the Trinity River.

Identification of a Fault Active in Quaternary

A normal fault displacing Quaternary sediments was observed on a bend in the Trinity River immediately upstream of a major northward river loop (fig. 12). The fault is located in Leon County 22 km west of the town of Elkhart. The fault trends N68^{o}E, with a southeasterly dip of 80 degrees. It displaces Eocene Claiborne strata at the base, with a throw of 90 cm, and extends upward through unconsolidated Quaternary gravels and sands (fig. 13). The well-defined bedrock fracture translates upward into closely-spaced multiple shear planes and small step faults, which traverse the unconsolidated sediments over a width of 1.5 m, and provide a cumulative Quaternary throw of 66 cm.

The Quaternary gravels and sands at this locality were probably deposited during the late Pleistocene. Quaternary deposits of the upper Trinity River are topographically expressed in three well-defined terraces. Thurmond (1968) related the uppermost and oldest terrace to the Sangamon Interglacial (Last Interglacial), which lasted from 128,000 to 73,000 B. P. (Suggate, 1974). The middle terrace was dated by Thurmond at 37,000 B. P., whereas a date of 10,000 B. P. was obtained for the lowermost level. The terrace deposits through which the fault extends have been mapped as the middle level (Geologic Atlas of Texas, 1967), which would correspond to the 37,000-year terrace of Thurmond (1968).

Relationship to Regional Fault Systems

The Trinity River Quaternary fault is aligned with the Mount Enterprise fault system to the east (fig. 12). The Mount Enterprise system comprises down-to-the-basin normal faults with dips of 35 to 60 degrees steepening towards the surface. The westernmost part of this fault system, the Elkhart Graben, shows surface displacement on Claiborne strata of up to 100 m. Fault movement may have commenced in the Early Cretaceous (Murray, 1961) and is generally regarded as having ended before the Quaternary.

Lineations in the Trinity River Area

Examination of aerial photographs reveals a number of subparallel linear trends (fig. 14), the majority of which accord with the Elkhart Graben fault alignment. A strong east-west trend is developed west of the Trinity River and may represent an extension of the Quaternary fault system.

Subsurface Correlations

Electric logs of wells drilled in Leon, Freestone, and Anderson Counties in the general area of the Trinity River Quaternary fault were studied for evidence of subsurface structures. Using the Nacotoch, Pecan Gap, and Austin Chalk stratigraphic markers it is possible to demonstrate the persistence of several faults: westward of the Elkhart Graben faults, through the area of the Trinity River fault, and corresponding to aerial photographic lineations.

Regional Seismicity

Although East Texas is regarded as an area of low earthquake risk, 10 earthquakes of intensity V (modified Mercalli scale of 1931) have been recorded since 1891. A "high damage" earthquake reported from Rusk in 1891 has since been designated "questionable" by von Hake (1977), who regards the localized damage to have been more likely of storm origin.

On March 19, 1957, there were four shocks of intensity V, with the epicenter in the vicinity of the town of Mount Enterprise, located within the Mount Enterprise fault system (fig. 12). Shocks of intensity I-V were felt over an area of approximately 10,000 square miles (26,000 square km), and the towns of Elkhart, Gladewater, Marshall, Nacogdoches, and Troup (fig. 1) all recorded shocks of intensity V. The first two shocks were recorded in Dallas (U. S. Coast and Geodetic Survey, 1957).

These tremors indicate the possibility of tectonism associated with the Mount Enterprise fault system, of which the Quaternary fault on the Trinity River may be a local manifestation.

Discussion

The significance of the Trinity River fault is that it establishes positive evidence of Quaternary tectonism in East Texas. The fault is in moderately close proximity to Palestine, Oakwood, and Keechi Domes, presently under consideration as potential sites for the isolation of nuclear waste. However, none of the three domes is directly affected. The fault trends in the general direction of Oakwood Dome, but probably terminates east of the dome. To date, it has not been possible to establish the relationship, if any, between Oakwood Dome structures and the east-trending fault.

The Quaternary faulting may be related to regional Gulfward downwarping. In studies of Quaternary terrace elevations, Bernard and LeBlanc (1965) show that the landward part of the coastal plain was uplifted while the offshore zone subsided. A second less likely possibility is that of fault reactivation by fluid extraction or injection associated with oil field activity related to the Mount Enterprise fault system.

GEOMORPHOLOGY AND REMOTE SENSING STUDIES

The geomorphology and remote sensing studies are directed principally toward testing the tectonic stability of the East Texas Basin. The immediate areas overlying and surrounding known salt structures require detailed examination.

Drainage Network Analysis

The purpose of the drainage network analysis is to recognize any evidence of Quaternary tectonic instability in salt-related structures of the East Texas Basin. It is assumed that structural uplift of salt will affect geomorphology and thereby impact local drainage. The simplest case is the local steepening of gradient and increased erosion by a stream. In fact, the result of uplift would be so complex as to alter an entire drainage network by means of increased channelization of runoff.

Drainage density is channel length per unit area (mi/mi^2) for the area measured. Many factors influence drainage density, including climate, lithology, and relief produced by structural uplift. If conditions such as vegetation, soil permeability, and precipitation intensity and distribution are constant and uniform, channelization will be most developed and frequent where the most runoff is collected. Therefore, slopes will cause runoff to be collected into channels, and the channels will be more numerous on slopes than on flatter topography.

Because drainage density measures channel length per unit area, topography with the most stream channels will also have the highest drainage densities. According to the above-mentioned hypothesis, slopes with the most stream channels will have the highest drainage densities. If this is true, increased relief over domes may produce greater drainage densities than those drainage densities for non-dome areas. Together with a measure of relief, drainage density may be useful as an indicator of domal uplift if such uplift has produced greater topographic relief over the dome.

Dome Location

In order to measure the drainage density and relief of a dome-affected area one must obviously know the areal extent of the dome-affected surface geology. However, only two domes, Palestine and Keechi, are presently mapped in any detail. Even then, the areal extent of dome-disturbed surface geology is unknown.

