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ONWI-106

Geologic Evaluation of Gulf Coast Salt Domes: Overall Assessment of the Gulf Interior Region

Technical Report

October 1981

Law Engineering Testing Company
2749 Delk Road
Marietta, GA 30067

ONWI
Office of Nuclear Waste Isolation

BATTELLE Project Management Division

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Department of Energy
National Waste Terminal
Storage Program Office
... King Avenue
Columbus, Ohio 43201

January 5, 1982

Dear Reader:

This report, The Geologic Evaluation for the Gulf Coast Salt Domes: Assessment of the Gulf Interior Region (ONWI 106), marks the completion of the documents of the regional geologic studies in the states of Louisiana, Mississippi, and Texas, and provides an overview of the entire region.

Copies of a draft version of this were distributed to a broad spectrum of reviewers in the three states in March, 1978. Comments received were incorporated into this report, and copies of letters and responses are included as an appendix.

This report and a comparison report on the Regional Environmental Characterization for the Gulf Interior Region (ONWI 67) are summarized in Summary Characterization and Recommendation of Study Areas for the Gulf Interior Region (ONWI 18).

Regional environmental and geologic studies are part of the process by which the Department of Energy is identifying and qualifying potential sites in suitable geologic environments for the disposal of radioactive waste. Salt deposits in the Gulf Interior Region are among the geologic formations being considered. Studies are also under way in bedded salt formations in Utah, Texas and New Mexico, basalt in Washington State, and tuff in Nevada. Studies on granitic formations are now being developed with the Lake Superior, Northern Appalachian and Southern Appalachian states.

Providing copies of this document to those who reviewed the draft, as well as to other public officials and members of the public, is in keeping with the open information policy of DOE regarding the National Waste Terminal Storage Program.

We appreciate your participation and involvement in this program.

Sincerely,

J. O. Neff

J.O. Neff
Program Manager
NWTS Program Office

NPO:MJB:ksh

GS# 145

MGW

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Geologic Evaluation of Gulf Coast Salt Domes: Overall Assessment of the Gulf Interior Region

Technical Report

October 1981

Law Engineering Testing Company
2749 Delk Road
Marietta, GA 30067

This report was prepared by Law Engineering Testing Company under Subcontract E512-00400 with Battelle Project Management Division, Office of Nuclear Waste Isolation, under Contract No. DE-AC06-76-RLO1830-ONWI with the U.S. Department of Energy. This contract was administered by the Battelle Office of Nuclear Waste Isolation.

ABSTRACT

The three major phases in site characterization and selection are regional studies, area studies, and location studies. This report characterizes regional geologic aspects of the Gulf Coast Salt Dome basins. It includes general information from published sources on the regional geology; the tectonic, domal, and hydrologic stability; and a brief description the the salt domes to be investigated.

After a screening exercise, eight domes were chosen for further characterization: Keechi, Oakwood, and Palestine Domes in Texas; Vacherie and Rayburn's Domes in North Louisiana; and Cypress Creek and Richton Domes in Mississippi. A general description of each, maps of the location, property ownership, and surface geology, and a geologic cross section were presented for each dome.

PREFACE

This report was originally issued in draft form in 1978 as the Geologic Evaluation of Gulf Coast Salt Domes - Site Selection Program Plan by Law Engineering Testing Company. Approximately 300 copies were distributed for comments to state and local government officials and members of the general public, and copies were placed in the U. S. Department of Energy's regional reading rooms. Nine comment letters were received and the issues raised were addressed, where appropriate in the revised text. Comment letters are included as Appendix A.

The report has undergone extensive editorial modifications from the previous drafts. Studies during 1979 and 1980 have vastly increased our understanding of the geology and geohydrology of the areas studied, and reports of the additional data and evaluations are now in preparation. Although our understanding of the study areas has been enhanced by these continuing studies, the technical content of this report is presented as it was understood in 1978.

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1 INTRODUCTION

This report is published as a product of the National Waste Terminal Storage (NWTS) program. The objective of this program is to develop terminal waste storage facilities in deep, stable geologic formations for high-level nuclear wastes, including spent fuel elements from commercial power reactors and transuranic (TRU) nuclear waste for which the federal government is responsible.

As part of the effort to develop the technology for geologic disposal of high-level radioactive waste, the U.S. Energy Research and Development Administration (ERDA) contracted in 1976 with Union Carbide Corporation, Nuclear Division, to manage the principal portion of the National Waste Terminal Storage (NWTS) program. In 1977, ERDA was absorbed by the newly created U.S. Department of Energy (DOE) and, subsequently, the responsibilities of Union Carbide Corporation were transferred to the Battelle Memorial Institute (BMI). The Office of Nuclear Waste Isolation (ONWI), established within the Project Management Division of BMI, assumed responsibility for a contract with Law Engineering Testing Company (LETCo) that had been established with Union Carbide Corporation to act as Geologic Project Manager (GPM) for technical studies on the Gulf Coast Salt Domes.

Criteria for selecting salt domes were provided by NUS[1], Brunton and McClain[2], and Brunton et al[3]. ONWI also developed repository-related criteria applicable to any medium for nuclear waste disposal, published in DOE/NWTS-33(2), NWTS Program Criteria for the Mined Geologic Disposal of Nuclear Waste: Site Performance Criteria[4]. Abbreviated definitions of these criteria follow:

1. Site Geometry - The repository site shall be located in a geologic environment with geometry adequate for repository placement.

2. Tectonic Environment - The repository site shall be located such that credible tectonic events can be shown to cause no unacceptable reduction in repository performance.

3. Subsurface Hydrology and Geochemistry - The repository site shall have subsurface hydrologic and geochemical characteristics compatible with waste isolation.

4. Surface Hydrology - The repository site shall be located so that the surficial hydrologic system, both during anticipated climatic cycles and during extreme natural phenomena, will not cause unacceptable adverse impacts on repository performance.

5. Geologic Characteristics - The repository site shall have geologic characteristics compatible with waste isolation.

6. Surface Topography - The repository site and its surrounding area shall possess surface characteristics which are compatible with waste isolation.

7. Human Intrusion - The repository site shall be located so that the likelihood or consequences of past or future human intrusion will cause no unacceptable adverse impacts on repository performance.

8. Proximity to Population Centers - The repository site shall have characteristics that tend to minimize the risk to the population from potential radiation exposure.

9. Environment - The repository site shall be located with due consideration to potential environmental impacts, present land-use conflicts, and ambient environmental conditions.

10. Social, Political, and Economic Impact - The repository shall be sited with due consideration to social, political, and economic impacts on communities affected by the repository.

Since these criteria are general, they are applicable to any repository system and comprise only a portion of the total criteria for a given repository facility. More specific criteria (specifications) are applied as required in subsequent phases of the siting process.

Figure 1-1 outlines the major steps in the site characterization and selection process and illustrates how geologic and environmental inputs are integrated into the decision process. The sequence of characterization steps includes three major phases:

1. Regional Studies - Formation-wide surveys, over broad multistate regions, resulting in selection of study areas.

2. Area Studies - More detailed studies of approximately 2,600-square-kilometer (1,000-square-mile) areas within the regions that appear to have favorable characteristics for repository sites. These studies result in selection of locations for further study.

3. Location Studies - Detailed surveys of approximately 80-square-kilometer (30-square-mile) areas to identify potential sites.

These three phases lead to a sequence of steps resulting in eventual licensing of a nuclear waste repository site or sites.

Law Engineering Testing Company is the Geologic Project Manager (GPM) for the Gulf Interior Region (GIR). Geologic studies conducted by the GPM and other scientific organizations provide the information needed to evaluate selected salt domes as potential repositories from the standpoint of engineering feasibility, safety, public health, and resource conflicts (Criteria 1 to 7).

Bechtel Group, Inc. (BGI) is the Regulatory Project Manager (RPM) for the GIR. Bechtel's environmental characterizations are intended to ensure that data on ecological, socioeconomic, and other environmental factors required by the National Environmental Policy Act (NEPA) of 1969 are considered (Criteria 7 to 10).

The present report characterizes regional geologic aspects of the Gulf Coast Salt Dome basins. It includes general information from published sources of the following subjects:

- Regional geology
- Tectonic stability

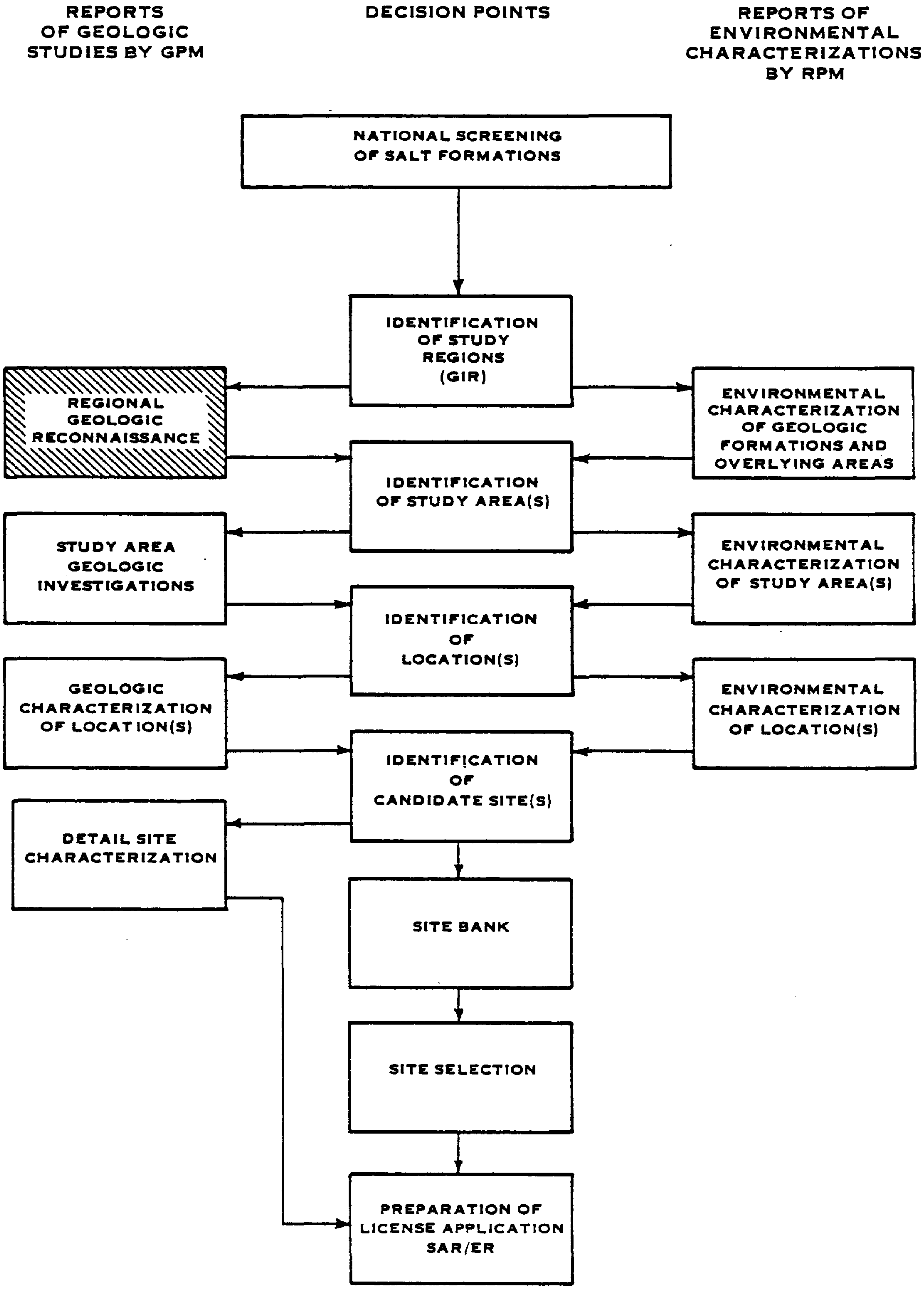


FIGURE 1-1 SITE CHARACTERIZATION AND SELECTION PROCESS

- Dome stability
- Hydrologic stability
- Geologic description of salt domes to be investigated.

At the conclusion of the regional studies by the GPM and RPM, a summary report will be prepared recommending study areas in the GIR. Each study area will be an area of about 2,600 square kilometers (1,000 square miles) and will contain one or more domes.

Both the GPM and RPM, as well as other technical organizations, will conduct area studies, developing more detailed information than is found in the present regional study. Those studies will be summarized, and locations (domes) in the GIR will be identified for characterization in the location phases of the NWTS program. As a final step, candidate sites will be identified. Concurrently, the GPM may conduct, as required, a detailed site characterization for input to a license application. The first repository site will be selected from four to five sites in different geologic media. Media currently under consideration include salt domes, bedded salt, basalt, tuff, and granite.

1.1 NEED FOR STORAGE OF NUCLEAR WASTES

The nuclear power industry in the United States is based almost solely on the operation of light-water reactors (LWRs). The LWR fuel cycle is shown diagrammatically in Figure 1-2. Uranium ore is first mined and milled to produce uranium concentrates. Since the fissionable isotope of uranium, ^{235}U, constitutes only about 0.7 percent of natural uranium, and LWRs require uranium with about 3 percent of ^{235}U for operation, the concentrate is next converted to uranium hexafluoride (UF_6), the chemical form of uranium required as feed material for a gaseous diffusion isotopic enrichment plant. The enrichment plant produces uranium that is enriched to about 3 percent in the fissionable ^{235}U isotope; the by-product (^{238}U) uranium tailings, reduced in ^{235}U, are stockpiled. The enriched product is converted to uranium oxide and fabricated first into fuel pellets and then sealed in zirconium alloy tubes (fuel rods).

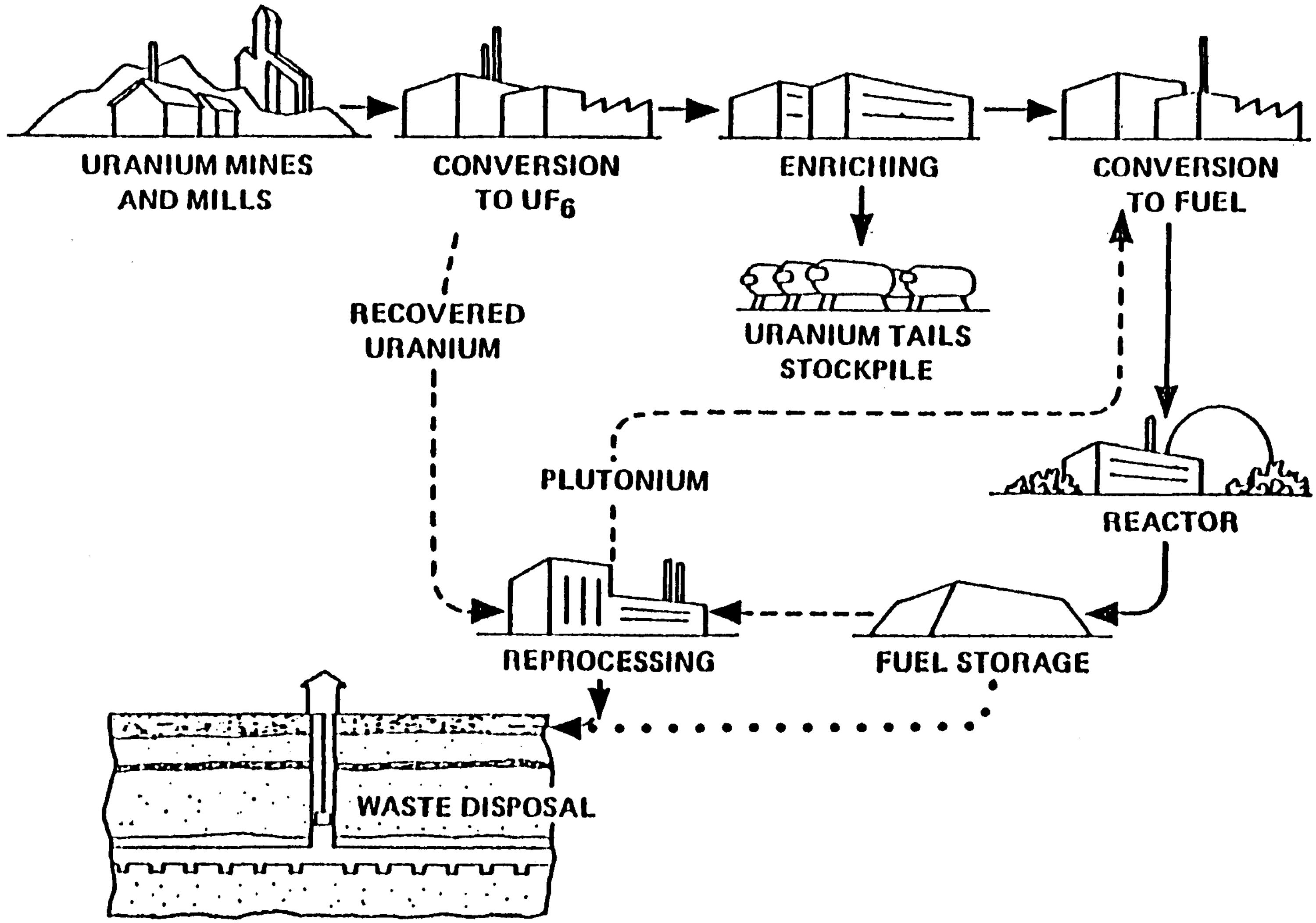


FIGURE 1-2 **THE LIGHT-WATER REACTOR NUCLEAR FUEL CYCLE**

After about 3 years in the LWR, spent fuel elements are removed and stored under water at the LWR site in spent fuel pools. Storage in these pools provides time for the radioactive decay of shorter lived fission products. The spent fuel may then be either reprocessed or stored permanently.

Reprocessing, shown by the dashed line in Figure 1-2, has been eliminated as an option for the present by U.S. governmental policy. Therefore, permanent storage must be provided for the nuclear wastes that have been and continue to be generated by nuclear plants and nuclear fuel preparation facilities. Proposed terminal waste disposal, indicated by the dotted line in Figure 1-2, is the subject of this study.

1.2 DEVELOPMENT OF THE TECHNOLOGY OF NUCLEAR WASTE TERMINAL STORAGE IN SALT DEPOSIT FORMATIONS

In response to a request from the U.S. Atomic Energy Commission (AEC), the National Academy of Sciences - National Research Council (NAS-NRC) established in 1955 a committee of geologists to consider the possibilities of disposing of high-level radioactive wastes in the United States. The committee issued a report[5] that states:

> "The most promising method of disposal of high level waste at the present time seems to be in salt deposits. The great advantage here is that no water can pass through salt. Fractures are self-healing. Abandoned salt mines or cavities are, in essence, long-enduring tanks.
>
> The second most promising method seems to be in forming a silicate brick or slag which would hold all elements of the waste in virtually insoluble blocks. These could be stored in sheds on the surface in arid areas or in dry mines."

Research and development efforts have predominantly followed these two parallel paths in the intervening 23 years: development of insoluble matrices for waste and verification of the suitability of salt deposits for waste isolation.

In the search for insoluble bonding matrices for waste, a form of borosilicate glass has been developed that shows promise of retarding the dissolution of waste for extended periods in the event of exposure to ground water. However, this waste form requires that the spent fuel receive further processing after removal from the reactor. Such additional processing is not presently planned in the United States, but other nations, including France and England, do plan to reprocess spent fuel and utilize more stable waste forms.

The suitability of salt deposits as a geologic medium for waste disposal was extensively investigated in both laboratory and field experiments by the Oak Ridge National Laboratory beginning in 1957. Factors investigated included thermal properties, such as thermal conductivity, heat capacity, and thermal expansion coefficients; structural and mechanical properties, such as stress-strain relationships, creep behavior, and elastic and plastic moduli; trapped moisture effects; and radiation effects on salt crystal structure and brine inclusions. All of these properties indicated that a repository in salt could be designed to provide the required degree of waste containment[6].

Early work on salt was directed toward determining its suitability for the isolation of high-activity wastes in liquid form. In late 1961, the NAS-NRC committee, after reviewing progress in waste solidification as well as the salt investigations, recommended that the program be reoriented to focus on the storage of solidified, packaged wastes in those formations[7].

Field experiments, collectively known as Project Salt Vault, were carried out at an abandoned salt mine in Lyons, Kansas, beginning in the early 1960s; these experiments included the determination of in situ salt properties, demonstration of emplacement equipment, demonstration of salt stability under the effects of heat and radiation from emplaced irradiated fuel elements and electric heaters, and, overall, "the feasibility and safety of handling highly radioactive materials in an underground environment"[6].

Based on successful experimental results from Project Salt Vault, it was proposed to establish the facility as a pilot demonstration repository to handle prospective solidified commercial high-level waste and a large volume of low-level plutonium-contaminated debris from a fire at the AEC weapon facility at Rocky Flats, Colorado(8).

The safety of using the mine for this purpose was questioned by some geologists in Kansas and elsewhere(9). The 1972 AEC Authorization Bill was then amended by Congress to allow work to continue on conceptual design and certain safety tests, but also to require that periodic progress reports be made to Congress, and that the Implementation of the Waste Repository Project be contingent on its certification by an advisory committee. Later, the operator of a solution mining project in a salt mine located a few miles south of the Lyons site reported the unexplained loss of approximately 175,000 gallons of water during the course of his mining operations. The implications of the possible effects of this water on the salt formation, together with difficulties associated with locating and plugging old oil and gas wells, raised sufficient concern about the integrity of the potential repository to result in the cancellation of the project in February 1972. However, geologic exploratory work with respect to bedded salt formations continues at other locations in Kansas and New Mexico.

In May 1976, ERDA issued an extensive evaluation of technical alternatives for the management of radioactive wastes from the commercial nuclear fuel cycle(10). This assessment concluded that, of the alternatives examined for the management of high-level wastes, emplacement of solidified wastes in deep geologic formations was the option having the highest probability of acceptable use in a reasonable time frame. The alternatives have not been permanently foreclosed, but their potential use will require extensive additions to the technical information base as well as time for development and assessment.

As a result of Presidential policy statements in October 1976 and April 1977, geologic exploratory work is being concentrated in states where promising salt deposits are located, in hard rock formations at the Nevada Test Site near Las Vegas, Nevada, and at the Hanford site near Richland, Washington(11).

In 1978 the President established the Interagency Review Group on Nuclear Waste Management (IRG), composed of representatives from 14 federal agencies, the White House, and regulatory and cabinet-level agencies that have a role in the energy and nuclear waste areas. The IRG was to develop a strategy for dealing with the waste management problem. The final IRG report, issued in March 1979, recommended that initial emphasis be given to the mined geologic repository concept with an evaluation of a number of different sites in various types of rock formations, extensive testing of repository performance prior to final commitment, and full compliance with NEPA. The IRG also urged continued exploration of alternative disposal concepts, expanded public knowledge of the program to increase public interaction, and the establishment of a State Planning Council to represent public interests and concerns at both state and local levels(12).

In February 1980, President Carter announced his comprehensive Nuclear Waste Management Policy. The primary objective of the policy is to isolate existing and future high-level waste (HLW) in mined geologic repositories in order to protect the biosphere and public health and safety. The U.S. Department of Energy (DOE) is responsible for program management. The U.S. Nuclear Regulatory Commission (NRC) will have the authority to license the repository site and facility. Once DOE selects a site and applies for a license to construct and ultimately operate the repository, the State Planning Council, established in the President's February 1980 policy statement, will advise the Congress and the President, as well as the DOE, of concerns and issues affecting state, tribal, and local governments.

On October 25, 1979, the NRC issued a Notice of Proposed Rulemaking regarding its confidence as to whether methods of safe disposal of high-level nuclear wastes will be available when they are needed. The DOE responded on November 23, 1979, with a Notice of Intent to be a Full Participant in the rulemaking proceeding. Their mutual goal for the subsequent proceeding on April 15, 1980, was:

> "...to assess generically the degree of assurance now available that radioactive waste can be safely disposed of, to determine when such disposal or off-site storage will be available, and to determine whether radioactive wastes can be safely stored on-site past the expiration of existing facility licenses until off-site disposal or storage is available."

It was concluded at the proceeding that, although there is no technical reason spent nuclear fuel cannot be stored at reactor sites for extended periods of time, additional storage facilities off site are desirable due to shortage of on-site storage capacity. The knowledge and capability to provide such facilities are currently available, so that storage and safe disposal off site should be possible by the mid-1980s. It was also concluded that a repository could be in operation as early as 1997 or as late as 2006, depending on whether the repository would be located in bedded or dome salt or in hard rock, such as granite, which would require a longer time period before construction could begin. The NWTS program is an integral part of this federal effort to provide terminal storage of high-level nuclear waste.

1.3 DEVELOPMENT OF OTHER WASTE DISPOSAL CONCEPTS

The use of other options for radioactive waste disposal has not been foreclosed, but development and assessment of these options is expected to require long lead times and extensive additions to the technical information base(11). A final environmental impact statement (EIS), issued in October 1980(13), described other waste disposal concepts currently being analyzed. These include:

- Disposal in a very deep hole
- Subseabed disposal
- Disposal in a rock melt cavity
- Disposal in space
- Disposal in rock forms other than salt.

The deep hole concept relies on using a very deep shaft in strong, unfractured rock such as crystalline rock, or some deep sedimentary basins. The hole would be 4,500 to 10,500 meters deep (15,000 to 35,000 feet) and its great depth would prevent the escape of nuclear material to the biosphere.

In the subseabed disposal concept, shielded waste containers would be dropped from ships to become embedded in seafloor sediments. The clay sediments considered for this concept are found in the vast, remote abyssal hill regions in the centers of tectonic plates, for example, the central North Pacific. These areas are biologically unproductive and geologically stable.

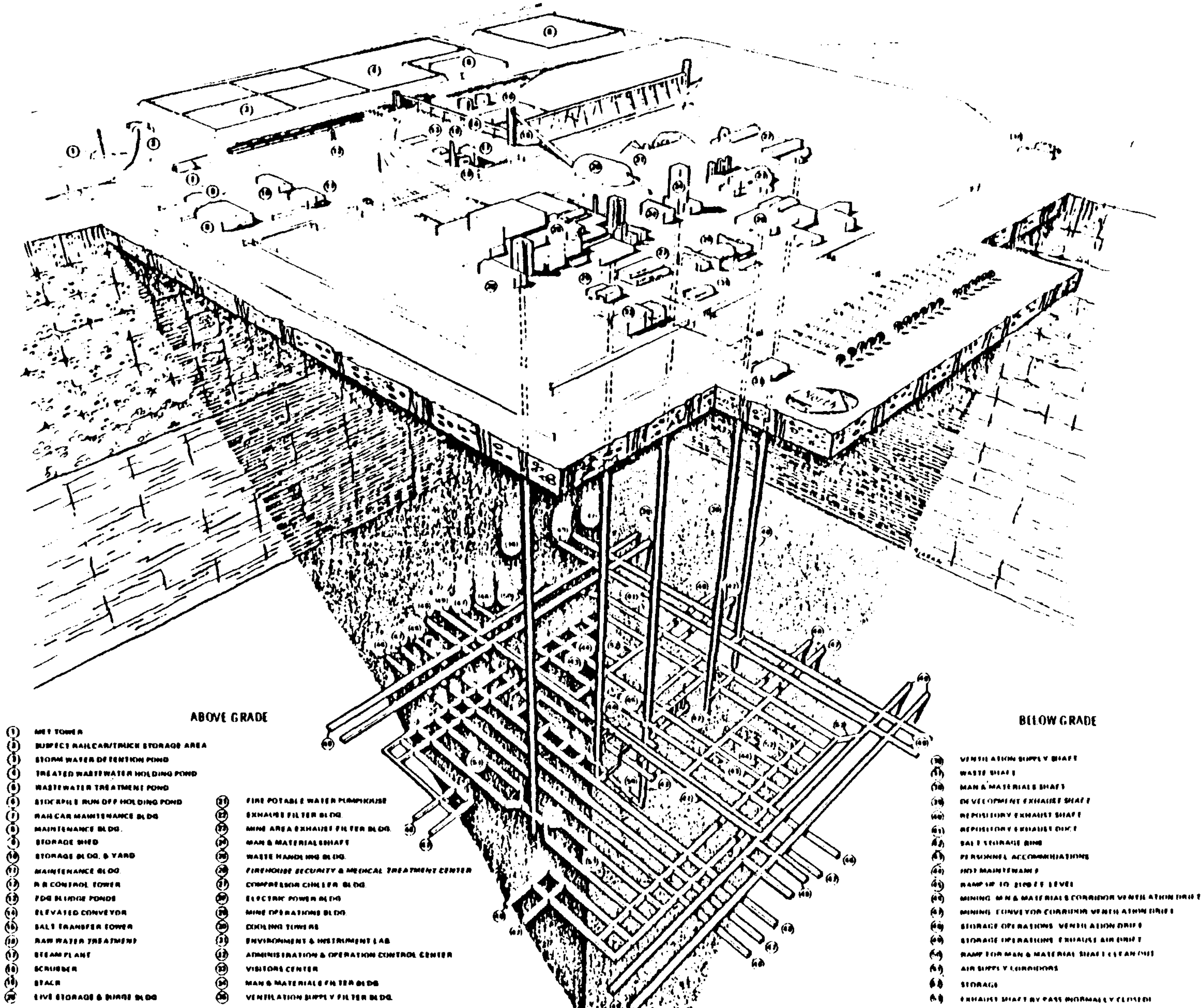
The rock melting concept would involve the emplacement of unshielded waste containers in a deep underground hole or cavity. After the hole is sealed, heat generated by radioactive decay would cause melting of the surrounding rock. In time the waste-rock solution would solidify, trapping the radioactive material in a relatively insoluble matrix deep underground.

The dominant attraction of disposal of nuclear waste in space is the promise of permanent separation of waste from the human environment. The currently favored concept is to use the space shuttle to lift shielded waste containers into earth orbit, then to emplace the containers in a stable solar orbit.

Disposal in rock forms other than salt would require a repository similar in design to that described for salt. Other geologic media currently under consideration are tuff, basalt, granite, and shale. Differences in design of repositories in other rock forms are necessary to deal with different requirements for water removal, structural support, and heat dispersion.

1.4 REPOSITORY OPERATION

Although the descriptions that follow are primarily for encapsulated spent fuel, the same general processes and procedures would be followed for vitrified and encapsulated wastes derived from a reprocessing industry. It is anticipated that the nuclear waste will be received over a period of several decades and must be isolated in a safe and environmentally acceptable manner. Current concepts call for encanistering and terminal storage at the same site. A conceptual design for such a facility located in a salt dome has been prepared(14) (Figure 1-3).



Source: BNI, 1979 (14)

FIGURE 1-3 **OVERALL SCHEMATIC OF WASTE REPOSITORY IN A SALT DOME**

2 SALT DOME BASIN INVESTIGATIONS

2.1 GULF COAST SALT DOME STUDIES

2.1.1 Previous Gulf Coast Salt Dome Studies

Anderson, Eargle, and Davis summarized the geology and hydrology of the salt domes of the Gulf Coastal province and their suitability for containment of radioactive wastes(20). In that report the 263 known or suspected on-shore salt domes in the Gulf Coastal Province were narrowed down to 36 potential repository sites. The criteria used to select the 36 domes included the depth to the salt (less than 2,000 feet was thought desirable), and the lack of use by industry for gas storage or for the production of oil, gas, salt, brine, or sulfur. These criteria were adopted in consultation with personnel of the Oak Ridge National Laboratory (ORNL) and are similar to those developed for potential repository sites in bedded salt. The 36 potentially acceptable domes are listed in Table 2-1. No ranking of the 36 potentially acceptable domes was made.

To avoid later exploration drilling in the vicinity of the facility, one objective of the NWTS program is to locate a repository in a dome which does not contain significant petroleum reserves. The petroleum-engineering consulting firm of Netherland, Sewell, and Associates, Inc. (NSAI) was hired to study the present and possible future oil and gas development of areas immediately surrounding the interior salt domes. NSAI and the Office of Waste Isolation (OWI) compiled the available literature on 25 of the interior "unrejected domes" recommended by Anderson, Eargle, and Davis. These domes are listed in Table 2-1. Netherland, Sewell, and Associates listed the following information for each of these domes(21):

1. Depth to top of caprock
2. Thickness of caprock
3. Depth to top of salt
4. Hydrologic stability
5. Number of wells drilled into caprock or salt

TABLE 2-1 (Page 1 of 3)

GULF COAST SALT DOMES CONSIDERED FOR POSSIBLE SELECTION AS RADIOACTIVE WASTE REPOSITORY SITES

COASTAL BASINS	Anderson, Eargle and Davis, 1973:	Netherland and Sewell, 1975:	Ledbetter et al 1975	Mellen 1976:
Davis Hill	x			
Gulf	x			
Gyp Hill	x			
Hawkinsville	x			
Hockley	x			
Hoskins Mound	x			
Long Point	x			
INTERIOR BASINS				
Northeast Texas:				
Brooks	x	x		
Bullard	x	x		
Keechi	x	x		
Mount Sylvan	x	x	x	
Palestine	x	x		
Steen	x	x		
Whitehouse	x	x	x	
North Louisiana:				
Castor Creek	x	x		
Cedar Creek	x	x		
Kings	x	x		
Prices	x	x		
Prothro	x	x		
Rayburns	x	x		
Vacherie	x	x	x	
Winfield	x	x		

TABLE 2-1 (Page 2 of 3)

GULF COAST SALT DOMES CONSIDERED
FOR POSSIBLE SELECTION AS
RADIOACTIVE WASTE REPOSITORY SITES

COASTAL BASINS	Anderson, Eargle and Davis, 1973:	Netherland and Sewell, 1975:	Ledbetter et al 1975	Mellen 1976:
Mississippi:				
Allen				x
Arm	x	x		x
Bothwell				x
Brownsville				x
Bruinsburg	x			x
Byrd	x	x		x
Carmichael				x
Carson				x
Caseyville				x
Centerville				x
County Line	x	x		x
Crowville	x			
Cypress Creek	x			
D'Lo				x
Dont				x
Dry Creek				x
Eagle Bend				x
Edwards				x
Eminence				x
Galloway				x
Gilbert	x			
Glass				x
Grange				x
Halifax				x
Hazlehurst	x	x		x
Hervey				x
Hubbard				x

TABLE 2-1 (Page 3 of 3)

GULF COAST SALT DOMES CONSIDERED FOR POSSIBLE SELECTION AS RADIOACTIVE WASTE REPOSITORY SITES

COASTAL BASINS	Anderson, Eargle and Davis, 1973:	Netherland and Sewell, 1975:	Ledbetter et al 1975	Mellen 1976:
Kings				x
Kola				x
Lampton	x	x	x	x
Learned				x
Leedo	x	x		x
McBride				x
McLaurin	x	x	x	x
Midway				x
Monticello				x
Moselle				x
New Home				x
Oakley				x
Oakvale				x
Petal				x
Prentiss				x
Raleigh				x
Richmond	x	x		x
Richton				x
Ruth				x
Sardis Church	x	x		x
Tatum	x	x		x
Utica				x
Vicksburg				x
Wesson				x
Zion Hill Church				x

6. Number of wells drilled for oil and gas within a 2-mile radius of the dome's center
7. Oldest formation penetrated
8. Total depth of the deepest well
9. Reported hydrocarbon shows
10. Distance to nearest oil or gas field
11. Producing formations in those fields
12. Approximate oil and gas production as of January 1, 1975.

This report also described in considerable detail one salt dome in each of the three salt dome basins: Keechi Dome in Northeast Texas, King's Dome in Northern Louisiana, and Tatum Dome in Mississippi. NSAI concluded that these domes are barren of hydrocarbons and are not on trend with any present oil and gas development, nor are they likely to be in the future. They also indicated that there are other domes in each basin with similar characteristics.

An overall review of the concept of radioactive waste disposal by burial in salt domes was published by Ledbetter, Kaiser, and Ripperger of the University of Texas(22). They concluded that no valid technical or geologic reason exists for not using salt domes as repository sites for high-level radioactive waste. They stated that the salt domes in the interior basins are tectonically stable, and suggested that, if a salt dome is surrounded by shale and lies below the base of actively circulating fresh ground water, it would be hydrologically stable. They described the characteristics of a theoretical dome which would be ideal for a radioactive waste repository and recommended further consideration of five domes. These domes are the following:

1. Mount Sylvan and Whitehouse Domes in Northeast Texas
2. Vacherie Dome in Northern Louisiana
3. McLaurin and Lampton Domes in Mississippi.

The report outlined a systematic pattern of study which should be followed before installing a repository in one of these domes. The studies they recommended include:

1. Hydrologic study of salt solution and the dissolved solids content of ground water surrounding the dome
2. Caprock structure, mineralogy, and evolution
3. Precision leveling to detect present dome movement
4. Geomorphic analysis to determine recent dome movement
5. Geophysical studies, both seismic and gravity, to determine dome geometry.

Louisiana State University - Institute for Environmental Studies (LSU-IES) began a study of the Gulf Coast Salt Domes in the spring of 1974. The goals of this program are:

1. To assess the relative stability of salt domes and develop more precise methods of stability evaluation.
2. To assess the hydrologic stability of selected domes
3. To establish measurements of the size and shape of certain domes.

This group has reported their findings in three annual reports[23, 24, 25].

The LSU-IES group, drawing on the recommendations contained in the earlier reports described above and on their own experience, have focused their attention on two salt domes, Vacherie and Rayburn's, for repository siting in the North Louisiana Basin. A third dome, Prothro, was selected as a "backup candidate" in the event the primary domes were found to be unsuitable. The LSU-IES approach to analyzing tectonic stability has included installation of instruments to monitor any present dome movement, geomorphic studies of Quaternary terraces and sediments, and stratigraphic studies of Mesozoic and Tertiary deposits. Efforts to determine hydrologic stability have involved surface and subsurface geohydrologic studies (with a concentration on subsurface methods for detecting salinity plumes); caprock mineralogy, petrography, and structure (to determine patterns of past and present salt dissolution); and numerical modeling of domal-salt transfer by ground water.

Frederic F. Mellen of Jackson, Mississippi, studied and collected information on domes that are known, and three domes that are expected (Table 2-1), to rise to within 5,000 feet of the surface in the Mississippi Basin[26]. For each dome, his data include:

1. Location
2. Topographic quadrangle name
3. Source of data
4. Seismic support
5. Areal extent of the salt 1,000 feet below the crest
6. Configuration
7. Depth to caprock
8. Depth to anhydrite
9. Depth to salt
10. Estimated elevation of the base of fresh water
11. Available transportation facilities
12. Discovery well
13. Other drilling on the dome.

Maps showing the land ownership, topography, and well locations were also provided.

Netherland, Sewell, and Associates, Inc. assessed dome movement and hydrologic stability of the interior salt domes of the Northeast Texas Basin [27]. The Office of Radiohydrology of the U.S. Geological Survey (USGS), at the request of DOE, conducted a study of the geohydrologic aspects of the storage of radioactive waste in Northern Louisiana salt domes[28]. This study described the different hydrologic conditions that may exist around a salt dome and stressed the need for an understanding of these conditions prior to the installation of a repository. The major factors considered were the following:

1. Water quality in the aquifers
2. Ground-water flow (local and regional)
3. Relationships between ground water and surface water
4. Permeability of the salt
5. Influence of caprock
6. Hydrologic effects of heat from waste
7. Relationships between aquifers and domes.

2.1.2 Current Gulf Coast Salt Dome Studies

The National Waste Terminal Storage program has organized a team of investigators to determine if Gulf Coast Salt Domes are suitable repository sites and to rank any domes that are found to be suitable. This team includes ONWI, scientific and technical investigators from the states where salt dome basins occur, the USGS, and a Geologic Project Manager. All of the project participants will coordinate their activities to minimize both surface disturbance during field operations and costs.

The state-specific scientific and technical investigators are the Texas Bureau of Economic Geology (TBEG), Louisiana State University - Institute for Environmental Sciences (LSU-IES), and the University of Southern Mississippi (USM). These investigators will research and evaluate the characteristics of salt domes that may eventually be considered within their state as suitable repository sites.

The USGS has been selected to evaluate the influence regional hydrologic factors may have on specific domes. They possess expertise in the fields of hydrology and transport analyses and knowledge of advanced methodology. Their expertise can thus benefit all participants to the studies. The USGS will conduct studies from three district offices located in the salt dome basin states. The Geologic Project Manager (GPM) will coordinate all study activities and data acquisition by all project participants.

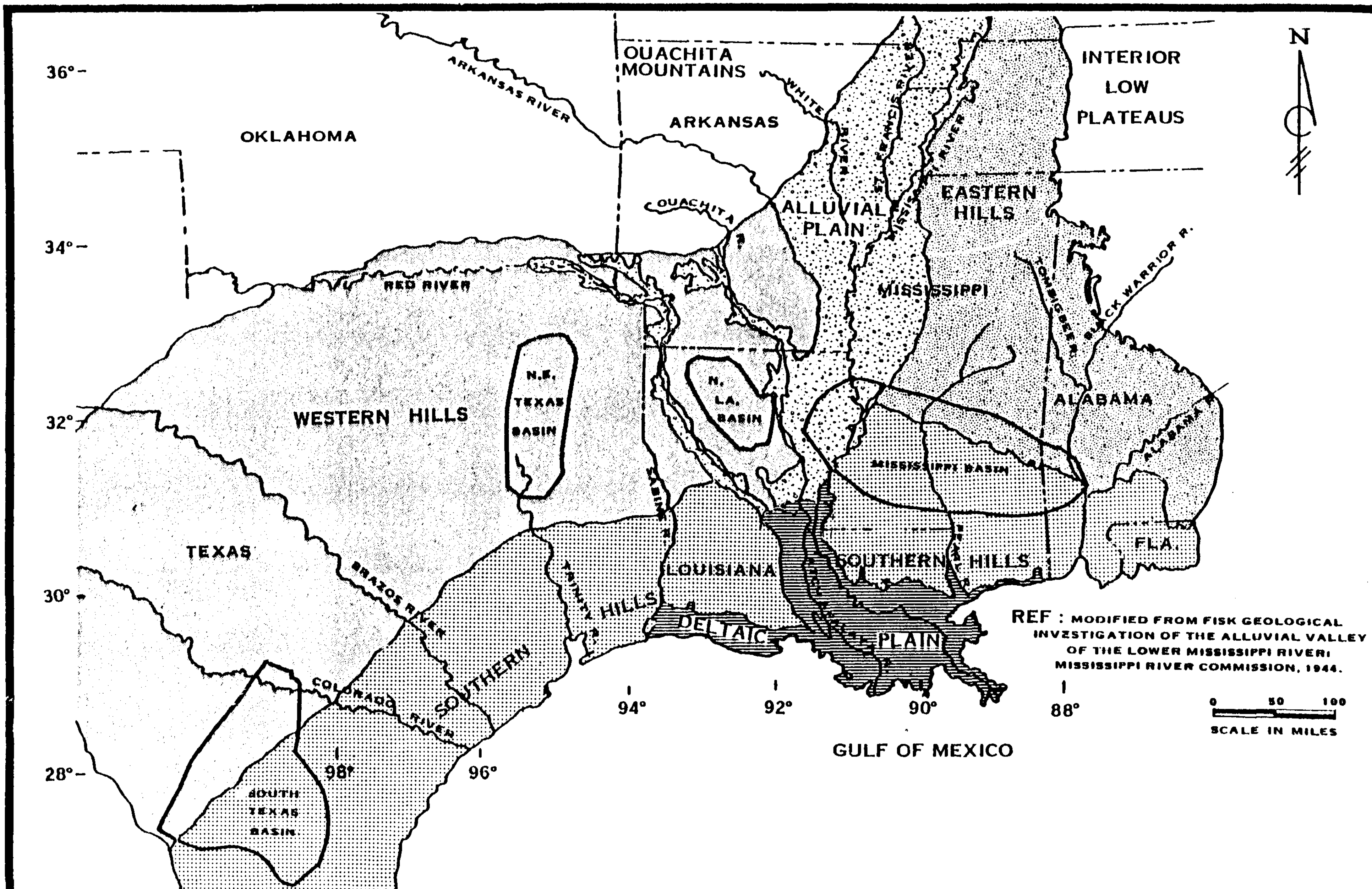
2.2 REGIONAL GEOLOGY

The Mississippi, North Louisiana, and Northeast Texas Basins occur beneath the Coastal Plain which forms the northern periphery of the Gulf Basin, as shown in Figure 2-1. Deep drilling, reflection seismic surveys with deep penetration, and regional refraction surveys have contributed to a knowledge of the total Gulf Basin and its relationship to the underlying crust.

