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STRATEGIC PETROLEUM RESERVE (SPR) GEOLOGICAL SITE CHARACTERIZATION REPORT SULPHUR MINES SALT DOME

Section I "SULPHUR MINES CAVERN STABILITY ISSUES"
G.H. WHITING

Section II "GEOLOGICAL SITE CHARACTERIZATION, SULPHUR MINES SALT DOME"
LAW ENGINEERING TESTING COMPANY

Section III "SALT PROPERTIES FOR SULPHUR MINES DOME"
R.R. BEASLEY



Sandia National Laboratories

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SPR GEOTECHNICAL
DIVISION

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G. H. Whiting

Section II Geological Site Characterization, Sulphur Mines Strategic Petroleum Reserve Site, Law Engineering Testing Company

Section III Salt Properties for Sulphur Mines Dome,
R. R. Beasley

Edited By Glen H. Whiting
SPR GEOTECHNICAL DIVISION 4543

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Section I
G. H. Whiting, "Sulphur Mines Cavern Stability Issues"

Section II
Law Engineering Testing Company, "Geological Site Characterization," Sulphur Mines Strategic Petroleum Reserve Site, Sulphur, Louisiana

Section III
R. R. Beasley, "Salt Properties for Sulphur Mines Dome"

Edited by
Glen H. Whiting
SPR Geotechnical Division
Sandia National Laboratories
Albuquerque, NM 87185

INTRODUCTION

SPR Program Description

The Energy Policy and Conservation Act (EPCA) enacted in December 1975 provided the legislative authorization for the Strategic Petroleum Reserve (SPR). The objective of the SPR is to store substantial quantities of crude oil in order to diminish US vulnerability to the effects of a severe interruption in supply. The current plan for the SPR consists of three phases that, when complete, will provide the US with a 750-million-barrel (MMB) reserve. The legislation authorized up to a 1-billion-barrel reserve, but plans have not been completed for the last 250 MMB.

The Phase 1 portion of the reserve uses existing storage volume at five sites. Four of the sites (Bryan Mound, TX; West Hackberry, LA; Sulphur Mines, LA; and Bayou Choctaw, LA) have solution-mined caverns that were originally created to produce brine as chemical feedstock; and the fifth site, Weeks Island, LA has a conventional salt mine. The total existing capacity of these five sites is 248 MMB. Phase 2 plans are to expand the Bryan Mound and West Hackberry sites by solution-mining 12 and 16 additional caverns, respectively, of 10 MMB each. Plans for the remainder of the storage capacity to reach the 750-MMB reserve are being developed by the US Department of Energy (DOE).

Sandia SPR Participation

Sandia National Laboratories at DOE request has made a short-term systems integration and engineering support study. The results of this study have been published.[1] Several geotechnical recommendations resulted from this study, and Sandia was assigned the responsibility to provide a coordinated program of geotechnical investigations to support continued development of the SPR. The geotechnical program will provide a sufficiently comprehensive, site-specific data base to support the planning, design, construction, and operation of SPR crude-oil storage facilities. These data will be used in assessing the long-term stability of SPR storage caverns and mines to minimize the potential for cavity failures that could result in significant environmental impacts, economic losses, or failure to withdraw oil when needed. A long-term monitoring plan will be developed that will assure maintenance of the quantity and quality of the stored crude oil in a readily recoverable condition. The geotechnical program includes the following activities: geological site characterization; engineering design

assistance and evaluation, including numerical simulation studies; laboratory and bench-scale testing of salt cores from SPR sites; monitoring and interpretation of field events; and instrumentation evaluation and development. These efforts pertain to the five sites currently in the SPR program.

An additional task to provide interim technical support for leaching the first five three-well caverns at the Bryan Mound site was added by the SPR Project Manager's Office (SPRPMO) to the Sandia SPR Geotechnical Program.

Report Description

Section I reviews cavern stability, integrity, and usability at the existing caverns at Sulphur Mines. The early analyses were done by using typical material properties. Future analyses will be done by using the information reported in Sections II and III of this report. As these analyses are completed, results and recommendations will be published.

Section II of this report is a comprehensive geological site characterization study done by Law Engineering Testing Company for Sandia. In the first phase, a comprehensive study has been prepared from existing data; and in the second phase, field programs would be used to gather specific information as needed. Section II represents the results of Phase 1 only.

Section III of this report will be amended in the future to summarize the materials property work that may be done at Sandia and by contractors. Currently, neither geophysical logs from wells at Sulphur Mines nor cores are available that would provide the information from which specific properties could be assembled for use in our analytical models.

Sandia Recommendations Resulting from Geological and Material Studies

- Do not completely fill Caverns 6 and 7 until after the distance from Cavern 7 to the edge of the dome has been determined. The most practical and accurate technique is a directionally drilled well combined with borehole geophysical logging.

- Do not completely fill the 2-4-5 cavern gallery until the distance from Cavern 4 to the edge of the dome has been defined.

If oil storage is required before the distance to edge of the dome is determined, we recommend a thorough test of both cavern groups. This would include a low-pressure test to determine the current condition of the caverns, and continuous monitoring of cavern pressures during oil storage to immediately detect any change that could result from communication between the caverns and the exterior of the dome.

Assuming the edge-of-dome concerns are resolved satisfactorily, the following actions are recommended.

(1) Drill and case a well into Cavern 5 to eliminate the potential for trapping any gas that could cause unacceptably high pressures at the casing seat.

(2) Recertify the 2-4-5 cavern gallery.

(3) Take sonar caliper surveys of all caverns after Pittsburgh Plate Glass (PPG) stops brining and before oil is stored.

(4) Maintain the same type oil in Caverns 6 and 7.

(5) Establish a program to monitor the well casings for corrosion, especially through the caprock.

(6) Limit the number of freshwater drawdown cycles to one.

SECTION I

SECTION I

SULPHUR MINES CAVERN STABILITY ISSUES

MARCH 1981

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ABSTRACT

Cavern stability, integrity, and usability issues regarding existing and planned storage caverns in the Sulphur Mines salt dome are reviewed. Previous studies are discussed, ongoing investigations are summarized, and data needed to support the assessments are described.

SECTION I

CONTENTS

	Page
INTRODUCTION AND SUMMARY	2
CAVERNS AT SULPHUR MINES	3
Sulphur Mines Cavern 2	4
Sulphur Mines Cavern 4	4
Sulphur Mines Cavern 5	5
Sulphur Mines Cavern 6	5
Sulphur Mines Cavern 7	6
REFERENCES	7

ILLUSTRATIONS

Figure

1	Locations of Caverns at Sulphur Mines Salt Dome	9
2	Sulphur Mines Cavern 2	10
3	Sulphur Mines Cavern 4	11
4	Sulphur Mines Cavern 5	12
5	Sulphur Mines Cavern 6	13
6	Sulphur Mines Cavern 7	14

INTRODUCTION AND SUMMARY

The US Strategic Petroleum Reserve (SPR) program currently uses five existing caverns in the Sulphur Mines salt dome near Lake Charles, LA for storage of crude oil. Locations of the caverns are shown in Figure 1. This report summarizes current concerns and briefly describes previous work in assessing the stability, integrity, and usability of each cavern and the proposed new caverns.

There are many common issues of concern at each site--depressurization effects, long-term creep closure, etc. The techniques used to address concerns at one site apply at all sites.

A review of cavern stability issues for each SPR site was provided in Reference 1 in 1979. From this blueprint for action, Sandia National Laboratories began a program of geotechnical investigations to support the continued development of the SPR. Initial evaluations of cavern integrity have been based upon the use of generic or "typical" salt properties. These evaluations have attempted to bound concerns associated with creep-closure rates, depressurization of the caverns to zero surface pressure on the oil column, and pillar or web thickness. Concurrently with these evaluations, a materials testing program was begun to characterize the salt from each site. Data from the materials testing program will be used in ongoing and future studies to more accurately represent the geomechanical response of the caverns in the Sulphur Mines dome. These data also serve as input to leaching-simulation activities. Initial evaluations of cavern integrity were based upon cavern spacing data and dome boundary locations of questionable accuracy. Site characterization activities (Section II) have now brought together accurate, consistent geological and geometrical data on sediments, caprock, salt stock, and cavern locations that will be valuable in assessing stability concerns. Additional data will be required in order to understand the failure or fracture of the salt.

Site characterizations, and careful consideration of the numerical analyses made to date on Sulphur Mines caverns and caverns in other domes, have resulted not only in several useful observations about the existing caverns but have also helped define additional evaluations that are needed.

Caverns 2 and 5 have shapes that are geomechanically stable but are coalesced with Cavern 4. Caverns 4 and 7 are located close to the edge of the dome, and the long-term stability of these caverns cannot be determined with existing data. Stresses developed in Cavern 6 ledges approach failure levels when the cavern is filled with oil. These ledges could break and damage the hanging strings.

CAVERNS AT SULPHUR MINES

Table 1 summarizes the geometrical data regarding the location of the five existing caverns in the Sulphur Mines dome. Similar tables have been published previously by Tillerson[2] for each SPR site; however, Table 1 contains new data obtained in the site characterization work or recently generated. The Sulphur Mines cavern volumes range from about 3 MMB to more than 6 MMB. Cavern heights vary from 450 to 1400 ft; diameters from 299 to 680 ft. Cavern roofs vary from a depth of 2447 to 2910 ft below the surface, while maximum depths are between 3086 and 3420 ft. Because the cavern geometry (as related to the vertical and horizontal distances to the dome boundaries and to adjacent caverns) largely governs its suitability for storage from a geomechanics viewpoint, these properties and ensuing ratios to the cavern diameter, D, have been recorded in Table 1. The parameters for the Sulphur Mines caverns (Table 1) are seen as the bounds on several of the parameters in the overall program.

The distance between adjacent caverns, P, is the current wall thickness (not the center-to-center spacing between caverns) used as a measure of the likelihood for cavern coalescence. The P/D ratio indicates the pillar width relative to cavity size and inversely relates to the intensity of the loading that might be felt in the pillar; i.e., a 100-ft pillar between 500-ft-dia caverns (P/D = 0.2) would be more intensively loaded than if the surrounding caverns at the same depth had only a diameter of 100 ft (P/D = 1).

The roof or back thickness, B (amount of salt between cavern roof and the caprock), is important to cavern stability since the salt must be thick enough to ensure proper grouting of the casing. The B/D ratio indicates the thickness-to-span ratio for the cavern roof. As the B/D ratio decreases to well below 1.0, concern intensifies regarding how adequate the roof material is for transmitting loads from the caprock to the cavern walls without developing tensile stresses.

Another parameter, E, that can limit the suitability of an existing cavern for the storage of crude oil is how near the caverns are to the edge of the dome. The salt near the edge of a dome is more likely to be locally fractured and to contain impurities other than the salt in the interior of the dome. Any linkage between geologic formations bordering a dome and caverns within the dome must be avoided since the product stored in a cavern could conceivably be lost. Proximity of caverns to the edge of the dome may therefore limit the number of withdrawal cycles of a cavern.

Engineering, construction, and storage activities at the Sulphur Mines site have been briefly described in annual SPR reports.[3-5] New wells have been drilled at the site to enhance the operating capabilities of the caverns. Each cavern at Sulphur Mines was pressure-tested and certified as suitable for storage of crude oil.[6] In addition, sonar surveys were obtained,

logs were run of casing integrity, cement bond, and temperature, and new casings were cemented into existing wells as needed.

Sulphur Mines Cavern 2

Cavern 2 was reported at certification in November 1977 to have a volume of 6.2 MMB and a height of 640 ft (Figure 2). Its shape at that time was irregular, with its chambers of largest diameter located at the top and bottom. The largest diameter averaged in all directions at the referenced depth was 642 ft at a depth of 2930 ft. Pittsburgh Plate Glass (PPG) continued to brine with weak brine in Cavern 2 after certification in agreement with the DOE. A sonar survey in May 1979 showed the cavern volume had increased to 6.4 MMB, although the height had not changed. The largest averaged diameter was 680 ft at a depth of 2940 ft. Cavern 2 has coalesced with Caverns 4 and 5 to create a 13.6-MMB gallery.

Sandia has not made a detailed geomechanical analysis of the structural shape of Cavern 2. We have, however, compared the general shape of the structure with those where detailed analyses were made, and Cavern 2 is judged stable.

Sulphur Mines Cavern 4

Cavern 4 was reported to have a volume of 2.9 MMB and a height of 310 ft at certification in August 1977 (Figure 3). Its general shape at that time was very irregular, with the chambers of intermediate diameter located at the top and bottom of the cavern. Necked-down regions of smaller diameter connected these extremities to a pancake-shaped chamber of large diameter near the middle of the cavern. The largest averaged diameter was 748 ft a a depth of 2930 ft. PPG continued to brine in Cavern 4 with weak brine after certification in agreement with the DOE. Cavern 4 has coalesced with Caverns 2 and 5 to create a 13.6-MMB gallery.

A sonar survey of Cavern 4 in May 1979 showed its volume had increased to 3.8 MMB, and the height increased to 450 ft. The distance from the cavern to the edge of the dome has been studied in Section II of this report. For Cavern 4 that distance is reported as 185 ft. Sandia has stated[7] that the minimum thickness of competent salt required to assure the long-term integrity of the cavern is 50 ft. When the following factors are considered, the 185 ft is reduced close to the 50-ft requirement and is therefore considered marginal: (1) The tolerances on the edge of the dome, ±75 ft, (2) the tolerance on the well survey, 2.6 ft radial deviation per 1000 ft of depth, (3) the sonar caliper survey tolerance, ±5% of cavern radius, and (4) the shear zone at the dome edge consisting of a jagged rough surface with shale intrusion and clay gauges as reported by Kupfer.[8]

Sandia has not made a detailed geomechanical analysis of Cavern 4 but has compared the Cavern 4 shape with similar cavern shapes where analyses have been made. The shape of Cavern 4 is judged stable. The overall cavern stability and integrity will depend on a more favorable definition of the edge of dome (much greater spacing) or on accurately and satisfactorily defining the cavern-to-dome edge distance and salt quality to reduce the previously described tolerances.

Sulphur Mines Cavern 5

Cavern 5 was certified with the condition that the 4½-in. casing be removed, or the leak in the casing be repaired, or the casing be plugged to the surface. It was the understanding of Gulf Interstate at certification that a new Well 5A would be drilled to replace Well 5. Well 5 has been plugged, but no reentry well has been drilled; this has created a trap where 32 MB of oil cannot be recovered by conventional means and also a trap for released gas from the formation. This latter condition could result in unacceptably high pressures at the casing seat.

Cavern 5 was reported to have a volume of 3.3 MMB and a height of ~1400 ft at certification in September 1977 (Figure 4). Its general shape was irregular, with long slender spirals at the top and bottom and varying diameters in the middle. The largest averaged diameter was 460 ft at a depth of 2950 ft. A sonar survey of Cavern 5 taken just before the plugging operation in May 1979 showed very little increase in volume (3.4 MMB) caused by continued PPG brining in the 2-4-5 coalesced gallery.

Sandia has not made a detailed geomechanical analysis of Cavern 5 but has compared its shape with similar cavern shapes where analysis has been made. Cavern 5 is judged stable.

Sulphur Mines Cavern 6

Cavern 6 was reported to have a volume of 5.2 MMB and a height of 415 ft at certification in December 1977 (Figure 5). Its general shape was very irregular, with large-diameter chambers at the bottom and at the two-thirds-height level. The September 1979 sonar showed a third large-diameter pancake-shaped cavity was formed at the top of the cavern as the result of additional brining. The largest averaged diameter was 618 ft at a depth of 3080 ft.

Section II of this report indicated that Caverns 6 and 7, which are separated by only 20 ft, are on the verge of coalescing. This judgment is based on well directional surveys and cavern sonar caliper surveys.

The shape of Cavern 6 raises questions as to whether possible insoluble layers within the salt dome were causing the multiple-ledged structure. In the absence of core material, Sandia has used the PPG brining schedule as input and controls

for use in the Salt 77 Leaching Code to analyze this cavern. Results indicated that the shape was a result of the brining schedule, not of large insoluble layers.

Sandia has made a detailed geomechanical analysis of Cavern 6 that shows the ledges approach failure when the cavern is filled with oil. Ledge failure could result in damage to the hanging strings but should not affect the overall structural integrity of the cavern.

Sulphur Mines Cavern 7

Cavern 7 was reported to have a volume of 5.6 MMB and a height of 405 ft at certification in December 1977 (Figure 6). Its general shape was irregular, with two large-diameter chambers connected by a necked-down region. The maximum diameter was 460 ft. A sonar survey retaken of Cavern 7 in December 1979 after additional PPG brining showed that its cavern volume had increased to 6.3 MMB and its height to 585 ft.

Section II of this report indicated that Caverns 7 and 6, which are separated by only 20 ft and are on the verge of coalescing. This judgment is based on well directional surveys and cavern sonar caliper surveys.

Section II has also studied the distance of the cavern to the edge of the salt dome. That distance is 160 ft for Cavern 7. Sandia has stated[8] that the minimum thickness of competent salt required to assure the integrity of the cavern is 50 ft. The 160 ft is reduced by the tolerances and dome properties discussed under Cavern 4 above and is considered potentially unacceptable. The most practical, accurate technique to reduce the uncertainties is a directionally drilled well combined with borehole geophysical logging.

Sandia's geomechanical analysis of the Cavern 7 shape has shown the cavern to be stable; however, the overall stability and integrity of Cavern 7 can only be determined by defining the salt and by defining the cavern-to-dome-edge distance.

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3. Strategic Petroleum Reserve - Annual Report, DOE/RA-0004/1(77), DOE/SPRO, February 1978.

4. Strategic Petroleum Reserve - Annual Report, DOE/US-003, DOE/SPRO, February 1979.

5. Strategic Petroleum Reserve - Annual Report, DOE/RA-0047, DOE/SPRO, February 1980.

6. Gulf Interstate Engineering Company, Solution Cavern Certificates of Usability and Integrity for Sulphur Mines Site, 1978.

7. Memorandum to File from M. H. Gubbels of Sandia National Laboratories, dated October 7, 1980, "Edge of Dome Effects Due to Pressurization/Depressurization of Caverns."

8. D. H. Kupfer, "Boundary Shear Zones in Salt Stock," Presented at Fourth Symposium on Salt, 1974.

Table 1

Geometrical Data for the Five Sulphur Mines Caverns

SULPHUR MINES

Cavern Number	Year Constructed	Volume (mmb)	Oil Stored (mmb)	Type of Oil	DEPTHS - ft: Top of Caprock	Top of Salt	Casing Seat	Top of Cavern	Bottom of Cavern	Cavern Diameter, D (at roof/max)	Cavern Height, H	H/D	Nearest Cavern	Distance to Nearest Cavern, P	P/D**	Roof Thickness, B	B/D	Distance to Dome Edge, E	E/D**
2	1946	6.4	*	*	500	1460	1562	2447	3086	450/680	640	1.4				987	1.45		
4	1949	3.8	*	*	819	1620	1640	2640	3090	432/748	450	1.04				1020	1.36	185	.25
5	1953	3.4	*	*	829	1480	1714	2448	3420	299/460	1400	4.7	Allied #2 Well	380	.83	968	3.2		
													PPG #1-A	250	.54				
6	1955	5.9	*	*	620	1470	1836	2910	3390	284/618	480	1.7	#7	20	.03	1440	2.33	383	.62
7	1957	6.3	*	*	962	1500	1822	2770	3195	328/460	585	1.78	#6	20	.04	1270	3.88	160	.35

*No oil is currently stored at the Sulphur Mines site.

NOTE: All distances are given in feet.

**At maximum diameter

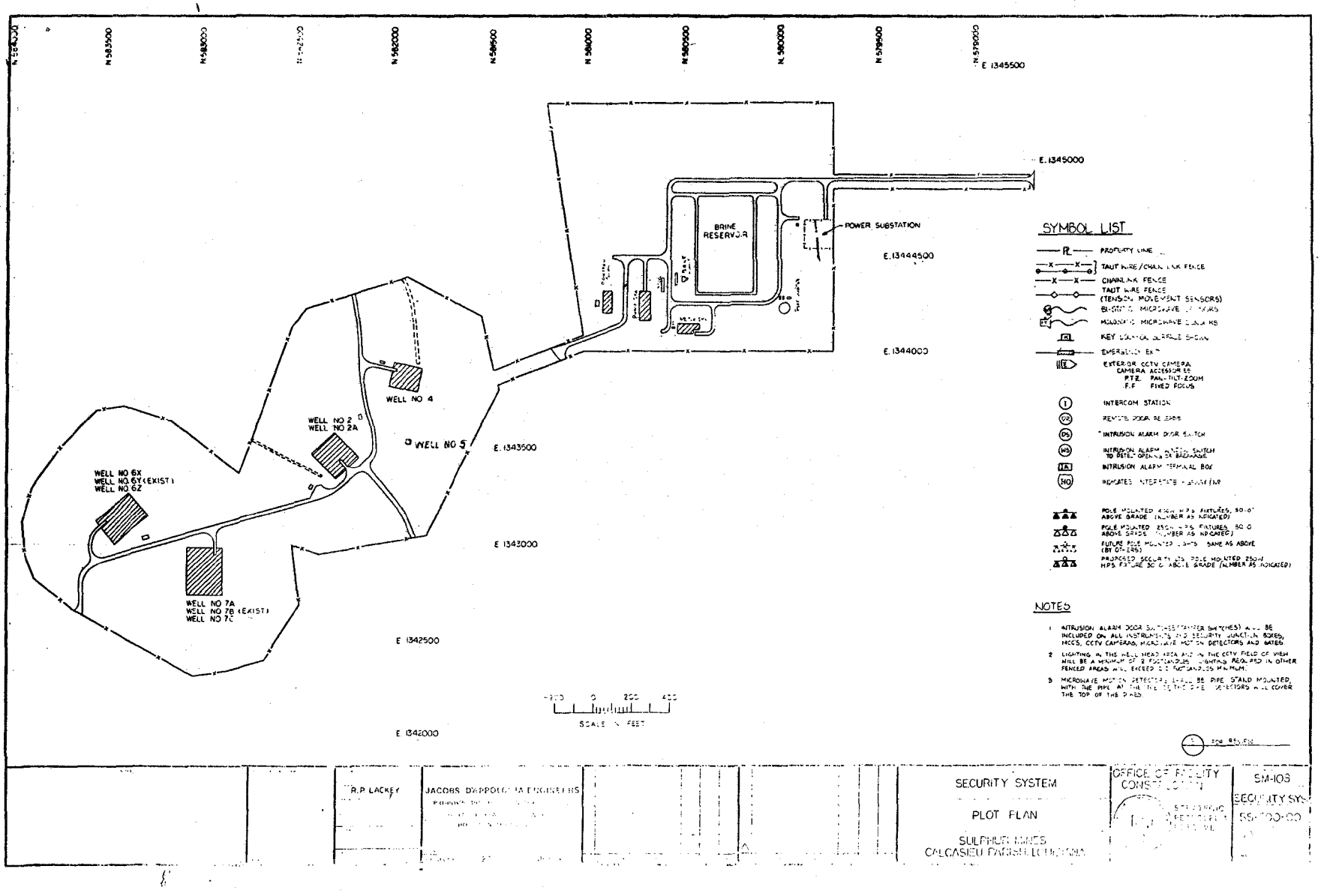


Figure 1. Locations of Caverns at Sulphur Mines Salt Dome

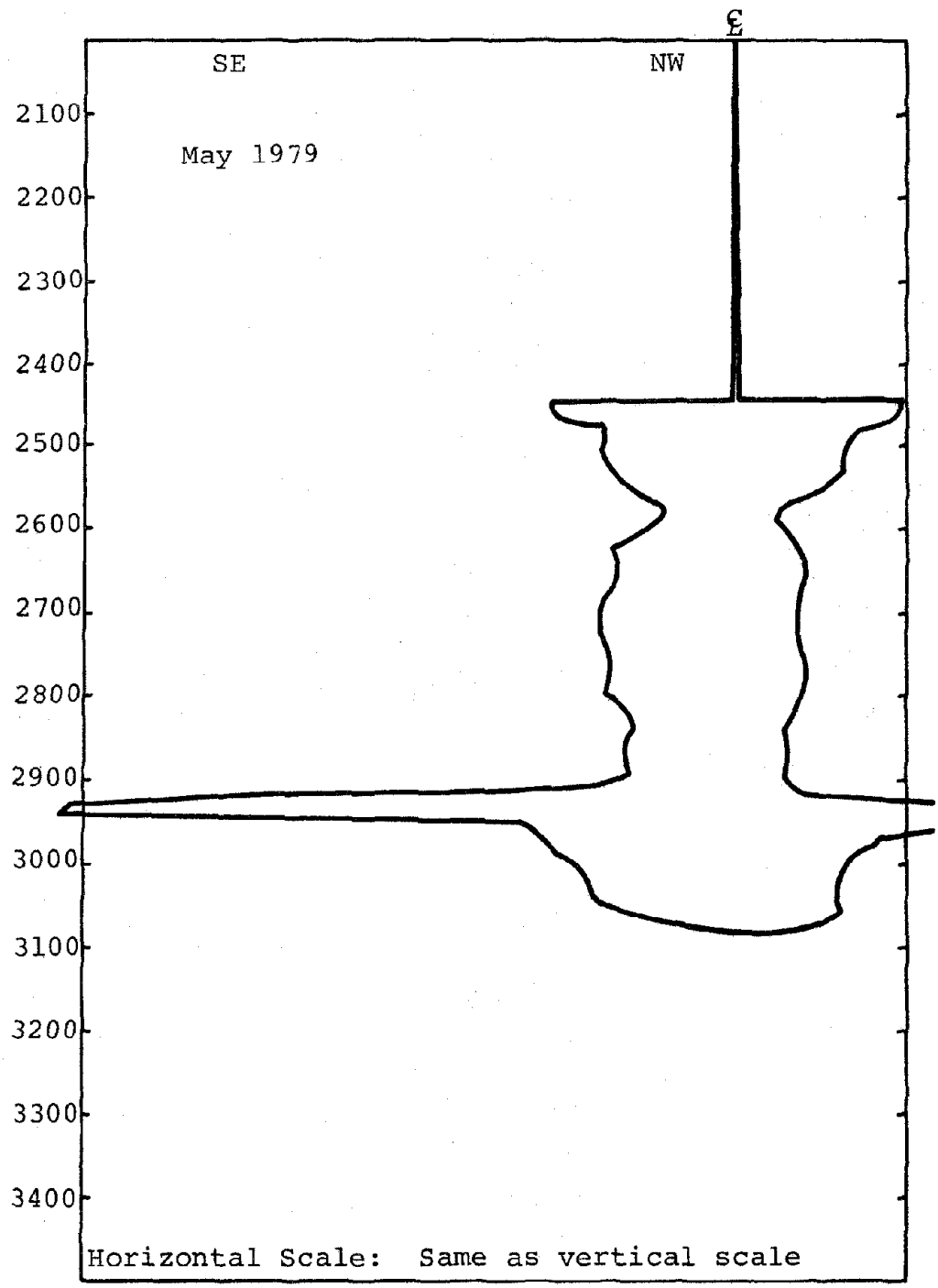


Figure 2. Sulphur Mines Cavern 2

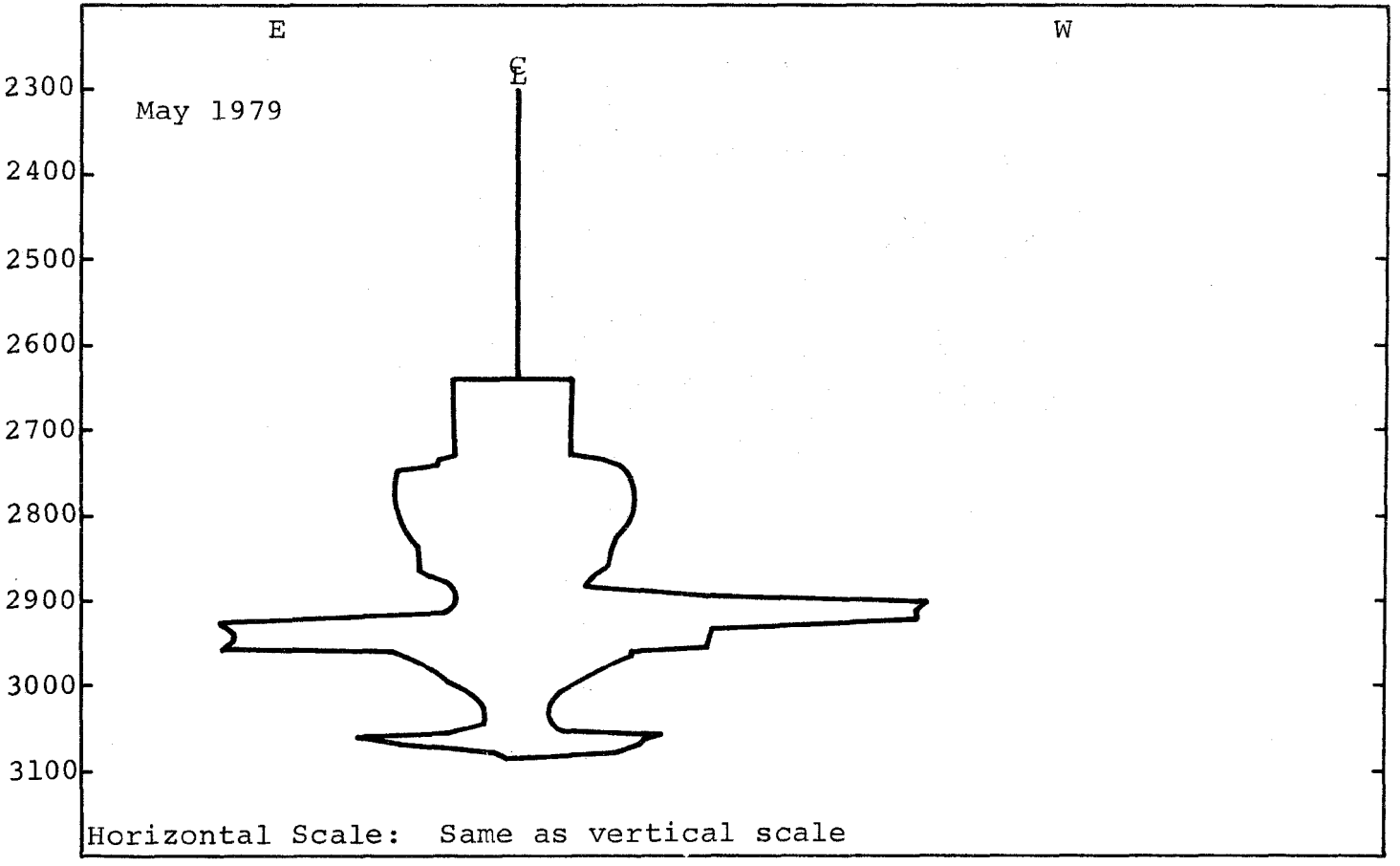


Figure 3. Sulphur Mines Cavern 4

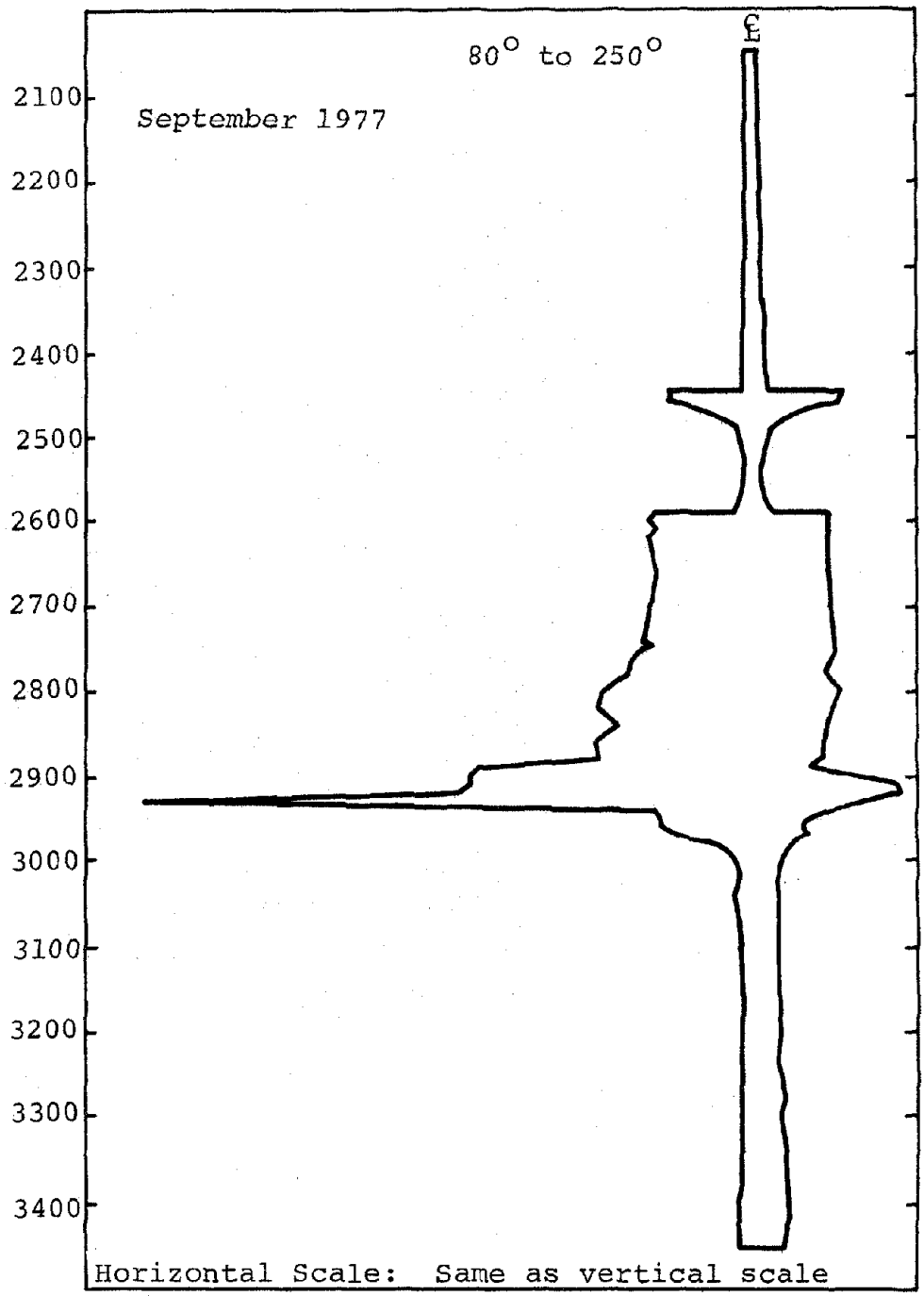


Figure 4. Sulphur Mines Cavern 5

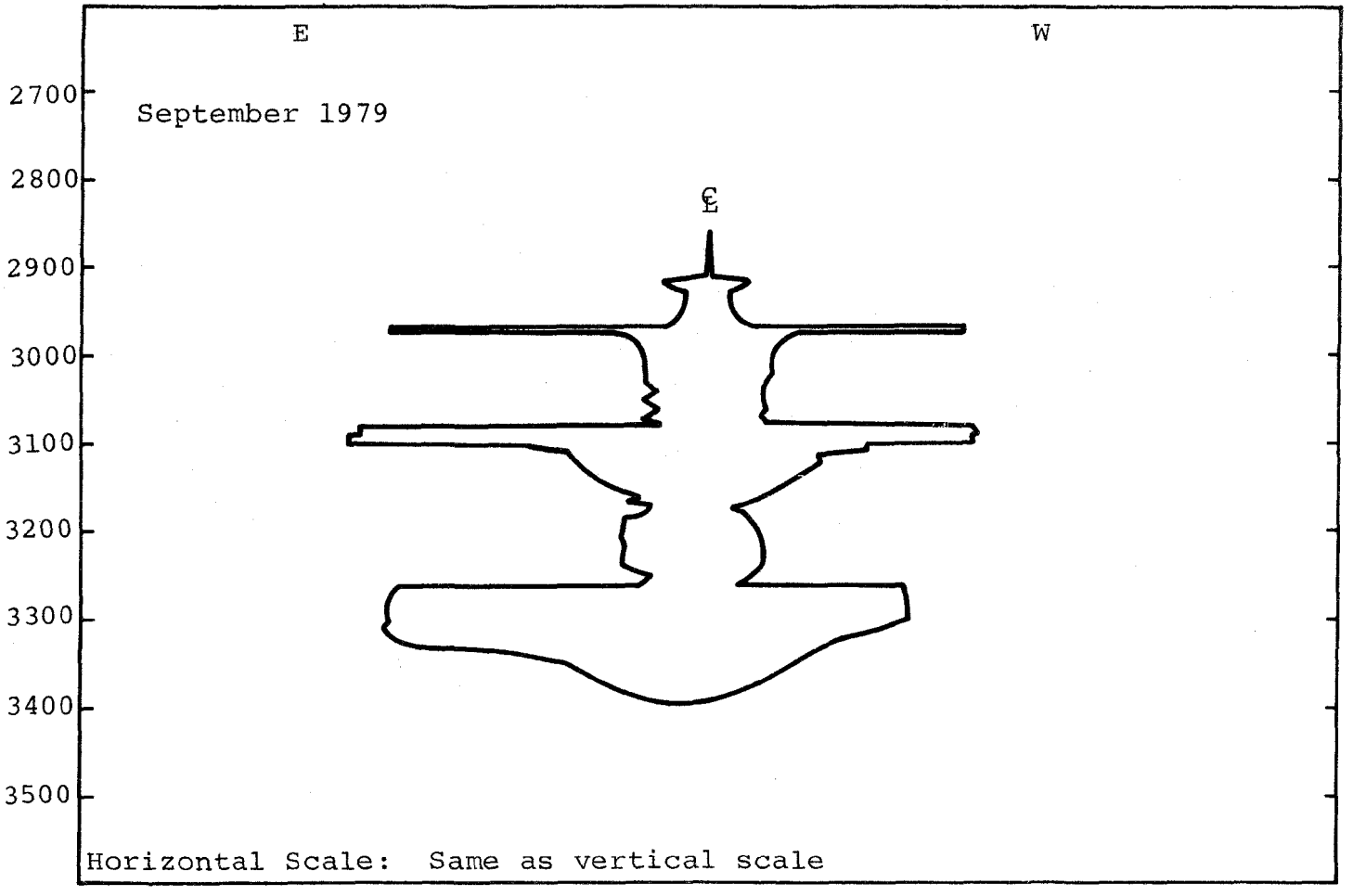


Figure 5. Sulphur Mines Cavern 6

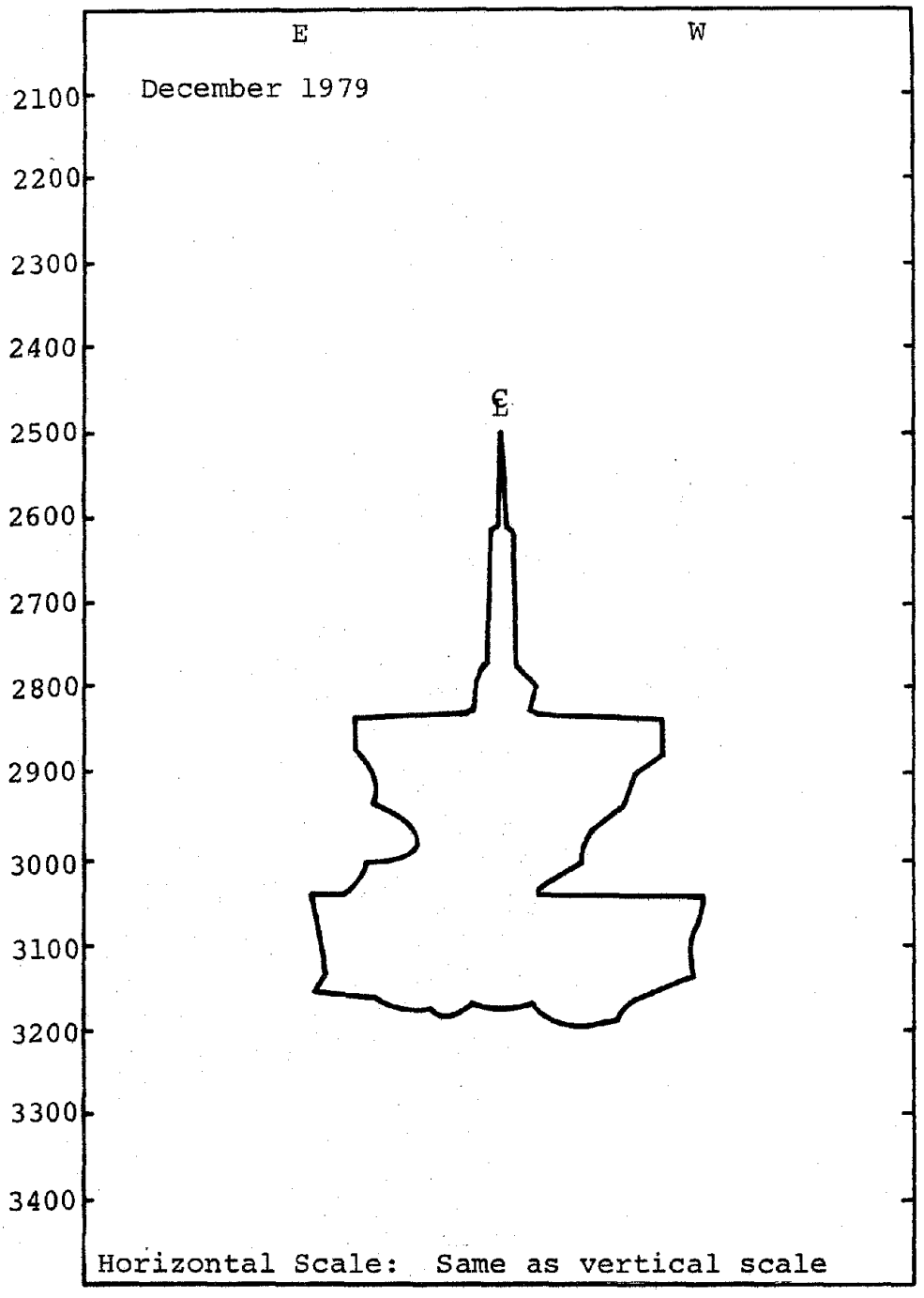


Figure 6. Sulphur Mines Cavern 7

SECTION III

SALT PROPERTIES FOR SULPHUR MINES DOME

NOVEMBER 1980

Section Editor
R. R. Beasley

ABSTRACT

This section is to contain the results of three areas of salt evaluation--mineralogy analyses, mechanical property tests, and geophysical log analyses--and is to cover the materials pertinent to cavern structural analysis. There are no material samples or geophysical logs available that relate to the material properties of the salt. If material properties information becomes available, it will be added in this section.

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INTRODUCTION

SPR Program Description

The Energy Policy and Conservation Act (EPCA) enacted in December 1975 provided the legislative authorization for the Strategic Petroleum Reserve (SPR). The objective of the SPR is to store substantial quantities of crude oil in order to diminish US vulnerability to the effects of a severe interruption in supply. The current plan for the SPR consists of three phases that, when complete, will provide the US with a 750-million-barrel (MMB) reserve. The legislation authorized up to a 1-billion-barrel reserve, but plans have not been completed for the last 250 MMB.

The Phase 1 portion of the reserve uses existing storage volume at five sites. Four of the sites (Bryan Mound, TX; West Hackberry, LA; Sulphur Mines, LA; and Bayou Choctaw, LA) have solution-mined caverns that were originally created to produce brine as chemical feedstock; and the fifth site, Weeks Island, LA has a conventional salt mine. The total existing capacity of these five sites is 248 MMB. Phase 2 plans are to expand the Bryan Mound and West Hackberry sites by solution-mining 12 and 16 additional caverns, respectively, of 10 MMB each. Plans for the remainder of the storage capacity to reach the 750-MMB reserve are being developed by the US Department of Energy (DOE).

Sandia SPR Participation

Sandia National Laboratories at DOE request has made a short-term systems integration and engineering support study. The results of this study have been published.[1] Several geotechnical recommendations resulted from this study, and Sandia was assigned the responsibility to provide a coordinated program of geotechnical investigations to support continued development of the SPR. The geotechnical program will provide a sufficiently comprehensive, site-specific data base to support the planning, design, construction, and operation of SPR crude-oil storage facilities. These data will be used in assessing the long-term stability of SPR storage caverns and mines to minimize the potential for cavity failures that could result in significant environmental impacts, economic losses, or failure to withdraw oil when needed. A long-term monitoring plan will be developed that will assure maintenance of the quantity and quality of the stored crude oil in a readily recoverable condition. The geotechnical program includes the following activities: geological site characterization; engineering design

assistance and evaluation, including numerical simulation studies; laboratory and bench-scale testing of salt cores from SPR sites; monitoring and interpretation of field events; and instrumentation evaluation and development. These efforts pertain to the five sites currently in the SPR program.

An additional task to provide interim technical support for leaching the first five three-well caverns at the Bryan Mound site was added by the SPR Project Manager's Office (SPRPMO) to the Sandia SPR Geotechnical Program.

Report Description

Section I reviews cavern stability, integrity, and usability at the existing caverns at Sulphur Mines. The early analyses were done by using typical material properties. Future analyses will be done by using the information reported in Sections II and III of this report. As these analyses are completed, results and recommendations will be published.

Section II of this report is a comprehensive geological site characterization study done by Law Engineering Testing Company for Sandia. In the first phase, a comprehensive study has been prepared from existing data; and in the second phase, field programs would be used to gather specific information as needed. Section II represents the results of Phase I only.

Section III of this report will be amended in the future to summarize the materials property work that may be done at Sandia and by contractors. Currently, neither geophysical logs from wells at Sulphur Mines nor cores are available that would provide the information from which specific properties could be assembled for use in our analytical models.

Sandia Recommendations Resulting from Geological and Material Studies

- Do not completely fill Caverns 6 and 7 until after the distance from Cavern 7 to the edge of the dome has been determined. The most practical and accurate technique is a directionally drilled well combined with borehole geophysical logging.

- Do not completely fill the 2-4-5 cavern gallery until the distance from Cavern 4 to the edge of the dome has been defined.

If oil storage is required before the distance to edge of the dome is determined, we recommend a thorough test of both cavern groups. This would include a low-pressure test to determine the current condition of the caverns, and continuous monitoring of cavern pressures during oil storage to immediately detect any change that could result from communication between the caverns and the exterior of the dome.

Assuming the edge-of-dome concerns are resolved satisfactorily, the following actions are recommended.

(1) Drill and case a well into Cavern 5 to eliminate the potential for trapping any gas that could cause unacceptably high pressures at the casing seat.

(2) Recertify the 2-4-5 cavern gallery.

(3) Take sonar caliper surveys of all caverns after Pittsburgh Plate Glass (PPG) stops brining and before oil is stored.

(4) Maintain the same type oil in Caverns 6 and 7.

(5) Establish a program to monitor the well casings for corrosion, especially through the caprock.

(6) Limit the number of freshwater drawdown cycles to one.

SECTION I

SULPHUR MINES CAVERN STABILITY ISSUES

MARCH 1981

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ABSTRACT

Cavern stability, integrity, and usability issues regarding existing and planned storage caverns in the Sulphur Mines salt dome are reviewed. Previous studies are discussed, ongoing investigations are summarized, and data needed to support the assessments are described.

SECTION I

CONTENTS

	Page
INTRODUCTION AND SUMMARY	2
CAVERNS AT SULPHUR MINES	3
Sulphur Mines Cavern 2	4
Sulphur Mines Cavern 4	4
Sulphur Mines Cavern 5	5
Sulphur Mines Cavern 6	5
Sulphur Mines Cavern 7	6
REFERENCES	7

ILLUSTRATIONS

Figure

1	Locations of Caverns at Sulphur Mines Salt Dome	9
2	Sulphur Mines Cavern 2	10
3	Sulphur Mines Cavern 4	11
4	Sulphur Mines Cavern 5	12
5	Sulphur Mines Cavern 6	13
6	Sulphur Mines Cavern 7	14

INTRODUCTION AND SUMMARY

The US Strategic Petroleum Reserve (SPR) program currently uses five existing caverns in the Sulphur Mines salt dome near Lake Charles, LA for storage of crude oil. Locations of the caverns are shown in Figure 1. This report summarizes current concerns and briefly describes previous work in assessing the stability, integrity, and usability of each cavern and the proposed new caverns.

There are many common issues of concern at each site--depressurization effects, long-term creep closure, etc. The techniques used to address concerns at one site apply at all sites.

A review of cavern stability issues for each SPR site was provided in Reference 1 in 1979. From this blueprint for action, Sandia National Laboratories began a program of geotechnical investigations to support the continued development of the SPR. Initial evaluations of cavern integrity have been based upon the use of generic or "typical" salt properties. These evaluations have attempted to bound concerns associated with creep-closure rates, depressurization of the caverns to zero surface pressure on the oil column, and pillar or web thickness. Concurrently with these evaluations, a materials testing program was begun to characterize the salt from each site. Data from the materials testing program will be used in ongoing and future studies to more accurately represent the geomechanical response of the caverns in the Sulphur Mines dome. These data also serve as input to leaching-simulation activities. Initial evaluations of cavern integrity were based upon cavern spacing data and dome boundary locations of questionable accuracy. Site characterization activities (Section II) have now brought together accurate, consistent geological and geometrical data on sediments, caprock, salt stock, and cavern locations that will be valuable in assessing stability concerns. Additional data will be required in order to understand the failure or fracture of the salt.

Site characterizations, and careful consideration of the numerical analyses made to date on Sulphur Mines caverns and caverns in other domes, have resulted not only in several useful observations about the existing caverns but have also helped define additional evaluations that are needed.

Caverns 2 and 5 have shapes that are geomechanically stable but are coalesced with Cavern 4. Caverns 4 and 7 are located close to the edge of the dome, and the long-term stability of these caverns cannot be determined with existing data. Stresses developed in Cavern 6 ledges approach failure levels when the cavern is filled with oil. These ledges could break and damage the hanging strings.

CAVERNS AT SULPHUR MINES

Table 1 summarizes the geometrical data regarding the location of the five existing caverns in the Sulphur Mines dome. Similar tables have been published previously by Tillerson[2] for each SPR site; however, Table 1 contains new data obtained in the site characterization work or recently generated. The Sulphur Mines cavern volumes range from about 3 MMB to more than 6 MMB. Cavern heights vary from 450 to 1400 ft; diameters from 299 to 680 ft. Cavern roofs vary from a depth of 2447 to 2910 ft below the surface, while maximum depths are between 3086 and 3420 ft. Because the cavern geometry (as related to the vertical and horizontal distances to the dome boundaries and to adjacent caverns) largely governs its suitability for storage from a geomechanics viewpoint, these properties and ensuing ratios to the cavern diameter, D, have been recorded in Table 1. The parameters for the Sulphur Mines caverns (Table 1) are seen as the bounds on several of the parameters in the overall program.

The distance between adjacent caverns, P, is the current wall thickness (not the center-to-center spacing between caverns) used as a measure of the likelihood for cavern coalescence. The P/D ratio indicates the pillar width relative to cavity size and inversely relates to the intensity of the loading that might be felt in the pillar; i.e., a 100-ft pillar between 500-ft-dia caverns (P/D = 0.2) would be more intensively loaded than if the surrounding caverns at the same depth had only a diameter of 100 ft (P/D = 1).

The roof or back thickness, B (amount of salt between cavern roof and the caprock), is important to cavern stability since the salt must be thick enough to ensure proper grouting of the casing. The B/D ratio indicates the thickness-to-span ratio for the cavern roof. As the B/D ratio decreases to well below 1.0, concern intensifies regarding how adequate the roof material is for transmitting loads from the caprock to the cavern walls without developing tensile stresses.

Another parameter, E, that can limit the suitability of an existing cavern for the storage of crude oil is how near the caverns are to the edge of the dome. The salt near the edge of a dome is more likely to be locally fractured and to contain impurities other than the salt in the interior of the dome. Any linkage between geologic formations bordering a dome and caverns within the dome must be avoided since the product stored in a cavern could conceivably be lost. Proximity of caverns to the edge of the dome may therefore limit the number of withdrawal cycles of a cavern.

Engineering, construction, and storage activities at the Sulphur Mines site have been briefly described in annual SPR reports.[3-5] New wells have been drilled at the site to enhance the operating capabilities of the caverns. Each cavern at Sulphur Mines was pressure-tested and certified as suitable for storage of crude oil.[6] In addition, sonar surveys were obtained,

logs were run of casing integrity, cement bond, and temperature, and new casings were cemented into existing wells as needed.

Sulphur Mines Cavern 2

Cavern 2 was reported at certification in November 1977 to have a volume of 6.2 MMB and a height of 640 ft (Figure 2). Its shape at that time was irregular, with its chambers of largest diameter located at the top and bottom. The largest diameter averaged in all directions at the referenced depth was 642 ft at a depth of 2930 ft. Pittsburgh Plate Glass (PPG) continued to brine with weak brine in Cavern 2 after certification in agreement with the DOE. A sonar survey in May 1979 showed the cavern volume had increased to 6.4 MMB, although the height had not changed. The largest averaged diameter was 680 ft at a depth of 2940 ft. Cavern 2 has coalesced with Caverns 4 and 5 to create a 13.6-MMB gallery.

Sandia has not made a detailed geomechanical analysis of the structural shape of Cavern 2. We have, however, compared the general shape of the structure with those where detailed analyses were made, and Cavern 2 is judged stable.

Sulphur Mines Cavern 4

Cavern 4 was reported to have a volume of 2.9 MMB and a height of 310 ft at certification in August 1977 (Figure 3). Its general shape at that time was very irregular, with the chambers of intermediate diameter located at the top and bottom of the cavern. Necked-down regions of smaller diameter connected these extremities to a pancake-shaped chamber of large diameter near the middle of the cavern. The largest averaged diameter was 748 ft a a depth of 2930 ft. PPG continued to brine in Cavern 4 with weak brine after certification in agreement with the DOE. Cavern 4 has coalesced with Caverns 2 and 5 to create a 13.6-MMB gallery.

A sonar survey of Cavern 4 in May 1979 showed its volume had increased to 3.8 MMB, and the height increased to 450 ft. The distance from the cavern to the edge of the dome has been studied in Section II of this report. For Cavern 4 that distance is reported as 185 ft. Sandia has stated[7] that the minimum thickness of competent salt required to assure the long-term integrity of the cavern is 50 ft. When the following factors are considered, the 185 ft is reduced close to the 50-ft requirement and is therefore considered marginal: (1) The tolerances on the edge of the dome, ±75 ft, (2) the tolerance on the well survey, 2.6 ft radial deviation per 1000 ft of depth, (3) the sonar caliper survey tolerance, ±5% of cavern radius, and (4) the shear zone at the dome edge consisting of a jagged rough surface with shale intrusion and clay gauges as reported by Kupfer.[8]

Sandia has not made a detailed geomechanical analysis of Cavern 4 but has compared the Cavern 4 shape with similar cavern shapes where analyses have been made. The shape of Cavern 4 is judged stable. The overall cavern stability and integrity will depend on a more favorable definition of the edge of dome (much greater spacing) or on accurately and satisfactorily defining the cavern-to-dome edge distance and salt quality to reduce the previously described tolerances.