Because drainage density and relief should be measured specifically for the dome-disturbed areas, one needs to know what areas to measure. Since this is unknown, an arbitrary distinction as to size of the dome-affected area must be made.

During preliminary testing of this technique, it was assumed that all of the effects of domal uplift, if present, were confined within the area of a circle (radius = 2 miles) centered over the dome. We should avoid arbitrary decisions about dome-affected areas and measure values for the domes only when more information on their surface geology is available. In the meantime, because the values for non-dome areas must also be determined, these values need to be determined first. When better surface geological information is available, the dome-affected areas can be accurately measured. In 1978, all measurements were made on topographic maps; aerial photographic coverage was not available.

Selection of Non-dome Control Areas

Because dome-area values must be checked against the values of areas having identical lithologies, but lacking domes, non-dome areas having the same lithologies as the dome areas must be measured. Each of these lithologies must be measured in areas which meet the following criteria:

1. Be located in a non-dome setting.
2. Be located away from known or suspected structures.
3. Be located away from urbanized areas.
4. Have an outcrop area large enough to permit the measurement of drainage density (the drainage density measuring technique works best with large areas; this will be mentioned again later.)

The mean value for each lithology should be determined and tabulated. They will be used in a weighting procedure to compare dome versus non-dome areas.

Measurement of Drainage Density

The first step in measuring drainage density is to make a drainage network map for the area of interest. This time-consuming task should be done simply by delineating drainageways on stereoscopically-viewed aerial photographs. It is important to map all drainageways, whether they contain water or not. If drainage is obscured, linear tonal variations should be sought, as should linear segments of vegetation which follow drainages. For additional information on photointerpretative techniques, see any standard text on the subject as well as Baker and Patton (1976).

Once the drainage network is mapped, the line-intersection method is used to determine the drainage density. To use the method, randomly lay lines across the drainage net. Count the total number of line intersections with stream segments and put this value into the following equation:

Drainage density = 1.8 + 1.27 (N/L)

where

N = number of line intersections with stream segments

L = total length of lines within measured area.

Comparison of Dome to Non-dome Areas

Once values are known for the domes and their lithologies in non-dome areas, comparisons between dome and non-dome areas can be made. In the simplest case, that of a single lithology over a dome, the dome value and the value of the same lithology in a non-dome area can be directly compared. However, most domes have several lithologies. The lithologies occur in varying proportions over different domes. To compare dome and non-dome areas, a simple weighting procedure must be followed. An example follows:

Dome affected area = 10 mi^2

Lithology A = 7 mi^2 = 70%

Lithology B = 2 mi^2 = 20%

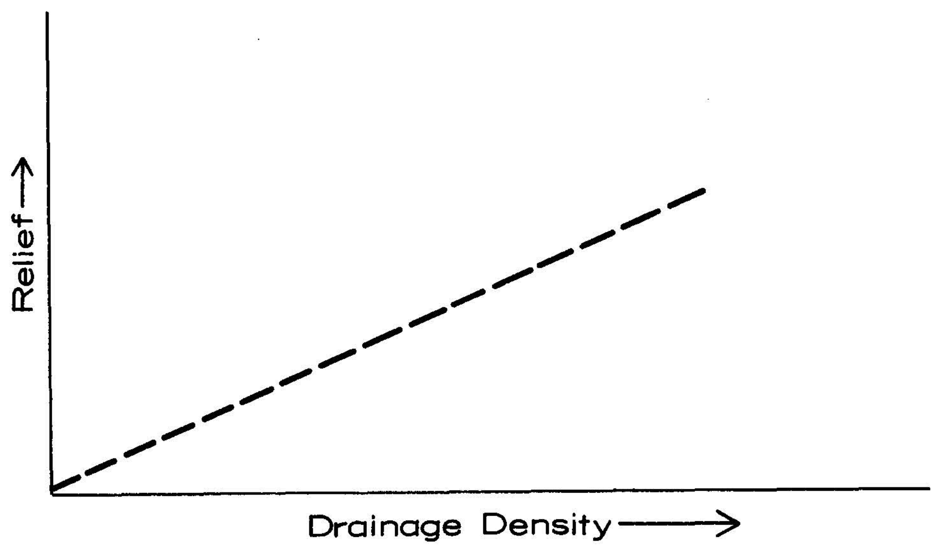
Quaternary alluvium = 1 mi^2 = 10%

Because only the effect of bedrock is to be evaluated, the percentage of area occupied by the alluvium should be redistributed among the other lithologies. Since the alluvium represents 10 percent of the total dome area, the 10 percent is redistributed equally among the number of bedrock lithologies found over the dome. Therefore, Lithology A now equals 7.5 mi^2 (75 percent) and Lithology B now equals 2.5 mi^2 (25 percent).

To find the drainage density for Lithologies A and B in a non-dome area, the percent of lithologies for the dome is multiplied by the value for non-dome area lithologies. The sum of these products equals the value for a non-dome area having the same rocks as a particular dome and with the same rocks occurring in identical proportions. These two values of dome and non-dome should be recorded and compared.

Application of Results

If differences are found to exist, particularly those where dome values are higher than non-dome values, the data may be useful in constructing a model of dome topography and causative domal uplift. For instance, if a relation of the form expressed in the following graph exists, the domes plotting higher on the graph may be those with more recent movement histories.



Such possibilities must be corroborated by other evidence, such as structurally deformed alluvium, radiocarbon dates, stream geometrics, and subsurface information. Nonetheless, the results may indicate something about the recent movement histories of the domes and their surface topographic expression.

Summary

Values for areas on domes and off domes were measured on available U. S. Geological Survey topographic maps and are reported in table 3. From measurements over eight domes, all but three domes have lower drainage density over domes than off

Table 3. Comparison of drainage densities for domes and non-domes determined from topographic maps.