2.2.1 Major Geologic Events

The Gulf Basin was initiated in the Late Triassic by block faulting and rifting of the continental crust, accompanied by basic igneous activity. Faults, some of which formed the northern boundary of the basin, developed along the southern flank of the Late Paleozoic Ouachita Orogenic Belt. Within the basin to the south, subregional crustal blocks developed similarly. This episode is attributed by various authors to early rifting of the continental crust, which also produced the Atlantic Ocean by seafloor spreading. An alternative theory ascribes the activity to development of an underlying thermal anomaly.

Throughout the Gulf Coastal Province, subregional crustal blocks of varying thickness provided a structural pattern that influenced subsequent geologic history. Areas of thicker crust behaved as positive elements or areas of uplift, while those of thinner crust behaved as negative elements, or areas of subsidence. During Late Triassic time, the positive elements were eroded, supplying large volumes of sediment which formed the distinctive redbeds in the adjacent subsiding basins. During regional subsidence areas of thinner crust received even thicker sedimentary deposits. During the Late Triassic to Early Jurassic, this process produced isolated basins in which the Louann Salt was subsequently deposited and buried by younger sediments. These include the three salt basins of interest, as well as other salt basins in Louisiana, Texas, and Mexico, and off shore. Intervening positive areas such as the prominent Sabine Uplift, the Monroe-Sharkey Uplift, and the Wiggins Uplift contain no salt domes because salt deposition on the positive areas either was thin or did not occur.



NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

FIGURE 2-1

PHYSIOGRAPHY OF GULF COASTAL PLAIN

JOB NO. MV9700

Virtually continuous marine sedimentation began in Late Jurassic time. This pattern was interrupted in Middle Cretaceous time by general emergence. The Sabine Uplift and peripheral portions of the Gulf Coastal Province were exposed to erosion during this episode. Accompanying igneous activity persisted into Late Cretaceous time, forming the Jackson Dome and producing numerous igneous occurrences in the Monroe-Sharkey Uplift and along the Balcones Fault. Marine deposition resumed in Late Cretaceous time, transgressing the continent broadly beyond the original limits of the Gulf Coastal Salt Basin, including the Mississippi Embayment. The Laramide orogeny in western North America affected only the southwestern margin of the Gulf Basin and, except for influx of terrigenous sediments, did not influence the northern Gulf Coastal Plain. Continental emergence recurred later in the Tertiary (Miocene and Pliocene) and extended progressively southward in association with sedimentation of geosynclinal proportions along the present northern margin of the Gulf of Mexico.

2.2.2 Stratigraphy

Depositional patterns in the northern portion of the Gulf Coastal Province reflect periods of inundation by shallow, quiet seas. These patterns are characterized by limestone and occasional evaporite deposition, alternating with regressive marine conditions, periods of erosion in the hinterlands to the north, and associated gulfward extension of deltas. These cycles have sufficient geographic extent for the resulting stratigraphic units to be correlated throughout the area, as depicted on the stratigraphic chart (Table 2-2). Major stratigraphic cycles are delineated below.

Postsalt inundation began in the Late Jurassic, with deposition of the Smackover carbonates. Southward regression of the sea, associated with clastic influx from the north during the transition from Jurassic to Cretaceous, was marked by the Cotton Valley and Hosston deposits, followed by the Sligo inundation. During Early Cretaceous Comanchean time, an extensive barrier reef developed peripheral to the Gulf Coastal Province gulfward from the Interior Salt Basins. North of the reef, a widespread carbonate lagoon developed in which deposits extensively overlapped the former limits of the Gulf Coastal Province westward across Texas.

TABLE 2-2

NORTHERN GULF COAST STRATIGRAPHIC COLUMN

SYSTEM	SERIES	GROUP	SUB GROUP	EAST TEXAS BASIN FORMATION	NORTH LOUISIANA BASIN FORMATION	MISSISSIPPI BASIN FORMATION	AGE IN MY
QUATERNARY	RECENT			RECENT	RECENT	RECENT	11,000 yr. bp
	PLEISTOCENE			BEAUMONT	COASTWISE PRAIRIE/ FORT HICKEY	COASTWISE PRAIRIE	SANGAMON (80-100,000 yr. bp)
				LISSIE	TERRACE SURFACES EXIST BUT BASINWIDE CORRELATION IS NOT OBVIOUS		
	PLIO-PLEISTOCENE			WILLIS (PRE-GLACIAL)	CITRONELLE (PRE-GLACIAL)	CITRONELLE (PRE-GLACIAL)	1.8
TERTIARY	PLIO-MIOCENE	GRAND GULF				PASCAGOULA	
	MIOCENE			FLEMING CATAHOULA	MISSING IN SECTION	HATTIESBURG CATAHOULA PAYNES HAMMOCK CHICKASAWHAY	5.5
	OLIGOCENE	VICKSBURG		MISSING IN SECTION	MISSING IN SECTION	BUCATUNNA BYRAM GLENDON MARIANNA MINT SPRING FOREST HILL/ RED BLUFF	22.5
	EOCENE	JACKSON		WHITSETT MANNING WELLBORN CADDELL MOODYS BRANCH	DANVILLE YAZOO MOODYS BRANCH	YAZOO MOODYS BRANCH	35
		CLAIRBORNE		YEGUA COOK MTN. STONE CITY SPARTA THERRILL WECHES QUEEN CITY REKLAW CARRIZO	COCKFIELD COOK MTN. SPARTA CANE RIVER (POSSIBLY WITH QUEEN CITY, REKLAW, AND CARRIZO EQUIV. AT ITS BASE)	COCKFIELD COOK MTN. KOSCIUSKO (SPARTA) ZILPHA WINONA TALLAHATTA	42 44.5 49
		WILCOX		SABINETOWN CALVERT BLUFF SIMSBORO	SABINETOWN PENDLETON	WILCOX UNDIFFERENTIATED	50
	PALEOCENE			HOOPER SEQUIN	MARTHAVILLE HALL SUMMIT LOGANSPORT NABORTON	NAHEOLA	53.5
		MIDWAY		WILLS POINT KINCAID	PORTERS CREEK CLAYTON	PORTERS CREEK CLAYTON	58
CRETACEOUS	GULFIAN	NAVARRO		KEMP NACHATOCH 66 NEYLANDVILLE MARLBROOK	ARKADELPHIA NACATOCH 66 SARATOGA MARLBROOK	PRAIRIE BLUFF RIPLEY	65
		TAYLOR		PECAN GAP WOLFE CITY OZAN	ANNONA OZAN	DEMOPOLIS CHALK	71 76
		AUSTIN		GOBER BROWNSTOWN BLOSSOM BONHAM ECTOR	BROWNSTOWN TOKIO- (INCLUDES BLOSSOM) RAPIDES-ECTOR	ARCOLA MOOREVILLE CHALK (INCLUDES COFFEE SAND)	79 81
		EAGLEFORD		EAGLE FORD UNDIFFERENTIATED	EAGLE FORD UNDIFFERENTIATED	EAGLE FORD	92
		WOODBINE		WOODBINE UNDIFFERENTIATED	TUSCALOOSA (LEWISVILLE)	UPPER T. MIDDLE T. LOWER T.	
	COMANCHEAN	WASHITA		SOUTH TYLER MANESS BUDA GRAYSON	WASHITA-FREDRICKSBURG	DANTZLER MANESS BUDA GRAYSON	100
			GEORGETOWN	MAIN STREET WENO-PAWPAW DENTON FORT WORTH DUCK CREEK	UNDIFFERENTIATED (LOCALLY ABSENT)	GEORGETOWN	
		FREDRICKSBURG		KIAMICHI GOODLAND-COMANCHE PEAK WALNUT		FREDRICKSBURG UNDIFFERENTIATED	
		TRINITY		PALUXY RUSK	PALUXY RUSK-MOORINGSPORT	PALUXY MOORINGSPORT	104 105
			GLEN ROSE	FERRY LAKE RODESSA JAMES PINE ISLAND SLIGO (PETTET) HOSSTON	FERRY LAKE RODESSA JAMES PINE ISLAND SLIGO HOSSTON	FERRY LAKE RODESSA PINE ISLAND SLIGO HOSSTON	106 107 108 113
	COAHUILAN	NUEVO LEON (AND DURANGO)					
JURASSIC	UPPER	COTTON VALLEY		SCHULER 139 BOSSIER HAYNESVILLE	SCHULER 139 BOSSIER HAYNESVILLE-BUCKNER	DORCHEAT SHANGALOO HAYNESVILLE-BUCKNER	135 143
	MIDDLE-LOWER	LOUARK		SMACKOVER NORPHLET	SMACKOVER NORPHLET	SMACKOVER NORPHLET	
		LOUANN		LOUANN SALT	LOUANN SALT	LOUANN SALT	
	LOWER OR PRE-JURASSIC			WERNER EAGLE MILLS	WERNER EAGLE MILLS	WERNER EAGLE MILLS	

Emergence during Middle Cretaceous time was most pronounced over the Sabine Uplift, where the previously deposited Lower Cretaceous sediments were partially eroded. The regressive phase was least noticeable in portions of the Interior Salt Basins, where clastic deposition was almost uninterrupted. Woodbine-Tuscaloosa clastic deposits represent resumed sedimentation in the Late Cretaceous, but the Sabine Uplift was not overlapped completely until Middle Gulfian time by deposits of the Austin Group. By then, extensive inundation characterized by chalk and marl deposits had widely overlapped the northern margin of the Gulf Coastal Province, including the newly formed Mississippi Embayment. Renewal of deltaic deposition, influenced by the uplift of the Laramide Belt to the west, culminated in regional deposition of the Wilcox Group during Early Tertiary time. The succeeding cyclic Claiborne-Jackson-Vicksburg deposition was characterized by interbedded marine and nonmarine formations. A regressive pattern, which has been in effect from Late Miocene time to the present, was initiated by the Grand Gulf delta building and the associated development of a geosyncline in the present coastal region. Late Tertiary-Quaternary terrace formations are discussed in the section on physiography (2.2.4).

2.2.3 Structure

Regional dip of the surficial sediments in the upper Gulf Coastal Province generally averages about 1 degree to the south; however, major structural elements locally interrupt this trend. Southwesterly dips on the eastern side of the Mississippi Embayment and southeasterly dips on the western side produce outcrop belts which extend far inland, outlining the northern configuration of the embayment.

Basement block faults, mainly of Late Triassic age as well as younger flexure fault zones, developed peripheral to the initial Gulf Coastal Province. Faults in these zones show evidence of recurrent movement, as indicated by the graben blocks of the Pickens-Quitman-Gilbertown-Pollard Fault Zones to the east in Alabama and Mississippi, extending westward to the South Arkansas Fault Zone and the Mexia-Talco and Balcones Fault Zones in central Texas. The Mount Enterprise Fault Zone is a flexure fault to the southeast of the East Texas Basin. Growth faults, featuring deposition contemporaneous with displacement, are common in the geosynclinal deposits to the south. The significance of these faults is discussed in a later section on surface faulting (3.1.1).

Movement of the Louann Salt, resulting from the weight of overlying sediments, is a pronounced structural mechanism. Mobilization of the salt commenced as early as the Late Jurassic Smackover deposition by migration into linear ridges, and continued as additional sedimentation occurred. Where the salt was sufficiently thick and adjacent sedimentation continued, pillowing and then diapirism occurred in the form of salt domes. As discussed in a subsequent section on domal stability (3.2), salt mobilization and diapirism climaxed during the Mesozoic in the interior salt basins and during the Late Tertiary in the coastal salt basins, and are still in effect offshore. The timing of salt migration and stabilization in the Interior Salt Basins was controlled by the gradual gulfward shift of the centers of clastic deposition from Cretaceous through Recent times.

2.2.4 Physiography

The Upper Gulf Coastal Plain is the emergent portion of the Gulf Coastal Province, 200 to 600 miles wide along the northern perimeter of the Gulf of Mexico. The plain extends inland from the gulf to the inner margin of the Mesozoic and Cenozoic outcrop belt, including the northernmost portion of the Mississippi Embayment region at its farthest inland position. From Georgia to Northeastern Texas these Mesozoic and Cenozoic sediments overlap older Paleozoic rocks of the Appalachian Provinces, the Interior Lowlands, and the Ouachita province. Through central Texas, where Lower Cretaceous strata extend westward beyond the Coastal Plain, the Balcones Fault Zone is designated its inner boundary.

Elevations average several hundred feet above sea level, and drainage generally extends gulfward within the province. The Mississippi River, with its enormous drainage basin, is a trunk stream with an alluvial valley 25 to 125 miles wide, extending southward to the Gulf of Mexico along the axis of the Mississippi Embayment. This lowland effectively separates the higher topography east and west of the valley into the Eastern and Western Hills

Physiographic Provinces. Tributary streams of the Mississippi River have also formed valleys. From the standpoint of this study, the most important tributary is the Red River and its nearly 10-mile-wide valley which traverses the Arkansas-Louisiana-Texas region from the northwest. Tributaries flowing southwest in Mississippi include the Homochitto and the Big Black Rivers.

Both east and west of the Mississippi River drainage basin trunk streams flow southward directly to the Gulf. East of the Mississippi River are the Amite, Tangipahoa, Pearl, and Pascagoula River drainage systems in Louisiana and Mississippi, and to the west are the Calcasieu in Louisiana, and the Sabine, Neches, and Trinity drainage systems in East Texas.

Modern topography is primarily a product of Quaternary drainage incisement associated with broad, continental emergence. The Citronelle-Willis terraces probably represent an extensive braided peneplain formed in preglacial time. The existing stream patterns were probably established by incisement caused by sea-level fall associated with the Nebraskan glacial cycle. Successive sea-level changes have caused deepening and widening of these valleys and the removal of the Citronelle-Willis terrace in inland areas. It now is preserved mainly as a coastal belt in Mississippi and eastward and also in Western Louisiana and Texas. Younger terraces, particularly the Beaumont of Sangamon age, occur coastward from the Citronelle-Willis belt and extend inland as fluviatile terraces adjacent to the modern stream valleys. Modern deltas and flood plains are similar Recent deposits. In interfluvial areas where the Citronelle-Willis terrace has been removed, Tertiary formations are primarily exposed. These form ridges and valleys dependent on the erosional resistance of the formations.

2.2.5 Interior Salt Basins

The Northeast Texas, North Louisiana, and Mississippi Basins represent subprovinces of the northern Gulf Coastal Plain described above. Of these, the Northeast Texas and North Louisiana Basins are smaller and, due to the Sabine Uplift separating them, they have more exact boundaries than the Mississippi Basin. The LaSalle Arch, the southern projection of the Monroe-Sharkey Uplift, narrowly separates the North Louisiana Basin from the

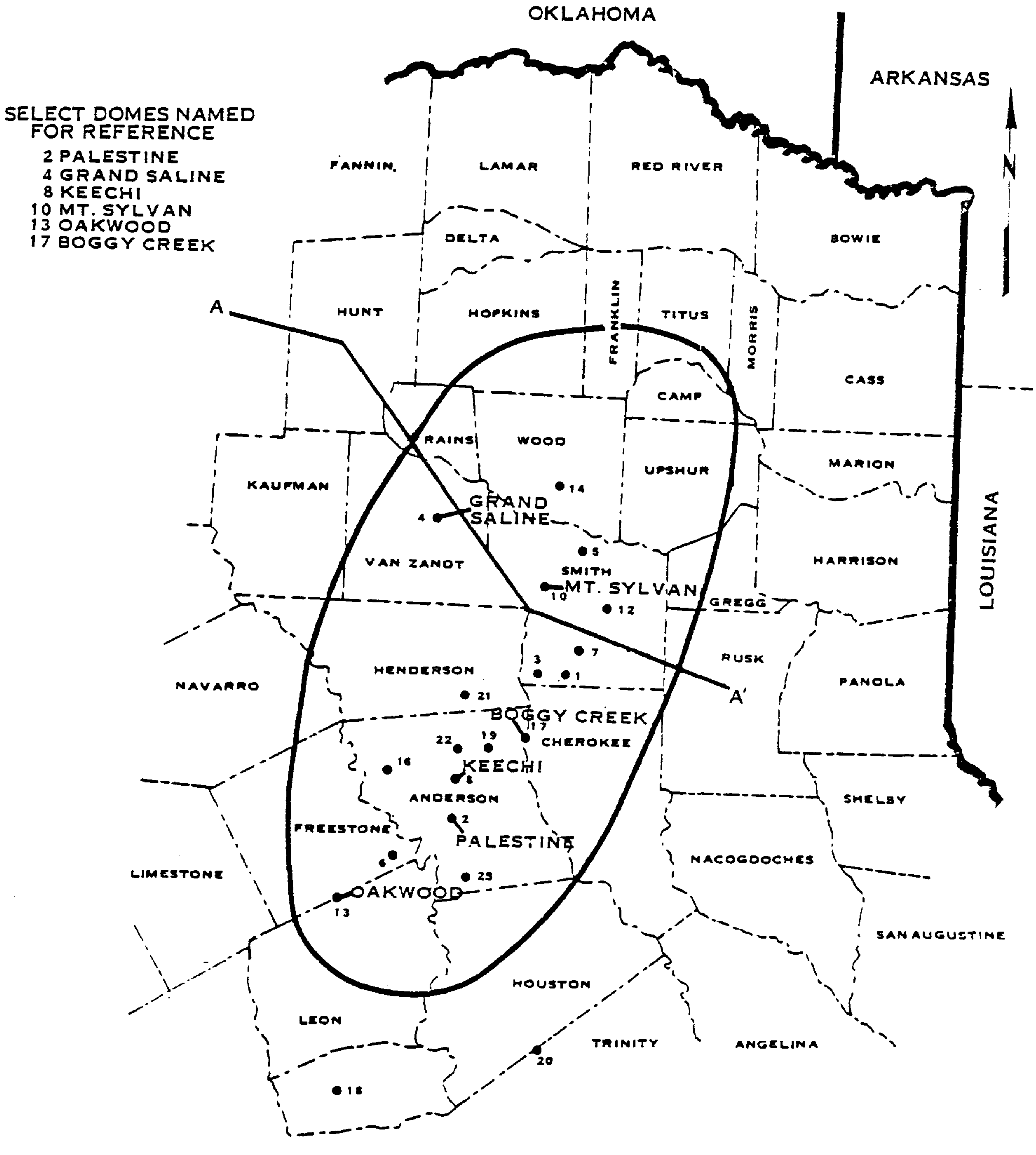
Mississippi Basin. The latter is a much larger basin, with more numerous domes, and is located further gulfward than the other two. As a result, the youngest Tertiary sediments in the Texas and Louisana Basins are Eocene, and the Citronelle-Willis terrace has been removed by erosion. In the Mississippi Basin, Tertiary sediments through the Plio-Miocene are present, and the Citronelle is widely preserved. The western portion of the Citronelle, however, extends beneath the Mississippi alluvial valley so that low-lying Recent deposits form the present terrain.

2.2.5.1 Northeast Texas Basin Geology

The East Texas Embayment is a crustal depression which occupies about 15,000 square miles of Northeast Texas. It is defined by the Mexia-Talco Fault Zone on the west and north, the Sabine Uplift on the east, and the Mount Enterprise Fault Zone on the south.

The Northeast Texas Basin occupies the central portion of the East Texas Embayment where the greatest thickening of Mesozoic and Cenozoic sediments occur (Figure 2-2). The Northeast Texas Basin trends roughly north-south through Leon, Houston, Freestone, Anderson, Henderson, Cherokee, Smith, Van Zandt, Rains, Upshur, and Wood Counties. It is about 150 miles long and 90 miles wide. Within the Northeast Texas Basin, salt movement has produced at least 20 piercement salt domes and related structures.

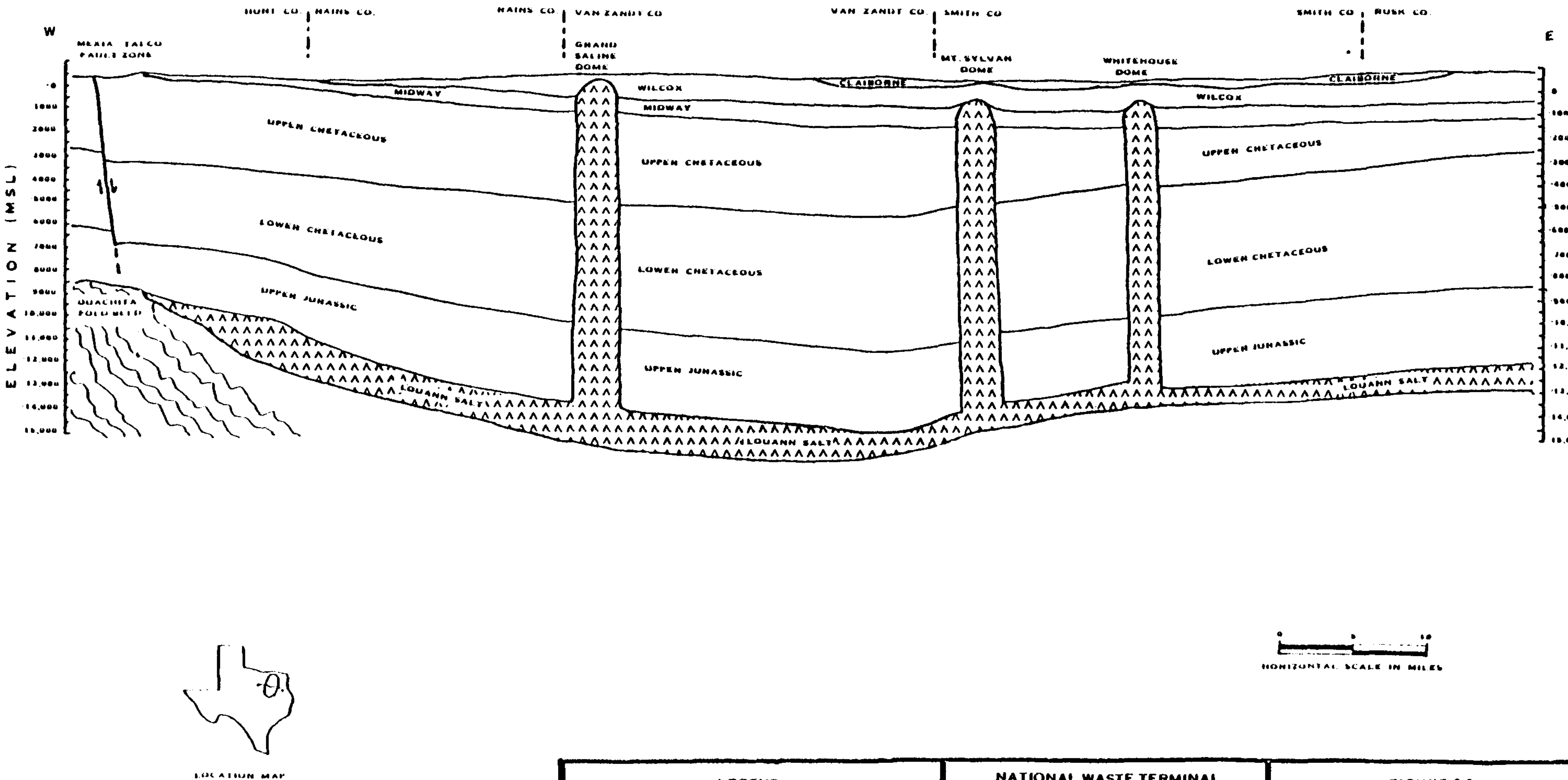
The stratigraphy of the Northeast Texas Basin is characterized by Mesozoic sedimentation, beginning with a transgression over the complex and deformed Paleozoic rocks of the Ouachita Belt. Some clastic sediments were deposited, but the most important sedimentation is an evaporite sequence marked by the thick accumulation of Louann Salt (Figure 2-3). The Lower Cretaceous strata present in the Northeast Texas Basin consist predominantly of carbonates with lesser amounts of evaporites and clastic sediments. The Upper Cretaceous is characterized by clastic sedimentation with lesser amounts of carbonates. Tertiary sediments are comprised mainly of clastic sediments, consisting of alternating sands and clays.



NOTE: 1. NUMBERED DOMES ARE LISTED ON TABLE 4-1

2. A-A' SHOWN ON FIGURE 2-3

	NATIONAL WASTE TERMINAL STORAGE PROGRAM GEOLOGIC EVALUATION GULF COAST SALT DOMES LAW ENGINEERING TESTING COMPANY MARIETTA GEORGIA	FIGURE 2-2 NORTHEAST TEXAS BASIN LOCATION MAP JOB NO. MV9700



LEGEND	NATIONAL WASTE TERMINAL STORAGE PROGRAM GEOLOGIC EVALUATION GULF COAST SALT DOMES	FIGURE 2-3
- - - COUNTY LINE FAULT	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	NORTHEAST TEXAS BASIN GEOLOGIC CROSS SECTION JOB NO. MV9700

32

The water-bearing characteristics of the Tertiary and younger geohydrologic units are presented in Table 2-3. Significant freshwater supplies are found in the Wilcox Group and in the sandy members of the Carrizo and Sparta Formations. The Carrizo-Wilcox aquifer is the most important freshwater aquifer and is defined as a single hydrologic unit because the Wilcox Group and Carrizo Formation are hydrologically connected. Below the Midway Group all aquifers are saline. Table 2-3 presents the characteristics of the saline aquifers expected to be studied in the current investigation.

2.2.5.2 North Louisiana Basin Geology

The North Louisiana Basin is a roughly rectangular structural trough some 100 miles long and 30 to 50 miles wide, centered in Webster, Bienville, and Winn Parishes, Louisiana (Figure 2-4). The surface extension of the basin is approximately 4,000 square miles. It is bordered on the southwest side by the Sabine Uplift, on the northeast by the Monroe Arch, and on the north by the southern flank of the Ouachita Mountain Uplift. On the south, the basin opens into the southward-dipping units of the Mississippi Embayment.

The thickness of Jurassic and Cretaceous sediments is greater in the North Louisiana Basin than in adjacent positive areas[30]. The maximum thickness of these sediments is estimated to be near 10,000 feet at the center of the basin. Tertiary sediments are present within the basin, but were not affected by subsidence as the basin was not active during the Tertiary. The entire basin is underlain by the Jurassic Louann Salt, which has given rise to 19 known salt domes[31]. A northwest-southeast geologic cross section of the basin is shown in Figure 2-5.

The stratigraphy of the North Louisiana Basin is very complex. Sedimentation during the Jurassic time was fairly consistent throughout the basin, with clastic redbeds deposited prior to the deposition of the Louann Salt. The Lower Cretaceous is characterized by clastics, carbonates, and evaporites. Clastic and carbonate deposition continued into Upper Cretaceous time, interrupted by one major unconformity. The Upper Cretaceous ended with the deposition of fine-grained clastic sediments. Tertiary sedimentation consisted of alternating marine and continental sands and clays, being more marine downdip or towards the basin's center[32].

TABLE 2-3

NORTHEAST TEXAS BASIN GEOHYDROLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

Units	Approximate Thickness(ft)	Lithology	General Water-Bearing Properties	Quality of water	Extent
Alluvium Deposits	50	Gravel, sand, silt, and clay.	Yields small quantities of water.	Ranges from fresh to highly mineralized.	Terrace and flood plain deposits along the principal tributaries.
Cook Mountain Formation	125	Varies from a glauconitic sandstone at the base to a clay at the top.	Yields only very small quantities of fresh water.	Fresh.	Outcrops in Southern Cherokee and Anderson Counties.
Sparta Formation	255	Reddish-gray to white, very fine to coarse-grained sand with layers of interfingering shale.	Aquifer; however, not a major source of water due to its limited extent in area and/or high topographic position, capping the highest hills.	Fresh with possible high iron concentration and acidity problems. CH_4 is sometimes present.	Hills in S.E. Van Zandt, eastern Wood, and within Henderson, Anderson, Cherokee, and Smith Counties.
Weches Formation	155	Varies in lithology over short distances; but consists in Smith County mainly of black to brown clay in the lower part and grades upward into glauconitic sands at the top.	Yields very small quantities of water in outcrop area.	Fresh in outcrop areas.	Outcrops within the hills of Van Zandt, Anderson, and Cherokee Counties. Outcrops in belts within Smith and Wood Counties.
Queen City Formation	555	Alternating layers of fine to very fine-grained sand and clay.	Aquifer, widespread and shallow, that supplies ground water for rural domestic and livestock purposes. The average permeability is approximately 57 gallons per day per sq. ft.	Fresh (200-500 ppm TDS), high iron content, acidic, and CO_2 and CH_4 dissolved gases are present.	Outcrops in S.E. Van Zandt and Wood Counties. Also outcrops in Anderson, Cherokee, Freestone, Henderson and Smith Counties.
Reklaw Formation	315	Newby sand, lower member consists of gray to green, fine to very fine-grained glauconitic quartz sand. Upper member, Marquery Shale, soft, carbonaceous, black to chocolate-brown clay.	Aquiclude in Rains and Van Zandt Counties where the Marquery Shale member prevents or retards the vertical movement of ground water.		Outcrops in Van Zandt, Wood, Freestone, Anderson, Henderson, Cherokee, and Smith Counties.

TABLE 2-3

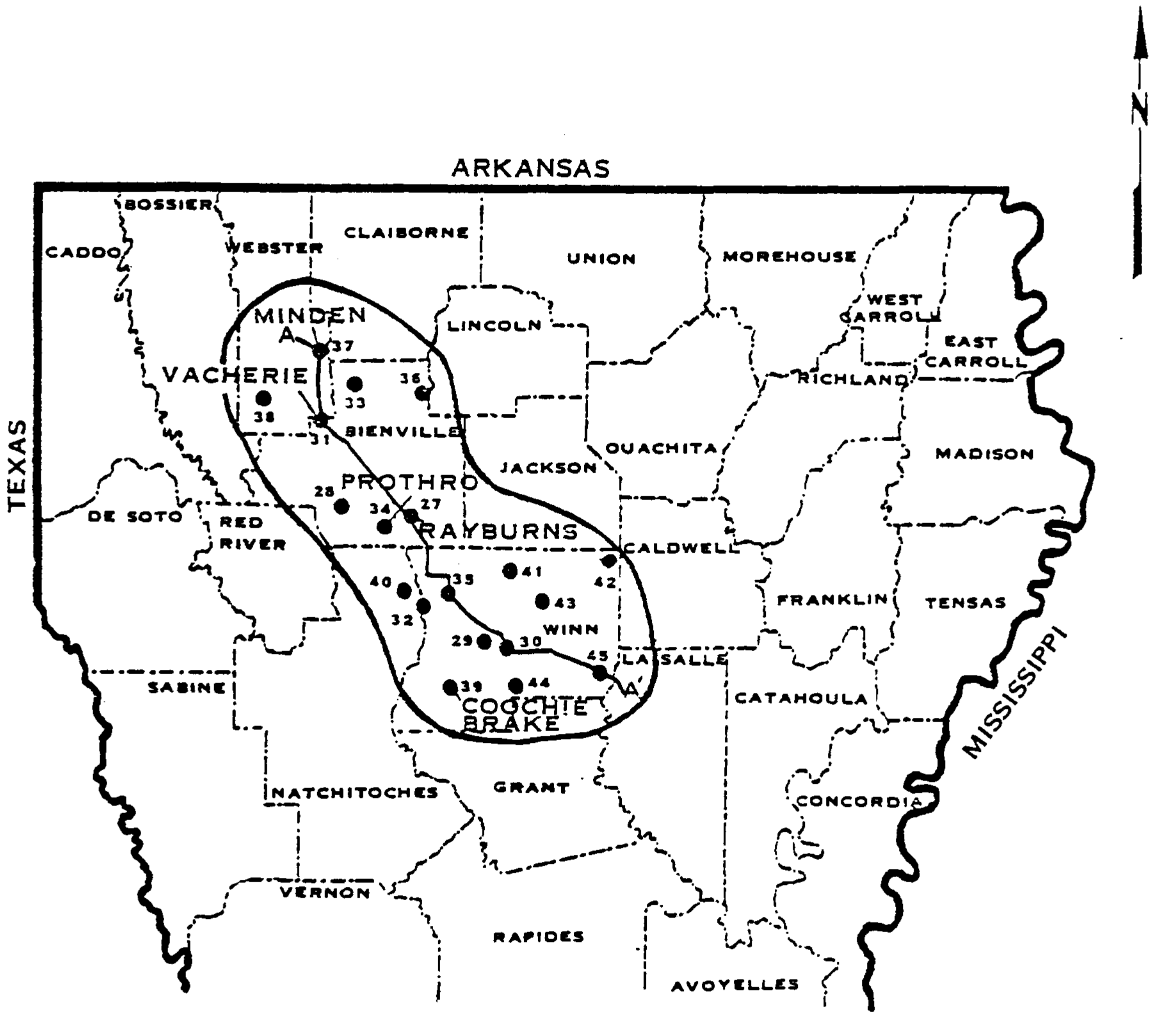
NORTHEAST TEXAS BASIN GEOHYDROLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

Units	Approximate Thickness(ft)	Lithology	General Water-Bearing Properties	Quality of water	Extent
Carrizo Formation	220	Gray to white, fine to medium-grained, porous clean sand that grades upward into a silty sand.	Aquifer. Yields small to moderate quantities. Hydraulic continuity with the Wilcox. Avg. permeability is approx. 184 gpd/ft.[2]	Fresh (200 ppm, TDS), moderate concentrations of iron.	Outcrops within the East Texas Basin.
Wilcox Group	2,710	White to gray fine-grained sands, thinly bedded, and discontinuous. Middle to lower Wilcox contains coarser grained sands and are thicker bedded.	Aquifer. Yields range over wide limits due to interfingering of sands & clay layers. Supplies nearly all of the municipal and industrial ground water demands. Avg. permeability 88 gpd/ft.[2]	Mainly fresh water, but does increase in salinity downdip in the basin.	Outcrops in Van Zandt, Rains, Wood, Freestone, Henderson, and around certain salt domes.
Midway Group	1,400	Calcareous silt and clay.	Aquiclude downdip from its outcrop area. In the outcrop area a few wells draw fresh water.	Yields fresh water in outcrop area.	Outcrops in Freestone, Henderson, Rains, Van Zandt, and around certain salt domes.
Navarro Group (includes Kemp Clay, Corsicana Marl, Nacatoch Sand, Neylandville Marl)	1,000	The Navarro Group, with the exception of the Nacatoch sandstone, consists of microfossiliferous, micaceous shale interbedded with marly, calcareous, nonporous sandstone with stringers of bentonite. The Nacatoch consists of massive beds of fossiliferous, porous to nonporous fine-grained sand.	With the exception of the Nacatoch sandstone the Navarro group is an aquiclude. Net sand thickness of the Nacatoch is 100'. Hydraulic properties vary due to facies change in the subsurface.	Saline.	Northeast Texas Basin.
Taylor Group (includes Marlbrook Marl, Pecan Gap Chalk, Wolfe City Sand, and Ozan Marl)	1,500	The Taylor Group consists of marl and shale with the exception of the Wolfe City Sands. Wolf City Formation consists of fine-grained glauconitic nonporous sandstone with local fairly porous sands.	With the exception of the Wolfe City Sands, the Taylor Group is an aquiclude.	Saline.	Northeast Texas Basin.

TABLE 2-3

NORTHEAST TEXAS BASIN GEOHYDROLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

Units	Approximate Thickness(ft)	Lithology	General Water-Bearing Properties	Quality of water	Extent
Austin Group (includes Gober Chalk, Brownstown Marl, Blossom Sandstone and Ector Chalk)	1,100	The Austin Group, with the exception of the Blossom Sandstone (Tokio Form.) consists of chalk and marl with interbeds of shale. The Blossom Sandstone consists of bentonitic, glauconitic sands.	With the exception of the Blossom Sandstone, the Austin Group is an aquiclude.	Saline.	Northeast Texas Basin.
Eagle Ford Group	800	In western N.E. Texas, the unit consists of micaceous shale. Eastward, the unit consists of fine-grained, glauconitic, micaceous, nonporous sand with local lenses of fine to medium-grained, porous sands.	Aquifer with average porosity of 24 percent. Permeabilities range from 1 to 10 gpd/ft^2 due to facies change. Net thickness of sands, 50 feet.	Saline, attains 100,000 ppm of dissolved solids in center of the basin.	Northeast Texas Basin.
Woodbine Group	900	Sands with interbedded varicolored mudstones.	Aquifer. Net sand thickness of 400+ feet. Average permeabilities of over 18 gpd/ft^2 and average porosities can attain 25 per cent.	Saline. Attains 100,000 ppm of dissolved solids in center of basin.	Northeast Texas Basin.



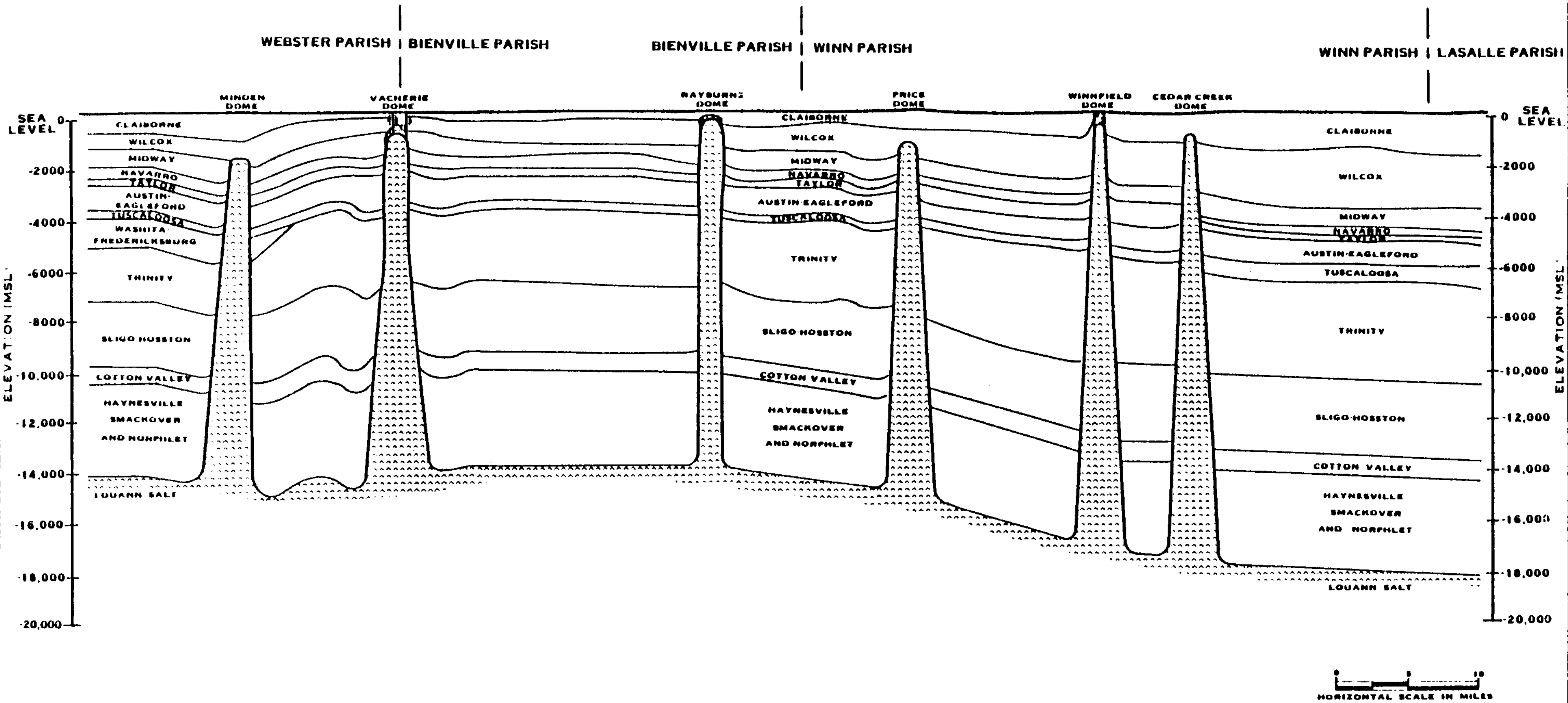
SELECT DOMES NAMED FOR REFERENCE

27 RAYBURNS
31 VACHERIE
34 PROTHRO
37 MINDEN
39 COOCHIE BRAKE

NOTE: 1. NUMBERED DOMES ARE LISTED ON TABLE 4-1
2. A-A' SHOWN ON FIGURE 2-5

REF: AN INVESTIGATION OF SALT DOMES. U.S. BUREAU OF MINES. U.S. DEPT. OF INTERIOR, P. 8, 1961

LEGEND	NATIONAL WASTE TERMINAL STORAGE PROGRAM GEOLOGIC EVALUATION GULF COAST SALT DOMES LAW ENGINEERING TESTING COMPANY MARIETTA GEORGIA	FIGURE 2 - 4 NORTH LOUISIANA BASIN LOCATION MAP JOB NO. MV9700
● SALT DOME		



REF.: MODIFIED AFTER HOSMAN, 1976

LEGEND

- PARISH BOUNDARY
- FAULT
- CAPROCK
- SALT

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES
LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

FIGURE 2-5

NORTH LOUISIANA BASIN GEOLOGIC CROSS SECTION

JOB NO. MV9700

Tertiary and younger sediments in the North Louisiana Basin are important freshwater aquifers. The characteristics and properties of the geohydrologic units are presented in Table 2-4. The Sparta Formation is the most important freshwater aquifer in the basin. Aquifers below the Tertiary sediments (Midway Group) are saline. Table 2-4 presents information about the Upper Cretaceous saline aquifers to be studied.

2.2.5.3 Mississippi Basin Geology

The Mississippi Basin is approximately 250 miles long by 60 miles wide. It extends east-southeasterly across southern Mississippi from northeastern Louisiana into southwestern Alabama. The locations of the Mississippi Basin and salt domes are shown in Figure 2-6. The Mississippi Basin is bounded on the south by the Hancock Ridge, a basement (continental crust) high, and on the north and east by a series of graben faults. These grabens, the Pickens-Quitman-Gilbertown-Pollard Fault Zone, form a portion of the hinge-line faults which bound the Gulf of Mexico Basin. On the west, the Monroe Uplift separates the Mississippi and North Louisiana Basins. Figure 2-7 shows a geologic cross section of the eastern portion of the Mississippi Basin.