Sulphur Mines Cavern 5

Cavern 5 was certified with the condition that the 4½-in. casing be removed, or the leak in the casing be repaired, or the casing be plugged to the surface. It was the understanding of Gulf Interstate at certification that a new Well 5A would be drilled to replace Well 5. Well 5 has been plugged, but no reentry well has been drilled; this has created a trap where 32 MB of oil cannot be recovered by conventional means and also a trap for released gas from the formation. This latter condition could result in unacceptably high pressures at the casing seat.

Cavern 5 was reported to have a volume of 3.3 MMB and a height of ~1400 ft at certification in September 1977 (Figure 4). Its general shape was irregular, with long slender spirals at the top and bottom and varying diameters in the middle. The largest averaged diameter was 460 ft at a depth of 2950 ft. A sonar survey of Cavern 5 taken just before the plugging operation in May 1979 showed very little increase in volume (3.4 MMB) caused by continued PPG brining in the 2-4-5 coalesced gallery.

Sandia has not made a detailed geomechanical analysis of Cavern 5 but has compared its shape with similar cavern shapes where analysis has been made. Cavern 5 is judged stable.

Sulphur Mines Cavern 6

Cavern 6 was reported to have a volume of 5.2 MMB and a height of 415 ft at certification in December 1977 (Figure 5). Its general shape was very irregular, with large-diameter chambers at the bottom and at the two-thirds-height level. The September 1979 sonar showed a third large-diameter pancake-shaped cavity was formed at the top of the cavern as the result of additional brining. The largest averaged diameter was 618 ft at a depth of 3080 ft.

Section II of this report indicated that Caverns 6 and 7, which are separated by only 20 ft, are on the verge of coalescing. This judgment is based on well directional surveys and cavern sonar caliper surveys.

The shape of Cavern 6 raises questions as to whether possible insoluble layers within the salt dome were causing the multiple-ledged structure. In the absence of core material, Sandia has used the PPG brining schedule as input and controls

for use in the Salt 77 Leaching Code to analyze this cavern. Results indicated that the shape was a result of the brining schedule, not of large insoluble layers.

Sandia has made a detailed geomechanical analysis of Cavern 6 that shows the ledges approach failure when the cavern is filled with oil. Ledge failure could result in damage to the hanging strings but should not affect the overall structural integrity of the cavern.

Sulphur Mines Cavern 7

Cavern 7 was reported to have a volume of 5.6 MMB and a height of 405 ft at certification in December 1977 (Figure 6). Its general shape was irregular, with two large-diameter chambers connected by a necked-down region. The maximum diameter was 460 ft. A sonar survey retaken of Cavern 7 in December 1979 after additional PPG brining showed that its cavern volume had increased to 6.3 MMB and its height to 585 ft.

Section II of this report indicated that Caverns 7 and 6, which are separated by only 20 ft and are on the verge of coalescing. This judgment is based on well directional surveys and cavern sonar caliper surveys.

Section II has also studied the distance of the cavern to the edge of the salt dome. That distance is 160 ft for Cavern 7. Sandia has stated[8] that the minimum thickness of competent salt required to assure the integrity of the cavern is 50 ft. The 160 ft is reduced by the tolerances and dome properties discussed under Cavern 4 above and is considered potentially unacceptable. The most practical, accurate technique to reduce the uncertainties is a directionally drilled well combined with borehole geophysical logging.

Sandia's geomechanical analysis of the Cavern 7 shape has shown the cavern to be stable; however, the overall stability and integrity of Cavern 7 can only be determined by defining the salt and by defining the cavern-to-dome-edge distance.

REFERENCES

1. Systems Integration and Engineering Support Study for the Strategic Petroleum Reserve (SPR) Program - Final Report, prepared by Sandia National Laboratories for the US Department of Energy, June 1979.

2. J. R. Tillerson, "Geomechanics Investigations of SPR Crude Oil Storage Caverns," Invited Paper presented at Solution Mining Research Institute Fall Meeting, Toronto, Canada, October 1979.

3. Strategic Petroleum Reserve - Annual Report, DOE/RA-0004/1(77), DOE/SPRO, February 1978.

4. Strategic Petroleum Reserve - Annual Report, DOE/US-003, DOE/SPRO, February 1979.

5. Strategic Petroleum Reserve - Annual Report, DOE/RA-0047, DOE/SPRO, February 1980.

6. Gulf Interstate Engineering Company, Solution Cavern Certificates of Usability and Integrity for Sulphur Mines Site, 1978.

7. Memorandum to File from M. H. Gubbels of Sandia National Laboratories, dated October 7, 1980, "Edge of Dome Effects Due to Pressurization/Depressurization of Caverns."

8. D. H. Kupfer, "Boundary Shear Zones in Salt Stock," Presented at Fourth Symposium on Salt, 1974.

Table 1

Geometrical Data for the Five Sulphur Mines Caverns

SULPHUR MINES

Cavern Number	Year Constructed	Volume (mmb)	Oil Stored (mmb)	Type of Oil	DEPTHS - ft: Top of Caprock	Top of Salt	Casing Seat	Top of Cavern	Bottom of Cavern	Cavern Diameter, D (at roof/max)	Cavern Height, H	H/D	Nearest Cavern	Distance to Nearest Cavern, P	P/D**	Roof Thickness, B	B/D	Distance to Dome Edge, E	E/D**
2	1946	6.4	*	*	500	1460	1562	2447	3086	450/680	640	1.4				987	1.45		
4	1949	3.8	*	*	819	1620	1640	2640	3090	432/748	450	1.04				1020	1.36	185	.25
5	1953	3.4	*	*	829	1480	1714	2448	3420	299/460	1400	4.7	Allied #2 Well PPG #1-A	380 250	.83 .54	968	3.2		
6	1955	5.9	*	*	620	1470	1836	2910	3390	284/618	480	1.7	#7	20	.03	1440	2.33	383	.62
7	1957	6.3	*	*	962	1500	1822	2770	3195	328/460	585	1.78	#6	20	.04	1270	3.88	160	.35

*No oil is currently stored at the Sulphur Mines site.

NOTE: All distances are given in feet.

**At maximum diameter

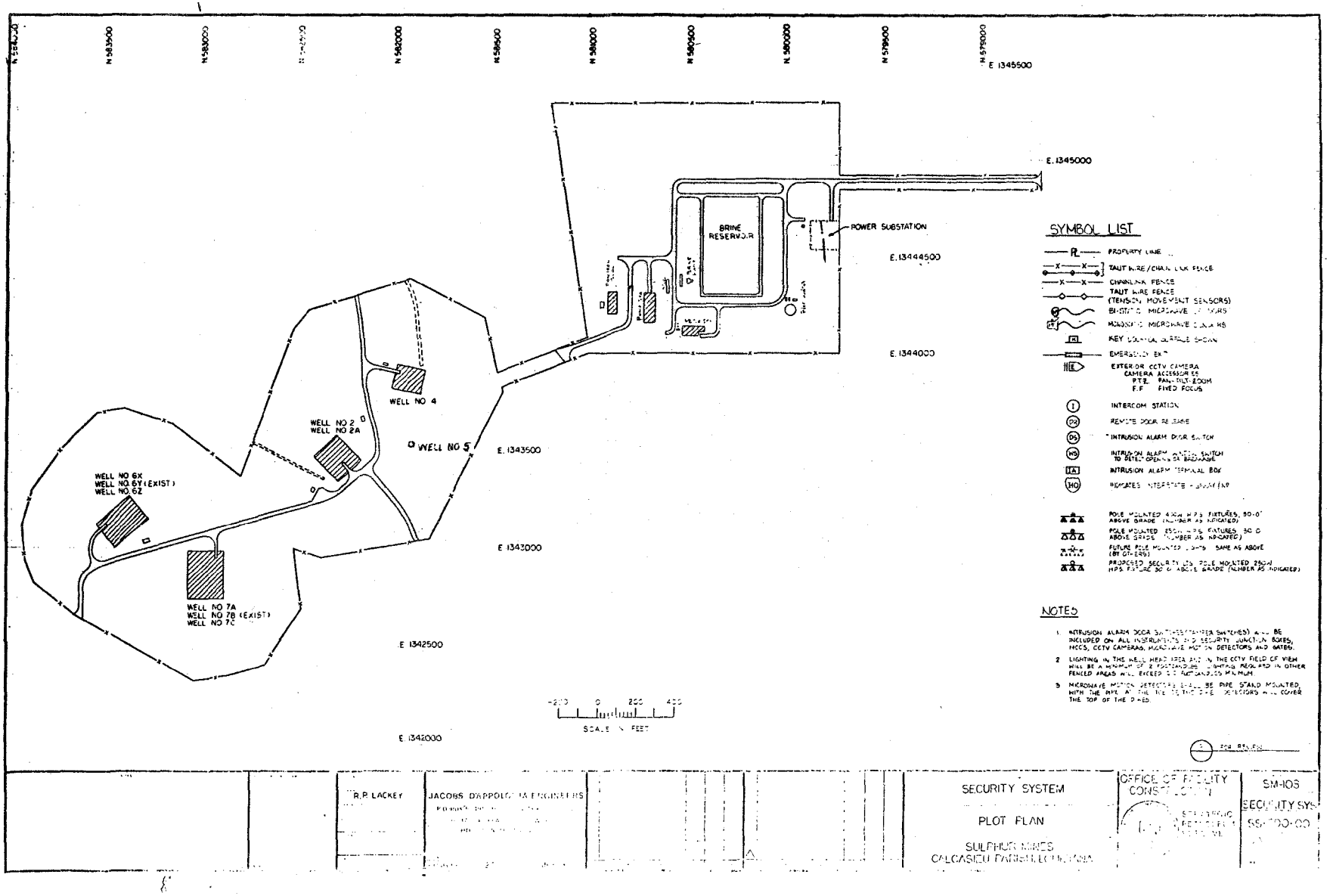


Figure 1. Locations of Caverns at Sulphur Mines Salt Dome

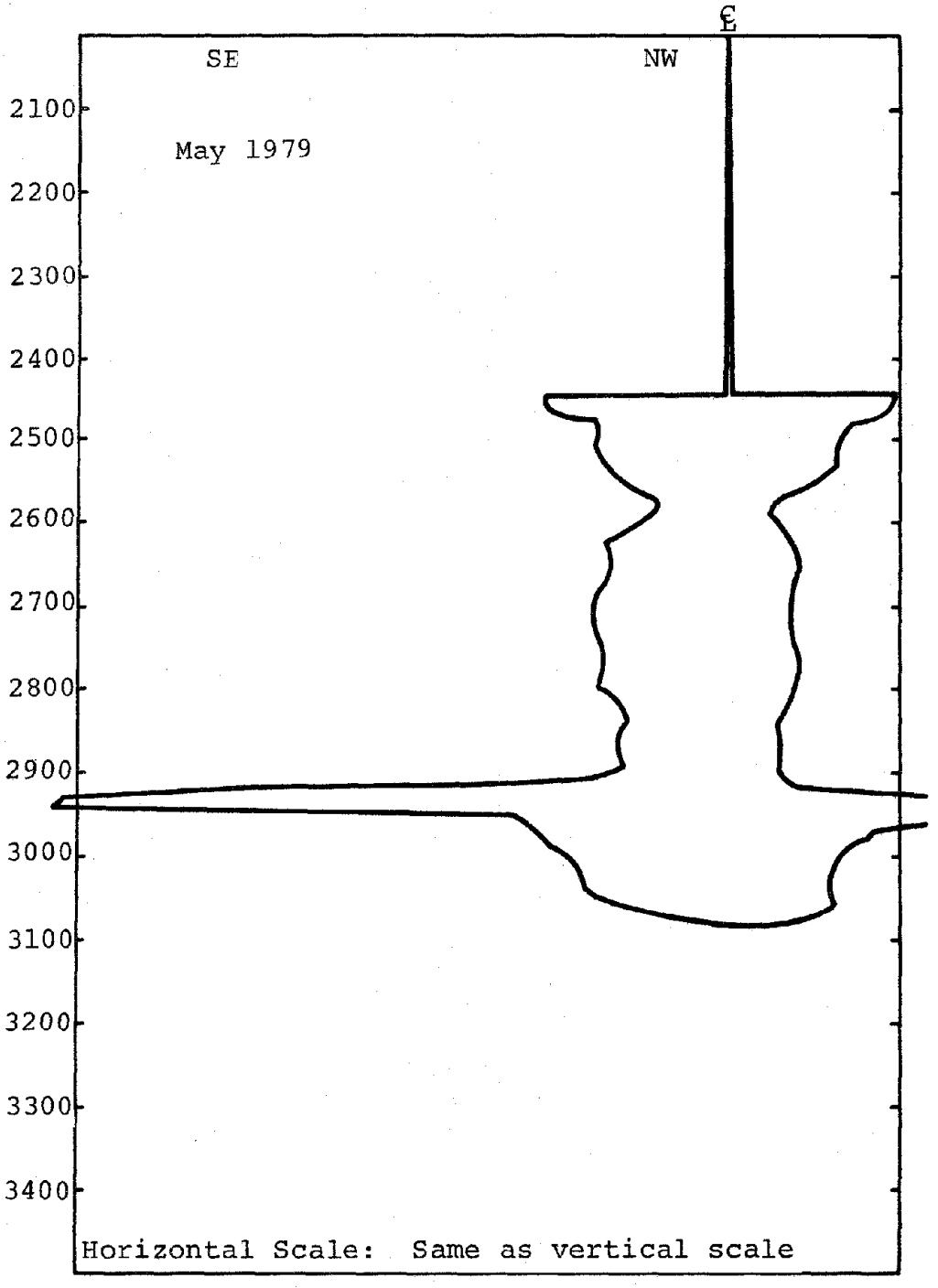


Figure 2. Sulphur Mines Cavern 2

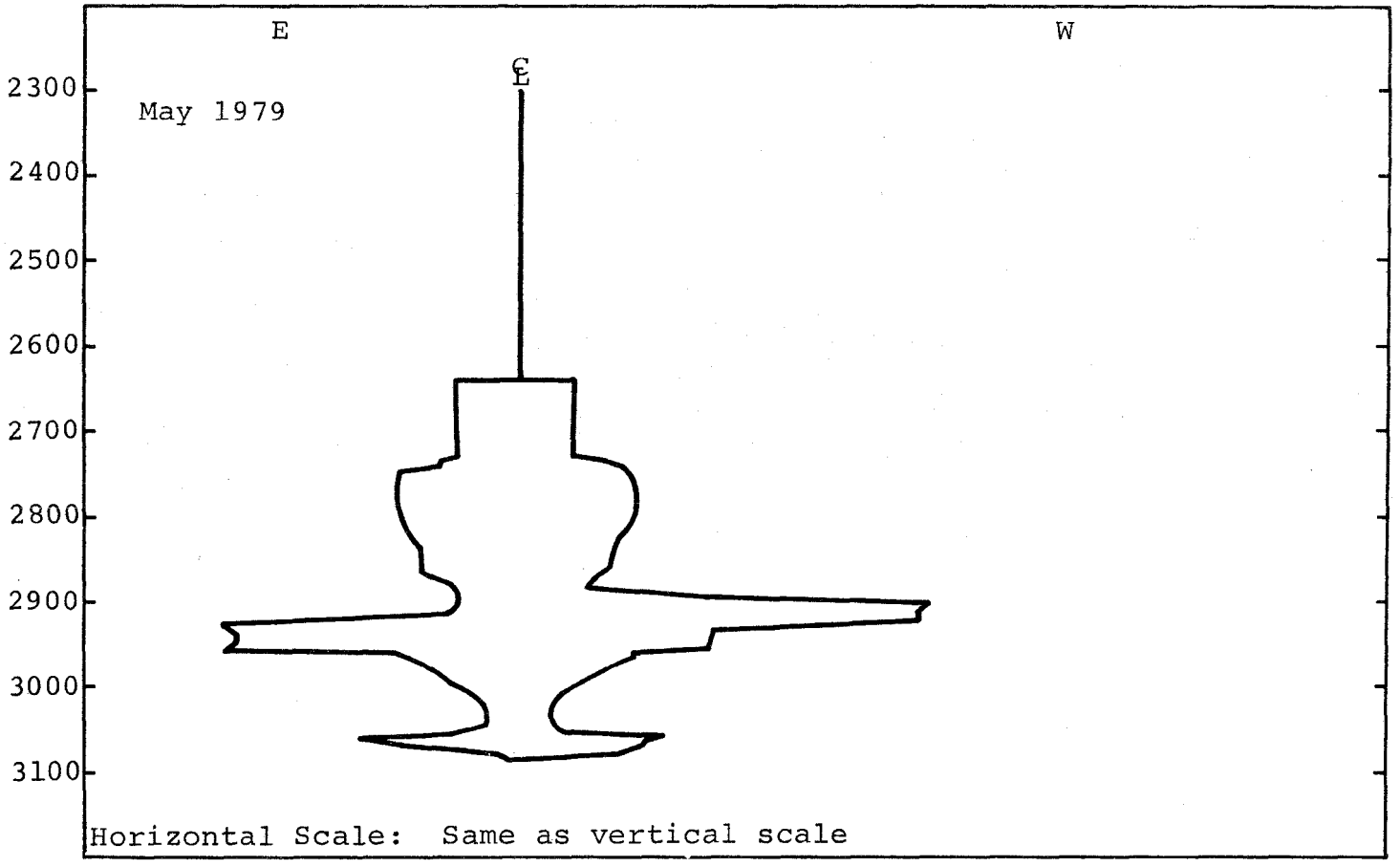


Figure 3. Sulphur Mines Cavern 4

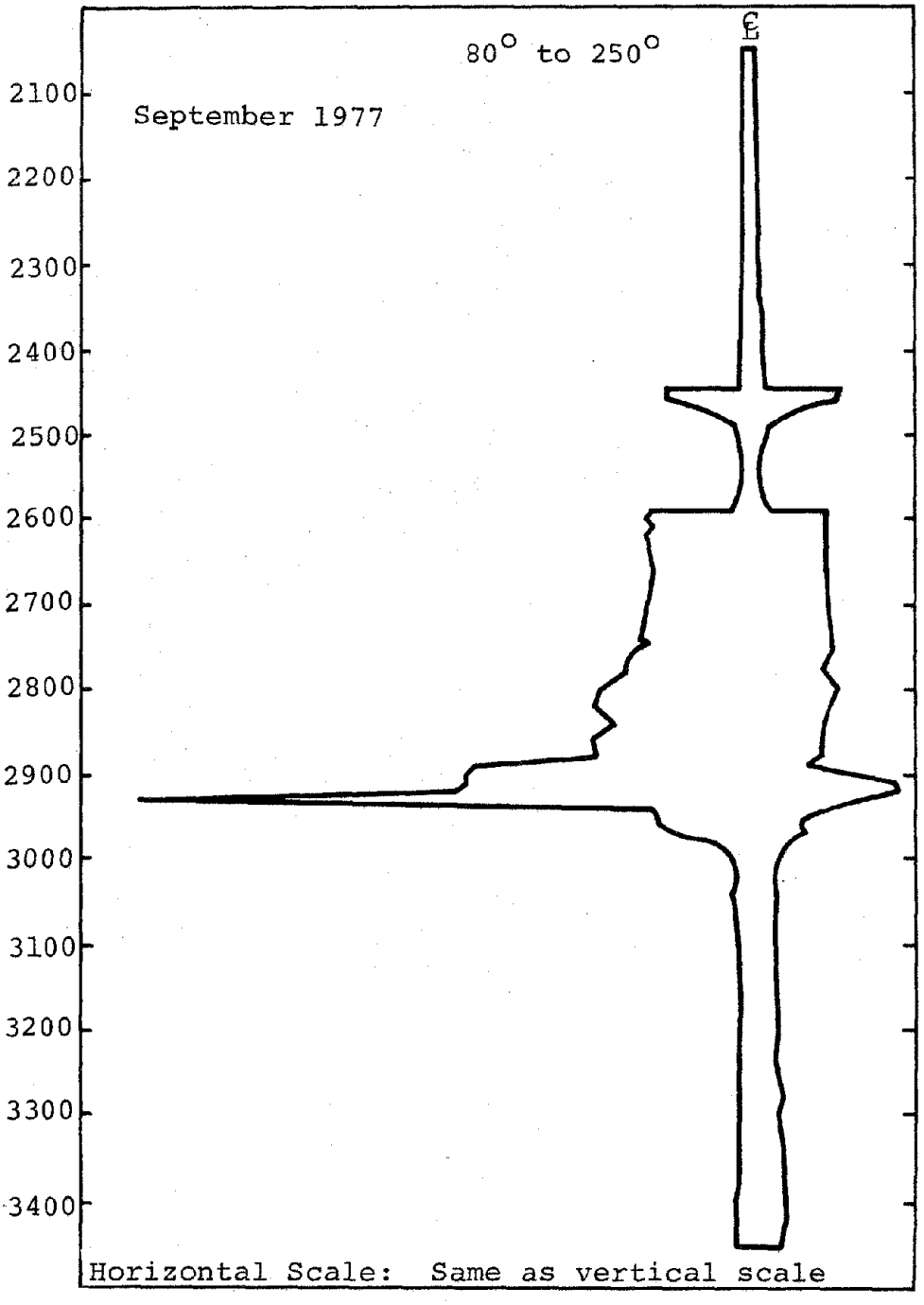


Figure 4. Sulphur Mines Cavern 5

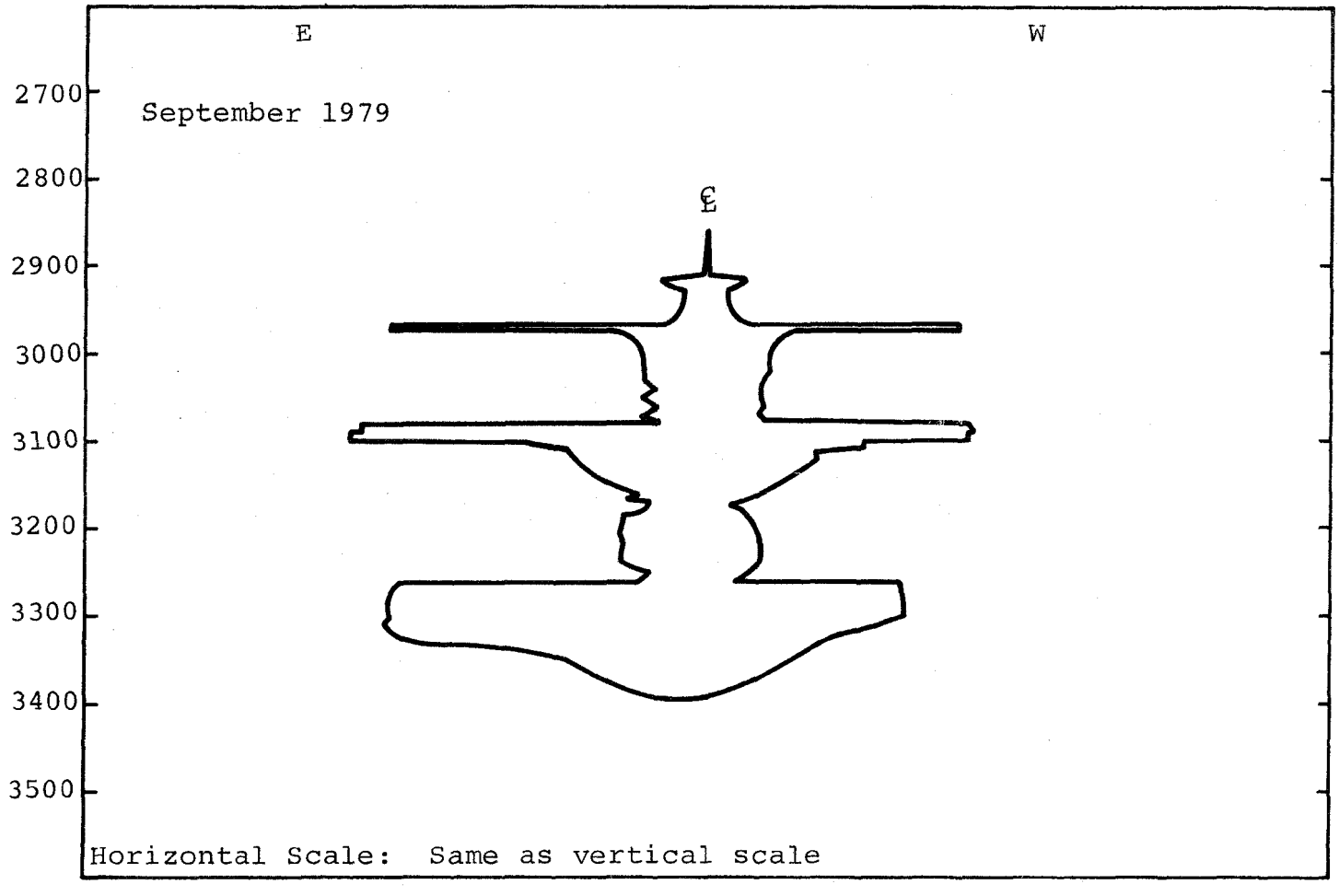


Figure 5. Sulphur Mines Cavern 6

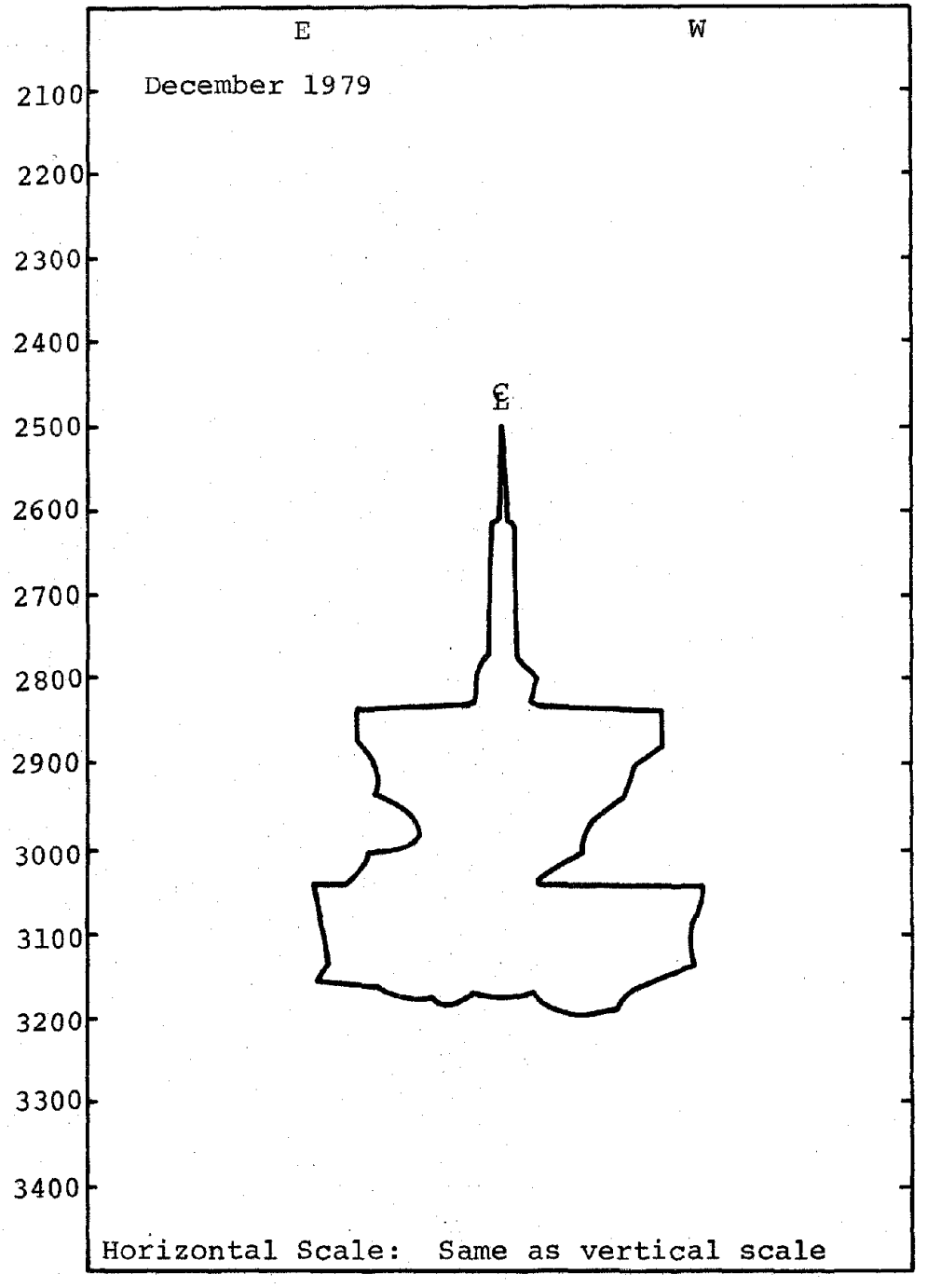


Figure 6. Sulphur Mines Cavern 7

SECTION II

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October 10, 1980

Sandia Laboratories
SPR Geotechnical Division (4543)
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Albuquerque, New Mexico 87185

Attention: Mr. Glen Whiting

Subject: Transmittal of Final Report
Geotechnical Characterization of Sulphur Mines
Strategic Petroleum Reserve (SPR) Site
Sandia Contract Number 46-6272

Dear Mr. Whiting:

Law Engineering Testing Company is pleased to submit 72 copies of the final report entitled, "Geological Characterization of the Sulphur Mines SPR Site, Sulphur, Louisiana."

We appreciate the opportunity to serve Sandia Laboratories on this project.

Very truly yours,

LAW ENGINEERING TESTING COMPANY

Louis S. Karably
Project Manager

Gerald H. Fogle
Chief Geologist
Assistant Vice-President

LSK/GHF:lc

TABLE OF CONTENTS

		Page
1.0	SUMMARY AND CONCLUSIONS	1-1
1.1	SUMMARY	1-1
1.1.1	Regional Geology and Hydrology	1-1
1.1.2	Site Geology and Hydrology	1-1
1.1.3	Caprock Geology and Hydrology	1-2
1.1.4	Salt Dome Geology and Hydrology	1-2
1.1.5	Geologic and Hydrologic Hazards	1-2
1.1.5.1	Subsidence	1-2
1.1.5.2	Flooding	1-2
1.2	CONCLUSIONS	1-2
1.2.1	Regional	1-2
1.2.1.1	Flooding	1-2
1.2.2	Site	1-3
1.2.2.1	Subsidence	1-3
1.2.2.2	Corrosive Environment	1-3
1.2.3	Caprock	1-3
1.2.3.1	Circulation Losses	1-3
1.2.4	Salt Dome	1-3
1.2.4.1	Cavern Coalescence	1-3
1.2.4.2	Cavern Breach	1-3
2.0	INTRODUCTION	2-1
2.1	CONTRACTURAL BACKGROUND	2-1
2.2	SITE DESCRIPTION AND HISTORY	2-1
2.2.1	Pre-DOE Site Development	2-1
2.2.2	DOE Site Development	2-1
2.3	PURPOSE OF CHARACTERIZATION	2-2
2.4	SCOPE OF GEOLOGIC CHARACTERIZATION	2-2
2.5	SCOPE OF HYDROLOGIC CHARACTERIZATION	2-2
2.6	DATA AQUISITION	2-3
3.0	REGIONAL GEOLOGY AND HYDROLOGY	3-1
3.1	REGIONAL GEOLOGY	3-1
3.1.1	Physiography	3-1
3.1.2	Surficial Geology	3-3
3.1.3	Soil Distribution	3-3
3.1.4	Statigraphy	3-5
3.1.5	Structural Geology	3-5
3.1.6	Regional Seismicity	3-6
3.1.6.1	Historic Seismicity	3-6
3.1.6.2	Regional Tectonics and Seismicity	3-7
3.1.6.3	Seismic Risk Analysis	3-7

TABLE OF CONTENTS (cont'd)

		Page
3.2	REGIONAL HYDROLOGY	3-7
3.2.1	Surface Hydrology	3-7
3.2.1.1	Climatic Conditions	3-8
3.2.1.2	Drainage Basins	3-8
3.2.1.3	Flooding Potential	3-9
3.2.2	Subsurface Hydrology	3-10
3.2.2.1	General Hydrogeologic Setting	3-10
3.2.2.2	Alluvial Aquifers of Recent Age	3-11
3.2.2.3	Chicot Aquifer System	3-11
3.2.2.4	Evangeline Aquifer	3-14
3.2.2.5	Jasper and Deeper Aquifers	3-15
3.3	IMPACT ON SPR FACILITIES	3-15
3.3.1	Regional Geology	3-15
3.3.2	Regional Hydrology	3-16
4.0	SITE GEOLOGY AND HYDROLOGY	4-1
4.1	SITE GEOLOGY	4-1
4.1.1	Physiography	4-1
4.1.2	Surficial Geology	4-2
4.1.2.1	Pleistocene	4-2
4.1.2.2	Recent	4-3
4.1.3	Soils Distribution and Properties	4-4
4.1.3.1	Soils of the Prairie Formation	4-4
4.1.3.2	Soils of Recent Geologic Deposits	4-4
4.1.3.3	Fill Soils	4-5
4.1.3.4	Collapsable Soils	4-5
4.1.4	Stratigraphy	4-6
4.1.4.1	Vicksburg Group (Oligocene)	4-6
4.1.4.2	Catahoula Group (Oligocene)	4-6
4.1.4.3	Fleming Group (Miocene)	4-8
4.1.4.4	Citronelle Group (Pliocene)	4-8
4.1.4.5	Houston Group (Pleistocene)	4-8
4.1.5	Structural Geology	4-10
4.1.6	Oil and Gas Exploration and Production	4-12
4.2	SITE HYDROLOGY	4-13
4.2.1	Site Surface Hydrology	4-13
4.2.1.1	Site Drainage	4-14
4.2.1.2	Flooding Potential	4-15
4.2.1.3	Water Quality	4-16
4.2.2	Site Subsurface Hydrology	4-16
4.2.2.1	Site Hydrogeologic Conditions	4-16
4.2.2.2	Hydrogeologic Conditions Above the Caprock	4-17
4.3	IMPACT ON SPR FACILITIES	4-18
4.3.1	Site Geology	4-18
4.3.2	Site Hydrology	4-19

TABLE OF CONTENTS (cont'd)

		Page
5.0	CAPROCK GEOLOGY AND HYDROLOGY	5-1
5.1	CAPROCK GEOLOGY	5-1
5.1.1	Formation of Caprock at Sulphur Mines	5-1
5.1.2	Caprock Geometry	5-2
5.1.2.1	Method of Geometric Definition	5-2
5.1.2.2	Analysis of Shape	5-3
5.1.3	Mineral Exploration and Production	5-4
5.1.4	Subsidence	5-5
5.1.4.1	History of Subsidence	5-5
5.1.4.2	Mud-Filling of Caprock	5-7
5.2	CAPROCK HYDROLOGY	5-8
5.2.1	Caprock Hydrogeologic Zones	5-8
5.2.2	Caprock Ground-Water Quality	5-9
5.3	IMPACT ON SPR FACILITIES	5-10
5.3.1	Caprock Geology	5-10
5.3.2	Caprock Hydrology	5-10
6.0	SALT DOME GEOLOGY AND HYDROLOGY	6-1
6.1	SALT DOME GEOLOGY	6-1
6.1.1	Growth History of Salt Domes	6-1
6.1.2	Formation of Sulphur Mines Salt Dome	6-2
6.1.3	Salt Dome Geometry	6-4
6.1.3.1	Analysis of Salt Dome Shape	6-6
6.1.4	Brine Production and Storage	6-6
6.1.4.1	Brining	6-6
6.1.4.2	Storage	6-9
6.1.5	Cavern Breach	6-9
6.1.5.1	Potential for Cavern Breach	6-9
6.1.6	Cavern Coalescense	6-12
6.1.6.1	Potential Cavern Coalescense	6-12
6.2	SALT DOME HYDROLOGY	6-12
6.3	IMPACT OF SPR FACILITIES	6-13
6.3.1	Salt Dome Geology	6-13
6.3.2	Salt Dome Hydrology	6-14
7.0	GEOLOGIC AND HYDROLOGIC HAZARDS	7-1
7.1	SUBSIDENCE	7-1
7.1.1	Subsidence Potential	7-1
7.1.2	Impact of SPR Facilities	7-2

TABLE OF CONTENTS (cont'd)

		Page
7.2	FAULTING	7-2
7.2.1	Faulting Potential	7-2
7.2.2	Impact on SPR Facilities	7-3
7.3	EARTHQUAKE	7-4
7.3.1	Earthquake Potential	7-4
7.3.2	Impact on SPR Facilities	7-4
7.4	FLOODING	7-4
7.4.1	Impact on SPR Site	7-4

Appendix A References
Appendix B List of Contact
Appendix C Well Control Data
Appendix D Modified Mercalli Intensity Scale
Appendix E Unified Soil Classification System
Appendix F Detailed investigation of dome flank proximity to SPR Cavern No. 4

LIST OF TABLES

NUMBER	TITLE
3-1	Soil Interpretations for Selected Uses
3-2	Stratigraphic Column of Southwestern Louisiana
3-3	Louisiana Area Earthquakes
3-4	Characterization of Hydrogeologic Units in the Region
4-1	Well Locations
4-2	Ponds and Reservoirs in the Vicinity of Sulphur Mines SPR Site
4-3	Data on Wells Within Approximately 2 Miles of the Site
4-4	Ground-Water Quality in Vicinity of the Dome
5-1	Ground-Water Quality Analysis
6-1	Status of Brine Well Carverns
6-2	Brine Well Production and Cavern Development Summary

LIST OF FIGURES

NUMBER	TITLE
2-1	Sulphur Mines SPR Site Location Map
3-1	Gulf Coast Regional Geologic Map
3-2	Louisiana North-South Geologic Cross-Section
3-3	Physiographic and Geologic Map of Southwest Louisiana
3-4	Profile Illustrating Effects of Geosynclinal Subsidence
3-5	Correlation of Glacial Stages with Terrace Deposits of Louisiana
3-6	Regional Soils Map
3-7	Thickness of Cenozoic Sediments in the Gulf Coast Geosyncline
3-8	Louisiana Regional Historic Earthquakes Location Map
3-9	Earthquake Return Period and Probability of Exceedence Curves
3-10	Monthly Normal Precipitation for the Sulphur Mines SPR Site
3-11	Regional Surface Water Features
3-12	100 and 500-year Flood Plains Near SPR Site
3-13	Generalized Outcrop Areas of Alluvial and Chicot Aquifer Systems
3-14	Generalized Cross-Sections of the Chicot Aquifer System in Calcasieu Parish
3-15	Ground Water Levels and Pumpage in the Chicot Aquifer System
3-16	Potentiometric Surface of the "200-Foot" Sand in Calcasieu Parish, March, 1969
3-17	Potentiometric Surface of the "500 Foot" Sand in Calcasieu Parish, Spring, 1970

LIST OF FIGURES (cont'd)

NUMBER	TITLE
4-1	Site Topographic Map
4-2	SPR Property Map
4-3	Premining-Site Topographic Map
4-4	Site Area Lineation Map
4-5	Site Geologic Map
4-6	Site Geologic North-South Cross-Section Map
4-7	Site Geologic East-West Cross-Section Map
4-8	Growth Fault Line in Louisiana
4-9	Salt Pillow Map
4-10	Location Map for North-South Regional Cross-Section
4-11	North-South Regional Cross-Section Through Sulphur Mines Dome
4-12	Base of Anahuac Shale Contour Map
4-13	Projected Surface Expression of Faults
4-14	Disposal Zone Isopach Map
4-15	Seismic Reflection Survey Location Map
4-16	Interpreted Inexco North-South Seismic Section
4-17	Sulphur Mines Dome Interpretation of North-South Seismic Line
4-18	Sulphur Mines Dome Interpreted Southwest-Northeast Seismic Line
4-19	Marginulina Horizon Iso-Cum Map
4-20	Hazzardi Cibicides Horizon Iso-Cum Map
4-21	Miocene Horizon Iso-Cum Map
4-22	Sulphur Mines Site Surface Water Features

LIST OF FIGURES (cont'd)

NUMBER	TITLE
4-23	Well Locations in the Vicinity of the Site
4-24	Generalized Hydrogeologic Cross-Section Through Site
4-25	Location Map of Profiles over the Caprock
4-26	Hydrogeologic Profile (North-South)
4-27	Hydrogeologic Profile (East-West)
5-1	Well Locations for the Northeast-Southwest, Northwest-Southeast Salt Dome Cross-Sections
5-2	Northwest-Southeast Caprock Cross-Section
5-3	Southwest-Northeast Caprock Cross-Section
5-4	Top of Caprock Contour Map
5-5	Sulphur Production Contour Map
5-6	Caprock Collapse Contour Map
5-7	Site Subsidence Monitoring Graph
5-8	Generalized Hydrogeologic Cross-Section Through the Caprock
5-9	Location Map of Water-Quality Profile Through the Caprock
5-10	Generalized Water-Quality Profile Through the Caprock
5-11	Thermal Regime Within Sulphur Mines Salt Dome
6-1	Interpretation of Salt Structure - Morton Salt Co. Mine, Grand Saline Salt Dome
6-2	Gravity Station Location Map
6-3	Top of Salt Contours
6-4	Northwest-Southeast Salt Dome Cross-Section Brine Wells 7, 2, 5 and 4
6-5	Southwest-Northeast Salt Dome Cross-Section through Brine Wells 7 and 6

LIST OF FIGURES (cont'd)

NUMBER	TITLE
6-6	Maximum Cavern Extent and Salt Contours 1000'-3400' Depth Interval
6-7	Maximum Cavern Extent and Salt Contours 1000'-2000' Depth Interval
6-8	Maximum Cavern Extent and Salt Contours 2400'-2600' Depth Interval
6-9	Maximum Cavern Extent and Salt Contours 2600'-2800' Depth Interval
6-10	Maximum Cavern Extent and Salt Contours 2800'-3000' Depth Interval
6-11	Maximum Cavern Extent and Salt Contours 3000'-3200' Depth Interval
6-12	Maximum Cavern Extent and Salt Contours 3200'-3400' Depth Interval
6-13	Site Cross-Section Location Map
6-14	Salt Contour Map (Northwest Quadrant) with SPR Caverns 6 and 7
6-15	Caverns 6 and 7 Showing Cross-Section along A-A'
6-16	Cavern 4 Dome Edge Cross-Section F-G
6-17	Cavern 4 Dome Edge Cross-Section H-F
6-18	Cavern 7 Dome Edge Cross-Section B'-B
6-19	Cavern 6 Dome Edge Cross-Section C-E
6-20	Cavern 6 Dome Edge Cross-Section C-D
6-21	SPR Storage Cavern 2, Growth Relationships
6-22	SPR Storage Cavern 4, Growth Relationships
6-23	SPR Storage Cavern 5, Growth Relationships
6-24	SPR Storage Cavern 6, Growth Relationships
6-25	SPR Storage Cavern 7, Growth Relationships

1.0

1.0 SUMMARY AND CONCLUSIONS

1.1 SUMMARY

The Phase I Geological Characterization of the Sulphur Mines SPR Site in southwestern Louisiana was prepared by Law Engineering Testing Company for Sandia Laboratories as part of the U. S. Department of Energy's Strategic Petroleum Reserve (SPR) program. The primary purpose of this investigation was to review the geologic and hydrologic conditions at the site and to certain if any existing or near-term conditions might adversely pact SPR site operations. A secondary purpose of this report to assist Sandia Laboratories and DOE contractors with future planning and development at the site. The report is organized to seven chapters, chapter 1.0 presents a summary and conclusions, chapter 2.0 is an introduction, chapters 3.0 through 6.0 describe the geology and hydrology of the region, site, prock, and salt dome. The seventh chapter analyzes the hazards scribed in the characterization chapters 3.0 through 6.0.

1.1. Regional Geology and Hydrology

The Sulphur Mines SPR site is located in southwestern Louisiana on the Gulf Coastal plain. The regional topography is nearly flat and subject to poor drainage. The flat topography and high annual rainfall (56 in.) combine to create frequent flooding conditions.

The region is tectonically stable. Damaging earthquakes seldom occur. The maximum historic earthquake within the region is less than Modified Mercalli intensity VI (.06g). Active "growth" faults exist in the region; movement on these faults is in the form of creep. They are not connected to the basement rock and the physical properties of the Gulf Coast sediments do not allow the storage of the high strain-energies required to generate large earthquakes.

The subsurface hydrologic gradients indicate flow to the southeast toward pumping centers in the upper aquifers. Some of the near surface fresh water aquifers are interconnected.

1.1.2 Site Geology and Hydrology

The surface geology immediately around the dome is typical of southwestern Louisiana. Pleistocene terraces have been elevated and eroded relative to sea-level, with Recent sediments deposited in drainageways and swamps. Modern subsidence over the Sulphur Mines salt dome has required fill to be dumped over the areas that had been previously mined for sulphur.

The salt dome has substantially modified the subsurface stratigraphy during its growth process and created numerous structural features, mostly faults. None of these faults are capable of generating earthquakes, however, they could contribute to differential subsidence and act as hydrologic barriers.

1.1.3 Caprock Geology and Hydrology

The Sulphur Mines salt dome caprock is much thicker than average. It once contained vast quantities of sulphur, which was mined during the early 1900's. The mining of the sulphur deposits left large voids in the upper caprock which subsequently collapsed and created the continuing subsidence at the site.

1.1.4 Salt Dome Geology and Hydrology

Sulphur Mines salt dome is small in areal extent when compared to most Gulf Coastal domes. The interior structure of the dome is not well defined. No cores or mapped openings exist. The salt dome has been used for brining and storage operations. The brining operations created numerous irregularly shaped caverns in the salt mass. Most of these caverns are scheduled for hydrocarbon storage.

Caverns 2-4-5 have coalesced, and Caverns 6 and 7 are within 20 feet of coalescence. Caverns 4 and 7 are within 185 feet and 160 feet of breaching the flank of the dome.

1.1.5 Geologic and Hydrologic Hazards

Several geologic and hydrologic hazards exist at the Sulphur Mines SPR site. The following are the most pressing and obvious.

1.1.5.1 Subsidence

Site subsidence is presently occurring over the dome area at approximately one inch per year. The subsidence is the result of earlier sulphur mining in the caprock and subsequent collapse of the resulting voids. The subsidence can be expected to continue at its present rate for the life of the SPR operations at the site.

1.1.5.2 Flooding

The site is located on flat topography with poor drainage and high rainfall. The site has often been flooded and very little can be done to mitigate this hazard. The 100-year flood elevation at the site has been estimated to be + 18 feet MSL.

1.2 CONCLUSIONS

Law Engineering Testing Company concludes that the following could have potential adverse impacts on the Sulphur Mines SPR site.

1.2.1 Regional

1.2.1.1 Flooding

Due to inadequate drainage on and around the site, severe thunderstorm activity may cause localized flooding, creating

operating problems and limiting access to the site. Although all the facilties on the site have been constructed above the 100 year flood elevation, the occurrence of this flood would affect operations by limiting access to the site. Hurricane surges are not believed to affect the site, but associated weather conditions could disrupt operations and potentially cause damage to buildings and other structures on the site.

1.2.2 Site

1.2.2.1 Subsidence

Subsidence has been and will continue to be a problem at the Sulphur Mines SPR site. The ongoing rate of subsidence over the dome is approximately one inch per year.

1.2.2.2 Corrosive Environment

The corrosive groundwater environment at the Sulphur Mines SPR site could cause damage to structures, surface and subsurface piping systems. The corrosion of unprotected casings within the caprock is anticipated

1.2.3 Caprock

1.2.3.1 Circulation Losses

Significant circulation losses could cause time delays during the drilling of additional SPR cavern wells. Zones which create circulation losses could also hamper the construction of the SPR wells by preventing the return of cement or other materials pumped outside of the casing.

1.2.4 Salt Dome

1.2.4.1 Cavern Coalescence

Coalescence of SPR Storage Caverns 2,4 and 5 has already occurred in Sulphur Mines salt dome. SPR Storage Caverns 6 and 7 have approximately 20 feet of separation remaining before they coalesce. Assuming existing brining activities continue, SPR Storage Caverns 6 and 7 will coalesce during the life of the storage program. Coalescense not only prohibits independent operation of the storage caverns, but it also leads to cavern stability problems.

1.2.4.2 Cavern Breaching

Two groups of SPR storage caverns at the Sulphur Mines SPR site are approaching breach conditions. SPR Storage Cavern 4 is approximately 185 feet from the flank of the salt dome. SPR Storage Cavern 7 is approximately 160 feet from the flank of the salt dome.

2.0

2.0 INTRODUCTION

2.1 CONTRACTUAL BACKGROUND

Sandia National Laboratories (Sandia) contracted Law Engineering Testing Company on February 21, 1980 to conduct the Phase 1 Geological Characterization of the Sulphur Mines Strategic Petroleum Reserve (SPR) site. This contract (Sandia No. 46-6272) defined the Phase 1 work as consisting of the compilation, analysis and interpretation of existing data and data currently being generated as a part of SPR activities.

2.2 SITE DESCRIPTION AND HISTORY

The Sulphur Mines SPR site is located in southwestern Louisiana (Figure 2-1), approximately two miles northwest of the town of Sulphur in Calcasieu Parish.

2.2.1 Pre-DOE Site Development

The site has a long commercial history which dates back to 1868 when the Louisiana Petroleum and Coal Oil Company drilled the first oil exploration well. Subsequent exploration efforts discovered large deposits of high quality native sulphur in the caprock of the salt dome. After several abortive attempts to sink shafts and mine the sulphur conventionally, Herman Frasch invented a method to melt and recover the sulphur using pressurized hot water. Approximately 9,400,000 tons of sulphur was removed from the caprock using the Frasch process.

The removal of this vast amount of sulphur caused the overlying caprock to collapse and created subsidence at the surface. In addition to the sulphur industry, oil and gas have been produced by Union Texas Petroleum Company from the flanks of the dome. Pittsburgh Plate Glass (PPG) and Allied Chemical still have active brining operations in the dome. PPG produces brine from caverns BW 6, BSW 14, BSW 15, and BW 2-4-5. Allied Chemical stores ethylene in BW 1 and BW 3.

2.2.2 DOE Site Development

In 1977 the DOE acquired approximately 640 acres for the SPR facilities at Sulphur Mines from Allied Chemical Corporation. During 1977, Gulf Interstate Engineering Company undertook certification studies for each of the acquired caverns. These were the 2-4-5 gallery and caverns 6 and 7. All were determined to be suitable for oil storage for five storage cycles. Later, DOE determined that Sulphur Mines would only be utilized for one storage cycle. The storage potential in 1977 was approximately 24 million barrels. The present storage potential is greater, as Allied Chemical Corporation is continuing to provide brine feed stock from some of these caverns to PPG under previous committments. Brining is expected to continue until Allied Chemicals new brine wells at Sulphur Mines reaches the production stage.

2.3 PURPOSE OF CHARACTERIZATION

The purpose of the geologic site characterization is to utilize existing information and obtain new information as required for the development of an accurate geological/geotechnical baseline of the Sulphur Mines site. This baseline provides to the SPR program:

- an organized comprehensive geologic characterization of the site, with information useful for design and decision making,

- a means of predicting, monitoring or measuring geologic and hydrologic hazards.

- a definition of existing or future geologic and hydrologic hazards.

This stated purpose has served as a guideline in carrying out the characterization study and in defining the nature and organization of material presented in this report.

2.4 SCOPE OF GEOLOGIC CHARACTERIZATION

The geologic characterization includes consideration of both regional and site, surface and subsurface geologic conditions. The impact of regional and site geologic conditions on the SPR facility at the Sulphur Mines salt dome are examined.

The regional geologic characterization is based on existing available data. The surface geologic characterization includes consideration of physiography, surficial geology, and soils. The regional subsurface geologic characterication presents information on stratigraphy, structural geology, and seismicity. Each of these issues is evaluated as to its impact on the SPR facilities.

The site geology characterization is based on existing available data. The site geology explains the relationships which exist between the subsurface structures (salt dome, caprock, faults, adjacent sedimentary beds) and the ongoing surface activities. The site surface geology section describes the site physiography, soils, and subsidence. The site subsurface geology section describes the adjacent sediments, faults, caprock and salt dome geometries.

The results of the geologic characterization are then compared with the SPR facilities to ascertain where critical issues exist and estimate where future problems may be encountered. These issues and problems are described as potential geologic impacts.

2.5 SCOPE OF HYDROLOGIC CHARACTERIZATION

The hydrologic characterization includes consideration of both regional and site surface and subsurface hydrologic

conditions. The impact of regional and site hydrologic conditions on the SPR facility at the Sulphur Mines salt dome site are examined. The discussion of regional surface hydrology deals primarily with the Calcasieu River basin. The regional subsurface hydrology focuses on conditions in Calcasieu Parish.

The regional hydrologic characterization is based on existing data. The surface hydrologic characterization includes the consideration of climatic conditions, drainage basins, and flooding potential. The regional subsurface hydrology characterization presents information on the alluvial aquifers of Recent age, the Chicot aquifer system, the Evangeline aquifer, and the Jasper and deeper aquifers. Hydrogeologic characteristics, ground-water quality and usage are discussed for each pertinent aquifer.

The site hydrology characterization describes the surface and subsurface hydrology for the area around the Sulphur Mines salt dome. The surface water characterization includes consideration of local drainage conditions, flooding potential for the 50 and 100 years, and general water quality assessment. The subsurface hydrology characterization includes consideration of aquifers at the site and local injection disposal zones. The discussion of site surface and subsurface hydrology is limited to a 2 mile radius of the dome.