Dome	Dome DD[2]	Non-Dome DD
Bethel[1]	6.48	8.47
Butler	8.86	8.41
Hainesville	7.55	7.94
Larve[1]	7.23	8.40
Opelika[1]	5.49	8.43
Steen	8.76	8.19
Grand Saline	8.52	9.50
Van	7.18	9.50
Oakwood (assuming Eqc)	10.53	8.4

1 = from 15' topography maps
2 = miles of drainage/square mile

domes. For these domes, no correlation exists between measured drainage densities and the surficial expression of domes on a geologic map. Moreover, for the five domes having opposite numerical relationships, the comparison of measures on topographic maps of two different scales and contour intervals is suspect. In conclusion, (1) measurement of drainage density on topographic maps was a learning experience, (2) topographic measurements are believed incomplete measures of whole integrated drainage systems, and (3) the evolved technique should be tested in stereographic aerial photography in FY 1979.

Lineation Analysis

An important aspect of the remote sensing studies is an analysis of lineations or fractures. This analysis is based on the premise that joints and faults in the East Texas Basin will be apparent on remote sensing imagery, and thereafter, several assumptions follow. The joints and faults will reflect the structural history of the basin. There are regional fracture sets which can be separated from fractures which are controlled by local structural events of which the emplacement of salt domes is the most prominent. A very recent structural event, particularly recent salt dome movement, is expected to produce an anomalous pattern relative to older regional structural patterns. Such an anomaly may be found by means of a statistical treatment of the lineations representative of fractures and faults. In this way, the tectonic stability of East Texas salt domes may be tested relevant to management of isolated nuclear wastes in salt domes.

A preliminary identification and plot of lineations measured on Landsat imagery was completed. The method and results of that study are presented in the following discussion.

Methodology

Lineations are recognizable as dark- or light-toned linear elements resulting from zones of different moisture content, vegetation, or substrate aligned over a fracture. Recognition of the lineations is strongly dependent on the contrast of the imagery. The contrast may vary considerably on adjacent imagery (table 4).

Table 4. Landsat scenes used in East Texas Basin lineation analysis.

1073-16235	04 Oct. 72	5	High contrast
1146-16302	16 Dec. 72	5	Low contrast
1146-16305	16 Dec. 72	5	Low contrast
1451-16224	17 Oct. 73	5	High contrast
2393-16094	19 Feb. 76	5, 7, CC	-----
2393-16100	19 Feb. 76	5, 7, CC	-----
5673-15232	20 Feb. 77	5, 7, CC	Oversaturated in blue
5673-15234	20 Feb. 77	5, 7, CC	Oversaturated in blue

The end points of lineations observed from varied reflectivity of the imagery were located with arrows. The lineations were transferred to the base map (fig. 15). A counter of 2 inches on a side was moved over the lineations. Movement of the counter was by means of overlapping the square 1 inch east-west and 1 inch north-south. For each location of the counting square, the number of lineations per unit area was labeled in the center of the square. The product is a moving average of the number of lineations per unit area, and this value was then contoured (fig. 16).

Results

The relationship of Landsat lineations and salt domes (fig. 15) is summarized in table 5.

Table 5. Relationship of the position of Landsat lineations and salt domes.

Domes	Relationship
Hainesville, Van, Steen, Mount Sylvan, East Tyler, Bethel, Concord, Brushy Creek, Palestine, and Oakwood	None apparent
Grand Saline, Brooks, and Keechi	1 tangent
LaRue	2 tangent
Bullard	1 tangent and 1 centered
White Horse and Boggy Creek	1 centered

In this preliminary study of Landsat lineations, it was noted that the shallow salt domes are not readily apparent. Even the Butler, Keechi, and Palestine Domes are difficult to locate although they have strong surficial evidence of tilted beds and radial faulting. Resolution of a domal structure is no better on either black-and-white or false-color Landsat imagery. It is suspected that the interaction of climate, vegetation, and terrain is partly responsible because the Iranian salt domes, where there is an arid climate, make a strong appearance on Landsat imagery.

It is clear that the Landsat lineations conform strongly to regional structure. From north to south in the East Texas Basin there is a general increase in the number of lineations per unit area (fig. 16). The largest concentration of lineations occurs in the vicinity of the Mount Enterprise Fault System and Elkhart Graben. The same relationship is apparent in a histogram showing the orientation of Landsat lineations (fig. 17). The dominant orientations of Landsat lineations fall between N 51°E and N 80°E; the average trend for the Mount Enterprise Fault System is approximately N 75°E. The en echelon faults of that system generally strike nearer N 60°E, as does the Elkhart Graben.

It is surprising that no lineations complementary to the fault systems were measured, because fracture systems commonly occur as orthogonal sets at about 90° complementary to one another. This anomaly will be rechecked in the next year.

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ANNUAL REPORT OF SALT DOMES IN EAST TEXAS BASIN FOR THE NATIONAL WASTE TERMINAL STORAGE PROGRAM, U. S. DEPARTMENT OF ENERGY