Within the Mississippi Basin, sediments ranging from Tertiary to Jurassic in age overlie the Louann Salt. The Tertiary sediments were not affected by subsidence, as the basin was not active during the Tertiary. The Louann Salt has an inferred (unproven) thickness of 6,000 feet along the structural axis of the basin. Most of the structures within the basin were caused by salt movement. Eighty salt domes and many salt pillows or ridge structures have been identified within the Mississippi Basin. The stratigraphy of the Mississippi Basin is similar to that of the other interior salt dome basins. After the deposition of a thick sequence of Louann Salt over the pre-Louann redbed clastics, Upper Jurassic carbonates and evaporites, grading upward into clastics, were deposited. This clastic deposition continued through Lower Cretaceous time and into Upper Cretaceous time. The uppermost portion of the Upper Cretaceous sequence is characterized by carbonate sediments. Tertiary sediments are primarily clays and sands except for some Oligocene marls, chalks, and limestones[33].

TABLE 2-4

(Page 1 of 3)

NORTH LOUISIANA GEOHYDROLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

Units	Approximate Thickness(ft)	Lithology	General Water-Bearing Properties	Quality of water	Extent
Quaternary Deposits	50 (Alluvial) 100 (Terraces)	Gravel, sand, silt, and clay.	The Quaternary alluvial deposits have reported max. yield to wells of 4,000 gpm. Yields in terrace deposits have been reported small, generally because of the thin saturated zone of the deposits.	High iron content.	Terrace and flood plain deposits along the principal tributaries.
Cockfield Formation	500-600	Composed of lignitic sand, silt, and clay. The sands are very fine to fine-grained with the thicker deposits of sands being in the lower part of the formation.	Aquifer. Important in northeastern Louisiana with reported maximum yields of 700 gpm.	Fresh, soft to very hard, possible high iron content locally. The water may have a yellow color locally.	Outcrops in north-central Louisiana.
Cook Mountain Formation	100	Clay, marl, and in places sandy and glauconitic.	Aquiclude downdip from its outcrop area. The sand lenses yield small quantities of fresh water in its outcrop area. Not as effective barrier to ground water flow as some thicker clayey units.	Fresh water in its outcrop area.	Outcrops in northwestern Louisiana.
Sparta Formation	500-900	Lower part consists of fine to medium-grained sands with interbeds of sandy clay. Upper part consists of more clay than the lower and is part lignitic.	The most significant fresh water aquifer that supplies large quantities of water to industrial, domestic and municipal wells. Well yields of 2,000 gpm have been reported.	Fresh water, soft and high iron content in most areas.	Outcrops in northwestern Louisiana.
Cane River Formation	200-500	Lower part is a glauconitic sandy silt and shale. Upper part consists of a chocolate brown silty shale.	Aquiclude downdip from its outcrop area.	Sands contain fresh water in northern Bossier and Caddo Parishes.	Outcrops in North Louisiana near Natchitoches and Winn Parishes.

TABLE 2-4

NORTH LOUISIANA GEOHYDROLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

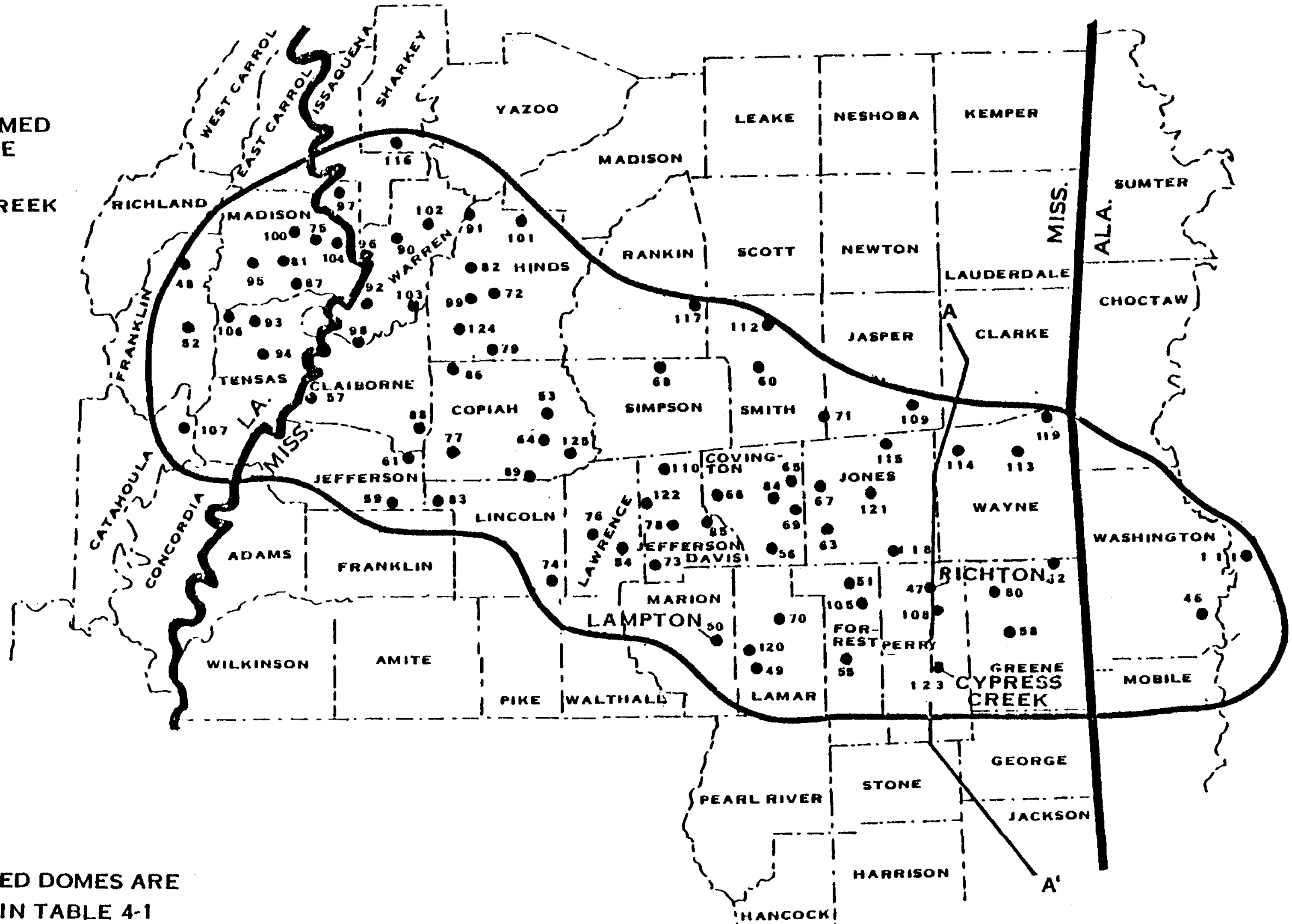
Units	Approximate Thickness(ft)	Lithology	General Water-Bearing Properties	Quality of water	Extent
Carrizo Formation	50-150	Fine to medium-grained sand.	Aquifer in northwestern Louisiana. The Carrizo is not considered a major fresh water aquifer due to non-deposition in places and does not contain fresh water over a large area.	Fresh water only in northwestern Louisiana.	Previously, the Carrizo has been mapped as part of the Wilcox.
Wilcox Group	350-1,500	Interbedded mixture of fine grained sands, silt and clay with various amount of lignite. Sand beds vary in thickness and generally are not interconnected.	Aquifer in northwestern Louisiana. Maximum yields are reported 500 gpm.	Fresh water only in northwestern Louisiana. Soft to moderately hard locally, iron content variable and yellowish color in some places due to organic material.	The Wilcox outcrops in northwestern Louisiana.
Midway Group	550-650	Carbonaceous, calcareous clay.	Aquiclude. No yields have been reported from Midway in Louisiana.		Outcrops in a belt in central Caddo Parish.
Navarro Group:					
Arkadelphia Marl	200	Gray marl, chalky in places.	Aquiclude. Confines the Nacatoch Sand.		North Louisiana Basin.
Nacatoch Sand	150-400	Fine-grained sand to coarse grained glauconitic sand w/beds of marl and clay.	Aquifer.	Saline.	North Louisiana Basin.
Taylor Group:					
Saratoga Clay	50	Light-gray chalk with beds of shale.	Aquiclude, may contain permeable fractures.		North Louisiana Basin.
Marlbrook Marl	200-300	Chalk and marl.	Aquiclude.		North Louisiana Basin.
Annona Chalk	100-200	Fossiliferous chalk.	Aquiclude. May contain permeable fractures.		North Louisiana Basin.
Ozan Chalk	200	Chalk with interbeds of calcareous shale and marl.	Aquiclude.		North Louisiana Basin.

TABLE 2-4

NORTH LOUISIANA GEOHYDROLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

Units	Approximate Thickness(ft)	Lithology	General Water-Bearing Properties	Quality of water	Extent
Austin Group:					
Brownstown Marl	300	Dark-gray calcareous mudstone with some sand	Aquiclude. Confines the Tokio Formation.		North Louisiana Basin.
Tokio Formation	300	Poorly sorted sands with silt ash and ranges from lignitic to calcareous.	Aquifer.	Saline.	North Louisiana Basin.
Eagle Ford Group	200	Micaceous silty shale with lenses of very fine-grained imperme-able sands.	Aquiclude. Confining bed for the Woodbine Group.		North Louisiana Basin.
Woodbine Group					
(Tuscaloosa)	1,000	Medium to coarse-grained sands, interbeds of shale and sands, ash, and generally has a trace of gravel at the base.	Aquifer; however, upper unit is shale and yields are reported small in outcrop area.	Saline.	North Louisiana Basin.

SELECT DOMES NAMED
FOR REFERENCE
47 RICHTON
50 LAMTON
123 CYPRESS CREEK



NOTE: 1. NUMBERED DOMES ARE LISTED IN TABLE 4-1
2. A-A' SHOWN IN FIGURE 2-7

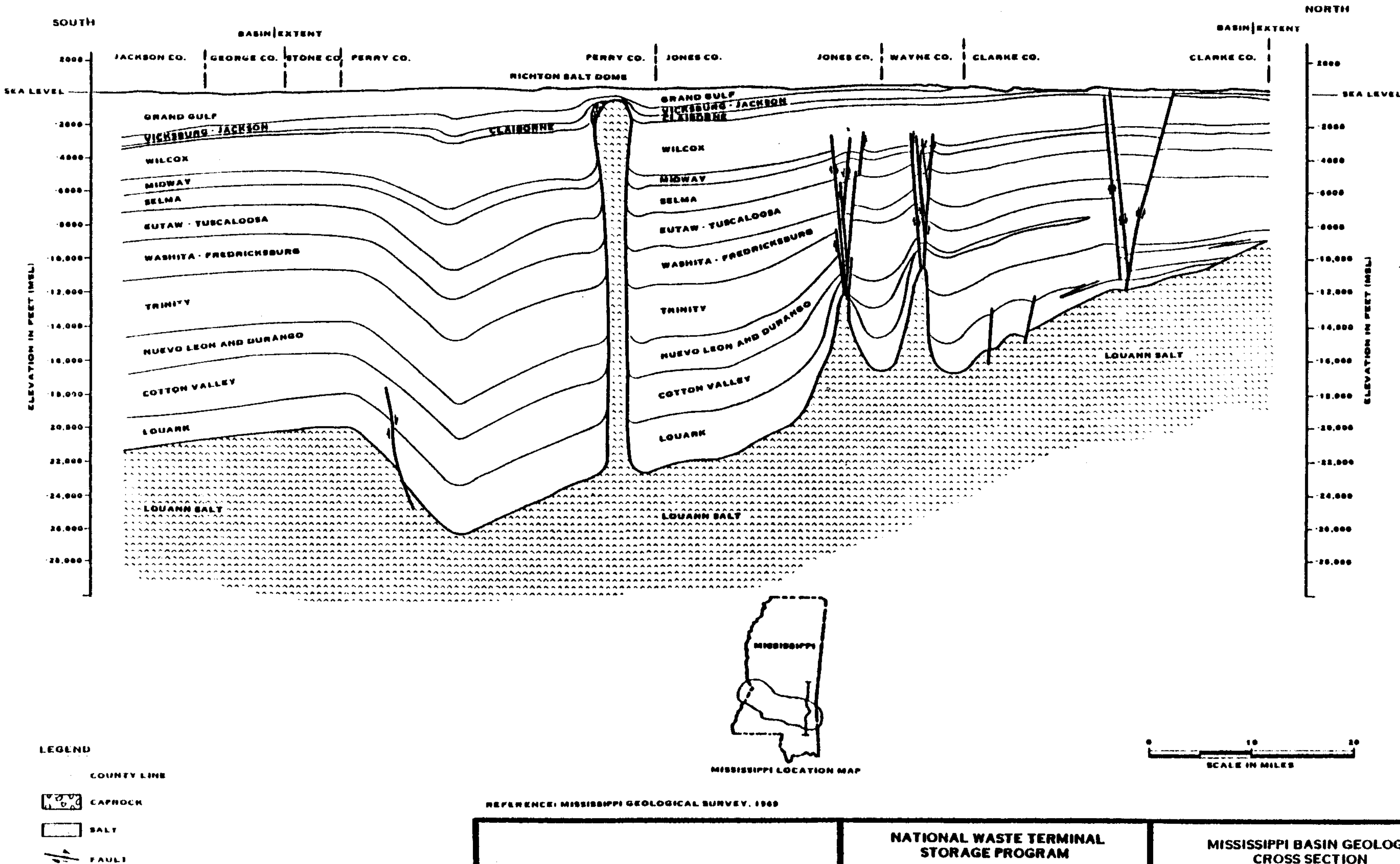
REF: AN INVESTIGATION OF SALT DOMES,
U.S. BUREAU OF MINES,
U.S. DEPT. OF INTERIOR, P.S.,1961

0 10 20 30
SCALE IN MILES

LEGEND
● SALT DOME

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES
LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

FIGURE 2-6
MISSISSIPPI BASIN LOCATION MAP
JOB NO. MV9700



REFERENCE: MISSISSIPPI GEOLOGICAL SURVEY, 1969

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES
LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

MISSISSIPPI BASIN GEOLOGIC CROSS SECTION

JOB NO. MV9700

FIGURE 2-7

The characteristics and properties of the geohydrologic units within the Tertiary and younger sediments are presented in Table 2-5. The undifferentiated Miocene sequence is the most important aquifer in the area of study. In the central portion of the basin the Citronelle Formation is also important. In the western part of the basin the most productive aquifer is in the Mississippi River alluvial plain, which is composed of sand and gravel deposits. All aquifers below the Tertiary (Midway Group) in the basin are saline; however, in Marion and Perry Counties the base of freshwater is within the lower unit of the Miocene undifferentiated. Table 2-5 presents pertinent information on the saline formations.

TABLE 2-5

MISSISSIPPI BASIN GEOHYDROLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

Units	Approximate Thickness(ft)	Lithology	General Water-Bearing Properties	Quality of water	Extent
Alluvium Deposits	200	Clay, silt, sand, and gravel.	Aquifer. In the Miss. River, the alluvium has reported yields of 2000 gpm or more. Most productive aquifer in western part of basin.	Fresh, very hard, high in iron concentration and a calcium bicarbonate type.	Occupies the major river valleys.
Loess Deposits	50	Brown calcareous silt.	Deposits prevent recharge to aquifers.		Occupies the eastern bank of Miss. River in western Mississippi.
Terrace Deposits	80	Red-gray gravel and sand with lenses of clay.	Yield small-quantity of water for domestic supplies.	Fresh, hard, calcium bicarbonate water.	Occupies the major stream valleys.
Citronelle Formation	200	Clay, sand, and gravel.	Aquifer. Generally water table conditions exist in the Citronelle. Important source of water for domestic uses.	Fresh, low in dissolved solids, ph between 5.0 to 6.0 generally.	Outcrops in southern Mississippi.
Miocene Undifferentiated	800-2800	Clay, sandy clay, sand, and gravel.	Aquifer. The Miocene beds are the most important fresh water aquifers in eastern Mississippi Basin because of large yields of water, good quality and extensive depths to saline water. Sands beds are thick and lens shaped. Transmissivity values of 400,000 gpd/ft have been reported.	Fresh, dissolved solids content less than 300 ppm.	Outcrops in southern Mississippi.
Vicksburg Group Undiff.	90-160	Limestone beds with layers of limey sand and clay layers.	Generally not an aquifer. Well in S. Central Miss. reported yield of 150 gpm.	Probably higher mineralized in northern part of study area and saline in the southern part.	Outcrops in an east to west belt in central Mississippi.
Forest Hill Formation	90-140	Fine-grained sand and carbonaceous clay.	Aquifer. Yields small quantity of water supplies for domestic wells mainly in its outcrop area.	Fresh in northern portion of basin.	Outcrops in an east to west belt in central Mississippi.

TABLE 2-5

MISSISSIPPI BASIN GEOHYDROLOGIC UNITS AND
THEIR WATER-BEARING CHARACTERISTICS

Units	Approximate Thickness(ft)	Lithology	General Water-Bearing Properties	Quality of water	Extent
Yazoo Formation	140-300	Clay, calcareous sand with thin beds of limestone.	Aquiclude. Thin sand beds (Cocoa Sand member) not important except in N.E. Wayne County where it supplies ground water to domestic and rural wells.		Outcrops in a belt throughout central Miss.
Moodys Branch Formation	15-30	Glauconitic, fossiliferous sandy marl.	Unimportant as an aquifer.		Outcrops in a belt throughout central Miss.
Cockfield Formation	20-340	Sands and clays with lignite.	Clay dominates downdip in the basin and acts as an aquiclude. Aquifer. Yields fresh water in Copiah and Simpson Counties with permeability approximately 250 gpd/ft.[2]	When fresh, northern portion of basin, mineralized and water is colored.	Outcrops in a N.W. trending belt.
Cook Mountain Formation	150-300	Shale, clay sands and limestone. Lower formation is generally clay and upper formation consists of limestone.	Aquiclude.		Outcrops in a N.W. trending belt.
Koscinsko (Sparta) Formation	210-740	Sand, sandy clay, and clay with layers of lignite. Primarily a clay in southern portion of basin.	Fresh water aquifer in northern portion of study area and in southern portion the formation is primarily clay, acts as an aquiclude and sometimes is difficult to differentiate from the underlying Zilpha clay.	Saline in southern portion of basin.	Outcrops in a N.W. trending belt.
Zilpha Formation	120-250	Brown mudstone with glauconite.	Aquiclude.		Outcrops in a N.W. trending belt.
Winona Formation	20-90	Calcareous sand and clay with thin sand beds. Clay and marl occurs in south-central Miss. where sand beds are not developed.	In south-central Miss. where clay and marl replace the sand beds, the unit is an aquiclude.	Saline water within sand beds.	Outcrops in a N.W. trending belt.

TABLE 2-5

MISSISSIPPI BASIN GEOHYDROLOGIC UNITS AND THEIR WATER-BEARING CHARACTERISTICS

Units	Approximate Thickness(ft)	Lithology	General Water-Bearing Properties	Quality of water	Extent
Tallahatta Formation	130-220	Brittle clay with a thick sequence of sand in the lower part of the formation.	Aquiclude, except for the lower Meridian Sand member which is commonly mapped as a part of the Upper Wilcox Group.		Outcrops in a N.W. trending belt.
Wilcox Group	2700-3200	Medium to coarse-grained calcareous sand, sandy shale and clay with beds of lignite.	Aquifer, saline mainly. The transmissivity ranges from 35,000 to 75,000 gpd per ft.	Mainly a saline aquifer in the Mississippi Basin; however, it does contain fresh water in upper 250 ft. in N.E. Simpson Co.	Outcrops in a N.W. trending belt.
Midway Group	1000+	Shales and fine sands with lignite beds near top in the upper unit and lower unit consists of shale, chalk and marl with local beds of bentonitic shale.	Aquiclude in the subsurface basin.		Outcrops in a N.W. trending belt.

3 OVERALL ASSESSMENT

3.1 TECTONIC STABILITY

Investigations for nuclear power plant sites in Texas, Louisiana, and Mississippi in the past decade have carefully examined the tectonic stability and seismic activity of the region. The Upper Gulf Coastal Plain appears tectonically stable, having been subjected only to crustal movements, mainly downward, since the Late Triassic. Regional faulting, terrace uplift, and seismicity are discussed in greater detail in the following subsections.

3.1.1 Surface Faulting

Regional faults within the Coastal Plain sediments are related to hinge-lines or flexures on the periphery of the Gulf Basin and above the boundaries of the subregional crustal blocks and growth faults within the basin. Hinge-line or flexure faults farther inland, such as the Pickens-Quitman-Gilbertown-Pollard Fault Zone, the Mount Enterprise Fault Zone, etc., displace the youngest Tertiary sediments along the faults, but the literature does not include specific reports on their relationships to the Late Cenozoic terrace deposits. Even though faults in the pre-Jurassic basement are reported beneath some of these trends, the shallow faults may result from hinge-line stresses rather than recurrent movement of possible underlying basement faults. Growth faults due to sedimentary instability are common in the thick geosynclinal sediments. Although displacement on growth faults generally ceases when the unstable shelf-edge environment builds farther gulfward, some faults show evidence of recurrent movement to Recent time. The Baton Rouge Fault Zone on the south side of the Hancock Ridge is currently moving, though aseismically, as are faults along the westward extension of this trend in the Houston and Corpus Christi areas.

3.1.2 Uplift of Terraces

Terrace deposits can be used to measure relative movement during the time interval they represent. Various terrace correlations across the Coastal Plain have been proposed by several authors. The Beaumont terrace of Texas has been correlated with the Prairie or Port Hickey terrace in

Louisiana and also extended eastward through the Mississippi coastal area as the Pamlico terrace. This terrace is probably Sangamon is age. Older terraces are less readily correlated or identified. The oldest terrace has been mapped as the Citronelle in Mississippi and the Willis in Texas, although there is uncertainty as to its age, which is either Pliocene or early Pleistocene.

3.1.3 Seismicity

The Upper Gulf Coastal Plain is assigned a seismic risk of Zone 0 (no damage) or Zone 1 (minor damage), which corresponds to intensities V and VI of the modified Mercalli (MM) scale[34]. The Northeast Texas Basin and the Mississippi Basin straddle the Zone 0 - Zone 1 boundary. The North Louisiana Basin falls within Zone 1. This is the result of its proximity to the New Madrid seismotectonic region.

Within the Gulf Coast seismotectonic region, the maximum historic earthquake (the 1930 Donaldsonville event, South Louisiana) is less than VI MM. Events of intensity VII (MM) occurred in the adjacent Ouachita region, which extends inland from the peripheral flexure faults.

3.1.4 Summation

Tectonic activity related to rifting and block faulting occurred in Late Triassic time and resulted in the formation of the Gulf Basin and subregional blocks of varying crustal thickness within it. Subsequently the region has been nontectonic, affected mainly by sedimentary and epeirogenic processes. The latest igneous activity known in the Upper Gulf Coastal Plain occurred in Late Cretaceous time. Normal faulting is present, related to differential sedimentary thickness and flexures. The entire Gulf Basin is a region of low seismicity.

3.2 DOME STABILITY

3.2.1 Concepts of Salt Dome Formation

The early theories of salt dome formation, postulated before drilling and geophysical information were sufficient to define the subsurface, will not be reviewed in this report. The movement of salt masses throughout the world is currently believed to be caused by a combination of tectonic forces, sediment loading, isostatic (halokinetic) forces, and heat. In Europe and the Middle East, a combination of tectonic and isostatic forces are thought to have been responsible for salt movement. In the Gulf Coast region, most current workers in the field see isostatic (halokinetic) forces alone as being responible for this movement of salt and the resulting formation of salt domes. In 1933 and 1934, Barton and Nettleton proposed similar theories of salt dome formation and movement. Barton proposed a theory of "isostatic downbuilding", wherein the salt dome remained at approximately constant depth while the sediments sank around it as a result of basin sinking and sediment compaction(35). Horizontal flow of salt from the mother salt supplied the base of the growing dome. Nettleton developed a "fluid mechanical concept", in which both the salt and the surrounding sediments acted as viscous fluids and the prime force involved was the density contrast between the salt and the sediments(36). These theories of Gulf Coast Salt Dome formation have been refined and modified by several authors in recent years. Halbouty summarized the history of thought concerning Gulf Coast Salt Dome development(37). Kupfer has studied in detail salt dome movements in the North Louisiana Basin(39). Kupfer proposed the same driving force (isotasy) for salt dome movement as suggested by Barton and Nettleton. Kupfer also investigated the interior structure of of salt domes and concluded that salt plugs move as a series of spines separated by shear zones(39).

Gussow challenged the theories of salt dome movement described above and proposed a heat-driven mechanism paralleling current thinking on igneous extrusive phenomena(40).

3.2.2 <u>Growth History Studies</u>

The relationships between dome movement (growth) and other geologic processes (such as basin sedimentation) have been used to deduce the stability of domes. Stratigraphic and structural studies, caprock studies, and studies of the internal structure of salt domes have been used to infer salt dome growth and history. The bulk of the stratigraphic studies to date have been carried by LSU-IES under contract with DOE for the North Louisiana Basin

(23, 24, 25). Dr. Ralph Kehle of the University of Texas has studied domes in the Northeast Texas Basin. Both investigators use stratigraphic data from both the immediate vicinity of the dome and the basin beyond the dome to estimate the volume of salt which has moved per unit of time. LSU-IES has primarily utilized drilling data, while Kehle has primarily used seismic reflection data. LSU-IES estimates 0.2 millimeters per year (mm/yr) vertical movement rate for Vacherie Salt Dome in mid-Cretaceous time, 0.02 mm/yr in late Cretaceous time, and cessation of salt movement about 30 million years ago.

Netherland, Sewell, and Associates, Inc. studied the rates of movement of six domes in the Northeast Texas Basin[27], relying on structural data to measure the amount of uplift of formations around the dome. Their results can be summarized as follows: (1) dome movement stopped sometime after Wilcox time (Lower Eocene - Upper Paleocene), and (2) the rates of movement were greatest in the Late Jurassic and Early Cretaceous (0.153 mm/yr and 0.044 mm/yr). The results of LSU-IES and NSAI are in general agreement, although the work was performed in different basins and using different approaches.

Gussow's igneous extrusive view of salt dome emplacement postulates very rapid salt movement, perhaps 4,000 feet in a month[41, 42]. Movement, however, could occur only once in the lifetime of a dome by this mechanism. All of the interior basin salt domes are therefore considered stable. Gussow's alternative to the orthodox view of salt dome movement proposes no threat of present or future instability.

Knowledge of the genesis of caprock relates to the question of salt dome kinetic stability. Most current views on the mechanism of caprock formation fall under the residual accumulation theory, the precipitation-in-place theory, or the modified precipitation-in-place theory[43, 44, 45]. The residual accumulation theory assumes that the caprock is formed as the top of the salt dome is dissolved by ground water, leaving behind the less soluble materials (mainly anhydrite). According to this theory the salt dome moves upward into the zone of dissolution. If the percentage of insoluble residue is known for the salt (usually thought to be between 1 and 5 percent), then the amount of vertical movement corresponding to a given caprock thickness may be calculated. Consequently, the caprock thickness is considered to be evidence of salt dome growth. Movement of salt by this process is internal to the dome, and the forming caprock is assumed to be stationary with respect to the aquifer that surrounds it. Given an insoluble residue of 3 percent of the salt dome material, every foot of caprock thickness would require 33 feet of vertical movement of salt.

The precipitation-in-place theory assumes that saline brine rises along the salt dome stock and precipitates the caprock on top of the salt dome when the dome top is surrounded by a freshwater aquifer. This theory implies an indirect link between salt dome movement and caprock formation, but does not allow a simple calculation of dome movement from caprock thickness.

Some geologists suggest that the caprock material has been brought up along with the growing dome from beneath the salt in the evaporite basin. Paulson discusses this possibility(46).

LSU-IES has been studying the occurrence and genesis of caprock as part of their investigation of the utility of Gulf Coast Salt Domes for radioactive waste disposal. Similarities between the caprock of different salt domes were investigated to see if correlations existed that would provide information on caprock genesis(23). The following parameters were examined: thickness of caprock; size (diameter, depth to salt); highest formation penetrated; aquifer(s) in contact with the dome; dome shape; and presence or absence of overhang. Comparisons of these parameters for the Northeast Texas and North Louisiana salt domes failed to provide an explanation for apparent differences in the degree of caprock development in these two basins. To date, caprock formation is not understood well enough to relate it to salt dome growth except in a general way.

Most knowledge of salt dome internal structure comes from salt mines in domes. Most Gulf Coast salt mines are located in coastal domes, the exceptions being Grand Saline and Hockley in Texas, and Winnfield in Northern Louisiana (now flooded). The knowledge of the internal structure of the mined domes as mapped by geologists is important to present concepts of salt dome movement. Kupfer describes coastal salt domes as having risen in spines rather than as a single plug(39). Between spines are near-vertical shear zones which may contain clay, sand, water, gas, or other impurities. This condition makes study of the growth history of such a dome complex. It has been suggested that interior basin salt domes may not have had as complex a growth history and that shear zones may not be common or even present in the interior basin salt domes. LSU-IES is actively studying salt dome internal structure [25]. They have mapped and sampled salt mines and geochemical studies are under way. Their studies include in the interior salt basin salt cores from Vacherie and Rayburn's Domes.

3.2.3 Evidence of Dome Stability

Three approaches have been taken to study the evidence of current or recent salt dome movement: (1) mapping of Quaternary deposits over the domes, (2) instrumentation of domes to measure current vertical movement, and (3) remote sensing studies to look for surface expressions of recent movement. LSU-IES has conducted Quaternary studies of Vacherie and Rayburn's Domes in Northern Louisiana. Field work has included mapping, shallow borings, and shallow geophysical surveys. The researchers have tentatively concluded that Pleistocene terraces at Vacherie Dome show no structural offset. Work at Rayburn's Dome has not progressed sufficiently to allow a tentative conclusion.

The purpose of instrumentation of salt domes is to determine if measurable salt dome movement is presently occurring. LSU-IES has developed an instrumentation program on two Northern Louisiana salt domes, Vacherie and Rayburn's. The program began with finite-element modeling of idealized and actual salt domes and their surrounding sediments to determine how vertical movement of the salt dome stock would be manifested at the ground surface above the dome. These results allowed LSU-IES to design a monitoring system which is presently being installed and calibrated. The system designed for Vacherie Dome consists of four tiltmeters in the hills surrounding the domal depression, laser ranging stations to detect horizontal spreading above the dome, precise leveling stations for vertical control, and a seismic monitoring network. Results will probably not be available for further screening of candidate domes, but they may play a role in eventual licensing studies.

Remote sensing analysis has been performed by LSU-IES to determine if fracture or shear zones observed in coastal Louisiana salt domes were expressed at the surface as mappable lineaments[24]. Available remote sensing data, including high-altitude NASA color infrared (IR) and USDA black-and-white photography, were used in this study. In the course of the investigation, techniques were developed to map and classify lineaments. The success of correlating the lineations with previously mapped fractures or faults was mixed.

LSU-IES made a subsequent remote sensing study of the domes in the North Louisiana Basin, particularly Vacherie, Rayburn's, and Prothro Domes [25]. NASA high-altitude color IR, low-altitude black-and-white and color photography, and sidelooking aerial radar (SLAR) imagery were used in this study.

3.3 HYDROLOGIC STABILITY

The term "hydrologic stability", when applied to salt domes, is used in discussions of possible or actual dissolution of domes by ground water. Domes which are undergoing little or no dissolution are referred to as hydrologically stable while those that are considered to be rapidly dissolving are referred to as hydrologically unstable. There have been no quantitative criteria established by which a dome may be classified as either stable or unstable. The lack of criteria for hydrologic stability is due, at least in part, to a lack of knowledge of the ground-water flow patterns adjacent to domes.

Ground-water flow patterns near domes are expected to be extremely complex. A better understanding of ground-water flow will require a comprehensive test-drilling program, including lithologic sampling, geophysical logging, water sampling, potentiometric mapping, and aquifer testing[28]. In a general sense, ground-water flow patterns are expected to be determined by the geometry of the dome and by the hydrologic and geometric properties of the aquifers penetrated by the dome.

Although the rate of transfer of salt to the ground-water system is thought to be most strongly influenced by the ground water flow system, transfer of the salt to the ground water is also considered to be controlled by the water-salt solution rate and by the potential presence of a layer of anhydrite or shale next to the salt[27]. It has been suggested that evidence of salt dome dissolution might be obtained by examining the ground water downgradient of domes[23]. It is hypothesized that active dissolution would be indicated by the presence of elevated salt concentrations in the ground water in the vicinity of a dome. The higher concentrations would be expected to form an elongated pattern in the direction of groundwater flow. Such a situation is referred to as a salt plume. No systematic water quality studies have been conducted to determine whether dissolved solids from domes are present in the ground water surrounding the domes.

Wesselman[49] noted an adverse effect on the quality of ground water in the vicinity of domes in Fort Bend County, Texas. The deterioration of ground-water quality in this area of South Texas may be related to oil-field operations or other factors not associated with dissolution.

It has been suggested that saline ground-water anomalies near salt domes are caused by brine from deep formations which moves upward along flow paths created by the salt diapir and discharges into shallower aquifers[24]. As it is not uncommon for petroleum to be impounded in structural traps on the flanks of salt domes, it might be inferred that such structural traps may also prevent the upward movement of brine.

Freshwater aquifers overlie saline aquifers in all the salt dome basins under consideration. The saline aquifers are generally considered to be saline because of a lack of flushing by fresh meteoric water. This lack of flushing implies an absence of movement of the saline water. If the saline water in the aquifers is truly stationary, it will become saturated when it contacts the salt dome and will have little effect on salt dissolution. However, if upward flow from these saline aquifers occurs along the periphery of the dome, dissolution could result because the salinity levels in these aquifers are considerably below saturation levels. Convective currents resulting from density gradients caused by saturated water at the water-salt interface could also provide a mechanism for dissolution in saline aquifers.

LSU-IES is currently attempting to evaluate a potential plume at Vacherie Dome. By examination of electric logs from oil wells around the dome they found that the identified "plume" east of Vacherie Dome does not indicate a significant amount of hydrologic instability.

The presence of "salt licks", "surface salines", or "saline prairies" above salt domes has been occasionally considered as evidence of salt dome dissolution. Anderson studied this question and reported that the depth of the salt dome below the ground surface was not correlated with the presence of this type of phenomenon(20). The depth to salt over domes with surface salines varied from 115 to 1,500 feet. Anderson stated his conclusions on this matter as follows:

> "Because the detailed movement patterns of ground water around salt domes are not known, the source of salt in the surface 'salines' is not known. It could either be leached from uplifted masses of strata that contain saline connate water or it could be derived from dissolution at the top of the salt mass and slow upward circulation of the resulting brine through pore spaces as suggested by Goldman (1931). However, as Bodenlos (1970) has noted, the second process (upward circulation through pores) does not take into account the relatively low permeability of anhydrite caprock."

Anderson also noted that the development of salines over domes in North Louisiana is independent of the thickness of the caprock. It was concluded that this information on the depth of domes and caprock thickness beneath salines argues against the derivation of surface salines from dissolution of the top of the salt mass.

The presence of caprock is considered by some to be clear evidence of salt dissolution over long periods of geologic time(24). One thesis argues that the condition of the interface between the salt mass and the caprock may indicate whether dissolution is continuing. It is assumed that an open zone at the contact would be consistent with continuing dissolution, while a solid contact between salt and anhydrite would indicate that salt dissolution has ceased. A boring into Vacherie Dome(25) encountered a tightly closed interface between salt and caprock. The proper interpretation regarding the hydrologic stability of this dome is not apparent from these data.

Preliminary interpretation of the information obtained from the LSU-IES drilling program over Vacherie Dome has made a rough estimate of a dissolution rate possible. This estimate is based on an apparent down-dropped section of Tertiary units that places these units approximately 800 feet lower over the dome than they would normally be expected to occur. If it is assumed that this apparent displacement was caused by dissolution of the top of the dome, then the combination of the drop of elevation and time required for dissolution allows an estimation of the dissolution rate, which in this case is 0.005 mm/yr[25]. However, the age of the sediments over the dome is still very much in question, and confirmation of this salt dissolution theory at Vacherie Dome requires further study.

Water leaks in salt mines are yet another possible indication of hydrologic instability. Some mines have been found to be dry, while others are not[25]. Kupfer has found some "leaks" to be associated with anomalous occurrences of included sediments, impure salt, and a type of structure marked by banding of the salt[38]. However, the source of the water seen in the leaks has not been determined, nor has it been determined why water is found in some mines and not in others. Apart from the overview-type studies, such as those conducted by Anderson and by Netherland, Sewell, and Associates, Inc., little was known about the hydrologic stability of Gulf Coast Salt Domes prior to the initiation of studies by LSU-IES and, to date, many of the LSU-IES findings await confirmation[10, 20, 21, 23, 24, 25]. elsewhere, investigations of dissolution in bedded salt by Piper and Bachman have produced estimates of vertical dissolution rates approximately 0.1 mm/yr [47, 48]. The results of these studies in bedded salt can only be correlated with actual or potential dissolution in domed salt when more information on ground-water flow around salt domes becomes available.

4 SCREENING APPLICATIONS

4.1 DOME COMPLIANCE

Anderson et al[20] determined that 263 Gulf Coast Salt Domes were to be screened. These domes were divided according to the subprovince of the Gulf Coast in which they were located. The coastal subprovince contains approximately 144 salt domes. The interior subprovince and the South Texas Basin contain approximately 125 salt domes, 80 of which are in the Mississippi Basin, 20 in the Northeast Texas Basin, 19 in the North Louisiana Basin, and 6 in the South Texas Basin.

The salt domes of the coastal subprovince were eliminated from consideration in the previous screening processes by Anderson et al, based on a general consensus of geologic opinion on the relative instability and structural complexity of the coastal domes[20]. In addition, many coastal domes are exploited for their abundant mineral resources (salt, brine, oil, and gas).

Table 4-1 lists the 125 salt domes located in the interior provinces and the South Texas Basin. These domes were used in the initial screening process. Of these domes, 114 were screened based on the dome size, repository depth and cover, and dome utilization criteria given in the OWI Screening Draft Specifications. From the remaining 11 potential domes, 8 were chosen for additional studies. The selection of candidate domes from each basin was based primarily on the areal extent of the dome at the repository level and the depth to top of salt. These domes are Richton, Lampton, and Cypress Creek Domes in the Mississippi Basin; Vacherie and Rayburn's Domes in the North Louisiana Basin; and Keechi, Oakwood, and Palestine Domes in the Northeast Texas Basin.

4.2 DOME DESCRIPTION

The salt domes listed in Table 4-2 from each of the three interior salt dome basins appear to have the greatest potential for development as repositories.

TABLE 4-1

LISTING OF ALL DOMES
APPLICATION OF DOME SCREENING CONSIDERATIONS
OVERALL ASSESSMENT
GULF COAST SALT DOME STUDY

NORTHEAST AND SOUTH TEXAS BASINS

NO.	DOME	POTENTIALLY ACCEPTABLE	REASON FOR REJECTION	DEPTH TO SALT (ft)	DEPTH TO SALT VERIFIED BY WELL DRILLED INTO SALT	AREA OF SALT (acres/depth)	LPG STORAGE	PETROLEUM PRODUCTION WITHIN 2.5 MI RADIUS OF DOME CENTER	BRINE PRODUCTION OR SALT MINE CURR.	BRINE PRODUCTION OR SALT MINE PREV.	BRINE PRODUCTION OR SALT MINE NONE
1	Bullard	no	Too small	100	yes	350 @ 3000'	no	no			x
2	Palestine	yes	--	120	yes	1330 @ 2000'	no	no		x	
3	Brooks	no	Lake	200	yes	2000 @ 1000'	no	no			x
4	Grand Saline	no	Brine production	210	yes	2496 @ 340'	no	no	x		
5	Steen	no	Too small	300	yes	885 @ 3000'	no	yes			x
6	Butler	no	LpG storage, too small	312	yes	500 @ 312'	yes	no			x
7	Whitehouse	no	Too small	400	yes	600 @ 2000'	no	no			x
8	Keechi	yes	--	400	yes	1100 @ 3000'	no	no			x
9[1]	Palangana	no	Brine & sulfur prod.	500	yes	n/a	no	yes	x[2]	x	
10	Mt. Sylvan	yes	--	613	yes	1820 @ 2000'	no	yes			x
11[1]	Gyp Hill	no	Too small	831	yes	364 @ 2000'	no	yes			x
12	East Tyler	no	LPG storage	890	yes	1498 @ 800'	yes	no			x
13	Oakwood	yes	--	900	yes	1820 @ 2000'	no	yes			x
14	Hainesville	no	LPG storage	1100	yes	5299 @ 1000'	yes	yes			x
15[1]	Piedras Pintas	no	Petroleum production	1350	yes	1000 @ 2000'	no	yes			x
16	Bethel	no	Too small	1500	yes	640 @ 1500'	no	yes			x
17	Boggy Creek	yes	--	2000	yes	2800 @ 3000'	no	yes			x
18	Day	no	Too deep	3153	yes	n/a	yes	no			x
19	Brushy Creek	no	Too deep	3570	yes	1498 @ 3570'	no	yes			x
20	Kittrell	no	Too deep	3855	yes	998 @ 3865'	no	yes			x
21	LaRue	no	Too deep	4450	yes	2995 @ 4450'	no	yes			x
22	Concord	no	Too small & too deep	5994	yes	992 @ 6000'	no	yes			x
23[1]	Moca	no	Too deep	6366	yes	n/a	no	yes			x
24[1]	Dilworth Ranch	no	Too deep	7645	yes	n/a	no	yes			x
25	Elkhart	no	Too deep	10165	yes	n/a	no	yes			x
26[1]	Pescadito	no	Too deep	14070	yes	n/a	no	no			x

[1] South Texas Basin Domes
[2] Sulfur

TABLE 4-1

LISTING OF ALL DOMES
APPLICATION OF DOME SCREENING CONSIDERATIONS
OVERALL ASSESSMENT
GULF COAST SALT DOME STUDY

NORTH LOUISIANA BASIN

NO.	DOME	POTENTIALLY ACCEPTABLE	REASON FOR REJECTION	DEPTH TO SALT (ft)	DEPTH TO SALT VERIFIED BY WELL DRILLED INTO SALT	AREA OF SALT (acres/depth)[4]	LPG STORAGE	PETROLEUM PRODUCTION WITHIN 2.5 MI RADIUS OF DOME CENTER	BRINE PRODUCTION OR SALT MINE CURR.	PREV.	NONE
27	Rayburns	yes	--	130	yes	1730 @ 2000'[6]	no	no		x	
28	Kings	no	Too small	192	yes	472 @ 2000'[6]	no	no	x		
29	Winnfield	no	Too small	200	yes	512 @ n/a'[7]	no	no		x	
30	Cedar Creek	no	Too small	750	no	768 @ n/a'[7]	no	no	x		
31	Vacherie	yes	--	777	yes	2400 @ 2000'[8]	no	no[5]			x
32	Drakes	no	Too small	850	yes	240 @ 2000'[6]	no	no		x	
33	Gibsland	no	LPG storage	885	yes	2432 @ n/a[7]	yes	yes			x
34	Prothro	no	Too small	1058[3]	yes	1014 @ 2000'[6]	no	no			x
35	Prices	no	Too small	1300	no	600 @ 2000'[6]	no	no	x		
36	Arcadia	no	LPG storage	1400	yes	960 @ n/a[7]	yes	no			x
37	Minden	no	Petroleum prod.	1912	yes	1728 @ n/a[6]	no	no			x
38	Bistineau	no	Too small	2300[3]	yes	832 @ n/a[7]	no	no	x		
39	Coochie Brake	yes	--	2440[3]	yes	1880 @ 2000'[6]	no	no			x
40	Chestnut	no	Surface graben faulting	2450	yes	2000 @ n/a[7]	no	no			x
41	Milam	no	Too deep & too small	4430	yes	790 @ 2000'[6]	no	no			x
42	Chester	no	Too deep & too small	4840	no	499 @ n/a[7]	no	no			x
43	Sikes	no	Too deep & too small	4931	yes	704 @ n/a[7]	no	no			x
44	Packton	no	Too deep & too small	6425	yes	499 @ n/a[7]	no	no			x
45	Castor Creek	no	Too small	n/a	no	640 @ n/a[7]	no	n/a			x

[3] Flank wells penetrated salt.
[4] Depth shown is the depth in feet below ground level.
[5] Sibley field about 2¼ miles from SE end of dome outline.
[6] New gravity estimates.
[7] Calculated from maps of Martinez and others, 1975.
[8] Calculated from maps of Martinez and others, 1977.