2.6 DATA ACQUISITION

Law Engineering Testing Company has acquired data from numerous published and unpublished sources to prepare this report. All three commercial operators at the site (Union Texas Petroleum, Allied Chemical, Pittsburgh Plate Glass) provided information which allowed Law Engineering to create this comprehensive site characterization. In addition to the operators at the Sulphur Mines site, data and reports were provided by or from the following:

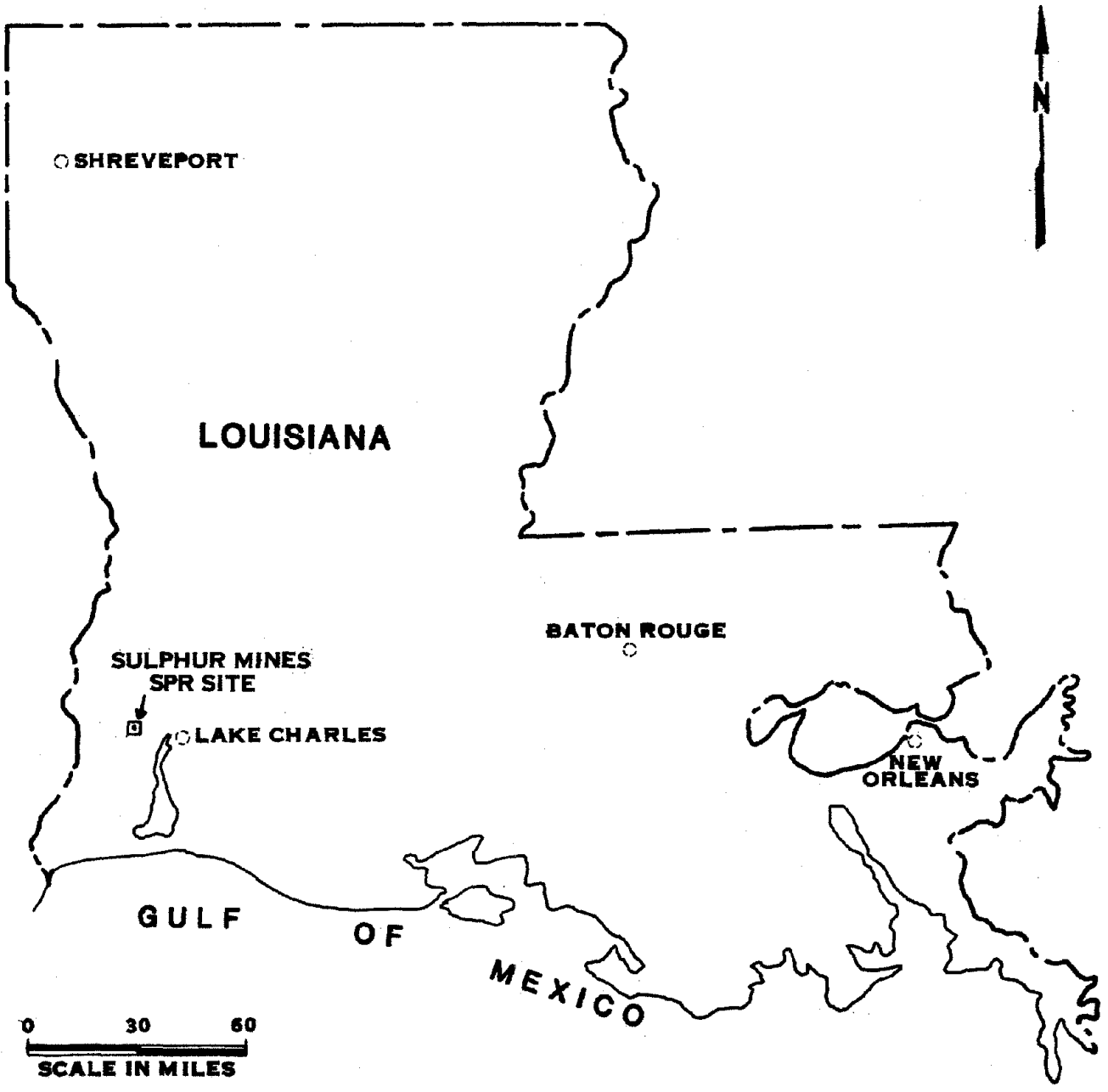
- DOE files in New Orleans and Sulphur, Louisiana
- Sandia Laboratories in Albuquerque, New Mexico
- DOE Contractors
- Well Log Libraries
- Louisiana State and Federal Agencies
- Dowell Sonar Scans
- Published Literature

The data acquisition and organization activities revealed some problem areas related to data availability and reliability. Geologic information is abundant for the caprock and sediments adjacent to the dome where sulphur and oil was produced. However, specific information regarding the subsurface sediments over the caprock and in the salt below the caprock is minimal. Over 700 wells were drilled into the caprock but only 19 were drilled into the top of the salt dome. Of those drilled into the salt only 2 were geophysically logged, so that information regarding the internal structure of the salt at cavern level could not be accurately determined. Hydrologic information is lacking over and in the caprock for the same reasons cited for geologic information. Missing data includes the hydrologic properties of

sedimentary units above the caprock and water quality data over and in the caprock. Water quality data is also lacking for many surface water bodies in the vicinity of the dome.

There are several discrepancies in the location of surface facilities, such as wells, roads, buildings, etc, as a result of four different coordinate systems being used over the years at the site.

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REVISED BY ____ DATE ____
APPROVED BY [illegible] DATE [illegible]

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SULPHUR MINES SPR SITE
LOCATION MAP

FIGURE 2-1

3.0

3.0

3.0 REGIONAL GEOLOGY AND HYDROLOGY

3.1 REGIONAL GEOLOGY

The site overlies the Gulf Coast geosyncline which is the major structural element of the larger Gulf basin (Figure 3-1). The geosyncline developed in response to subsidence associated with massive offshore sedimentation from the northern portion of the Gulf basin. The structural relationships between the geosynclinal sediments and the continental area to the north is illustrated by the general cross-section in Figure 3-2. During Triassic or Jurassic time, the area was submerged in marine seas (Kuenan, 1950; Halbouty, 1979) and the Louann Salt was deposited over much of the shallow closed Gulf basin. The Sulphur Mines salt dome as well as the many other coastal salt domes are believed to be derived from the Louann Salt.

The coastal salt domes, including Sulphur Mines, probably began their major growth during Tertiary time, Ocamb (1961). As the sediment load increased in the basin, the Louann Salt became plastic due to the high lithostatic pressures and temperatures. With the continuing subsidence toward the south, the salt began to flow basinward due to the combined effects of gravity and differential overburden load. As the salt flowed, its surface developed into ridges or pillows forming coastwise trending salt anticlines bounded by troughs or synclines (Boernhauser, 1958; Ocamb, 1961). These anticlines blocked the transport of sediment from the continental areas to the basin until each trough was buried. Eventually the entire salt anticline areas were covered, stopping further anticlinal growth. As the sediment load increased, piercement salt domes developed from the salt anticlines and continued to grow and move upward contemporaneous with sedimentation (Antoine, 1971).

3.1.1 Physiography

The Sulphur Mines SPR site lies within the Western Gulf Coastal Plain physiographic province (Fenneman, 1938). The characteristics of this province include low elevation, low relief, a gentle gulfward slope, and poorly developed drainage systems.

The Pleistocene and Recent deposits form three physiographic subregional belts, lying roughly parallel to and becoming younger towards the Gulf margin (Doering, 1935) (Figure 3-3). These belts are terrace surfaces formed by a coalescence of low gradient stream deposits. They extend virtually uninterrupted from the Sabine River to the west, to the Bayou Teche and Bayou Cocodrie drainage systems to the east (western margin of the Mississippi River alluvial basin). The northernmost and oldest belt is formed by the outcropping Bentley and Montgomery Formations described by Fisk (1948). South of this belt and onlapping the Bentley Formation is the broad largely undissected surface of the Prairie Formation. A low escarpment, subparallel to the coast, follows the junction of the Bentley-Montgomery physiographic belt with the Prairie belt. The Prairie surface grades imperceptibly

southward into the Recent coastal deposits which include marshland and beach deposits. The Recent deposits are also present farther inland along existing rivers and their tributaries which are normally poorly drained and swampy. They possess a dense growth of oak, gum, magnolia and undergrowth which distinguishes them from the less densely vegetated Pleistocene deposits (Jones, et al., 1956 and Holland, et al., 1952). The principal distinguishing features of these subregional belts are the degree of stream dissection and regional slope of their surfaces. Both slope and amount of dissection increases progressively northward with each older belt. The increasing slope of each older surface is a result of the continued downwarping of the region into the Gulf Coast geosyncline. This may have occurred contemporaneous with isostatic uplift to the north. This effect is graphically demonstrated in Figure 3-4.

Somewhat modifying the subregional physiographic surfaces is the influence of regional and local structures such as faulting and piercement salt domes. Faulting, which has been active during the Pleistocene and Recent epochs, tends to form very subdued linear surface features paralleling the coast such as linear swampy areas or as a slight topographic escarpment. Shallow piercement salt domes in the region are sometimes reflected by circular topographic highs as a result of differential erosion or active dome movement upward. Sulphur Mines salt dome had approximately 20 feet of topographic expression prior to sulphur mining activities. Superimposed on these generally featureless subregional physiographic belts are topographic features of more local extent. These include:

1. Natural levees.
2. Beach ridges and cheniers.
3. Bagols.
4. Pimple mounds.

Natural levees and distributary channel ridges formed along with and in association with the courses of ancient and modern streams create meandering topographic highs. These features generally have better drainage than the adjacent flatland areas and were the principal location of roads and buildings during early development of the region. Dredging to improve drainage has also created elongate ridges composed of spoil along some of the modern streams.

Other elongate and fairly continuous ridge-type features parallel to the coastline are the ancient beach ridges on Pleistocene surfaces. An ancient beach ridge, 1/2 mile wide with maximum relief of about 10 feet above the surrounding surface, extends across northern Calcasieu Parish approximately 5 miles north of the Sulphur Mines SPR site. Cheniers are similar but younger features on the Recent surface. The cheniers found on the coastal marshlands approximately 35 miles south of the site are not as gently rounded by erosion as the ancient beach ridges. They average 500 to 1,000 feet in width and 5 to 15 feet in height, and exhibit a steep gulfward slope face relative to a gentle backslope.

Elliptical or round topographic lows called bagols by Holland, et al. (1952) form swampy areas which are heavily vegetated by pin oak and bay trees. Bagols range from 100 feet to 1/2 mile in diameter and are usually about 2 feet lower than the surrounding land. These features are commonly formed along ancient channel scars in which both ends have silted up. Later floodplain clays fill the central portion and were subsequently compacted leaving a swampy depression.

Pimple mounds are somewhat similar smaller features with positive relief, and are the most common and conspicuous relief feature in the region. They are small, circular mounds of sandy and silty materials which profusely dot some areas giving the surface a mottled appearance. Pimple mounds are generally 30 to 50 feet in diameter and about 1 to 5 feet in height.

3.1.2 Surficial Geology

The outcropping geologic formations within the Western Gulf Coastal Plain of southwestern Louisiana are of Pleistocene and Recent age and correlate to the physiographic subdivisions discussed in Section 3.1.1. The outcrops of these sedimentary units are roughly parallel to and become younger towards the coast, as shown in Figure 3-3. These sediments were deposited during a period of continental glacial activity, however, no direct effect on sedimentation due to glaciation has been noted in the Gulf Coast. Cyclic fluctuations of sea level due to the advancement and retreat of continental glaciers during the Pleistocene caused indirect effects on Gulf Coast sedimentation. Figure 3-5 illustrates the relative position of the Quaternary formations in the stratigraphic column and their respective correlation with the stages of glacial advances and retreats. Outcropping Quaternary sediments were deposited as fluvial and deltaic deposits. They grade into more marine deposits downdip. Each outcropping Pleistocene formation constitutes part of a major deltaic plain deposited during an interglacial stage (Holland, et al., 1952). Sea level drop during glaciation, resulted in a lowered base level and a period of active erosion while the deltas prograded beyond the present coastline in response to the fall. This resulted in the entrenchment of streams into their own deltiac plain and widening of stream valleys on shore. Raised sea level during the interglacial intervals resulted in the drowning of stream valleys and renewal of fluvial and deltiac sedimentation over the previously eroded deltaic plain. The Recent marshland south of the Pleistocene outcrops represents deposition during the final stage in the post glacial rise of sea level and the subsequent standstill of the sea at its present level. The Pleistocene and Recent sedimentary units are discussed in more detail as they relate to the Sulphur Mines SPR site in Section 4.1.

3.1.3. Soil Distribution

The soils of the region represent a very surficial subdivision of the Pleistocene Prairie Formation and are illustrated on Figure 3-6, Table 3-1, and described as soil associations below.

The region is characterized by five similar U. S. Department of Agriculture soils associations: (1) the Kinder-Acadia, (2) the Morey-Judice, (3) the Mowata-Morey-Crowley, (4) the Mowata-Crowley, and (5) the Bibb-Mantachie.

The Kinder-Acadia soil association is an area of level to very gently sloping soils on low ridges and broad flats, mostly in the central part of Calcasieu Parish. The poorly drained Kinder soils have a gray silt loam surface and a gray silty clay loam subsoil mottled with brown or red and make up about 55 percent of the Kinder-Acadia association. The somewhat poorly drained Acadia soils have a grayish-brown silt loam surface and a brownish-yellow silty clay loam upper subsoil mottled with gray and red and a gray clay lower subsoil mottled with red and brown and make up about 25 percent of the association. Gore, Caddo, and Beauregard soils, and soils in small drainageways, make up most of the remaining 20 percent of the association.

The Morey-Judice soil association is an area of level to depressed, poorly drained soils on broad flats mostly in the southwestern and southeastern part of the parish. The Morey soils have a very dark gray or black silt loam or silty clay loam surface and a gray silty clay loam subsoil mottled with yellowish-brown and make up about 70 percent of the association. The Judice soils have a very dark gray or black silty clay loam or clay surface and a gray silty clay or clay subsoil mottled with yellowish-brown and make up about 15 percent of the association. Mowata soils make up most of the remaining 15 percent of the association.

The Mowata-Morey-Crowley soil association is an area of nearly level to depressed soils on low ridges and depressed areas mostly in the south-central and southeastern part of the parish. The poorly drained Mowata soils have a gray silt loam surface, a gray sandy clay loam upper subsoil mottled with brown and a gray clay lower subsoil mottled with brown and make up about 43 percent of the association. The poorly drained Morey soils have a very dark gray or black silt loam or light silty clay loam surface and a gray silty clay loam subsoil mottled with yellowish-brown and make up about 29 percent of the association. The somewhat poorly drained Crowley soils make up an additional 18 percent of the association.

The Mowata-Crowley soil association is an area of nearly level to depressed soils on low ridges and depressed areas in the south-central part of the parish. The poorly drained Mowata soils have a gray silt loam surface, a gray sandy loam upper subsoil mottled with brown and a gray clay lower subsoil mottled with brown and make up about 60 percent of the association. The somewhat poorly drained Crowley soils have a very dark grayish-brown very fine sandy loam surface and a gray silty clay subsoil mottled with red and make up about 25 percent of the association. Morey soils make up most of the remaining 15 percent of the association.

The Bibb-Mantachie soil association is an area of level bottomland soils that are frequently flooded. They occur along the drainageways throughout the parish. These soils are used mostly for woodland. The poorly drained Bibb soils have a brown, gray

and yellowish-brown silt clay loam lower subsoil mottled with brown and make up about 65 percent of the association. Local alluvial land and Chastain soils make up most of the remaining 20 percent of the association.

3.1.4. Stratigraphy

Sedimentation in the region began with the deposition of Late Paleozoic and Early Mesozoic clastics in localized basins. These clastic rocks were then overlain by restricted and closed basin deposits of Early and Middle Mesozoic, including thick deposits of Louann Salt. Later Mesozoic deposits consisted predominantly of carbonates ranging from shallow to deep water marine, lagoonal, and evaporitic facies. Late Mesozoic deposits are cyclic sequences of transgressive and regressive sediments including marine shelf carbonates and deep basin lime muds separated by clastic wedges of alluvial and deltaic sediments. Subsidence within the Gulf Coast geosyncline was slowly occurring during this time. Clastic sediments were rapidly deposited into the subsiding geosyncline during the Cenozoic and represent a generally regressive sequence with several major fluctuations of the strandline. These conditions resulted in lithology composed predominately of sands, silts, and clays.

The major marine transgression of the Cenozoic era extended sufficiently updip to produce the lithologic changes which have been used to subdivide the outcropping units. However, the subsurface identification and the correlation of these units on a rock-stratigraphic basis is extremely difficult because of the facies changes which occur downdip. This has led to the currently used system of time-stratigraphic nomenclature in the Gulf Coast subsurface. Units are identified on the basis of characteristic foraminiferal assemblages which occur in the transgressive marine strata. Even with the use of this method, correlation can still be difficult because gulfward deposits of deeper water facies contain different faunal assemblages than their shallower neritic counterparts (Tipsword, 1962). A stratigraphic column of the Louisiana Gulf Coast Cenozoic, including the commonly used foraminiferal guide species, is presented on Table 3-2.

The sediments, which accumulated in the Gulf Coast geosyncline are about 50,000 to 60,000 feet thick in the deepest basin areas, and 30,000 to 40,000 feet thick in the southwestern Louisiana area (Figure 3-7).

3.1.5. Structural Geology

The structural elements in this region are predominantly controlled by subsidence and salt movement within the Gulf Coast geosyncline (Hardin, 1962). High-angle normal faulting, associated with the active subsidence of the region, has resulted in structural modification of the basin sediments. This type of faulting forms regional trends that develop major down-to-the-coast fault systems with compensating up-to-the-coast faults aligned roughly parallel to the east-west trending axis of the

geosyncline and outlining localized depositional embayments along the border of the geosyncline. These "trend growth faults", which are thoroughly discussed by Ocamb (1961), may have occurred initially from a combination of faulting along the axes of fold troughs of salt-formed synclines and isostatic adjustment on basement blocks (Walper, et al., 1979). Movement along many of these regional faults has been contemporaneous with deposition and is still active as is indicated along the Texas and Louisiana coasts (Howe, et al., 1935; Fisk, 1944; Kreitler, 1978; and Sveter, et al., 1980).

Sediments along the Gulf Coast have also been modified by large positive and negative structural features in the northern Gulf basin. Sediments tend to thicken and dip at progressively greater angles eastward into the Mississippi structural trough of southeastern Louisiana (Fisk, 1944). The thinning of formations toward the flanks of the Sabine uplift in northwestern Louisiana is described by Granata (1963). Similar effects, although not as dramatic, occur in the extension of these structures into the Gulf Coast geosyncline.

Piercement salt domes and deep-seated salt structures have created local features within the monoclinal gulfward dipping deposits of the geosyncline. The plastic nature of this bedded salt formation at depth contributed to its movement horizontally down regional dip and its ability to flow contemporaneously with sedimentation. Structural features generated by salt movement include local doming of sediments, formation of local anticlinal and synclinal features, normal faulting, and complex graben and radial fault systems associated with piercement domes.

3.1.6 Regional Seismicity

The region around the dome was evaluated to determine the seismic risk to the SPR site. The historic earthquakes of the region were compiled, evaluated, and then compared with tectonic features and non-tectonic sources of the region to determine if any correlations exist. Since no positive tectonic correlations were found, the concept of seismotectonic regions was used to perform seismic risk analysis on the SPR site. The seismic risk analysis estimated the maximum credible earthquake, return period, and the probability of earthquake occurrence.

3.1.6.1 Historic Seismicity

Southwestern Louisiana is located in a region of low seismic activity. Figure 3-8 illustrates the locations of the historic earthquakes which occurred within the region. Table 3-3 elaborates on the details of each earthquake.

There have been eight historic earthquakes greater than intensity IV MMI (Modified Mercalli Intensity Scale, see Appendix D), within 200 miles of the site. These historic events include one IV-V MMI, five V MMI, one V-VI MMI, and one VI MMI earthquakes.

3.1.6.2 Regional Tectonics and Seismicity

The regional tectonism is discussed in Sections 3.1.1 and 3.1.3, which presents the basic tectonic concepts and structuralevaluation of the Gulf Coast geosynclinal province. The regional seismicity derived from regional historic earthquakes has little apparent association with the known tectonic structures that extend into the region around the site.

An attempt was made to correlate reported earthquakes with faults, fault zones, other geologic structures, storms, reservoirs, explosions, and oil and gas field activity. Possible correlations were only established with a few oil and gas fields.

The known major geologic structures in and around the Coastal Salt dome basin (Figure 3-1) are discussed in Section 3.1.5. None of the faults in the Gulf Coast region are known to be capable of generating "felt" earthquakes (>IV MM). Figure 3-8 illustrates the earthquakes that have been recorded in the region. The earthquakes are probably being generated by deep basement faults which have not been mapped, or by shallow growth faults. The injection and withdrawal of fluids in the subsurface has been shown to induce earthquakes (Lee, 1978; Evans, 1970; Bardwell, 1970; Scopel, 1970; Munson, 1970; Carder, 1970). The extraction of fluids and suspended solids during production of oil and gas will cause subsidence (Sellards, 1930) and the consequent reorientation of subsurface stresses. The injection of fluids during oil and gas production increases hydrostatic pressure resulting in decreased values of shear strength along existing fault planes. Both extraction and injection, especially when occuring at the same time, may induce local earthquakes.

3.1.6.3 Seismic Risk Analysis

Analysis based on seismotectonic regions was used to establish seismic risk since no positive correlations were made between geologic structures and documented historic earthquakes in this region. Seismotectonic regions are areas of similar tectonic history and seismic activity. A return period and probability of exceedence calculation ..as generated for the site. Figure 3-9 describes the results of this analysis.

The seismic activity for the study area is lo.. The site can expect a maximum ground motion surface intensity of VI MMI. No tectonic features ..ere identified ..ithin the site area as capable of generating earthquakes.

3.2 REGIONAL HYDROLOGY

3.2.1 Surface Hydrology

The discussion of regional surface hydrology deals primarily ..ith the Calcasieu River basin. The hydrologic characterization includes consideration of climatic conditions, drainage basins, and flooding potential in the region.

3.2.1.1 Climatic Conditions

The climate in the vicinity of the Sulphur Mines SPR site is classified as humid-subtropical with strong marine influences. The average annual rainfall is 56 inches. Monthly normal precipitations for Lake Charles, Louisiana are shown in Figure 3-10. A precipitation surplus of approximately 16 inches occurs in the winter and spring while during certain months of the growing season between February and November there is a precipitation deficit of approximately 6 to 7 inches (Final Environmental Impact Statement, Sulphur Mines Salt Dome, 1978).

The maximum 24-hour precipitation on record for Lake Charles before 1980 was 16.01 inches. During the May 16, 1980 storm, 15.67 inches of rain fell in 24 hours at the Lake Charles airport. Other locations in Lake Charles unofficially reported rainfall amounts of 16.02 and 22.05 inches for the same 24 hour period.

Both hurricanes and tornadoes have occurred in the area. A major hurricane passes through the area about once every four years with high winds and heavy rainfall, causing local and regional flooding (Final Environmental Impact Statement, Sulphur Mines Salt Dome, 1978).

3.2.1.2 Drainage Basins

The Sulphur Mines salt dome is located in the Calcasieu River basin. Major surface water features in the region include the Calcasieu River to the east, the Houston River and Sabine River Diversion Canal to the north, the Sabine River to the west, and the Intracoastal Waterway to the south (see Figure 3-11).

The Calcasieu River drains an area estimated to be 3,770 square miles (Sloss, 1971). It flows approximately 215 miles from its headwaters in Vernon Parish south to the Gulf of Mexico. In the upper portion of the basin the highest land surface elevation is around 400 feet mean sea level (MSL), and topographic relief on the order of 60 feet is not uncommon. Since the surficial soils are tightly cemented sands and doughy clays, most of the flow in the river is surface runoff. In the vicinity of DeRidder, Louisiana, a gravel belt crosses the basin in a generally east-west direction. Tributaries intersecting this gravel exposure receive large amounts of ground-water flow. The Calcasieu River also receives large amounts of ground-water discharge as it crosses this belt. The Calcasieu River becomes wider and deeper as it approaches Lake Charles. In this reach the River becomes a sluggish tidal stream. The lower portion of the basin lies in the Prairie belt, where surface clays are relatively impervious and significantly retard percolation of rainfall into the ground-water system. Stream channels do not generally cut through these surface clays.

The Houston River, located approximately 4 miles north of the site, is a principal tributary of the Calcasieu River. The principal Houston River tributaries, including Bear Head and Beckwith Creeks, flow from north to south. The Houston River itself flows from west to east emptying into the West Fork Calcasieu River.

It drains an area of approximately 325 square miles and derives the majority of its flow from surface runoff.

Fround surface elevations in the watershed range from approximately 180 feet MSL at the upper end of the basin to 5 feet MSL in the vicinity of the site. No quantitative hydrologic data are available for the Houston River. However, an extreme variation in flow ranging from 5 to 3,500 cfs has been suggested based on the monthly and weekly stream flows for this region taken from 1947 to 1951 (Final Environmental Impact Statement, Sulphur Mines Salt Dome, 1978).

The Sabine River Diversion Canal (formerly the Houston River Canal) is located approximately two miles north of the Sulphur Mines SPR site. The Sabine River is the primary source of water for the canal with the Houston River serving as a back-up source. The purpose of the canal is to provide water to the Lake Charles Industrial Area.

The Sabine River and the Intracoastal Waterway are located approximately 16 miles and 13 miles from the site, respectively. Therefore, they have a minor impact on the site and will not be discussed in detail.

Surface waters of southwestern Louisiana, where they are not affected by salt water encroachment or industrial wastes, are typically soft, have pH values of about 7 and contain calcium and magnesium bicarbonates, very small amounts of sulfate and are typically low in suspended sediments (Jones, 1956).

3.2.1.3 Flooding Potential

100-Year and 500-Year Floods: A Flood Insurance Study (FIS) of Calcasieu Parish, Louisiana was performed by the Corps of Engineers for the Federal Insurance Administration. This study was published in 1979. Standard hydrologic and hydraulic methods were used to investigate the existence and severity of flood hazards in the unincorporated areas of Calcasieu Parish. In this area, flooding occurs primarily as a result of overflow of streams. The flooding resulting from hurricane surge was also taken into account in this study.

Floods having recurrence intervals of 10, 50, 100 and 500 years were estimated. A flood having a 100-year recurrence interval is that flood event having a one-percent chance of occurring in any given year. A 500-year flood event has a 0.2 percent chance of occurring in any given year. The 100- and 500-year flood plains as determined in the flood insurance study are shown in Figure 3-12.

The Sulphur Mines SPR site is beyond the limits of detailed study in the flood insurance study. The Army Corps of Engineers has indicated that according to preliminary hydrologic investigations, floods with return frequencies of once in 50 and 100 years would produce stages of 17.0 and 18.0 feet National Geodetic Vertical Datum of 1929 (NGVD) in the vicinity of the site.

Flooding which would result from hurricane surge effects in the low areas to the west and east of the Calcasieu River was taken into account in the 1979 Flood Insurance Study. Hurricane surge is considered to have no impact on the Sulphur Mines SPR

site. Hurricane surge studies for Cameron and Vermillion Parishes are currently underway, but no data from these studies are available. When completed, these studies will provide more detailed information on how far inland hurricane surge effects will extend.

3.2.2 Subsurface Hydrology

The discussion of regional subsurface hydrology for the Sulphur Mines SPR site is primarily focused on conditions in Calcasieu Parish. Calcasieu Parish is within the Gulf Coastal Plain physiographic province and is underlain by unconsolidated sediments of Tertiary and Quaternary age. The sediments form a wedge which thickens to the south (gulfward) and is composed of interbedded sands, gravels, silts, and clays.

3.2.2.1 General Hydrogeologic Setting

Southwestern Louisiana aquifers are composed of permeable sands and gravels. The aquifers are confined in many parts of the region by less permeable beds of silt and clay. The aquifers which are recognized in Calcasieu Parish include, in descending depth:

- alluvial aquifers of Recent age,
- the Chicot aquifer system,
- the Evangeline aquifer, and
- the Jasper and deeper aquifers.

The sequence of hydrogeologic units and their pertinent properties and characteristics are summarized in Table 3-4.

The alluvium of Recent age forms shallow aquifers which supply small amounts of water for domestic use in the Calcasieu Parish. The Chicot aquifer system is the principal and most heavily pumped source of ground water in the Parish. The Evangeline aquifer supplies limited amounts of fresh water to the northern portion of Calcasieu Parish, and is saline in the vicinity of the site. The Jasper and deeper aquifers are also saline in the majority of Calcasieu Parish.

The aquifer systems in the region have certain characteristics in common. Recharge to aquifers commonly occurs directly as precipitation in areas where the formations are exposed near the land surface. Significant amounts of recharge to deeper aquifers can occur as vertical leakage through overlying and underlying confining layers. Many streams such as the Calcasieu River and its tributaries are hydrologically connected to aquifers which are near the land surface (such as the upper Chicot and alluvial aquifer systems). The streams may serve as a source of recharge (influent streams) or an area of discharge (effluent streams), depending primarily upon seasonal water level differences between the aquifer and the surface water feature.

Discharge of aquifers in the region is through pumpage, inter-aquifer leakage, evapotranspiration, springs, and by flow into effluent sections of streams.

Faults are the primary structural features which locally affect the hydrologic properties of aquifers. A number of normal faults are present in southwestern Louisiana. They generally trend from west to east parallel to the gulf shore line (refer to section 3.1.5 for a more detailed discussion of structural geology). These faults, which are typically downthrown to the south, offset aquifers and confining layers. This has a profound effect on the flow and quality of ground water (Jones and others, 1954).

Salt domes are a second structural feature that cause anomalies in ground-water conditions. The salt mass of a piercement-type dome, such as the Sulphur Mines salt dome, is generally sealed from ground water causing flow to be diverted locally around the dome. The quality of ground water in the beds adjacent to the dome is usually not influenced by a piercement dome (Jones and others, 1954). The thining and faulting of sedimentary beds, which typically overlie piercement domes, may also have localized influences on ground-water conditions by displacing aquifers.

3.2.2.2 Alluvial Aquifers of Recent Age

Sediments of Recent age primarily occur along the southern edge of Calcasieu Parish and in the Sabine and Calcasieu River valleys. These sediments were deposited in the ancestral Gulf of Mexico and in the valleys of streams. They generally consist of fine sand, silt, clay and a few thin lenses of coarser sand.

Aquifers formed by the coarser alluvial deposits range from narrow belts along small streams to a maximum width of about 5 miles in the Calcasieu River basin (Harder, 1950) (Figure 3-13). The alluvial aquifers are unconfined and their water levels fluctuate in response to seasonal conditions. The exact thickness and areal extent of the Recent sand deposits has not been determined and it is difficult to estimate the hydrologic characteristics and potential yields of these deposits (Harder, 1966). Shallow wells less than 50 feet in depth typically yield an average of only 2 to 3 gallons per minute (gpm). The water is moderately hard and in some places has a chloride content as high as 1,300 milligrams per liter (mg/l) (Harder, 1960).

3.2.2.3 Chicot Aquifer System

The Chicot aquifer system is a Pleistocene sedimentary sequence containing thick and extensive sand and gravel beds. The primary outcrop area of the Chicot aquifer system is shown in Figure 3-14. This aquifer system supplies most of the ground water utilized in Calcasieu Parish. Three fairly extensive beds of sand form fresh-water aquifers within the Chicot aquifer system. These sands are referred to as the "200", "500", and "700" foot sands on the basis of their depth at which they occur in the Lake Charles Industrial area of Calcasieu Parish (Jones, 1950).

The dominant direction of ground-water flow in the Chicot aquifer system in 1903 was gulfward and water levels in wells penetrating the aquifer were above the land surface. By 1944,

significant changes had occurred in the direction of ground-water movement due to pumpage. An extensive cone of depression had developed by this time in the Lake Charles industrial district, and regional ground-water flow began to be diverted toward this pumping center (Figure 3-15).

Ground-water utilization from the Chicot aquifer system in Calcasieu Parish has varied. In 1955 it averaged about 105 million gallons per day (mgd). Pumpage increased to about 150 mgd by 1964 and to about 205 mgd by 1969 (Zack, 1971).

Industrial pumpage of ground water in the Lake Charles area peaked in 1973. Since then, pumpage has decreased slightly (Figure 3-15). The decrease in use of ground water since that time probably reflects the impact of environmental controls and increasing costs of pumping water (Water Situation in Louisiana, 1979). Since 1970, water levels in the industrial area have risen slightly and are at an average of about 130 feet below sea level in the center of the cone of depression (Jones and others, 1954). There are seasonal reversals of ground-water flow that are related to pumping. This is particularly evident during the irrigating season (Jones, et al, 1954).

The direction of ground-water flow in the Chicot aquifer system could potentially return to near-original conditions when the Sabine River diversion canal becomes operational, and the use of ground water is diminished. The purpose of this canal is to supply the bulk of industrial water needs in the Lake Charles area with surface water from the Sabine River.

All fresh ground water in the Chicot aquifer system is believed to have originated as precipitation, and differences in its chemical quality are largely attributed to changes that have occurred since the water entered the aquifer. Variations in quality occur locally, due to recharge from the underlying Evangeline aquifer and diffusion of salt water in the vicinity of the fresh-water salt-water interface.

The rate of movement of salty water from deeper saline aquifers vertically into the Chicot aquifer system has increased as the result of extensive ground-water withdrawals from the Chicot aquifer (Harder and others, 1967). Salt-water encroachment has moved from the south northward toward regions of heavy pumpage at a rate of about 70 feet per year (Zack, 1970).

"200-Foot" Sand

About 13 percent of the water pumped from the Chicot aquifer system comes from the "200-foot" sand (Zack, 1971). The aquifer is mainly used to supply water for domestic and irrigation purposes. In the central part of the parish, the aquifer provides water for industrial use.

In Calcasieu Parish, the general direction of ground-water flow in the "200-foot" sand is toward the Lake Charles industrial area from all directions. There may be some localized deviations in the direction of ground-water flow because of smaller pumping centers. Large water level declines have resulted in the "200-foot" sand in response to increases in industrial pumpage.

The potentiometric surface of the "200-foot" sand is shown in Figure 3-16 for 1969. In the Lake Charles industrial area the "200-foot" sand is hydrologically independent of the "500-foot" and "700-foot" sands.

The water in the "200-foot" sand is generally of the sodium biocarbonate type, but it contains sufficient concentrations of calcium and magnesium to make it moderately hard to hard. The iron content is generally less than about 1 mg/l. The chloride content of water from this sand unit is generally less than 100 mg/l.

"500-Foot" Sand

The "500-foot" sand supplies about 92 percent of the ground water used in the Lake Charles industrial area. Large volumes of water are also used for municipal and irrigation purposes. Most pumping from the aquifer is in the north and central parts of the parish. About 160 mgd was pumped from this aquifer in 1969. (Zack, 1971).

Nearly all of the ground-water flow in the "500-foot" sand in Calcasieu Parish is toward the Lake Charles industrial district. A 1970 potentiometric map of the "500-foot" sand in Calcasieu Parish is provided in Figure 3-17. The potentiometric surface reflects the effects of pumpage.

Until the mid 1970's, water levels were declining as much as 14 feet per year in the "500-foot" sand (Zack, 1971). Since the mid 1970's, water levels in the industrial area have risen slightly because of a decrease in use. Water levels in the center of the cone of depression presently average about 130 feet below sea level (Figure 3-17).

Chemical analyses of water from wells screened in the "500-foot" sand indicate that the ground water is moderately hard. The pH of the water generally ranges between 6.7 and 8.6. The average concentration of dissolved solids in the aquifer is about 300 mg/l. The chloride content is generally low in the northern and central parts of the parish where it averages about 30 mg/l.

There are no indications of widespread saltwater intrusion in the southern part of Calcasieu Parish. Concentrations of chloride of more than 600 mg/l are found locally above salt dome structures. The total iron content in the aquifer ranges from about 0.04 to 11 mg/l (Harder, 1960).

"700-Foot" Sand

The "700-foot" sand supplies about 13 percent of the total ground water pumped in Calcasieu Parish. About 40 percent of the water withdrawn is used for municipal purposes in the city of Lake Charles, and the remainder is used for industry and irrigation in the parish. This sand is most heavily developed north of the city of Lake Charles and is mainly used for irrigation supplies (Dial, 1970). Upward leakage from underlying salt-water aquifers has caused the abondonment of many wells screened in the "700-foot" sand.

Ground-water flow in the "700-foot" sand is similar to that in the "500-foot" sand, and is toward the cone of depression in the Lake Charles industrial area. Water levels respond similarly to those in the "500-foot" sand because of direct hydrologic connections between the two aquifers in the area of the site (Figure 3-14). Water levels declined as much as 10 feet per year in the aquifer until the mid 1970's when heavy pumpage ceased (Zack, 1971). The "700-foot" sand yields large quantities of water throughout the Parish.

Wells screened in the "700-foot" sand generally yield a moderately hard water that has a greater sodium-to-calcium ratio than water obtained from the "500-foot" sand. The iron content averages about 3.2 mg/l. Generally the chloride content of water in the "700-foot" sand is greater than that in the "200"- and "500-foot" sands (Harder, 1960). Several wells screened in the "700-foot" sand in the Lake Charles industrial district have shown a significant increase in chloride content since their installation, and some have been abandoned. In the site area the base of the "700-foot" sand, which occurs at an approximate depth of about 800 feet, is considered to be the base of fresh water.

3.2.2.4 Evangeline Aquifer

The Evangeline aquifer of the Pliocene and Late Miocene age underlies the Chicot aquifer system. The lowermost beds of the Evangeline (Miocene age) underlie the Chicot north of Calcasieu Parish and crop out only locally in stream valleys. The upper beds (Pliocene age) lie near the surface north of Calcasieu Parish, but are probably not exposed as they are covered with a thin veneer of Pliocene deposits (Jones and others, 1954).

The Evangeline primarily consists of fine to medium sand interbedded with silt, laminated clay, and local beds of coarse sand. The sands within the Evangeline are locally separated and semiconfined by fairly extensive clays. On a regional scale, however, the sands are interconnected sufficiently so that they function as one aquifer (Whitfield, 1975). Sand beds typically make up about 50 percent of the Evangeline aquifer. Near the site, the Evangeline aquifer occurs generally between 800 and 2,800 feet below sea level. The Evangeline is separated from the underlying Jasper aquifer by the Burkeville confining beds; a confining layer which consists primarily of calcareous clay 200 to 500 feet thick.

Ground-water flow in the Evangeline aquifer is generally toward the southeast. The direction of movement is affected locally by pumpage, but the regional gradient probably is similar to the gradient that existed before wells tapped this aquifer (Whitfield, 1975).

Fresh water from the Evangeline aquifer is mostly a soft-sodium bicarbonate type and is low in iron concentrations. Variations in iron and fluoride concentrations occur laterally and with depth in the aquifer. In the vicinity of the site the water in the Evangeline is saline. In this area, the upper 300 feet of the aquifer contains water with a salinity range of 3,000 to

10,000 mg/l. The lower portion of the aquifer has a salinity in excess of 10,000 mg/l.

Data concerning the utilization of ground water from the Evangeline aquifer in Calcasieu Parish is limited. The aquifer is used as a source of fresh water in the northern part of the parish, and for salt-water disposal in the central and southern portion of the parish (Final Environmental Impact Statement, Sulphur Mines Salt Dome, 1978).

3.2.2.5 Jasper and Deeper Aquifers

The Jasper aquifer is composed of deltaic and marine sediments of Miocene age. Sands with occasional traces of gravel make up approximately 50 percent of the aquifer. The sands of the Jasper aquifer are generally well sorted, very fine to medium grained, and interbedded with clays.

In the vicinity of the site, the depth to the top of the Jasper is approximately 3,400 feet below sea level. The depth to the base of the aquifer is not known with certainty near the site, but is believed to be as great as 4,800 feet below sea level.

Ground-water flow within the Jasper aquifer is generally southeastward. The hydraulic gradient in the aquifer is probably similar to that which existed before wells tapped the aquifer. The direction of movement is locally affected by pumpage, and structural features such as salt domes and faults.

Ground water in the Jasper aquifer is saline throughout Calcasieu Parish. In the vicinity of the site, ground water in the aquifer has a salinity well in excess of 10,000 mg/l (Winslow and others, 1968). Portions of the Jasper aquifer are used for brine disposal near the site (Williams-Fenix and Scisson, Brine Disposal Well History Reports, 1980).

An unnamed clay confining bed underlies the Jasper aquifer and is approximately 500 feet thick at the site (Final Environmental Impact Statement, Sulphur Miles Salt Dome, 1978). Below this clay is a sequence of unconsolidated sediments of increasing age that reaches a maximum thickness of 30,000 feet along the Louisiana coastline. Deeper saline and highly mineralized aquifers probably exist within this sedimentary sequence.

3.3 IMPACT ON SPR FACILITIES

3.3.1 Regional Geology

The regional geology has no significant adverse impact on the SPR facilities other than that commonly associated with the region and considered in engineering design, construction and maintenance. These include lithologic variation from one formation to the other, lithologic variation within each formation both horizontally and vertically, small topographic irregularities associated with these formations, and the regional structure. More regionally significant than physiographic features, and the surficial distribution of geologic formations, are the soils associated with these. The significant soils to be considered are as follows:

1. Relatively stiff and incompressible soils associated with Pleistocene sediments.
2. Relatively weak and compressible soils associated with Recent sediments.
3. Collapsible silts associated with both Recent and Pleistocene sediments.

The significant impact of these soil conditions on the SPR facilities is discussed in detail in Section 4.1.3.

Active regional geologic phenomenon have created the existing surface conditions and will eventually alter them in the future. However, the time interval for these changes is of such a long duration as compared to the expected life of the SPR facility that no impact of significant consequences, which would alter the design, constructions or operational methods and procedures, is expected.

3.3.2 Regional Hydrology

The regionl subsurface hydrology has no significant adverse impact on the SPR facilities. All fresh water aquifers in the site area are well above the proposed storage caverns. Aquifers which are adjacent to the caverns are saline and highly mineralized. These deeper aquifers are hydrologically separated from the overlying fresh water aquifers by confining layers.

The impact of regional surface flooding is significant and is discussed in Section 7.4 of this report.

TABLE 3-1

SOIL INTERPRETATIONS FOR SELECTED USES

	DOMINANT SOIL AND PROPORTION OF ASSOCIATION	DWELLINGS (WITHOUT BASEMENTS)	SEPTIC TANKS FILTER FIELDS	LOCAL ROADS AND STREETS	POND RESERVOIR AREAS	LAND GRADING AND LEVELING	CULTIVATION
KINDER ACADIA ASSOCIATION	KINDER-55%	SEVERE Wetness, shrink-swell, plasticity, seasonal high water table	SEVERE Permeability seasonal high water table	SEVERE Wetness, shrink-swell, plasticity	No significant factor	Wetness, clay subsoil difficult to work	Low fertility, fair response to fertilizers needs drainage
	ACADIA-25%	SEVERE Wetness, shrink-swell, plasticity, seasonal high water table	SEVERE Permeability, seasonal high water table	SEVERE shrink-swell, plasticity	No significant factor	Wetness slope where >1%, clayey subsoil difficult to work	Low fertility, moderate wetness, fair response to fertilizers, needs time
MOREY-JUDICE ASSOCIATION	MORLEY-70%	SEVERE Wetness, shrink-swell, plasticity, seasonal high water table	SEVERE Permeability, seasonal high water table	SEVERE Wetness, shrink-swell plasticity	No significant factor	Wetness	Needs drainage, fair response to fertilizers
	JUDICE-15%	SEVERE Wetness, shrink-swell, plasticity, seasonal high water table	SEVERE Permeability, seasonal high water table	SEVERE Wetness, shrink-swell plasticity	No significant factor	Wetness clay texture, difficult to work	Needs drainage, fair response to fertilizers,
MOWATA-MOREY-CROWLEY ASSOCIATION	MOWATA-43%	SEVERE Wetness, shrink-swell plasticity, seasonal high water table	SEVERE Permeability, seasonal high water table	SEVERE Wetness, shrink-swell plasticity	No significant factor	Wetness	Needs drainage, fair response to fertilizers
	MOREY-29%	SEVERE Wetness, shrink-swell, plasticity, seasonal high water table	SEVERE Permeability, seasonal high water table	SEVERE Wetness, shrink-swell plasticity	No significant factor	Wetness	Needs drainage, fair response to fertilizers
	CROWLEY-loam-18%	MODERATE Wetness, shrink-swell, plasticity, seasonal high	SEVERE Permeability, seasonal high water table	SEVERE Wetness, shrink-swell plasticity	No significant factor	Wetness, clay subsoil, difficult to work	Fairly low fertility, drainage may be needed
MOWATA-CROWLEY ASSOCIATION	MOWATA-60%	SEVERE Wetness, shrink-swell, plasticity, seasonal high water table	SEVERE Permeability, seasonal high water table	SEVERE Wetness, shrink-swell plasticity	No Significant factor	Wetness	Needs drainage, fair response to fertilizers
	CROWLEY-25%	MODERATE Wetness shrink-swell, plasticity, seasonal high water table	SEVERE Permeability seasonal high water table	SEVERE Wetness, shrink-swell, plasticity	No Significant factor	Wetness, clay subsoil, difficult to work	Fairly low fertility, drainage may be needed
BIBB-MANTACHIE ASSOCIATION	BIBB-65%	VERY SEVERE Flooding, wetness, seasonal high water table	SEVERE Flooding, seasonal high water table	SEVERE Wetness, Flooding	Dugout may seep	Wetness, flooding	Flooding too severe for cropland in most years
	MANTACHIE-15%	VERY SEVERE Flooding, wetness, seasonal high water table	SEVERE Flooding, seasonal high water table	SEVERE Flooding	Dugout may seep	Flooding, moderate wetness	Flooding to severe for cropland in most years

HOW TO USE THE MAP AND SOIL INTERPRETATIONS

This General Soil Map shows the soil associations in Calcasieu Parish. A soil association is a landscape that has distinctive proportional patterns of soils. It normally consists of one or more major soils for which it is named, although several minor soils may also be included.

This map is useful to people who want a general idea of the soils in the region around the SPR site, who want to compare different parts of the parish, or who want to determine suitability of soils to certain land uses for general planning. More specific interpretations should be based on a more detailed soil survey and an on-site examination. The soils within one association may differ widely in slope, drainage, texture and other characteristics that affect use and management.

The intepretation table lists the degree of limitation and principal factors affecting use for the major soils within each association. The table lists only the principal adverse factors affecting farm uses. The soils of small acreage within the associations are not rated in the table.

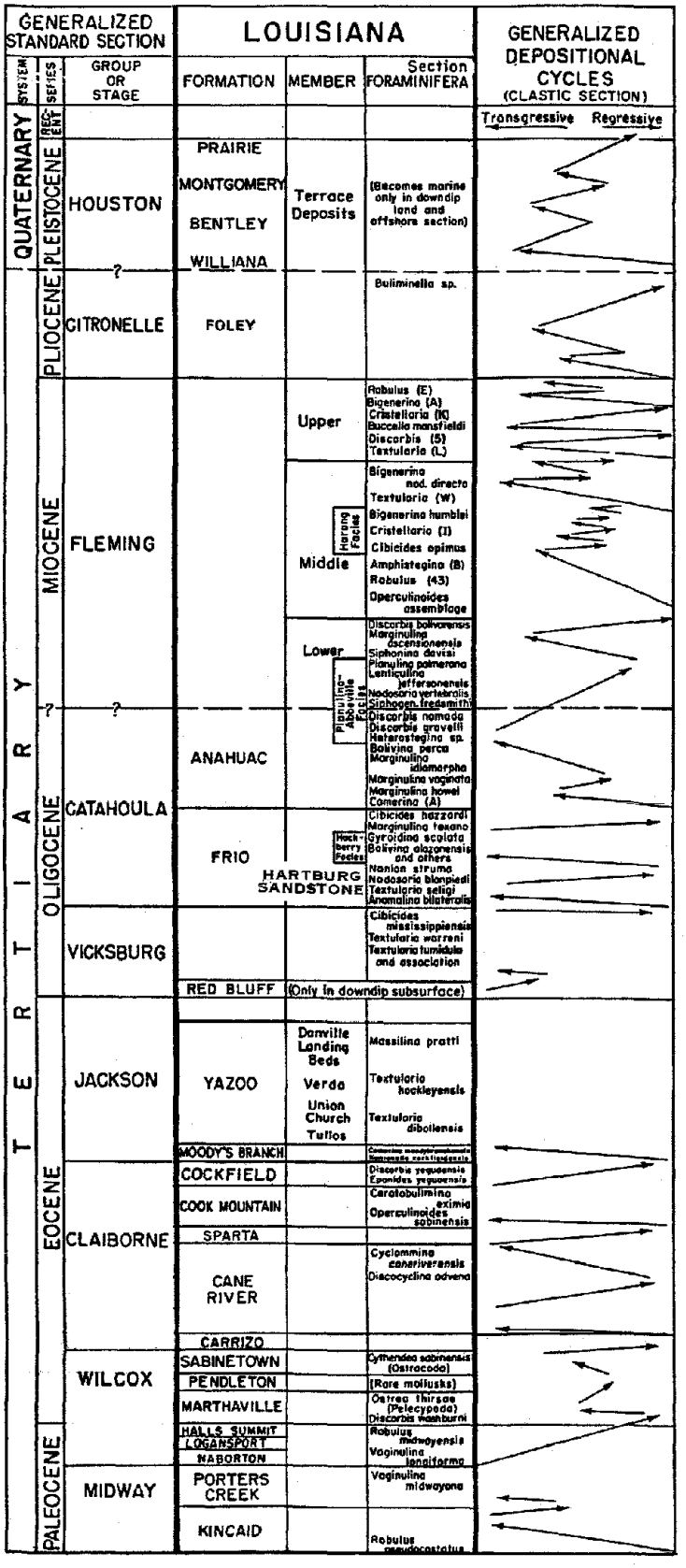
Definitions of Degree of Limitations are as follows:

Slight - The limitation is not serious and is easily tolerated or overcome.

Moderate - The limitation needs to be recognized, but it can be tolerated or overcome.

Severe - The limitation cannot be easily tolerated or is difficult or too costly to overcome.

Very Severe - The limitation is so restrictive that the stated use is generally impractical.