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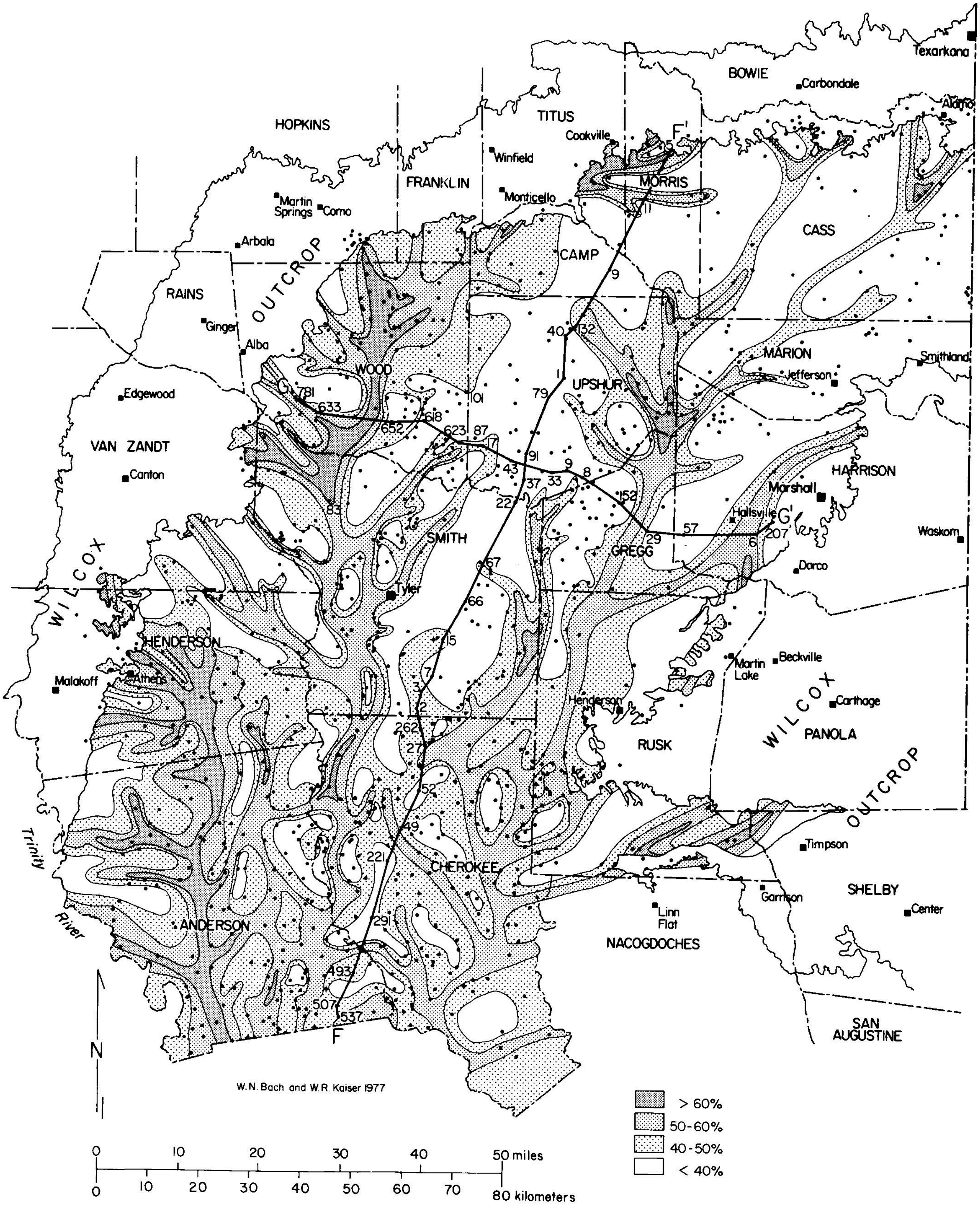


Figure 9. Percent-sand map of Wilcox aquifer in East Texas Basin, Texas. Note the dip-oriented depositional patterns, resulting from fluvial sedimentation (from Kaiser and others, 1978).