TABLE 4-1

LISTING OF ALL DOMES
APPLICATION OF DOME SCREENING CONSIDERATIONS
OVERALL ASSESSMENT
GULF COAST SALT DOME STUDY

MISSISSIPPI BASIN[9]

NO.	DOME	POTENTIALLY ACCEPTABLE	REASON FOR REJECTION	DEPTH TO SALT (ft)	DEPTH TO SALT VERIFIED BY WELL DRILLED INTO SALT	AREA OF SALT[9] (acres/depth)	LPG STORAGE	PETROLEUM PRODUCTION WITHIN 2.5 MI RADIUS OF DOME CENTER	BRINE PRODUCTION OR SALT MINE CURR.	PREV.	NONE
46	McIntosh	no	Brine production	400	yes	n/a	no	no	x		
47	Richton	yes	--	720	yes	4025 @ 1000'*	no	no			x
48	Crowville	no	Too small	800	no	<640 @ n/a	no	n/a			x
49	Tatum	no	Atomic test site & too small	1503	yes	750 @ 1000'	no	no			x
50	Lampton	yes	--	1650	yes	1440 @ 3000'*	no	no			x
51	Petal	no	LPG storage	1739	yes	1200 @ 1000'	yes	n/a			x
52	Gilbert	no	Too small	1778	yes	640 @ 1000'	no	n/a			x
53	Hazelhurst	no	Too small	1850	yes	800 @ 1000'	no	no			x
54	Arm	no	Too small	1930	yes	750 @ 1000'	no	no			x
55	McLaurin	no	Too small	1933	yes	<1300 @ 3000'	no	no			x
56	Richmond	no	Too small	1954	yes	800 @ 1000'	no	no			x
57	Bruinsburg	no	Too small	2016	yes	700 @ 1000'	no	yes		x	
58	Byrd	no	Too small	2058	yes	640 @ 1000'	no	no			x
59	Leedo	no	Too small	2065	yes	800 @ 3000'	no	no			x
60	Raleigh	no	Too small	2140	yes	1000 @ 1000'	no	n/a			x
61	McBride	no	Too small	2205	yes	300 @ 1000'	no	n/a			x
62	County Line	no	Too small	2169	yes	800 @ 1000'	no	no			x
63	Moselle	no	Too small	2300	no	<1300 @ n/a	no	n/a			x
64	Sardis Church	no	Too Small	2300	no	<1300 @ n/a	no	n/a			x
65	Dont	no	Too small	2300	no	900 @ 1000'	no	n/a			x
66	Dry Creek	no	Too small	2300	no	900 @ 1000'	no	n/a			x
67	Centerville	no	Too small	2400	no	1000 @ 1000'	no	n/a			x
68	D'Lo	no	Too small	2400	no	1280 @ 1000'	no	n/a			x
69	Eminence	no	Too small	2440	yes	640 @ 1000'	no	n/a			x
70	Midway	no	Too small	2522	yes	750 @ 1000'	no	n/a			x
71	New Home	no	Too small	2595	yes	640 @ 1000'	no	n/a			x
72	Oakley	no	Too small	2634	yes	640 @ 1000'	yes	n/a			x
73	Oakvale	no	Too small	2696	yes	1280 @ 1000'	no	n/a			x
74	Ruth	no	Too small	2700	no	1000+ @ 1000'	no	n/a			x
75	Walnut Bayou	no	Too small	2740	yes	<1000 @ 1000'	no	n/a			x
76	Monticello	no	Too small	2757	yes	640 @ 1000'	no	n/a			x
77	Allen	no	Too small	2774	yes	460 @ 1000'	no	n/a			x
78	Prentiss	no	Too small	2800	no	1280 @ 1000'	no	n/a			x
79	Carmichael	no	Too deep & too small	2966	yes	1000 @ 1000'	no	n/a			x
80	Bothwell	no	Too deep & too small	3000	no	640 @ 1000'	no	n/a			x
81	South Tallulah	no	Too deep	3023	yes	n/a	no	n/a			x
82	Edwards	no	Too deep	3026	yes	1000 @ 1000'	no	n/a			x
83	Caseyville	no	Too deep	3035	yes	640 @ 1000'	no	n/a			x
84	Kola	no	Too deep	3048	yes	1000 @ 1000'	no	n/a			x

[9] Area shown for each Mississippi dome is area of salt at 1000 feet below top of salt unless noted by *. Obtained from Mellen, 1976; and others.

TABLE 4-1

LISTING OF ALL DOMES
APPLICATION OF DOME SCREENING CONSIDERATIONS
OVERALL ASSESSMENT
GULF COAST SALT DOME STUDY

MISSISSIPPI BASIN[9]

NO.	DOME	POTENTIALLY ACCEPTABLE	REASON FOR REJECTION	DEPTH TO SALT (ft)	DEPTH TO SALT VERIFIED BY WELL DRILLED INTO SALT	AREA OF SALT (acres/depth)	LPG STORAGE	PETROLEUM PRODUCTION WITHIN 2.5 MI RADIUS OF DOME CENTER	BRINE PRODUCTION OR SALT MINE CURR.	PREV.	NONE
85	Carson	no	Too deep	3080	yes	640 @ 1000'	no	n/a			x
86	Utica	no	Too deep	3135	yes	640 @ 1000'	no	n/a			x
87	Coleman	no	Too deep	3352	yes	n/a	no	n/a			x
88	Hervey	no	Too deep	3547	yes	2000 @ 1000'	no	n/a			x
89	Wesson	no	Too deep	3550	yes	600 @ 1000'	no	n/a			x
90	Kings	no	Too deep	3845	yes	1200 @ 1000'	no	n/a			x
91	Halifax	no	Too deep	3995	yes	1000 @ 1000'	no	n/a			x
92	Glass	no	Too deep	4030	yes	1500 @ 1000'	no	n/a			x
93	Ashwood (Somerset)	no	Too deep	4073	yes	n/a	no	n/a			x
94	Newellton	no	Too deep	4123	yes	n/a	no	n/a			x
95	Singer	no	Too deep	4197	yes	n/a	no	n/a			x
96	Vicksburg	no	Too deep	4386	yes	640 @ 1000'	no	n/a			x
97	Eagle Bend	no	Too deep	4425	yes	1000 @ 1000'	no	n/a			x
98	Galloway	no	Too deep	4432	yes	2000 @ 1000'	no	n/a			x
99	Learned	no	Too deep	4437	yes	640 @ 1000'	no	n/a			x
100	North Tallulah	no	Too deep	4537	yes	n/a	no	n/a			x
101	Brownsville	no	Too deep	4689	yes	640 @ 1000'	no	n/a			x
102	Oakridge	no	Too deep	5062	yes	n/a	no	n/a			x
103	Newman	no	Too deep	5108	yes	n/a	no	n/a			x
104	Duck Port	no	Too deep	5345	yes	n/a	no	n/a			x
105	Sunrise	no	Too deep	5940	yes	n/a	no	n/a			x
106	Snake Bayou	no	Too deep	5989	yes	n/a	no	n/a			x
107	Foules	no	Too deep	6013	yes	n/a	no	n/a			x
108	Glazier	no	Too deep	7685	yes	n/a	no	n/a			x
109	Heidleberg	no	Too deep	9390	yes	n/a	no	n/a			x
110	Gwinville	no	Too deep	10000	no	n/a	no	n/a			x
111	South Carolton	no	Too deep	11176	yes	n/a	no	n/a			x
112	Burns	no	Too deep	11310	no	n/a	no	n/a			x
113	Yellow Creek	no	Too deep	11422	yes	n/a	no	n/a			x
114	Eucutta	no	Too deep	11804	yes	n/a	no	n/a			x
115	Laurel	no	Too deep	12304	yes	n/a	no	n/a			x
116	Valley Park	no	Too deep	12424	yes	n/a	no	n/a			x
117	Rufus	no	Too deep	12485	yes	n/a	no	n/a			x
118	Ovette	no	Too deep	13156	yes	n/a	no	n/a			x
119	Hiwanee	no	Too deep	13598	yes	1280 @ 1000'	no	n/a			x
120	Baxterville	no	Too deep	14000	no	n/a	no	n/a			x
121	Ellisville	no	Too deep	14075	yes	n/a	no	n/a			x
122	Grange	no	Too deep	15274	yes	1000 @ 1000'	no	n/a			x
123	Cypress Creek (New Augusta)	yes		1447	yes	> 1000 @ 1500'*	no	yes			x
124	Hubbard	no	Too deep & too small	>4300	no	1000 @ n/a	no	n/a			x
125	Zion Hill Church	no	Too small	n/a	no	<640 @ n/a	no	n/a			x

[9] Area shown for each Mississippi dome is area of salt at 1000 feet below top of salt unless noted by *. Obtained from Mellen, 1976; and others.

TABLE 4-2

RANKING OF DOMES WHICH MEET CRITERIA OF DEPTH TO SALT, AREA OF SALT, PETROLEUM STORAGE, LPG STORAGE AND BRINE PRODUCTION APPLICATION OF DOME SCREENING CONSIDERATIONS OVERALL ASSESSMENT GULF COAST SALT DOMES STUDY

RANKING WITHIN BASIN	DOME	SALT DEPTH VERIFIED BY DRILL (FT)	APPROXIMATE AREA OF SALT (Acres)		
			Feet Below Ground Surface		
			1000	2000	3000
LOUISIANA BASIN					
1.	Vacherie	777	1620	2400	2860
2.	Rayburns	130	940	1730	2370
3.	Coochie Brake	2440 (flank)	770	1880	2220
MISSISSIPPI BASIN					
1.	Richton	720	4025	4500	4275
2.	Lampton	1650 (flank)	170	1040	1440
3.	Cypress Creek	1447 (flank)	2200	2850	3300
EAST TEXAS BASIN					
	Boggy Creek	2300	-	-	2800
	*Keechi	400	80	500	1100
	Mt. Sylvan	380	730	1820	2310
	*Oakwood	900	760	1820	2140
	*Palestine	100	715	1330	2275

*Domes ranked approximately equal based on current knowledge. Keechi, Oakwood, and Palestine selected for further study.

Of the domes in Texas which appear to have the greatest potential for development as a repository, the Texas Bureau of Economic Geology (TBEG) and LETCo have selected Keechi, Oakwood, and Palestine Domes for further study. At this time the available data on these domes are limited and, as additional information is obtained, their size or prior use may render them unacceptable. Although Mt. Sylvan appears to be compatible with the repository screening criteria, the current land use and its proximity to Tyler suggest that other potentially acceptable domes for which less information is presently available should be studied further at this time. This will allow a better comparison of these domes' characteristics with other domes in the Interior Gulf Coast Salt Dome Basins.

Two domes in North Louisiana, Vacherie and Rayburn's, have been selected for study by LSU-IES. Application of the OWI draft screening criteria to North Louisiana domes confirms the inclusion of Vacherie and Rayburn's Domes.

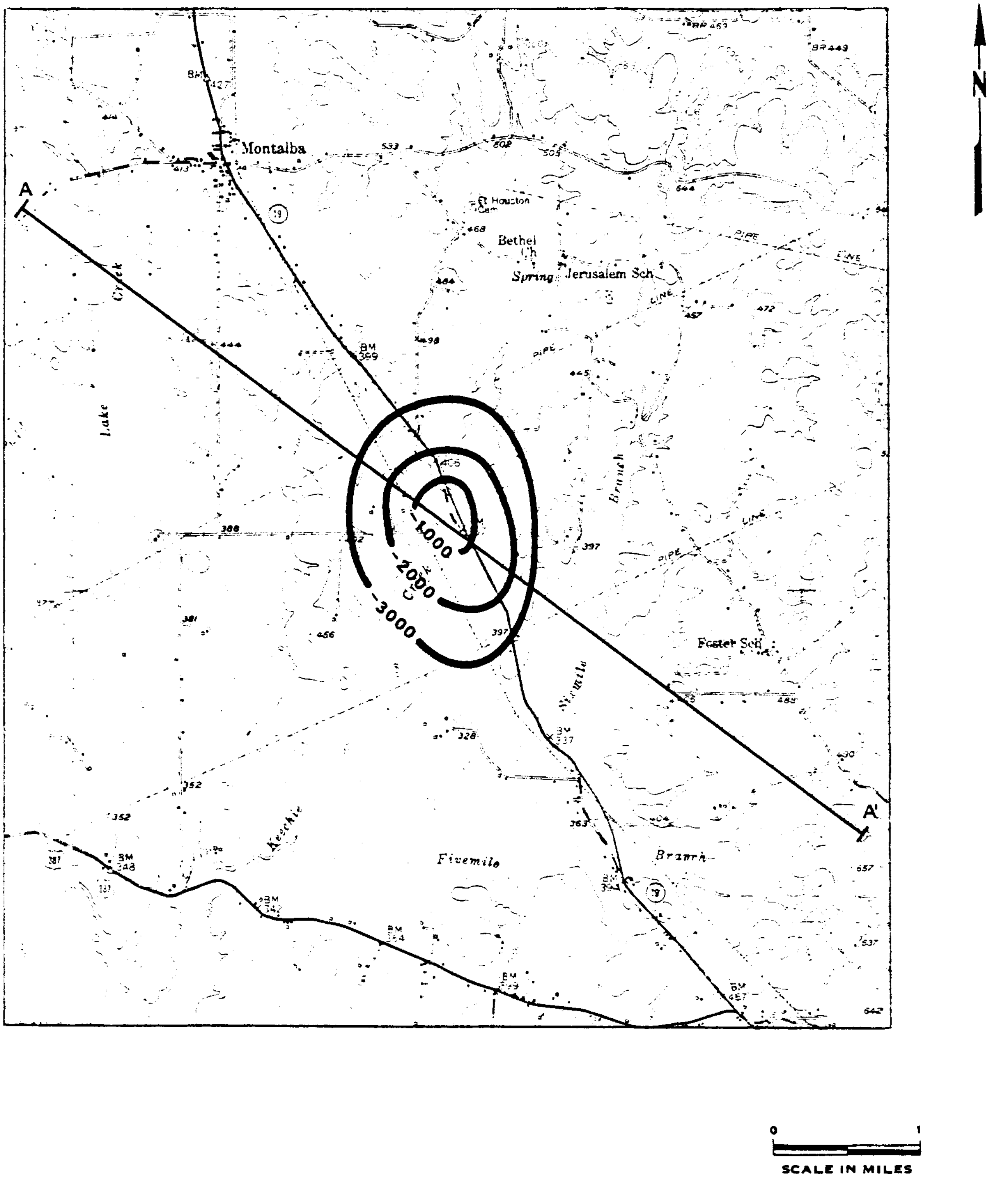
In Mississippi, Cypress Creek, Lampton, and Richton Domes were selected for further study.

The following discussion includes descriptions of each of the candidate domes and the area which surrounds it. The location, topography, and current land use are briefly described for each dome. In addition, the dome's configuration, surface and subsurface geologic conditions, and the past, present, and projected development of mineral resources in the dome's vicinity are addressed.

4.2.1 Keechi Dome

Keechi Dome is located in the western portion of Anderson County, approximately 7 miles northwest of the city of Palestine and 2.5 miles southeast of the small rural community of Montalba. The land in the dome's vicinity is currently used for livestock grazing and agriculture, and portions are wooded. The location of the dome is shown in Figure 4-1 and the abstract surveys are shown in Figure 4-2.

Domal structure is expressed as a topographic low. Topographic relief over the area is on the order of 30 to 40 feet. Keechi Creek traverses the central dome area and flows to the south into the Trinity River.



LEGEND

SALT STRUCTURAL CONTOURS

A A' CROSS SECTION LOCATION

NATIONAL WASTE TERMINAL STORAGE PROGRAM

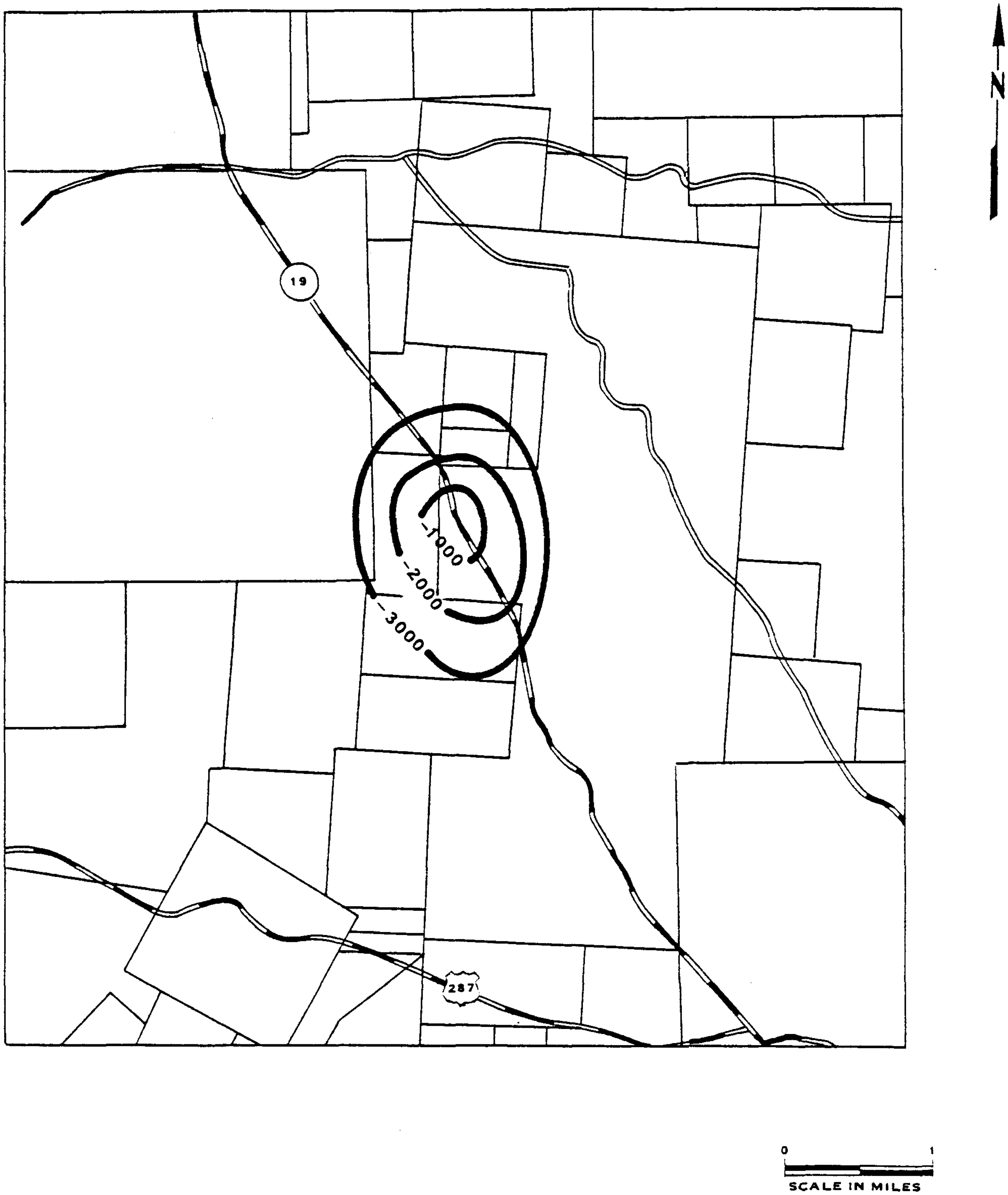
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-1

KEECHI DOME LOCATION MAP

JOB NO. MV9700



LEGEND

SALT STRUCTURAL CONTOURS
STATE AND U.S. ROUTE
SECONDARY ROADS

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES
LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-2

KEECHI DOME ABSTRACT SURVEY MAP

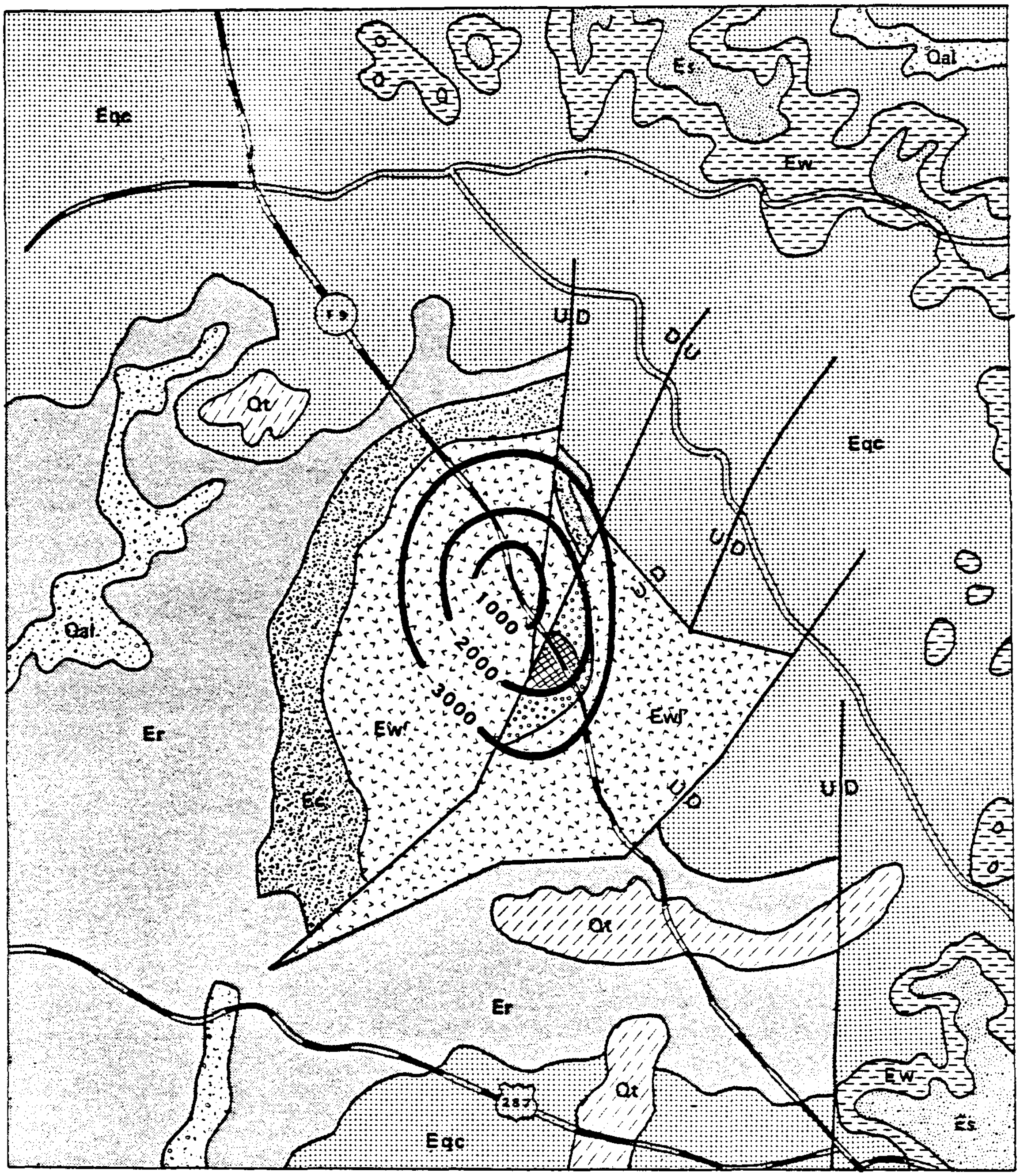
JOB NO. MV9700

The salt at Keechi Dome extends to within 435 feet of the surface[21]. Caprock is believed to drape over the dome and varies in thickness from 0 to 300 feet[27]. Good well control along the northern portion of the dome is lacking; therefore, the interpreted size and shape of Keechi can vary depending on the interpretation. Keechi Dome is interpreted from gravity and well data to be oval in shape, with a long axis trending north-south. Above elevation -5,000 feet mean sea level (MSL), the dome becomes egg-shaped and has a slight overhang on the south at about elevation -2,000 feet MSL. The estimated minimum horizontal area is 80 acres at a depth of 1,000 feet, 500 acres at 2,000 feet, and 1,100 acres at 3,000 feet.

Formations as old as the Cretaceous Taylor and Navarro Groups have been brought to the surface near the center of the dome. Away from the dome, surface sediments generally become progressively younger, forming a somewhat concentric outcrop pattern. These outcrop patterns are interrupted by radial faulting associated with dome movement. Sediments as young as the Reklaw and Queen City Formations of the Eocene Claiborne Group have been deformed by salt movement and exhibit a concentric outcrop pattern[50]. Recent alluvial deposits from small streams in the area mask portions of the older sediments at the dome. A surface geologic map of Keechi Dome and a geologic cross section are presented in Figures 4-3 and 4-4, respectively.

The surface geologic map for Keechi Dome (Figure 4-3) shows the surface sediments to be highly faulted and disrupted. It is expected that subsurface sediments are dipping at relatively steep angles, and that they are highly vaulted adjacent to the dome. The sediments become less deformed and faulted away from the dome. The Wilcox Group is believed to be effectively shielded from the salt mass by shales of the Midway Group, which is exposed at the surface and drapes over portions of the salt mass. However, on the southern side of the dome, the Pecan Gap Formation of the Taylor Group is brought to the surface by faulting and may be in contact with the salt mass at depth[27]. A geologic cross section of Keechi Dome is shown in Figure 4-4.

Oil and gas have not been produced in any commercial amounts over or adjacent to Keechi Dome. However, some shows of oil have been reported in wells drilled in the vicinity of the dome. Only Concord Field and Mount



Qal — ALLUVIUM
Qt — PLEISTOCENE FLUVIAL DEPOSIT
Es — SPARTA SAND
Ew — WECHES FORMATION
Eqc — QUEEN CITY SAND
Er — REKLAW FORMATION
Ec — CARRIZO FORMATION
Ewl — WILCOX GROUP
Em — MIDWAY GROUP
K — UPPER CRETACEOUS

0 1
SCALE IN MILES

REF: MODIFIED FROM PALESTINE SHEET, TEXAS BUREAU OF ECONOMIC GEOLOGY, 1968.

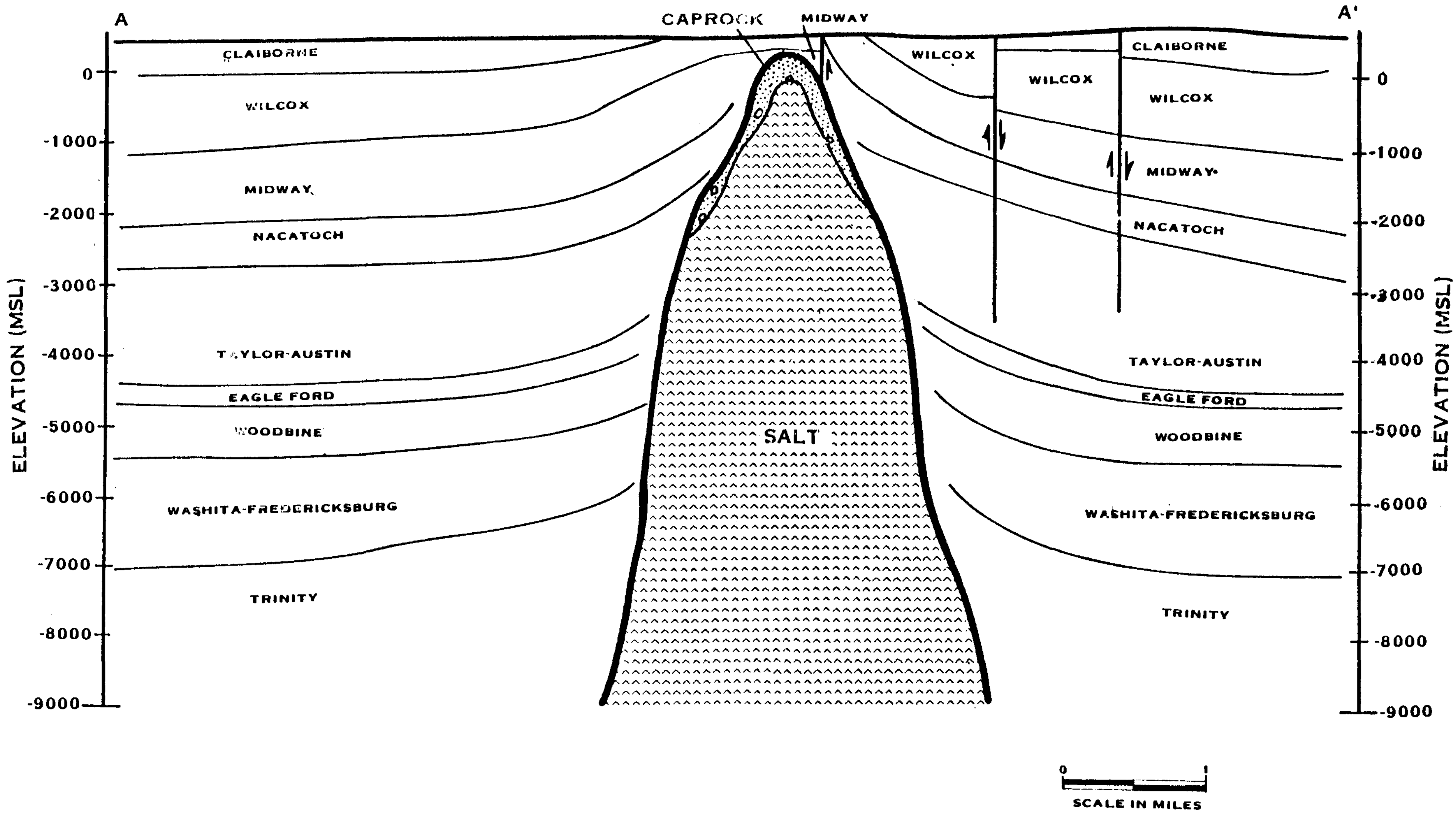
LEGEND
SALT STRUCTURAL CONTOURS
STATE AND U.S. ROUTE
SECONDARY ROADS
U/D FAULT

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES
LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-3

KEECHI DOME SURFACE GEOLOGY MAP

JOB NO. MV9700



NOTE: LOCATION OF CROSS SECTION IS SHOWN ON FIGURE 4-1

REF.: MODIFIED FROM NETHERLAND, SEWELL AND ASSOC.: 1976

LEGEND

FAULT

NATIONAL WASTE TERMINAL STORAGE PROGRAM

GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

FIGURE 4-4

KEECHI DOME CROSS SECTION

JOB NO. MV9700

Prairie Field, located approximately 5 miles north and northeast of Keechi Dome, respectively, have significant production. The locations of wells in the vicinity of the dome are shown in Figure 4-1. No other mineral resources have been reported in the vicinity of the dome.

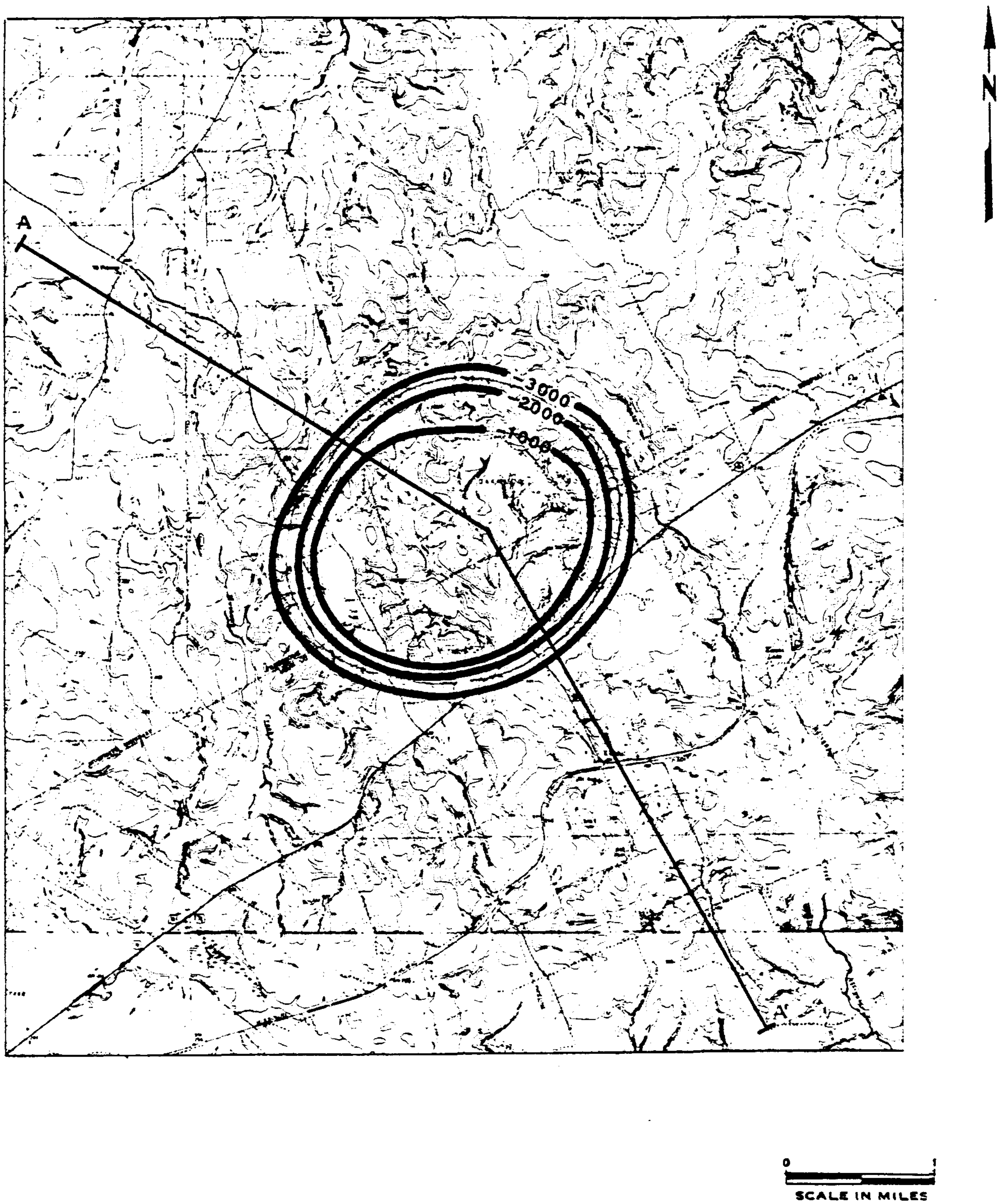
4.2.2 Oakwood Dome

Oakwood Dome is located on the Freestone-Leon County line, approximately 5 miles east of the small town of Buffalo and 1.5 miles north of the small rural community of Keechi. Approximately one-third of the area over the dome is cleared and used for farming and cattle raising, and the rest is tree-covered. The location of the dome is shown in Figure 4-5, and abstract surveys are shown in Figure 4-6.

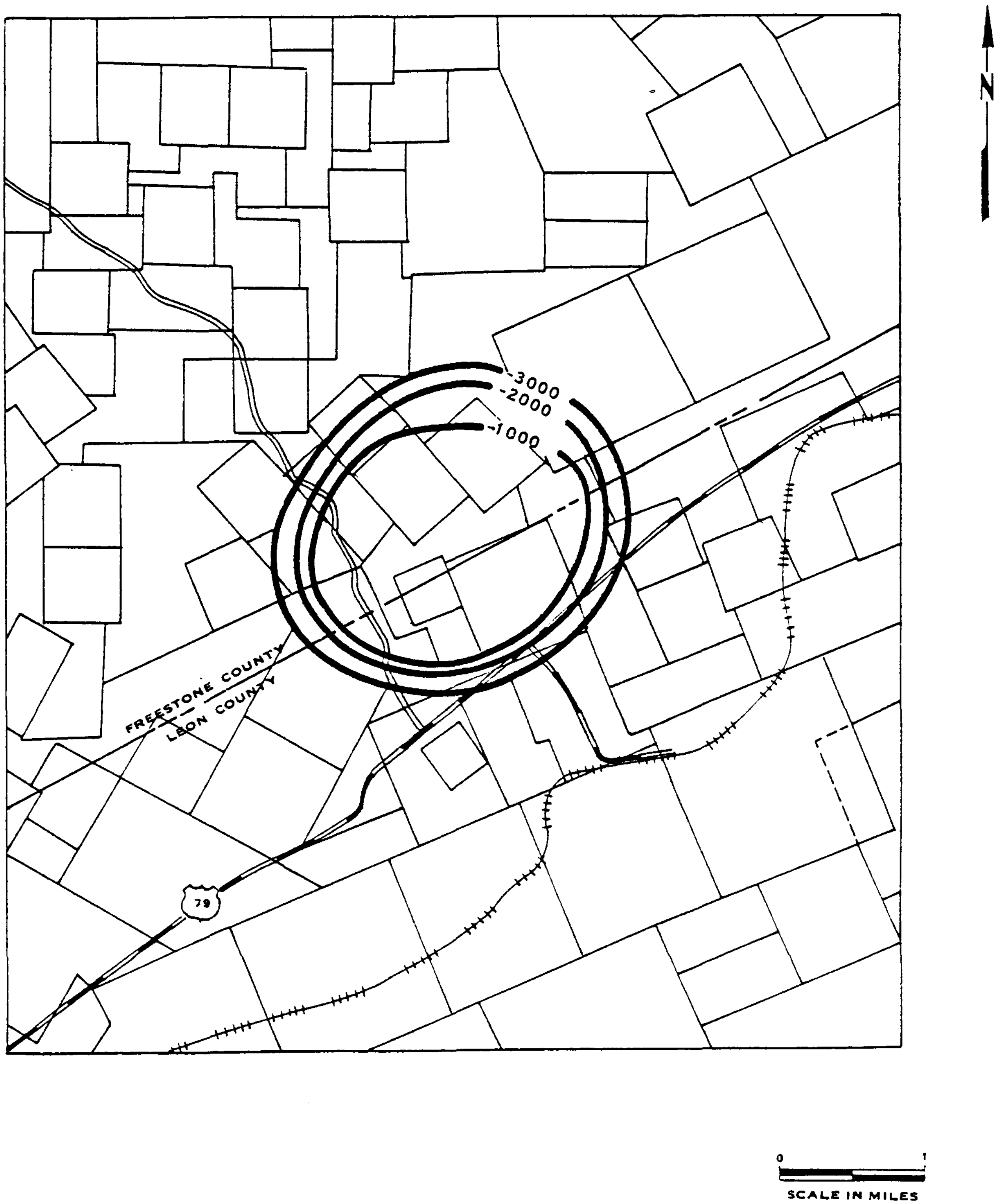
Topographically, the area is characterized by low rolling hills with relief on the order of 70 feet. The area is drained by the Alligator and Mustang creeks which flow to the Trinity River. The dome apparently has some effect on the drainage pattern which exhibits a somewhat annular pattern. The surface is dotted with several small stock ponds and ponds which are the result of abandoned oil or gas well mud pits.

The salt at Oakwood Dome extends to within 900 feet of the surface. Oakwood Dome is interpreted from well data to be circular in shape with a symmetrical slope and overhang on all sides, giving the appearance of a mushroom. The base of the overhang exists at 4,000 to 5,000 feet below the surface(51). Caprock has been encountered in numerous wells around the dome. The thickness of the caprock, which consists of anhydrite and sand, varies from 25 to 300 feet. The caprock extends over the dome and down to the overhang. Additionally, what has been termed "gouge" has been identified under the overhang. The estimated horizontal area is 760 acres at 1,000 feet, 1,820 acres at 2,000 feet, and 2,140 acres at 3,000 feet below the surface.

The surface formations over the dome have been reported as belonging to the Queen City Formation of the Claiborne Group(50); however, earlier reports have stated sediments as young as the Cook Mountain Formation are present overlying the dome(52). If true, this would indicate the possible



LEGEND	NATIONAL WASTE TERMINAL STORAGE PROGRAM	FIGURE 4-5
SALT STRUCTURAL CONTOURS	GEOLOGIC EVALUATION GULF COAST SALT DOMES	OAKWOOD DOME LOCATION MAP
A A' CROSS SECTION LOCATION	LAW ENGINEERING TESTING COMPANY MARIETTA GEORGIA	JOB NO. MV9700



LEGEND
- COUNTY LINE
- SALT STRUCTURAL CONTOURS
- U.S. ROUTE
- SECONDARY ROAD
- RAILROAD

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES
LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-6

OAKWOOD DOME ABSTRACT SURVEY MAP

JOB NO. MV9700

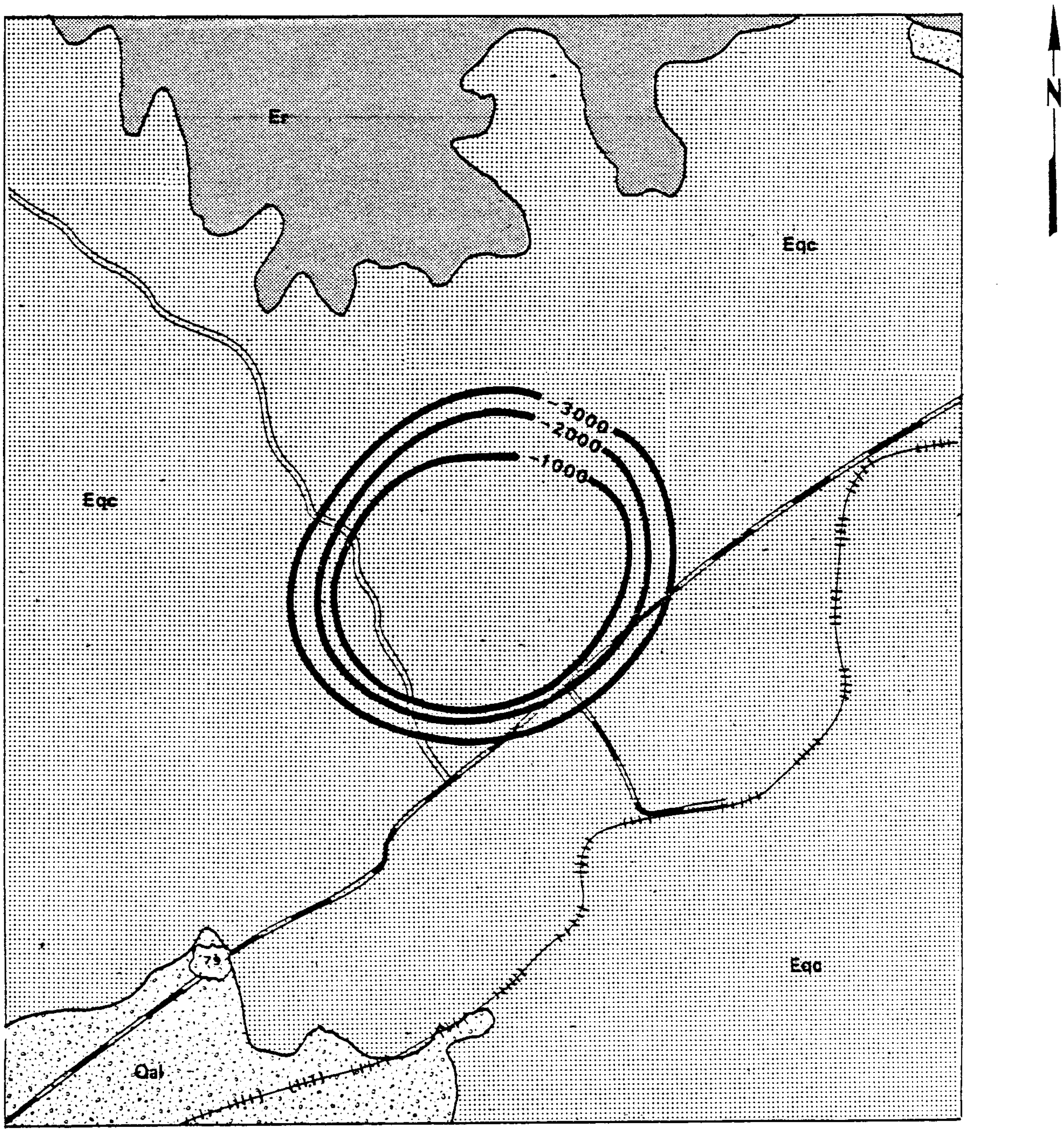
existence of a graben feature. Additional evidence of a possible graben was reported in 1928 by Renick, who stated that dome growth has resulted in dips on all sides of the dome in the Queen City Formation, the Cane River Formation (Weches equivalent), and the Carrizo Formation(53). Recent alluvium occupies portions of the small flood plains of the creeks which cross over the dome.