REFERENCE:

MODIFIED FROM TIPSWORTH, H.L. 1962

PREPARED BY JSD DATE 8/16/80
CHECKED BY _____ DATE _____
REVISED BY _____ DATE _____
APPROVED BY _____ DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

STRATIGRAPHIC COLUMN OF SOUTHWESTERN LOUISIANA

TABLE 3-2

Date		Time	Intensity	Location	Coordinates		Felt Area	Remarks
1882	Oct. 22	16:15 CST	VII	Paris, Texas	33.4	95.3	195,000	Docekal
1891	Jan. 08	00:00 CST	VI	Rusk, Texas	31.7	95.2	Local	EHUS; prob. tornado
1911	Mar. 31	10:57 CST	V	Rison, Arkansas	33.8	92.2	18,000	EHUS, aftershock 12:10 CST
1918	Oct. 04	3:32 CST	V	Arkansas	34.7	92.3	30,000	EHUS
1929	Jul. 28	11:00 CST	felt	Burrwood, Louisiana	29.0	89.4	Local	USE
1930	Oct. 19	6:17 CST	V-VI	Donaldsonville, Louisiana	30.0	91.0	18,000	USE, LETCo
1931	Dec. 16	21:40 CST	VI-VII	Batesville, Mississippi	34.1	89.8	65,000	EHUS, USE
1932	Apr. 09	4:15 CST	V	Mexia-Wortham, Texas	31.7	96.5	1,000	USE; EHUS; Sellards, 1933
1934	Apr. 11	11:40 CST	V	Paris, Texas	33.9	95.5	3,000	USE; EHUS; Sellards, 1933
1936	Mar. 14	11:20 CST	V	Valliant, Oklahoma	34.0	95.0	900	USE; EHUS
1939	Jun. 19	15:43 CST	V	Arkadelphia, Arkansas	34.1	93.1	-	EHUS
1940	Dec. 02	10:16 CST	IV	Rodessa, Louisiana			Local	USE
1941	Jun. 28	12:30 CST	felt	Vicksburg, Mississippi			Local	USE
1947	Sep. 20	15:30 CST	IV-V	Winnfield, Louisiana	31.9	92.7	Local	Docekal
1950	Mar. 20	7:24 CST	IV	Chico, Texas	33.5	97.1	Local	USE; Docekal
1952	Oct. 17	9:48 CST	IV	Orange, Texas	33.5	97.1	Local	USE
1955	Feb. 01	8:45 CST	V	Gulfport, Mississippi	30.4	89.1	-	EHUS
1956	Jan. 07		IV	Galveston Island, Texas			Local	USE
1957	Mar. 19	10:38 CST	V	Northeast Texas	32.0	95.0	10,000	EHUS
1958	Nov. 19	12:15 CST	V	Baton Rouge, Louisiana	30.3	91.1	Local	EHUS
1959	Oct. 15	9:45 CST	IV	Creole, Louisiana				USE
1961	Jan. 10	19:40 CST	V	Southeast Oklahoma				EHUS
1961	Apr. 27	1:30 CST	V	Southeast Oklahoma	35.0	95.0		EHUS
1964	Apr. 23	19:21 CST	V	Pineland, Texas	31.5	93.8	-	USE (Mag 3.7)
Series	Apr. 24	1.34 CST	V	Hemphill, Texas	31.6	93.8	-	USE (Mag 3.7)
	Apr. 27	18:31 CST	V	Pineland, Texas	31.5	93.8	-	USE (Mag 3.4)
	Apr. 28	15:19 CST	V	Milam, Texas	31.7	93.6	-	USE (Mag 4.4)
	Apr. 30	14:30 CST	felt	Pineland, Texas				USE
	May 07	14:10 CST	felt	Pindland, Texas				USE
	June 02	17:00 CST	IV	Texas-Louisiana Border	31.3	94.0		USE
	June 02	19:30 CST	IV	Texas-Louisiana Border				USE
	June 02	20:27 CST	IV	Texas-Louisiana Border				USE (Mag 4.2)
	Aug. 16	5:36 CST	V	Hemphill, Texas	31.4	93.8		USE; EHUS
1967	June 04	10:14 CST	VI	Greenville, Mississippi	33.6	90.9	25,000	EHUS, aftershock June 29
1968	Oct. 14	8:43 CST	VI	Durant, Oklahoma	34.0	96.8	Local	EHUS
1969	Jan. 01	17:36 CST	VI	Central Arkansas	34.8	92.6	23,000	EHUS
1974	Feb. 15	22:49 GMT	V	South Arkansas	33.96	93.03	6,600	USE (Mag 3.8 MB, z = 1km) Aftershock 22:53 GMT (II), Mag 2.8, z = 1km

REFERENCE:

U.S. EARTHQUAKES, 1928-1977
EARTHQUAKE HISTORY OF THE U.S., 1975
DOCEKAL, 1970
NOAA, 1979

PREPARED BY _____ DATE _____
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REVISED BY _____ DATE _____
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STRATEGIC PETROLEUM RESERVE PROGRAM

GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

PROJECT

LOUISIANA AREA EARTHQUAKES

TABLE 3-3

GEOLOGIC SYSTEM	GEOLOGIC SERIES	UNITS		APPROXIMATE DEPTH NEAR SITE (FEET)	TRANSMISSIVITY (gpd/ft)
QUATERNARY	RECENT	ALLUVIAL AQUIFERS		not present at site	–
	PLEISTOCENE	CHICOT AQUIFER SYSTEM	UNNAMED CONFINING BED	0 to 30	–
			"200-Foot" Sand	110 to 180	75,000 to 270,000
			"500-Foot" Sand	370 to 550	130,000 to 560,000
			"700-Foot" Sand	600 to 800	150,000 to 190,000
TERTIARY	PLIOCENE	EVANGELINE AQUIFER		800 to 2800	7,500 to 70,000
	MIOCENE	BURKEVILLE CONFINING BEDS		2800 to 3400	–
		JASPER AQUIFER		3400 to 6000	7,500 to 150,000
		UNNAMED CONFINING BED		6000 to 6500	–
TERTIARY AND OLDER SYSTEMS	MIOCENE AND OLDER SERIES	DEEPER SALINE AQUIFERS AND CONFINING BEDS		6500 to 30,000	–

MODIFIED AFTER:

- HARDER, 1960
- WHITFIELD, 1975
- ZACK, 1971
- FINAL ENVIRONMENTAL IMPACT STATEMENT, SULPHUR MINES SALT DOME, 1978
- WILLIAMS - FENIX AND SCISSON, BRINE DISPOSAL WELL HISTORY REPORTS, 1980

PREPARED BY RAS
CHECKED BY
REVISED BY
APPROVED BY LSK

UNITS		APPROXIMATE DEPTH NEAR SITE (FEET)	RANGE OF HYDROLOGIC PROPERTIES	
			TRANSMISSIVITY (gpd/ft)	HYDRAULIC CONDUCTIVITY (gpd/ft^2)
ALLUVIAL AQUIFERS		not present at site	–	–
CHICOT AQUIFER SYSTEM	UNNAMED CONFINING BED	0 to 30	–	–
	"200-Foot" Sand	110 to 180	75,000 to 270,000	660 to 1,520
	"500-Foot" Sand	370 to 550	130,000 to 560,000	930 to 2,000
	"700-Foot" Sand	600 to 800	150,000 to 190,000	1,070 to 1,360
EVANGELINE AQUIFER		800 to 2800	7,500 to 70,000	225 to 750
BURKEVILLE CONFINING BEDS		2800 to 3400	–	–
JASPER AQUIFER		3400 to 6000	7,500 to 150,000	200 to 970
UNNAMED CONFINING BED		6000 to 6500	–	–
DEEPER SALINE AQUIFERS AND CONFINING BEDS		6500 to 30,000	–	–

VIRONMENTAL IMPACT STATEMENT,
MINES SALT DOME, 1978

- FENIX AND SCISSON, BRINE DISPOSAL
TORY REPORTS, 1980

PREPARED BY BAS DATE 5/19/80
CHECKED BY _____ DATE _____
REVISED BY _____ DATE _____
APPROVED BY LSS DATE 10/1/80

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RANGE OF HYDROLOGIC PROPERTIES		GENERAL GROUND-WATER QUALITY CONDITIONS	GENERAL USAGE IN CALCASIEU PARISH
HYDRAULIC CONDUCTIVITY (gpd/ft^2)	STORAGE COEFFICIENT		
–	–	Generally hard & contains iron. May contain chlorides up to 1,300 mg/l	Yields small supplies for domestic use only
–	–	–	Yields little or no water
660 to 1,520	.0008 to .0009	Sodium bicarbonate type, moderately hard to hard.	Domestic and irrigation usage. supplies 13% of water used in the Chicot aquifer system.
930 to 2,000	.0001 to .0011	Moderately hard water, generally low in chlorides	Major aquifer used for municipal, industrial and irrigation purposes, supplies 74% of water pumped from Chicot aquifer system
1,070 to 1,360	.0002 to .0017	Moderately hard water, may be high in chlorides locally	Used for irrigation, industrial and municipal purposes. Supplies 13% of water pumped from the Chicot aquifer system.
225 to 750	.0002	Contains from 3,000 mg/l to more than 10,000 mg/l chloride in the vicinity of the site	Used as a source of fresh water in the northern part of the Parish. Used for salt water disposal in the central and southern portion of the parish
–	–	–	Yields little or no water
200 to 970	–	Contains highly mineralized water in the vicinity of the site	Used for salt water disposed in some areas near the site
–	–	–	Yields little or no water
–	–	Likely to contain highly mineralized water	No known use in Calcasieu Parish

DATE 5/19/80
DATE
DATE
DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM

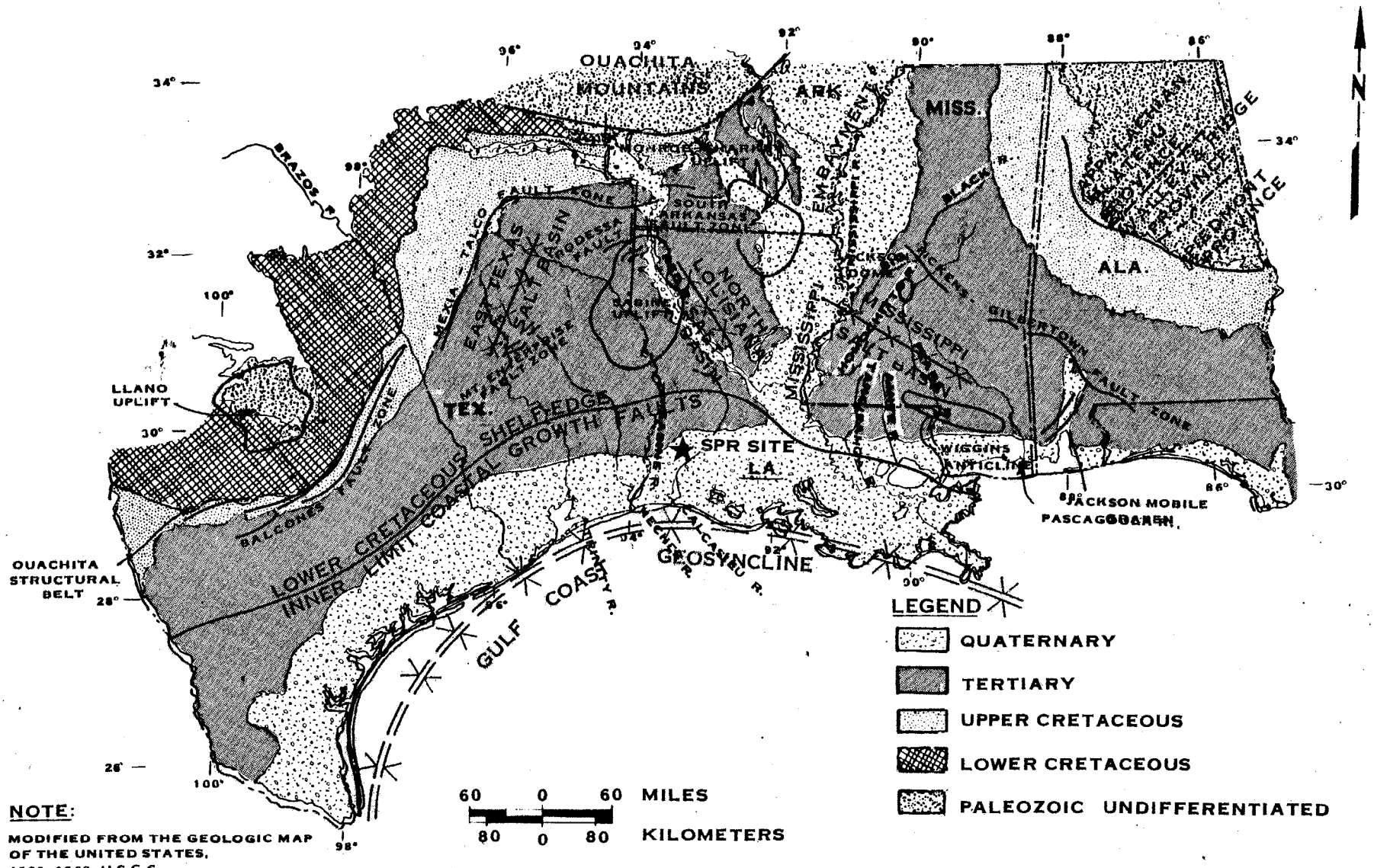
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

CHARACTERIZATION OF HYDROGEOLOGIC UNITS IN THE REGION

TABLE 3-4

AF 12338 B



NOTE:

MODIFIED FROM THE GEOLOGIC MAP OF THE UNITED STATES, 1932, 1960, U.S.G.S.

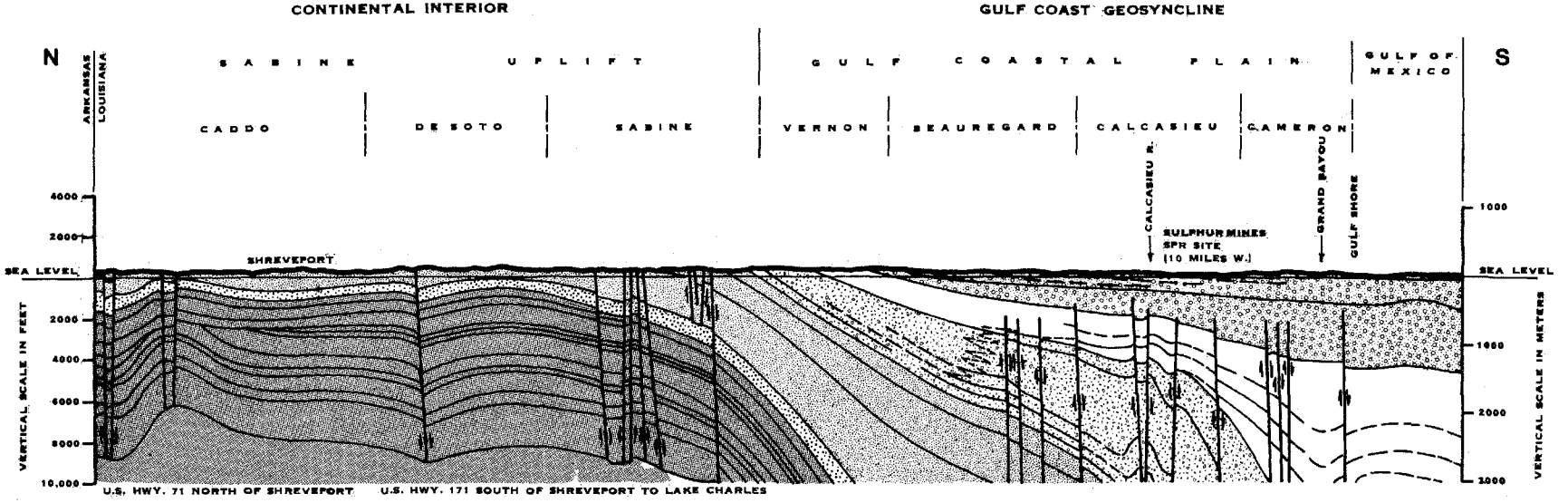
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REVISED BY ____ DATE ____
APPROVED BY LSK DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
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SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

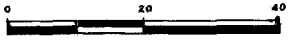
GULF COAST REGIONAL GEOLOGIC MAP

FIGURE 3-1





REFERENCE:
GEOL. HWY MAP, APPG 1975



LEGEND

- PLIO-PLEISTOCENE
- MIOCENE
- OLIGOCENE
- EOCENE
- PALEOCENE
- CRETACEOUS

NOTE- MAP SYMBOLS HAVE NO LITHOLOGIC SIGNIFICANCE

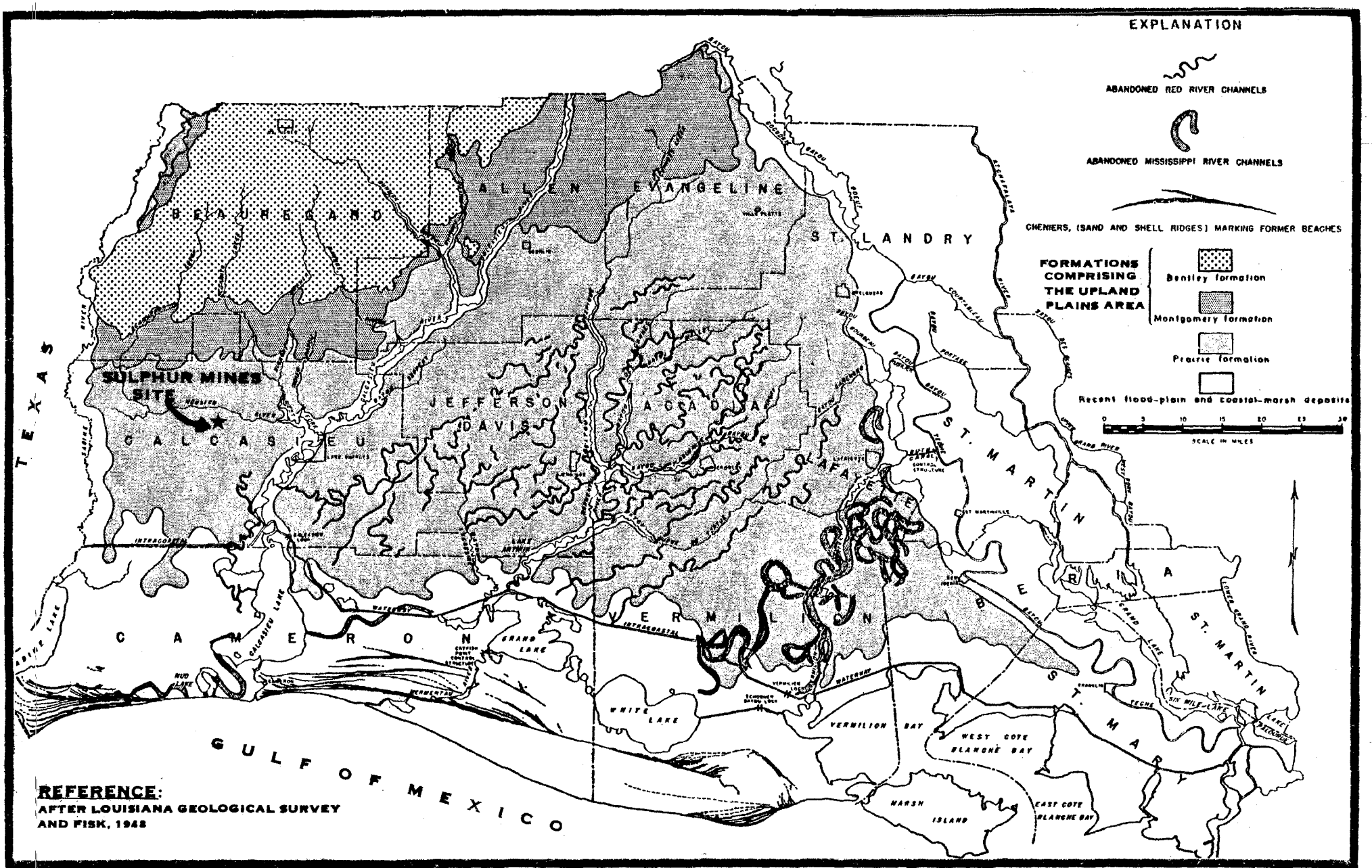
PREPARED BY	S/F	DATE	7/1/80
CHECKED BY	L.S.K	DATE	7/14/80
REVISED BY	S/F	DATE	9/15/80
APPROVED BY	L.S.K	DATE	10/1/80

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SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

LOUISIANA NORTH - SOUTH
GEOLOGIC CROSS-SECTION

FIGURE 3-2



REFERENCE:
AFTER LOUISIANA GEOLOGICAL SURVEY AND FISK, 1948

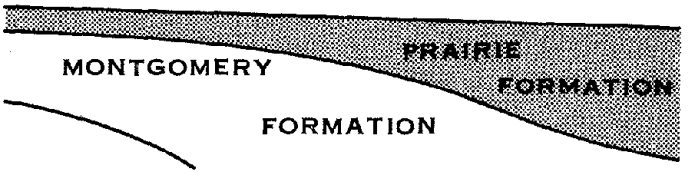
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REVISED BY SJE	DATE	9/3/80
APPROVED BY JSK	DATE	10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

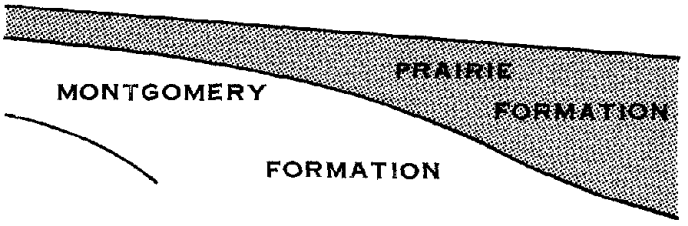
LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

PHYSIOGRAPHIC AND GEOLOGIC MAP OF SOUTHWEST LOUISIANA

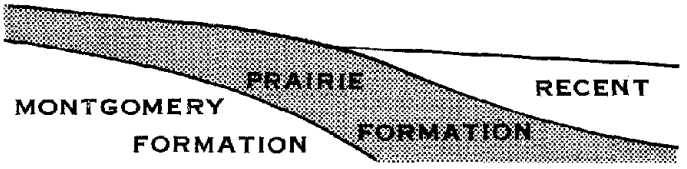
FIGURE 3-3



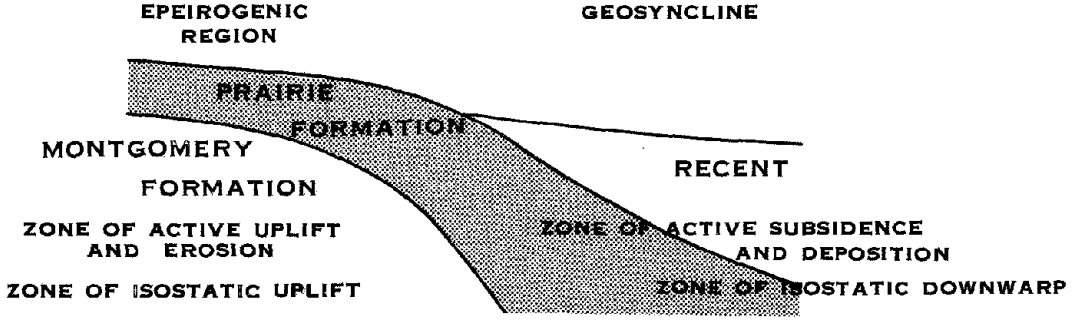
PRAIRIE FORMATION AS IT WAS FIRST DEPOSITED.
NOTICE DELTAWARD THICKENING AND VERY SLIGHT DIP



PRAIRIE FORMATION NEAR CLOSE OF TIME OF DEPOSITION.
NOTICE INCREASED DELTAWARD DIP.



PRAIRIE FORMATION FOLLOWING DEPOSITION OF RECENT SEDIMENTS.
NOTICE SLIGHT DOWNDRAG OF SURFACE UNDER RECENT DEPOSITS.

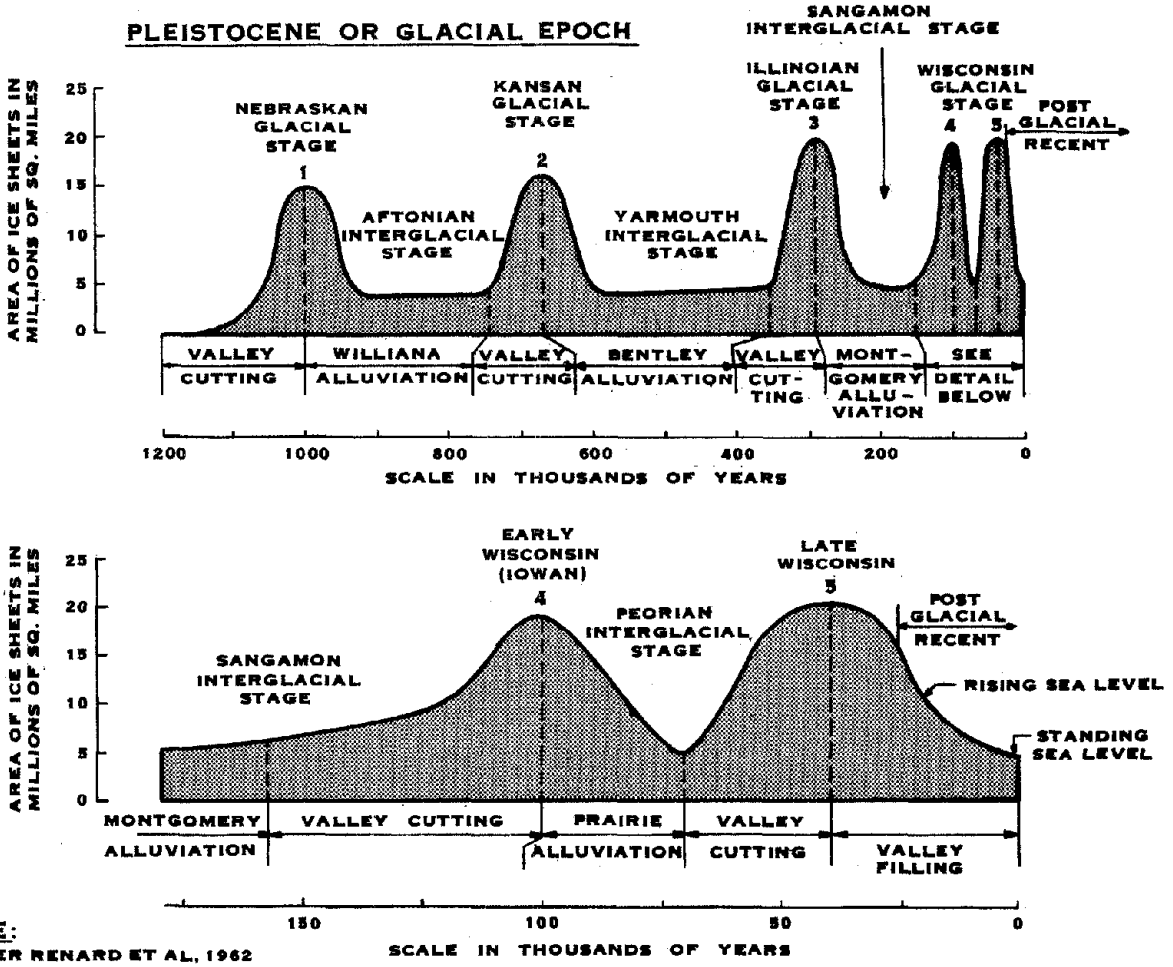


PRESENT DAY RELATIONSHIP BETWEEN PRAIRIE FORMATION AND RECENT SEDIMENTS
NOTICE SUBSIDENCE UNDER LOAD AND WARPING OF PRAIRIE SURFACE.

REFERENCE:
HOLLAND, ET AL., 1952

PREPARED BY JSR DATE 2/11/81 CHECKED BY ____ DATE ____ REVISED BY ____ DATE ____ APPROVED BY ____ DATE ____	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	PROFILE ILLUSTRATING EFFECTS OF GEOSYNCLINE SUBSIDENCE FIGURE 3-4

		Glacial stages	American Glacial Terminology	Louisiana Terraces
QUATERNARY	RECENT		Recent	Flood plains
	PLEISTOCENE	Glacial stage	Wisconsin	
		Interglacial stage	Peorian	Prairie
		Glacial sub-stage	Iowan	
		Interglacial stage	Sangamon	Montgomery
		Glacial stage	Illinoian	
		Interglacial stage	Yarmouth	Bentley
		Glacial stage	Kansan	
		Interglacial stage	Aftonian	Williana
		Glacial stage	Nebraskan	



REFERENCE:
MODIFIED AFTER RENARD ET AL, 1962

PREPARED BY JSB DATE 12/18/
CHECKED BY ____ DATE ____
REVISED BY ____ DATE ____
APPROVED BY ____ DATE 1/20

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME
LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

CORRELATION OF GLACIAL STAGES WITH TERRACE DEPOSITS OF LOUISIANA

FIGURE 3-5



LEGEND

- KINDER - ACADIA ASSOCIATION
- MOREY - JUDICE ASSOCIATION
- MOWATA - MOREY - CROWLEY ASSOCIATION
- MOWATA - CROWLEY ASSOCIATION
- BIBB - MANTACHIE ASSOCIATION

REFERENCE

U.S. DEPT. OF AGRICULTURE
SOIL CONSERVATION SERVICE

0 6000 12,000

SCALE IN FEET

PREPARED BY LSK DATE 1/23/80
CHECKED BY OPS DATE 2/20/80
REVISED BY ____ DATE ____
APPROVED BY LSK DATE 10/1/80

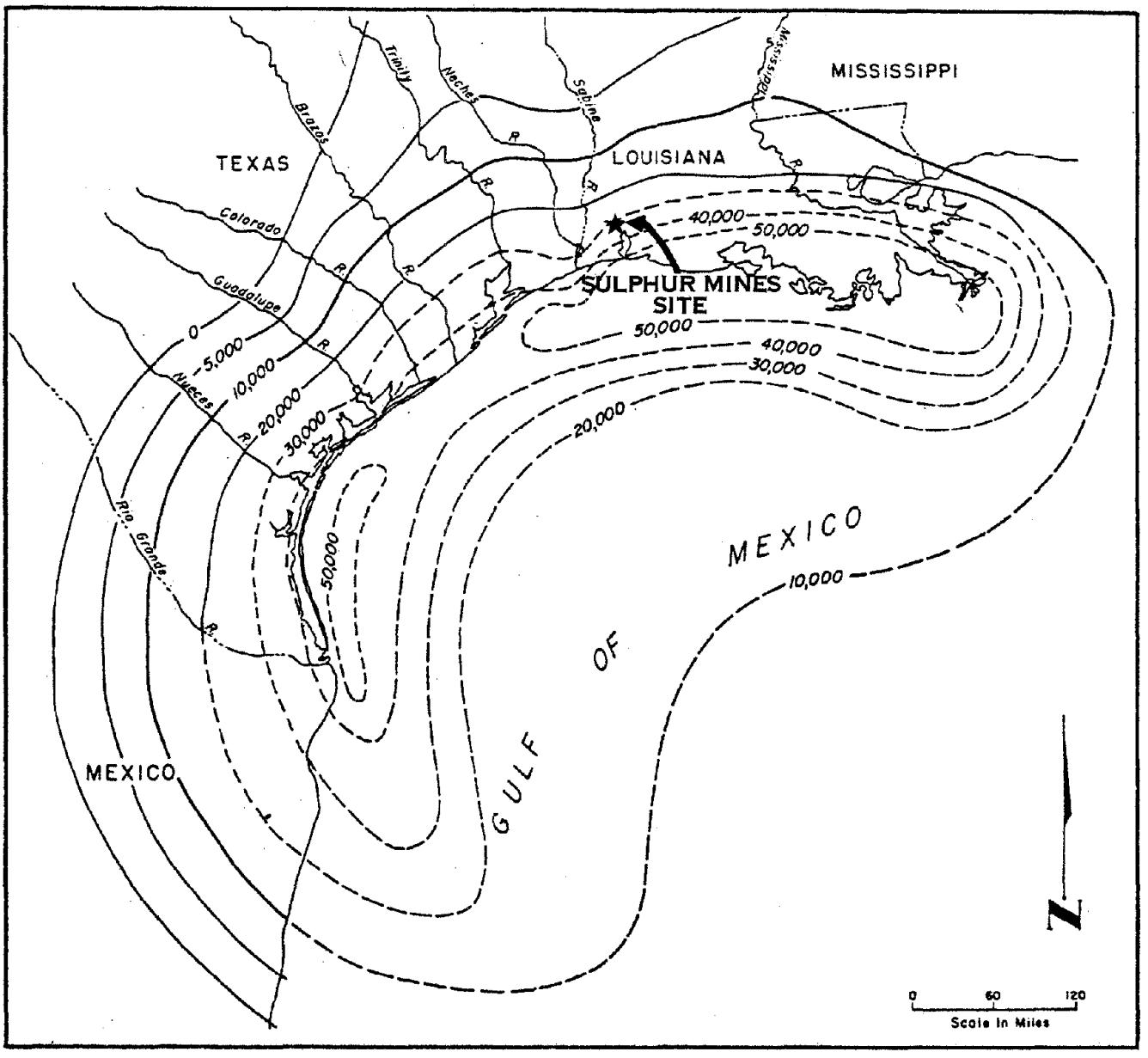
STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

REGIONAL SOILS MAP

FIGURE 3-6

AF 12338A



REFERENCE:
AFTER HARDIN, 1962

NOTE:
CONTOURS IN FEET MSL

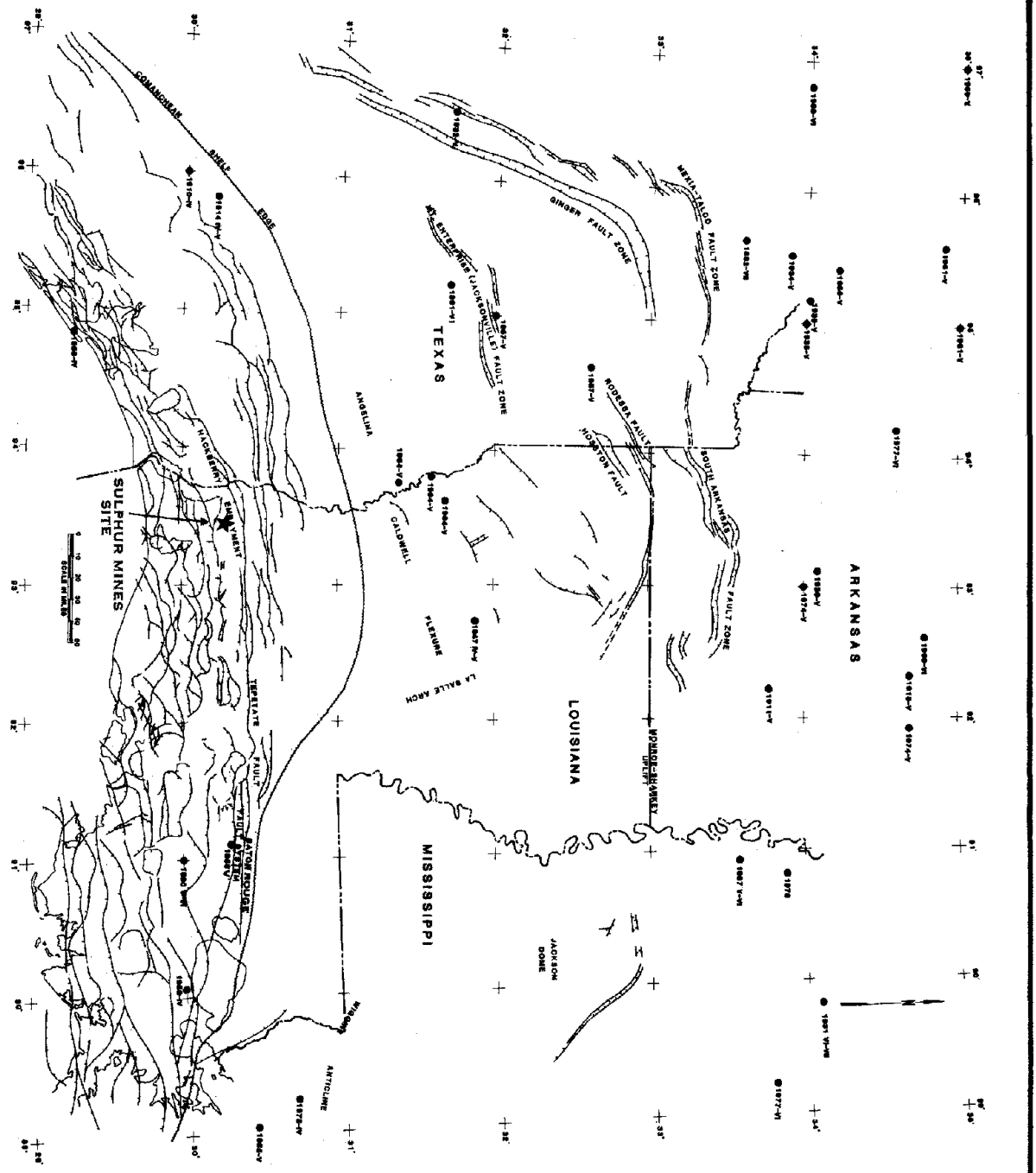
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APPROVED BY ____ DATE 7/8/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

THICKNESS OF CENOZOIC SEDIMENTS IN THE GULF COAST GEOSYNCLINE

FIGURE 3-7



LEGEND

- EARTHQUAKES EPICENTERS
- FAULTS

REFERENCE

U.S. EARTHQUAKES, 1928 - 1977
EARTHQUAKE HISTORY OF THE U.S., 1975
DOCEKAL, 1970
NOAA, 1979

PREPARED BY		DATE
CHECKED BY		DATE
REVISED BY		DATE
APPROVED BY		DATE

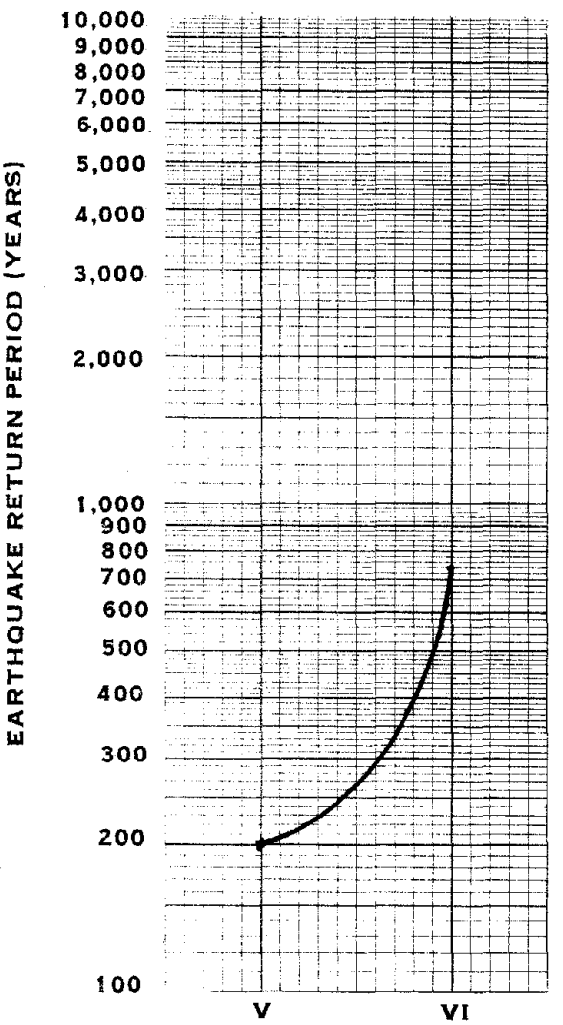
STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

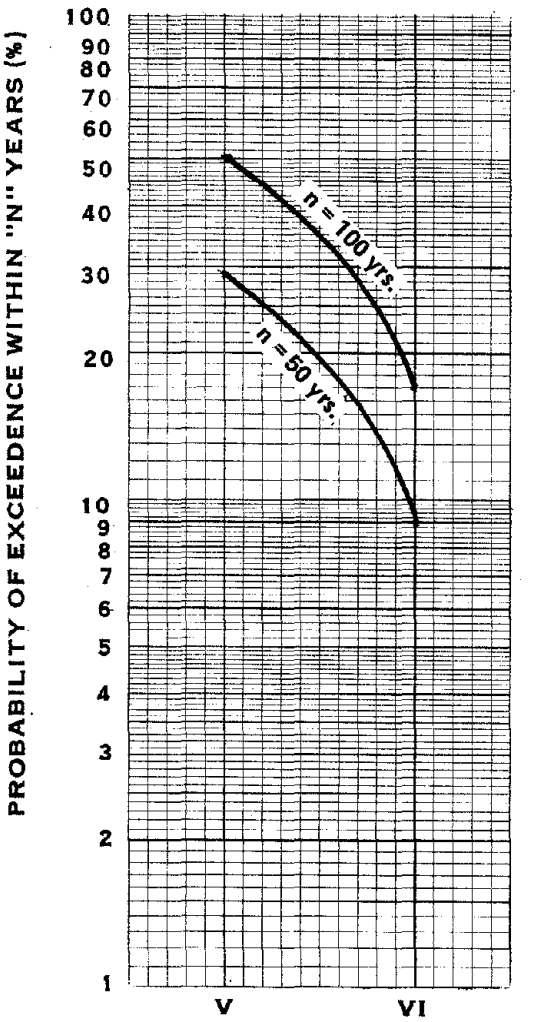
LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

LOUISIANA REGIONAL
HISTORIC EARTHQUAKES
LOCATION MAP

FIGURE 3-8

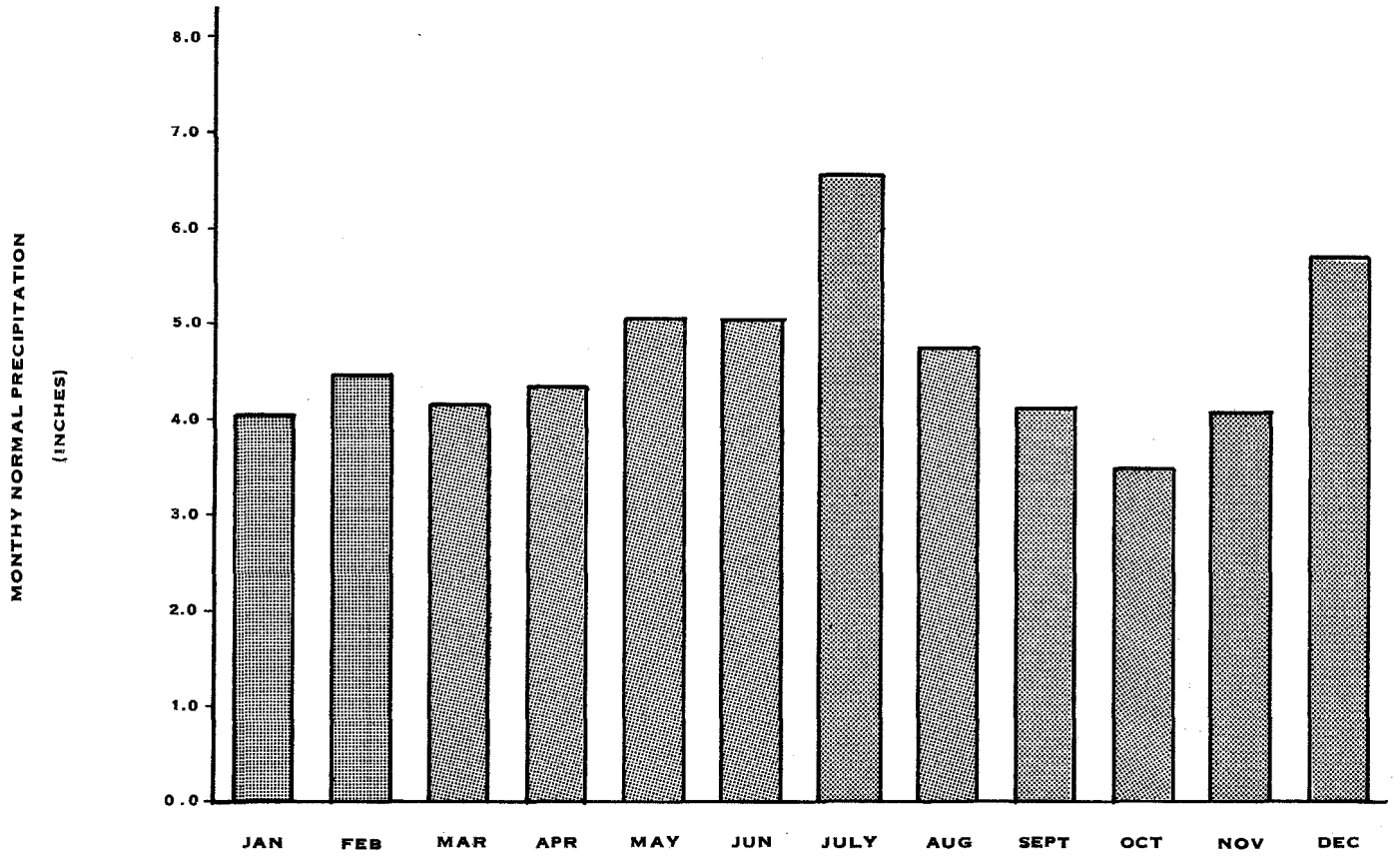
AF 12338A





PREPARED BY LSK DATE 9/15/80 CHECKED BY GHF DATE 9/16/80 REVISED BY ____ DATE ____ APPROVED BY LSK DATE 10/1/80 T-1012-6	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	EARTHQUAKE RETURN PERIOD AND PROBABILITY OF EXCEEDENCE CURVES FIGURE 3-9

AF 12338 B



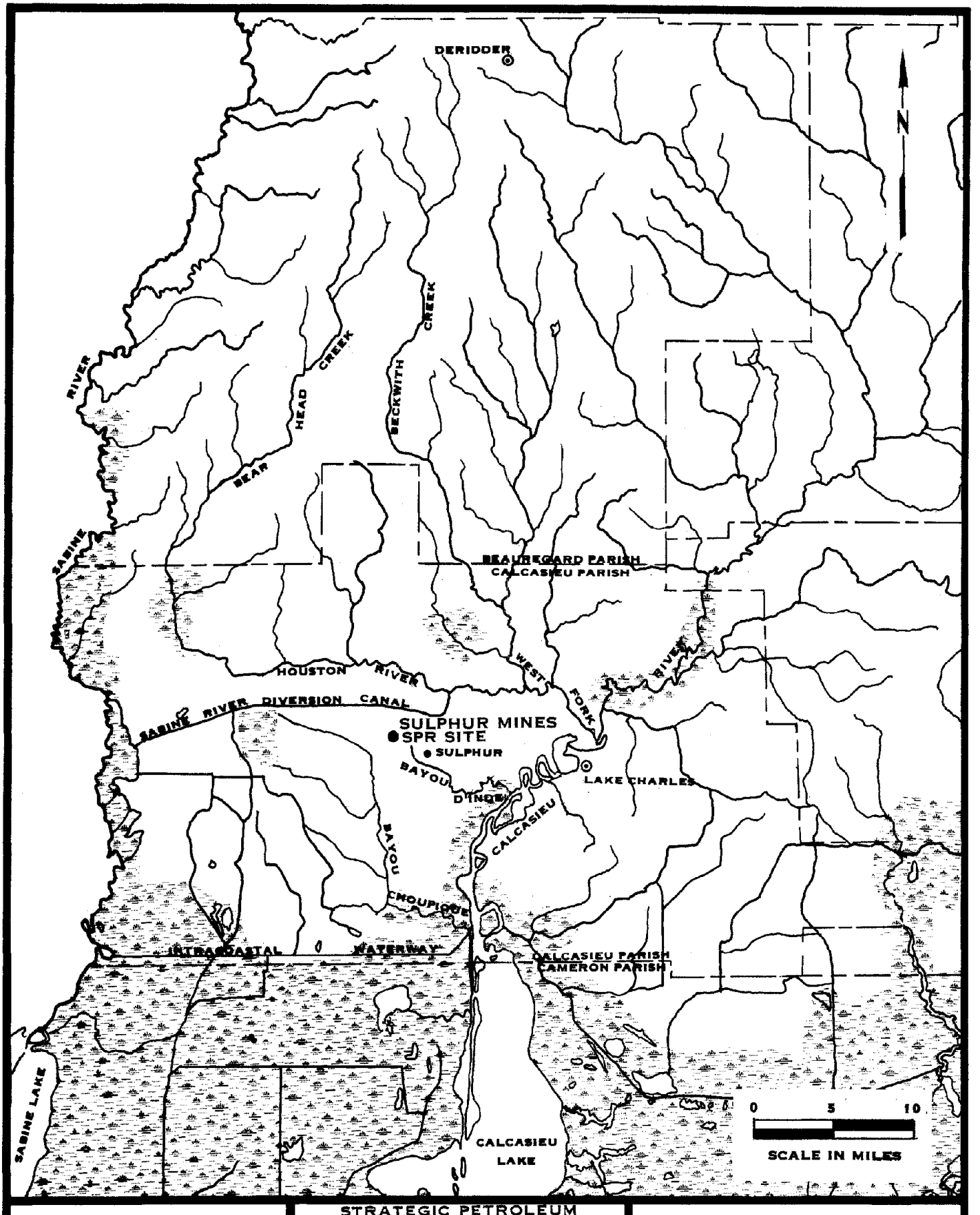
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STRATEGIC PETROLEUM
RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

MONTHLY NORMAL PRECIPITATION
FOR THE SULPHUR MINES SPR SITE

FIGURE 3-10



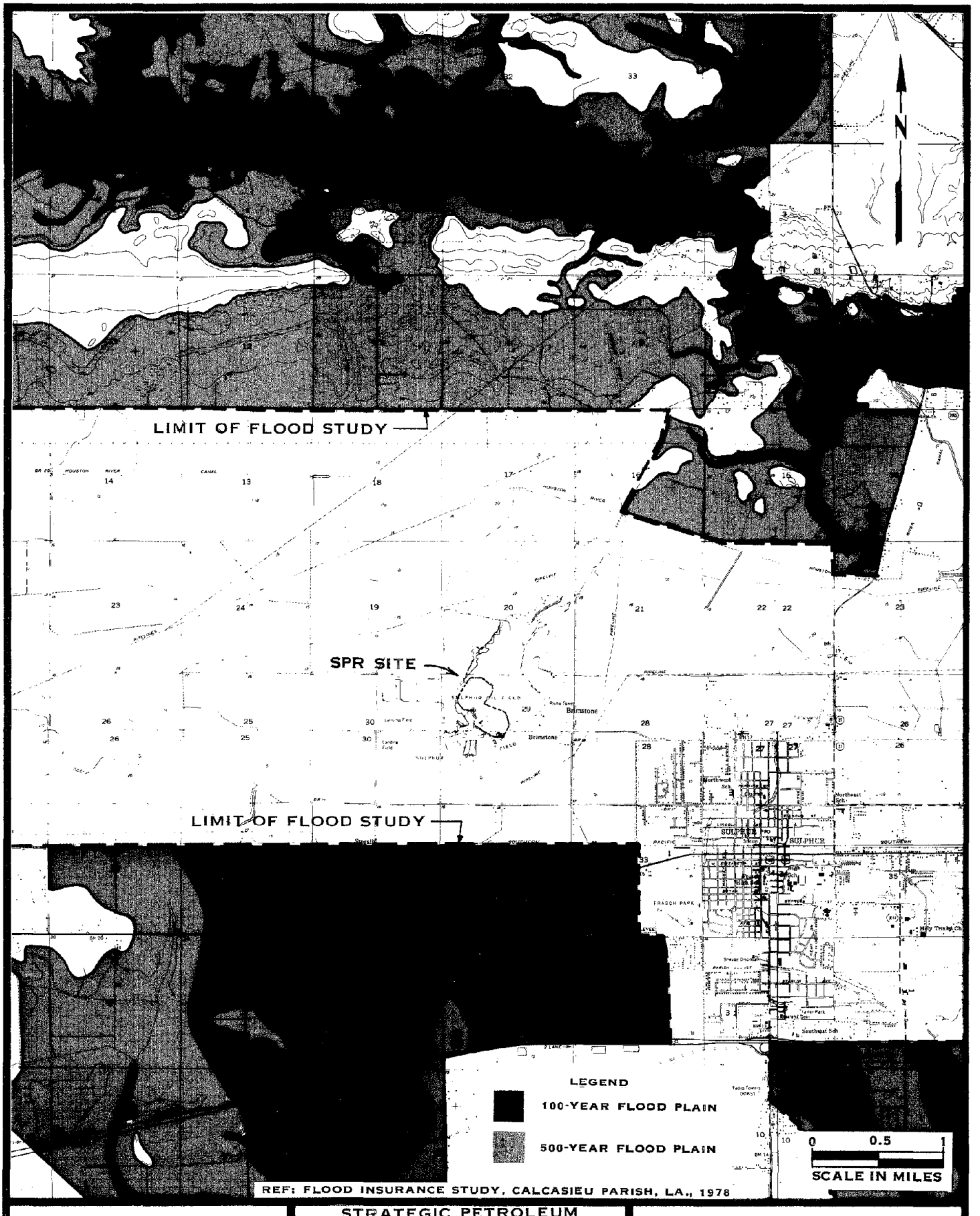
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STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

REGIONAL
SURFACE WATER FEATURES

FIGURE 3-11



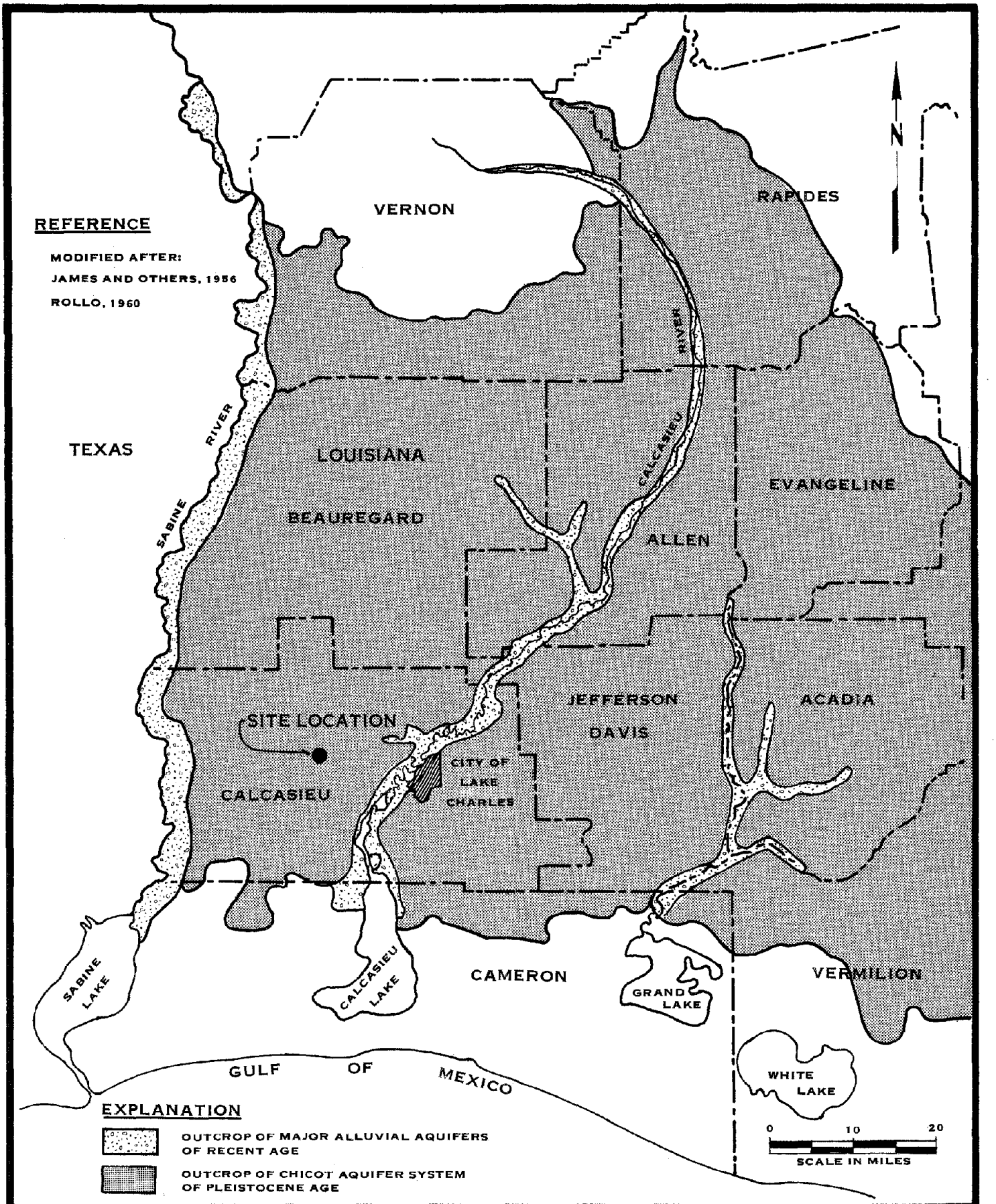
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STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

100 AND 500-YEAR FLOOD PLAINS NEAR SPR SITE

FIGURE 3-12

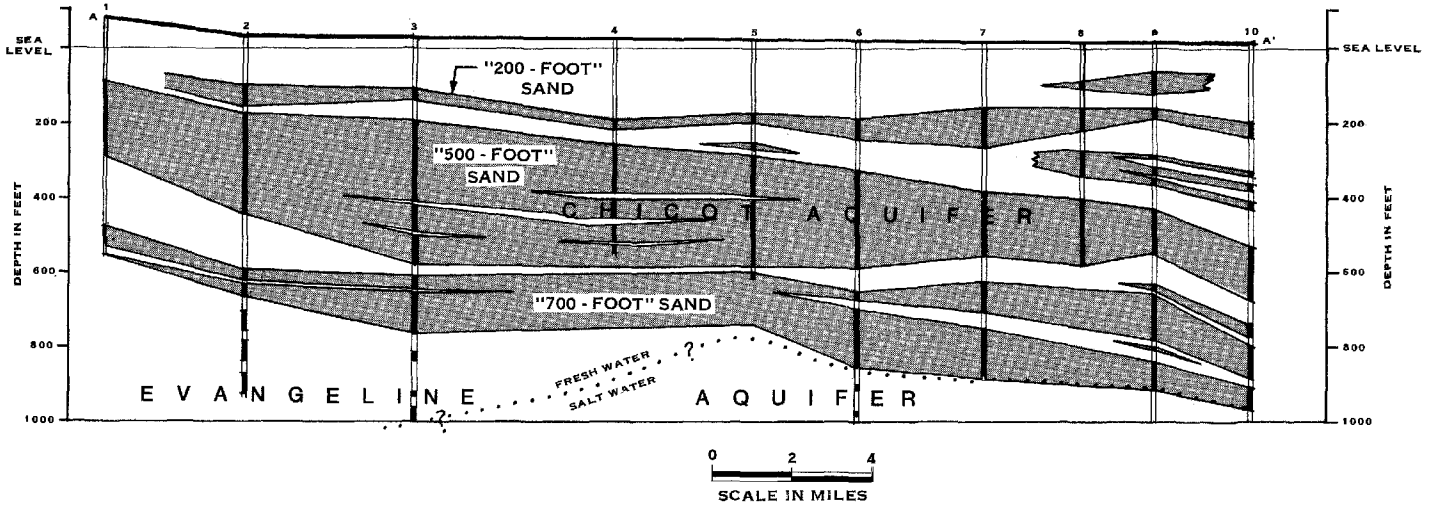


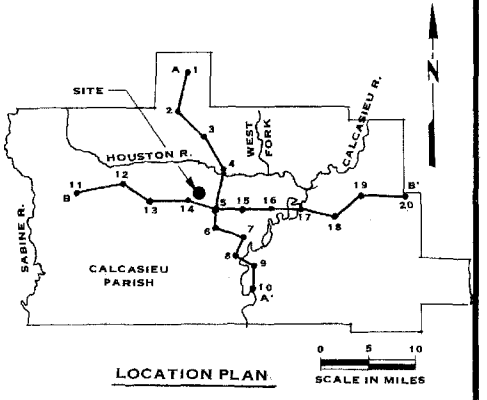
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STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME
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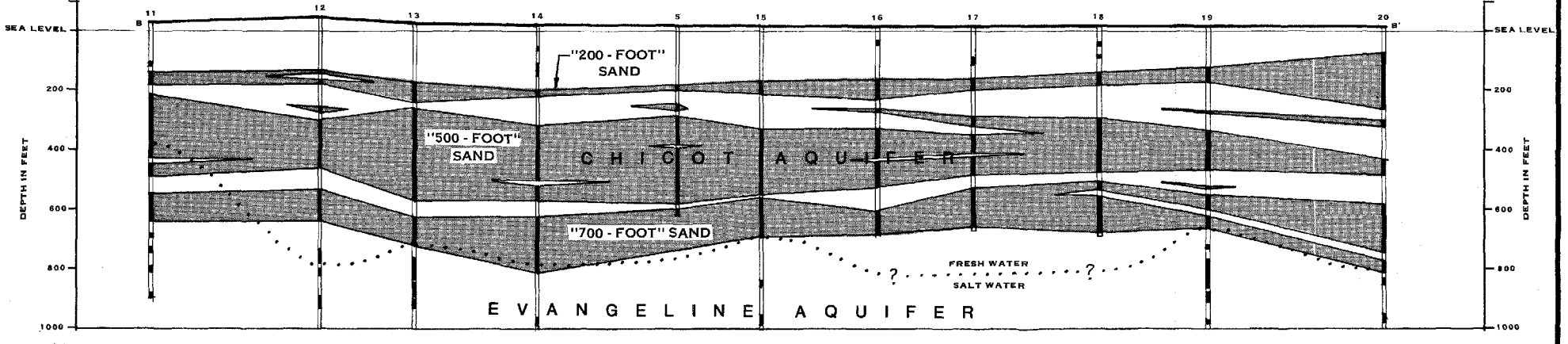
GENERALIZED OUTCROP AREAS OF ALLUVIAL AND CHICOT AQUIFER SYSTEMS