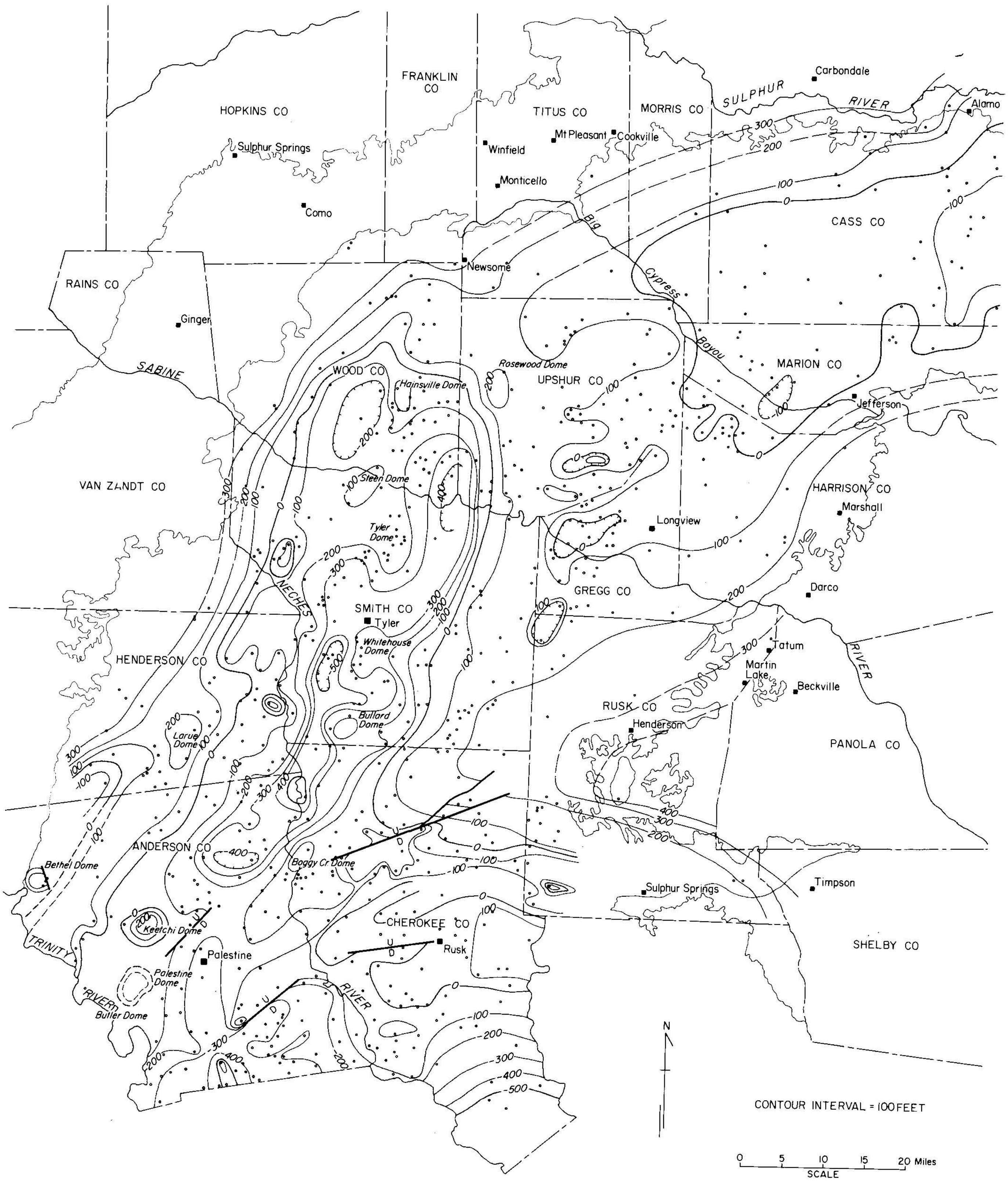


Figure 10. Structure map on top of the Wilcox group, East Texas Basin (from Kaiser, W. R., personal communication, 1978).

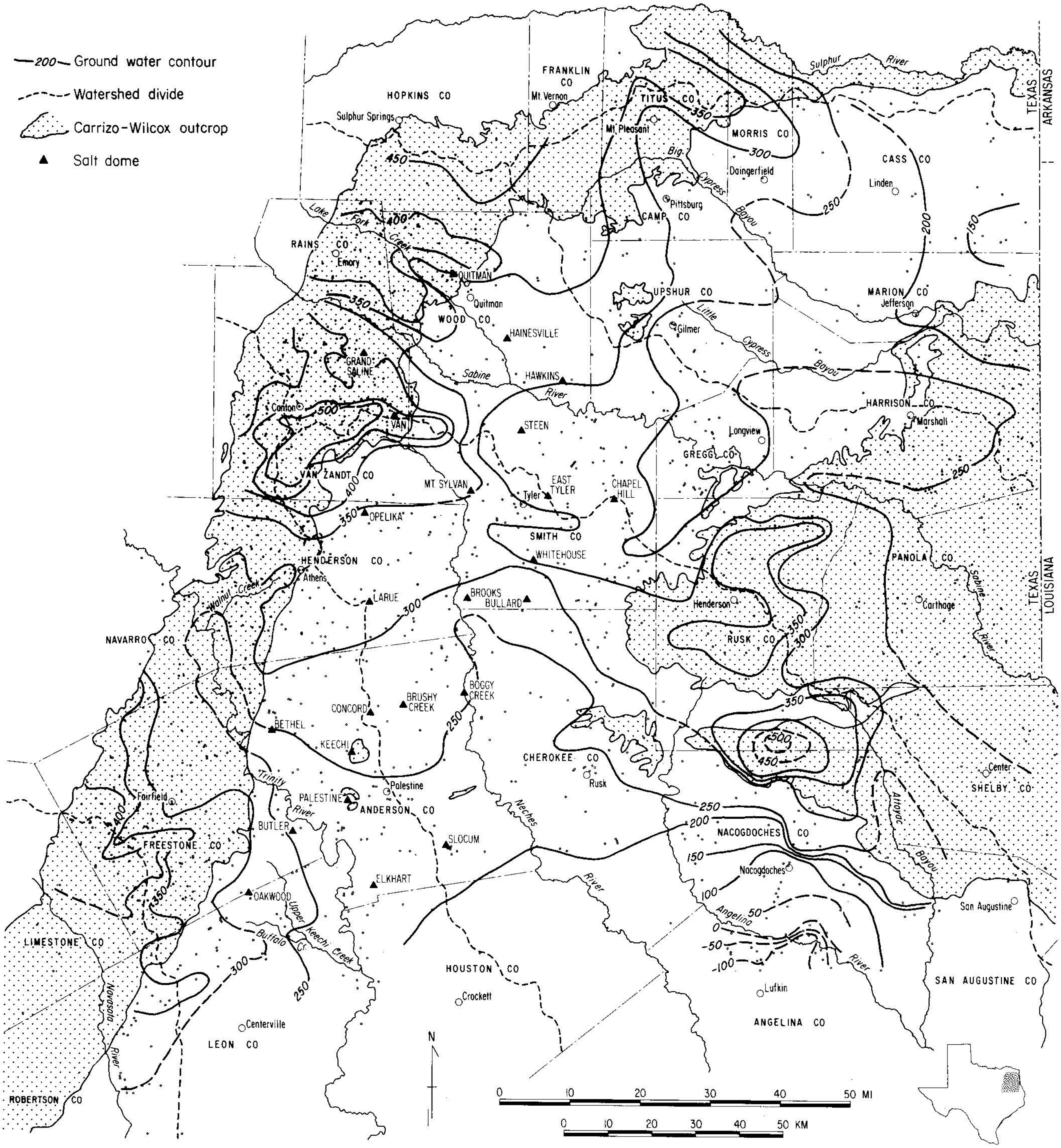
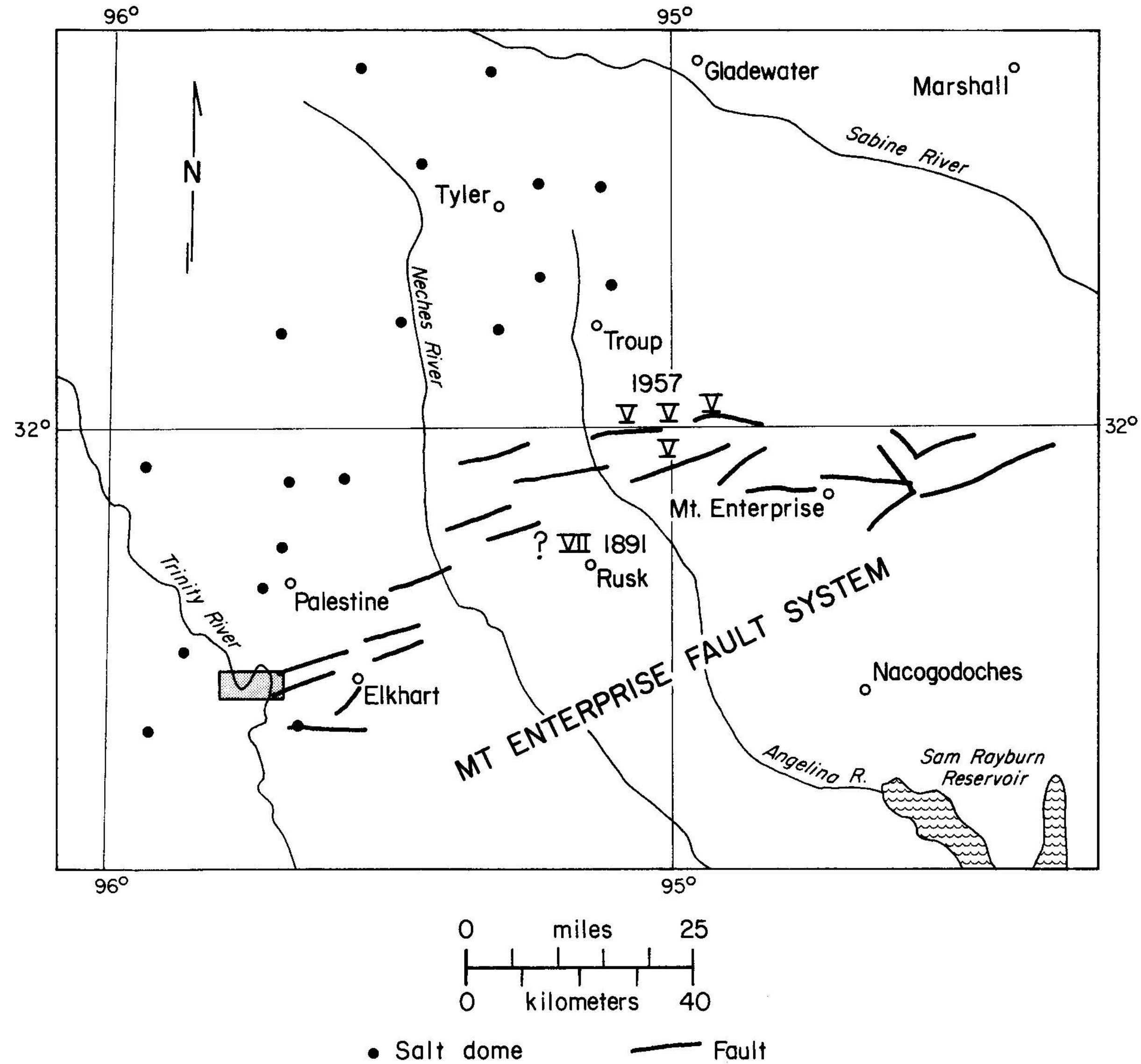