Subsurface sediments exhibit structural discord, radial faulting, and thinning and thickening as a result of dome growth. The Wilcox Group, a major freshwater aquifer, lies in contact adjacent to the dome at approximately 1,500 feet below the surface and is believed to extend across the top of the dome. The Eagle Ford and Woodbine Groups lie in contact with the salt stock just under the overhang at a depth below the surface of 5,000 to 7,000 feet. A surface geologic map and a geologic cross section of the dome are presented in Figures 4-7 and 4-8, respectively.

From 50 to 60 oil wells have been drilled within the vicinity of the dome. Oil and gas production was established under the overhang from wells drilled into the Woodbine Group through the overhang. Production has been declining during the last five years. In 1975, four wells drilled into the Woodbine Group produced 10,000 barrels of oil and 3,712 million cubic feet of gas. In 1976, three wells produced two-thirds of the 1975 production(54). All other wells around the dome are plugged and abandoned. No other production exists within a 2-mile radius of the dome. Some production exists 4 to 5 miles southwest in Red Oak Field. No other mineral resource deposits have been developed in the vicinity of the dome.

4.2.3 Palestine Dome

Palestine Dome is located in the western portion of Anderson County, 6 miles west of the city of Palestine. The dome is expressed topographically as a low, centered on Duggey's Lake (Old Salt Works Lake). Drainage to the north enters Wolf Creek and drainage to the south enters Town Creek, both of which are tributaries of the Trinity River. Relief across the dome is between 40 and 50 feet. The area over and around the dome is rural and is mainly used for agriculture and grazing. A salt lick has been reported on the western side of Duggey's Lake, and salt marsh deposits occur one-half mile to the east of the dome. The dome's location is presented in Figure 4-9, and abstract surveys are shown in Figure 4-10.



Qal ALLUVIUM

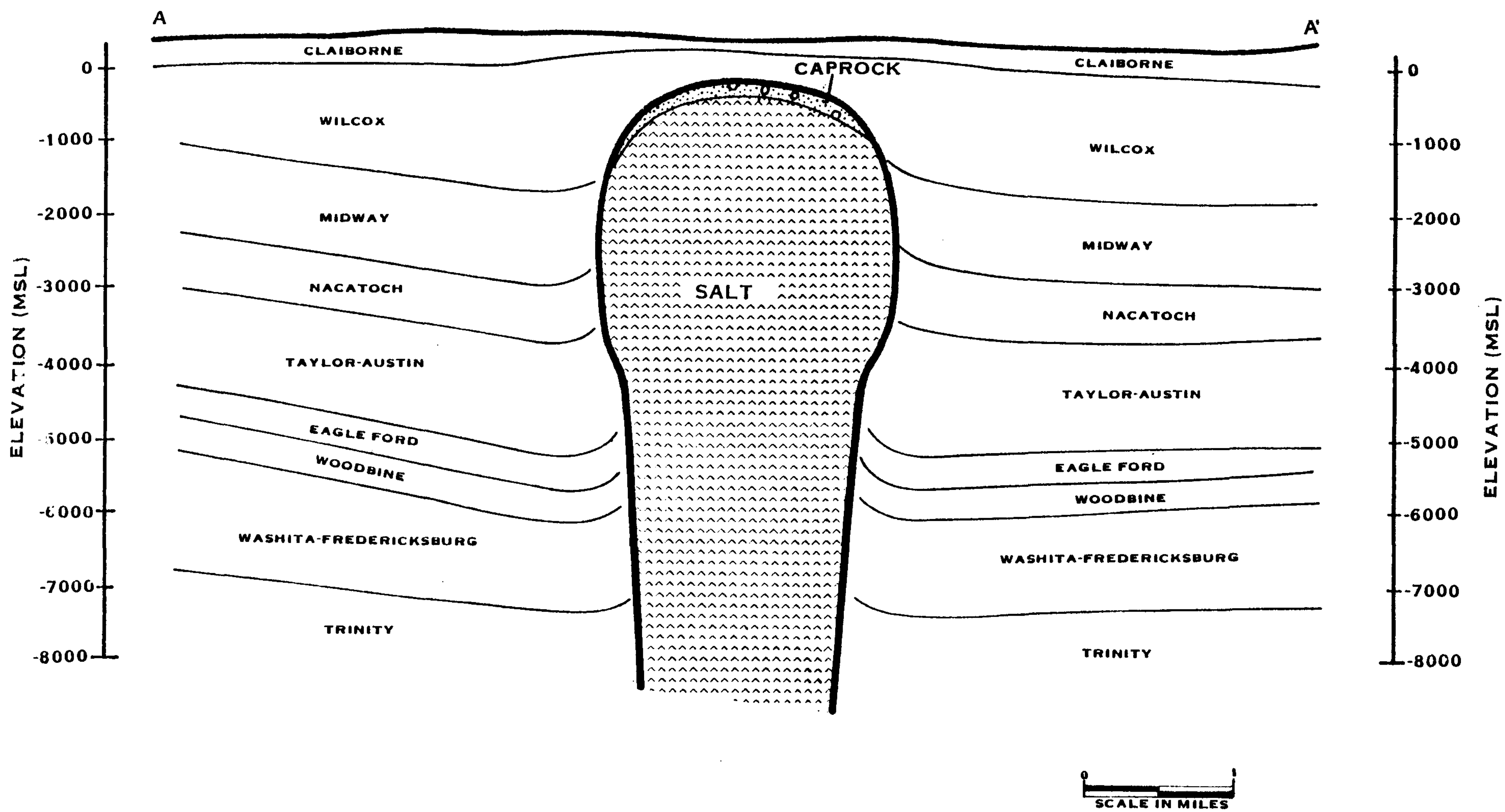
Eqc QUEEN CITY SAND

Er REKLAW FORMATION

0 1
SCALE IN MILES

REF: MODIFIED FROM PALESTINE SHEET, TEXAS BUREAU OF ECONOMIC GEOLOGY, 1968.

LEGEND	NATIONAL WASTE TERMINAL STORAGE PROGRAM GEOLOGIC EVALUATION GULF COAST SALT DOMES	FIGURE 4-7
SALT STRUCTURAL CONTOUR STATE AND U.S. ROUTE SECONDARY ROAD RAILROAD	LAW ENGINEERING TESTING COMPANY MARIETTA GEORGIA	OAKWOOD DOME SURFACE GEOLOGIC MAP JOB NO. MV9700



NOTE: LOCATION OF CROSS SECTION IS SHOWN ON FIGURE 4-5

NATIONAL WASTE TERMINAL STORAGE PROGRAM

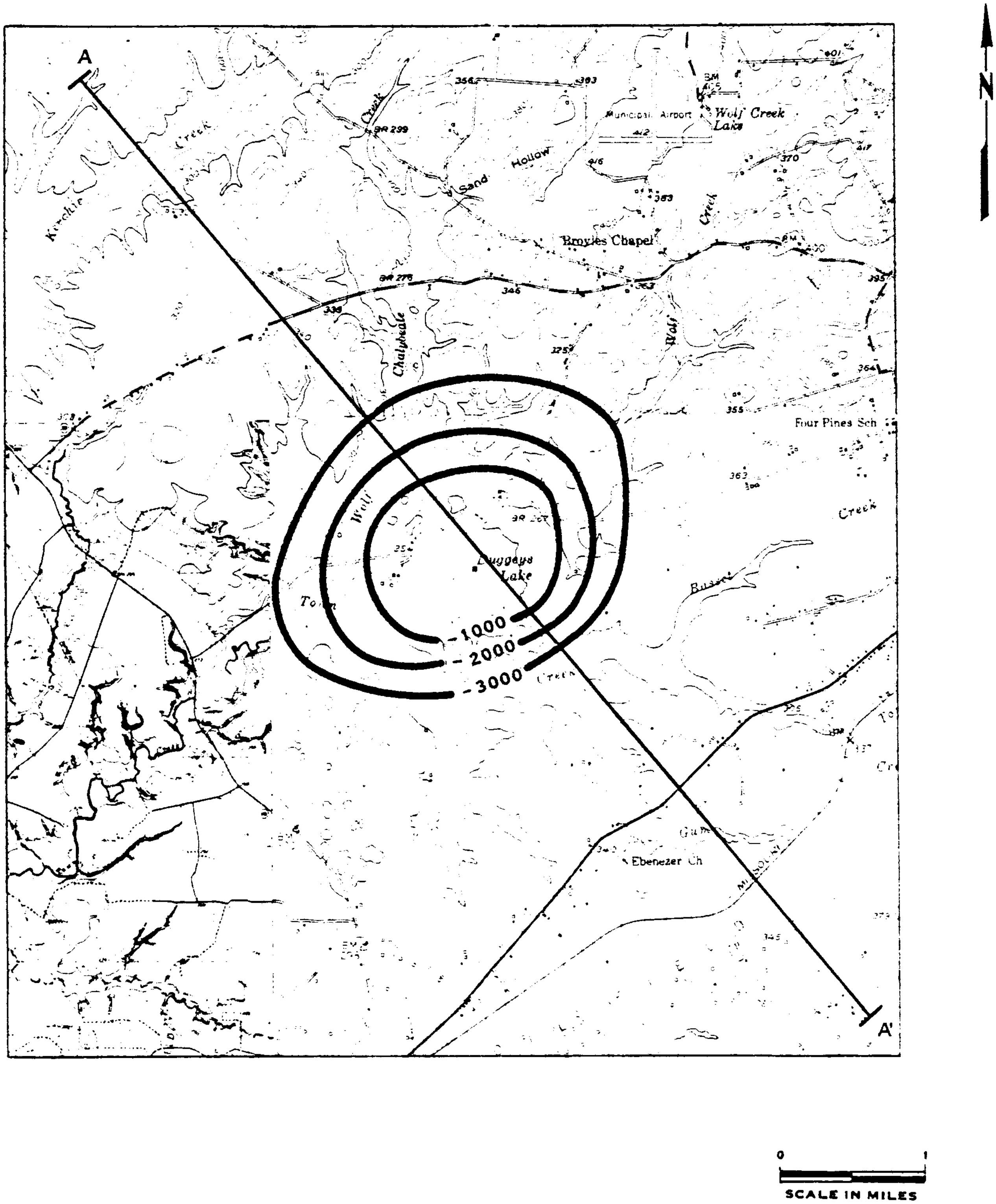
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

FIGURE 4-8

OAKWOOD DOME CROSS SECTION

JOB NO. MV9700



LEGEND

SALT STRUCTURAL CONTOURS

A A' CROSS SECTION LOCATION

NATIONAL WASTE TERMINAL STORAGE PROGRAM

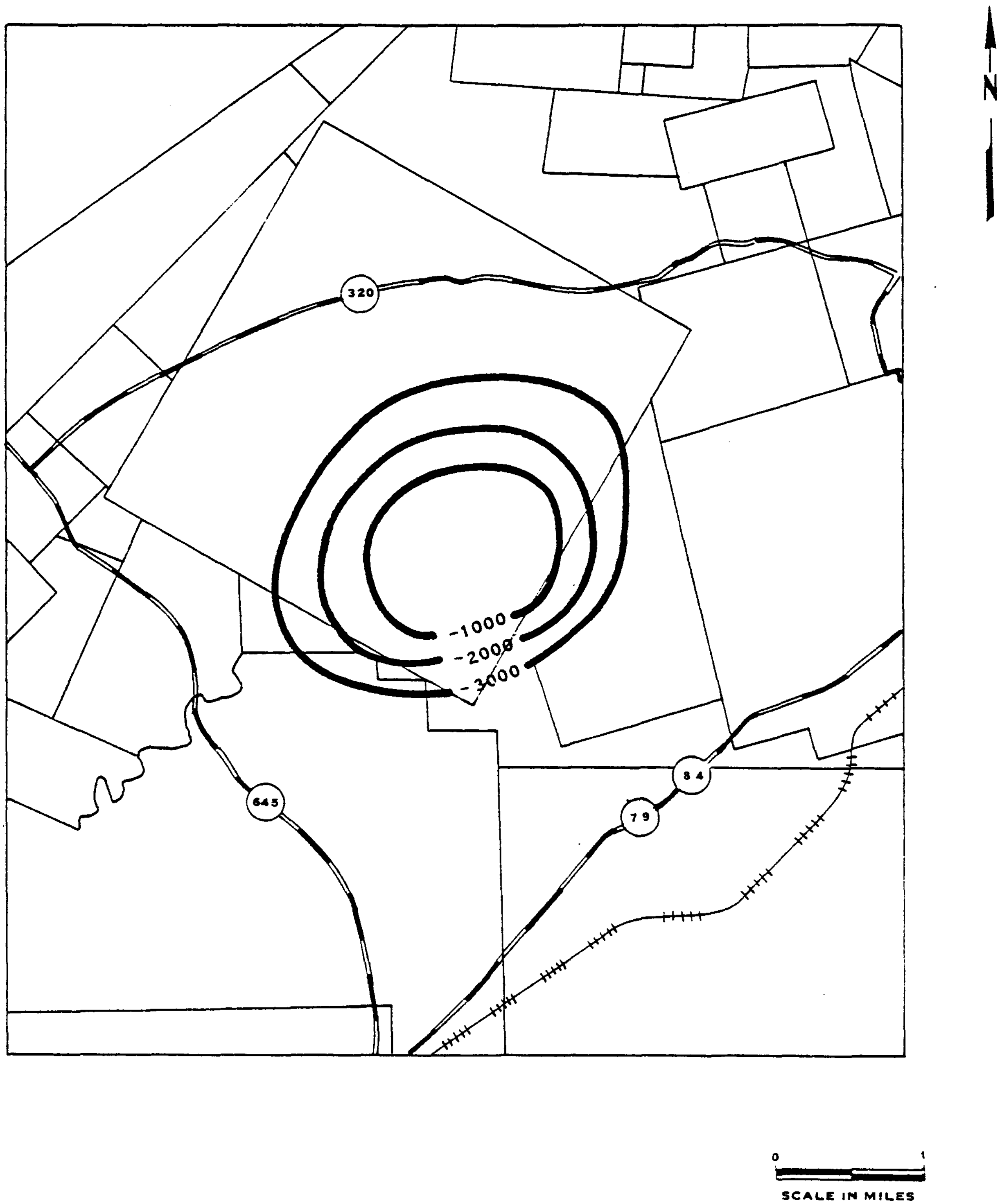
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-9

PALESTINE DOME LOCATION MAP

JOB NO. MV9700



LEGEND

SALT STRUCTURAL CONTOURS
STATE ROUTE
RAILROAD

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES
LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-10

PALESTINE DOME ABSTRACT SURVEY MAP

JOB NO. MV9700

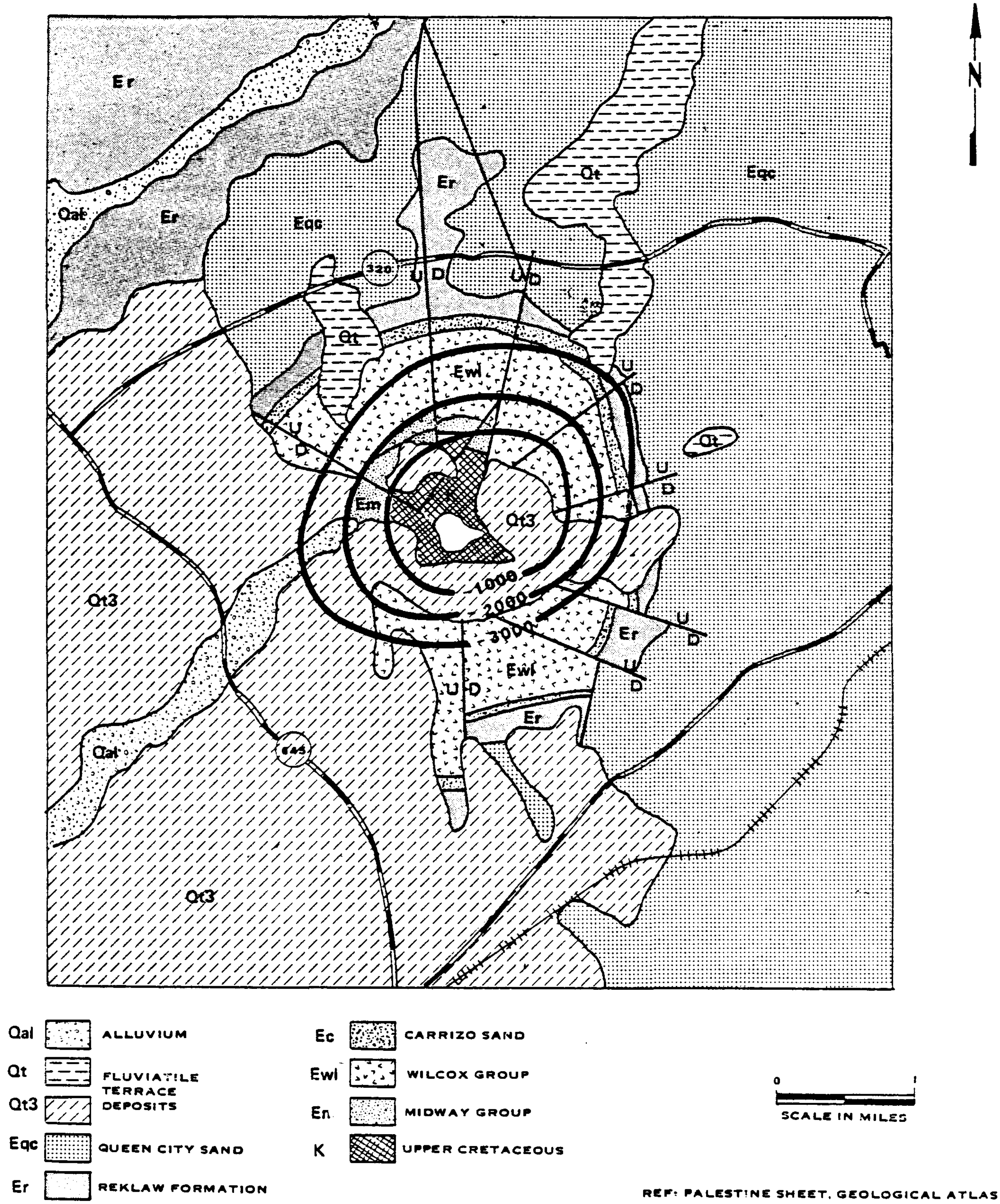
Duggey's Lake is believed to have been formed by structural collapse over the dome. The areal extent of Duggey's Lake has been increased by a road embankment, which acts as a dam, and a small amount of subsidence resulting from brine production just under the caprock.

The salt mass rises to within 75 to 100 feet of the surface at Palestine Dome. Caprock overlies the salt mass and in some cases is believed to be exposed at the surface, however, this has not been established. The salt mass is fairly symmetrical, tapering towards the surface. Gravity and well data indicate that the horizontal area of the salt mass is 715 acres at 1,000 feet, 1,328 acres at 2,000 feet, and 2,275 acres at 3,000 feet.

Sediments as old as the Cretaceous Buda Formation have been brought to the surface near the center of the dome(55). Away from the dome, surface sediments become progressively younger, forming a concentric outcrop pattern interrupted only by radial faulting associated with dome movement. Sediments as young as the Reklaw Formation of the Eocene Claiborne Group have been deformed by salt movement and exhibit this concentric outcrop pattern. Recent alluvial deposits from small streams in the area and Pleistocene terrace deposits mask portions of the older sediments at the dome.(50).

The surface geologic map of Palestine Dome (Figure 4-11) shows that the surface sediments are highly faulted and disrupted. This indicates that subsurface sediments are also deformed. It is expected that the subsurface formations are dipping at relatively steep angles and are highly faulted adjacent to the dome, becoming less deformed and faulted away from the dome. The Wilcox Group is shielded from the salt mass by shale of the Midway Group, which is exposed at the surface forming a concentric outcrop pattern. The Woodbine Group is also thought to be exposed at the surface. It is not known whether the Woodbine Group is in contact with the salt mass or shielded from the dome by older formations. A geologic cross section over Palestine Dome is shown in Figure 4-12.

Oil and gas have not been produced over or adjacent to Palestine Dome. Long Lake Field, located approximately 2.5 miles south of Palestine Dome, is the closest oil-producing area to the dome. Brine production at the dome was terminated in the 1930s. Prior to that time, up to 50 tons of salt per day were produced from salt beneath the caprock(56). A lignite mine was



LEGEND

SALT STRUCTURAL CONTOURS
STATE AND U.S. ROUTE
RAILROAD
U/D FAULT

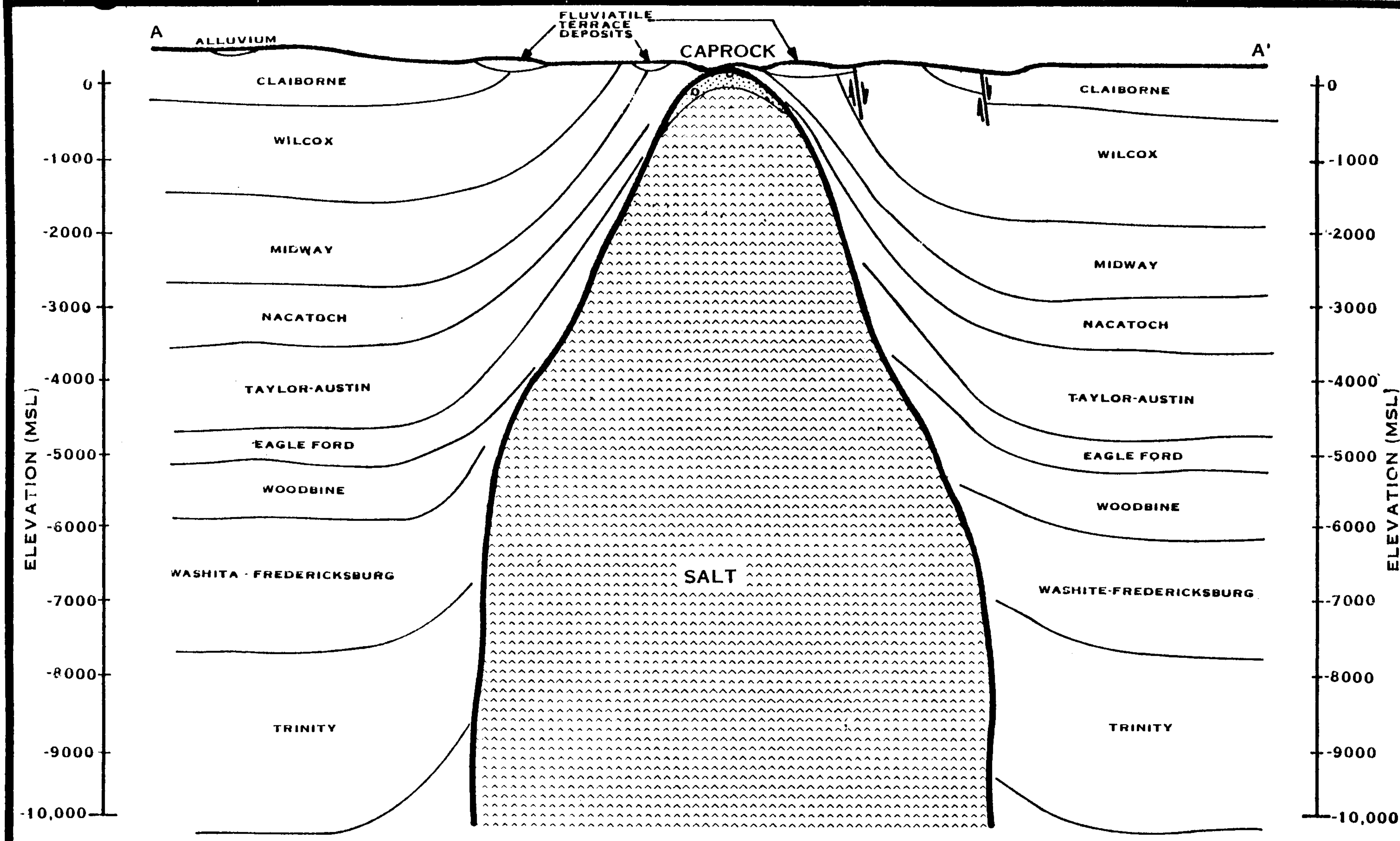
NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-11

PALESTINE DOME SURFACE GEOLOGY MAP

JOB NO. MV9700



NOTE: LOCATION OF CROSS SECTION IS SHOWN ON FIGURE 4-9

REF: MODIFIED FROM NETHERLAND, SEWELL, AND ASSOC., 1976

0 1
SCALE IN MILES

LEGEND	NATIONAL WASTE TERMINAL STORAGE PROGRAM	FIGURE 4-12
FAULT	GEOLOGIC EVALUATION GULF COAST SALT DOMES	PALESTINE DOME CROSS SECTION
	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	JOB NO. MV9700

operated in 1923, approximately 1.25 miles to the northeast of the dome, to supply fuel for brine operations. The lignite was mined from the Wilcox Group. TBEG lists the Wilcox Group surrounding Palestine Dome as a potential source of lignite[57]. No other mineral resources have been produced in the vicinity of Palestine Dome.

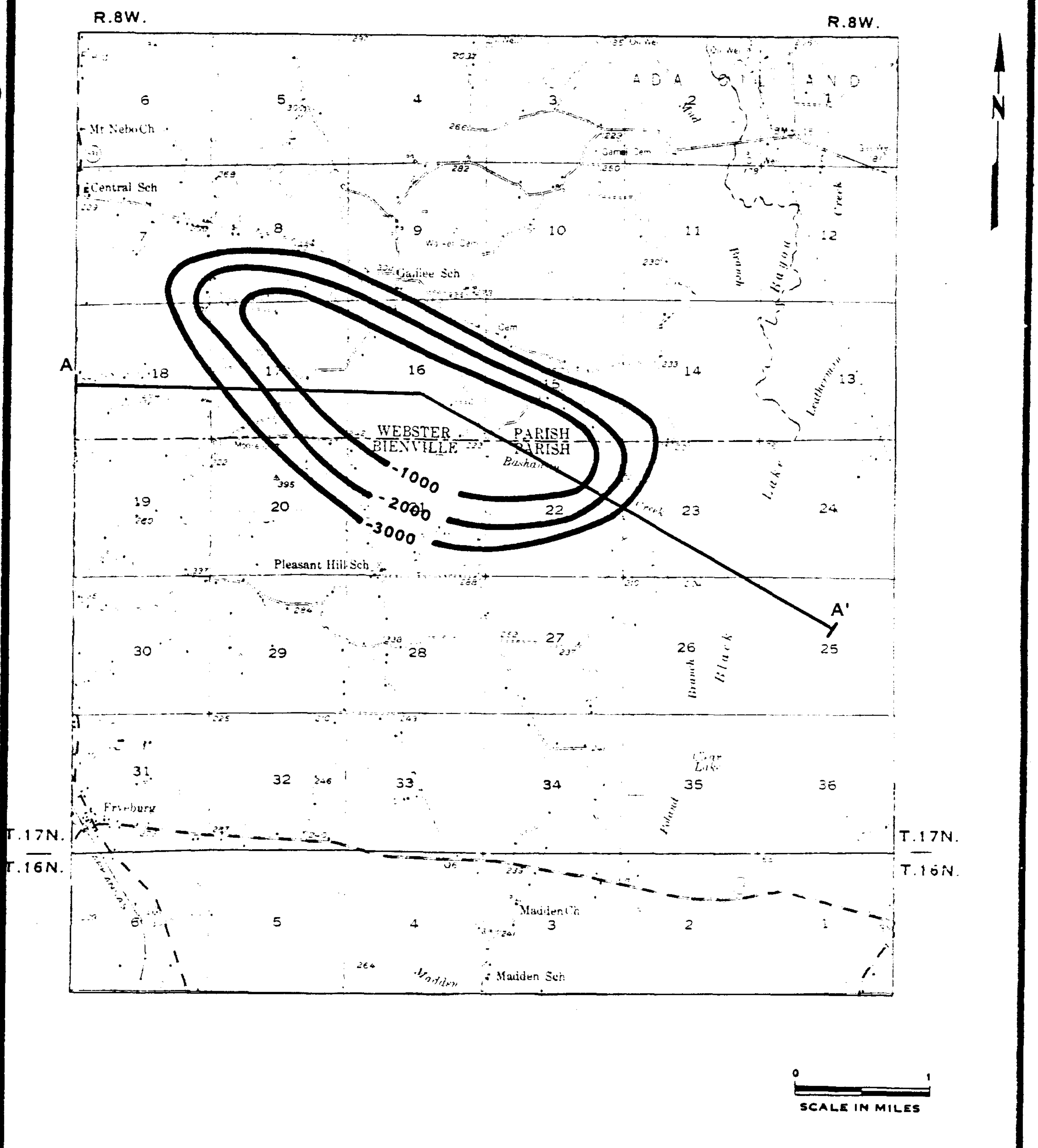
4.2.4 Vacherie Dome

Vacherie Dome is located in southeastern Webster Parish and northern Bienville Parish, Louisiana. No large population centers are located near Vacherie Dome. Heflin, approximately 4 miles west of the dome, is the nearest town. The topography at Vacherie Dome shows a characteristic central depression encircled by hills. Topographic relief in the area is over 200 feet. Bashaway Creek occupies the low central portion of the dome and drains to the east into Black Lake Bayou, a tributary of the Red River. In the vicinity of Vacherie Dome the land is largely forested with some pasture lands. Figure 4-13 shows the location of the dome and Figure 4-14 depicts the property ownership in the area.

The depth to salt has been determined by drilling to be 777 feet. The thickness of the caprock ranges from 90 to 120 feet. The dome trends northwest-southeast. The dome is 3.5 to 4 miles in length and approximately 2 miles wide at its center. Structural contours, based on seismic profiles and gravity data, show the area of the salt stock to be 1,620 acres at 1,000 feet deep, 2,400 acres at 2,000 feet, and 2,860 acres at 3,000 feet.

Vacherie Dome lies in the normal outcrop area of the Sparta Formation. The Cane River Formation and Wilcox Group are found as concentric inliers, exposed in a somewhat elliptical fashion around Vacherie Dome. The central depression of Vacherie Dome is covered by floodplain deposits and terrace sediments from Bashaway Creek. Figure 4-15 shows the generalized surface geology of the area.

The subsurface geology of Vacherie Dome is complicated by faulting, which is responsible for a possible horst and graben structure which is thought to be located above and on the flanks of the salt core. The sediments surrounding the dome dip away from the dome at angles up to



LEGEND

SALT STRUCTURAL CONTOURS

CROSS SECTION LOCATION

NATIONAL WASTE TERMINAL STORAGE PROGRAM

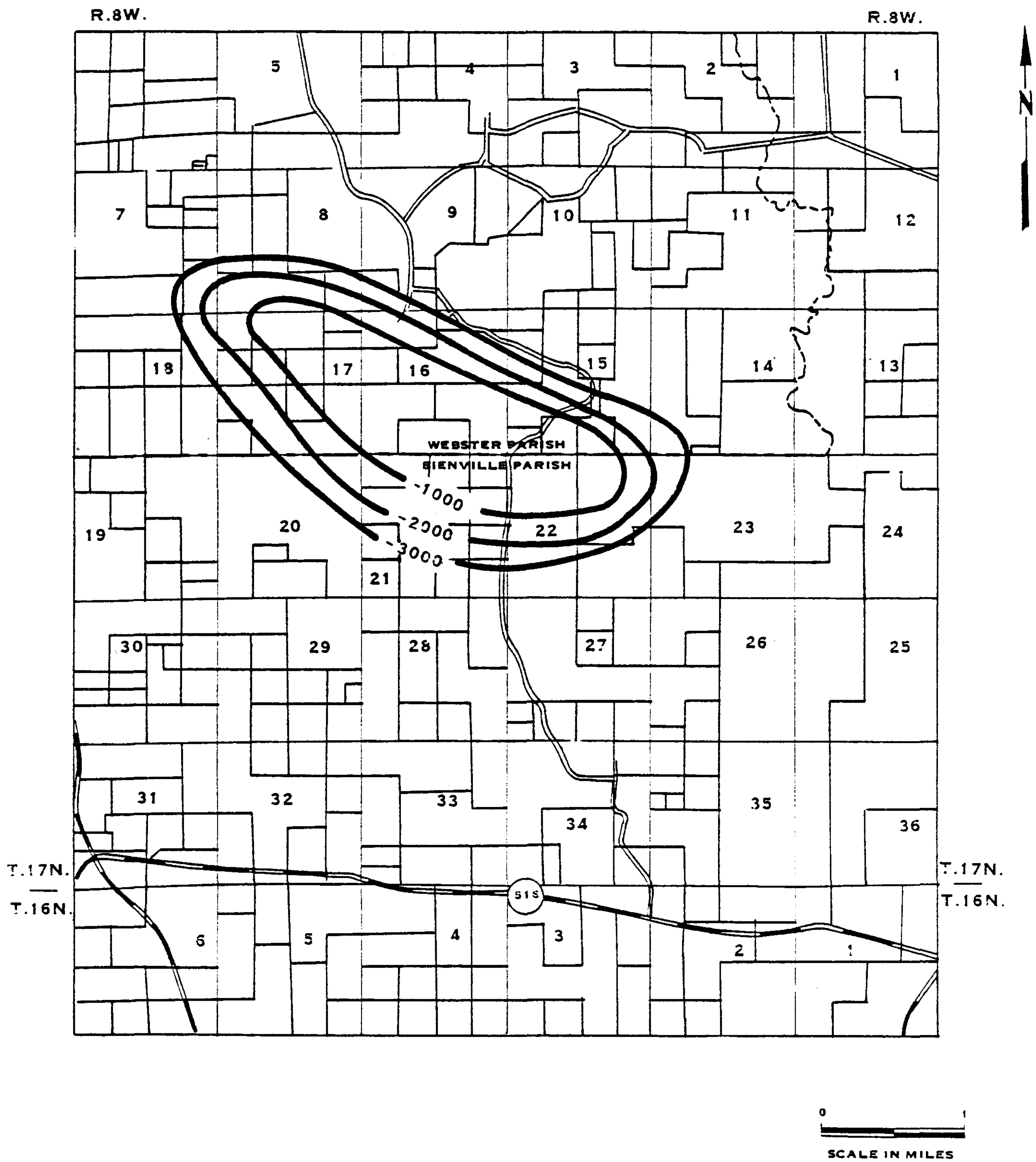
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-13

VACHERIE DOME LOCATION MAP

JOB NO. MV9700



LEGEND

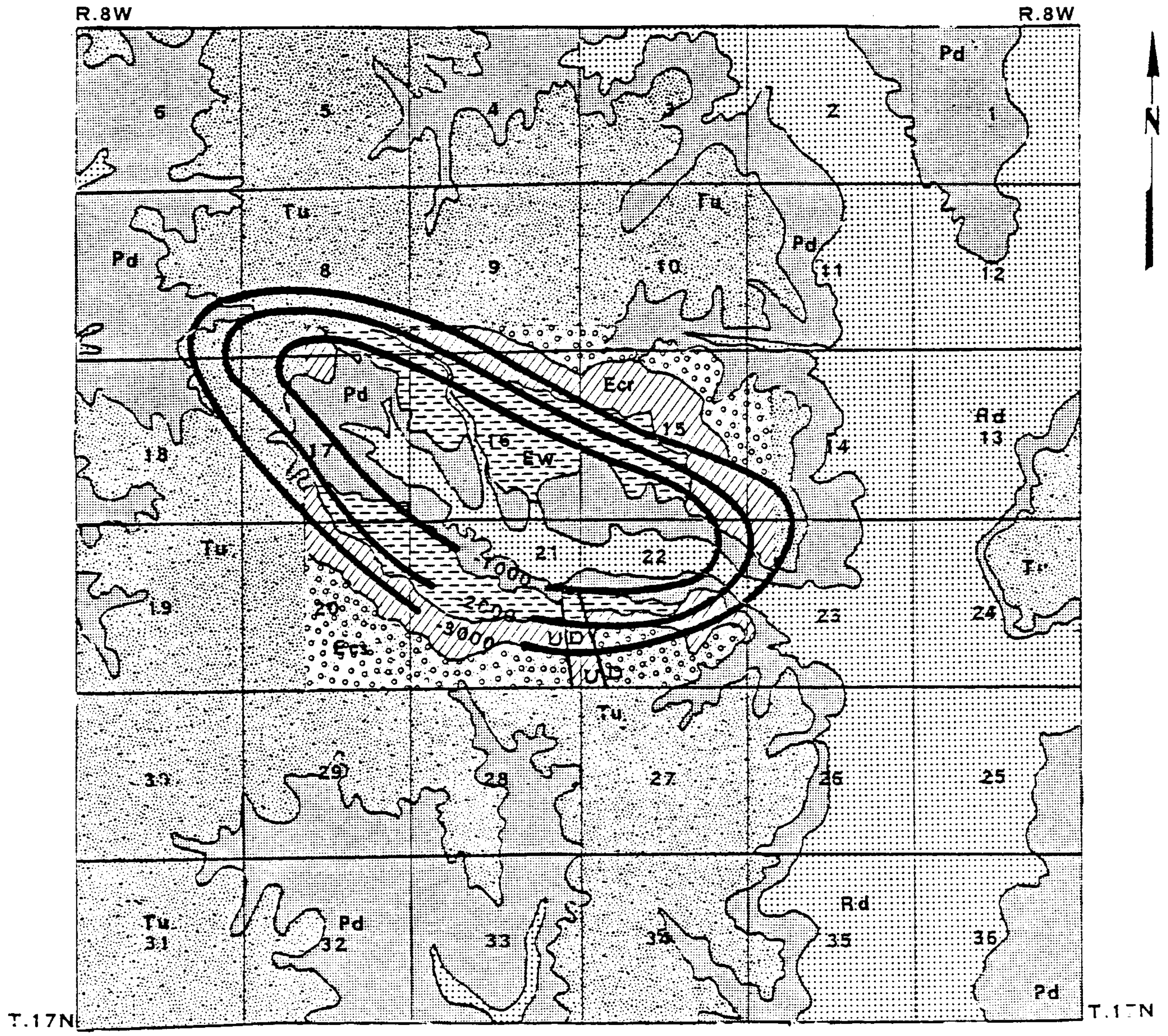
SALT STRUCTURAL CONTOURS
STATE ROUTE
SECONDARY ROAD
PARISH LINE

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES
LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-14

VACHERIE DOME PROPERTY OWNERSHIP MAP

JOB NO. MV9700



Rd	RECENT DEPOSIT	Ecr	CANE RIVER FORMATION		
Pd	PLEISTOCENE DEPOSIT	Ew	WILCOX GROUP		SCALE IN MILES
Ecs	SPARTA FORMATION	Tu	TERTIARY UNDIFFERENTIATED		

REF. MARTINEZ 1976

LEGEND

— SALT STRUCTURAL CONTOURS

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-15
VACHERIE DOME SURFACE GEOLOGIC MAP

JOB NO. MV9700

14 degrees. It is not known whether peripheral and radial faults surround Vacherie Dome, but both are believed to exist. Surface radial faults have been traced, except where concealed by Pleistocene terrace deposits. Figure 4-16 shows a geologic cross section of Vacherie Dome.

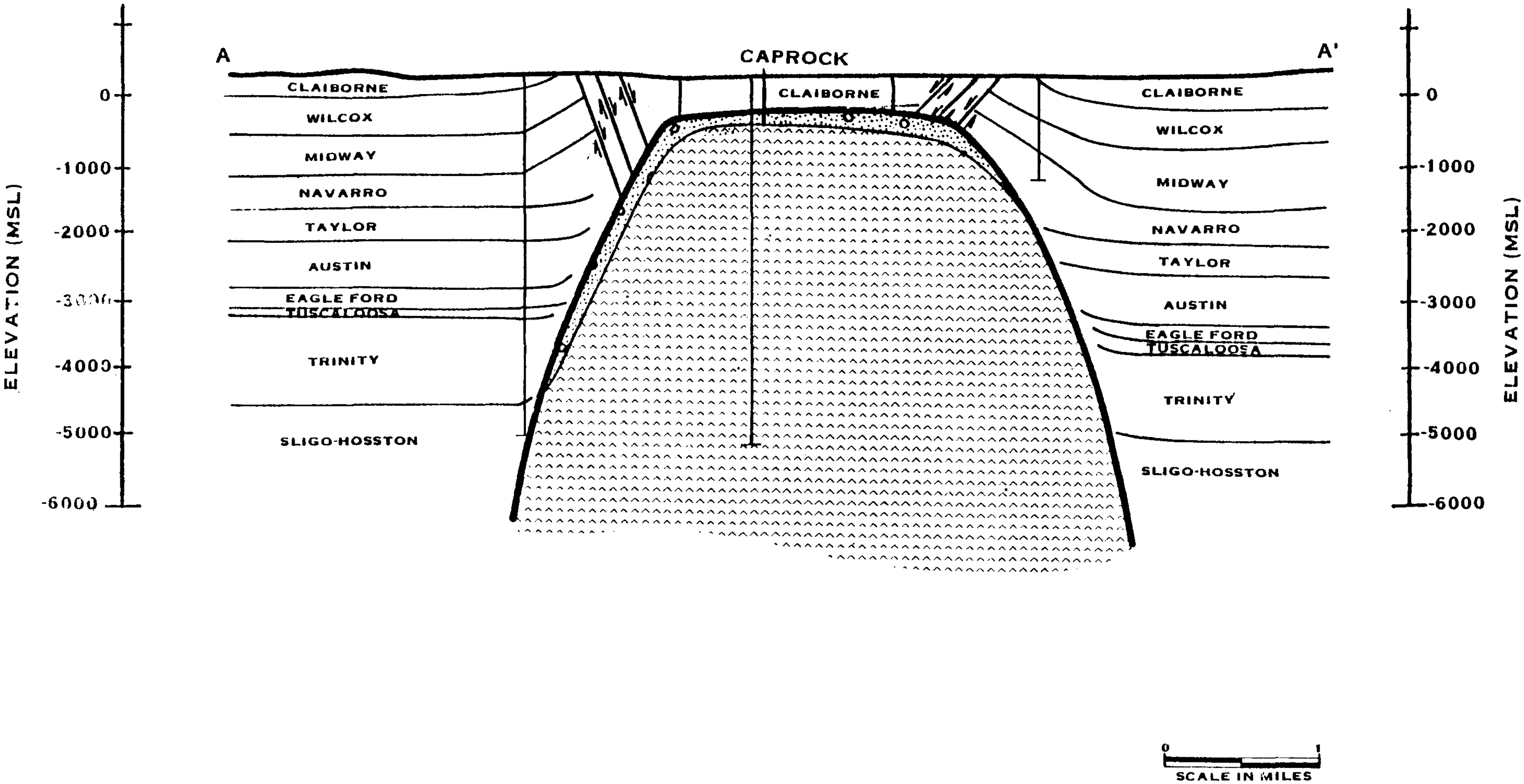
Several petroleum exploratory wells have been drilled on the flanks of Vacherie Dome. No oil or gas has been found, suggesting that Vacherie has little potential for hydrocarbon development. There are currently no active well sites on the dome, however, several production wells in the Ada Field are currently in operation 2 to 3 miles north to northeast from the general dome area. No present or past brine production is known to have occurred on Vacherie Dome. There is some development of sand and gravel deposits in the vicinity of the dome. No other mineral resources have been produced in the vicinity of the dome.