FIGURE 3-13





LOCATION PLAN



EXPLANATION

CONTROL WELL

PREDOMINANTLY SAND OF THE CHICOT AQUIFER SYSTEM

PREDOMINANTLY SILT AND CLAY CONFINING BEDS

REFERENCE

MODIFIED AFTER: HARDER, 1960

PREPARED BY	[illegible]	DATE	6-22-88
CHECKED BY	JA	DATE	7-8-88
REVISED BY		DATE	
APPROVED BY	[illegible]	DATE	12/1/88

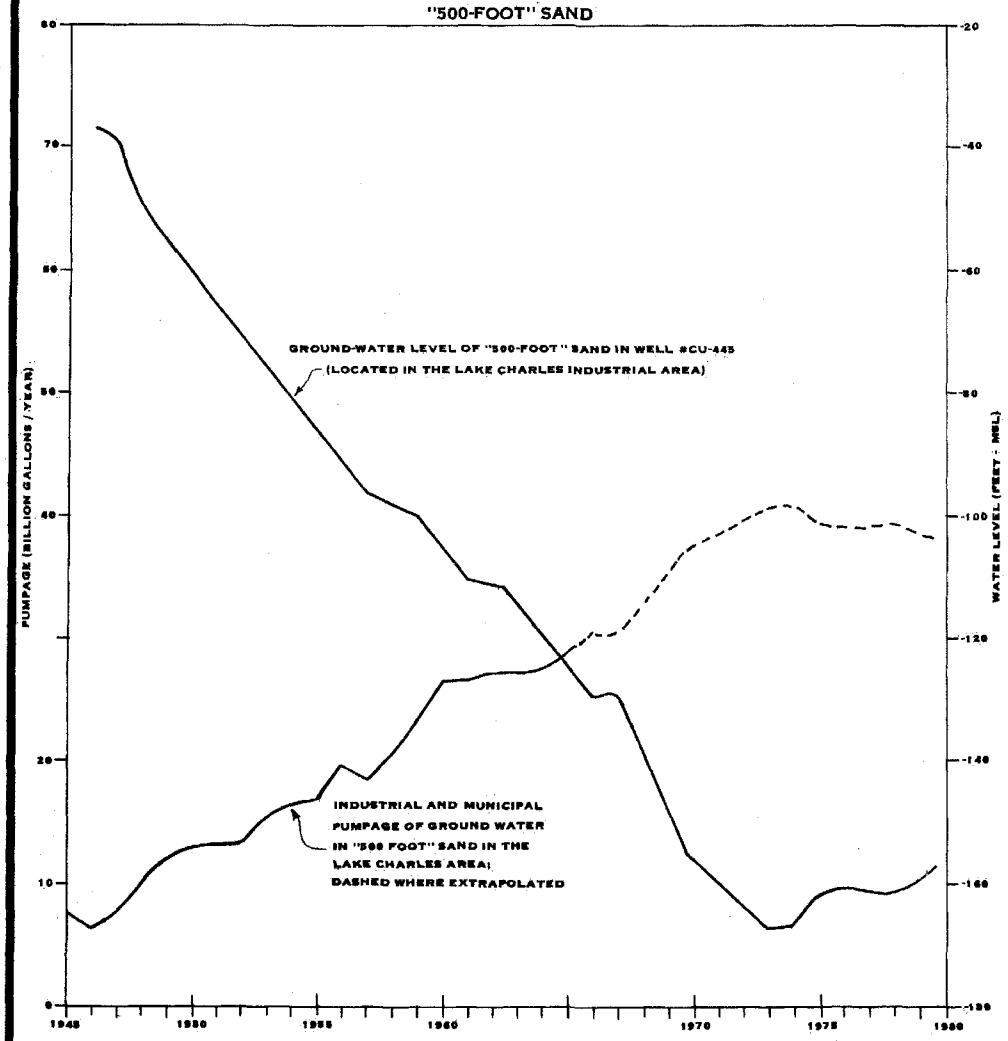
STRATEGIC PETROLEUM RESERVE PROGRAM

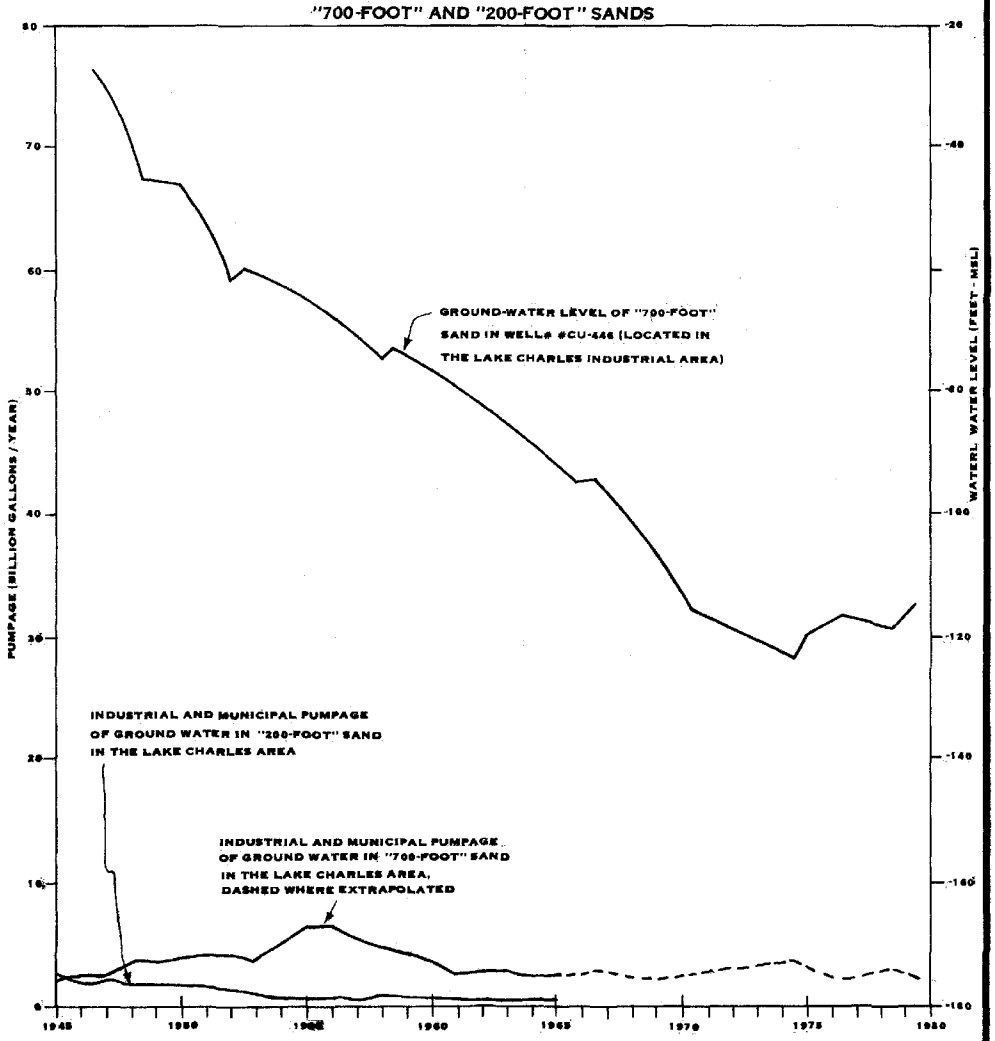
GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA

GENERALIZED CROSS SECTIONS OF THE CHICOT AQUIFER SYSTEM IN CALCASIEU PARISH

FIGURE 3-14





REFERENCE

MODIFIED AFTER:
HARDER AND OTHERS, 1967
WATER SITUATION IN LOUISIANA, 1979

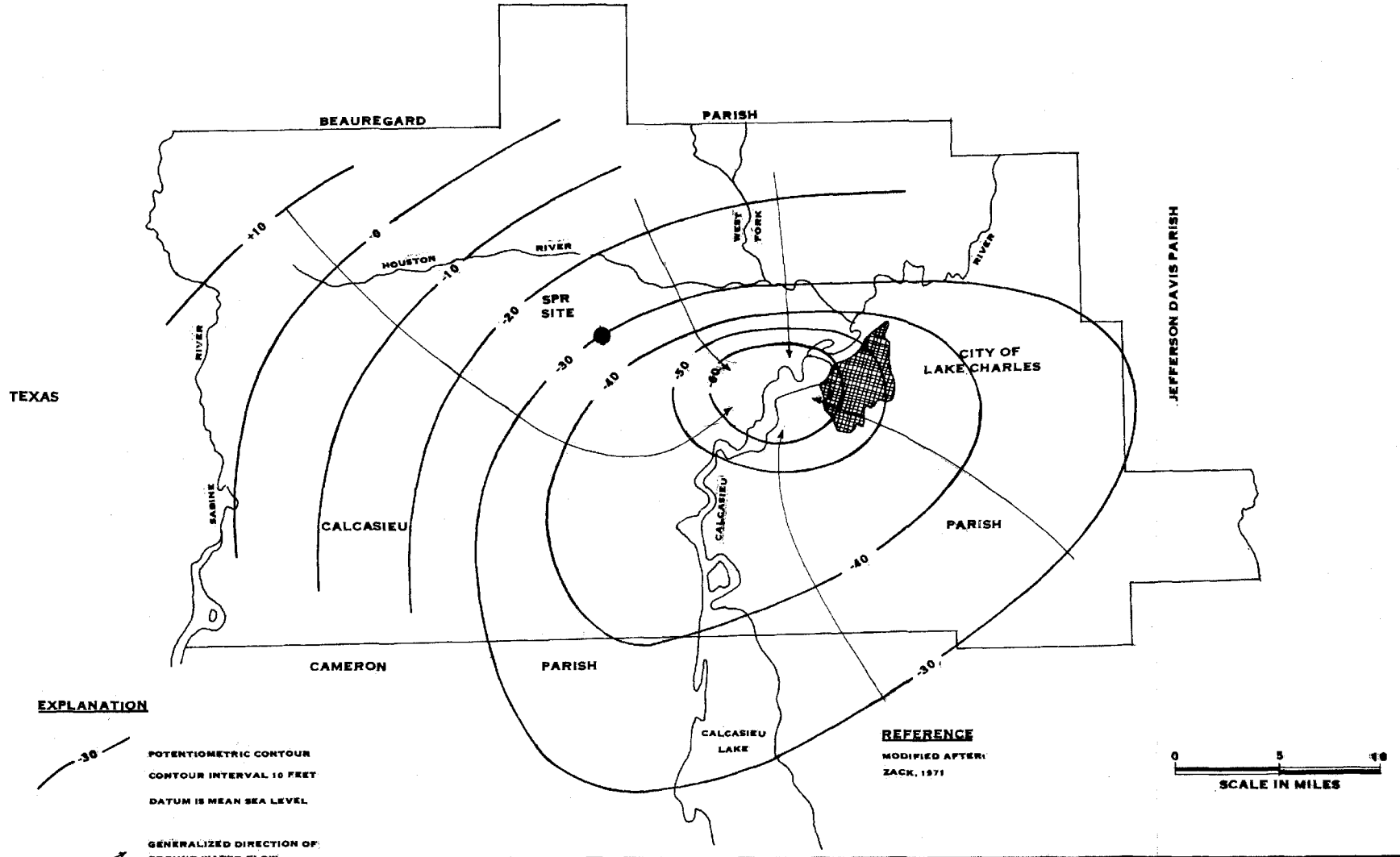
PREPARED BY RAS DATE 5-23-80
CHECKED BY JA DATE 7-8-80
REVISED BY ____ DATE ____
APPROVED BY CSS DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

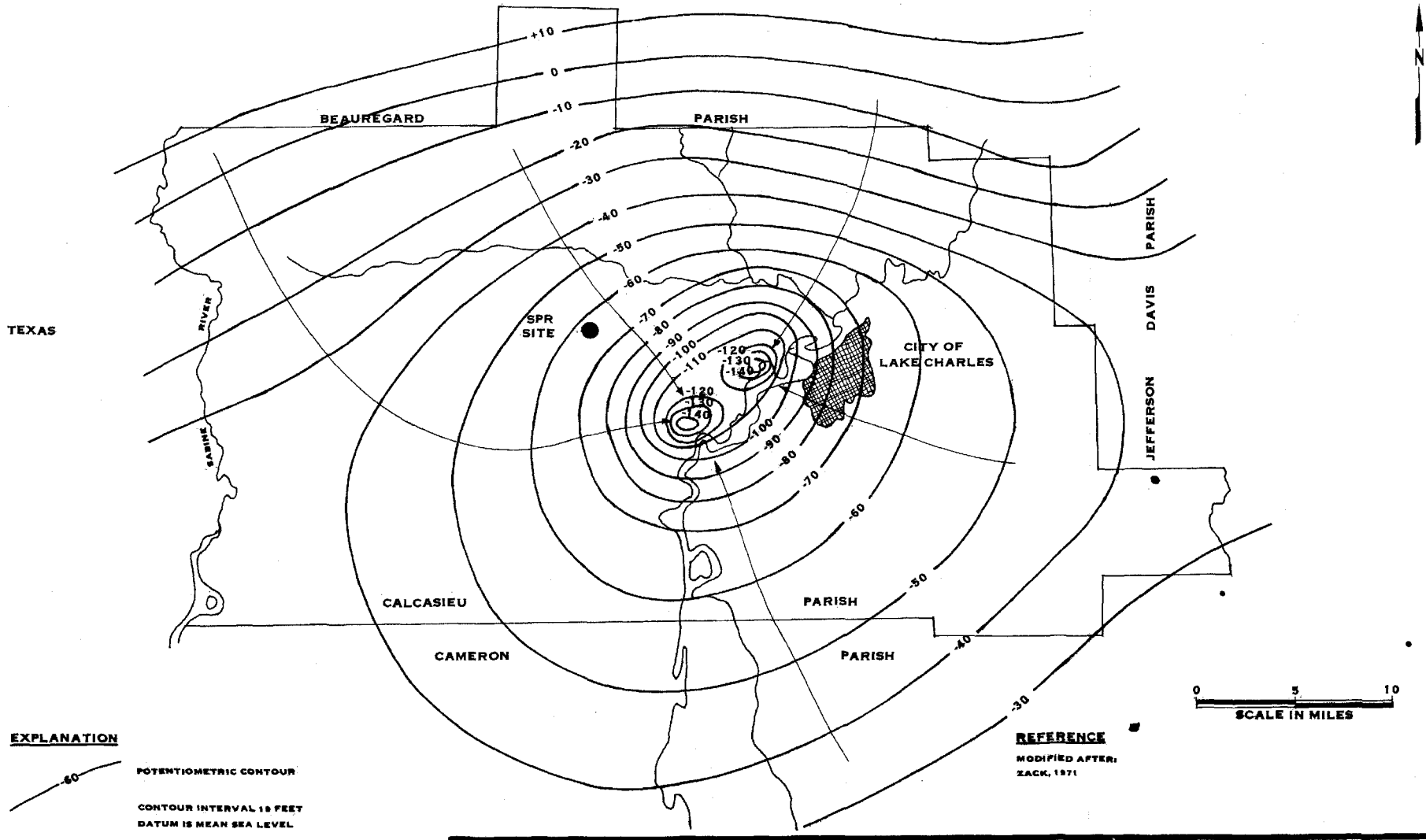
LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

GROUND-WATER LEVELS AND PUMPAGE IN THE CHICOT AQUIFER SYSTEM

FIGURE 3-15



PREPARED BY RAS	DATE 5-26-80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME	POTENTIOMETRIC SURFACE OF THE "200-FOOT" SAND IN CALCASIEU PARISH, MARCH 1969
CHECKED BY JA	DATE 7-9-80		
REVISED BY	DATE 7-14-80		
APPROVED BY LE	DATE 10/1/80	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	FIGURE 3-16



PREPARED BY RAS DATE 7/26/80
CHECKED BY JA DATE 8/20/80
REVISED BY RAS DATE 8/25/80
APPROVED BY LSK DATE 10/1/80

STRATEGIC PETROLEUM
RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

POTENTIOMETRIC SURFACE OF THE
"500-FOOT" SAND IN CALCASIEU
PARISH, SPRING 1970

FIGURE 3-17

4.0

4.0

4.0 SITE GEOLOGY AND HYDROLOGY

4.1 SITE GEOLOGY

The area influenced by Sulphur Mines salt dome extends out from the dome approximately four miles. The site area geology is typical for southwestern Louisiana. Domal influence is first seen in the oldest and deepest geologic units studied as the dome is approached from the edge of the study area. Close to the dome, progressively younger and shallower geologic units are influenced until adjacent to the dome the influence on the surface Pleistocene and Recent units occur.

4.1.1 Physiography

The site is characterized by low topographic relief developed on a surface with a gentle gulfward slope, only interrupted by the influence of Sulphur Mines salt dome. North of the dome, the Houston River marks the boundary between a somewhat hilly terrain to the north with elevations ranging from about 20 to 90 feet, and the flat Prairie terrace surface to the south where elevations range from 25 feet in the vicinity of the river to about 2 feet at the contact with the coastal Recent surface. The slope of the surface north of the Houston River averages 3 to 4 feet per mile gulfward whereas the Prairie surface slopes 1-1/2 to 2 feet per mile gulfward. The relief on the Prairie surface is almost imperceptible except along major streams. Relief of 10 to 20 feet is present between the tops of principal meander belt levees and their associated backswamp low areas.

Across the dome, ground elevations range from less than 4 feet in the central depressed area, to 14-20 feet along the perimeter road (Figures 4-1 and 4-2). These topographic features have been modified from their original state by mining activities. The approximate original topography, as it existed before sulphur mining activities, is shown in Figure 4-3. A comparison of this topography with the present land surface indicates that the central area over the dome has subsided as much as 18 feet in elevation. The previously existing topographic highs directly overlying the dome are now occupied by topographically lower features. This is discussed in detail in Section 5.1.4 on subsidence.

The original topographic surface also indicates a difference in surface features west and northeast of the dome. Before exploratory and mining activities began at Sulphur Mines, the terrain west and northeast of the dome was inundated forming a large swampy area (Figure 4-3). This swamp was subsequently drained and the area is now occupied by cultivated farmlands.

Several surface features appear as photographic lineations in the site area (Figure 4-4). Photographic lineations are linear tonal or color variations on aerial photographs. They can also be defined by the linear coincidence of certain geomorphic features such as drainage paths.

A major lineation, Number 1 on Figure 4-4, has good visibility and exists just east and south of the dome. This feature

is approximately 8 miles long, beginning in a wet area about 1 mile south of the site and trending northeastward along a tonal difference in an infrared photograph of the area. This lineation also crosses sharp southward bends in two east-southeast trending streams (Houston River and Little River) and crosses the ancient beach ridge north of the site at the point where the Houston River cuts through the ridge. It is also approximately coincident with the swampy area which once existed northeast of the dome. A portion of this lineation may correspond to the surface expression of a portion of a major trend growth fault in this region as will be discussed in Section 4.1.5 on subsurface structure.

Other lineations adjacent to the dome can be correlated with man-made drainage features. However, some of these features may have been natural originally and only recently modified by man. The lineations marked 2, 3, and 4 on the figure may possibly be surface expressions of some of the near vertically dipping radial faults which occur around the dome.

Other less significant and localized physiographic features in the Sulphur Mines site area include pimple mound scars and small meander or channel scars. Pimple mound scars appear on cultivated surfaces as circular areas up to 50 feet in diameter which are of a contrasting color to the surrounding soils and vegetation. The meander scars also create tonal or color differences within cultivated areas.

4.1.2 Surficial Geology

Sedimentary beds which outcrop near the site are Pleistocene to Recent in age. The geologic unit which outcrops throughout most of the parish is the Prairie Formation. As seen in Figure 3-3, the Sulphur Mines salt dome is located about halfway between the surface exposures of the base and the top of the Prairie Formation.

4.1.2.1 Pleistocene

The near-surface deposits of the Pleistocene Prairie Formation are similar throughout most of Calcasieu Parish. They consist predominantly of clays and fine sands with a small amount of coarse gravel, characteristic of deposition in alluvial to fluvial-deltaic environments. The Pleistocene deposits have been divided into four formations, the Williana, Montgomery, Bentley and Prairie. The Prairie Formation, the youngest, is the only Pleistocene formation which crops out in the site area (Figure 4-5).

According to Bernard, et al. (1962), the Prairie Formation was deposited during the Peorian interglacial stage between about 70,000 and 100,000 years ago (Figure 3-5). The axis of deposition of the Prairie was along a north-south line running approximately through the vicinity of Crowley in Acadia Parish (75 miles

east of the dome) as indicated by the occurrence of the formation's thickest and coarsest deposits in that area (Jones, et al., 1956). Westward and eastward from that line, the Prairie shows a textural fining, a thinning of the coarser deposits, and an increasing lenticularity of bedding. These trends, in addition to the high clay and silt content in the site area suggest that the near-surface Prairie Formation was deposited in a major flood plain or swamp environment near the western edge of a deltaic depocenter. Local concentrations of granular materials represent natural levee and channel deposits formed by small, meandering distributaries of a major stream.

Many driller's logs exist for wells drilled on or in the vicinity of the dome. The general descriptions of the materials penetrated by the wells are presented in Table 4-1. Several soil test borings have been made at the dome by Law Engineering Testing Company and others. The borings, below the fill and topsoils, indicate a lithology consisting of stiff to very stiff, brown to red, gray and yellow silty clays containing occasional calcareous nodules and a few fine sandy silt seams. Organic matter and large pieces of wood are also occasionally encountered. The clays predominate below 25 to 30 feet and change to a blue-gray to gray color.

4.1.2.2 Recent

All deposits of Recent age in the Sulphur Mines site area are of alluvial to paludal (marsh) origin (Figure 4-5). Those deposits are composed predominantly of fine grained sands and silts with localized clays and gravels. Coarser sediments occur within the major stream valleys and the clays are found within the flood plains of those streams.

Recent deposits of a slightly different nature may constitute a substantial portion of the surface sediments in the vicinity of the dome. These deposits are typically clays and sandy to silty clays which were laid down in a low-lying swamp or marsh that occupied a large area in the vicinity of the dome before mining activities began in the late 1800's. This swampy area is shown in the pre-mining topographic map (Figure 4-3). The thickness of these Recent deposits in the immediate dome area is difficult to determine because of the great amount of fill material, which is difficult to distinguish from Recent deposits, that has been laid down during the past 70 to 80 years. This fill material is generally loose and unconsolidated with sand and silt streaks and pockets. It appears, from soil test boring data, that the Recent swamp deposits may reach a thickness of 27 feet on the western edge of the dome. Farther west from the dome, they thin rapidly and are probably no thicker than one foot.

4.1.3 Soils Distribution and Properties

Data concerning near surface soils in the Sulphur Mines SPR site area are available from two reports of soil investigations, LETCo (1977) and PB/KBB (1978). Together, these reports included 51 soil test borings and three test pits. These sources allow for a review of subsurface conditions in the upper 50 feet.

Soils in the site area generally consist of uncemented, unlithified deposits of sand, silt, and clay, with clay predominating. In general, the entire site is underlain by soils of the Prairie Formation which are locally overlain by more recent geologic deposits off the dome or by very recent man-placed fill on the dome.

4.1.3.1 Soils of the Prairie Formation

The Prairie Formation consists of sediments deposited prior to the most recent glacial event. Due to the global lowering of sea level, which accompanied the last glaciation, the sediments of the Prairie Formation experienced an increase of effective stress due to a lowering of water levels and developed in many places an oxidized upper surface due to desiccation and weathering effects. These effects are evident at the site, where consolidation test results show overconsolidation ratios of 3:1 to 6:1 (ratio of maximum previous consolidation pressure to existing overburden pressure). This overconsolidation results in stiffer soils with relatively lower moisture contents. The oxidized zone is noted in many borings where a soil changes from an overlying softer gray soil to a gray and brown or red-brown stiff clay.

The soils of the Prairie Formation consist predominantly of clay to silty or sandy clay, with some thin zones or beds of sand and silt. Clays are somewhat variable in plasticity, with liquid limits in the range of 40 to 90 percent, plasticity indices of 20 to 60 percent, and natural moisture contents of 15 to 40 percent. The more plastic soils generally show slickensides. The clays classify as CL or CH according to the Unified Soil Classification System, Appendix E. Shear strength varies from approximately 1,500 to 4,000 pounds per square foot, with blow counts, determined by the standard penetration test, ranging from 7 to 20 blows per foot.

Sands and silts within the Prairie Formation in the dome vicinity occur as relatively thin zones or laminae within the clay, with a few zones up to 5 feet thick. The sands are fine grained, and classify under the Unified System as SC or SM. Silts occur as sandy or clayey silts and classify as ML or MH.

4.1.3.2 Soils of Recent Geologic Deposits

After and during the rise in sea level following the most recent glaciation, Recent soils were deposited on the Prairie Formation in the dome vicinity. These soils are distinguished by two factors. First, they overlie the erosional oxidation surface of the Prairie, and can thus be recognized as softer, generally gray clays and silts overlying the stiffer brown, gray and

red-brown Prairie soils. Secondly, the Recent soils have not experienced a long period of lowered sea level and desiccation. hey are normally consolidated, and as such have gher moisture contents and lower shear strengths than the soils the Prairie Formation. These Recent soils have approximately the same range of liquid limit and plastic limits as the Prairie soils, but generally contain more organic matter. Shear rengths range from several hundred pounds per square foot up to approximately 2,000 pounds per square foot. Moisture contents range from about 20 to over 100 percent for some soils in the pond bounding the west and northwest side of the dome.

Based on test boring records, Recent soils are thickest in the area immediately west of the dome and thin away from the dome. Recent soils are generally absent over the dome, and thin to absent immediately east and southward from the dome.

4.1.3.3 Fill Soils

Fill soils are a result of man's activity on the dome. As sulfur was mined and subsidence occurred, fill was placed to prevent flooding, to fill localized sink holes, and to provide a working platform. The majority of this fill was placed in the actively mined areas directly over the dome by the use of hydraulic dredges. The principal source of dredged material is the area of Recent deposits located west and northwest of the dome and Pleistocene deposits east and northeast of the dome. These hydraulically worked soils were placed in layers by the action of the dredge outlet, and as a result contain interlayered sand and silt pockets. The soils have been consolidated only by the weight of sediment and by some surface desiccation. As a result, the soils are normally consolidated, meaning the maximum overburden pressure and the present overburden are approximately the same. The fill material is generally soft to firm clay with moisture contents in the range of 20 to 50 percent and cohesion values ranging from several hundred pounds per square foot up to 2,000 pound per square foot where desiccated. Liquid and plastic limits are similar to the Prairie and Recent soils, from which the fill is derived. The fill soils are classified as CL or CH in the Unified System.

4.1.3.4 Collapsible Soils

Calcasieu Parish, including the site area, is dotted with low, round hummocks of silt from 1 to 3 feet high and 20 to 85 feet across (Arman, et. al, 1972). These structures are termed "pimple mounds" and have been identified as being present around the site from old aerial photography. The origin of pimple mounds is still in dispute, but they are considered depositional features, and are formed on low relief surfaces having silty and sandy soils and appear to be locally associated with vegetation peculiar to the pimple mounds. It is doubtful these structures ever existed over the dome. The soil structure of the pimple mounds is considered collapsible since in a wet condition they may collapse and flow when loaded.

4.1.4 Stratigraphy

In the immediate vicinity of Sulphur Mines salt dome, no sediments older than early Oligocene age have been penetrated by exploratory drilling. Early Oligocene and Paleocene sediments are believed to be similar in lithology to Oligocene and post-Oligocene sediments and consist predominantly of sands, silts, clays, and shales deposited in widely varying environments ranging from alluvial to deep-water marine. A generalization of the transgressive or regressive nature of each unit is shown in the stratigraphic chart along with the faunal assemblages used in formation recognition (Table 3-2). The sediments lying in contact with the dome are steeply upturned. At depths between 11,000 feet and the surface the sediments can be generalized as follows:

11,000 to 5,000 feet predominantly shales and limey shales

5,000 to 4,500 feet massive sands with interbedded shales

4,500 to 3,500 feet predominantly shales and few limey shales

3,500 to 600 feet interbedded sands and clays

above 600 feet predominantly massive sands and gravels with thin interbedded clays.

The following is a discussion of the detailed stratigraphy of individual geologic units between -11,000 feet MSL and the surface.

4.1.4.1 Vicksburg Group (Oligocene)

The upper portion of the Vicksburg Group is the deepest formation penetrated by drilling in the vicinity of Sulphur Mines, occurring at an average depth of 9,500 feet and possibly as shallow as 7,000 feet where uplifted by salt dome movement. The Vicksburg Group in the site area consists of a monotonous transgressive sequence of dark calcareous shale, marl, and smaller amounts of limestone representing deposition in an outer to inner neritic shelf environment where subsidence and deposition were nearly balanced.

4.1.4.2 Catahoula Group (Oligocene)

The Catahoula Group is sub-divided into two formations - the Frio and the Anahuac. The Frio is the oldest formation and is overlain by the Anahuac. The age of the Anahuac is disputable, it is considered by a few geolog-ists to be Miocene, but in this report it will be considered Oligocene.

Frio Formation - The total thickness of the Frio ranges from 2,300 feet in northern Calcasieu Parish to 3,500 feet in northern Cameron Parish. The Frio consists of dark to very dark colored shales, silty shales, and massive to thinly bedded calcareous

sands and silty sands. The Frio section is divided into three parts in the study area based on faunal zones; the Upper Frio, Middle Frio (including the Hackberry wedge) and Lower Frio (Warren, 1957 and Paine, 1966).

The Lower Frio is represented by sandstones and shales deposited in inner and outer neritic environments during a period of rapid sedimentation. The strand line during Lower Frio is presumed to have been near the northern boundary of Beauregard Parish (40 miles north from the site). Downdip or south of this locale, the Lower Frio becomes increasingly marine in character with shale predominating the lithology. The Lower Frio in the site area is generally very shaley. During Lower Frio deposition, local uplifting caused by salt movement occurred along the "Oligocene Domal Trend", including the site area (Paine, 1966). This was followed by a period of non-deposition or erosion forming local unconformity surfaces with relief of up to 150 feet. A short period of transgression followed, resulting in deposition of inner neritic sands and shales. Then a major regression began marking the beginning of Middle Frio deposition.

At the base of the Middle Frio is the Hartburg sandstone (Bornhauser, 1960) which is developed mainly in areas north of the site, where it attains thicknesses of 400 to 500 feet. After Hartburg deposition, another period of salt movement, accompanied by uplift and folding, occurred along the domal trend. Erosion followed, which in some areas cut as deeply into the strata as Vicksburg sediments. This created the major Lower Hackberry unconformity across Calcasieu and Jefferson Davis Parishes. Lower Hackberry sands were deposited within the deeply eroded channels formed during this period. Paleontologic data indicates the presence of shallow-water fauna (50-150 feet) in these sands, thus they apparently represent turbidity flow deposits (Paine, 1966). A very narrow channel deposit of this type is found north of Sulphur Mines salt dome and dips northwestward at its base. The top of this sand is at about -8,800 feet MSL and it reaches a thickness of almost 200 feet (Dawson Exploration, 1976).

Rapid subsidence and trangression took place after Lower Hackberry sand deposition. This resulted in deposition of the Hackberry shale, a predominantly outer neritic shale. The thickness of this section ranges from less than 100 feet at its updip limit in northern Calcasieu Parish to 3,000 feet in southeastern Calcasieu Parish. At the site area it obtains a maximum thickness of about 900 feet. A shale sheath or gouge zone containing Hackberry fauna is found on the salt dome flanks at depths as shallow as -4,100 feet MSL. Away from the dome its position is about 3,900 feet lower.

Regression followed Hackberry deposition, and the Upper Frio sand-shale sequence was deposited. This sequence represents deposition on a relatively stable, shallow-neritic shelf. The Upper Frio thickens rapidly southward of the domal trend across a series of growth faults.

Anahuac Formation - The Anahuac Formation of the Catahoula Group represents the top of the Oligocene. In the Sulphur Mines area the Anahuac consists of 500 feet of light to dark greenish gray, highly calcareous clay and shale with interbedded fine to medium grained sands and occasional lenses of limestone. Shales predominate in the upper 100 to 200 feet and fairly massive sands prevail in the lower portion. Reef-type limestone is developed locally in the Heterostegina zone, usually on the crests of domal structures (Warren, 1957). Heterostegina species of foraminiferas are noted in paleontological reports of wells around Sulphur Mines salt dome indicating a positive expression on the sea floor over the dome during Anahuac deposition. The Anahuac was deposited in inner to outer neritic environments. In the vacinity of the Sulphur Mines salt dome the Anahuac is present at an elevation of 6,000 feet MSL. Adjacent to the dome it is 2,000 feet shallower.

4.1.4.3 Fleming Group (Miocene)

The Miocene, represented by the Fleming Group, was deposited in a rapidly subsiding marginal sea by the ancestral Mississippi River. During times of abundant sediment supply, the shoreline prograded seaward; when sediment supply slowed or subsidence increased, the sea transgressed depositing an onlapping sequence of neritic shale over the coarser deltaic deposits. Therefore, a Miocene sequence has been developed which consists of 4,200 feet of alternating fluvial deltaic and shallow marine sands, silts, and clays. The Miocene section becomes thicker and more marine gulfward.

Specifically, the Lower Fleming consists of well-sorted, fine to medium grained sands, with traces of fine grained chert gravels, interbedded with silt, lignite, and clay with calcareous concretions. The sands are lenticular and generally massive with individual beds commonly less than 50 feet thick. Some of the massive sand beds approach 100 feet in thickness.

The Upper Fleming is predominantly regressive and commonly consists of thinly interbedded layers of calcareous clays and very fine to medium grained sands. Some lignite beds are present as well as some coarse sands and a small amount of pyrite and abundant shell fragments. Locally, the top of the Fleming is at elevation -800 feet MSL, and 200 feet shallower adjacent to the dome.

4.1.4.4 Citronelle Group (Pliocene)

The entire Pliocene is represented by the Foley Formation (Jones, et. al., 1956) and is distinguished from the Miocene Fleming Group by the occurrence of a specific faunal assemblage. Paleontological data is unavailable in the site area so that the Pliocene/Miocene contact cannot be accurately determined. For this reason, the approximate contact is shown as a dashed line in all cross-sections. The top of the Foley Formation is normally identified by a lithology consisting of interbedded fine to medium grained sands and silts and soft laminated clays as distinguished from the gravels of the overlying Pleistocene Williana Formation. However, it is not always reliable to differentiate

between the Foley and the Pleistocene by texture alone since variations do occur. Therefore, sediment color is used where good samples are available. The Foley is usually blue and gray to black with abundant finely divided lignite, whereas the overlying sediments are predominantly buff to red or tan.

The Foley is separated into two members. The upper member is a sequence of fine grained beds which contain abundant finely divided lignite. Driller's logs report scattered occurrences of "boulders" in the Upper Foley. The lower member is composed of medium to fine grained sands interbedded with light gray to greenish gray and black, massive to thinly bedded and laminated clays. Sand content ranges from 50 to 80% and the sand units are commonly laterally and vertically interconnected. Organic material, thin and lenticular bedding, and the amount of fine material present indicates a coastal marsh or back-swamp origin for the Foley. Abundant pyrite and marcasite indicate deposition below the water level.

Because of similiar lithology to units above and below the Foley, its thickness has not been determined locally. However, it is reported to vary from 1,000 to 2,500 feet thick, 18 miles south of the site (Jones, et al, 1956).

4.1.4.5 Houston Group (Pleistocene)

The Pleistocene of southwestern Louisiana is represented by a series of terraces deposited as coalescing fluvial-deltaic fans during successive periods of lowered sea level. Each Pleistocene unit is separated by an erosional surface of variable relief. The normal sequence of sediments in each unit consists of gravels and coarse sands at the base, grading to finer sands, silt, and clay at the top. All of the Pleistocene deposits were probably derived from the same source. A downdip thickening toward the Gulf is common to each unit and they become transitional to marine along the Gulf margin.

Williana Formation - The Williana Formation, which outcrops in southern Vernon and Rapides Parishes, was deposited on a pre-Pleistocene erosional surface that was not dissected too deeply. The thickness of this unit is irregular but most major irregularities were caused by structural influences, i.e., salt dome movement. The cross-sections (Figures 4-6 and 4-7) show the thickness of the Williana ranging from around 400 feet off the dome flanks to zero in some places over the caprock. The top of the Williana is uplifted over the dome as much as 50 feet above the surrounding area. The top of this formation is about -350 feet MSL at its shallowest point on the cross-sections. Gravels and coarse sands predominate the lithology with the thick coarse deposits occurring in lenses with considerable lateral transition. Clays are relatively rare and tend to occur in thin beds.

Bentley Formation - The cross-sections (Figures 4-6 and 4-7) show the Bentley to have an average thickness ranging from 120 to 180 feet in some locations directly over the caprock. The top of the Bentley ranges from -230 feet MSL around the dome to -200 feet MSL directly over the dome. Some of this variation may be

attributed to the deeper cutting of some stream channels during post-Williana and post-Bentley erosion.

The fairly thin top stratum of the Bentley consists of clays and silts and contains ferruginous clay pellets. The lithology grades downward to fine grained sands and very coarse grained gravel in a matrix of ferruginous sand with some thin clays. The Bentley outcrops in Beauregard and western Allen Parishes.

Montgomery Formation - The cross-sections (Figures 4-6 and 4-7) indicate a fairly uniform thickness of the Montgomery across the site. Thickness ranges from 80 feet northwest of the site, to 110 feet southeast of the site. The top of the Montgomery in the cross-sections ranges from about -100 to -160 feet MSL.

The Montgomery Formation, which outcrops in southern Beauregard and northern Calcasieu Parishes, generally consists of clays and silts with some interbedded sands in the upper half of the formation. The lower half is composed primarily of fine grained sands and gravel.

Prairie Formation - The uppermost unit of the Houston Group is the Prairie Formation, which outcrops across most of Calcasieu Parish. The Prairie is thickest in the southeastern part of the Parish. The depth to the base of this unit ranges from -100 feet MSL just south of the site to -150 feet MSL just west and north of the site. This area of deeper basal Prairie sands and gravels may be the location of a major tributary during early Prairie deposition and an area of deep post-Montgomery erosion.

The Prairie is generally composed of clays and silts in the upper one-half to two-thirds or more of the formation. These fine materials represent swamp or flood-plain and natural levee deposits. The lower portion of the Prairie is usually composed of gravel and sand grading from coarse to fine upward. Driller's logs describe the clays as "sticky gumbos" and the gravels as "pea size". Limestone concretions and large pieces of wood are common in the Upper Prairie.

4.1.5 Stuctural Geology

The major structural elements at the site are controlled by salt movement and regionally developed growth faulting. Major faulting is interpreted in seismic sections near the Sulphur Mines salt dome and is noted on electric logs from wells drilled in the area. The affects of tectonic activities divide southwestern Louisiana into several distinct structural segments as shown in Figure 3-1.

The Sulphur Mines salt dome lies within the "Oligocene Domal Trend" which occurs south of the "Eocene Fault Trend Area" and north of the "Growth Fault Area" (Ocamb, 1961). This area represents the northernmost occurrence of piercement salt domes within the Gulf Coastal basin (Figure 4-8). Major upward movement of salt probably began in this area during or just prior to Oligocene time and continued into the Pleistocene in some places.

During this time span, the irregular upward movement of salt domes caused the development of faulting typically associated with piercement structures including graben and radial fault systems. Fault trends are irregular in the "Oligocene Domal Trend" but do possess regional character. Growth or movement contemporaneous with deposition along the fault trends of this area is limited to the vicinities of salt domes. These fault trends, like those of the Eocene trend, have associated split faults. However, split faults of the Oligocene trend have a tendency to extend over to other major faults, thus lending to characteristics of regional development.

Seismic sections, electric logs, and gravity data indicate that the Sulphur Mines salt dome is a small piercement dome which is connected at depth to a much larger salt pillow. This is illustrated in Figure 4-9. Edgerly salt dome, about 5 miles west of Sulphur Mines is a similar salt piercement dome connected to the same salt pillow structure. Sulphur Mines salt dome pierces upward through sediments as young as Pleistocene age causing beds to up-turn and, in some cases, pinched out against the flanks of the dome (Figures 4-10 and 4-11).

The Anahuac shale, the most continuous and widespread unit in the region of Sulphur Mines salt dome is easily identifiable on electric logs and seismic sections. For these reasons, the base of the Anahuac shale, or the Marginulina idiomorpha marker, was mapped to show the general relationships of the area structure. As seen in Figure 4-12, there is significant Anahuac uplift immediately around the dome. An area which is structurally lower than regional conditions exists from one to four miles away from the dome. This "rim synclinal" area is a typical feature associated with many piercement salt domes and is caused by the downwarping of sediments into areas from which the Louann Salt withdrew to feed the piercement structure. The upward extent of the rim syclinal downwarping is seen in seismic sections in strata as young as late Miocene. The isopach map of the disposal zone of SPR Brine Disposal Wells 2 and 4 shows thickening of this Lower Miocene interval in the rim synclinal area west of the dome (Figure 4-14).

The base of the Pleistocene also demonstrates major uplifting over the dome. The Pleistocene was uplifted possibly more than 200 feet, above regional conditions. Seismic sections indicate uplift in later Pleistocene age strata also. The premining topography of the site area (Figure 4-3) indicates a small, almost circular hill located directly over the dome. This hill reaches an altitude of approximately 8 feet higher than the surrounding region. The low swampy area around and west of the dome may be surface expression of the rim syncline development mentioned above.

A north - south cross-section, just off the eastern flank of the Sulphur Mines salt dome, shows the effects that faulting has had on the structural development of the area (Figures 4-15, 4-16). Sulphur Mines salt dome has had no major effect on the sediments shown on this cross-section, even though the dome is only 1/2 mile west of the line. The gentle coastward dip of the sediments, increasing with depth, is typical of the "Oligocene

Domal Trend." The regional dip varies from 80-100 feet per mile in Ogliocene units, 60-80 feet per mile in Miocene and Pliocene units, and 4-20 feet per mile in Pleistocene units. All units generally dip to the south and southeast.

Salt movement has caused the upwarping of strata, through flexure and faulting, against the flanks of the salt dome. A major down-to-the-coast fault occurs just north of the dome and shows a thickening of sediments on the downthrown block and increasing displacement with depth. Displacement of about 700 feet is present at about 10,000 feet below sea level (Lower Oligocene). At 5,000 feet below sea level (Middle Miocene) displacement is around 250 feet. Another fault is present about 2 1/2 miles south of the dome where 1,000 feet of displacement has occurred at a depth of 13,000 feet. Both of these faults may reach shallower depths than indicated on the cross-section but sufficient evidence to substantiate that does not exist.

Other cross-sections, Figure 4-17 and 4-18, indicate rim-syncline development complicated by faulting north and south of the dome with a thickening of sedimentary units towards their axes. The salt shown in the cross-sections illustrates only the salt pillow structure. Development of a rim syncline west of the dome is also indicated by seismic and well data. Abrupt unwarping of sediments into the domal flanks occurs on both the east and west sides but no syncline development is evident east of the dome (Figure 4-16).

Numerous radial faults occur around Sulphur Mines salt dome (Figure 4-12). Faults of this type probably have throws of less than 50 feet and would be difficult to discern in seismic sections and logs. Some of the more evident radial faults are shown on the structure map of the Marginulina idiomorpha marker (Figure 4-12). Figure 4-13 illustrates the surface projection of faults identified in the Anahuac horizon (Figure 4-12).

4.1.6 Oil and Gas Exploration and Production

Interest in exploration and production of oil and gas as Sulphur Mines was initially the result of the presence of surface oil seeps which flowed into the surrounding marshes. Spurred on by the first oil strike in the United States at the famous Drake well in Pennsylvania, a shallow well was drilled in 1860 to just below 450 feet over a portion of the dome. Little production was obtained from this well (Haynes, 1942).

In 1867 two wells were drilled to approximately 1,200 feet by Louisiana Petroleum and Coal Oil Company over the dome into the caprock, but both wells were dry holes. Around 1900, two or three additional wells were drilled in the top of the caprock and produced a heavy black oil with a gas drive. Shortly the gas pressure dissipated and the oil flow stopped and was followed by a flow of sulphurous water.

It was not until 1915 that production from shallow horizons (2,800 feet deep) was developed in sands adjacent to the north flank of the dome (Kelly, 1925). After the 1920's, oil exploration and production along the flanks of the dome was common, being produced by Union Sulphur Company, now known as Union Texas Petroleum.

Exploration and production did not reach significant proportions until the late 1930's through 1950's. Since then oil production at Sulphur Mines Dome has been steadily declining. No significant amount of gas has been produced at Sulphur Mines salt dome, what small amount produced was generally flared off. Of a total of 204 wells drilled along the flanks at Sulphur Mines salt dome, 163 wells have produced approximately 27.5 million barrels of oil as of June, 1976. Of the 163 wells that have produced, only 14 are still producing as of June, 1976. The remaining 149 have been plugged and abandoned. However, a small percentage of these may only be temporarily abandoned or shut in. Approximately 20% of the holes drilled along the flanks of Sulphur Mines dome were dry holes.

A significant number of the wells which have produced were reworked, deepened, or sidetracked to other locations and depths as production in a specific horizon declined. It is not uncommon to find wells with two or three different sidetracks.

Production has been as shallow as 2,500 feet in the early period of the field's development. As the shallow reservoirs began declining, exploration and production moved further off the dome flanks and into deeper horizons. Today most of the production is on the southwest flank of the dome. However, three producing wells are located on the north and northeast flank of the dome. Production depth is generally 6,000 to 7,000 feet for the wells furthest off the dome and approach 4,000 feet for wells producing closer to the dome. The three wells on the north and northwest flanks of the dome produce from horizons as shallow as 3,000 to 4,000 feet.

The oil trapping mechanism is generally described as structural closure of inclined strata against the flanks of the dome. The reservoirs are generally small and broken up by radial faults which are associated with dome piercement. This has resulted in the numerous wells drilled along the dome flanks as the reservoirs have small lateral extent and are quickly depleated. Most of the production has been from Lower Miocene age sands and Oligocene Marginulina and Cibicides hazzardi sands.

Union Texas Petroleum Company has developed a 10 year program ending in 1989 for further development of Sulphur Mines. Prospectively for continuous production from the three producing horizons is good, although it will decline. Figures 4-19, 4-20, and 4-21 show an area of possible future production ("sweet spots").

4.2 SITE HYDROLOGY

4.2.1 Site Surface Hydrology

The surface hydrology characterization included considerations of all water features in the general vicinity of the dome. Site drainage included Bayou Choupique and Bayour D'Inde marshes in the vicinity of the dome, canals, ponds and reservoirs on the site, the Brimstone Ditch and other drainage ditches. Over-all flooding potential included the major regional surface water features which potentially affect the site (i.e. Calcasieu River,

Houston River, and the Sabine River Diversion Canal). Water quality analysis was limited to the general limit of the site.

4.2.1.1 Site Drainage

Surface water features in the immediate vicinity of the site include: (1) Bayou Choupique and Bayou D'Inde, (2) marshes in the vicinity of the dome, (3) canals, (4) ponds and reservoirs at the site, (5) the Brimstone Ditch and (6) numerous site drainage ditches. As discussed previously, major regional surface water features potentially affecting the site include the Calcasieu River to the east, and the Houston River and the Sabine River Diversion Canal to the north of the site. Locations of the various surface water features are shown in Figures 3-11 and 4-22.

Bayou Choupique is located approximately 1 1/2 miles southwest of the site. It flows south and east and empties into the Intracoastal Waterway (ICW) near its junction with the Calcasieu River. Bayou Choupique drains an area of approximately 126 square miles (Sloss, 1971). Drainage area determinations in the flat southern portions of Louisiana are somewhat arbitrary due to the extensive systems of canals and levees and the resulting interchange of flow between basins.

Bayou D'Inde is located southeast of the site. It flows southeast emptying into the Calcasieu River about 3 1/2 miles south of Lake Charles. Bayou D'Inde drains an area of approximately 26 square miles (arbitrarily determined) (Sloss, 1971). It is the receiving stream for domestic waste from the city of Sulphur and for industrial waste from several industrial facilities (FEIS, 1978).

Marshes are found around the north and east periphery of the dome site. Onion Grass Marsh lies between the South Sector of Salt Water Reservoir and the northeastern sector of Crystal Lake (FEIS, 1978). The area over Sulphur Mines dome was originally marsh. This marsh covered about 8,000 acres and was at approximately 14 to 15 feet MSL (Kelley, 1925). The area was drained and tilled after mining operations began (AAPG Bul, v. 14, 1930). The existence of these marshy areas is an indication of the impermeable nature of the soils in the area. The majority of the area is still artifically drained by a series of canals enclosed by levees .

A number of man-made ponds and reservoirs are located in the immediate vicinity of the Sulphur Mines SPR site as shown in Figure 4-22. Table 4-2 gives area, depth and volume data for these ponds and reservoirs as reported in the Final Environmental Impact Statement, Sulphur Mines Salt Dome, Calcasieu Parish, Louisiana, 1978.

The largest body of water, Salt Water Reservoir (SWR), is located northwest of the dome. Contrary to its name, the Salt Water Reservoir contains fresh water. SWR will serve as the primary source of displacement water (FEIS, 1978). SWR may originally have partially consisted of a natural body of water. Dredging operations have created the reservoir in its present configuration. In the past SWR has been used as a source for make-up water for the Frasch sulphur mining process and as a

dilution reservoir for brackish water from the Frasch process. SWR has also been used as a dilution pond for wastewater from oil production. The reservoir has been contaminated with crude oil and sulfur compounds (FEIS, 1978).

The SWR will receive storm water runoff from Well Pad Nos. 2, 6, and 7. In 1979, Jacobs/D'Appolonia Engineers performed a hydrologic study of Salt Water Reservoir. The results of this investigation showed that an average annual discharge of 0.23 cubic feet per second (cfs) occurs at an overflow point at the east side of the north sector of the SWR. This discharge flows generally southeast through a series of swamps, ponded areas and canals to the east and south of the site. The discharge eventually flows into the Brimstone Ditch which drains into Bayou D'Inde.

With the exception of the Waste Oil Residue Pit, other ponds and reservoirs in the immediate vicinity of the dome are believed to contain fresh water. The Waste Oil Residue Pit is not currently in use and retains rainwater to a shallow depth. Several of the shallow ponds dry up during periods of low precipitation. The deeper ponds do not appear to be as much affected by dry periods (FEIS, 1978).

The subsidence area over the dome is frequently flooded and is referred to as Center Lake. This area appears to have no natural drainage outlet. Water levels are kept drawn down by pumping and the water surface elevation fluctuates between elevations +5 and +10 feet MSL due to the intermittent operation of this dewatering system (PB/KBB). Water is currently pumped from the south end of the subsidence area.

No comprehensive drainage study of the Sulphur Mines SPR site has been undertaken to date. Surface drainage at the site is generally poor. Runoff collects in depressions and percolates slowly through the clayey surficial soils. Drainage patterns are complex and poorly defined. Local drainage occurs through a series of ditches, lakes and low lying areas. There is a general clockwise flow pattern arond the periphery of the dome. Surface drainage exits the site at the southeast corner discharging into the Brimstone Ditch. The Brimstone Ditch flows into Bayou D'Inde.

4.2.1.2 Flooding Potential

The Sulphur Mines SPR Site is subject to local flooding. Infiltration of surface water is very slow due to the low permeabillity of the surficial clayey soils. Drainage is further impeded by levees and spoil piles formed by dredging, the low relief in the area, and the lack of a coherent site drainage plan. During periods of heavy rainfall, considerable flooding occurs in the site facilities area.

The 100-year flood elevation at the site has been estimated to be +18 feet National Geodetic Vertical Datum of 1929 (NGVD) (Roy, 1980). The Soils and Corrosion Investigation and Design Report for the Sulphur Mines SPR site indicates that the proposed facilities will be placed with finished floors at elevation +19. Grades around structures will be raised to elevation +18.5, and

roadways will be at elevation +16.5. In essence, this design provides, for the protection of the site facilities from the 100-year flood. However, in the event of a flood of this magnitude, large portions of the site would be under water and it is probable that there would be no access to the site.

During the May 16, 1980 storm, 15.67 inches of rainfall fell at the Lake Charles airport during a 24 hour period. As a result of this rainfall, the entire study area was inundated to a depth of approximately 2 to 3 feet. Some high spots and roads were above water. However, the site was essentially inaccessible, and operations at the site were stopped for approximately two days. Pumping from the subsidence area at a rate of 700,000 gallons per day continued for over a week (Fruge, 1980).

4.2.1.3 Water Quality

Only limited surface water quality data are available for the Sulphur Mines SPR site. The available information consists primarily of water quality data for the Salt Water Reservoir and Crystal Lake. The Salt Water Reservoir is contaminated with crude oil and sulphur compounds. No site water quality monitoring program has been undertaken to date.

4.2.2 Site Subsurface Hydrology

The purpose of this section of the report is to describe the subsurface hydrology in the vicinity of the dome. The hydrology of the caprock and salt dome is discussed in Sections 5 and 6, respectively. The discussion of the subsurface hydrology of the site is limited to the area within a 2-mile radius of the Sulphur Mines salt dome (Figure 4-23).

4.2.2.1 Site Hydrogeologic Conditions

Regional aquifers that have been identified near the site include, in descending order:

1. the Chicot aquifer system;
2. the Evangeline aquifer, and
3. the Jasper and deeper aquifers.