Figure 11. Potentiometric surface of Wilcox aquifer, East Texas Basin. Note that ground water flows north in the northern half of the map, whereas in the southern half flow is to the south. Flow direction is partly controlled by the structural dip of the Wilcox (fig. 10).



V 1957 Epicenter of four earthquakes that occurred on March 19, 1957

VII 1891 Epicenter of "questionable" Rusk earthquake that occurred on January 8, 1891

Figure 12. Locality map of the East Texas area which includes the Mount Enterprise Fault System and its westward extension across the Trinity River.

Figure 13. Quaternary fault on the Trinity River. The two notebooks on the upthrown and downthrown blocks indicate the amount of Quaternary displacement.

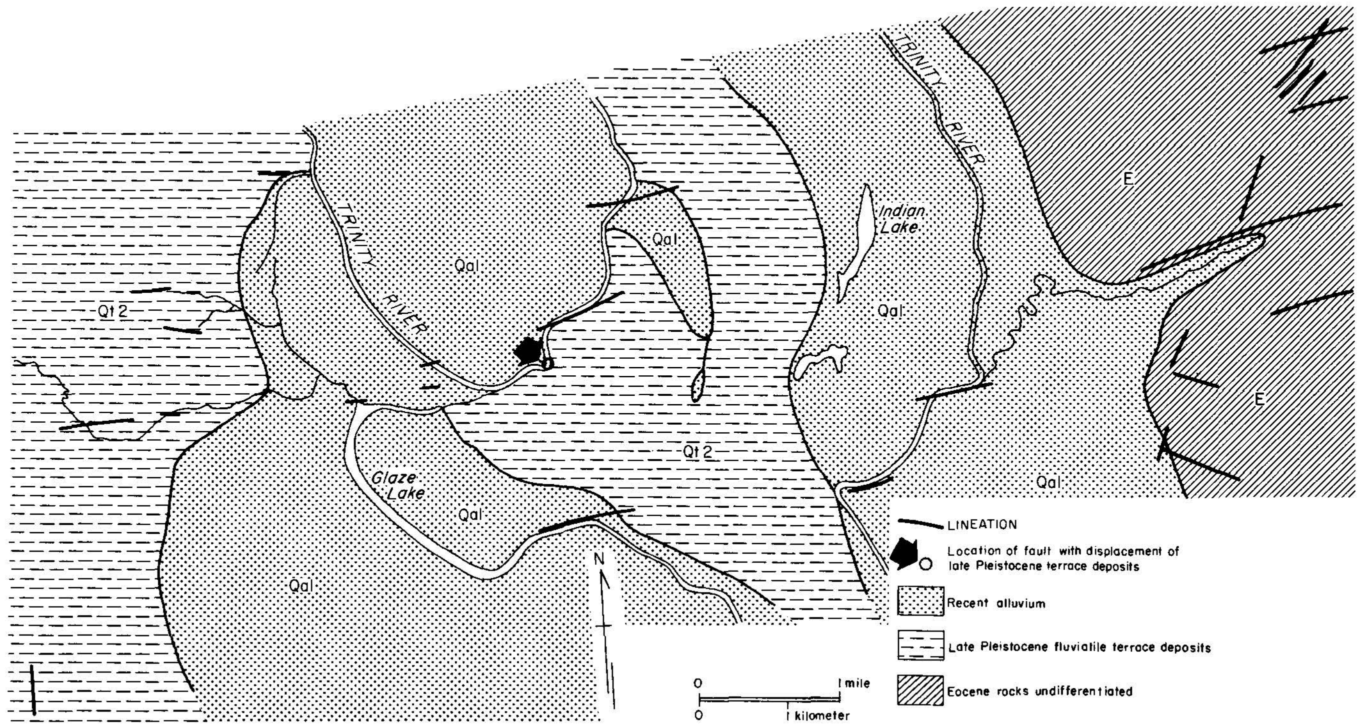


Figure 14. Map indicating location of Quaternary fault and linear airphoto trends in the Trinity River area.