4.2.5 Rayburn's Dome

Rayburn's Dome is located in southeastern Bienville Parish, Louisiana. The nearest town is Saline, 6 miles to the southwest. The unincorporated community of Friendship is located about 3 miles east of the dome. The dome is encircled by low hills with a central saline marsh approximately 2,000 feet in length which drains into Fouse Bayou. Topographic relief in the vicinity of Rayburn's Dome is about 60 feet. The land is generally forested, with a few small areas under cultivation. Timber production for lumber is an important land use in the Rayburn's Dome proximity. The location of the dome and the local topography are shown in Figure 4-17, and property ownership is shown in Figure 4-18.

The depth to salt at Rayburn's Dome is 175 feet, and caprock is found a few feet below the ground surface. The dome is slightly elongated in the northwest-southeast direction. Gravity models and seismic interpretations indicate no salt overhang is present. The horizontal area of salt, as determined by gravity, seismic, and well data, is 940 acres at a depth of 1,000 feet, 1,730 acres at 2,000 feet, and 2,370 acres at 3,000 feet.

Quaternary deposits cover the low central portion of the dome. Upper Cretaceous sediments, the Brownstown-Tokio and Marlbrook Formations, are



NOTE: LOCATION OF CROSS SECTION IS SHOWN ON FIGURE 4-13

REF. MODIFIED AFTER MARTINEZ, 1977

LEGEND

FAULT

NATIONAL WASTE TERMINAL STORAGE PROGRAM

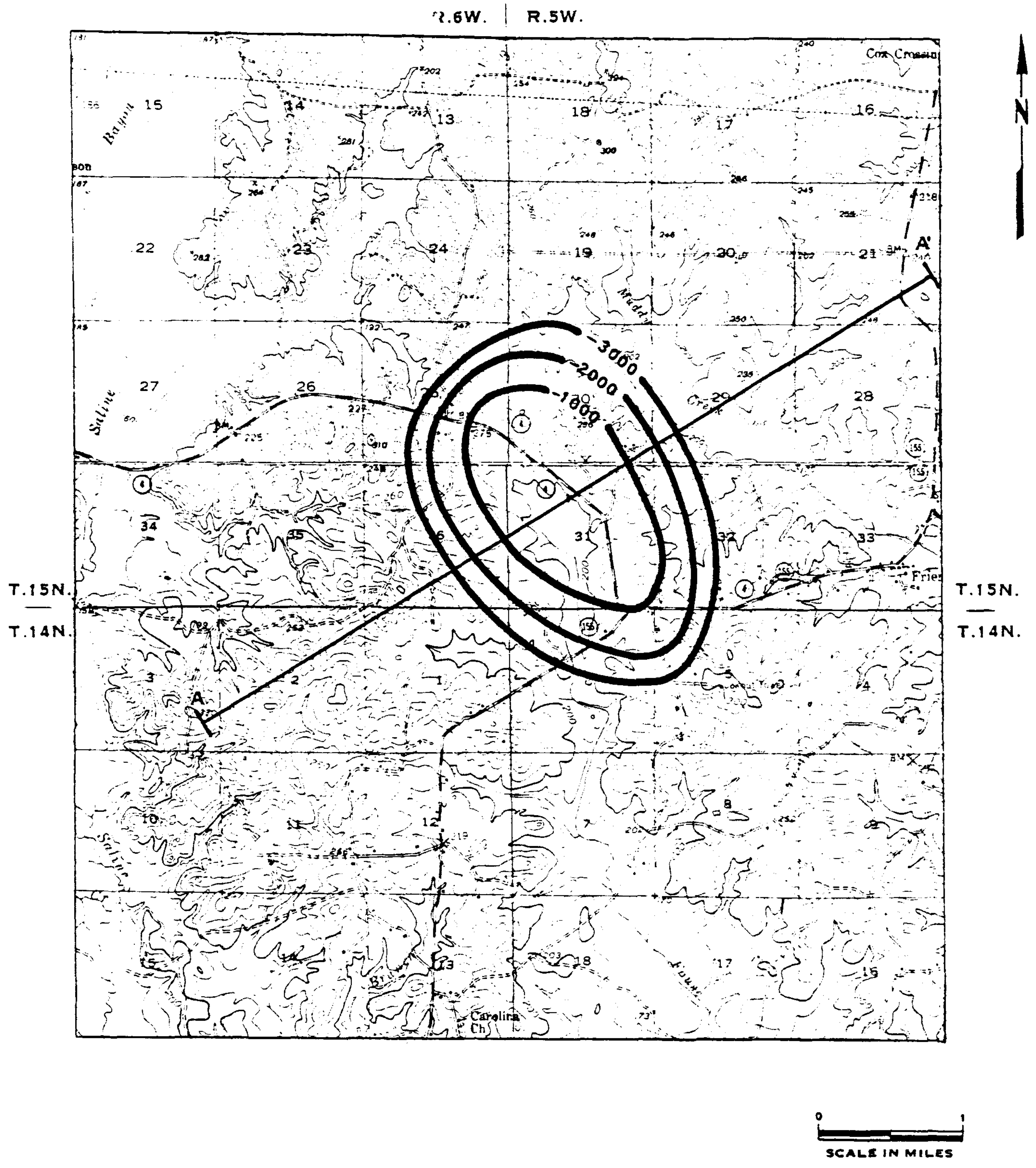
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

FIGURE 4-16

VACHERIE DOME CROSS SECTION

JOB NO. MV9700



LEGEND

SALT STRUCTURAL CONTOURS

A A' CROSS SECTION LOCATION

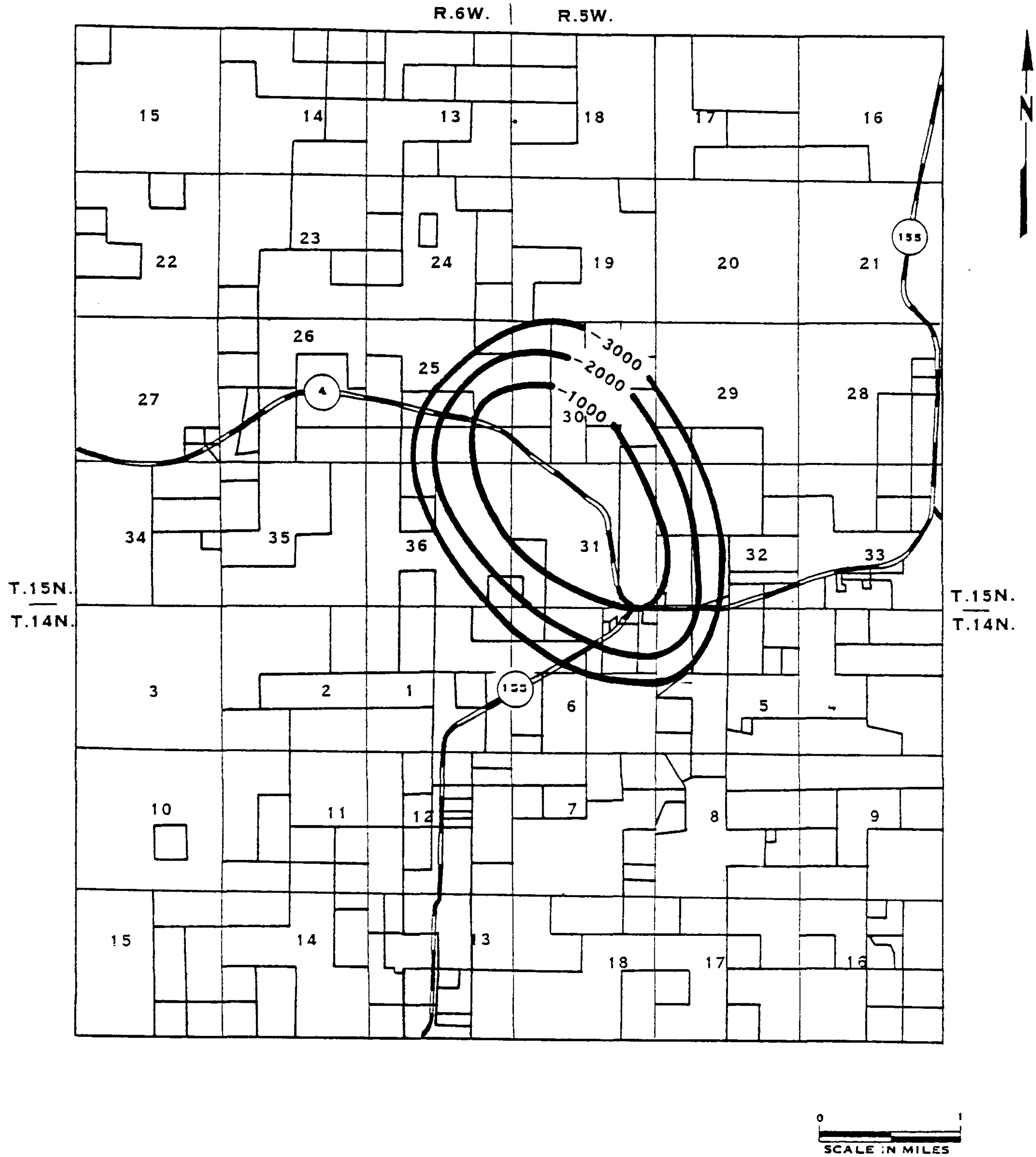
NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-17

RAYBURNS DOME LOCATION MAP

JOB NO. MV9700



LEGEND

SALT STRUCTURAL CONTOURS

STATE ROUTE

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-18

RAYBURNS DOME PROPERTY OWNERSHIP MAP

JOB NO. MV9700

exposed in outcrops east of the central saline marsh. The Midway Group and the Cane River and Sparta Formations are found as concentric outcrop bands surrounding most of the dome. Radial faulting has locally interrupted the continuity of the outcropping formations. The surface geology in the dome vicinity is illustrated in Figure 4-19.

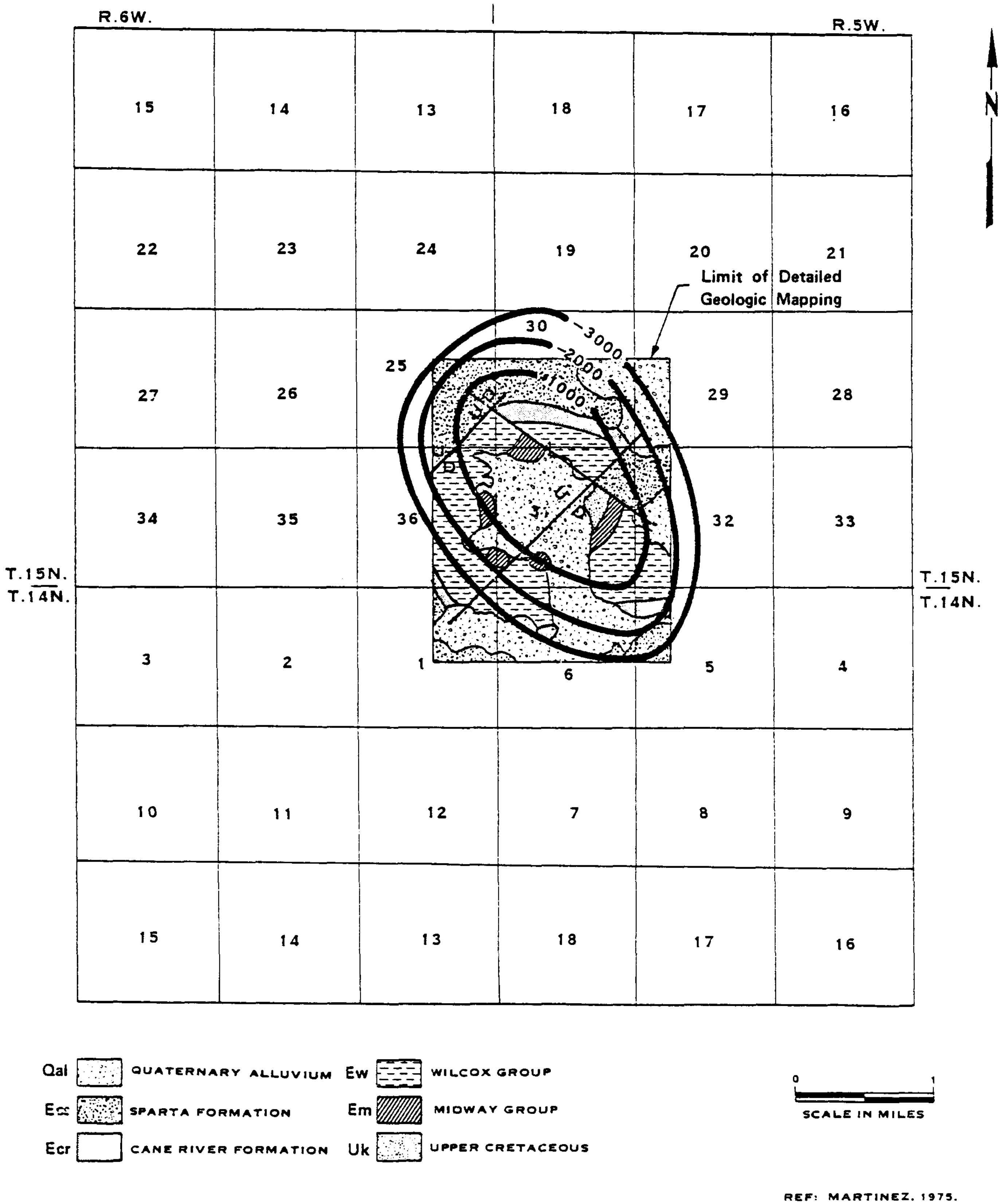
The general subsurface structure of Rayburn's is domal, dipping away in all directions. Seismic and well data indicate that the salt has penetrated sediments as young as the Wilcox Group. The Midway Group is thought to sheath the salt, but available data do not confirm the hypothesis. Figure 4-20 is a geologic cross section through the dome, illustrating subsurface structure.

Several oil and gas exploratory wells have been drilled on and around Rayburn's Dome; however, all were dry holes and subsequently were abandoned. The nearest petroleum production is located at the Danville Field, which is approximately 2 miles southwest of Rayburn's Dome. The Liberty Hill and Lucky Gas Fields are about 3.5 miles north and northwest of the dome's center.

An abandoned limestone quarry in the Saratoga Chalk is located over the dome. Brine was produced from the dome in the past, but solution mining was terminated prior to 1900. Potential for the development of sand and gravel deposits exists near the dome, but no producing pits or quarries have been identified. No other mineral resources are known to have been produced in the vicinity of the dome.

4.2.6 Richton Dome

Richton Dome is located in northern Perry County, about 15 miles east of Hattiesburg, Mississippi. The small town of Richton is located about 1.5 miles southeast of the center of the dome. The dome is located beneath the drainage divide between the valleys of Bogue Homo and Thompson Creek, tributaries of the Leaf River. Surface elevations on the dissected divide range between 290 and 160 feet over the dome. The dome is generally covered by by forest. The location of the dome and local topography are shown in Figure 4-21 and property ownership in Figure 4-22.



LEGEND

SALT STRUCTURAL CONTOURS

U/D FAULTS

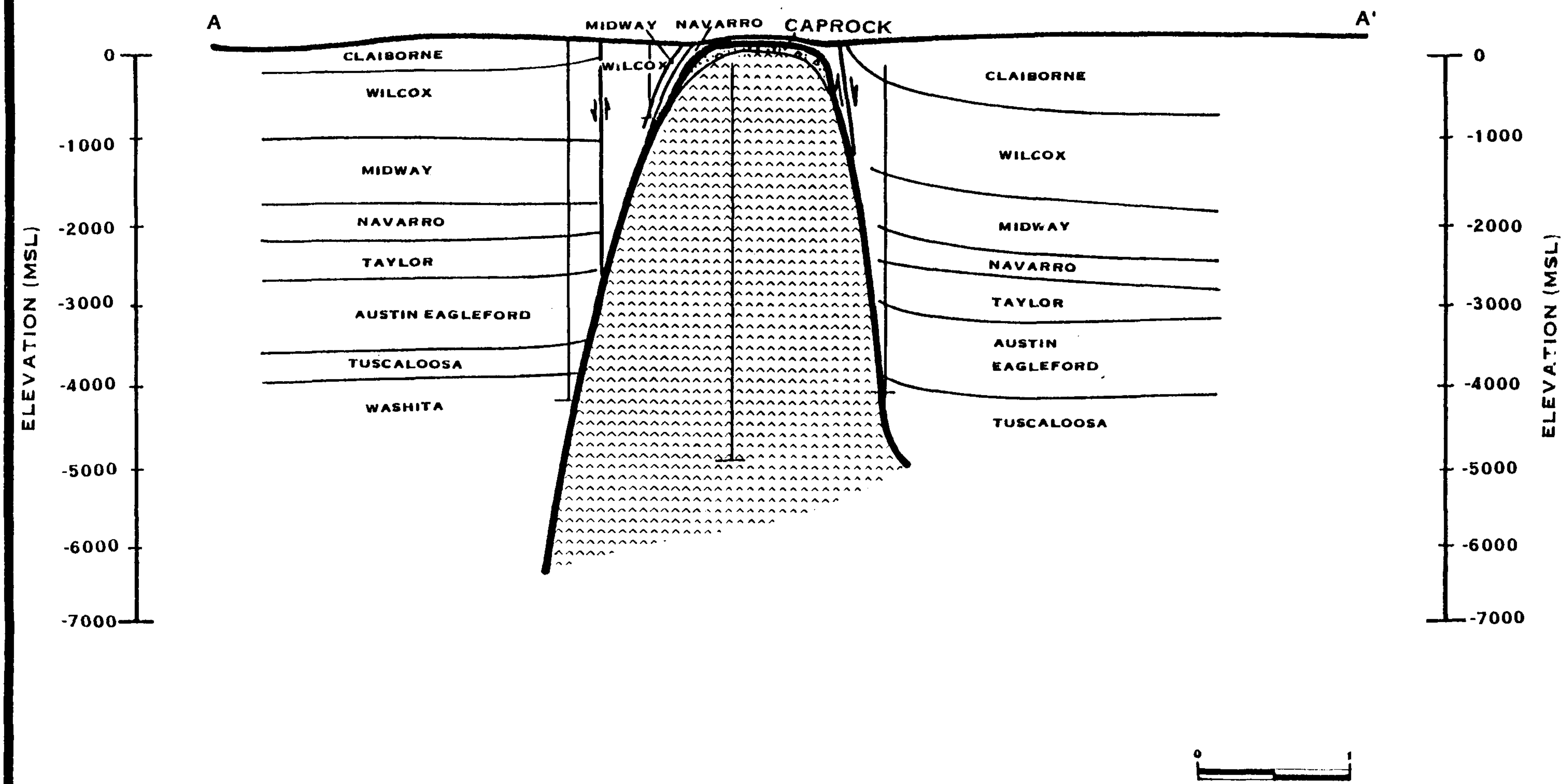
NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-19

RAYBURNS DOME SURFACE GEOLOGY

JOB NO. MV9700



NOTE: LOCATION OF CROSS SECTION IS SHOWN IN FIGURE 4-17

REF: MODIFIED AFTER MARTINEZ, 1975

LEGEND

FAULT

NATIONAL WASTE TERMINAL STORAGE PROGRAM

GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
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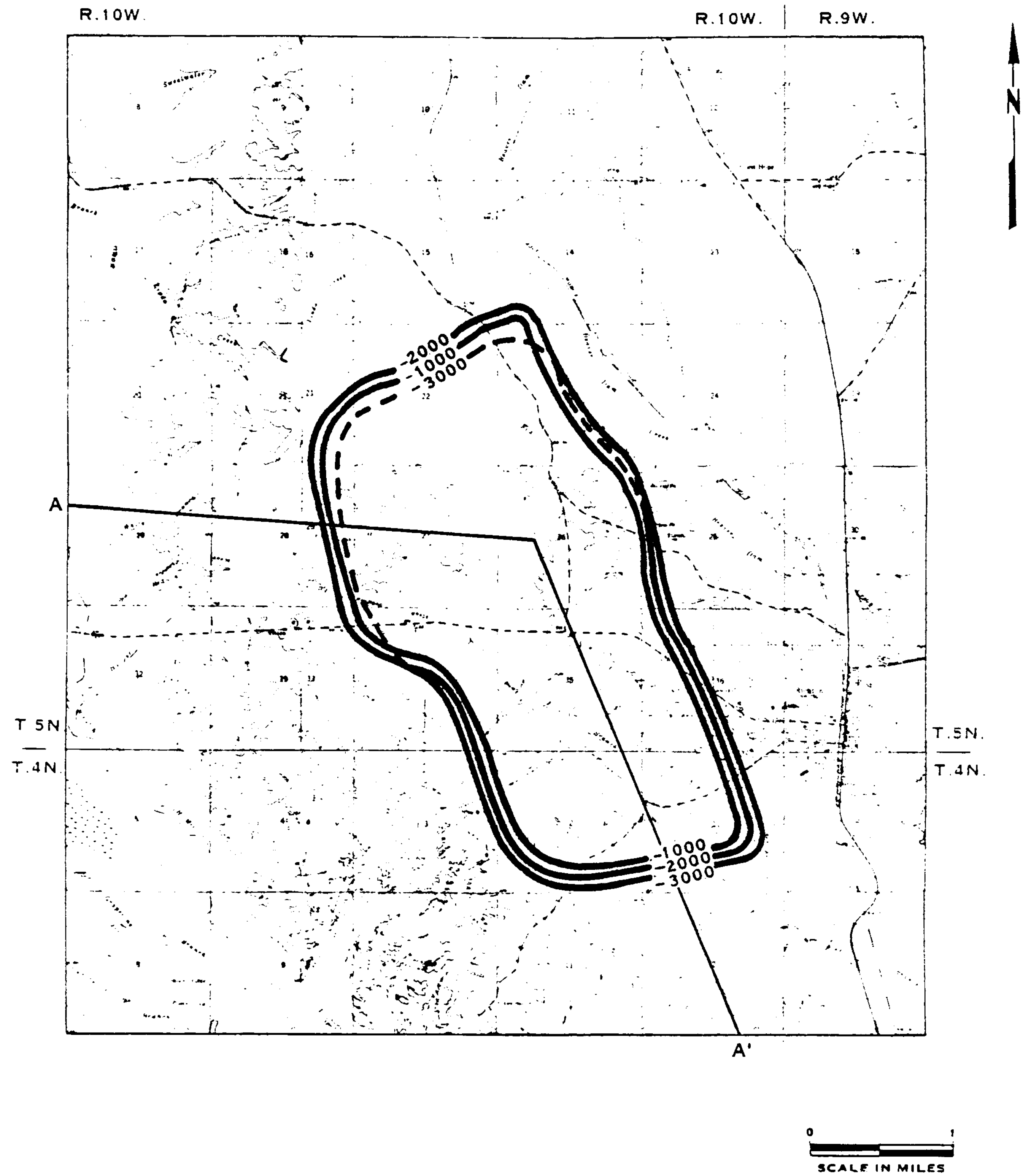
FIGURE 4-20

RAYBURNS DOME CROSS SECTION

JOB NO. MV9700



LEGEND

SALT STRUCTURAL CONTOURS

A A'

CROSS SECTION LOCATION

NATIONAL WASTE TERMINAL STORAGE PROGRAM

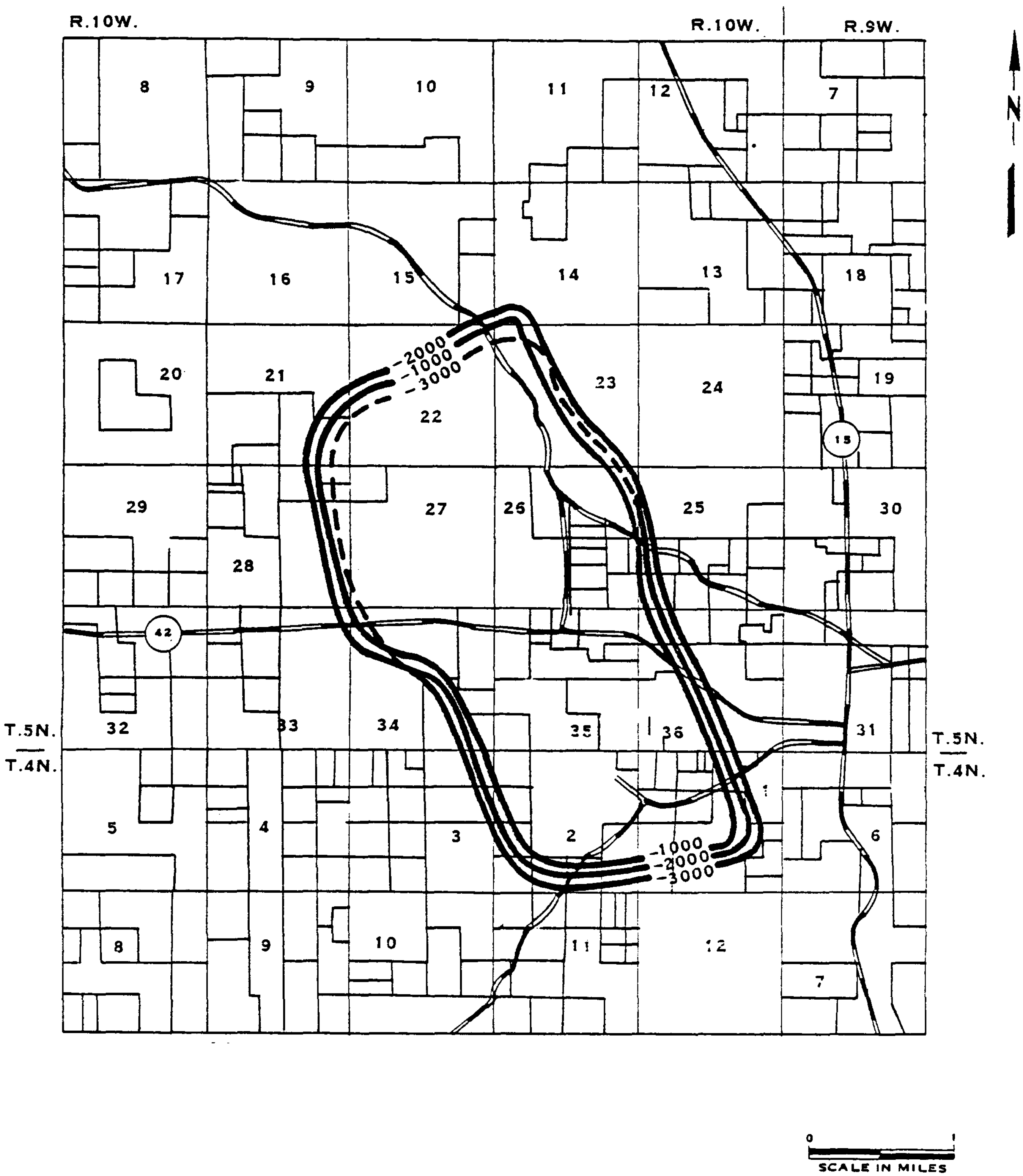
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-21

RICHTON DOME LOCATION MAP

JOB NO. MV9700



LEGEND

SALT STRUCTURAL CONTOURS

STATE ROUTE

NATIONAL WASTE TERMINAL STORAGE PROGRAM

GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-22

RICHTON DOME PROPERTY OWNERSHIP MAP

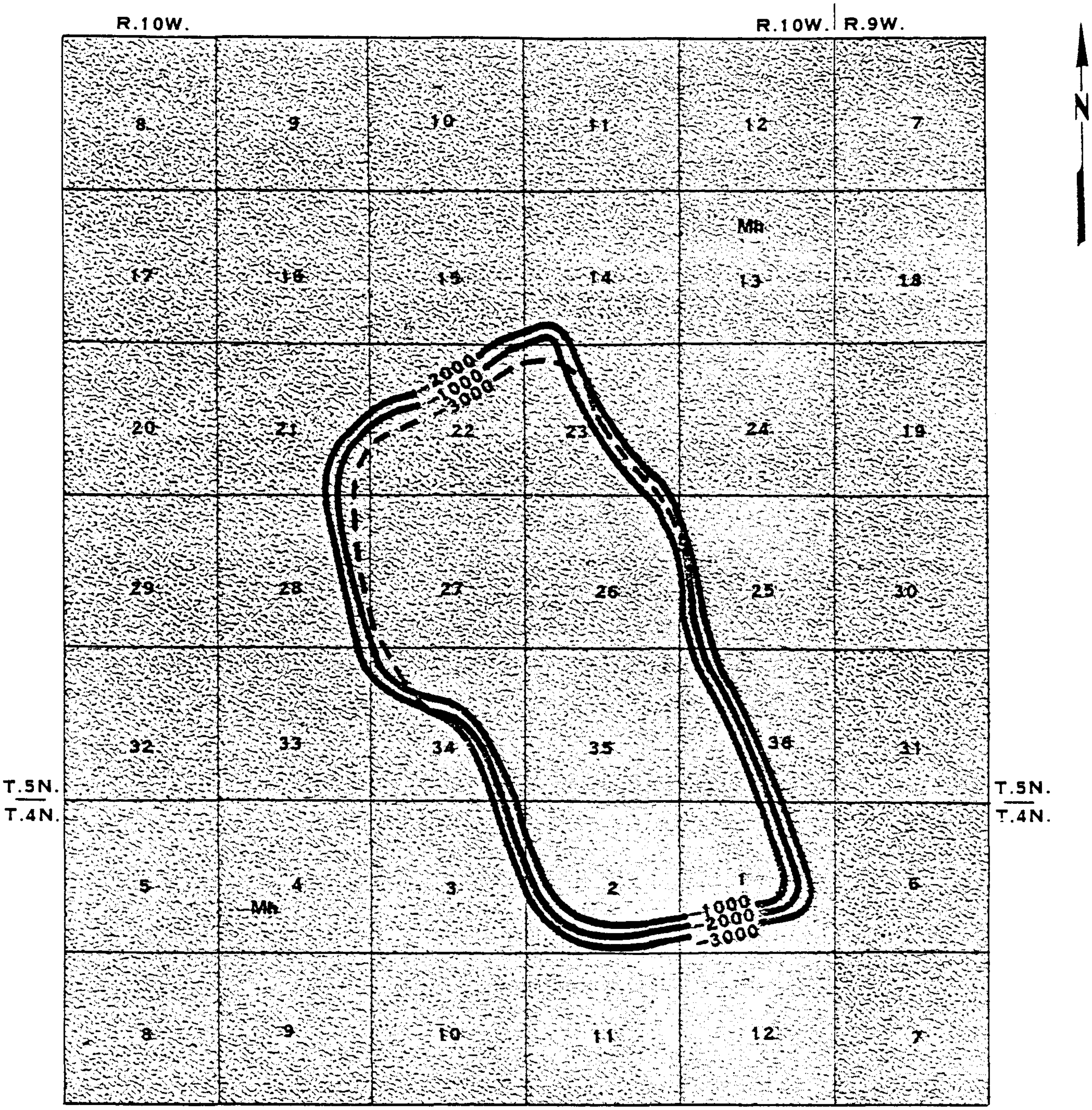
JOB NO. MV9700

The shallowest caprock and salt at Richton Dome were penetrated at depths of 497 and 722 feet, respectively. Richton was the location of extensive exploration for caprock sulfur deposits in the mid-1940s. Of 35 unsuccessful sulfur test wells drilled into the caprock, eight penetrated salt. Data from these wells and unsuccessful petroleum test wells located on the dome flanks show that the dome is relatively flat-topped, with an overhang on the northern end. Karges interpreted the configuration of the dome using the records of exploratory wells drilled over the dome[58]. The horizontal area of salt is 4,027 acres at a depth of 1,000 feet, 4,500 acres at 2,000 feet, and 4,275 acres at 3,000 feet, making Richton one of the largest of the shallow interior domes.

Published geologic maps show that the Miocene Hattiesburg Formation is exposed over the dome. Although no younger sediments have previously been mapped directly above the dome, Quaternary and Recent alluvial deposits associated with Bogue Homo and Thompson Creeks cross the western and eastern flanks. Figure 4-23 shows the generalized surface geology of the Richton area. Available well data describing the subsurface flank sediments are minimal, but the dome is interpreted to penetrate sediments as young as Eocene (the Zilpha Formation). Figure 4-24 presents a geologic section through the dome. Since data describing the sediments over the dome are not available from the majority of the sulfur test wells, no interpretation of shallow structural conditions over the dome has been made.

Investigation of the flanks of Richton Dome for petroleum has not identified significant quantities of petroleum in the uplifted strata. On the north flank of the dome, beneath the overhang, an oil show was reported in a 100-foot section of Lower Cretaceous sand. The sand, which is over 12,000 feet deep, was shown to be noncommercial by extensive testing. The well was subsequently abandoned[58]. The oil production area nearest the dome is the Tiger Field, located about 2.5 miles north-northwest. Production is also occurring from the flanks of Glazier Dome, which is about 2.7 miles south-southeast of Richton Dome.

The potential for caprock sulfur deposits at Richton Dome was investigated, unsuccessfully, in the late 1940s. Active and abandoned gravel pits are present over the dome, and a few sand and gravel clay pits are present over the flood plains of Bogue Homo and Thompson Creek. No other mineral resources have been identified or produced in the vicinity of the dome.



Mh HATTIESBURG FORMATION

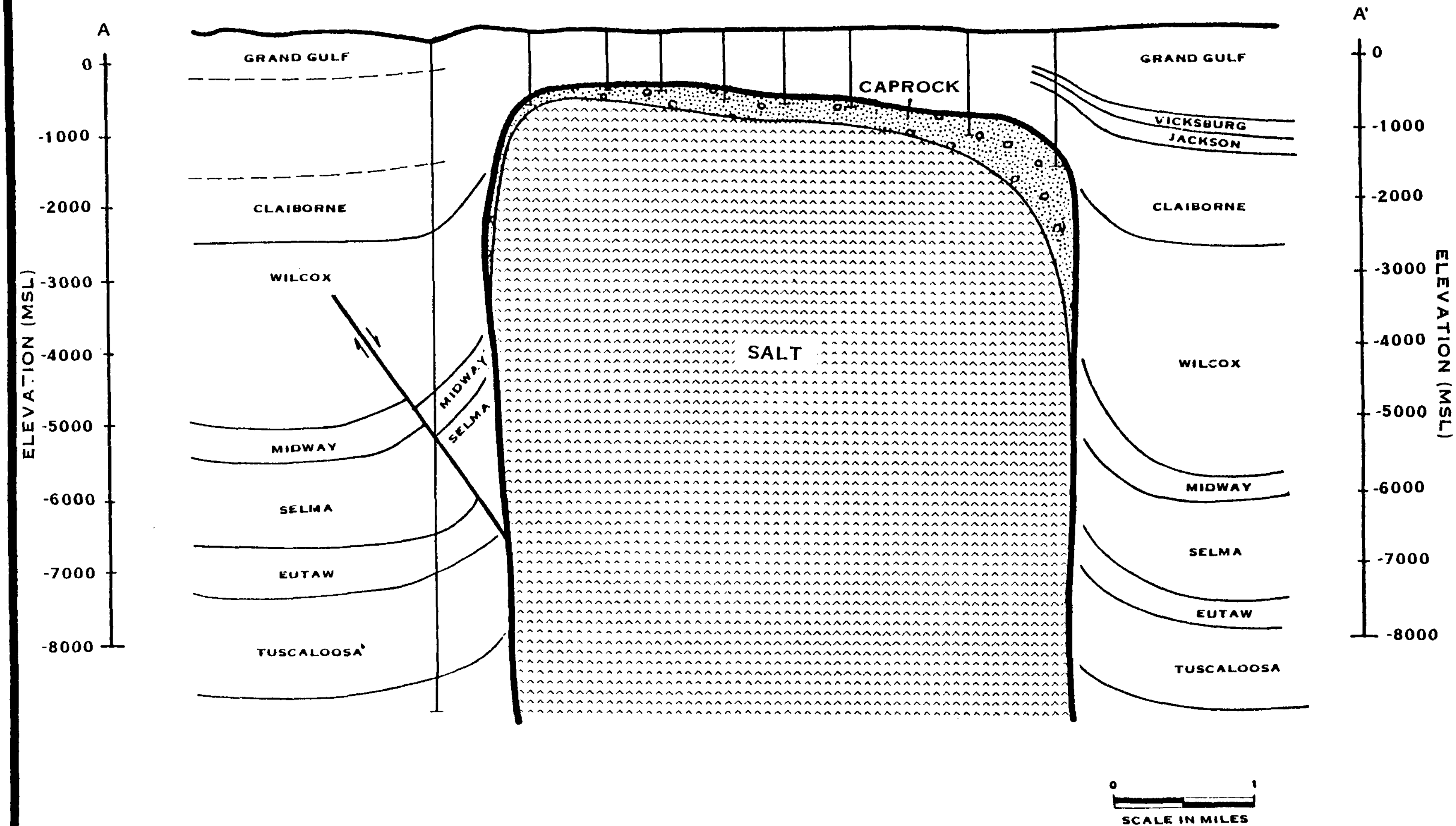
0 1
SCALE IN MILES

REF: FROM WATER FOR INDUSTRIAL DEVELOPMENT
U.S. GEOLOGICAL SURVEY AND MISSISSIPPI
RESEARCH DEVEL. CENTER, P.5, 1966.

NOTE: QUATERNARY TERRACE UNITS EXIST IN
DOME AREA BUT DETAILED MAPS ARE NOT
AVAILABLE AT TIME OF PUBLICATION

STRUCTURE CONTOURS FROM KARGES, 1975.

LEGEND	NATIONAL WASTE TERMINAL STORAGE PROGRAM	FIGURE 4-23
SALT STRUCTURAL CONTOURS	GEOLOGIC EVALUATION GULF COAST SALT DOMES LAW ENGINEERING TESTING COMPANY MARIETTA GEORGIA	RICHTON DOME SURFACE GEOLOGIC MAP JOB NO. MV9700



NOTE: LOCATION OF CROSS SECTION IS SHOWN ON FIGURE 4-21

NOTE: EXISTING EXPLORATORY WELLS ARE SHOWN

LEGEND

FAULT

NATIONAL WASTE TERMINAL STORAGE PROGRAM

GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

FIGURE 4-24

RICHTON DOME CROSS SECTION

JOB NO. MV9700

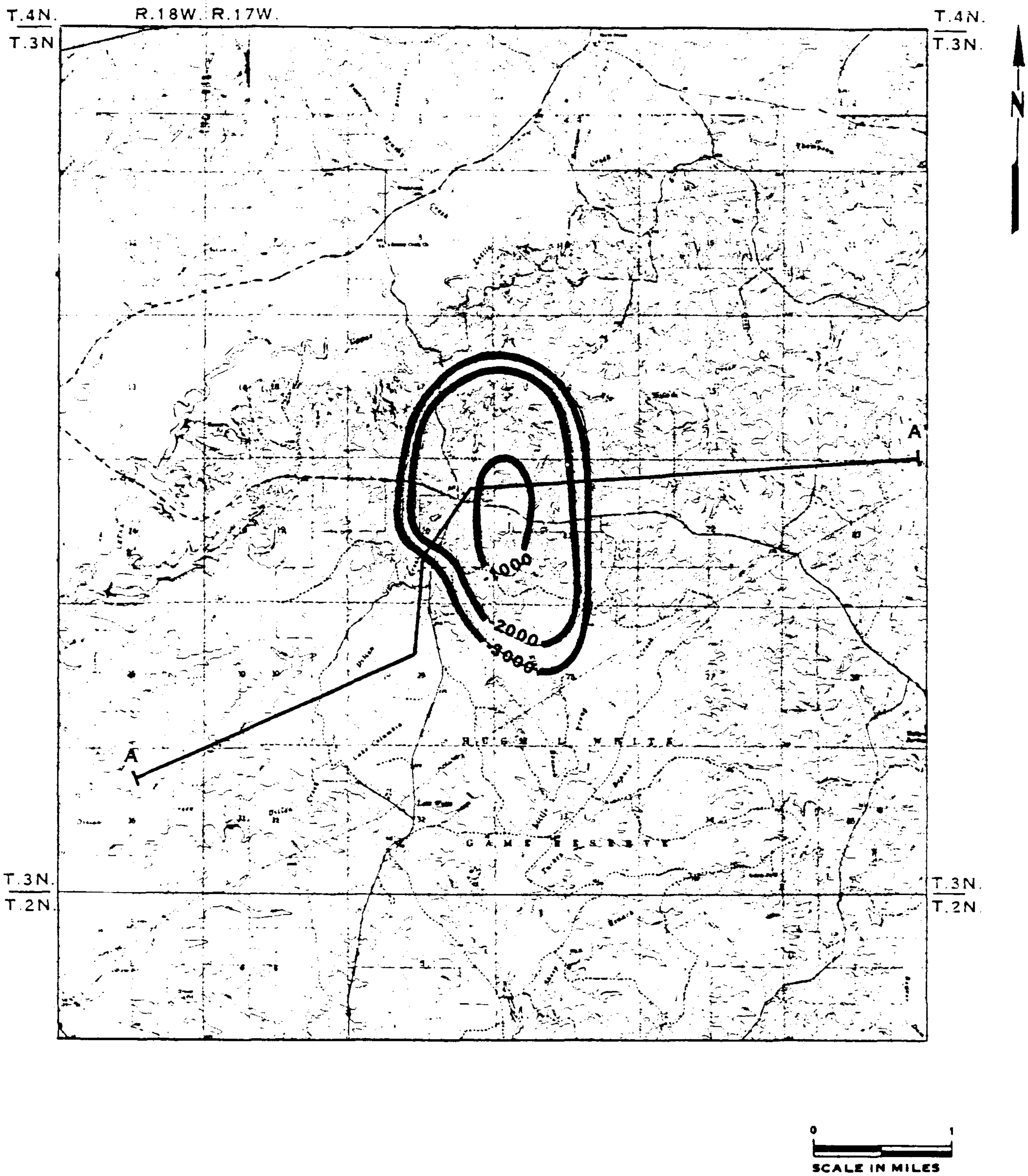
4.2.7 Lampton Dome

Lampton Dome is located in east-central Marion County, Mississippi. The dome is located 7 miles southeast of the city of Columbia, 2 miles northeast of Lake Columbia. The dome is located beneath an east-west trending, flat-topped ridge which divides drainage to Upper Little Creek and Lower Little Prong Creek, tributaries of the Pearl River. Elevations on the ridge vary from 370 to 200 feet. The southern portion of the dome lies beneath the Hugh L. White Game Reserve. With the exception of the cleared ridge crest, the area above Lampton Dome is forested. The dome's location and area topography are shown in Figure 4-25 and property ownership in Figure 4-26.