The fresh water of the Chicot aquifer system is heavily pumped in the Lake Charles industrial area, about 10 miles southeast of the site. The Chicot aquifer system is not heavily developed within 2 miles of the site. Only six active industrial supply wells are known to utilize the "500-foot" sand in this area. Some domestic wells are apparently present within 2 miles of the site. Data regarding wells within approximately 2 miles of the dome are provided in Table 4-3.

The depth of the base of fresh water (chlorides less than 250 mg/l) in the Chicot aquifer system is shown in Figure 4-24. The aquifers which underlie the Chicot are saline in the vicinity of the site. Ground-water quality data in the vicinity of the site is provided in Table 4-4.

Six brine injection wells are located in the vicinity of the dome (Figure 4-23). Four active brine injection wells are located about 2 miles southwest of the site. These wells are open to the Jasper and deeper aquifers generally between -4,400 and -5,700 feet, MSL. The chloride concentration within this disposal zone is interpreted to have been greater than 150,000 ppm prior to the brining operation. Two injection wells are also located about 2 miles north of the site (approximate locations are indicated in Figure 4-23). These two wells disposed of brine in the Evangeline and Jasper aquifers between 1976 and 1977.

The hydrogeologic units which exist in the vicinity of the dome are shown by a generalized north-south cross-section (Figure 4-24). It is apparent that only portions of the Chicot aquifer system extend over the Sulphur Mines salt dome. The Evangeline, Jasper and deeper aquifers appear to have been pierced by the dome. The proposed storage caverns are at the same elevation as the Burkeville confining beds and deep saline aquifers which appear to be present below an approximate elevation of -2,500 feet, MSL (Figure 4-24).

The average thickness of the Chicot aquifer thins from approximately 600 feet in the vicinity of the dome, to approximately 300 feet over the dome. The 700-foot sand of the Chicot aquifer system appears to be thin or absent over the dome.

The structural complexities around and over a piercement-type salt dome which can affect the hydrologic relationships between the dome and surrounding or overlying aquifers are many and varied (Hosman, 1980). The potential influences of the Sulphur Mines salt dome on ground-water flow or quality in surrounding aquifers can not be described with the available data base. It is likely that the major components of ground-water flow in the surrounding aquifers are influenced by regional conditions except in the immediate vicinity of the dome. Ground-water elevations measured in 1978 in 3 wells within about 3 miles of the dome generally conform to regional levels in the Chicot aquifer system (Figure 4-23).

4.2.2.2 Hydrogeologic Conditions Above The Caprock

Two hydrogeologic profiles were constructed over the caprock from selected wells (Figure 4-25). The profiles were developed from geophysical logs of the recent Sulphur Mines wells and two brine injection wells (Figures 4-26 and 4-27).

The hydrogeologic units over the dome can be characterized by fairly continuous sand and gravel beds which are interbedded with silt and clay confining layers. Two major water-bearing zones are recognized in Figure 4-26 and 4-27, and appear to coincide with the "200" and "500-foot" sands of the Chicot aquifer system.

The top of the "200-foot" sand appears to occur at an average elevation of about -65 feet, MSL over the caprock. The aquifer has an average thickness of about 155 feet. The "200-foot" sand is comprised of as many as four sand units which are interbedded with clays and silts. The aquifer is probably confined by clays and fill material which generally overlie elevation -65 feet, MSL.

The top of the "500-foot" sand of the Chicot aquifer system appears to occur at an average elevation of about -280 feet, MSL over the caprock. The aquifer has an average thickness of about 260 feet along the flanks of the dome but thins to less than 100 feet directly over the caprock. The aquifer is comprised of as many as six individual sand beds along the western flanks of the dome. In other locations above and around the dome, the "500-foot" sand is interbedded with only a few clay or silt beds, creating a fairly massive sand sequence.

The "500-foot" sand appears to be separated from the overlying "200-foot" sand by a fairly continuous clay or silt bed which has an average thickness of about 60 feet. A few sand beds are present within this confining layer and may be hydrologically connected to the "200" or "500-foot" sands.

The "700-foot" sand of the Chicot aquifer system appears to be thin or absent over the caprock. A sand bed which is interpreted to represent this aquifer is present at an average elevation of about -565 feet MSL, along the flanks of the dome. An individual clay bed appears to separate the "700-foot" sand from the overlying "500-foot" sand except along the southern flanks of the dome where the aquifers may be directly connected. Direct hydrologic connections are not uncommon between the "500-foot" and "700-foot" sands, as discussed in Section 3.2.2.3.

A 5 to 10 foot thick clay layer overlies portions of the caprock. A clay sheath occurs around the lower flanks of the Sulphur Mines salt dome. Clay sheaths around domes can act as impediments to the flow of ground water.

Few data are available regarding the quality of ground water which occurs above the caprock. In general, the ground water above the caprock is interpreted to have a chloride content of less than 500 mg/l.

The corrosive nature of the near surface soil/ground-water environment is evidenced by the deterioration of existing concrete pipe support structures discussed in the PB/KBB Corrosion Report (1978). Acidic and sulfate salt solutions attack the chemical compounds present in Portland cement, thus leading to the deterioration of concrete. The sulfates present in the surficial soils are probably a result of the sulphur mining at the site. The acidic conditions may result from the reaction of perched ground water with sulfates in the soil and the formation of a sulfuric acid solution in this soil/ground-water interaction.

The greatest use of ground water at the site was during the sulphur mining operations between 1903 and 1924. Water from the Chicot aquifer was used as a source of fresh water for mining operations.

4.3 IMPACT ON SPR FACILITIES

4.3.1 Site Geology

Impact of the site surficial geology on SPR surface facilities would primarily depend on the distribution of various soils over the site. Three types of soils exist at the site including

those associated with Pleistocene sediments, Recent sediments, and man-placed fill materials.

Pleistocene soils and fill soils are the predominant materials at the surface within the SPR site facilities. Very little Recent soil is expected to exist over the dome. Recent soils are mainly located around the outer perimeters of the site where it would probably be thin.

The Pleistocene soils at the site are typically composed of stiff clays and silty or sandy clays with cohesive shear strenghts in the range of 1,500 to 4,000 pounds per square foot. These soils are over-consolidated and provide good foundation support and performance for surface structures.

Fill soils, which were placed in various areas within the site as subsidence occurred, were drived from dredged Recent and Pleistocene deposits and placed hydraulically. This resulted in unconsolidated to normally consolidated soils composed of soft clays and silts with low cohesion values ranging from several hundred pounds per square food to 2,000 pounds per square foot. Large areas of fill exist at the site and create the need for thorough engineering evaluation of conditions before construction of new facilities.

Minor and highly localized zones of loose sand and silts are present above the caprock as a result of caprock collapse. These zones will result in drilling problems, i.e., caving of holes and losing circulation when encountered. The mechanics and effect of caprock collapse is discussed further in Section 5.0.

Subsurface conditions at Sulphur Mines dome should be carefully considered in developing design and operating programs for SPR caverns. Two major features to be considered include the lithology of formations in contact with and surrounding the salt, and the presence and nature of faulting around and over the dome.

Geologic formations consisting of fairly thick, massive sands make contact with the salt on the flanks of the dome. This condition may provide a path for escape of stored oil if breach of the dome occurs. Alternatively, the presence of impermeable shale would provide protection. Well logs indicate a continuous shale adjacent to the dome at 5,000 feet. Some well logs also indicate the shale to exist at shallower depths, but if present it would not be as continuous as is present at lower elevations.

Reactivation of faults by removal of subsurface fluids through petroleum or water well production is a possibility. This is not expected to occur at any location directly over the dome but may occur very near to the dome. More detailed discussions of impact due to faulting are presented in Chapter 7.2.

4.3.2 Site Hydrology

Surface drainage at the Sulphur Mines Site is poor. Poor drainage will tend to increase flooding across the site. The 100-year flood elevation at the site is estimated to be +18 feet NGVD. Flooding to this elevation would likely make portions of the site inaccessible and disrupt operations. The site facilities are designed to remain undamaged in the event of a flood of this magnitude.

The aquifers which overlie the caprock at the site are composed of permeable sands and gravels. The "500-foot" sand directly overlies the caprock and is the principal source of water in the area surrounding the site. Leakage of any petroleum from the SPR cavern wells which penetrate the aquifers would be difficult to recover.

The quality of the ground water above the caprock, or its potential interaction with the SPR cavern well casings cannot be described with the available data base. In general, the ground water above the caprock has an apparent chloride content of less than 500 mg/l, and is anticipated to be substantially less corrosive than caprock water. The numerous wells and borings (900+) which have been drilled at the site are believed to have interconnected the aquifers, caprock, and the salt dome.

TABLE 4-1

PRAIRIE FORMATION LITHOLOGY

Well	Materials Penetrated
Union Sulphur, #3 Kelly	0-41' Clay
	41-51' Sand
	51-84' Clay
Union Sulphur, Fee #731	0-110' Gumbo
La. Pet. Coal Mine, Well #1	1-160' Yellow & Blue Clay
Amer. Sulphur Mine, Well #2	1-165' Yellow & Blue Clay
Amer. Sulphur Mine, Well #3	1-141' Yellow & Blue Clay
Amer. Sulphur Mine, Well #4	1-165' Yellow & Blue Clay
Amer. Sulphur Mine, Well #5	1-176' Yellow & Blue Clay

TABLE 4-2

PONDS AND RESERVOIRS IN THE VICINITY OF

SULPHUR MINES SPR SITE

Water Body #	Name	Area (ft^2)	Depth (ft)	Volume (yd^3)
1	Salt Water Reservoir (North)	4,420,000	18.3	2,990,000
2	Salt Water Reservoir (West)	775,000	23.6	676,000
3	Salt Water Reservoir (South)	1,865,000	8.4	378,000
4	Crystal Reservoir (West Branch)	356,000	18.6	246,000
5	Crystal Reservoir (West-East Branch)	354,000	15.6	205,000
6	Crystal Reservoir (East Branch)	1,020,000	9.7	366,000
7	Patsy Franks Dredge Hole No. 1	408,000	8.7	132,000
8	Patsy Franks Dredge Hole No. 2	215,000	4.9	38,900
9	Northern Reservoir	740,000	7.4	201,500
10	Fresh Water Pond No. 1	554,000	9.9	130,000
11	Fresh Water Pond No. 2	288,000	9.5	100,800
12	Fresh Water Pond No. 3	256,000	8.5	81,400
13	Dredge Pond 1969	191,000	6.9	48,800
14	Triple Lake Area			
	Reservoir No. 1	270,000	1.5	14,300
	Reservoir No. 2	73,000	3.3	8,900
	Reservoir No. 3	73,000	2.3	6,500
	Reservoir No. 4	27,000	3.1	3,100
	Reservoir No. 5	27,000	2.8	2,800
15	Fresh Water Reservoir	670,000	0 (dry)	0
16	Waste Oil Residue Pit	230,000	0 (dry)	0
17	North Tank Battery Lake	160,000	1	6,000
18	Center Lake	17,000	(essentially dry)	0

Modified after Environmental Impact Statement, 1978

TABLE 4-3

DATA ON WATER WELLS WITHIN
APPROXIMATELY 2 MILES OF THE SITE

WELL IDENTIFICATION	OWNER	HYDROGEOLOGIC UNIT	WELL DEPTH (IN FEET BELOW GROUND SURFACE	WELL USE
102	Union Sulphur	"500-Foot" Sand	575	Unknown
103	Union Sulphur	"500-Foot" Sand	575	Industrial
104	Union Sulphur	"500-Foot" Sand	575	Industrial
466	Southern Alkali Co.	"500-Foot" Sand	469	Industrial
467	Southern Alkali Co.	"500-Foot" Sand	472	Industrial
580	Columbia-Southern Chemical Corp.	"500-Foot" Sand	469	Industrial
581	Columbia-Southern Chemical Corp.	"500-Foot" Sand	469	Observation Well
964	U.S. Geological Survey	"500-Foot" Sand	360	Observation Well
995	P.P.G. Industries	"500-Foot" Sand	485	Industrial[1)]
BDW-1	U.S. Department of Energy	Jasper and Deeper Aquifers	7,480	Brine Injection
BDW-2	U.S. Department of Energy	Jasper and Deeper Aquifers	5,290	Brine Injection
BDW-3	U.S. Department of Energy	Jasper and Deeper Aquifers	4,555	Brine Injection
BDW-4	U.S. Department of Energy	Jasper and Deeper Aquifers	4,845	Brine Injection
S-4	Union Texas Petroleum Co.	Caprock	1,488[3)]	Brine[2)] Injection Well
S-7	Union Texas Petroleum Co.	Caprock	1,460[4)]	Brine Injection Well
BSW-13	U.S. Department of Energy	SALT	5.005	Source of Brine
TW-1 Through TW-9	Unknown	Probably "700-Foot" Sand	Unknown	Oil Test Wells

TABLE 4-3
(Con't)

Notes: 1) Estimated Pumpage 864,000 gallons per day.

2) Estimated Pumpage 84,000,000 gallons between 1970 and 1977 (wells S-4 and S-7 were sulphur wells which were reworked for injection wells).

3) Apparent injection interval 1,212 to 1,488 feet; salt occurs at 1,620 feet.

4) Apparent injection interval 1,374 to 1,460 feet; salt occurs at 1,475 feet.

Modified from the following sources of data:

- Office of Public Works, Calcasieu Parish, 1980
- U.S. Geological Survey, 1978
- Louisiana Department of Conservation, 1979
- Williams, Fenix, and Scisson, 1979-1980 (Report to D.O.E.)

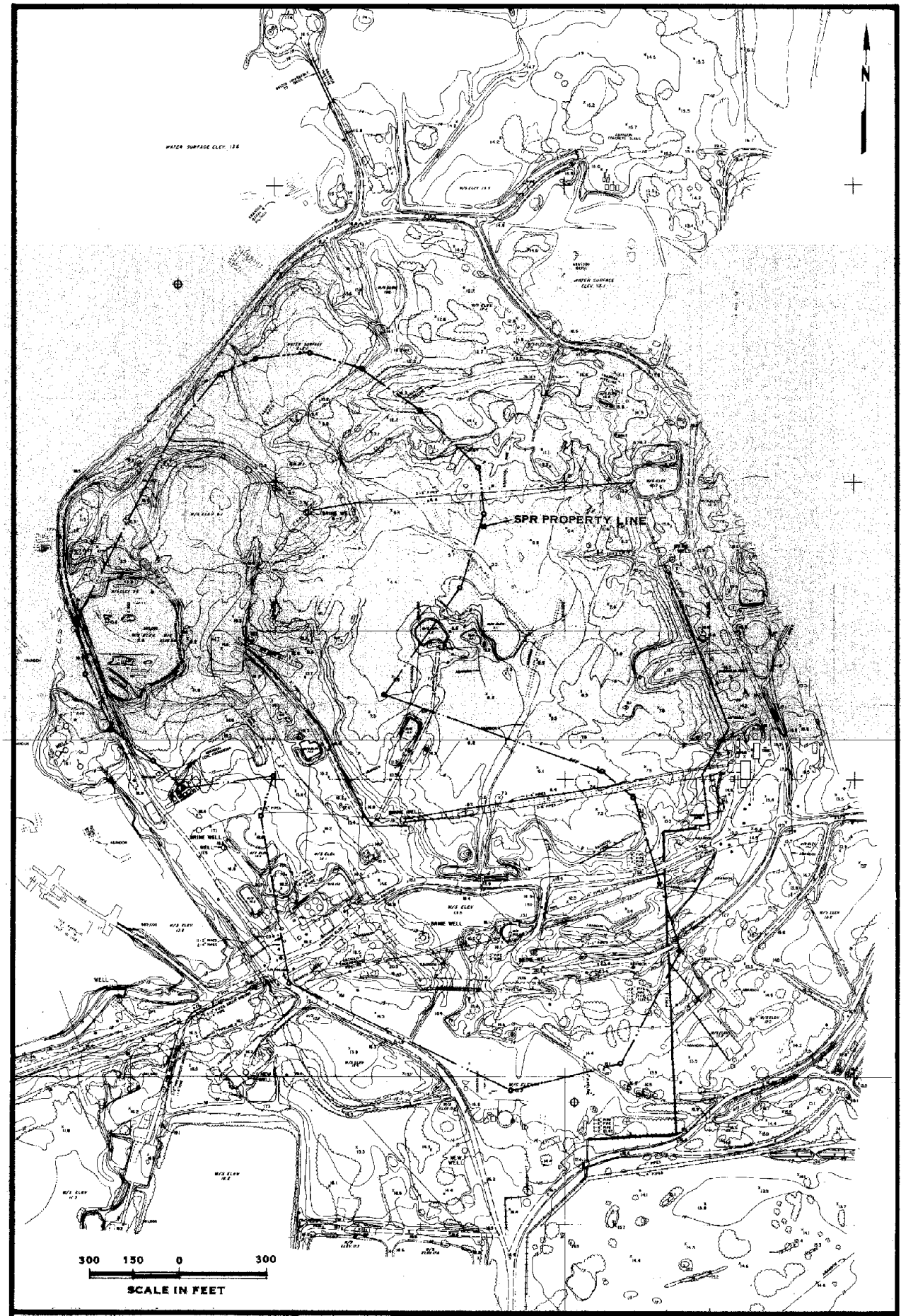
TABLE 4-4

GROUND-WATER QUALITY DATA IN VICINITY OF THE DOME

Chicot Aquifer

Sample Date: April 18, 1978

Time	1135 hours	Cadmium	<0.01 ppm
Temperature	24 °C	Calcium	25.7 mg/l
pH	6.5	Chromium, Total	<0.02 ppm
Specific Conductance	0.33K umhos/cm	Fluoride	0.20 mg/l
Dissolved Oxygen	2.7 mg/l	Potassium	2.94 ppm
Total Dissolved Solids	192 mg/l	Sodium	31.5 ppm
Hardness	93.5 mg/l as $CaCO_3$	Magnesium	7.1 mg/l
Bicarbonate	117.2 mg/l as $CaCO_3$	Silver	<0.02 ppm
Chloride	21.9 mg/l	Selenium	<0.001 ppm
Sulfate	4.1 mg/l	Nitrate	<0.10 mg/l
Fluoride	0.20 mg/l	Mercury	0.0035 ppm
Nitrate	<0.10 mg/l	Manganese	0.37 ppm
Total Coliform	<2/100 ml	Chromium	<0.02 ppm
Fecal Coliform	<2/100 ml	Iron	2.78 mg/l
Arsenic	0.0015 ppm	Lead	<0.001 ppm
Barium	0.427 ppm		



PREPARED BY SJL DATE 8/23/80
CHECKED BY _____ DATE _____
REVISED BY _____ DATE _____
APPROVED BY CSK DATE 10/11/80

STRATEGIC PETROLEUM RESERVE PROGRAM

GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SITE TOPOGRAPHIC MAP

FIGURE 4-1



PREPARED BY SLF DATE 9/26/80
CHECKED BY _____ DATE _____
REVISED BY _____ DATE _____
APPROVED BY LSE DATE 10/1/80

STRATEGIC PETROLEUM
RESERVE PROGRAM

GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SPR PROPERTY MAP

FIGURE 4-2



PREPARED BY JSB DATE 7/29/86
CHECKED BY DPS DATE 9/30/86
REVISED BY _____ DATE _____
APPROVED BY _____ DATE 10/1/86

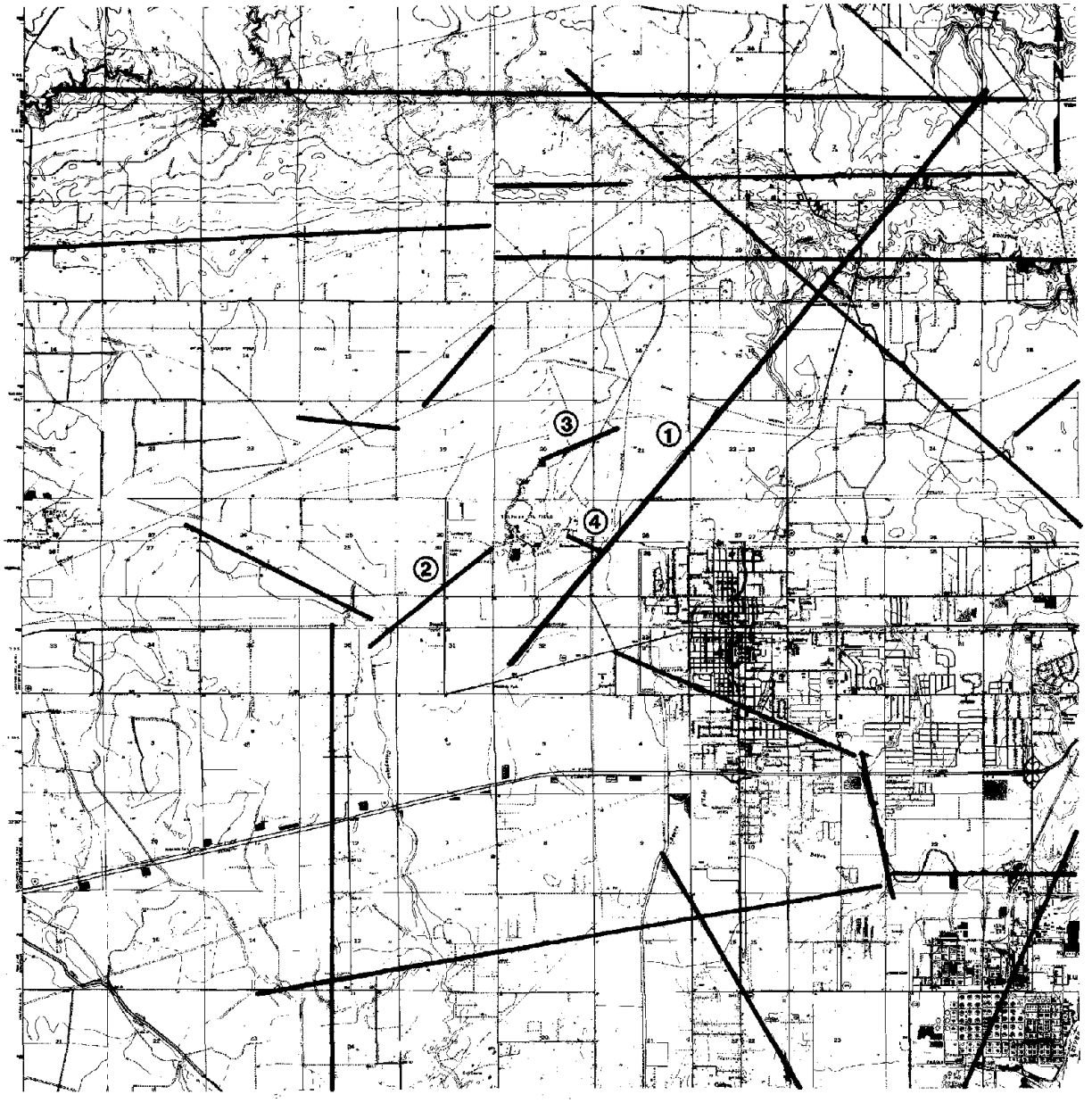
STRATEGIC PETROLEUM RESERVE PROGRAM

GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

PREMINING - SITE TOPOGRAPHIC MAP
(KELLY, 1925)

FIGURE 4-3



LEGEND

LINEATION LINES

SPR PROPERTY LINE

0 6000 12,000

SCALE IN FEET

PREPARED BY ODS DATE 8/20/80
CHECKED BY LEK DATE 8/21/80
REVISED BY ____ DATE ____
APPROVED BY [illegible] DATE 8/21/80

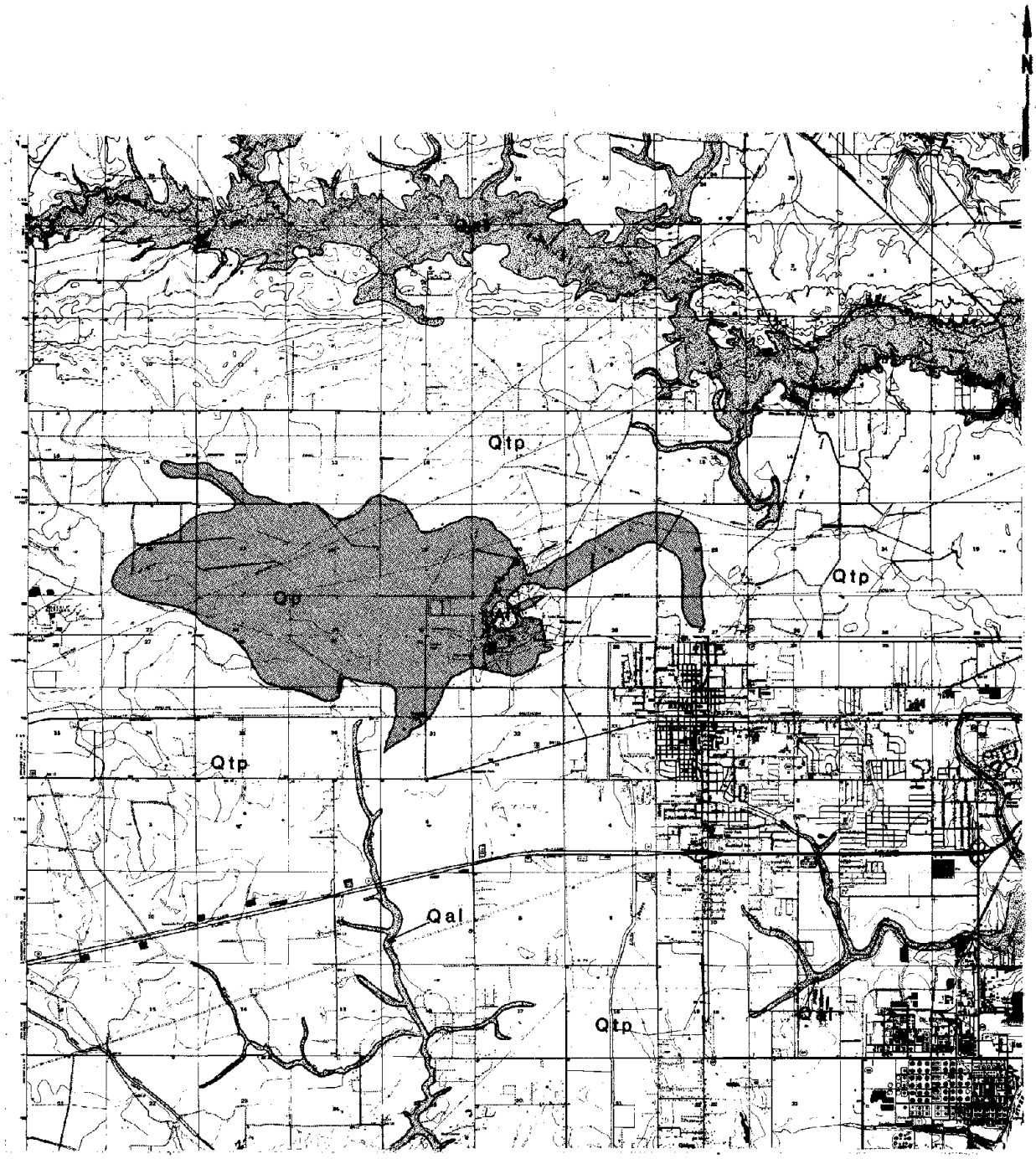
STRATEGIC PETROLEUM RESERVE PROGRAM

GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SITE AREA LINEATION MAP

FIGURE 4-4



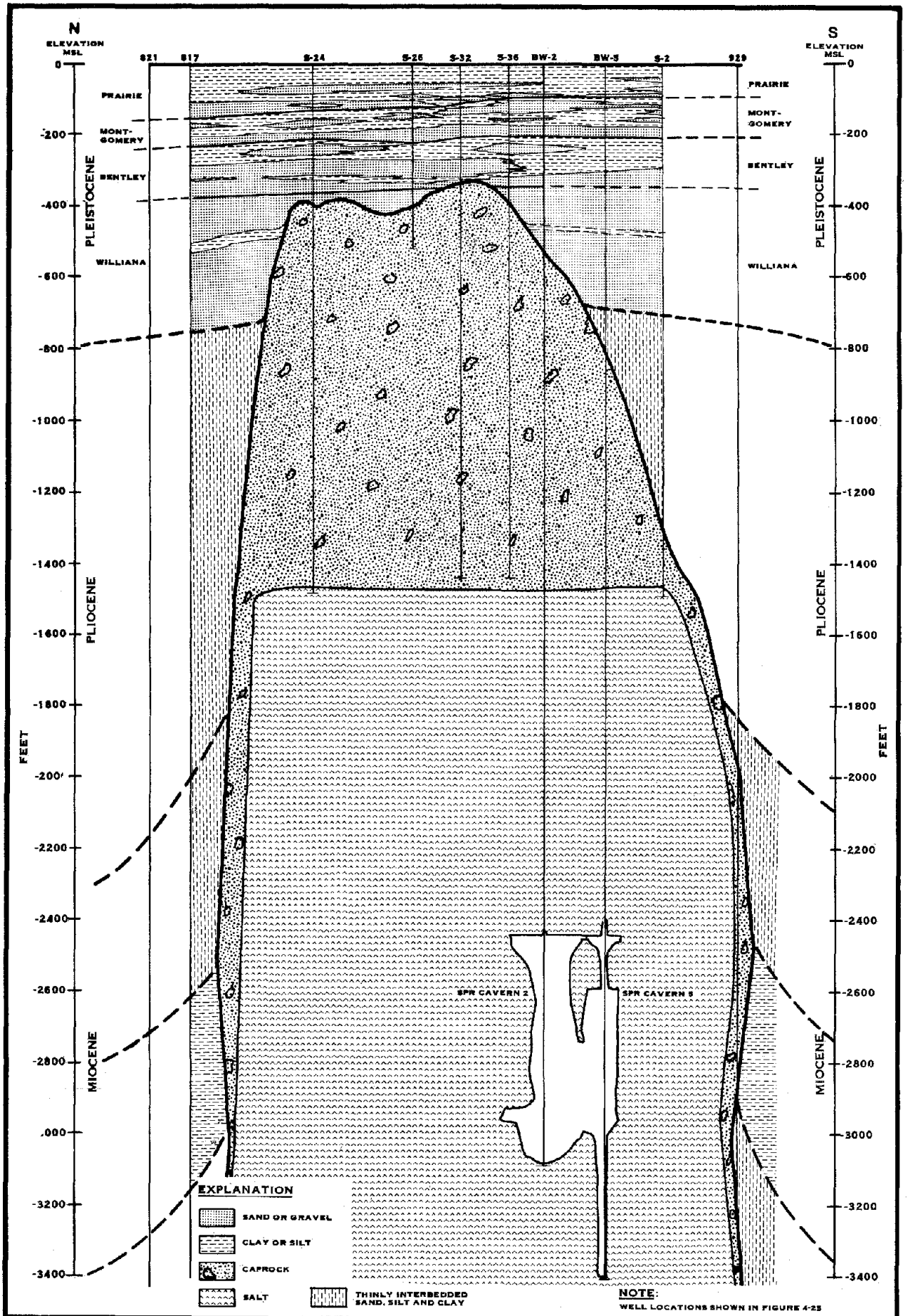
LEGEND

- Qtp - QUATERNARY PRAIRIE
- Qal - QUATERNARY ALLUVIUM
- Qp - QUATERNARY FALUDAL
- Af - RECENT FILL

0 6000 12000

SCALE IN FEET

PREPARED BY TAC DATE 3/20/80 CHECKED BY JSB DATE 9/15/80 REVISED BY _____ DATE _____ APPROVED BY LSK DATE 10/1/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	SITE GEOLOGIC MAP FIGURE 4-5



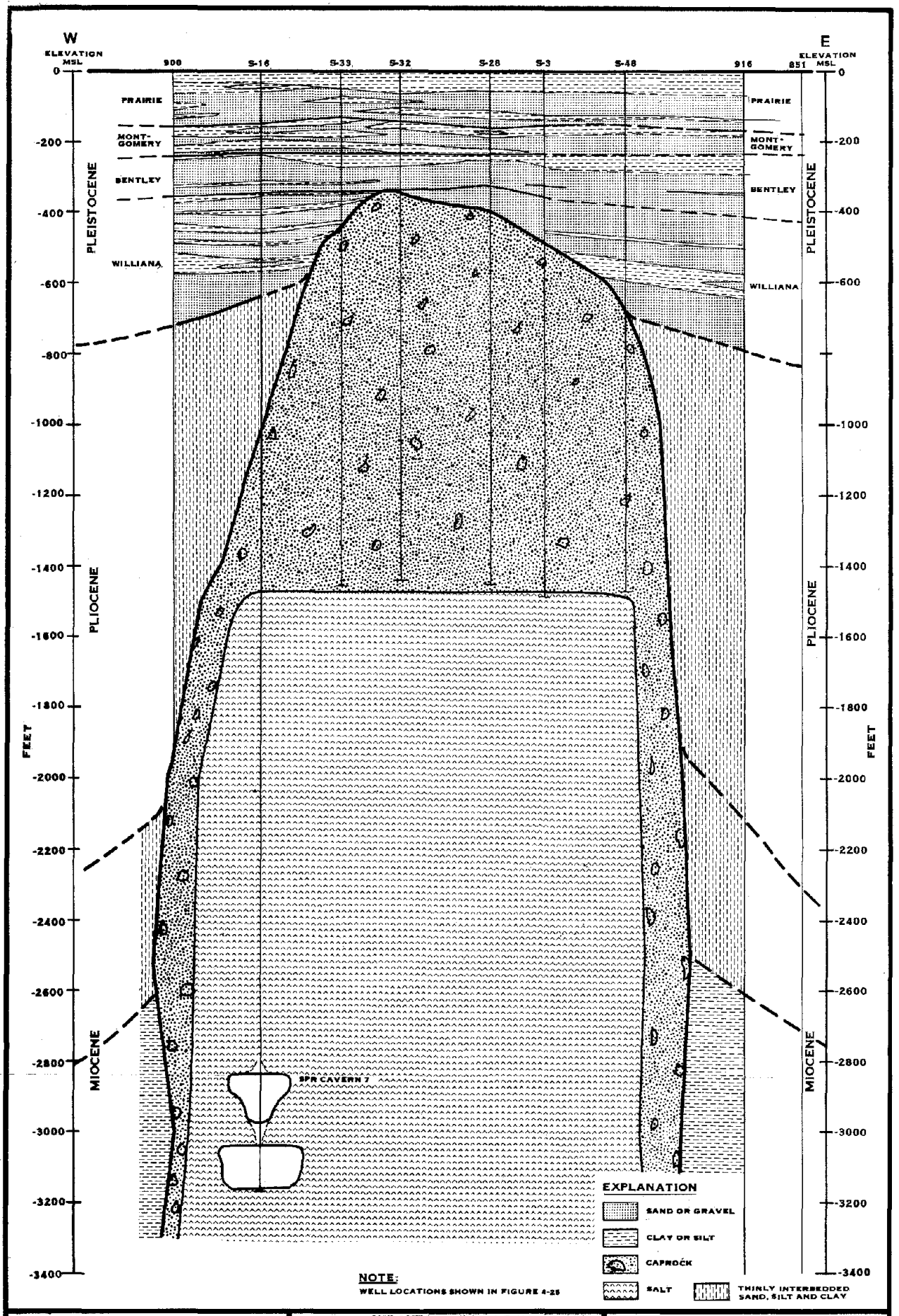
PREPARED BY TAO DATE 9/2/80
CHECKED BY JSP DATE 9/18/80
REVISED BY ____ DATE ____
APPROVED BY LSK DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SITE GEOLOGIC N-S CROSS-SECTION MAP

FIGURE 4-6



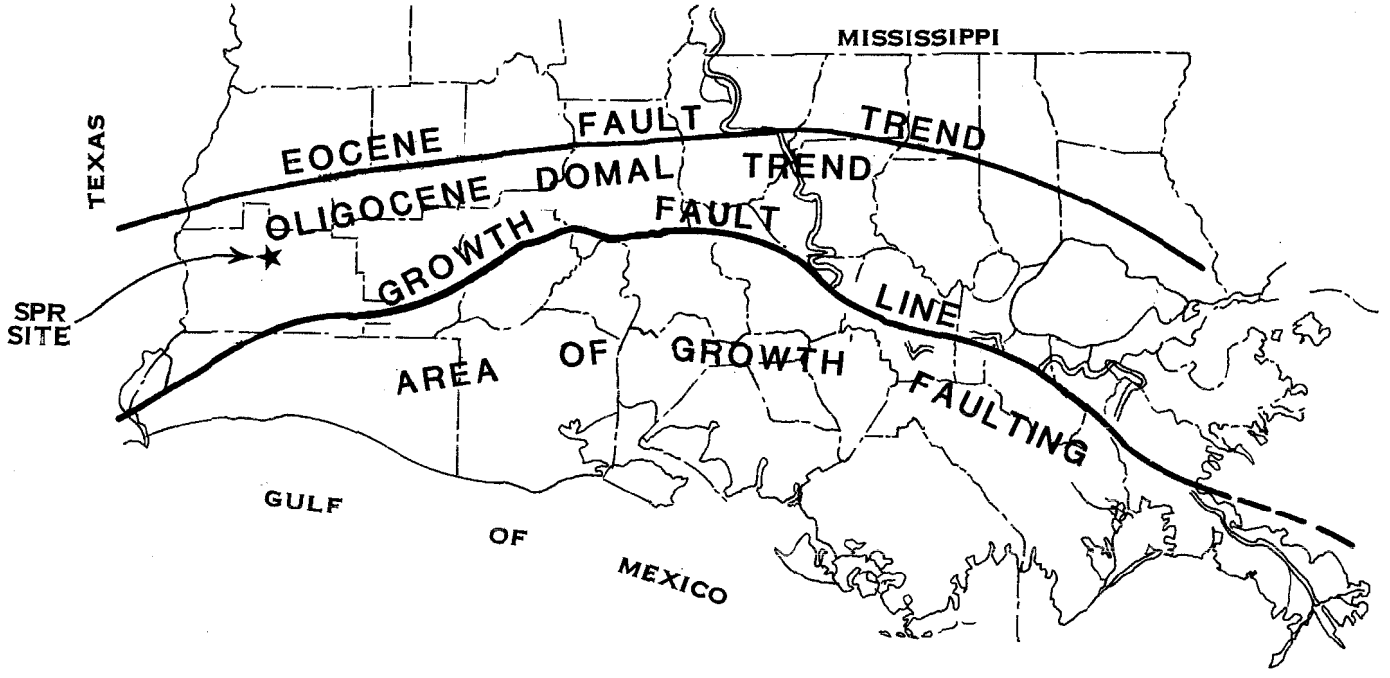
PREPARED BY JAO DATE 9/2/80
CHECKED BY JSD DATE 9/5/80
REVISED BY ____ DATE ____
APPROVED BY LSK DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SITE GEOLOGIC E-W CROSS-SECTION MAP

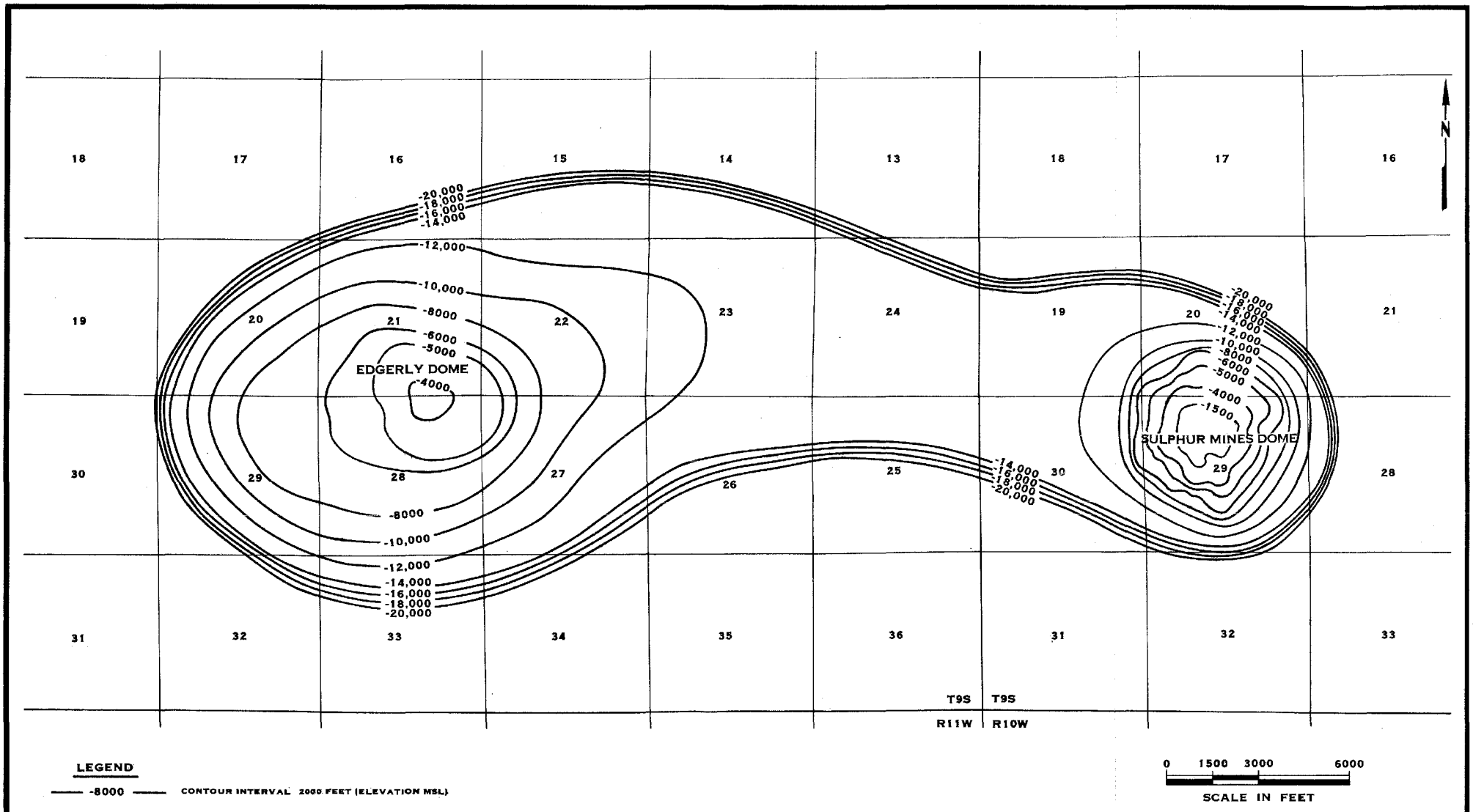
FIGURE 4-7



REFERENCE

MODIFIED FROM OCAMB (1961)

PREPARED BY SLF DATE 10/1/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	GROWTH FAULT LINE LOUISIANA
CHECKED BY ODS DATE 9/30/80		
REVISED BY ____ DATE ____		
APPROVED BY ____ DATE 10/1/80		FIGURE 4-8



PREPARED BY JSR DATE 3/24/80
CHECKED BY GES DATE 3/20/80
REVISED BY ____ DATE ____
APPROVED BY LSK DATE 10/1/80

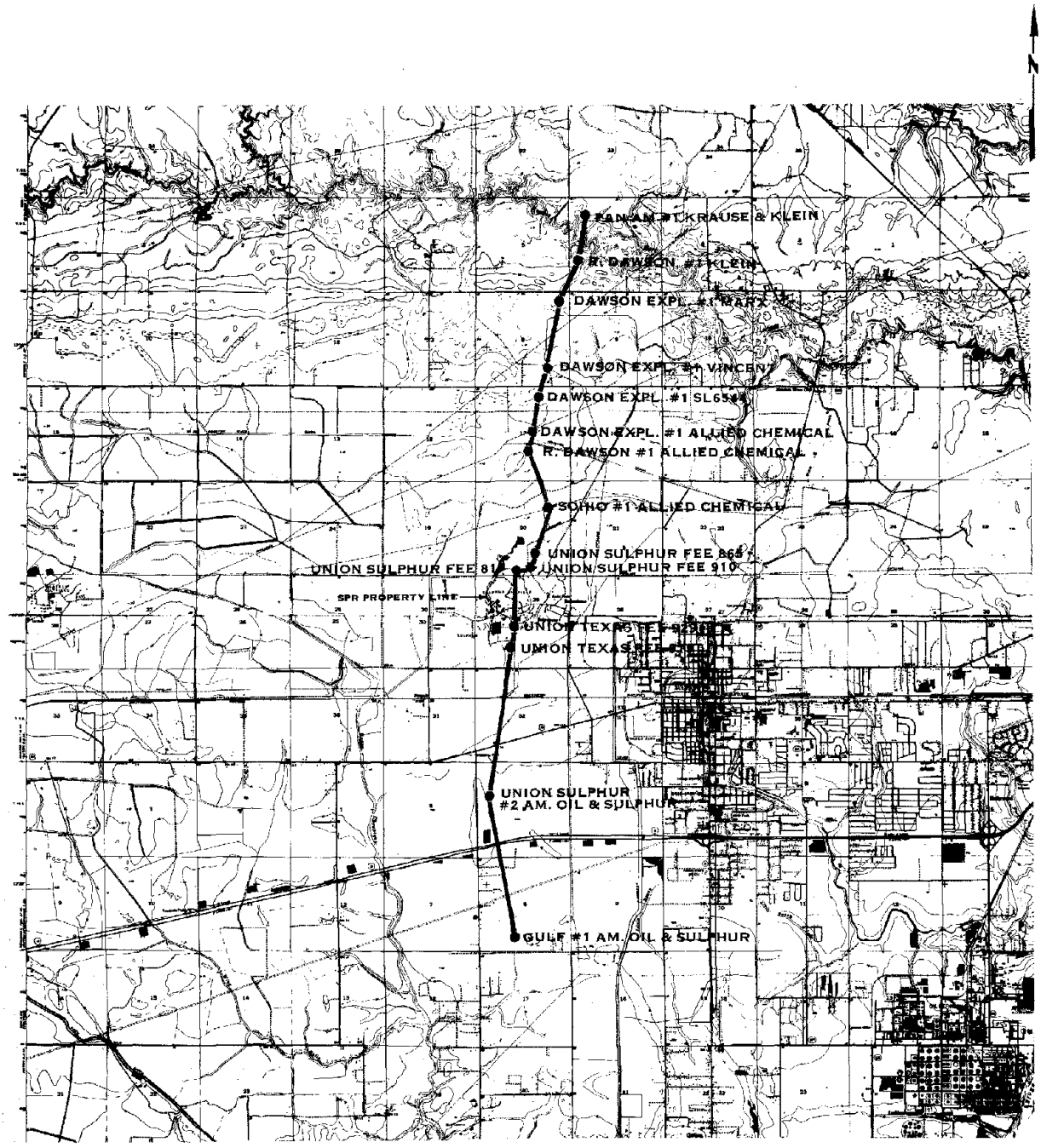
STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SALT PILLOW MAP

(INTERPRETED GRAVITY MODEL OF EDGERLY AND SULPHUR SALT DOMES)

FIGURE 4-9



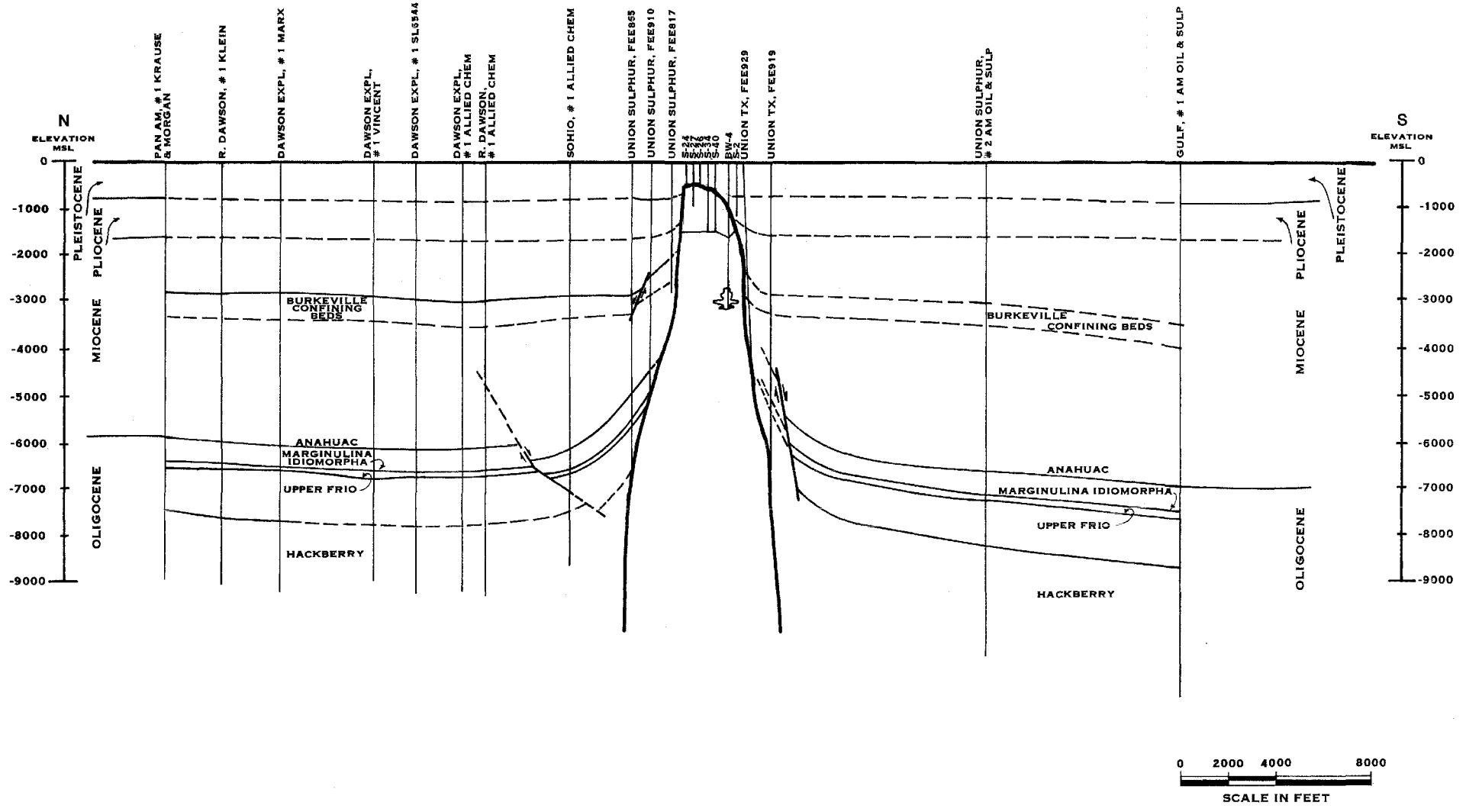
PREPARED BY SHF DATE 9/5/80
CHECKED BY ODS DATE 9/30/80
REVISED BY ____ DATE ____
APPROVED BY GSK DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

LOCATION MAP FOR NORTH - SOUTH REGIONAL CROSS-SECTION

FIGURE 4-10



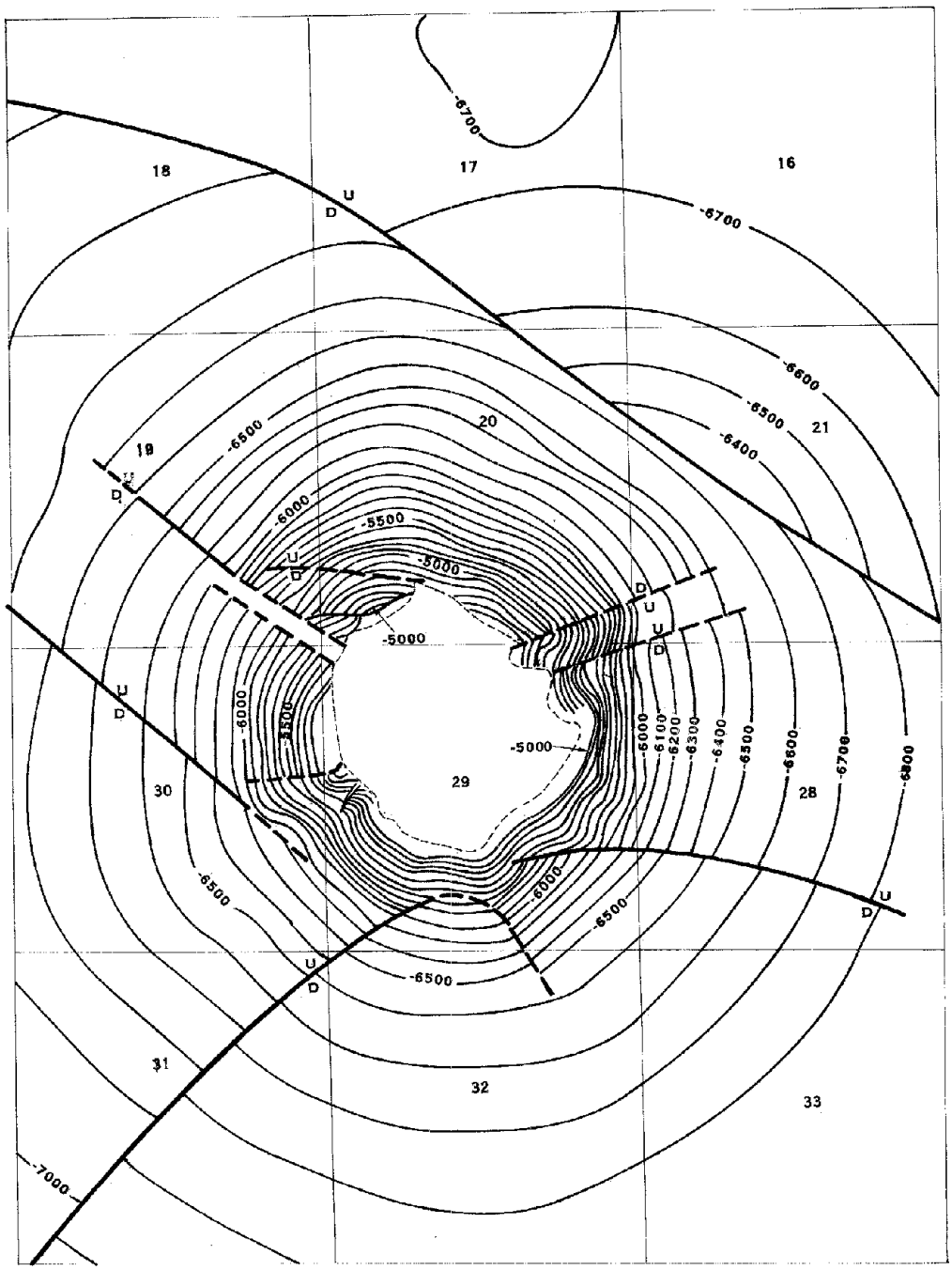
PREPARED BY SLF DATE 9/5/XC
CHECKED BY CDS DATE 11 30/30
REVISED BY ____ DATE ____
APPROVED BY SSK DATE 12/13/30