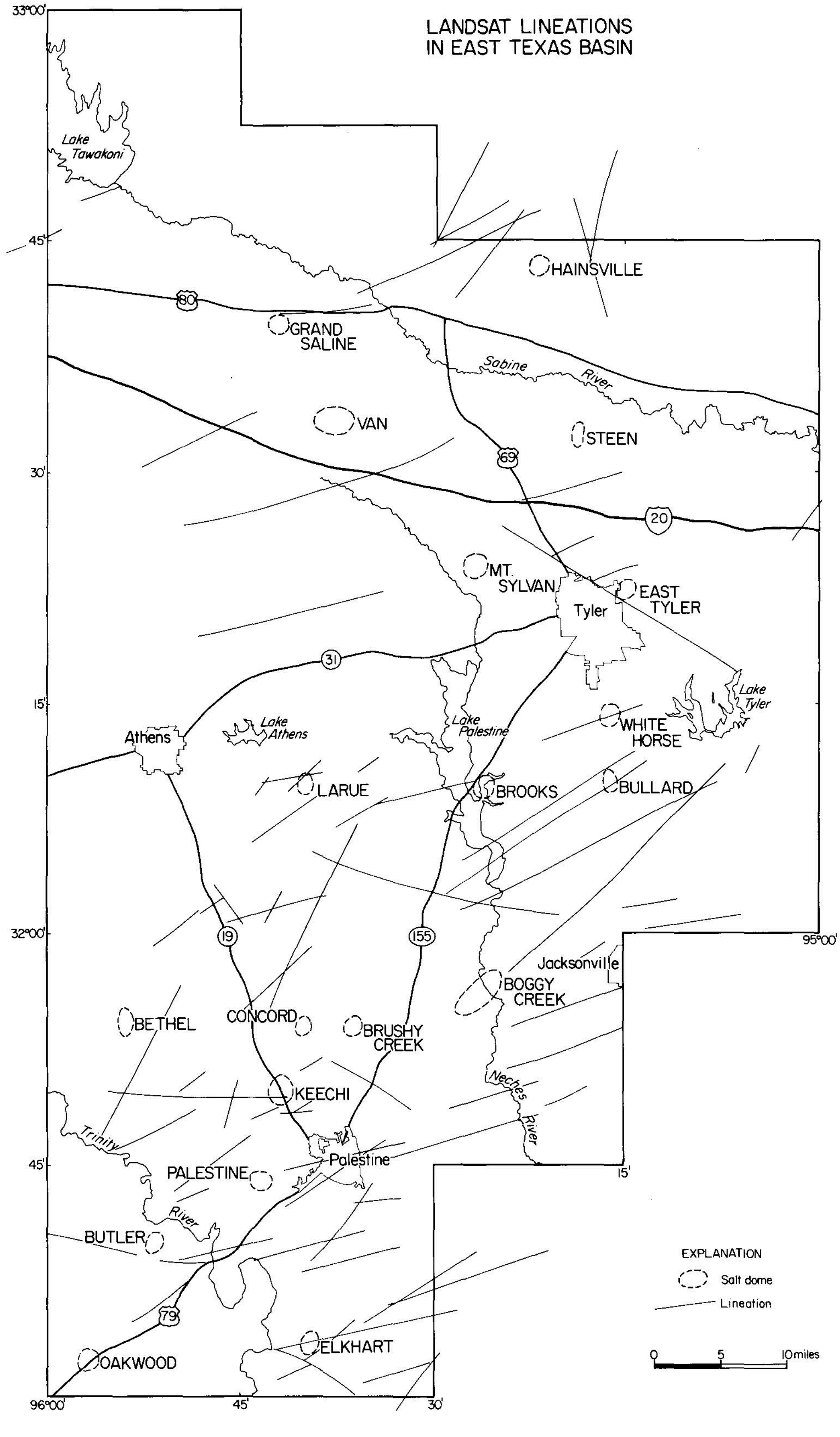


Figure 15. Lineations interpreted from Landsat imagery of the East Texas Basin, Texas.