Of 16 unsuccessful sulfur and petroleum exploration wells drilled over the southern portion of the dome, ten wells encountered caprock and three of these were extended to penetrate into salt. The shallowest caprock and salt were penetrated at depths of 1,293 and 1,356 feet deep, respectively. Well and gravity data show the dome to be conically shaped with no overhang. The gravity data interpretation shows that the horizontal area of the salt is 168 acres at a depth of 1,000 feet, 1,040 acres at 2,000 feet, and 1,440 acres at 3,000 feet.

Surface geologic mapping shows that the Miocene Pascagoula and Hattiesburg Formations are the youngest geologic units exposed over much of the area beneath which Lampton Dome lies. The Plio-Pleistocene Citronelle Formation covers the higher hills east of the dome and may cap the ridge beneath which the dome lies. Minor Quaternary alluvial deposits associated with the tributaries of Upper Little Creek and Lower Little Prong Creek occur over the dome flanks. Figure 4-27 presents the generalized surface geology of the Lampton area.

Interpretation of the data available from the exploration wells indicates that the dome has penetrated in‿o the Eocene Claiborne Group. The basal sedimentary unit which is interpreted to cross the dome is the Miocene Catahoula Formation. The dome flanks are known from only a few wells that indicate steeply dipping bedding and diapiric clay in contact with the dome.



LEGEND

SALT STRUCTURAL CONTOURS

A A' CROSS SECTION LOCATION

NATIONAL WASTE TERMINAL STORAGE PROGRAM

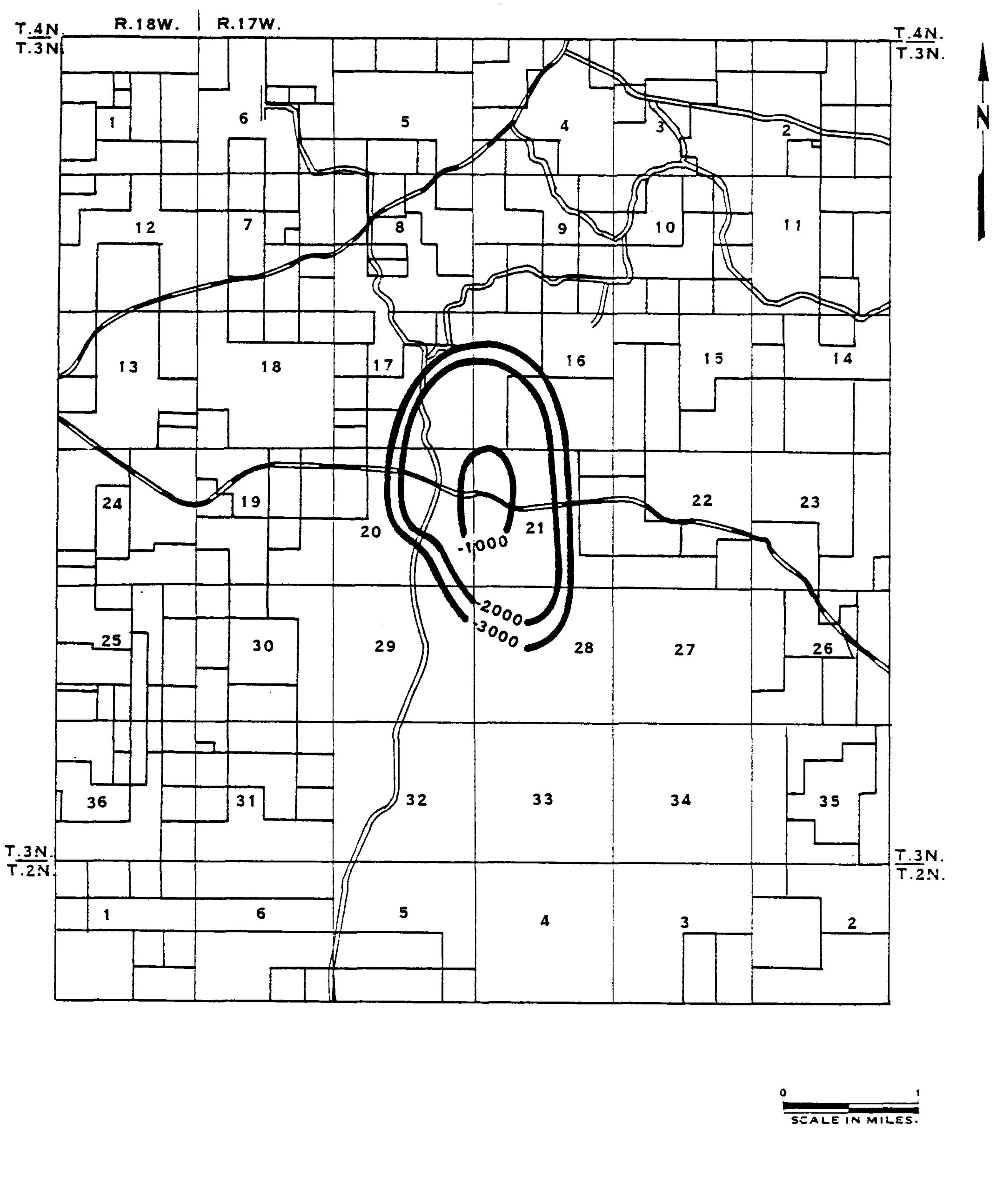
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-25

LAMPTON DOME LOCATION MAP

JOB NO. MV9700



LEGEND

SALT STRUCTURAL CONTOURS

PRIMARY ROAD

SECONDARY ROAD

NATIONAL WASTE TERMINAL STORAGE PROGRAM

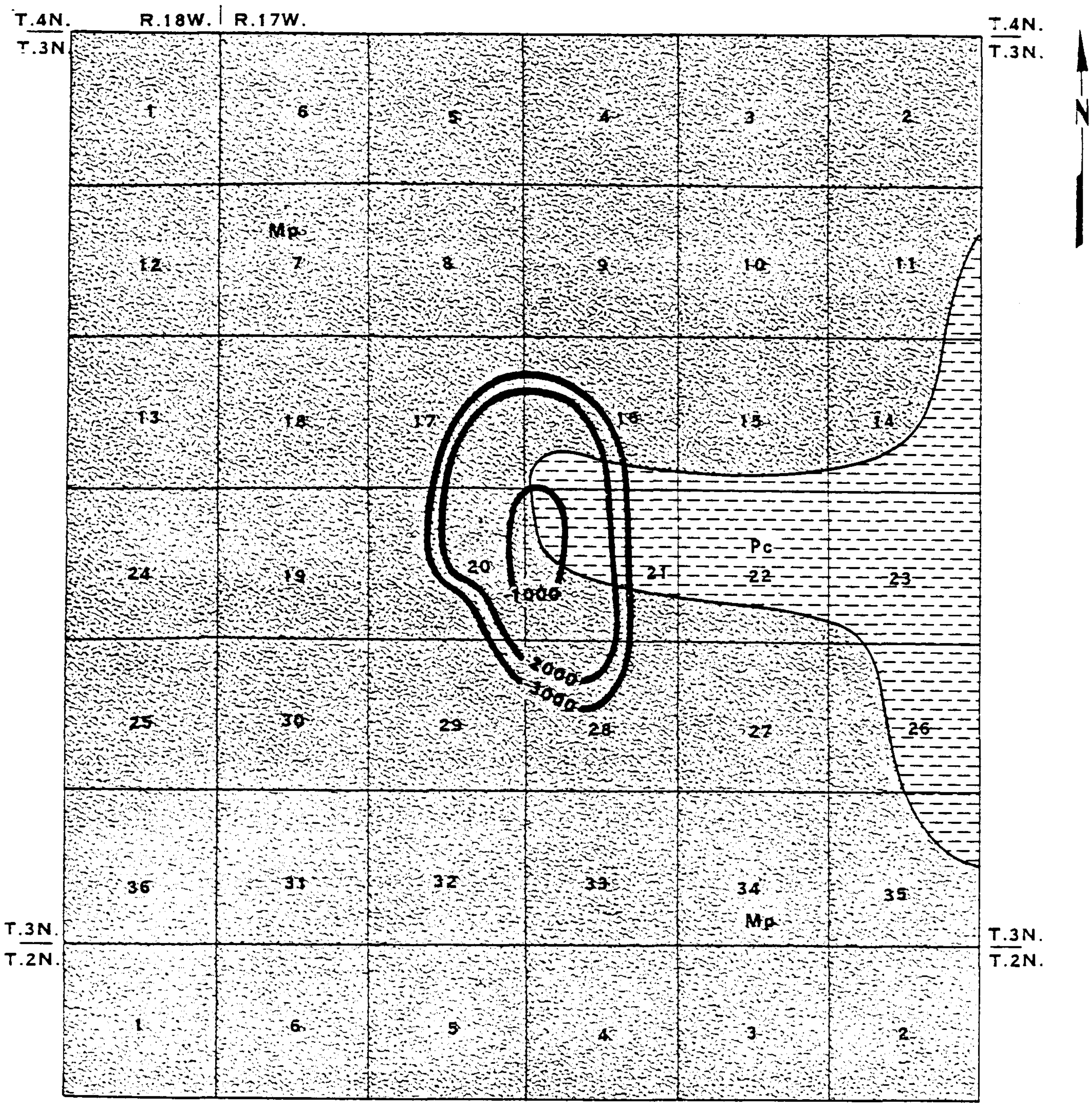
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-26

LAMPTON DOME PROPERTY OWNERSHIP MAP

JOB NO. MV9700



Pc CITRONELLE FORMATION

Mp PASCAGOULA/HATTIESBURG FORMATION

0 1
SCALE IN MILES

NOTE: QUATERNARY TERRACE UNITS EXIST IN DOME AREA BUT DETAILED MAPS ARE NOT AVAILABLE AT TIME OF PUBLICATION

REF: FROM WATER FOR INDUSTRIAL DEVELOPMENT, U.S.G.S. AND MISSISSIPPI RESEARCH DEVELOPMENT CENTER, P. 5, 1965.

LEGEND	NATIONAL WASTE TERMINAL STORAGE PROGRAM	FIGURE 4-27
SALT STRUCTURAL CONTOURS	GEOLOGIC EVALUATION GULF COAST SALT DOMES	LAMPTON DOME SURFACE GEOLOGY
	LAW ENGINEERING TESTING COMPANY MARIETTA GEORGIA	JOB NO. MV9700

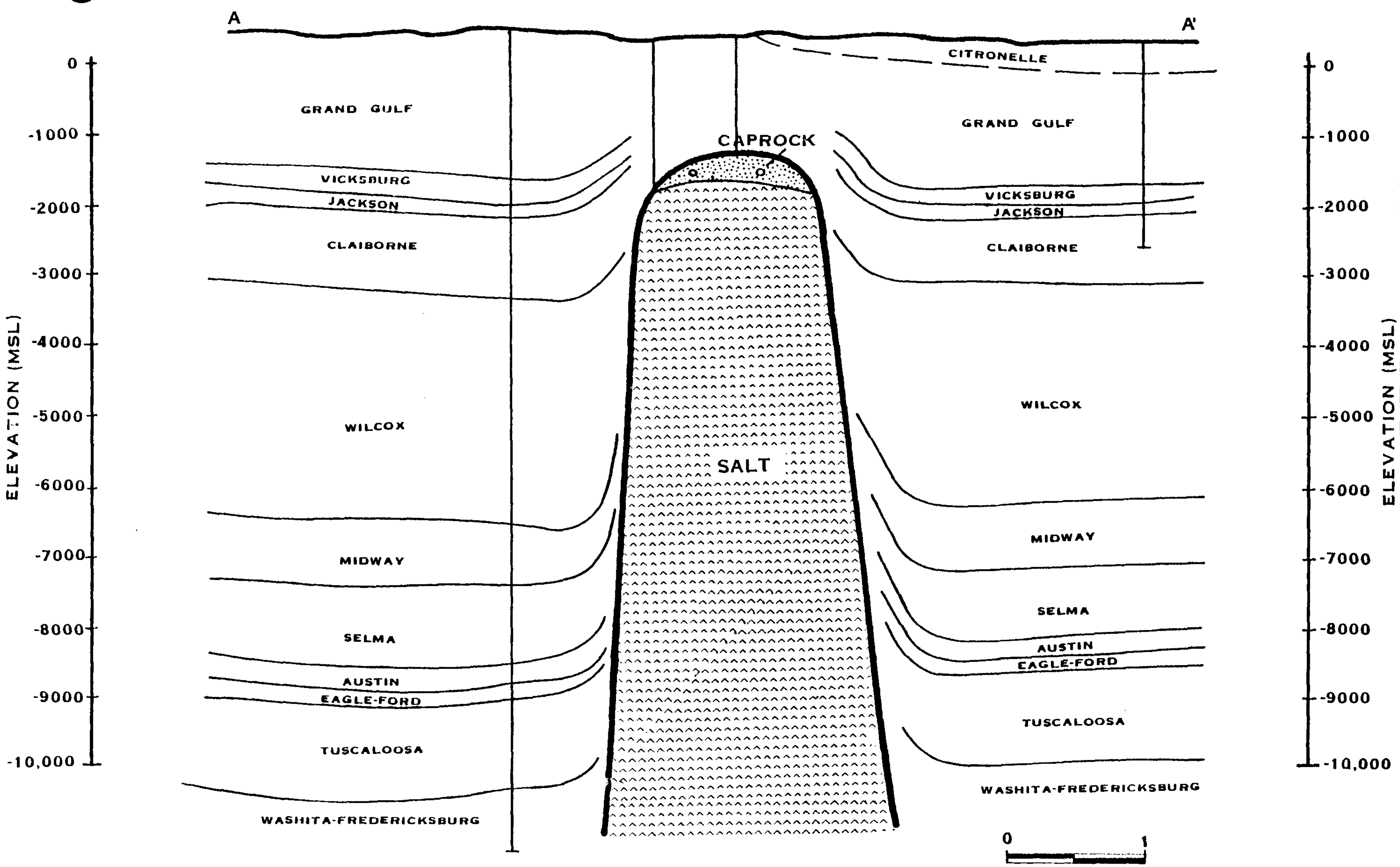
Figure 4-28 shows a geologic cross section through the dome. The oil- or gas-producing area nearest Lampton Dome is 4.5 miles southwest at Hub Field. Several exploratory wells have been drilled to investigate the petroleum potential of the dome's structure. None of these has been productive. Exploration in the 1940s for caprock sulfur deposits was also unsuccessful. No other mineral resources, with the exception of sand and gravel, have been produced in the vicinity of the dome.

4.2.8 Cypress Creek Dome

Cypress Creek Dome is located in central Perry County, Mississippi. The dome is centered about 4 miles south-southeast of the city of New Augusta, within the boundaries of the Camp Shelby Military Reservation. The dome lies beneath a broad swamp at the headwaters of Cypress Creek, which is a tributary of Black Creek and eventually drains into the Pascagoula River. Surface elevations over the dome vary from 180 feet at the point where Cypress Creek leaves the swamp to 290 feet on ridge tops east and west of the swamp. The swamp is mainly covered by shrubs and low ground cover, and the surrounding ridges are in pine forest. The dome's location and area topography are shown in Figure 4-29, and property ownership is shown in Figure 4-30.

Eight petroleum exploration wells have been drilled in the vicinity of Cypress Creek Dome, two in the mid-1930s and the remaining five since 1972. The earlier wells were drilled prior to knowledge of the existence of the dome. The recent wells, all drilled by Shell Oil Company, were drilled to test the structure on the flanks of the dome. Of these five wells, four have produced oil and gas, and three remain productive in mid-1978. Production has been from Clayton, Paluxy, and Hosston reservoirs at depths of about 8,100 and 13,000 feet beneath the overhang on the north flank. The overhang was penetrated by four wells; the shallowest salt was encountered at about 1,400 feet deep. Well and gravity data interpretation shows the horizontal area of the salt to be 2,200 acres at 1,000 feet deep, 2,850 acres at 2,000 feet, and 3,300 acres at 3,000 feet.

The swamp beneath which the dome lies is interpreted as surficial expression of the dome. Recent alluvial and colluvial materials occur at the surface in the swamp and along Cypress Creek. The Miocene Hattiesburg



NOTE: LOCATION OF CROSS SECTION IS SHOWN ON FIGURE 4-25

NATIONAL WASTE TERMINAL STORAGE PROGRAM

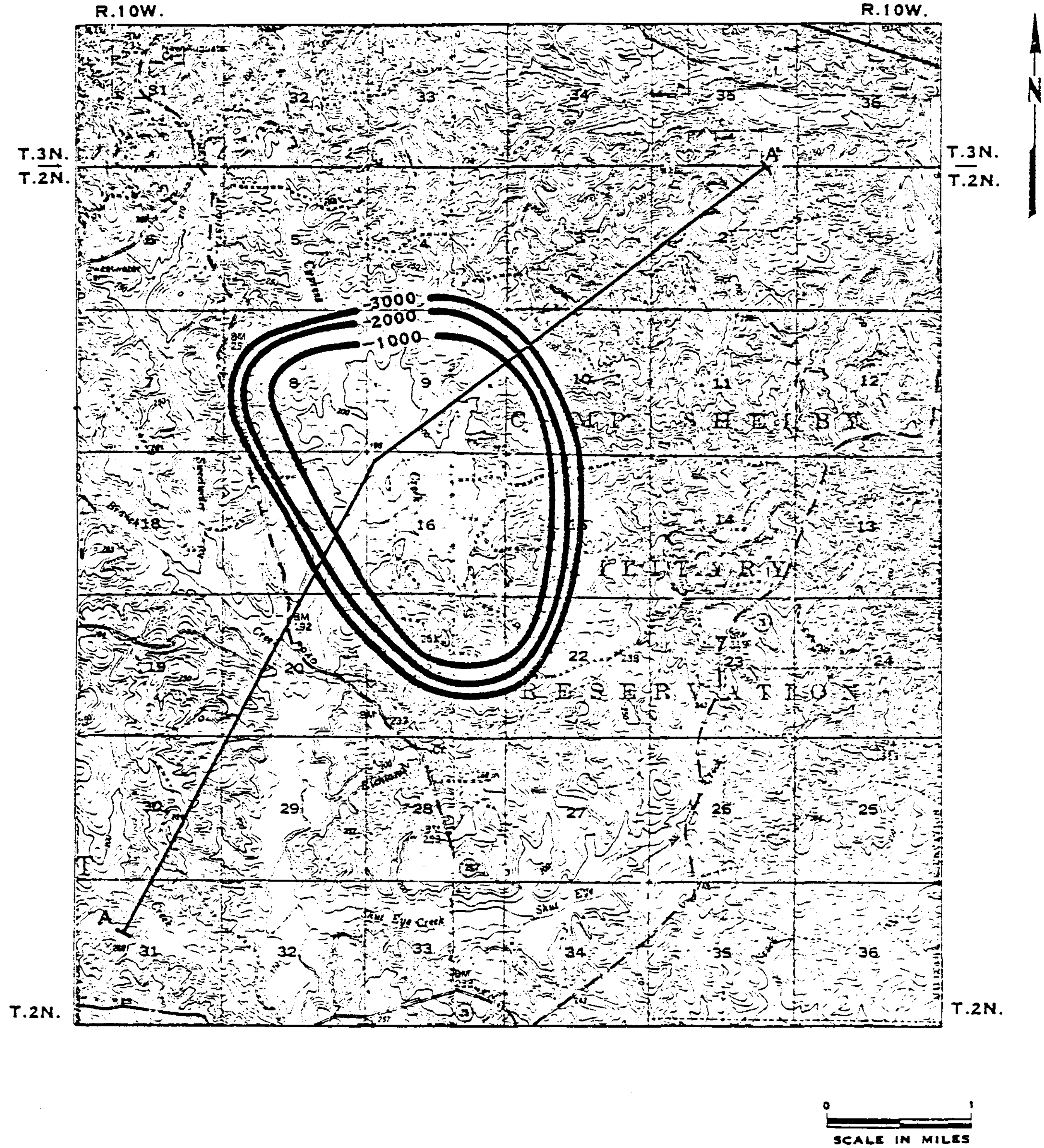
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

FIGURE 4-28

LAMPTON DOME CROSS SECTION

JOB NO. MV9700



LEGEND

SALT STRUCTURAL CONTOURS

A A' CROSS SECTION LOCATION

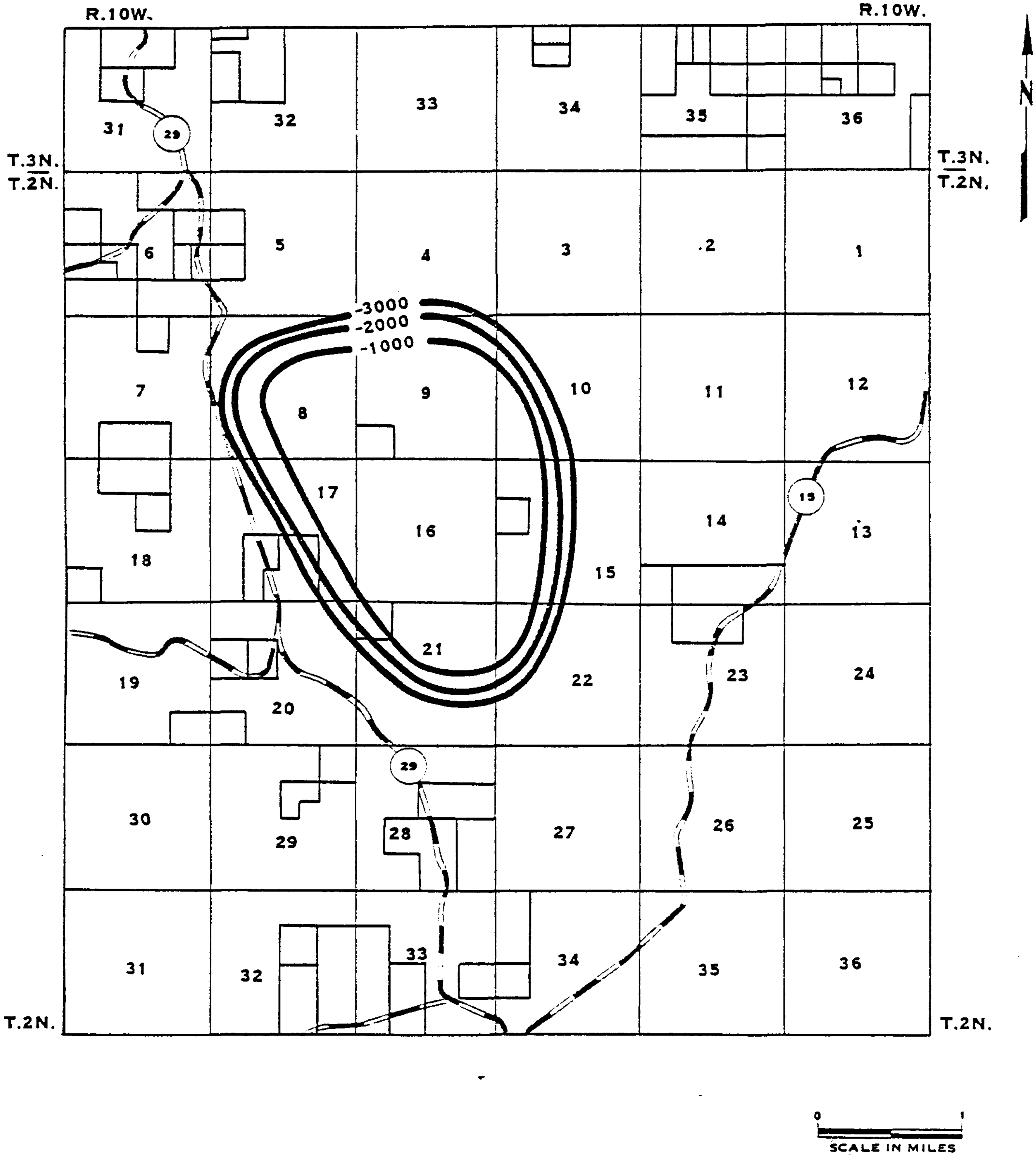
NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-29

CYPRESS CREEK DOME LOCATION MAP

JOB NO. MV9700



LEGEND

SALT STRUCTURAL CONTOURS

ROAD

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA GEORGIA

FIGURE 4-30

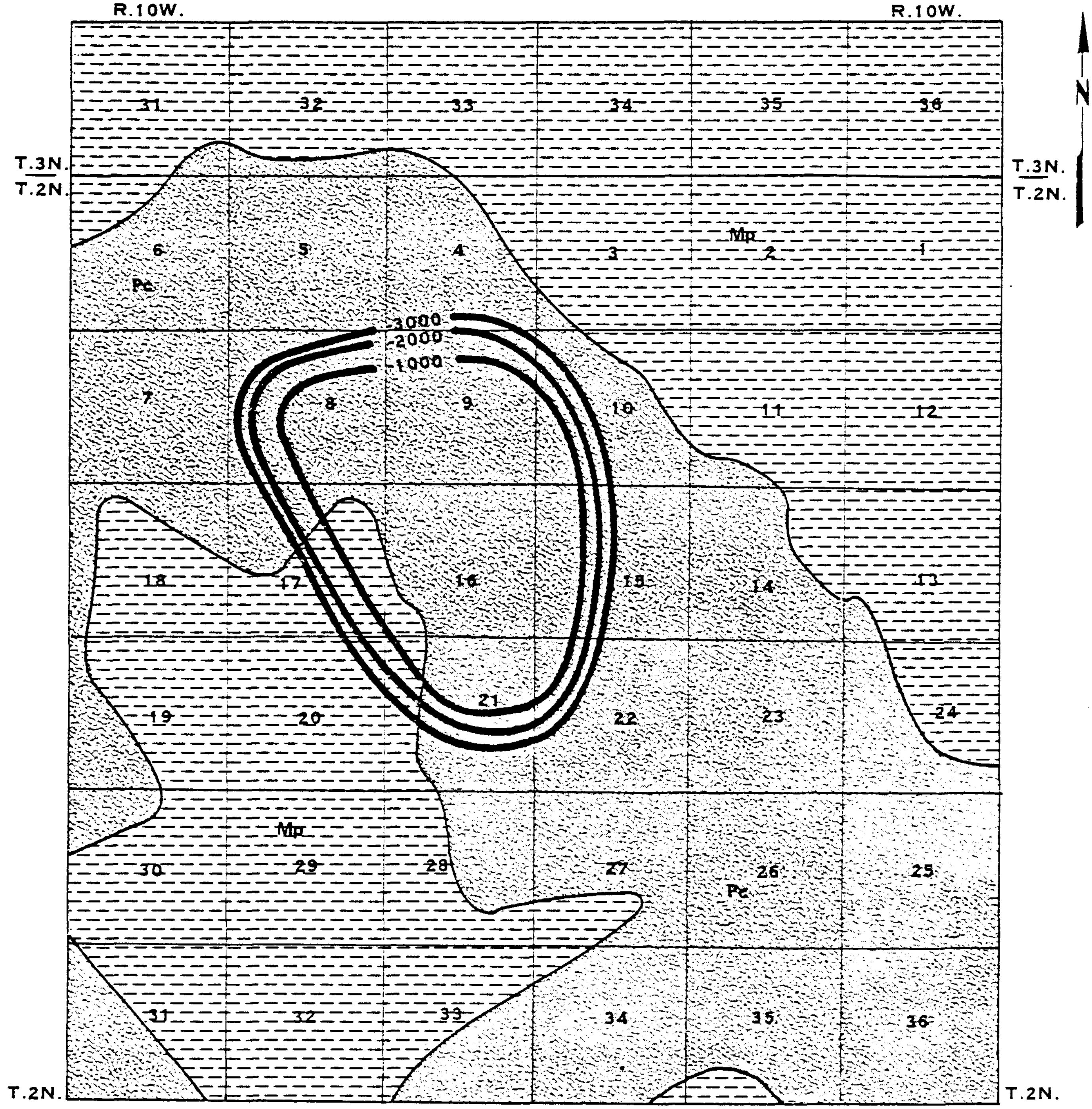
CYPRESS CREEK PROPERTY OWNERSHIP MAP

JOB NO. MV9700

and Pascagoula Formations (undifferentiated) lie immediately beneath the alluvium and, locally, at the surface. The Plio-Pleistocene Citronelle Formation caps the surrounding ridges. Figure 4-31 shows the general surface geology in the vicinity of the dome.

Well data indicate that subsurface sediments are highly faulted and upturned immediately adjacent to the dome. Available subsurface data are insufficient to describe these structures in detail or to determine which formations, if any, are continuous over the top of the dome. Figure 4-32 shows a geologic section through the dome.

Three of the four productive wells at the Camp Shelby Field are still producing oil and gas. The fifth well, which was not productive, was converted to a saltwater injection well. Production from this small field has been relatively minor. With the exception of these wells, the nearest production to the dome is located about 12 miles northwest, at Glazier Field. No other mineral resources, except sand and gravel, have been extracted in the vicinity of the dome.



Pc CITRONELLE FORMATION

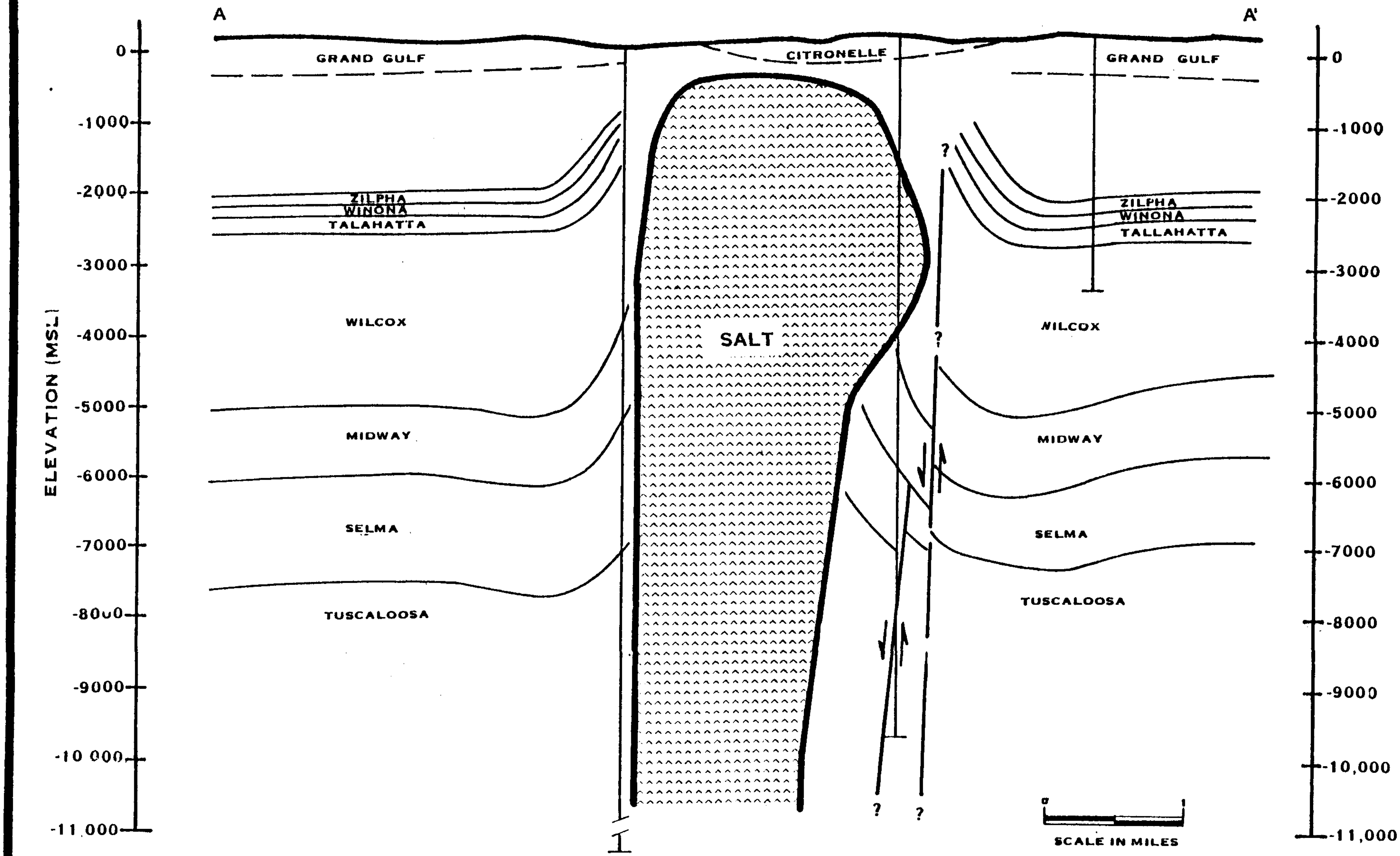
Mp PASCAGOULA/HATTIESBURG FORMATION

0 1
SCALE IN MILES

NOTE: QUATERNARY TERRACE UNITS EXIST IN DOME AREA BUT DETAILED MAPS ARE NOT AVAILABLE AT TIME OF PUBLICATION

REF: GEOLOGIC MAP OF MISSISSIPPI, MISSISSIPPI GEOLOGIC SURVEY, 1969.

LEGEND	NATIONAL WASTE TERMINAL STORAGE PROGRAM	FIGURE 4-31
SALT STRUCTURAL CONTOURS	GEOLOGIC EVALUATION GULF COAST SALT DOMES	CYPRESS CREEK DOME SURFACE GEOLOGY
	LAW ENGINEERING TESTING COMPANY MARIETTA GEORGIA	JOB NO. MV9700



NOTE: LOCATION OF CROSS SECTION IS SHOWN ON FIGURE 4-29

NOTE: EXISTING EXPLORATORY WELLS ARE SHOWN

LEGEND

FAULT

NATIONAL WASTE TERMINAL STORAGE PROGRAM
GEOLOGIC EVALUATION GULF COAST SALT DOMES

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

FIGURE 4-32

CYPRESS CREEK SALT DOME CROSS SECTION

JOB NO. MV9700

5 PROGRAM PLAN

5.1 INTRODUCTION

The identification of a potential repository site in salt is progressing with parallel efforts in several areas of the continental United States, one of which is the interior salt domes of the Gulf Coast Region. The Program Plan presented in this section is designed to provide sufficient information within the available time and budget to allow selection and recommendation of a smaller number of candidate domes for further evaluation.

5.2 PROGRAM PLAN METHODOLOGY

The Gulf Coast Salt Dome project is intended to provide sufficient data from potential sites in the three interior Gulf Coast Salt Dome basins to ultimately allow identification of an acceptable repository site. The geologic studies must determine:

1. The overall character of the Gulf Coast Region
2. The general character of an identified area within each salt dome basin
3. The characteristics of the domes identified as having the greatest potential as repository sites.

During the characterization studies, research and evaluation of geologic characteristics are being conducted by a number of organizations. These organizations include the Bureau of Economic Geology of the University of Texas (TBEG), the Institute for Environmental Studies - Louisiana State University (LSU-IES), the University of Southern Mississippi (USM), and the U.S. Geological Survey (USGS).

Geologic investigation studies are planned for the area characterization and subsequent phases of this program. These investigations and studies will be designed to identify those geologic and hydrologic factors which affect the present and projected behavior of candidate salt domes. The investigations and studies are designed to determine:

1. The general geologic and hydrologic character of the three interior salt dome basins
2. Geologic and hydrologic characterization of specific candidate domes
3. The geometry of candidate salt domes
4. The character of the interface between the candidate domes and the surrounding sediments
5. The interaction of near-dome and regional hydrologic conditions, and its relationship to candidate domes
6. The geologic development of salt domes in interior basins and predictions of their future behavior
7. The seismic characteristics of the region, and the effects of present and predicted seismicity on a repository
8. The characteristics of the salt stock at candidate domes and the interaction of the dome with intended repository concepts and operations
9. The potential surface and subsurface factors which may produce changes during the life of a repository.

The level of detailed knowledge of study areas and candidate domes is not uniform, since some areas of domes have received several years of scrutiny while relatively little detail is known of other potential areas and domes. In order to evaluate candidate domes on a more uniform basis, immediate emphasis will be placed on improving the understanding of those study domes of which the least is presently known.

It is recognized that pertinent information obtained as the program progresses may suggest or require a need for modification of the Program Plan. Interpretations of data acquired by LSU-IES, TBEG, USM, and USGS will influence such modifications.

5.2.1 Geologic Characterization

The purpose of the geologic characterization is to determine the general geologic and hydrologic characteristics of the three interior salt dome basins. This includes an evaluation of whether the host rock within the basin:

1. Has the minimum thickness and lateral extent necessary for containment
2. Occurs at an adequate depth for containment and to allow repository construction
3. Is located in an area where tectonic and seismic activities are within acceptable limits
4. Has acceptable hydrologic characteristics
5. Does not contain significant valuable mineral resources.

The regional geologic characterization consists of identifying study areas of approximately 1,000 square miles which will include potential repository sites with the above generalized criteria.

5.2.2 Area Geologic Characterization

The Area Characterization phase is directed toward a more detailed understanding of the geologic structure and stratigraphy, surface and ground-water hydrology, and the seismic characteristics of an area of approximately 1,000 square miles, with an emphasis on the immediate vicinity of candidate salt domes. Area Characterization studies will define the geologic and hydrologic properties of the study area in sufficient detail to allow comparison of geologic and hydrologic characteristics of the area with more localized features associated with specific salt domes. The studies will include additional compilation and evaluation of available data from oil and gas exploration and production operations, including well logs, cuttings and cores, geophysical surveys, and review of state records of injection and disposal wells. Additional data will be gathered, including shallow and deep borings, gravity measurements, seismic surveys, geologic mapping, and surface and subsurface water quality sampling and analyses.

Conclusions drawn from the area study evaluations will be used to compare the domes in the study areas for their suitability for more detailed location studies. The most promising domes will then be selected for comprehensive investigations and evaluations to determine their suitability as a repository site.

5.2.3 Detailed Dome Characterization

Those domes chosen for further studies will be subjected to a more detailed evaluation of the geology and hydrology of the area surrounding the dome. These studies will include acquisition of new data by additional borings for stratigraphic information, measurement of hydrologic properties of aquifers, and water quality analyses. Seismic reflection and refraction surveys will be made to more accurately define the dome geometry and the structure and stratigraphy of sediments which contact it. Gravity modeling of the salt stock will be refined as additional data are obtained.

Further investigation and evaluation of the geohydrologic characteristics of a larger area will continue since schedule and budgetary constraints will not allow an evaluation adequate for site qualification during the earliest phases of the program. Evaluation of the results of the further studies will be used to determine the suitability of each dome for development as a repository and as a basis to recommend a single dome for more detailed confirmation studies which will develop the required level of detail for preparing licensing documents.

During all phases of this study, it is possible that adverse geologic findings may eliminate any dome from further consideration. Similarly, adverse environmental findings may require that a dome be eliminated. The deferral of a dome during any phase of the studies, however, does not necessarily imply that the dome is unsuitable. Rather, it would only mean that available data at that time indicate that one or more other domes appear to have more favorable characteristics.

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APPENDIX A

LETTERS OF COMMENT ON THE DRAFT REPORT

COMMENTS TO THE DRAFT REPORT

DATE	COMMENTS BY
March 30, 1978	Bureau of Economic Geology, University of Texas
April 27, 1978	U.S. Department of the Interior, Geological Survey
June 15, 1978	Air and Pollution Control Commission, State of Mississippi
June 16, 1978	Texas Parks and Wildlife Department
June 21, 1978	Texas Department of Water Resources
July 10, 1978	Mississippi Power and Light Company
August 8, 1978	Honorable Roy Blake, State Senator, Texas
August 28, 1978	City of Natchitoches, Louisiana
November 8, 1978	University of Southern Mississippi

THE UNIVERSITY OF TEXAS AT AUSTIN
BUREAU OF ECONOMIC GEOLOGY
AUSTIN, TEXAS 78712

University Station, Box X
Phone 512—471-1534

March 30, 1978

Mr. James G. LaBastie
Law Engineering Testing Company
2749 Delk Road, S.E.
Marietta, GA 30067

Dear Jim:

Attached are editorial remarks which the Bureau of Economic Geology recommends for the report — "Geologic Evaluation of Gulf Coast Salt Domes." In addition we note that the bar scales on the maps do not agree with the actual map scale (especially comparing bar scales against section lines in LA and MS). Look forward to meeting with you on April 7.

Sincerely yours,

E. G. Wermund
Associate Director

EGW/gc

Attachments

4) Relations between the aquifers and domes,

5) Water quality in the aquifers,

6) Local ground water flow,

7) Regional ground water flow,

8) Relations between ground water and surface water.

Law Engineering Testing Company (LETCo) was selected as the Geologic Project Manager for the Gulf Coast Salt Dome Project as of July 8, 1977. The responsibilities of LETCo are:

from the candidate domes recommended by the Bureau of Economic Geology, LSU-IES, and the Mississippi scientific contractor,

1) To ~~identify,~~ qualify, rank, and recommend salt dome repository sites to OWI by September 30, 1979,

2) To coordinate the exploration activities of the other participants (LSU-IES, Texas Bureau of Economy Geology; and the USGS) ~~so that their work is done in the most time and cost efficient manner,~~

3) To coordinate the exchange of data and interpretations among all the participants,

4) To assist in obtaining ~~obtain~~ right-of-entry for field activities by all the participants,

5) To identify any gaps which may exist in the exploratory program and to insure that those gaps are filled,

6) To provide necessary field services to all the participants, either directly or by sub-subcontracting.

The initial tasks of LETCo have included a review of the published literature and an assessment of the existing studies relating to the project. LETCo has developed a program plan of activities which is to be performed during the ensuing 18-months to achieve the stated objectives of the program.

The roles of LSU-IES and Texas Bureau of Economic Geology (TBEG) are to act as principal scientific and technical investigators for Louisiana and Texas, respectively, and to conduct certain field and laboratory work related to the evaluation of specific domes as repository sites. The USGS will conduct regional (basin-wide) hydrologic studies in each of the three basins. DOE is expected to provide the necessary public affairs activities in all three states so that both state officials and the general public are informed of the progress of the project. In summary, LETCo will evaluate the above input toward selection of two repository sites in the Gulf Coast region.

2.0 OVERALL ASSESSMENT

2.1 TECTONIC STABILITY

Investigations for nuclear power plant sites in Texas, Louisiana and Mississippi in the past decade have carefully considered the tectonic stability and seismic activity of the region, an aspect not emphasized previously. The northern Gulf coastal plain appears tectonically stable, having been subject only to epeirogenic movements, mainly downward, since the Late Triassic. Block faulting during the Late Triassic, when the Gulf Basin formed, was the last major tectonic activity ~~of note~~. Igneous activity occurred then and subsequently in the Late Cretaceous. Regional faulting, terrace uplift, and seismicity are discussed in greater detail below.

2.1.1 Surface Faulting

Regional faults within the coastal plain sediments are related to hinge-lines or flexures, on the periphery of the Gulf Basin and above the boundaries of the subregional crustal blocks and growth faults within the basin. Hinge-line or flexure faults farther inland, such as the Pickens–Quitman–Gilbertown–Pollard trend, the Mount Enterprise fault zone, etc. displace the youngest Tertiary surface sediments along the faults, but the literature does not include specific reports on their relationships to the Late Cenozoic terrace deposits. Even though basement faults are reported beneath some of these trends, the shallow faults may result from hinge-line stresses rather than recurrent movement of possible underlying basement faults. In addition, growth faults due to sedimentary instability are common in the thick geosynclinal sediments. Although displacement on the growth faults ceases when the unstable shelf-edge environment builds farther gulfward, some faults show evidence of recurrent movement to Recent time. The Baton Rouge fault system on the south side of the Hancock ridge is currently actively moving, Nettleton. Kupfer also investigated the interior structure of salt domes and concluded that the salt plug moved as a series of spines separated by shear zones (6).