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

N-S REGIONAL CROSS-SECTION THROUGH SULPHUR MINES DOME

FIGURE 4-11



LEGEND

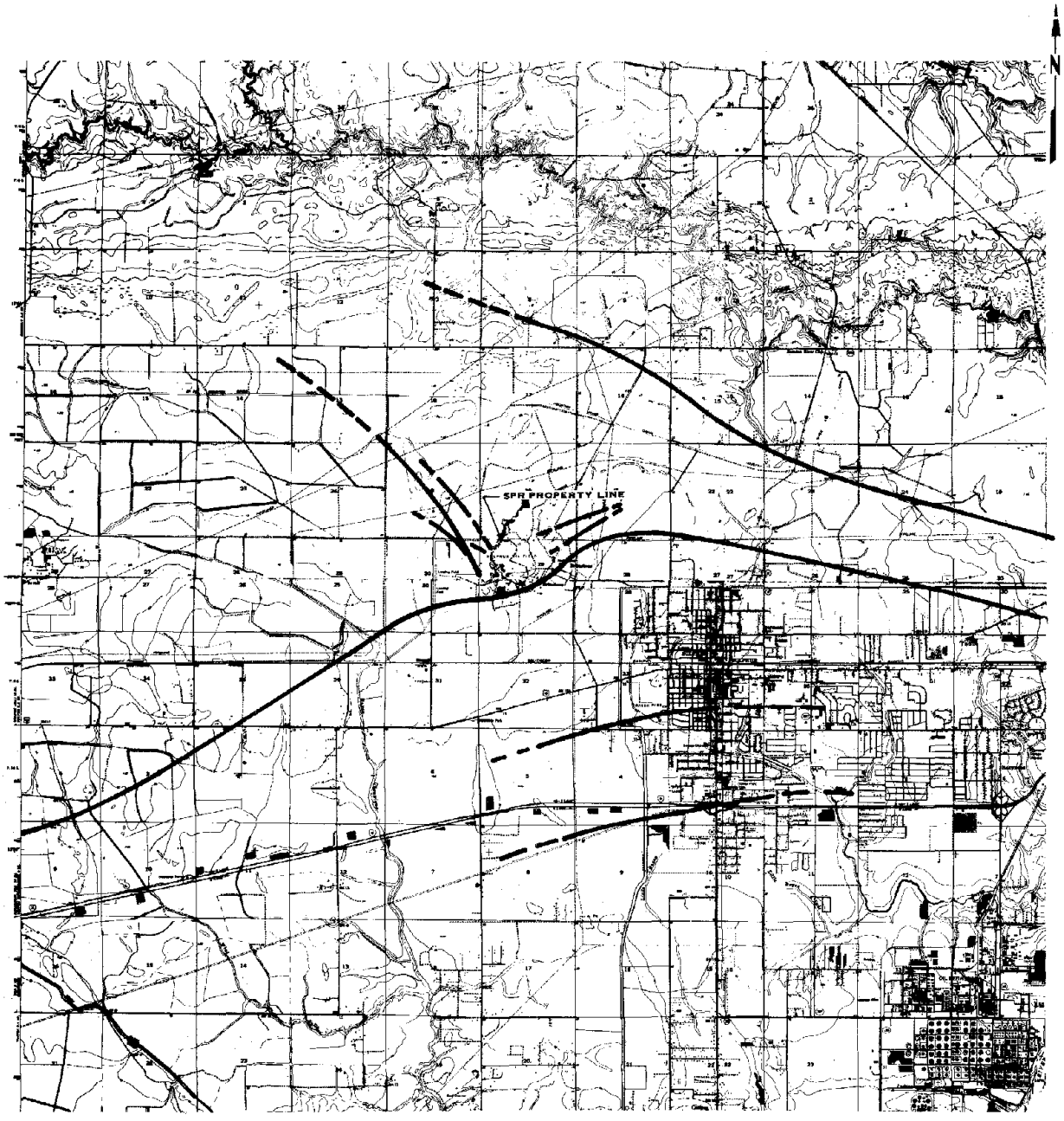
-6800 CONTOUR INTERVAL 100 FEET (ELEVATION MSL)

U D FAULT

0 2000 4000

SCALE IN FEET

PREPARED BY IBA DATE 3/30/90	STRATEGIC PETROLEUM RESERVE PROGRAM	BASE OF ANAHUAC SHALE CONTOUR MAP
CHECKED BY CDS DATE 3/30/90	GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME	
REVISED BY ____ DATE ____	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	FIGURE 4-12
APPROVED BY CDS DATE 10/1/90		



LEGEND

FAULT

0 300 600

SCALE IN FEET

PREPARED BY JDR DATE 9/14/80
CHECKED BY ODS DATE 9/30/80
REVISED BY _____ DATE _____
APPROVED BY LSK DATE 10/1/80

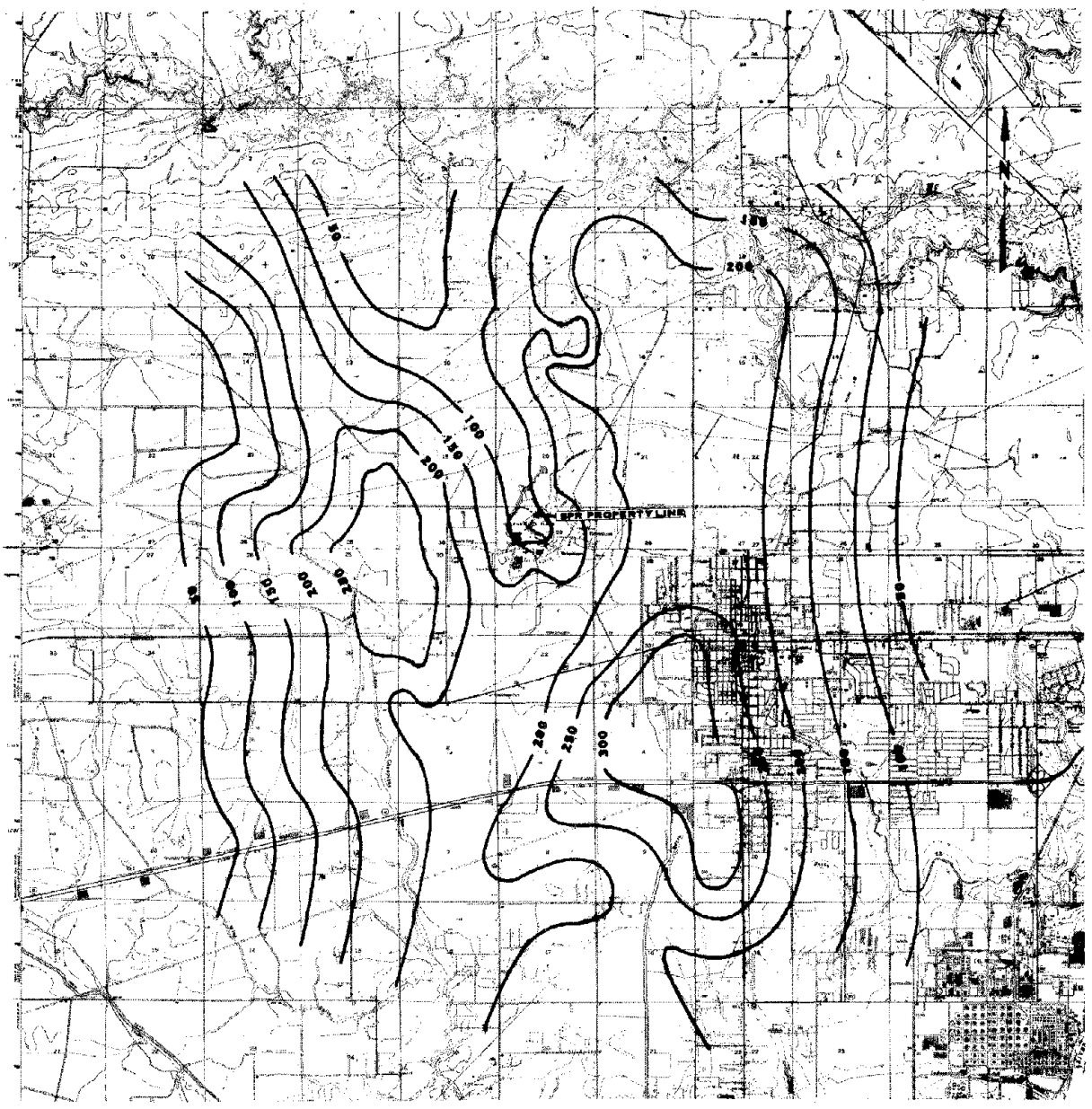
STRATEGIC PETROLEUM RESERVE PROGRAM

GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

PROJECTED SURFACE EXPRESSION OF FAULTS

FIGURE 4-13



REFERENCE

WILLIAMS, FENIX & SCISSON, 1986

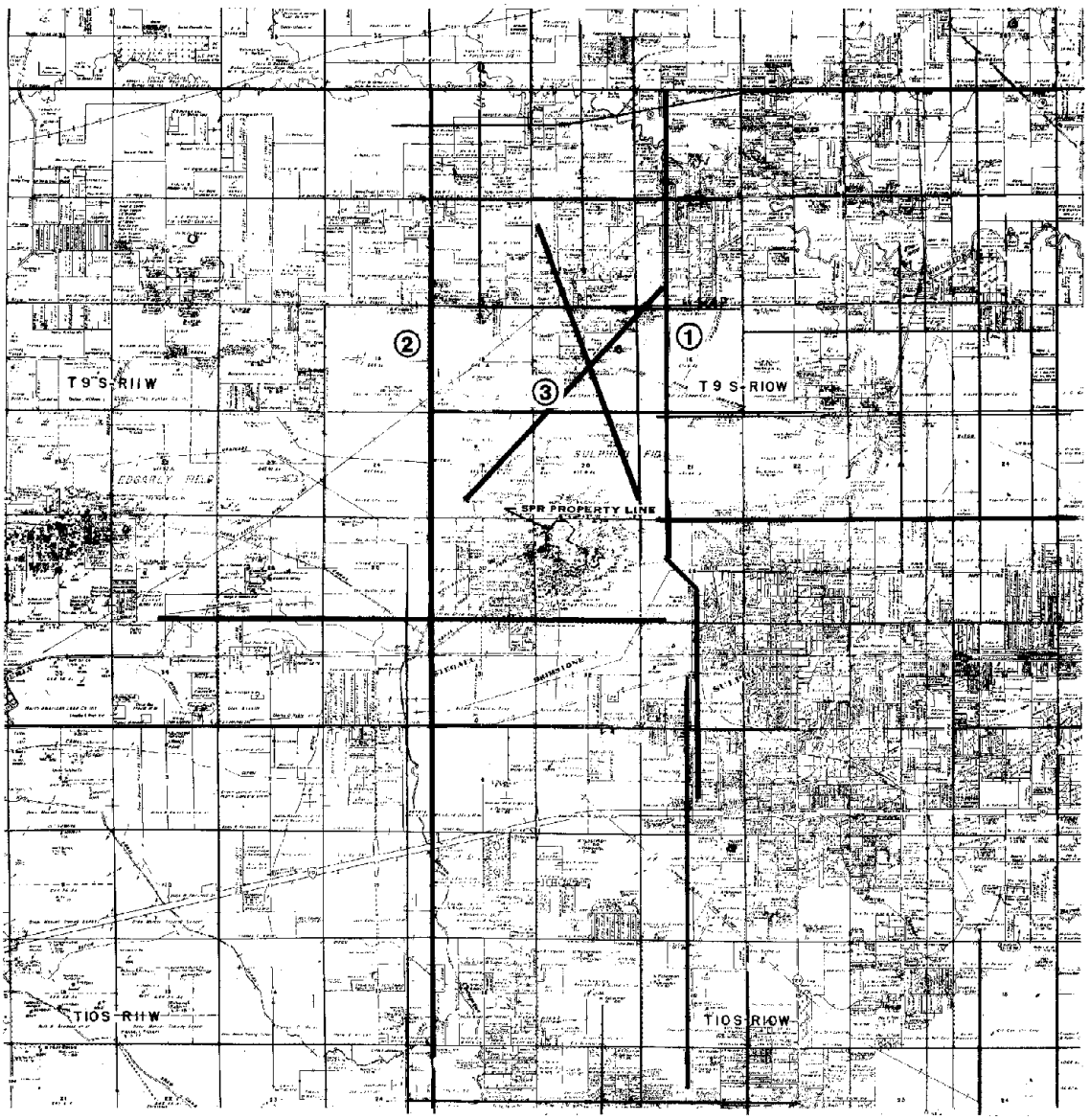
NOTE:

DISPOSAL ZONE IS SAND UNIT IN LOWER FLEMING GROUP

0 3000 6000 -12,000

SCALE IN FEET

PREPARED BY DPS DATE 8/27/80	STRATEGIC PETROLEUM RESERVE PROGRAM	DISPOSAL ZONE ISOPACH MAP
CHECKED BY JF DATE 9/30/80	GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME	SULPHUR MINES, LA.
REVISED BY ____ DATE ____	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	FIGURE 4-14
APPROVED BY LSK DATE 10/1/80		



LEGEND

SEISMIC SURVEY LINES

0 6000 12000

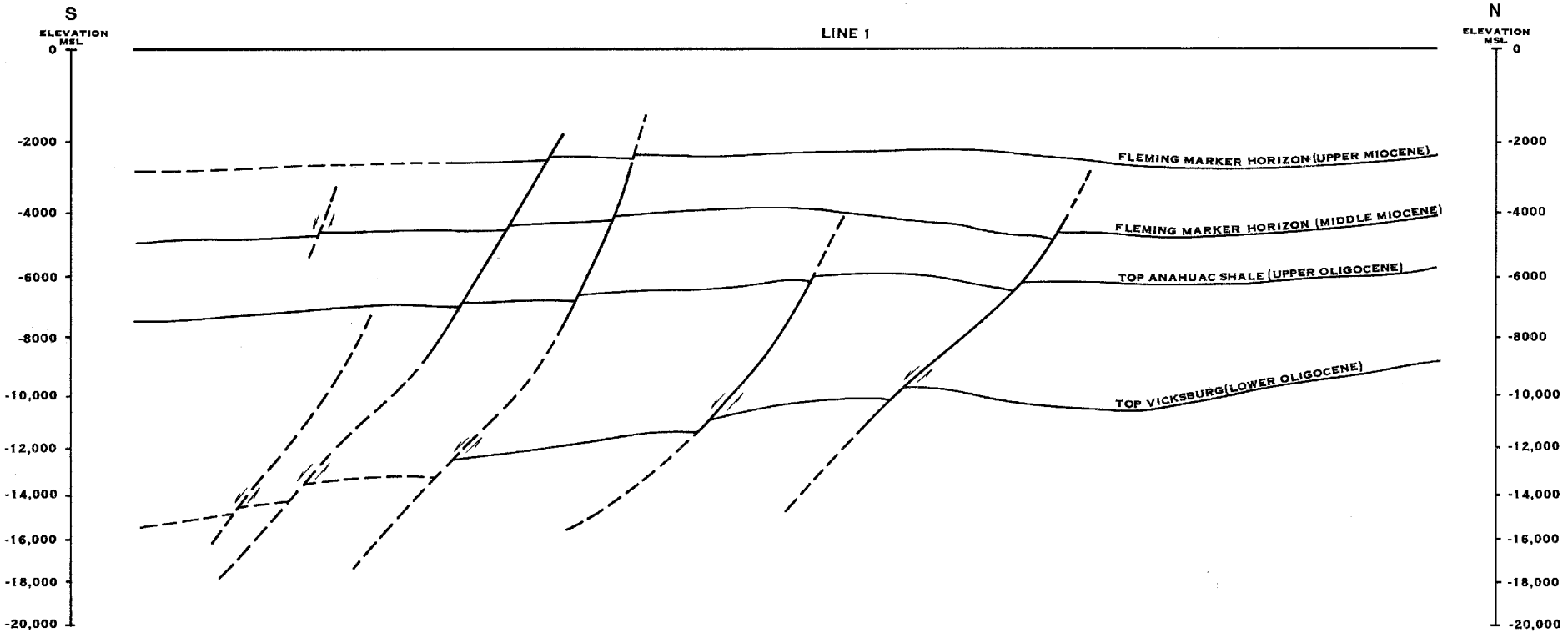
SCALE IN FEET

NOTE:

SEISMIC LINES USED BUT NOT NUMBERED WERE USED FOR INTERPRETATION

PREPARED BY JSR DATE 8/22/80	STRATEGIC PETROLEUM RESERVE PROGRAM
CHECKED BY ODS DATE 9/30/80	GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME
REVISED BY _____ DATE _____	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA
APPROVED BY LSE DATE 10/1/80	SEISMIC REFLECTION SURVEY LOCATION MAP

FIGURE 4-15



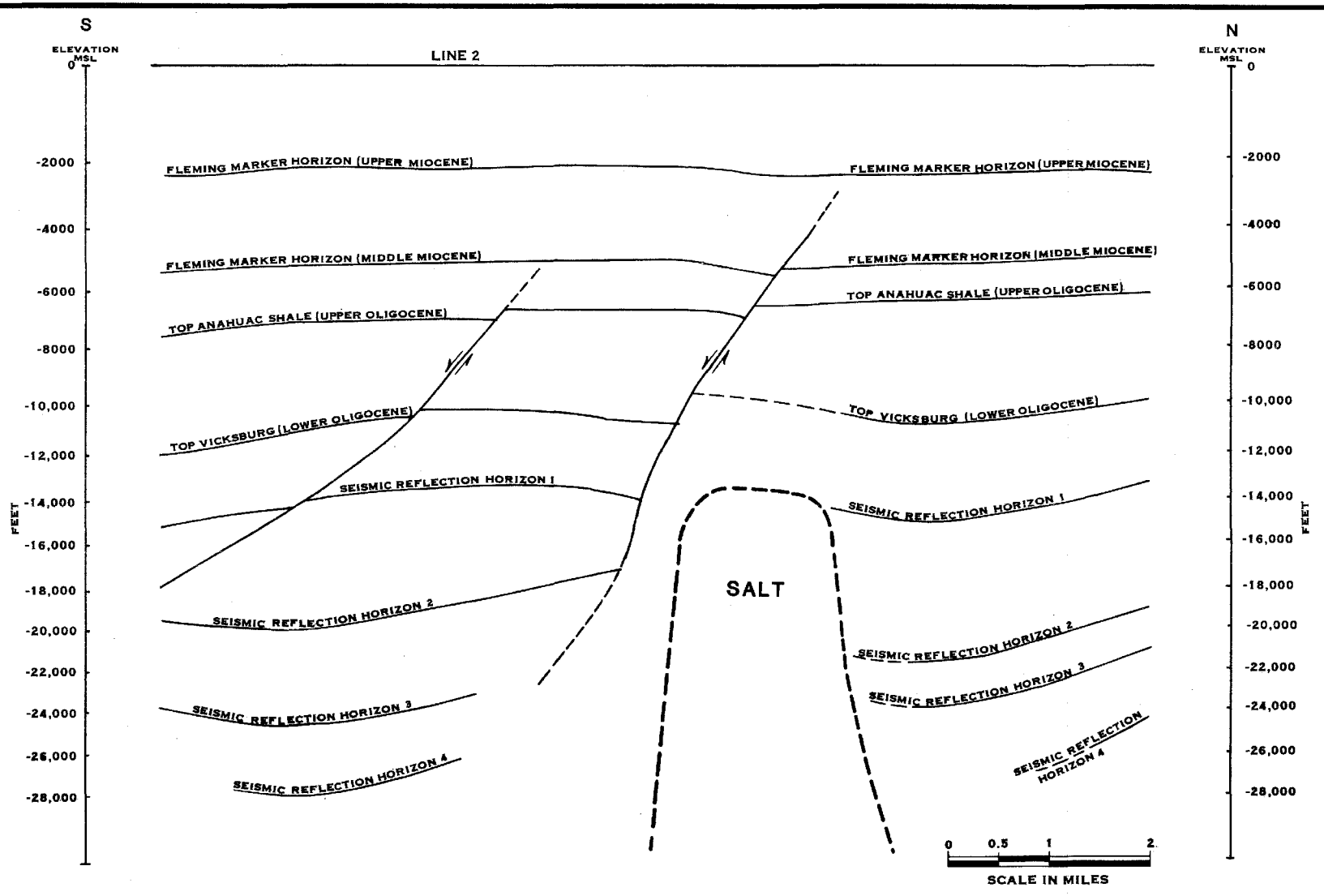
PREPARED BY ODS DATE 8/14/80
CHECKED BY SIF DATE 9/22/80
REVISED BY ____ DATE ____
APPROVED BY GSK DATE 12/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

INTERPRETED INEXCO
NORTH-SOUTH SEISMIC SECTION

FIGURE 4-16



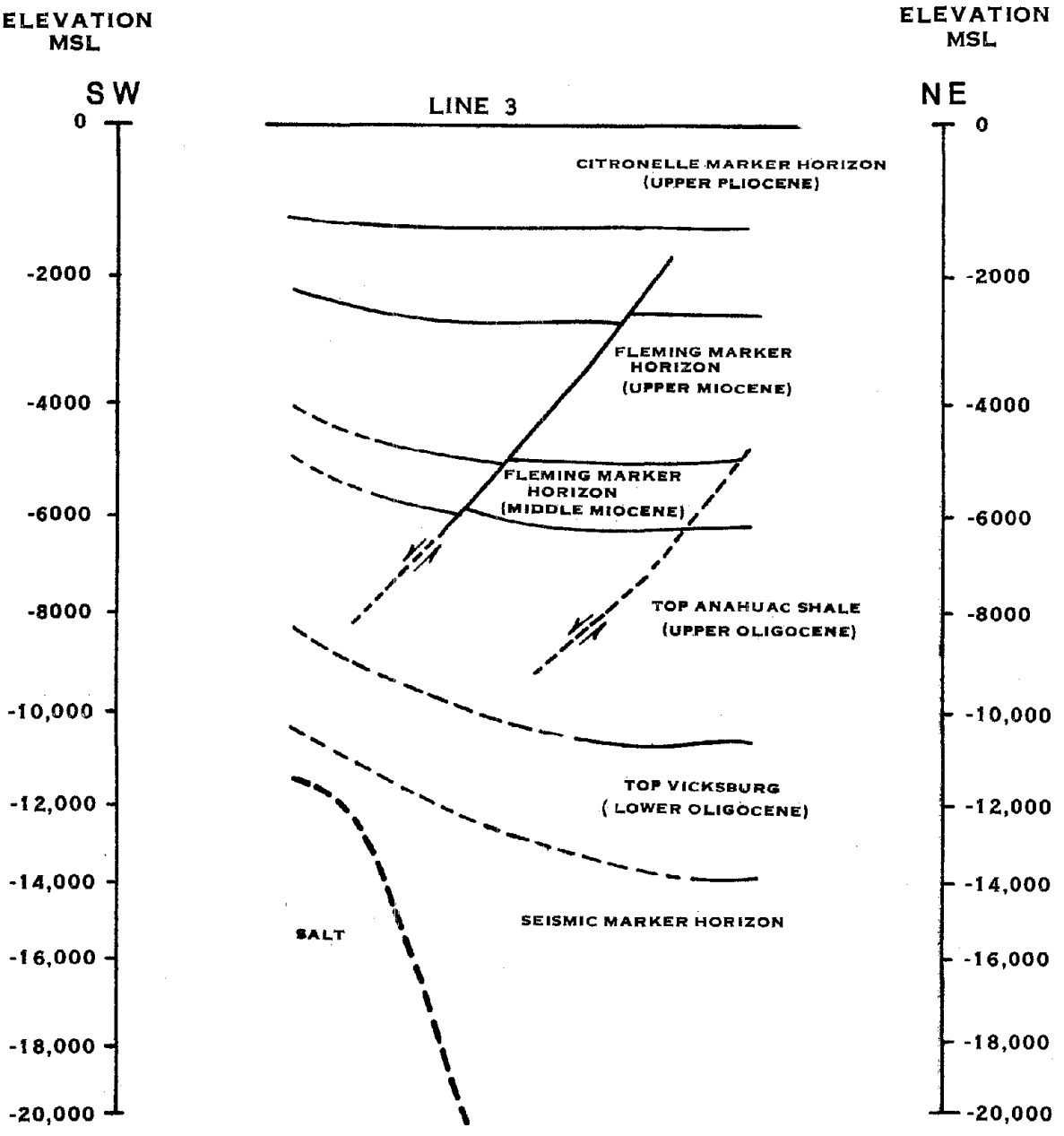
PREPARED BY GDS	DATE 8/27/80
CHECKED BY SIF	DATE 9/30/80
REVISED BY	DATE
APPROVED BY GS/E	DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SULPHUR MINES DOME INTERPRETATION OF NORTH-SOUTH SEISMIC LINE

FIGURE 4-17



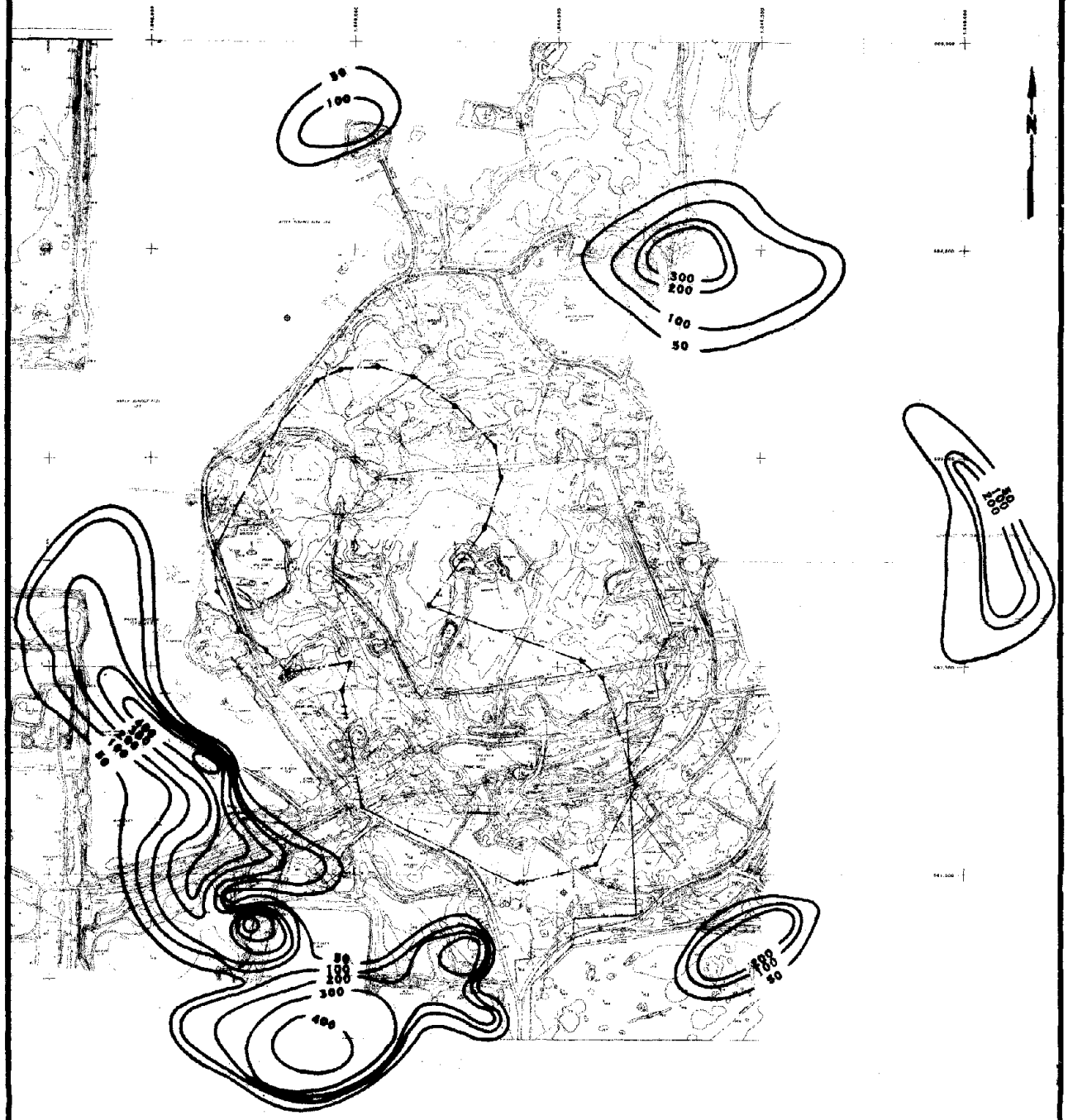
PREPARED BY _____ DATE _____
CHECKED BY _____ DATE _____
REVISED BY _____ DATE _____
APPROVED BY _____ DATE _____

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SULPHUR MINES DOME
INTERPRETED
SOUTHWEST - NORTHEAST
SEISMIC LINE

FIGURE 4-18



LEGEND

—100— THOUSAND BARRELS OF OIL PRODUCED

SPR PROPERTY LINE

0 250 500 1000

SCALE IN FEET

PREPARED BY SJF DATE 8/17/80 CHECKED BY ODS DATE 9/30/80 REVISED BY ____ DATE ____ APPROVED BY LSE DATE 10/1/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	MARGINULINA HORIZON ISO-CUM MAP FIGURE 4-19



LEGEND

— 100 — THOUSAND BARRELS OF OIL PRODUCED

SPR PROPERTY LINE

PREPARED BY SJF DATE 8/17/80 CHECKED BY ODS DATE 9/30/80 REVISED BY ____ DATE ____ APPROVED BY SJF DATE 10/1/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	CIBICIDES HAZZARDI HORIZON ISO-CUM MAP FIGURE 4-20

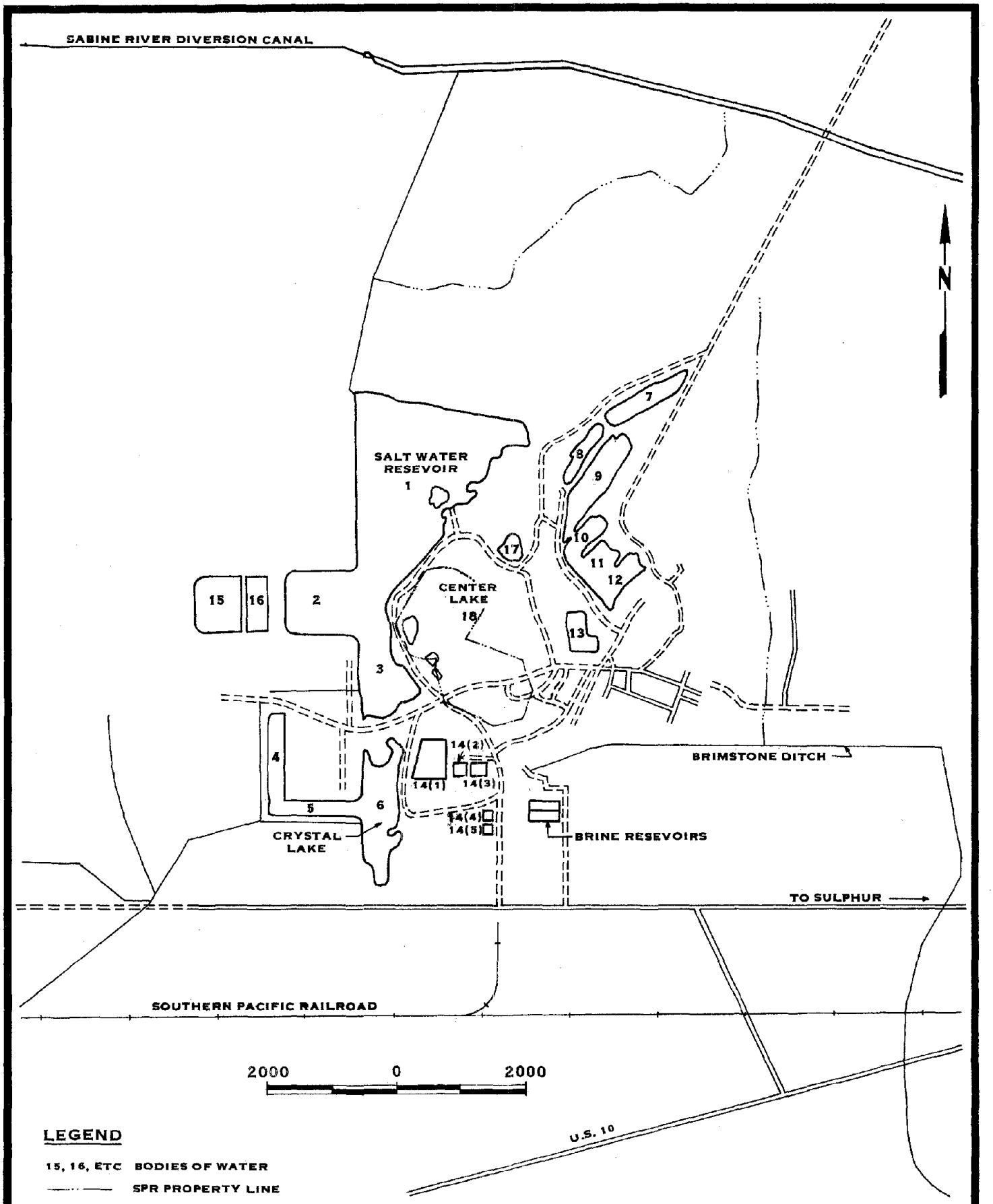


LEGEND

—100— THOUSAND BARRELS OF OIL PRODUCED

SPR PROPERTY LINE

PREPARED BY SIF	DATE 2/17/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	MIOCENE HORIZON ISO-CUM MAP FIGURE 4-21
CHECKED BY DDS	DATE 3/20/80		
REVISED BY	DATE		
APPROVED BY LSK	DATE 10/1/80		



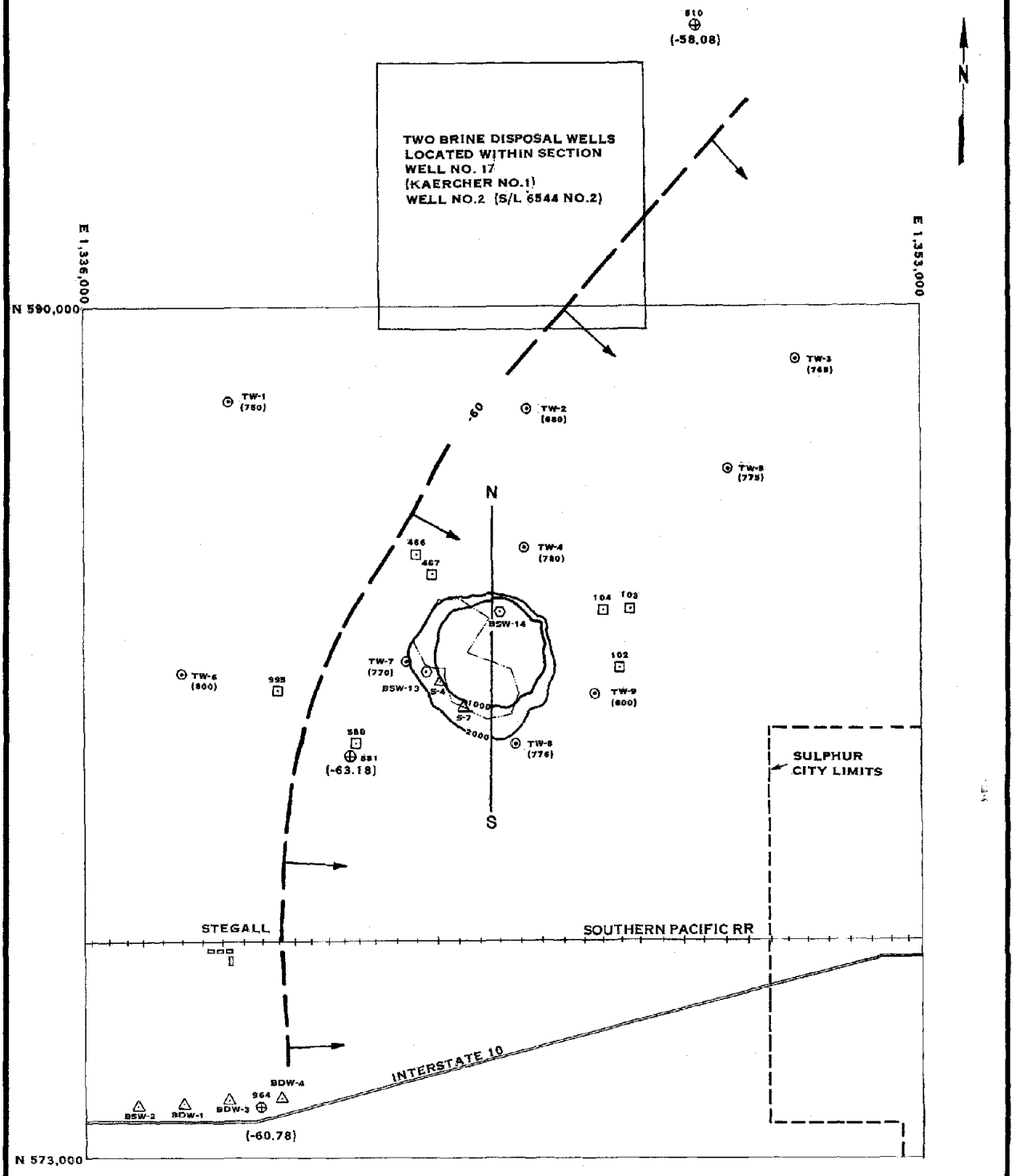
PREPARED BY ____ DATE ____
CHECKED BY ____ DATE ____
REVISED BY ____ DATE ____
APPROVED BY ____ DATE ____

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SULPHUR MINES SITE
SURFACE WATER FEATURES

FIGURE 4-22



EXPLANATION

- 1000 — CONTOUR INTERVAL OF SALT DOME
- ⊕ — U.S.G.S. OBSERVATION WELL AND GROUND-WATER ELEVATION IN 1978
- ⊡ — INDUSTRIAL WATER WELL
- △ — BRINE INJECTION WELL
- ⊙ — BRINE SOURCE WELL
- ⊙ TW-9 (800) — OIL TEST WELLS INDICATING THE DEPTH TO FRESH WATER IN FEET (BASED ON 250 MG/L CHLORIDE)
- 60 — INFERRED POTENTIOMETRIC SURFACE IN CHICOT AQUIFER, 1978. ARROW INDICATES GENERAL DIRECTION OF FLOW
- N S — LINE OF CROSS-SECTION SHOWN ON FIGURE 4-24
- SPR PROPERTY LINE

0 1
SCALE IN MILES

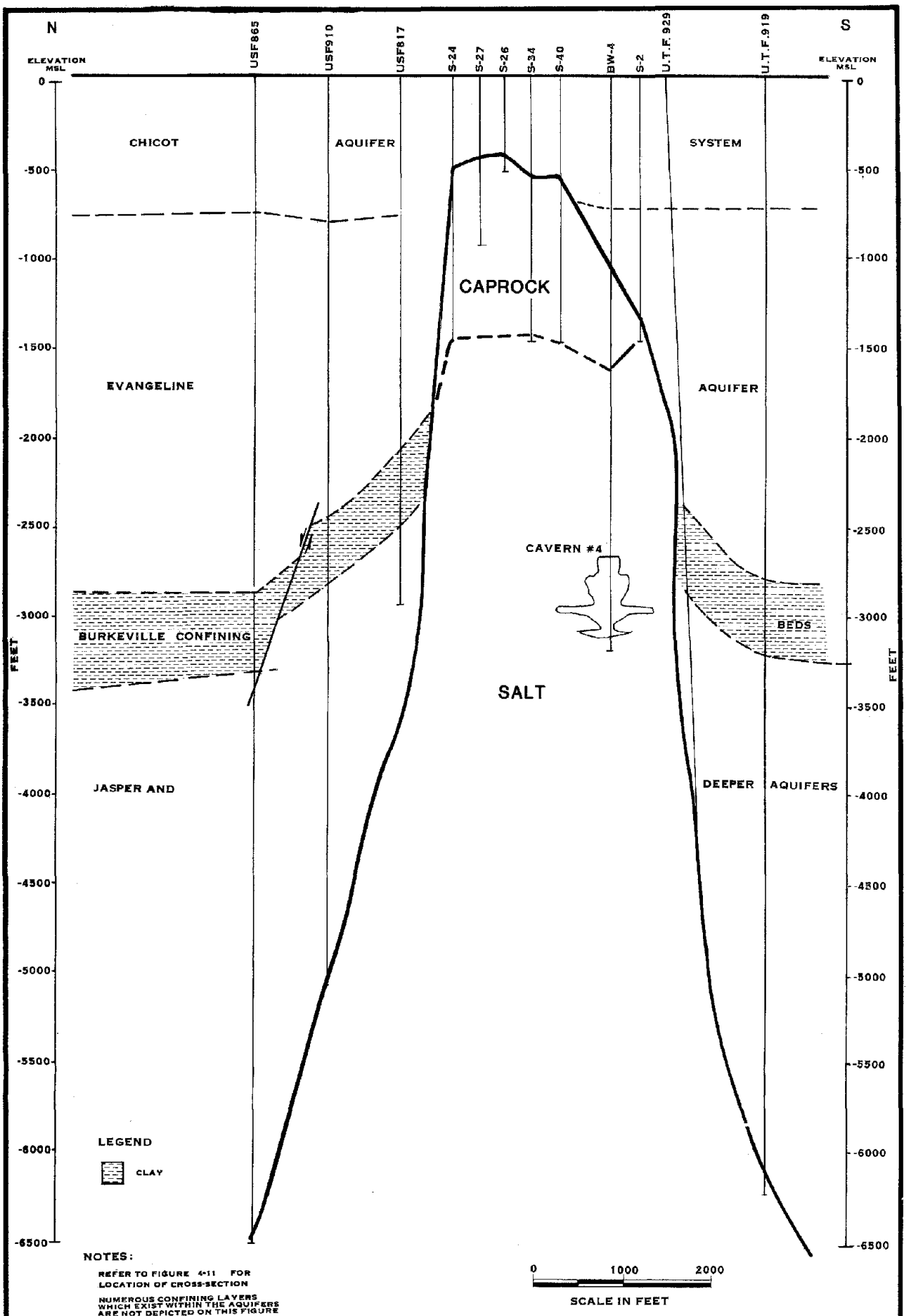
PREPARED BY _____ DATE 2/19/86
CHECKED BY _____ DATE _____
REVISED BY _____ DATE _____
APPROVED BY _____ DATE 2/19/86

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

WELL LOCATIONS IN THE VICINITY OF THE SITE

FIGURE 4-23



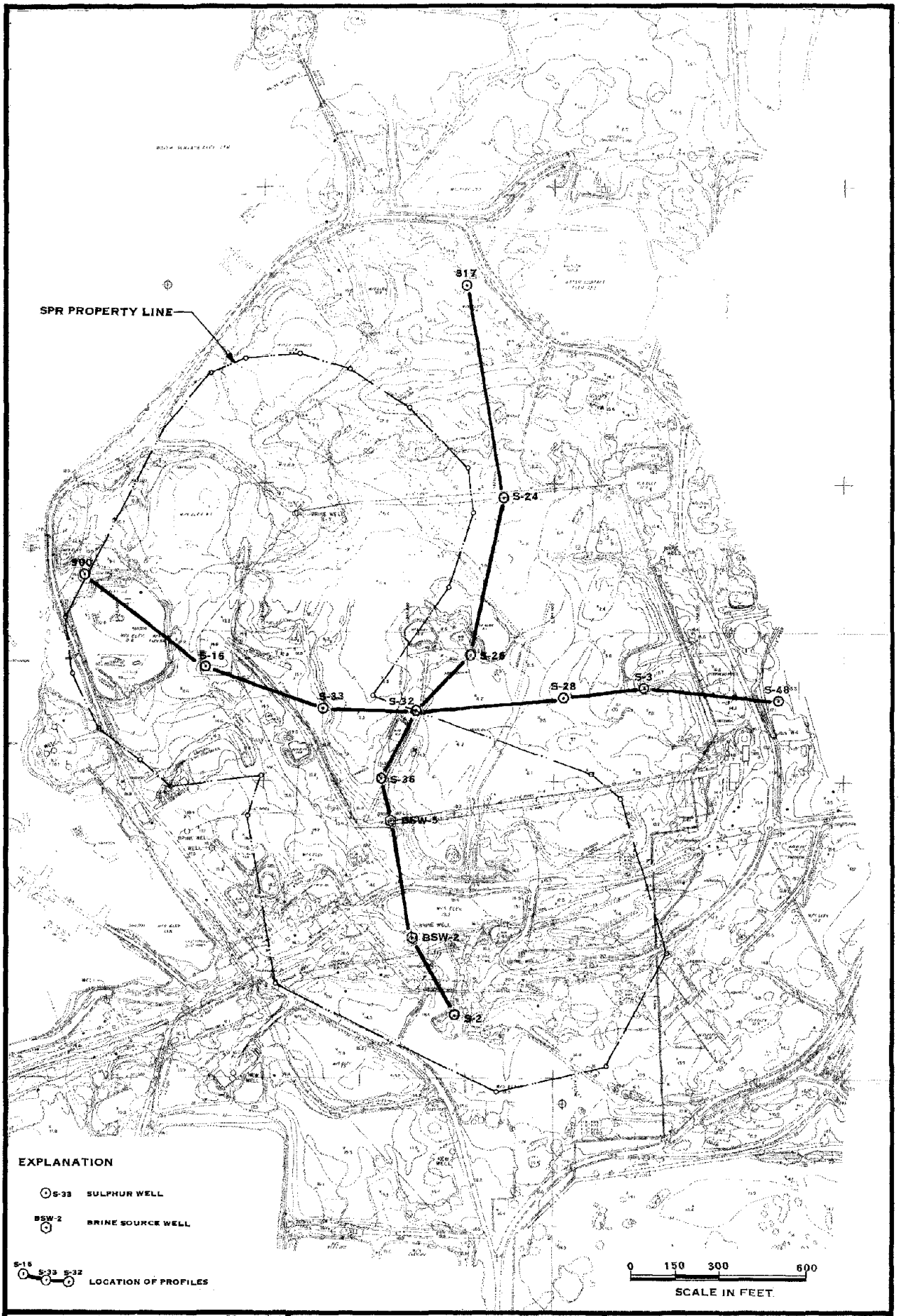
PREPARED BY AAS DATE 2/19/80
CHECKED BY CDS DATE 10/4/80
REVISED BY ____ DATE ____
APPROVED BY LSC DATE 10/14/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

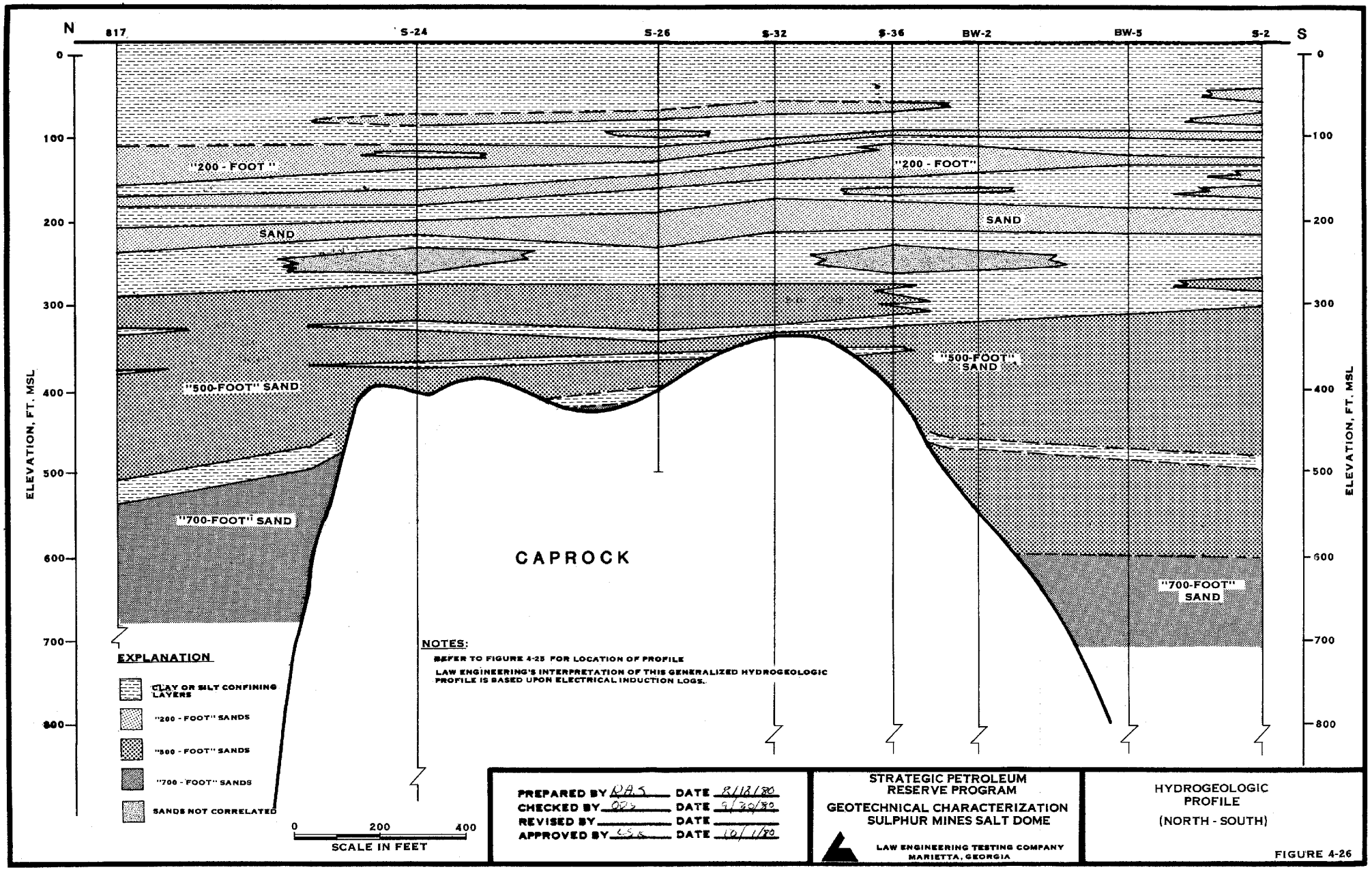
LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

GENERALIZED HYDROGEOLOGIC CROSS-SECTION THROUGH SITE

FIGURE 4-24



PREPARED BY RMS DATE 10/1/90 CHECKED BY ODS DATE 9/30/90 REVISED BY ____ DATE ____ APPROVED BY GSK DATE 10/1/90	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	LOCATION MAP OF PROFILES OVER THE CAPROCK CROSS-SECTIONS SHOWN AS FIGURES 4-26, 4-27, 4-6, 4-7 FIGURE 4-25



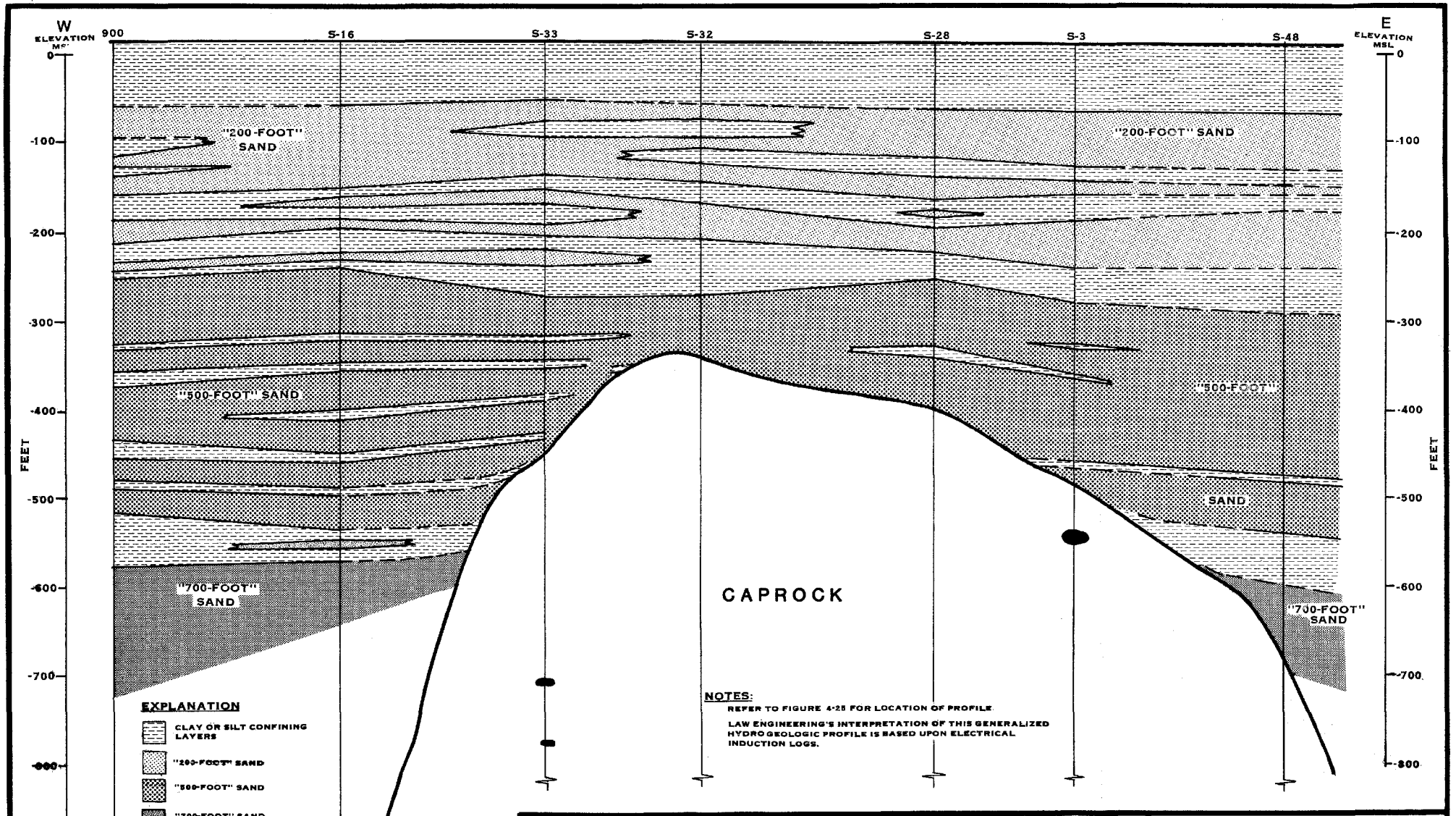
PREPARED BY RAS DATE 8/18/80
CHECKED BY DBS DATE 9/30/80
REVISED BY ____ DATE ____
APPROVED BY CSG DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

HYDROGEOLOGIC PROFILE
(NORTH - SOUTH)

FIGURE 4-26



PREPARED BY RAS DATE 8/18/80
CHECKED BY OD DATE 9/3-/80
REVISED BY ____ DATE ____
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STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

HYDROGEOLOGIC PROFILE (EAST-WEST)

FIGURE 4-27

5.0

5.0

5.0 CAPROCK GEOLOGY AND HYDROLOGY

5.1 CAPROCK GEOLOGY

The caprock over the Sulphur Mines salt dome is lithologically similar to the idealized model proposed by Murray (1966). Figures 5-1, 5-2 and 5-3 demonstrate generalized caprock lithologic zones at Sulphur Mines. The caprock is up to 1,100 feet thick. The upper caprock zone is predominantly calcite. There is a gradual transition from this carbonate zone into a gypsum, anhydrite, and calcite zone, which grades into an almost pure anhydrite zone at the caprock base. The sulphur bearing rock occurs predominantly in the transition zone directly below the upper carbonate zone. Sulphur usually occurs in a very vuggy and porous limestone matrix.