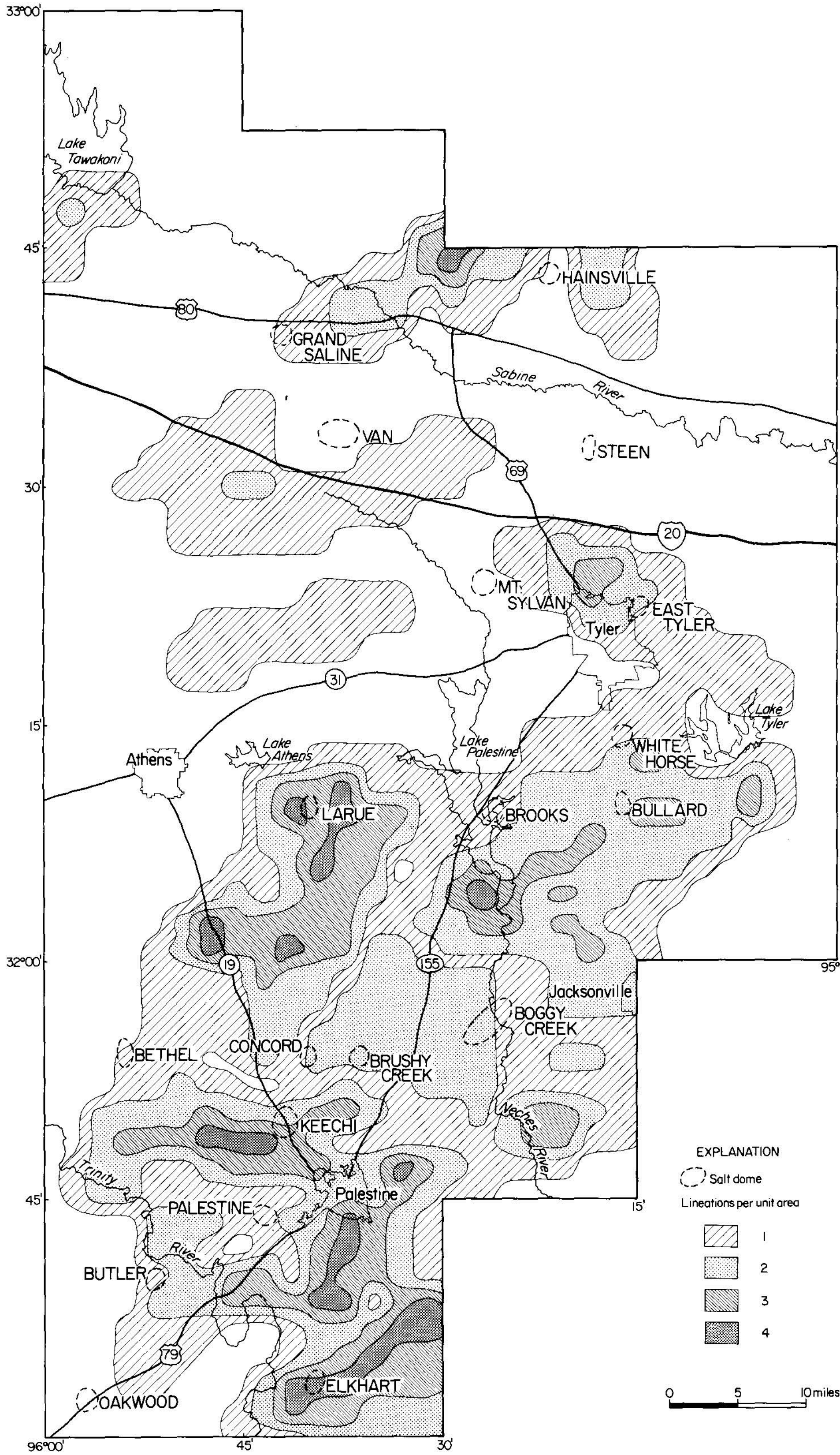


Figure 16. Moving averages of the number of Landsat lineations per unit area in East Texas Basin, Texas.

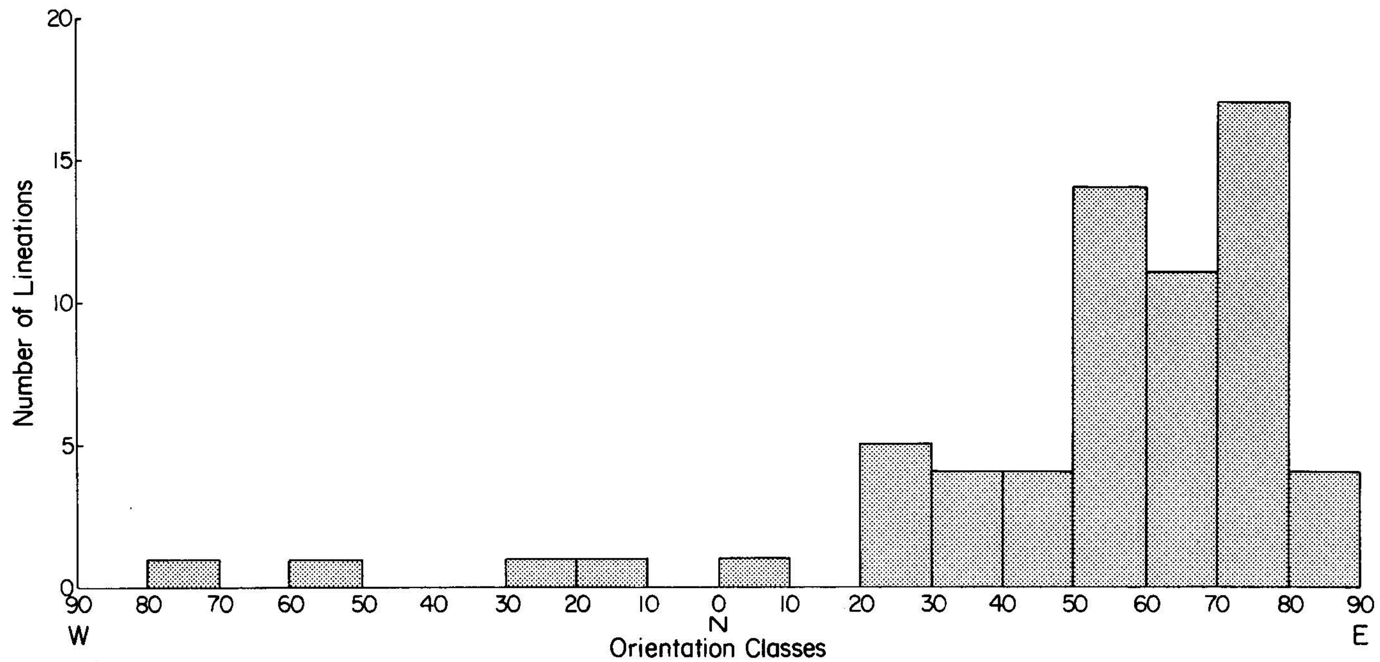


Figure 17. Orientation of lineations identified on Landsat imagery of East Texas Basin, Texas.