Gussow challenged the theories of salt dome movement described above and proposed a ~~heat driven mechanism paralleling current thinking on igneous extrusive phenomena (7).~~

2.2.2 Growth History Studies

The relationships between dome movement (growth) and other geologic processes (such as basin sedimentation) have been used to deduce the kinetic stability of domes. Stratigraphic studies, structural studies, caprock studies and studies of the interior structure of salt domes have been used to infer the history of domal growth.

The bulk of the stratigraphic studies to date have been carried out by LSU-IES in contract with OWI for the North Louisiana Basin (8, 9, 10). Dr. Ralph Kehle of the University of Texas has studied domes in the Northeast Texas Basin (ref.). Both investigators use stratigraphic data to deduce the volume of salt which has moved per unit of time. This approach requires stratigraphic information both in the immediate vicinity of the dome and in the basin beyond the dome. LSU-IES has primarily utilized existing drilling for stratigraphic data while Kehle has primarily used existing seismic reflection. LSU-IES estimates 0.2 mm/yr. vertical movement rate for Vacherie salt dome in mid-Cretaceous, .02 mm/yr. in late Cretaceous and cessation of salt movement about 30 million years ago.

Netherland, Sewell and Assoc., Inc. studied the rates of movement of six domes in the Northeast Texas Basin (11). They relied on structural data measuring the amount of local uplift a formation showed in the vicinity of a dome. Their results can be summarized as: 1) dome movement stopped sometime after Wilcox time (lower Eocene - Upper undergoing little or no dissolution are referred to as hydrologically stable while those that are considered to be rapidly dissolving are referred to as hydrologically unstable. There have been no quantitative criteria established by which a dome may be classified as either stable or unstable. The lack of criteria for hydrologic stability is due, at least in part, to a lack of knowledge of the ground water flow pattern adjacent to domes.

Ground water flow patterns near domes are expected to be extremely complex and become better understood only after a comprehensive test drilling program that would include lithologic sampling, geophysical logging, water sampling, potentiometric mapping and test pumping (18). In a general sense, the ground water flow patterns are expected to be determined by the geometry of the dome and by the hydrologic and geometric properties of the aquifers penetrated by the dome. Although the rate of transfer of salt to the ground water system is thought to be most strongly influenced by the ground water flow system, transfer of the salt to the ground water is also considered to be controlled by the water-salt solution rate and by the potential presence of a layer of anhydrite or shale next to the salt (11).

It has been suggested that evidence of salt dome dissolution might be obtained by examining the ground water down gradient of domes (8). It is hypothesized that active dissolution would be indicated by the presence of elevated salt concentrations in the ground water in the vicinity of a dome. The higher concentrations would be expected to form an elongated pattern in the direction of ground water flow. Such a situation is referred to as a salt plume. There have been no systematic water quality studies conducted to determine if dissolved solids from domes are present in the ground water surrounding the domes. An unpublished report by Wesselman noted an adverse effect on the quality of ground water in the vicinity of domes in Ft. Bend County, Texas (19). There is a possibility that the deterioration of ground water quality in the area of South Texas is related to oil field operations or other factors not associated with dissolutioning.

Wesselman J. B., 1972, Ground-water resources of Fort Bend County, Texas; Tex. Water Dev. Board, Report 155, 176 p.

3.2 DOME COMPLIANCE

Anderson, et al., determined that the total number of Gulf coast salt domes to be screened was 263. These domes were divided according to the subprovince of the Gulf coast in which they were located. The coastal subprovince contains approximately 144 salt domes. The interior subprovince contains approximately 119 salt domes; 80 of which are in the Mississippi Basin, 20 are in the Northeast Texas Basin, and 19 are in the North Louisiana Basin.

The salt domes of the coastal subprovince were eliminated from consideration in previous screening processes by Anderson, et al., and Netherland, Sewell and Associates based on a general consensus of geologic opinion on the relative instability and structural complexity of the coastal domes (2,3,4). In addition, many coastal domes are exploited for their abundant mineral resources (salt, brine, oil and gas).

Table 3-1 lists the 125 salt domes located in the interior subprovince and the South Texas Basin. These domes were used in the initial screening process. Of these domes, 116 were eliminated based on the dome size, repository depth and cover, and dome utilization criteria given in the OWI Screening Draft Specifications. From the remaining nine potential domes, two domes from each basin with the greatest potential for repository siting were chosen. The selection of the candidate domes from each basin was based primarily on the areal extent of the dome at the repository level and the depth to top of salt. These domes are: Richton dome and Lampton dome in the Mississippi Basin; Vacherie dome and Rayburns dome in the North Louisiana Basin; and Mt. Sylvan dome and Palestine dome in the Northeast Texas Basin. ~~These~~ Six domes will be the focal point of the extensive investigations which are discussed in detail in The Program Plan sections of this report.

Insert X

Table 3-2 lists the salt domes in each basin in order of greatest potential based on applicable screening specifications. The table indicates that the top three salt domes in the interior subprovince are Vacherie salt dome in the North Louisiana Basin, Richton salt dome in the Mississippi Basin, and Mount Sylvan salt dome in the Northeast Texas Basin.

3.3 DOME DESCRIPTION

The salt domes which have been selected from each of the three interior salt dome basins appear to have the greatest potential for development as repositories.

The domes selected in Texas, Mt. Sylvan and Palestine, represent two domes which are sufficiently large for repository development, however the character of the domes and their previous usage contrast. TBEG will complete a selection of study of domes in March 1978. At that time the rationale for dome selection will be coordinated and study dome selections finalized.

[illegible] to [illegible] p. 3-2

The two domes in North Louisiana, Vacherie and Rayburns, have been selected for study by LSU-IES. The application of the OWI draft screening criteria to North Louisiana domes confirms the ranking of Vacherie and Rayburns.

The following discussion includes descriptions of each of the six candidate domes and the area which surrounds it. The dome location, topography and current land-use are briefly described. In addition, dome configuration, surface and subsurface geologic conditions, and the past, present and projected development of mineral resources in the dome vicinity are addressed.

3.3.1 Mt. Sylvan Dome

Mt. Sylvan dome is located in northeast Smith County, 6.4 miles west-northwest of Tyler, Texas. The small rural community of Chandler is 5 miles south of the dome and the community of Mt. Sylvan is 4 miles northwest. ~~Several homesites are~~ A ranchette development is located over ~~and near~~ the dome. The land is currently used for livestock grazing and agriculture. The location of the dome is shown in Figure 3-1 and abstract surveys are shown on Figure 3-2.

The dome is ~~not well~~ defined topographically~~, however, it is surrounded~~ by a rim of hills. Prairie Creek flows southwest through the low central area of the dome into the Neches River. Relief across the dome is on the order of 70 to 80 feet.

The salt at Mt. Sylvan dome extends to within 380 feet of the surface. Caprock has been encountered in only one well on the eastern flank of the dome. It was encountered at 650 feet. From gravity and well data, Mt. Sylvan dome is interpreted to be cylindrical in shape with a slight bulge between elevations (-) 5000 to (-) 6000 feet MSL. The dome has a slight overhang in a southwest direction and is canted towards the southwest. The estimated horizontal area is 730 acres at 1000 feet deep, 1820 acres at 2000 feet, and 2310 acres at 3000 feet.

The surface formations over the dome belong to the Eocene Claiborne group which includes the Queen City, Weches and Sparta formations (5). Recent alluvium associated with Prairie Creek occupies the floodplain which is approximately 1/2 to 3/4 of a mile in width. Over the dome and extending south there is a small saline prairie and marsh that has been reported to include minor salt springs.

Surface sediments exhibit no pronounced structural discordance as the result of dome growth and are relatively flat-lying. The Wilcox group, a major freshwater aquifer,

TABLE 3-1

LISTING OF ALL DOMES
APPLICATION OF DOME SCREENING CONSIDERATIONS
OVERALL ASSESSMENT
GULF COAST SALT DOME STUDY

NORTHEAST AND SOUTH TEXAS BASINS[1]

NO.	DOME	POTENTIALLY ACCEPTABLE	REASON FOR REJECTION	DEPTH TO SALT (ft)	DEPTH TO SALT VERIFIED BY WELL DRILLED INTO SALT	AREA OF SALT (acres/depth)	LPG STORAGE	PETROLEUM PRODUCTION WITHIN 2.5 MI RADIUS OF DOME CENTER	BRINE PRODUCTION OR SALT MINE Curr.	Past	[illegible]
1	Bullard	no	Too small	100	yes	360 @ 3000'	no	no			x
2	Palestine	yes	--	120	yes	1330 [illegible] @ 2000'	no	no		x	
3	Brooks	no	Lake	200	yes	2000 @ 1000'	no	no			x
4	Grand Saline	no	Brine production	210	yes	2496 @ 340'	no	no	x		
5	Steen	no	Too small	300	yes	885 @ 3000'	no	yes			x
6	Butler	no	LPG storage, too small	312	yes	500 @ 312'	yes	no			x
7	Whitehouse	no	Too small	400	yes	660 @ 2000'	no	no			x
8	Keechi	no	Too small	400	yes	1100 @ 2000'	no	no			x
9*	Palangana	no	Brine & sulfur prod.	500	yes	n/a	no	yes	x**	x	
10	Mt. Sylvan	yes	--	613	yes	1830 @ 2000'	no	yes			x
11*	Gyp Hill	no	Too small	831	yes	364 @ 2000'	no	yes			x
12	East Tyler	no	LPG storage	890	yes	1424 @ 1000'	yes	no			x
13	Oakwood	yes	--	900	yes	2100 @ 3000'	no	yes			x
14	Hainesville	no	LPG storage	1100	yes	3200 @ 3000'	yes	yes			x
15*	Piedras Pintas	no	Petroleum production	1150	yes	1000 @ 2000'	no	yes			x
16	Bethel	no	Too small	1300	yes	640 @ 1150'	no	yes			x
17	Boggy Creek	yes	--	2000	yes	2800 @ 3000'	no	yes			x
18	Day	no	Too deep	2153	yes	n/a	yes	no			x
19	Brushy Creek	no	Too deep	3570	yes	1498 @ 3570'	no	yes			x
20	Kittrell	no	Too deep	3855	yes	990 @ 3183'	no	yes			x
21	LaRue	no	Too deep	4450	yes	2995 @ 4450'	no	yes			x
22	Concord	no	Too small & too deep	5994	yes	992 @ 6000'	no	yes			x
23*	Moca	no	Too deep	6366	yes	n/a	no	yes			x
24*	Dilworth Ranch	no	Too deep	7643	yes	n/a	no	yes			x
25	Elkhart	no	Too deep	10165	yes	n/a	no	yes			x
26*	Pescadito	no	Too deep	14030	yes	n/a	no	no			x

Abandoned brining, Lake

is larger ~ 1700 @ 3000'

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* South Texas Basin Domes

** Sulfur

[1] At each Texas dome, a depth below top of salt is shown for stated area.

4.0 PROGRAM PLAN

4.1 INTRODUCTION

The schedule of the National Waste Terminal Storage Program of the Department of Energy (DOE) requires that an operating repository be available by 1985. Due to licensing and construction time requirements, site selection must be made by the end of 1979. Although the interior salt domes of the Gulf coast region are only one of several geologic formations under consideration, the Geologic Project Manager (GPM) of the Gulf Coast Salt Domes Project has the primary responsibility for recommending candidate sites from this region to DOE for their final selection. The Program Plan presented in this section is designed to provide sufficient information within the available time and budget to allow selection and recommendation of candidate sites in accordance with DOE's required schedule.

Louisiana State University, Institute for Environmental Studies (LSU-IES) and the Texas Bureau of Economic Geology, University of Texas (TBEG), have been selected as the principal scientific and technical investigatory organizations to locate candidate domes in their respective states. The U.S. Geological Survey (USGS) has ~~the primary~~ responsibility ies for hydrologic studies in Texas, Louisiana, and Mississippi. Law Engineering Testing Company (LETCo) as the GPM has been assigned primary responsibility for recommendation of candidate sites from the entire region by the end of 1979, coordination of exchange of data, interpretations, and information between all participants as well as other activities.

The level of detailed knowledge of potential candidate domes is not uniform, since LSU-IES has conducted detailed studies of selected domes, while little detail is known of other potential candidate domes. In order to evaluate candidate domes on a more uniform basis, emphasis will be placed on improving the understanding of those domes for which the least is presently known.

4.2.1 Dome Internal Structure and Petrology

It is well known that salt domes contain complex structures and discontinuities which affect the operation of mines. LSU-IES has identified the internal structure of salt domes as an important study effort for 1978. LETCo recognizes the importance of the LSU-IES studies and the impact their findings may have on dome selection. These studies will have a bearing on all domes, therefore, they will require coordination and response by all principal investigators.

The planned studies of dome interiors involve the inspection and mapping of as many salt dome mines as is practicable. In addition to these observations, physical and chemical properties of selected features will be determined. The objectives of these studies will be to document the occurrence of discontinuities and correlate such discontinuities with physical properties.

The LSU-IES studies will include as many domes as are accessible. LETCo will support and supplement these studies by attempting to gain access to additional domes through LETCo's consultants. ~~In addition the TBEG will assist in these studies and utilize their potential access privileges to increase the domes available for study.~~

The petrology of domes will be studied using samples available from the mine inspections and core obtained from the specific domes studied. The petrology studies will include the caprock, caprock-salt transition zone, and the internal salt. These studies will be a continuing effort, depending on sample availability, during the site selection program.

In addition to mine samples, a salt core boring will be made at each of the study domes during 1978. Core samples from these borings will provide specific salt characteristics at selected domes for correlation with other data obtained from mines. During 1979 two additional salt core borings will be made at each of the primary domes.

United States Department of the Interior

GEOLOGICAL SURVEY
RESTON, VIRGINIA 22092

April 27, 1978

In Reply Refer To:
Mail Stop 410

R. B. Laughon
Project Manager
Office of Waste Isolation
Union Carbide Corporation, Nuclear Div.
P. O. Box Y
Oak Ridge, Tennessee 37830

Dear Bob:

As requested we have reviewed the draft copy of the report, "Geologic Evaluation of Gulf Coast Salt Domes, Site Selection Program Plan," prepared by Law Engineering and Testing Company (LETCO). The report is a relatively brief summation of previous authors' findings including selected excerpts which the authors felt appropriate. Unfortunately, little interpretation and evaluation by the authors is apparent and the conclusions of previous investigators is accepted or cited without comment. We believe that, as geologic project managers of this work, it would have been useful for LETCO to have presented their own interpretations and evaluations, including: arguments supporting and contravening the conclusions presented; a critical evaluation of the adequacy of available information; identification and ranking of problems to be addressed; and a detailed plan to accomplish the individual pieces of work in a realistic time frame.

Our response to the questions posed in your transmittal letter follow.

1. The general procedure of selecting study areas seems reasonable. However, selection of candidate domes from each basin, based primarily on the real extent of the dome at the repository level and the depth to the top of salt, leaves most geologic evaluation criteria and screening specifications unanswered. The adequacy of the program plan and the time frame for evaluating the many unknowns is discussed in # 4 & 5 below. The following comments pertain to the geoloic evaluation criteria and screening specifications:

> #4, 1st sentence - "The rate and amount of predictable regional uplift..." Predictable for what time frame--250,000 years? Is this possible? If there are not Quaternary or Recent sediments in which uplift might be observed, how will this be determined? Episodic uplift or differential movement of spines following periods of prolonged quiessence cannot be eliminated at this time and pose a major problem in predicting uplift.

#5 - What reasoning leads to limiting faults to three miles from the center of a candidate dome? Why are the faults of concern only regional tectonic faults? Shear zones bounding salt spines along which differential movement has occurred are also faults of very direct concern. They occur within a dome and imply episodic movement and may provide avenues of water movement to the surface.

#7 - The presence of a shale envelope effectively isolating a dome from the tertiary aquifers will require extensive exploration.. Also, demonstration that such an envelope is an effective water seal will be difficult or may be impossible. Collapse features in the caprock and overlying tertiary sediments are vertually proof positive of past dissolution of salt, and the presence of saline springs at the surface may well indicate that dissolutioning of salt is occurring at the present time.

#10 & 11 - Not everybody is convinced that salt is a suitable host rock for a repository. Not all of these questions pertaining to dome salt have been resolved and can only be answered with additional information.

#14 - The storage or disposal of excavated salt will have to be addressed, particularly in this humid climate with abundant rainfall.

#15 - What is significant oil production? Significant industrial use?

#16 - "Salt domes under bodies of surface water should be avoided." Duggey's Lake overlies Palestine dome. Therefore, does Palestine dome meet this screening criteria? Are streams considered bodies of surface water? If so, Rayburns dome, Vacherie dome, and Mt. Sylvan dome would not seem to meet this criteria.

2. In Mississippi we would have picked Richton dome to study first, but Lampton dome would not have been our second choice.

3. We are not aware that LETCO has ignored or misused available data. They have assumed that proposed studies will resolve favorably generic and site-specific questions pertaining to the utility of salt domes. For example, they assume that the inland domes were emplaced in such a manner that eposdoc movement of salt spines bounded by shear zones may not ave occurred in these domes. Reasons for this assumption are not given and are not readily apparent. They propose to study these features. The adequacy of the proposed study and time available for resolution of this problem is not apparent in the proposed schedule.

4. The program plan for the further evaluation of the study domes is constrained by a time frame that is generally perceived to be unrealistic. In our opinion the money unknowns at potential candidate domes cannot be evaluated adequately to permit meaningful site selection by the end of 1979. LETCO recognizes that even the basic generic problems such as internal structure, erosion and denudation, salt dissolution mechanisms, and geomechanics have yet to be resolved. The program plan outlines studies of these problems but does not present sufficient detail about the proposed work to provide any basis for an expectation of their early resolution. A primary deficiency of the report is the lack of detail describing proposed methods of investigation and evaluation. This pertains particulary to proposed methods of determining hydrologic stability. Numerical flow and transport modeling is proposed but the data required for this purpose are not identified and procedures for acquiring the necessary data are extremely sketchy and incomplete. Furthermore, it is not apparent that the number of borings or test wells is adequate to accomplish what is proposed. The test hole arrays shown in figures 4-1 thru 4-12 will not provide information on the areas immediately adjacent to the domes, one of the areas in which information is vital. The 12,500 feet of drilling assigned to each basin for the purpose of acquiring data on the regional hydrology appears arbitrary and unrelated to the need in the individual basins.

5. The program plan does not cover all of the squares. Caprock, although locally impervious, invariably contains fractures and solution openings through which water circulates. In our opinion understanding of the caprock hydrology is essential to any meaningful evaluation of a dome. The program plan does not identify caprock hydrology as a significant item of study and does not mention any studies to determine the hydrology of caprock at the various domes. We also believe that the hydrology of the area immediately adjacent to the domes is important and, as noted above, is not provided for in the array of test holes proposed. The Nacatoch Sand appears to abut the flanks of both Vacherie and Rayburns domes and it must be determined whether or not hydraulic connection exists between this zone and permeable zones in the caprock. Also, at some domes unconsolidated anhydrite sands extend for thousands of feet down the flanks of the dome and may provide vertical hydraulic connection between numerous aquifers and the caprock. Thus, the hydrology of the area immediately surrounding a dome must be thoroughly evaluated.

6. In Table 1-3, the description of "general water-bearing properties" of the Reklaw Formation should be changed to show that the Reklaw Formation is considered to be a confining unit where it is present in the Northeast Texas Salt Dome Basin.

7. References 1-12 and 2-18 should be deleted from this report. The report, "Geohydrologic Aspects of the Storage of Radioactive Waste in North Louisiana Salt Domes", by R. L. Hosman has not been released

to the Open File by the U.S. Geological Survey and should not be cited or quoted. This report was submitted to OWI for review and concurrence in its suitability for release and is currently being revised by the author. Numerous notations and inquiries were made in the text.

8. Figure 4-16 shows that modeling of the regional hydrology was to begin in February 1978. At the December 15 meeting in Jackson, Miss. we objected to this schedule and explained to LETCO that our work plans were governed by our project proposal and that we had no plans to initiate modeling until data from the regional test-drilling program became available. Figure 4-16 should be revised to reflect this.

We appreciate the opportunity to review this report and regret that our response has been unavoidably delayed.

We would appreciate a meeting at your earliest convenience to discuss our future role in the Gulf Coast Salt Dome Studies.

Sincerely yours,

George D. DeBuchananne
Chief, Office of Radiohydrology

Air & Water Pollution Control Commission

STATE OF MISSISSIPPI

CHARLES H. CHISOLM, ACTING EXECUTIVE DIRECTOR
P. O. BOX 827 - ROBERT E. LEE BUILDING
JACKSON, MISSISSIPPI 39205
(601) 354-2550

June 15, 1978

Dr. Cobin Heath
Assistant Director for Waste Isolation
Division of Waste Management
Department of Energy
Mail Stop B-107
Washington, D. C. 20545

Dear Dr. Heath:

Pursuant to a recent request, we are submitting comments on the "Draft National Waste Terminal Storage Program: Geologic Evaluation of Gulf Coast Salt Domes - Site Selection Program".

These comments are of a technical nature and related only to the proposal of studying these salt domes. These comments or lack thereof should in no way be considered an expression of opinion in the matter of the possible utilization of the domes for the disposal of the radioactive material.

In Chapter 4, Program Plan, Sections 4.3.2.1 and 4.3.3 on Diapirism and Hydrologic Stability, it is stated that a number of wells will be bored in and around the salt domes for the purpose of obtaining salt cores and hydraulic characteristics. Regarding the wells where water is pumped from an aquifer to determine hydraulic characteristics, the Commission is concerned about the possible contamination of subsurface and surface waters with saline water from the aquifer being tested. What mechanism will be provided to protect these waters from salt water contamination? Also, we are interested in the estimated volume of water to be pumped from an aquifer to determine the hydraulic characteristics for the aquifer.

Mr. James G. LaBastie stated that studies would be conducted on the Cypress Creek Dome as indicated in Tables 3-1 and 3-2 in Chapter 3, Screening Specifications. The present draft document does not include

Dr. Cobin Heath
June 15, 1978
Page -2-

any specific information on this particular dome since this Dome was apparently a last minute addition to the study. We assume that the final document will include information on the Cypress Creek Dome similar that described for the other salt domes to be studied.

If you have any questions concerning these comments, please advise.

Sincerely,

Charles H. Chisolm
Acting Executive Director

CHC:JBB:pa

cc: Mr. J. G. LaBastie This copy for

TEXAS PARKS AND WILDLIFE DEPARTMENT

HENRY B. BURKETT
EXECUTIVE DIRECTOR

4200 Smith School Road
Austin, Texas 78744

June 16, 1978

Dr. Colin Heath
Department of Energy
Mail Stop B-107
Washington, D. C. 20545

Re: Draft Report on Geologic Evaluation of Gulf Coast Salt Domes, Site Selection Program Plan, National Waste Terminal Storage Program

Dear Mr. Heath:

The Texas Parks and Wildlife Department has reviewed the above-mentioned document and has no comments to offer.

Thank you for the opportunity to review and comment on this document.

Sincerely,

Henry B. Burkett

HENRY B. BURKETT
Executive Director

HBB:BDK:lmw

cc: Mr. J. G. LaBastie
Law Engineering Testing Company
2749 Delk Road, S.E.
Marietta, Georgia 30067

Mr. Ward C. Goessling, Jr., Coordinator
Natural Resources Section
Governor's Budget and Planning Office
Executive Office Building
411 West 13th Street
Austin, Texas 78701

LETTERHEAD

TEXAS DEPARTMENT OF WATER RESOURCES
1700 N. Congress Avenue
Austin, Texas

June 21, 1978

Dr. Colin Heath
Department of Energy
Mail Stop B-107
Washington, D.C. 20545

Gentlemen:

Re: Draft, National Waste Terminal Storage Program,
"Geologic Evaluation of Gulf Coast Salt Domes-
Site Selection Program Plan"

Thank you for providing the referenced draft to the Texas Department of Water Resources for review, comment, and correction. The staff of this agency is extremely interested in keeping abreast of the National program for the disposal of radioactive wastes and is appreciative of the opportunity to participate in the assessment of interior salt domes as nuclear waste repositories.

Staff has reviewed the draft with emphasis on the scientific and technical data pertaining to the salt domes in the Northeast Texas Basin. Particular areas of interest are: surface and subsurface geology, surface and ground-water resources, remote sensing interpretations, hydrologic and domal stability, aquifer hydraulic properties, chemical characteristics of water in the geohydrologic units and in surface streams, and the geological containment of the radioactive wastes. We are pleased to see that the very capable Texas Bureau of Economic Geology has been selected as the principal scientific and technical investigatory organization to locate candidate domes in Texas, and that the U.S. Geological Survey has primary responsibility for hydrologic studies in the three states, Texas, Louisiana, and Mississippi, involved in the program.

Dr. Colin Heath
Page 2
June 21, 1978

The data in the draft concerning the geology, hydrology, and assessment of the salt domes and the program plan for continuing investigations in the remainder of 1978, and in 1979, appear to be very comprehensive and thorough. Because the data and plan are so complete, our staff has neither critical nor substantial constructive comments to present at this time. However, this agency would appreciate receiving draft reports of the results of the continuing investigations as they are completed. At this time, the Texas Department of Water Resources has not adopted an official position with regard to the feasibility and/or desirability of utilizing salt domes in Texas for the storage or disposal of radioactive wastes. We prefer to wait until the results of all of the studies are available for review before reaching any decision with regard to this matter.

In closing, we would like to again thank you for the submission of the draft report for review by this agency. If we may be of service in the future, please contact us.

Sincerely yours,

Harvey Davis
Executive Director

cc: Texas Energy Advisory Council
Dr. W. L. Fisher
Mr. J. G. LaBastie
Law Engineering Testing Company

MISSISSIPPI POWER & LIGHT COMPANY
Helping Build Mississippi
P. O. BOX 1640, JACKSON, MISSISSIPPI 39205

DONALD C LUTKEN

July 10, 1978

Dr. Colin Heath
Department of Energy
Mail Stop B-107
Washington DC 20545

Dear Dr. Heath

Comments on "National Waste Terminal Storage Program Geologic Evaluation of Gulf Coast Salt Domes - Site Selection Program Plan"

We have reviewed the subject study and offer the following comments:

Mississippi Power & Light Company is an investor-owned electric utility serving some 300,000 customers in Western Mississippi.

Mississippi Power & Light Company is one of the operating companies in the Middle South System and is presently constructing for the system two (2) 1,250,000 KW nuclear generating units in Claiborne County, Mississippi.

On completion of these two units in 1984, the Middle South System will have five (5) nuclear power plants in operation with a rated capacity of 5,413,000 KW. This will constitute a substantial portion of the capability of the system when all of these units become operational. (Present system capability is slightly more than 11,000,000 KW.)

Because we will be largely dependent on coal and uranium as fuel for our base load generating plants in the near-term and long-term, the expeditious resolution of the disposal of nuclear waste is of the utmost importance to us and to our customers.

Therefore, we respectfully urge the Department of Energy to give the highest priority to the development of a repository or repositories to receive and dispose of radioactive waste material.

MORE

MISSISSIPPI POWER & LIGHT COMPANY

Dr. Colin Heath
Washington, D. C. -2- July 10, 1978

We further suggest that federal policies be revised so that spent fuel assemblies from nuclear power plants can be reprocessed, as it is done with spent fuel assemblies from nuclear powered naval vessels. This will have the beneficial effect of the following:

(1) Prolonging and extending the supply of uranium
(2) Reducing the national dependence on imported oil
(3) Reducing the cost of electric energy to consumer
(4) Reducing the volume of nuclear waste, and
(5) Reducing the quantities of plutonium by using it as fuel in mixed oxide fuel pellets.

Respectfully submitted

Donald C. Lutken
President

DCL:sb

cc - Mr. J. G. LaBastie
Law Engineering Testing Company
2749 Delk Road, S. E.
Marietta, Georgia 30067

Mr. Travis Roberts, Director
Governor's Office of Natural Resources and Technology
Post Office Box 139
Jackson, Mississippi 39205

System Chief Executive Officers

The Senate of
The State of Texas
Austin 78711

ROY BLAKE
State Senator

Committees:
FINANCE
ADMINISTRATION
JURISPRUDENCE

August 8, 1978

Dr. Colin Heath
U.S. Department of Energy
Mail Stop B-107
Washington, D.C. 20545

Dear Dr. Heath:

Thank you for the Draft National Waste Terminal Storage Program, Geologic Evaluation of Gulf Coast Salt Domes, Site Selection Program Plan Prepared by LETCO.

1.1.3 Recent Studies, page 1-4 "The present schedule for the development of a repository requires that the geologic project manager identify acceptable sites in the three Gulf Coast Salt Dome Basins, Northeast Texas, North Louisiana and Mississippi by September 1979, so that the site of the first repository can be selected during early 1980. Site acquisition, design, and construction are to be completed so that the initial five-year phase of operation can begin by the end of 1985. As a safeguard against unforeseen hazards, and to permit possible future use of the radioactive waste, all of the radioactive waste material emplaced in the repository during the initial phase will be in retrievable cannisters. Subsequent repositories are being planned for development in other rock types in other areas in the country."

DOE officials have been asked the simple question: "Will the first terminal storage site definitely be in a salt formation?" The answer is invariably "No." The preceding quote seems to indicate otherwise. Surely the Lyons, Kansas experiment must leave some doubt as to the absolute ability of salt formations to guarantee the degree of safety desired. What is the truthful stand of DOE on location of the first terminal storage site?

1.1.4 Previous Salt Dome Studies, Pages 1-6,1-7 "Ledbetter, Kaiser, and Ripperger of the University of Texas concluded that there is no valid technical or geological reason for not using salt domes as repository sites for high-level radioactive waste." They recommended Mount Sylvan and Whitehouse domes in Northeast Texas.

If these gentlemen are correct in their assumptions, why are Keechi, Palestine, and Oakwood domes being studied rather than Mount Sylvan and Whitehouse.

P. O. Box 12068 • Austin 78711 • (512) 475-2671 P. O. Box 713 • Nacogdoches 75961 • (713) 564-1307

Dr. Colin Heath
August 8, 1978
Page 2

The Draft really does not furnish a great deal of information to supplement the first draft. It does go into greater detail of the domes currently being studied. I find no fault with this.

My greatest concern is the terminology used that would indicate that the geologic formation has already been selected. If it has not, then I strongly urge that the first chapter of the next draft so indicate.

I would further urge you to develop a more flexible schedule for solving the problem. The materials you will store are not like other waste materials. The potential hazard to this generation and generations to come is infinitely greater. Capability of handling waste materials has been demonstrated in above ground facilities. I realize that it will be more costly to construct more on site storage facilities and AFR facilities, but until the problem is solved this seems to be the most promising method.

Urge the President to reconsider recycling. This would reduce the degree of the problem.

It might be well to place a moratorium on licensing any new Nuclear Reactor construction until this problem is ultimately solved.

I realize that the waste problem is real and it is now. I am not a scientist, but in view of the widespread disagreement in the scientific community over the solution to your problem, I strongly urge that you invoke every amount of caution that you can muster.

Sincerely,

Roy Blake

Roy Blake

RB:cw

CC: Mr. J.G. LaBastie

ED DRANGUET
COUNCILMAN
District 1

ALVIN J. DEBLIEUX, JR.
COUNCILMAN
District 2

JOHN WINSTON
COUNCILMAN
District 3

JOHN BELOW
COUNCILMAN
District 4

CITY OF NATCHITOCHES

NATCHITOCHES, LOUISIANA 71457 – FOUNDED 1714 – P. O. BOX 37

ROBERT B. DEBLIEUX
MAYOR

PAT S. TODD
COUNCILMAN AT LARGE

August 28, 1978

Dr. Colin Heath
U. S. Department of Energy
Mail Stop B-107
Washington, D.C. 20545

RE: National Waste Terminal Storage Program. Geologic Evaluation of the Gulf Coast Salt Domes Site Selection Program Plan. DOE, Copy #197-R.

Dear Dr. Heath:

I am in receipt of the above study report and since it arrived in mid-August, I must submit a preliminary answer at this time and ask for a 10-day extension period to submit a more complete follow up review with supporting comments.

The Environmental Protection Agency issued the following statement on national television on August 9, 1978: "Eighty per cent of American industrial waste is treated improperly, representing a real health hazard." I can recently cite the Niagara Canal Syndrome "as an example." The entire approach of the Gulf Coast Salt Domes Evaluation is strictly based on geologic information and very preliminary surveys, thus not considering such areas of impact as biological, (plant, animal, human), ecological, environmental, socio-economical and demographical.

In Louisiana we do not have a complete understanding, cataloging, nor taxonomically definitive publication on the flora of the State. The recent geologic evolution and the intensity of plant speciation is both pronounced and unique. The value not only of our plants but our animals, especially wildlife, represents one of the key factors contributing to the financial backbone of this state. The current economic growth coupling industries with recreation, tourism, and areas of natural beauty have begun a logarithmic climb. As our medium sized cities become larger and our large cities become still larger, it is increasingly evident that Louisiana must learn

Dr. Colin Heath
Page 2

very rapidly the science of proper land management. Water management has historically been critically important in the development of this state, yet there is much to be learned about this science also. The oncoming Red River Navigation Project with the U. S. Corps of Engineers will significantly change the environmental profile of Louisiana. Therefore, until further real and widescale scientific studies are made of Louisiana, no storage of any kind of waste, especially radioactive, should be allowed. The North Louisiana Basin represents a complex natural environment that is at present poorly understood and changing rapidly with the impact of human affairs.

Very sincerely yours,

Robert B. DeBlieux

Robert B. DeBlieux, Mayor
City of Natchitoches, La.

mja
cc: Mr. J. G. LaBastie
Mr. Curtis E. Carlson, Jr.
Honorable Edwin Edwards, Governor
State of Louisiana

University of Southern Mississippi

Southern Station, Box 5165
Hattiesburg, Mississippi 39401

College of Science
and Technology

November 8, 1978

Dr. Colin Heath
Department of Energy
Mail Stop B-107
Washington, D.C. 20545

Dear Dr. Heath:

Attached are comments from two faculty members in the College of Science and Technology on your report entitled "National Waste Terminal Storage Program - Geologic Evaluation of Gulf Coast Salt Domes" dated February 3, 1978. I trust you will find these useful in your studies.

Sincerely yours,

Gary C. Wildman

Gary C. Wildman, Ph.D.
Dean

cm
Attachment
xc: J. G. LaBastie
Law Engineering Testing Company
2749 Delk Road
Southeast Marietta, GA 30067

UNIVERSITY OF SOUTHERN MISSISSIPPI

INTER-OFFICE CORRESPONDENCE

7/10/78
Date

TO: Dr. Gary C. Wildman, Dean
College of Science & Technology

FROM: Dr. Richard L. Bowen
Professor of Geology

RLB

SUBJECT: Review of and Comments Concerning "Geologic Evaluation of Gulf Coast Salt Domes: Site Selection Program Plan", National Waste Terminal Storage Program.

As requested in your memorandum of 22 June 1978, I have completed a careful study and review of the above mentioned document. My comments follow.

General Evaluation: The material incorporated in this document demonstrates a notably high standard of technical competence in the assembly, evaluation, and presentation of the problem under consideration, in the discussion of the present state of knowledge, and in the proposed program for securing the necessary additional information required for ultimate site selection. If any criticism should be leveled toward the last of these, it is that the program planned for additional accrual of data could, in some respects, considered to be overly thorough. I detected only one serious lapse in the report (See Comment 1 below).

With the above in mind, two caveats appear. The first, which is significant, is that the program is already several months behind schedule. The second, which is of minor importance, is that the document is irritatingly poorly edited with regard to the English language, and that occasional blunders in scientific terms occur (e.g., "dissolution" instead of "resolution", line 1, p. 4-11).

From my standpoint as a geologist with nearly thirty years of professional experience in many regions, countries, and fields of geology, I can state that this is an eminently sound document (with the exception noted in Item 1 below) and the proposals for additional investigations have been carefully considered, chosen, and scheduled. With regard to the details of geology of the region, however, I have a surprisingly lengthy list of points on which my understanding of the geology of the Gulf Coast differs to a

Dr. Gary C. Wildman
July 10, 1978
Page 2

greater or lesser degree from the authors of the report. Nevertheless, these differences, with few exceptions, have no essential bearing on the question of use of salt domes for underground waste disposal. Certain of these differences will appear in the comments below, which will be confined to the portions of the report which deal with the state of Mississippi.

Specific Comments:

1. (Sec. 4.2.2, p. 4-4). Considerable emphasis is directed in this report toward understanding conditions at the times of low ("glacial") sea levels. No clear emphasis is given to consideration of the effects of rise of sea level in the future, should the world's ice caps melt, as is visualized in many of the scenarios relating to global climatic warming. My calculations indicate total melting would result in a rise of sea level of 60-62m (197-203 ft.). Such a rise of sea level would cause portions of the Rayburns, Vacherie, and Richton domes to be inundated. This would lead to violation of Criterion 16 (p. 7 of "Screening Specifications for Gulf Coast Salt Domes"), although relatively low cost earthworks on the surface could eliminate this potential problem.

   Two additional factors are of concern here, with regard to this program plan. The first is the time frame. I understand the purpose of these planned disposal sites to be sequestering nuclear wastes until their radioactivity has greatly reduced through the passage of several half-lives. The rise of sea level referred to, with some frequency, in this report occurred at a rate of approximately 10m/1000yr. during the time interval 18000 to 6000 yr. ago, under normal (not involving human activities) Earth conditions. Therefore, under normal Earth conditions, a climatic change leading to melting of the remainder of the World's ice would cause sea level to rise to about 200' elevation within about 6000 yr. Some predictions of the consequences of human activities or future climate, however, suggest that this could occur in a much shorter time frame, involving no more than 500 years or even as few as 200 years.

   The second factor is that of isostatic compensation. Some geological theoreticians have advanced arguments which merit serious consideration that for each 2 1/2 to 4 feet of sea level rise, the land over which this rise occurs should isostatically subside by one foot.

Dr. Gary C. Wildman
July 10, 1978
Page 3

Should this argument hold true, the effective rise of sea level postulated in my discussion here would not be to 60-62m (197-203 ft.), but rather to an effective relative elevation of 75-87m (246-285 ft.). A sea level rise to a relative effective elevation of 285' through the combination of geological processes mentioned here would inundate portions of the Palestine Dome site, most of the Vacherie Dome site, a portion of the Lampton Dome site, and all of the Richton and Rayburns Dome sites.

2. (Sec. 4.3.1, p. 4-6). A thorough review of the seismic (earthquake) history of Mississippi was published a few years ago (1974 or 1975, I believe) in the Earthquake Information Bulletin of the U.S. Geological Survey. This should be adequate to meet the needs of this part of the program.

3. (Sec. 4.3.1.1, pp. 4-7 and 4-8). My regional mapping in the Hattiesburg District of the past few years (which extends to within 8 miles of the Richton Dome and 12 miles of the Lampton Dome) suggests that the feature referred to as "the Citronelle Terrace" in this report is in reality the upper surface of an immense alluvial plain (apparently mildly warped since the end of its depositional cycle). Moreover, my mapping suggests that the surface and near surface geology, as described in this report above and around these domes is significantly in error, but not, however, in any way likely to have serious negative implications with regard to proposed nuclear waste storage.

4. (Fig. 4-11). The indicated planned locations for the MRIH series of drill holes is puzzling to me and inadequately explained in the text of the report. I should like further information as to why the particular sites indicated have been chosen.

5. (Fig. 4-13). In my opinion, at least one additional drill hole in the MLAH series should be added, SE of the Lampton Dome, to provide a minimum data base for characterizing the subsurface hydrology and geology.

I hope these remarks will serve to meet the needs of your request for comments on the report. If not, please advise me what additional information is needed, and I will undertake to provide it.

RLB/drl

UNIVERSITY OF SOUTHERN MISSISSIPPI

INTER-OFFICE CORRESPONDENCE

August 14, 1978

To: Dr. Gary Wildman
Dean of the College of Science and Technology

From: Dr. James W. Pinson
Professor of Chemistry

Re: Comments and evaluations of the report titled "National Waste Terminal Storage-Program-Geologic Evaluation of Gulf Coast Salt Domes" are included below.

From the data in the report the Richton, Mississippi salt dome has an excellent possibility of being the salt dome selected in Mississippi for radioactive waste storage. The best asset it has is its large size having about 4500 acres of cross sectional area at 2000 feet depth. The dome is also near enough to the surface to be easily accessed. The Lampton dome in Marion County is the other Mississippi possibility. It is much smaller having only 1440 acres of cross-sectional area at 3000 feet depth. Both Mississippi sites have had many sulfur wells (none successful) drilled into their cap rock in the 1940's. Sand and gravel pits are close at hand and oil and gas producing wells are in the immediate area. In the Richton dome site the dome is very close to the city of Richton.

The timetable for site selections is September, 1979 while the timetable for a functioning waste disposal site is 1985. So Mississippi has little time to respond to this means of radioactive waste disposal.

A major problem Mississippi has with regard to site selection, state input, and in-state evaluation is that we are the only state of the three-Louisiana, Texas, and Mississippi-that has no state-sanctioned body to protect its interests. Texas has the Texas Bureau of Economic Geology at the University of Texas (TBEG) as its official body while Louisiana has the LSU Institute of Environmental Studies (LSU-IES) as its official body. We in Mississippi have no such body. This places us and our interests at a major disadvantage. In fact, Law Engineering Testing Company is going to do our studies for us while TBEG and LSU-IES do their own studies. There is no way our interests will be properly protected. This can be corrected rapidly by our state government and should be.

Other problems with the dome as sites come to mind. The ground water flow pattern in the dome vicinity is poorly understood. Surface salt licks and salt marshes near most dome sites are not understood. Will the salt in the dome dissolve slowly or become wet making it much more corrosive? Will the salt and salt water make its way into the water table and contaminate the drinking water supply? Will the drilling of numerous holes in the cap rock change the stability of the dome area? What effects will impurities in the salt domes have on dome stability? While many of these questions have been asked, they have <u>not</u> been studied in the Gulf Coast salt domes. The factor of salt or wet salt induced corrosion needs to be fully understood <u>before</u> solid waste containers are placed in the domes.

In my opinion all radioactive wastes need to be placed in such a manner that retrival is easily possible. Future technology should be such that radioactive wastes can be treated to reduce their long-lived effects. Will the radioactivity affect the people near the dome site? Will leaching into groundwater occur? Will area radioactive background be increased to a dangerous extent locally? Will the transportation of the wastes pose a major local hazard? These are all problems and questions that need to be studied and answered before wastes are stored.

I would much rather see the reactor sites process their own wastes without transportation. This is not feasible forever, but initially for many years (10-25) this would be possible. Should breeder reactors become a reality, then they could make use of some of these wastes as fuel.

To conclude, I do not currently favor using the salt domes as a storage site. They have not been carefully studied, but have been selected before such study. I feel other sites nationwide should be examined prior to their use. In addition, Mississippi had better provide itself with a means of protecting its own interests through establishing its own agency as Texas and Louisiana have done.

Gary, I did not go into the obvious disaster - an earthquake. But I hope the above comment helps.

Jay Nenain