Kelly (1925) states that the bottom 900 feet (82%) of the Sulphur Mines salt dome caprock is practically pure anhydrite. However, in a later study of the caprock core from Union Sulphur Well No. 192, Goldman (1952) found gypsum commonly associated with anhydrite in all but the bottom 300 feet (27%) of the core. Traces of sulphur were also found throughout the lower portion of the caprock. Law Engineering Testing Company's review of geophysical density logs shows the base of the caprock to be predominantly anhydrite but that gypsum, calcite and sulphur are also present. Logs show this massive anhydrite zone to comprise the lower 30-40% of the caprock over the center of the dome.

The sulphur, which occurs in the transition zone was in sufficient quantity to be economically mined for almost 30 years, see Section 5.1.3. Only 24 of the 329 onshore and offshore salt diapirs in the Gulf Coast are known to contain sulphur in economic quantities.

5.1.1 Formation of Caprock at Sulphur Mines

The caprock at Sulphur Mines attains a maximum thickness of 1,100 feet and is one of the thickest caprocks in the Gulf Coast region. Taylor (1938) believed that this thickness, plus the dome lithology, indicate that the development of the Sulphur Mines caprock was in a very mature stage and that there had been a cessation of caprock growth.

Goldman (1952) in his study of the caprock core believed the Sulphur Mines caprock had formed by residual accumulation resulting from dissolution of the salt diapir. The mechanics of this theory are discussed further by Goldman (1933), Taylor (1938), Murray (1966), Martinez (1978) and Davis and Kirkland (1979). Goldman (1952) also found extensive evidence of major stresses which had occurred in the gypsum-anhydrite section of the caprock after its formation. These stress effects, seen in polished thin sections included:

1) mylonization and flowage - predominantly fracture and deformation in rock which produced gouge,
2) fault and fold-displacement was found to range from at least several feet to as little as a millimeter,

3) stress effects along surfaces of weakness including shear zones, and
4) steep and irregular gypsified fissures.

Goldman concluded that it was impossible to determine the depth at which deformation took place. Since movement of salt domes is known to be episodic, there were probably periods of deformation at different depths. The evidences of deformation in the caprock indicates that some movement of the salt took place during or after the formation of the caprock.

Goldman concluded that gypsification of the primary anhydrite may take place, under present conditions, to a depth of 1,183 feet. Additionally, in many parts of the core, gypsum had reverted back to anhydrite, a phenomena referred to as "regenerated anhydrite." Evidence of the alteration of gypsum and anhydrite into sulphur was also found.

5.1.2 Caprock Geometry

The geometry of the Sulphur Mines dome caprock is similar to that encountered in other coastal domes. However, despite the small cross-sectional area of the dome, the caprock is one of the thickest among coastal domes. The caprock geometry was evaluated by the use of well and gravity data. The interpretation of well data was complicated by the wells being drilled prior to, during and after collapse of the caprock as a result of sulphur mining. The interpretation of present caprock geometry as presented in this report, represents the best fit to the data considering these problems.

5.1.2.1 Method of Geometric Definition

A combination of well log (including electric and driller's logs) and gravity data was utilized to define the geometry of the caprock. The 859 wells which have penetrated the top of caprock at Sulphur Mines salt dome placed tight constraints on the use of gravity to develop newer interpretations of the top of caprock. Complicating this, some wells were drilled before caprock collapse, while others were drilled after collapse. However, since only 25 wells penetrated through the caprock into the salt, the utilization of gravity with the well control allowed for a new interpretation of base of caprock (top of salt). This method for defining the base of caprock is discussed in Section 6.1.3, Salt Dome Geometry.

Two interpretations of the top of caprock were obtained from previous investigations. These include a 1925 top of caprock map published in the geologic literature (Kelly, 1925) and a 1965 top of caprock map provided by Union Texas Petroleum Company. Both maps were reevaluated by spot checking top of caprock picks on electric and driller's logs and comparing these to the preexisting maps. There was excellent agreement between our interpretation of caprock picks and the existing maps. The evaluation of interpreted structure between well control points on the top of caprock maps were reevaluated by utilizing sound geologic

interpretation techniques and reasoning. Due to the density of well control, no reasonable alternative top of caprock interpretations were developed from the use of well control and gravity data.

5.1.2.2 Analysis of Shape

In plan view the caprock (Figure 5-4) forms an irregular, circular shaped mass overlying the salt and draping off the salt dome flanks at depth. The most recent interpretation places the caprock at elevations as shallow as -350 feet MSL (360 feet depth) and as deep as -5,000 feet MSL (5,020 feet depth).

The irregular circular area (approximately 1,750 feet in diameter) defined within the -600 foot MSL contour, symmetrically overlies the salt mass at depth. Within the -600 foot MSL contour, the top of the caprock is fairly irregular, with elevations ranging up to -350 feet with the average being -400 feet. The -400 foot MSL contour forms an irregular half moon shape over the western portion of the salt mass. This higher elevation of the caprock is attributed to the existence of a thicker transitional zone in the caprock than the adjacent area on the eastern side of the dome. Within the -600 foot MSL contour, relief up to 50 feet over short distances occurs as pinnacles, depressions, troughs and ridges. The slope of the caprock top within the -600 foot MSL contour is fairly flat, 10 to 11 degrees except in the vicinity of the pinnacles and depressions where slopes exceeding 45° over short distances are present.

Between elevation -600 and -1,500 foot MSL, the caprock slopes downward away from the dome. On the western and southern portions of the dome, the top of the caprock has a slope of about 50 to 60 degrees. The northern and eastern portions of the dome have a higher slope on the top of the caprock which approaches 86° in some areas. Between the -1,500 to -2,000 foot MSL contour, the caprock is approaching an 85° slope away from the dome and is very irregular. Below the -2,500 to -3,000 foot MSL contour, small overhangs have developed on all sides of the dome. These overhangs are not completely continuous around the dome. The only portion of the caprock which suggests almost continuous overhang around the dome is that defined by the -3,500 foot MSL contour. The overhang recedes back under the caprock a maximum of 200 feet.

A comparison of the 1925 and 1965 top of the caprock (Figures 5-2 and 5-3) shows major differences within the area defined by the -600 MSL foot contour. In general, elevations are generally lower on the later vintage map and can be attributed for the most part, to collapse of the caprock as the result of sulphur mining. Some differences can also be attributed to different interpretative techniques between well control points and to the additional well control on the later map. No caprock is shown on the 1925 caprock structure map below elevation -900 foot MSL as well control was lacking to that depth at that date. There is good agreement between the -600 to -900 foot MSL contours on both maps, suggesting little collapse had occurred in that interval. The effects of caprock collapse on overburden and surface facilities is discussed in futher portions of this report.

The caprock thickness varies dramatically across the dome but in a uniform manner. The central portion of the dome contains the thickest portion of caprock and is generally defined by the -600 foot MSL contour. Here the caprock averages 1,000 feet thick but in places is as thin as 435 and as thick as 1,120 feet. Below the -1,500 foot MSL contour the caprock is approximately 200 to 300 feet thick. Further toward the edge of the dome, the caprock remains fairly constant in thickness, but is shown to thicken in wells as the caprock is sloping off the dome, conforming to the shape of the underlying salt mass. Local irregularities of caprock thickness within the -600 foot MSL contour are attributed to caprock collapse due to sulphur mining and to areas which had differing rates of caprock formation as discussed in Section 5.1.1. With the exception of the sides of the dome, these irregularities can not be attributed to fluctuations in the base of the caprock. Well control augmented by gravity indicates a nearly flat surface as is shown on the top of salt map (Figure 6-3). The caprock thickness differential due to sulphur extraction and thus collapse is believed to be significant, but of limited lateral extent in some areas. Caprock collapse is discussed further in Section 5.1.4, Subsidence.

5.1.3 Mineral Exploration And Production

The primary mineral production in the Sulphur Mines dome caprock is sulphur although small quantities of oil with some gas have been produced. The sulphur production accounts for some 735 wells drilled into the caprock. The production of sulphur resulted in caprock collapse and the subsequent subsidence of the ground surface.

The sulphur deposits located in the caprock of the Sulphur Mines salt dome were discovered in 1868 by the Louisiana Petroleum and Coal Oil Company. The exploration party was drilling in the area in search of oil which had been noticed in oil seeps in the surrounding marshes. They struck the caprock at a depth of 333 feet and encountered over 100 feet of pure sulphur at 551 feet.

After several unsuccessful attempts to conventionally mine the sulphur a new company, the Union Sulphur Company, contacted a chemical engineer named Herman Frasch for advice. In 1892, Mr. Frasch conceived the idea of melting the sulphur in the ground and pumping it out as a liquid (Kelly, 1925).

Frasch ran into numerous problems while trying to make this process practical. Unforeseen geological and physical properties of the deposit and mechanical malfunctions were common. It took ten years of experimentation before the site was commercially producing sulphur.

Sulphur was economically produced at Sulphur Mines between 1902 and 1924 using the Frasch hot water injection process. In all, 9.4 million long tons of sulphur were removed. Approximately 14 tons of water, heated to 330° F. was pumped into the caprock for each ton of sulphur pumped to the surface (Haynes, 1942). The distribution of sulphur production over the dome is shown in Figure 5-5. Only one area, in the southern portion of

the dome, has had production in excess of 500,000 tons per acre. Several areas along the perimeter of the dome had production exceeding 200,000 tons/acre.

In the mid 1960's, Union Texas Petroleum attempted to revive sulphur production at the site. This venture proved unprofitable and was soon abandoned. Estimated sulphur reserves based on UTPC data were 673,775 tons (approximately 7 percent of that produced to date. The location of reserves generaly corresponds to areas of the dome which have had production.

5.1.4 Subsidence

Subsidence of the ground surface at the Sulphur Mines SPR site, as the result of sulphur mining in its caprock, is typical of coastal domes which have had sulphur production. However, the magnitude of subsidence over such a wide area above the caprock and over such a long period of time is unusual. This is directly related to Sulphur Mines salt dome having such a large volume of sulphur for such a small dome. The discussion of the history of subsidence, mud filling of caprock and impact on the SPR facilities as presented in this section is the result of a review of historic records and reports of geologists and engineers over nearly 3/4 of a century. Most of the data was obtained from Union Texas Petroleum Co., although Pittsburg Plate Glass Co., DOE, and Law Engineering's own project files were also utilized.

5.1.4.1 History of Subsidence

Surface subsidence at Sulphur Mines salt dome is reported to have begun after 8 to 10 years of sulphur mining and by the late 1920's subsidence is reported to have been more than 20 feet in some areas (Hayne 1942). Prior to mining, the dome had considerable topographic expression, up to 20 feet of relief from the surrounding marsh (Figure 4-3). However, present topographic relief (Figures 4-1 and 4-2) is almost inverted from the pre-mining days, with a depression over the dome center. The subsidence, resulting from the collapse of voids left by sulphur extraction, made it necessary to frequently bring in fill to sustain the foundations of the boiler houses and other structures. A narrow guage railroad was initially used to bring in fill. When the demands for fill increased, hydraulic dredges replaced the railroad (Hayes 1942). Much of the fill came from areas which immediately surround the dome and today exist as ponds on the northern and western sides of the dome.

The primary mechanism of surface subsidence is caprock collapse due to sulphur extraction. In some areas, cavities already existed in the caprock (some up to 23 feet in vertical section), but extraction of sulphur is believed responsible for initiating collapse. A comparison of old sulphur production and exploration well penetrations into the caprock with caprock penetrations of sulphur wells drilled in 1965 shows a significant variation in caprock elevation, with the newest well data generally showing lower elevations of the top of the caprock. This data along with caprock elevation differences between the pre-mining top of

caprock map and the post mining top of caprock map (1965) was used in preparing a caprock collapse map (Figure 5-6). Cross-sections presented in Figures 5-2 and 5-3 also show elevation differences between the existing caprock and the caprock top of 1925. In places the caprock is shown to have collapsed as much as 163 feet, but 25 to 50 feet is typical. Additionally, a fair correlation between areas of sulphur production and significance collapse does exist (Figures 5-5 and 5-6).

However, in some areas correlation between the maps is poor. This appears to be related to the following:

1) Voids created in the caprock by sulphur mining which may not have collapsed completely.

2) Dissolution of the caprock is still going on without sulphur mining as a result of sulphurous acidic water circulating in the caprock.

3) Mud filling of the caprock during mining.

A direct correlation of caprock collapse areas to subsidence areas is not possible. The lack of correlation is due to the effect of the collapse occurring at the depth of the caprock. The effect is spread out over a wide area at the surface as a result of natural and fill soils adjacent to the collapse sliding into the collapse area forming a cone of depression or subsidence centered over the collapse. However, by considering the volume of total sulphur mined over the entire caprock area (approximately 75 acres) the average thickness of sulphur removed is 48 feet. This figure is more reasonable for the amount of subsidence and agrees with the average thickness of fill determined by shallow borings and probes plus the difference in elevation between the pre-and post-mining topographic maps.

The rate of collapse and related subsidence has varied from slow and catastrophic. One catastrophic event occurred around sulphur well no. well 366 during sulphur removal operations in 1914. This well is located 75 feet west of SPR storage cavern well 6x. A crater formed, approximately 100 feet in diameter. Over a six month period, 169,000 cubic yards of fill was dumped into the subsiding crater which eventually engulfed a drill rig. Other subsiding areas were less spectacular, amounting to slow subsidence (1 foot per year) over large areas and small depressed areas around well locations. Old drilling records report well casings being completely sheared, crushed and bent by subsurface soil movement due to caprock collapse. Present evidence may be some of the old casing still exposed at the surface but tilted from the vertical.

Recent measurements of subsidence over the last 11 years at various monitoring points over the dome were provided by PPG and show a steady rate of 0.1 foot per year (Figure 5-7). The subsidence is believed due to the following factors:

Factor 1) Continued collapse of the caprock by dissolution and creep at granular contacts.

Factor 2) Consolidation of natural and fill soils overlying the caprock.

Factor 3) Undermining or piping of soils overlying the caprock by water flowing through caprock fractures and cavities.

Of the three factors presented, only the magnitude of consolidation of natural and fill soils can be determined with any degree of accuracy. Engineering calculations based on natural fill and soil data at the site suggest the degree of primary consolidation of fill soils above the caprock is 95% or more at this time. Secondary consolidation, assuming approximately 30 feet of clay fill, would account for 0.01 feet of settlement per year, leaving 0.09 feet per year for factors 1 and 3. No settlement is calculated for natural soils underlying fill. Considering that some subsidence monitoring points are at well heads which are cemented into the caprock and are also subsiding at similar rates to other monitoring points, this suggests the total soil mass over the caprock is subsiding due to factors 1 and/or 3. Since the monitoring points are distributed widely over the dome, factor 3 is ruled out as a major cause as this method would tend to cause spot subsidence rather than area subsidence. Therefore, continued collapse of caprock must be causing the subsidence, probably due to slow creep at granular contacts and to dissolution in the caprock.

5.1.4.2 Mud-Filling of Caprock

During 1915, as a result of successful practices at other domes mined for sulphur, part of the standard procedure for sulphur mining at Sulphur Mines salt dome was to pump mud into the caprock. Much of this mud was extracted by hydraulic dredges at ponds on the northern and western sides of the dome. The mud was injected into the voids and cavities in the caprock. Justification for mud filling was threefold:

1) To replace the volume of sulphur mined with mud and perhaps minimize subsidence.

2) To slow down the dissipation of hot water used for melting the sulphur, as cold water in the caprock was apparently mixing with the hot water introduced and thus cooling it.

3) To regain drilling circulation for sulphur wells when circulation was lost, usually on encountering cavities.

Besides mud, considerable amounts of other material were substituted for mud, such as straw, tree limbs, sand, etc. No data is available on the total amount of mud filling of the caprock or its success in reducing subsidence. However, it was a common procedure and has been reported successful in preventing the

dissipation of hot waters introduced into the caprock and regaining lost drilling circulation. Well number 404, located 450 feet northeast of SPR Cavern Well 6x received approximately 25,000 cubic yards of sand and mud over a 382 day period to fill a 23 foot cavity in the caprock. Upon completion of the filling operation, that interval was pumped, returning only clear water to the surface with no trace of mud. A large number of the sulphur wells were drilled as, or converted to water wells to pump cool water from the caprock in order to enhance production and provide boiler water.

5.2 CAPROCK HYDROLOGY

5.2.1 Caprock Hydrogeologic Zones

A generalized hydrogeologic cross section through the caprock is shown in Figure 5-8. The center of the caprock averages about 1,100 feet in thickness and the top of the caprock occurs at an average elevation of about -500 feet MSL. The caprock is less than 100 feet thick along the flanks of the dome. The caprock extends around some portions of the dome as discussed in Section 5.1.2. A clay sheathing is also present along some of the lower portions of the dome (Refer to Section 5.1.2). Three distinct hydrogeologic zones are apparent within the caprock (Figure 5-8).

The uppermost hydrogeologic unit within the caprock consists of a dense permeable limestone zone. The limestone is sandy to dolomitic. The zone is typically about 100 feet thick. Drilling fluid circulation was often lost in the permeable areas of this zone during prior drilling operations. This uppermost zone has always been barren of sulphur.

A highly permeable limestone zone underlies the uppermost limestone unit. This zone is also known as the sulphur production zone which was extensively mined for sulphur. The sulphur apparently occurred within fractures and vugs in the limestone. The removal of more than 9.4 million long tons of sulphur by the Frasch process produced large cavities and increased the permeability of the zone. The permeability of this zone may have been high under pre-existing conditions. Ground water containing sulphides and salts are known to deposit sulphur by circulation through porous rock (Kelley, 1925 and Haynes, 1942). The zone is typically about 160 feet thick.

Examination of records for wells drilled in the sulphur production zone for the sulphur mining operation indicate the presence of many cavities as evidenced by the drop of the drill stems during the drilling operation. Most of the cavities are hydrologically connected between several well locations. Indications of these interconnections were noted during the mining operation and include:

- "steaming" of one well created a blow off of steam from an unrelated nearby well;
- the productivity of a "steamed" well was increased by pumpage from a "cold-water" well;

- the temperature of the ground water in the "cold-water" wells rose considerably when nearby production wells were "steamed."

Attempts were made to plug some of the cavities encountered in the sulphur production zone during the mining operation. More than 90,000 cubic yards of solid material was pumped into sulphur well number 225 without successful plugging of the cavity. Sand, mud, and straw were used to plug the cavities during the early mining operations.

A gypsum and anhydrite zone underlies the sulphur production zone (Figure 5-8). The zone is typically about 520 feet thick. The zone contains varying amounts of gypsum, anhydrite, limestone, and sulphur. The zone directly overlies the salt. Some water losses are known to have occurred within this zone. This region of the caprock becomes less porous and permeable with depth. The lowest anhydrite beds within this zone may have a low permeability.

5.2.2 Caprock Ground-Water Quality

The results of ground-water quality analyses of two samples collected in the caprock are shown in Table 5-1. These samples appear to have been collected from the gypsum and anhydrite zone and indicate a high concentration of chlorides, sulfates, and calcium.

A generalized water-quality profile was prepared through the caprock from selected recent sulphur wells (Figures 5-9 and 5-10). This profile indicates the increasing salinity of ground water with depth in the caprock. Chloride concentrations appear to be less than 500 mg/l above elevation -550 MSL. Between elevations -550 and -1,000 MSL, the chloride concentration is typically in the range of 500 to 1,000 mg/l. Chloride concentrations are typically above 25,000 mg/l below elevation -1,200 feet MSL, in the vicinity of the profile.

Temperature anomalies exist in the hydrogeologic zones above and within the caprock (Figure 5-11). For the most part, the thermal regime above the caprock is significantly higher than normal ground water and dome temperature gradients in the region. Although a portion of the elevated temperature may be from exothermic reactions related to the interaction of sulphur compounds with ground water, the majority of the temperature anomaly is probably associated with residual thermal storage in clays and low permeability zones. The elevated temperatures will tend to accelerate the existing potential for corrosion in the subsurface.

Previous oil and gas, and sulphur mining activities created approximately 900 borings into the caprock. Most of these early wells were not sealed or plugged. They still act as vertical conduits for ground-water migration between the caprock, overlying aquifers, and the surface.

5.3 IMPACT ON SPR FACILITIES

5.3.1 Caprock Geology

Subsidence and the dumping of fill into subsiding areas has left almost no natural soils at the surface over the dome. The majority of this fill is not considered an engineered fill and thus is not homogenous from the standpoint of engineering properties such as strength, moisture content, consolidation characteristics etc. The effects of continued subsidence and caprock integrity over the dome is discussed further in Section 7.1.

Sulphur mining is not presently ongoing at Sulphur Mines and has not occurred for 56 years. However, collapse of the caprock from sulphur mining has occurred and may still be occurring as a result of indirect effects of sulphur minig. Therefore the surface over the dome will continue to subside. This is discussed further in Section 7.1. Minor reserves of sulphur still exist at the dome site although substantial areas have been mined out. Future sulphur production would result in additional subsidence but is not considered economic at the present time.

The natural cavernous character of the caprock and the added effects resulting from sulphur mining will continue to cause drilling problems, i.e., losing circulation in the caprock when drilling and cementing casing.

5.3.2 Caprock Hydrology

The hydrogeologic zones within the caprock are permeable. The sulphur production zone is highly permeable. Installation of additional transfer wells could prove difficult because of large circulation losses that typically occur within the more permeable hydrogeologic zones. Petroleum losses within the caprock would be difficult to recover.

The corrosion of unprotected casing within the caprock is anticipated because of the abundance of ions in solutions within the caprock fluids and elevated temperatures. The corrosion potential is particularly high below a general elevation of -1,200 ft MSL.

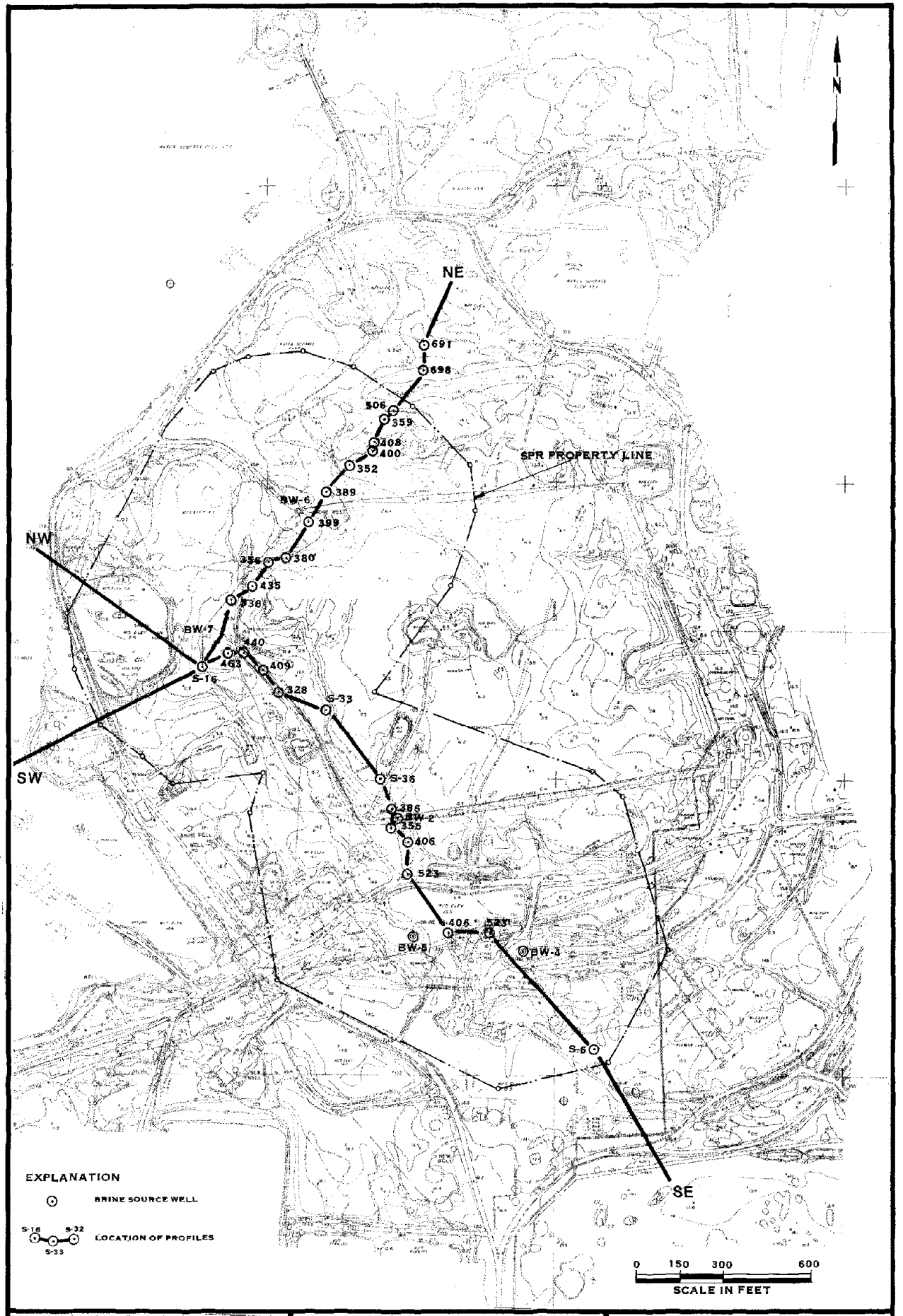
The caprock is overlain by relatively fresh ground water of the Chicot aquifer system. Any leakage of petroleum or fluids from previous operations at the SPR facility upward and into this aquifer could preclude the use of this resource at the site and in areas down gradient of the dome.

Table 5-1

GROUND-WATER QUALITY ANALYSES

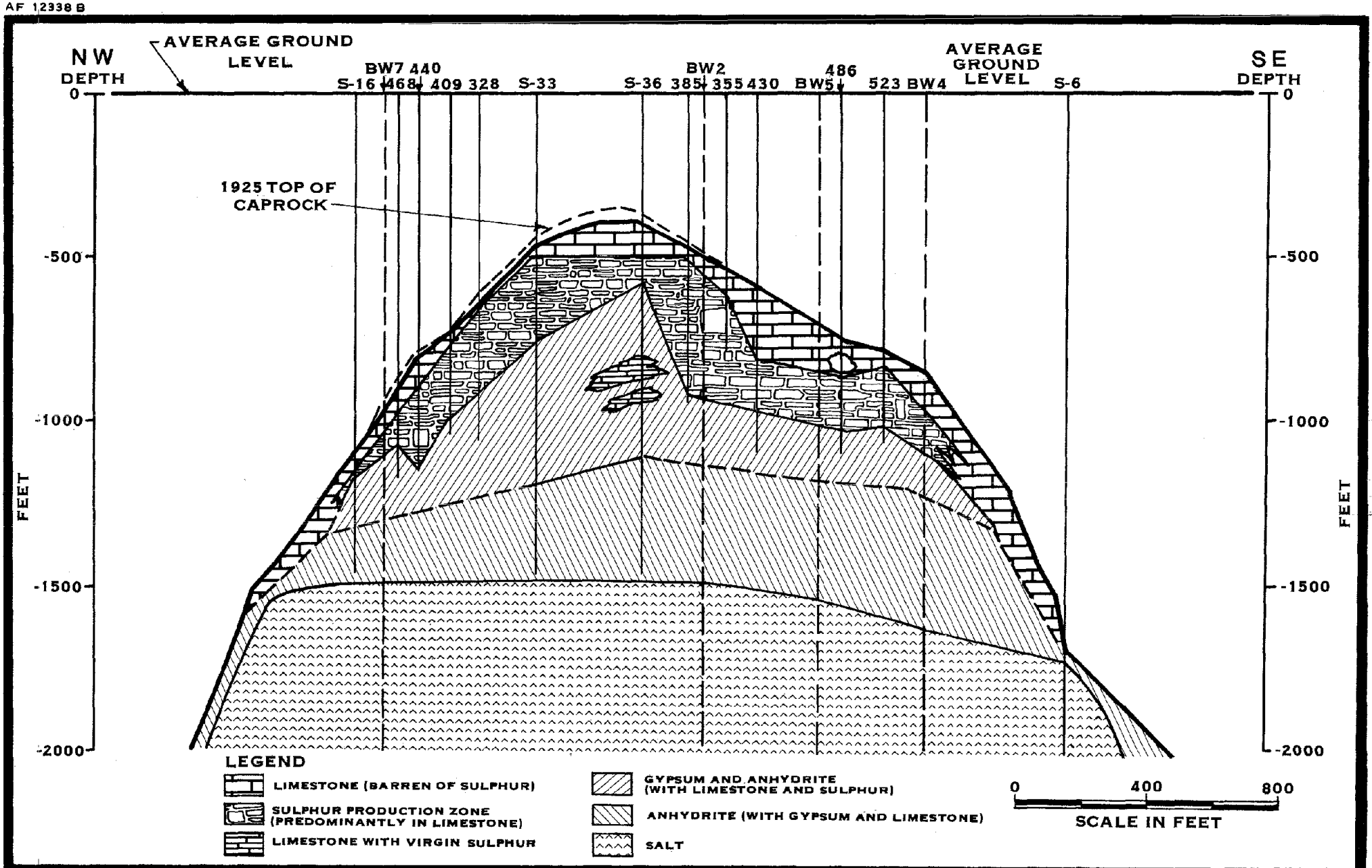
PARAMETERS	RESULTS	
	WELL S-5 (1161 Feet, MSL)	WELL S-1 (1460 Feet, MSL)
pH	7.2	7.15
Specific Gravity	1.005	1.036
Alkalinity ($CaCO_3$)	357 mg/l	276 mg/l
Bicarbonate (HCO_3)	434 mg/l	336 mg/l
Chlorides (Cl)	2,100 mg/l	32,130 mg/l
Sulfates (SO_4)	3,000 mg/l	6,750 mg/l
Calcium (Ca)	702 mg/l	2,106 mg/l
Magnesium (Mg)	28 mg/l	512 mg/l
Total Hardness ($CaCO_3$)	1,872 mg/l	7,371 mg/l
Total Iron (Fe)	0.4 ppm	1.2 ppm
Sample Date	July 13, 1965	July 12, 1965

Modified from:
Tretolite Co., 1965



PREPARED BY S.E DATE CHECKED BY C.D.S DATE 9/30/80 REVISED BY ____ DATE ____ APPROVED BY L.S.K DATE 10/1/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	WELL LOCATIONS FOR THE NORTHEAST - SOUTHWEST, NORTH WEST - SOUTHEAST SALT DOME CROSS-SECTIONS FIGURE 5-1

AF 12338 B

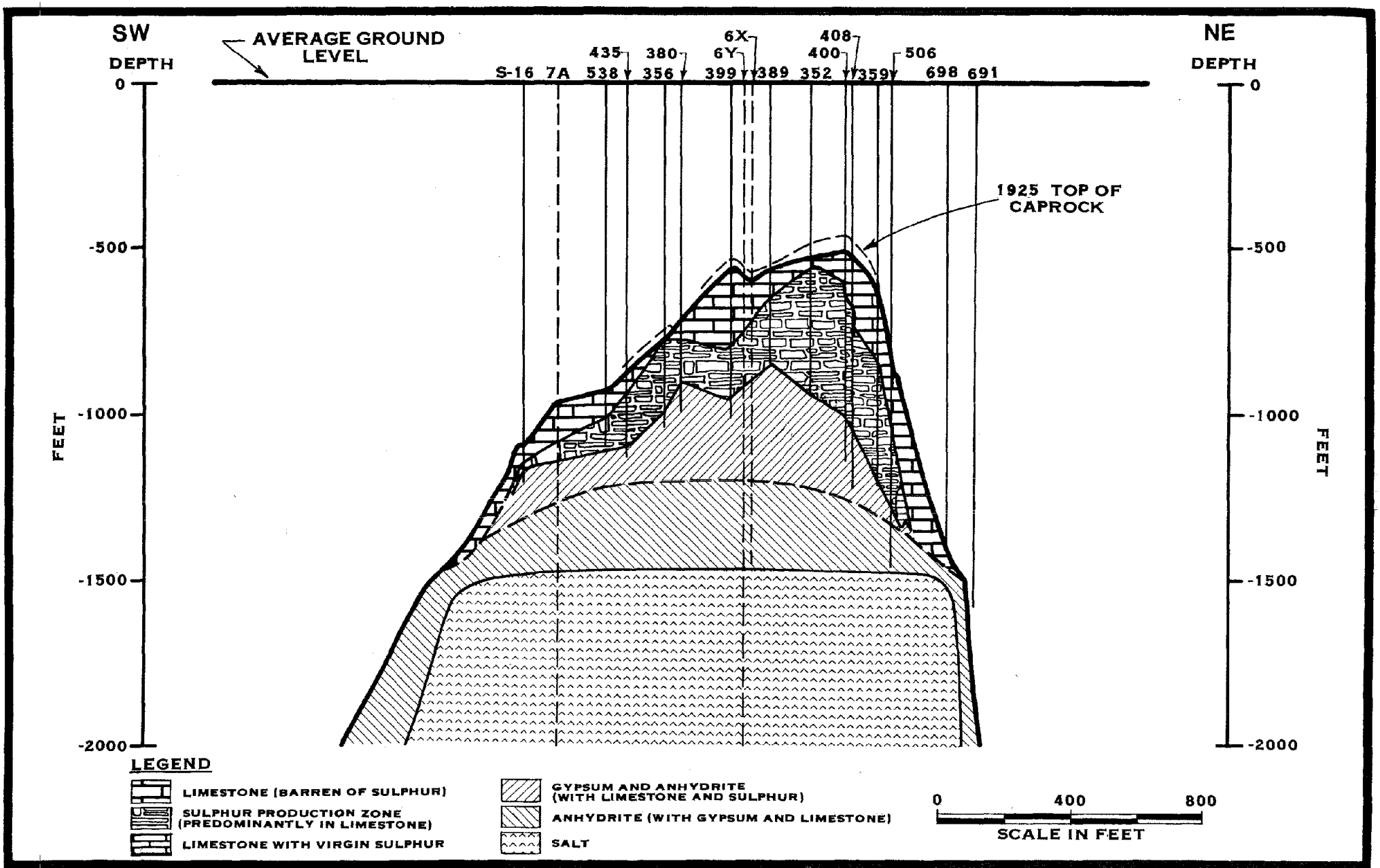


PREPARED BY JF DATE 3/25/80
CHECKED BY ODS DATE 9 Apr 80
REVISED BY ____ DATE ____
APPROVED BY LSK DATE 10/1/80

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SULPHUR MINES SALT DOME
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NW - SE CAPROCK CROSS-SECTION

FIGURE 5-2



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REVISED BY _____ DATE _____
APPROVED BY GSK DATE 10/1/80

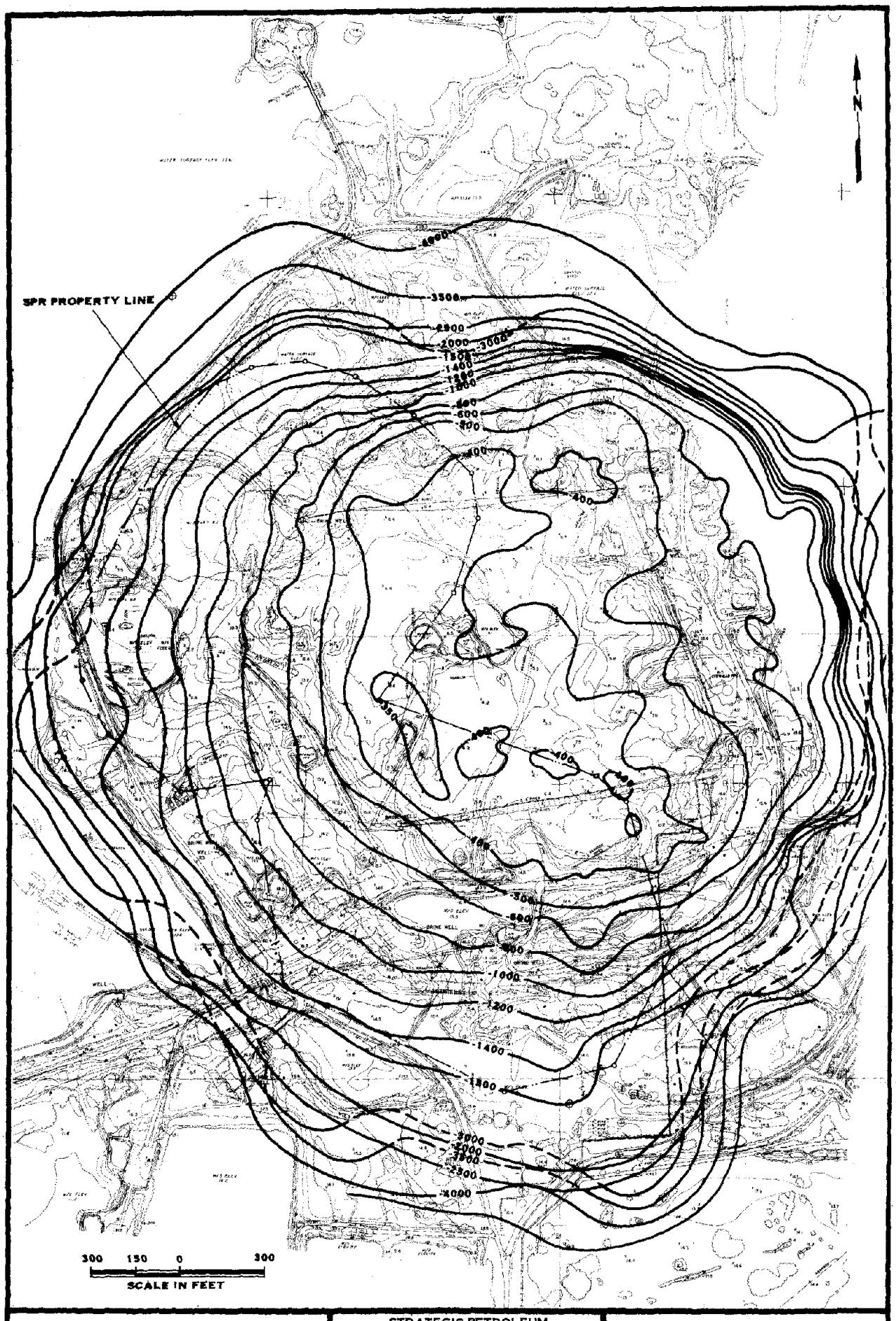
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SW - NE CAPROCK CROSS-SECTION

FIGURE 5-3



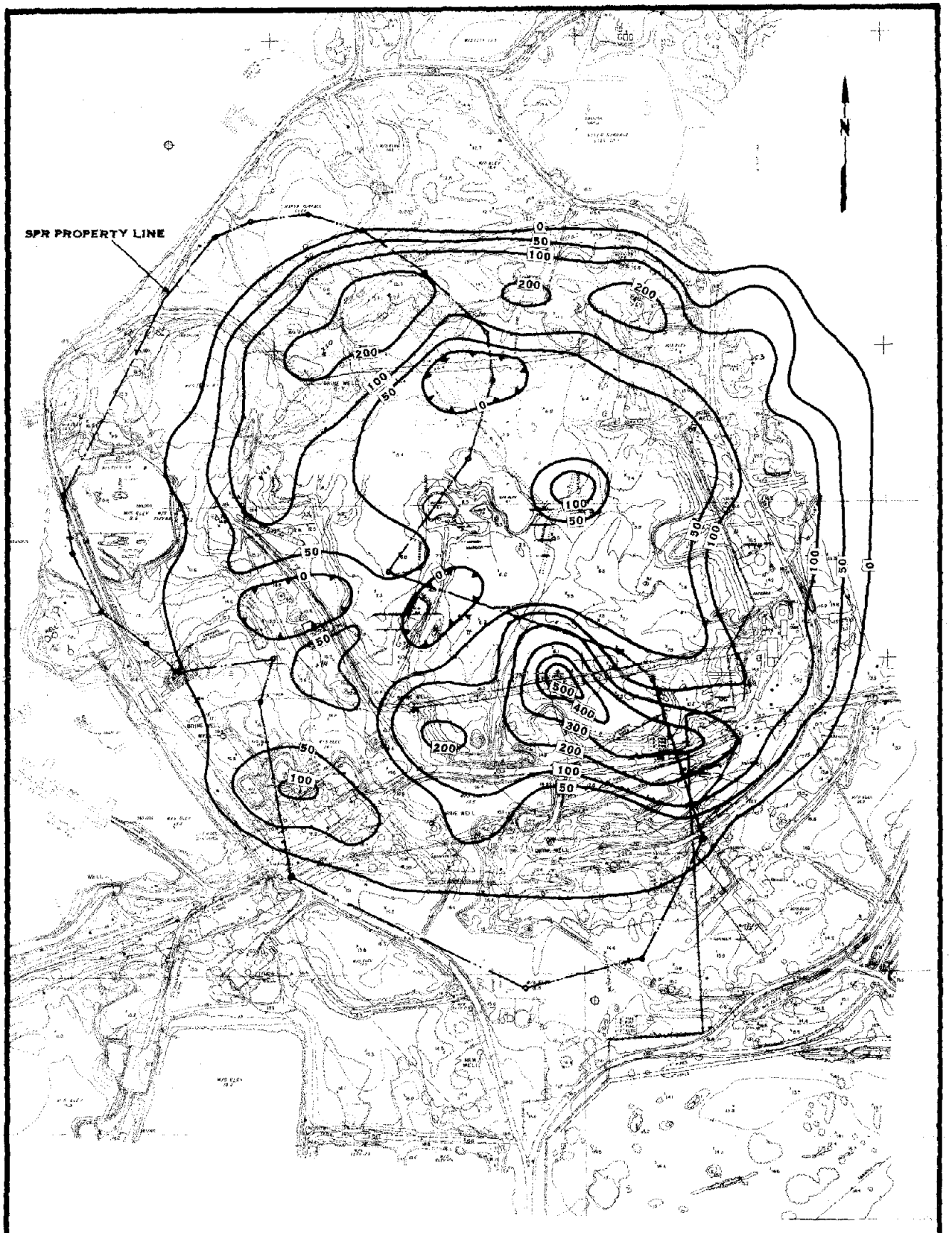
PREPARED BY JSB DATE 8/25/80
CHECKED BY ODS DATE 9/30/80
REVISED BY _____ DATE _____
APPROVED BY CSR DATE 10/1/80

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SULPHUR MINES SALT DOME

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TOP OF CAPROCK
CONTOUR MAP
(ELEVATION MSL)

FIGURE 5-4

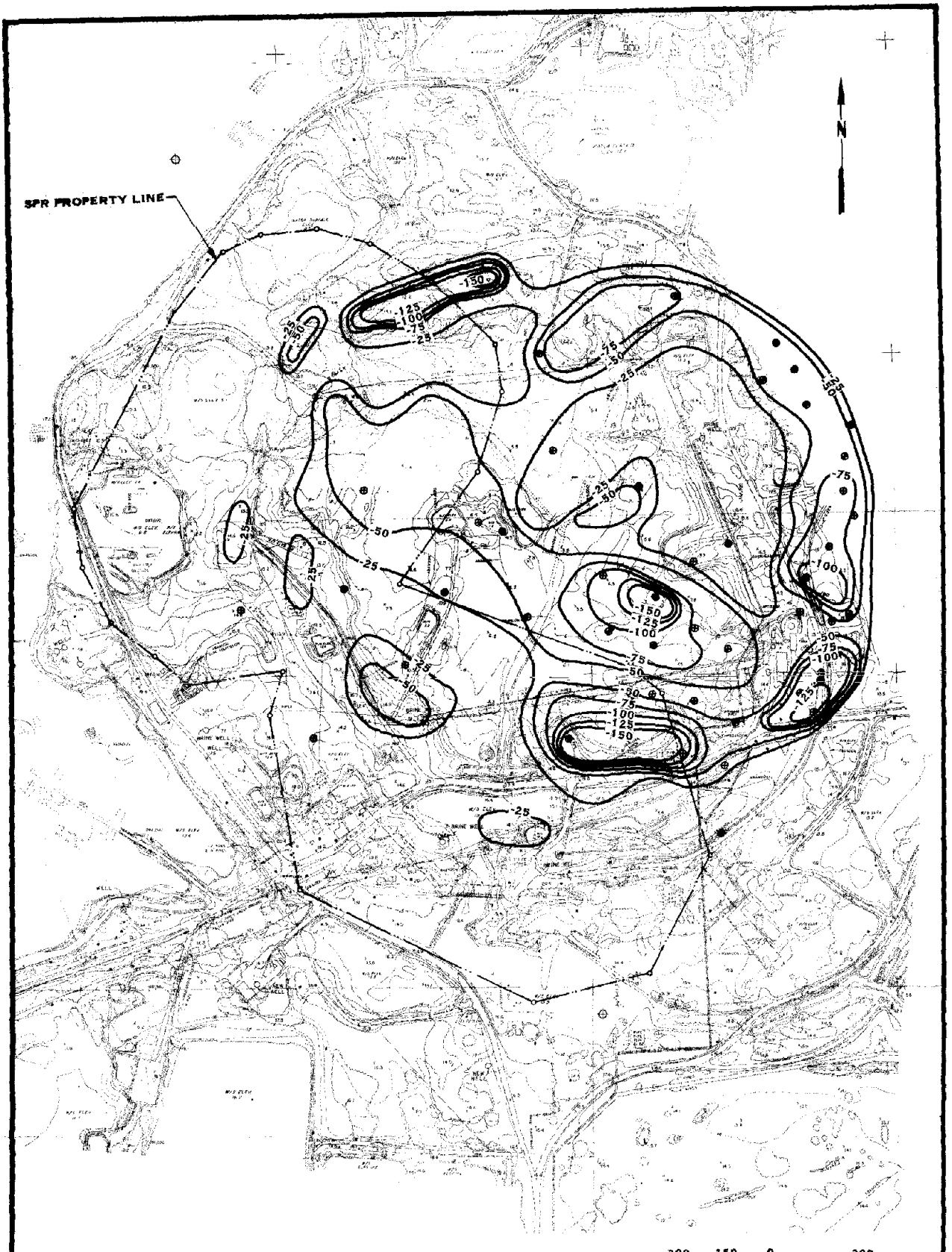


LEGEND

—50— SULPHUR PRODUCTION CONTOUR (1000 TONS PER ACRE)

PREPARED BY DDS	DATE 5/10/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	SULPHUR PRODUCTION CONTOUR MAP
CHECKED BY GHE	DATE 9/30/80		
REVISED BY	DATE		
APPROVED BY LSE	DATE 10/1/80		

FIGURE 3-3



LEGEND

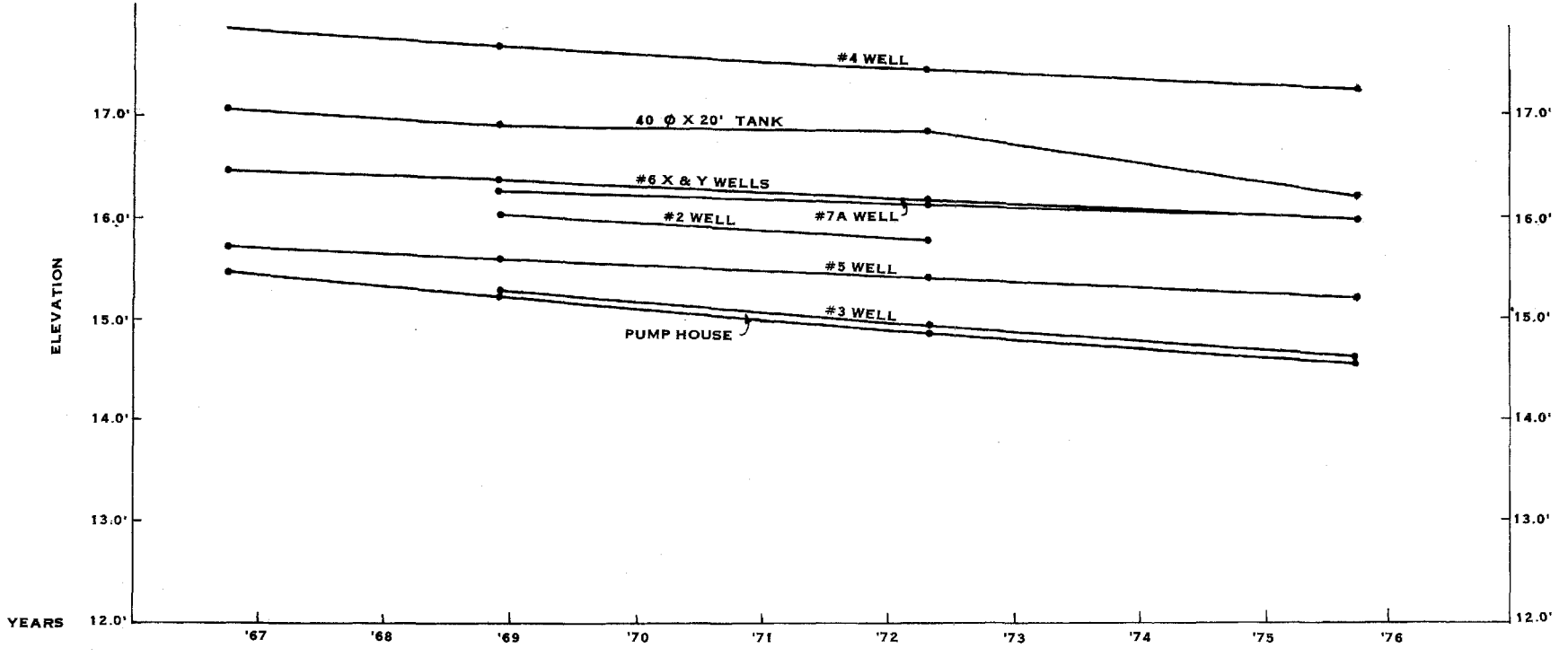
⊕ 1965 SULPHUR BORING CONTROL POINTS

—-25— TOTAL SUBSIDENCE (FEET)

NOTE:

OUTSIDE OF 25' CONTOUR COLLAPSE VARIES BETWEEN 0 - 25'

PREPARED BY DDS DATE 8/11/81 CHECKED BY GHF DATE 9/30/80 REVISED BY ____ DATE ____ APPROVED BY LSK DATE 10/1/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	CAPROCK COLLAPSE CONTOUR MAP FIGURE 5-6



10 YRS SUBSIDENCE AT SELECTED POINTS ON SULPHUR DOME

REFERENCE:

PITTSBURGH PLATE GLASS MEMO, 1976

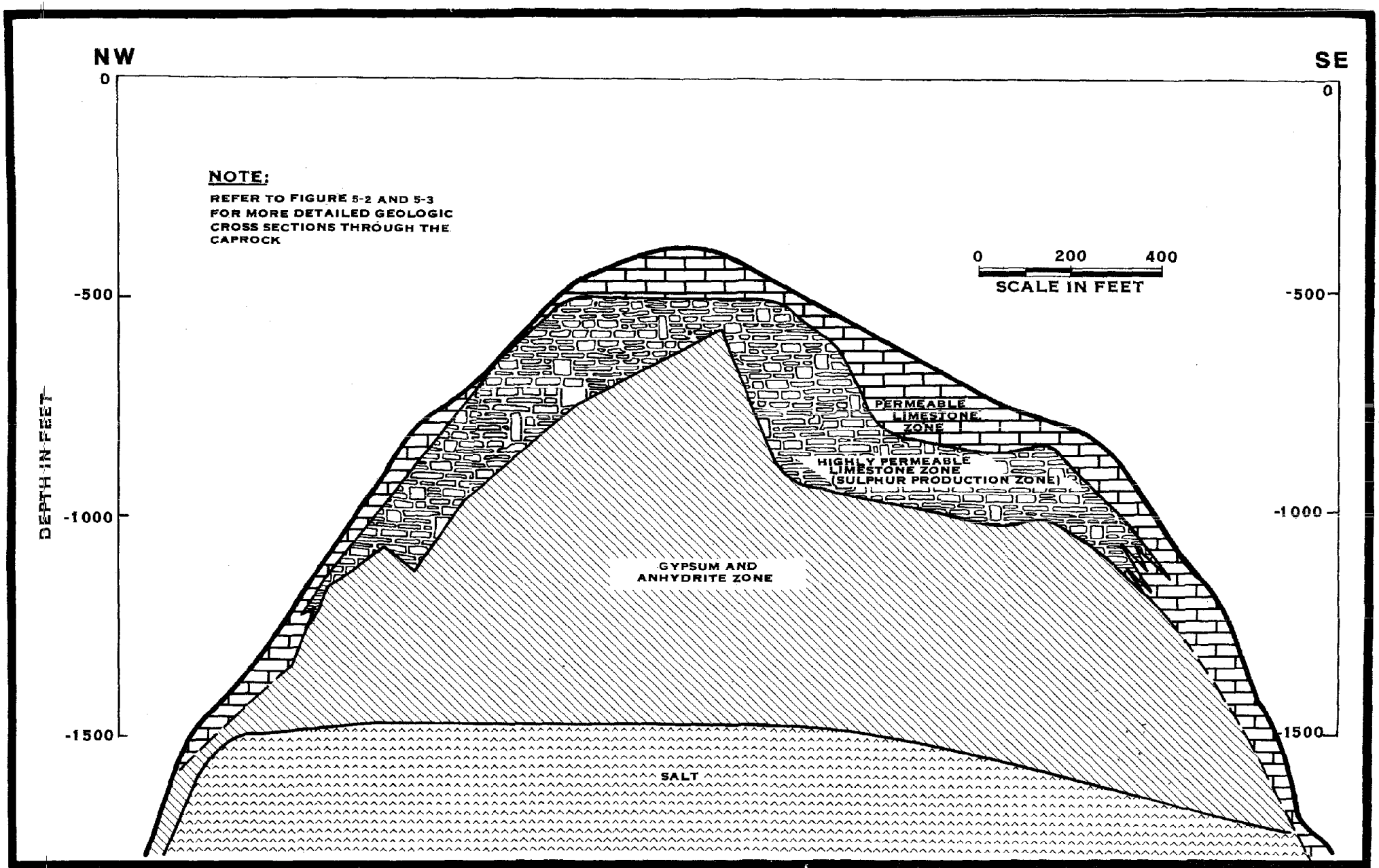
PREPARED BY JAG	DATE 6/15/82
CHECKED BY LEK	DATE 7/22/82
REVISED BY	DATE
APPROVED BY LEK	DATE 9/14/82

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SITE SUBSIDENCE MONITORING GRAPH

FIGURE 5-7



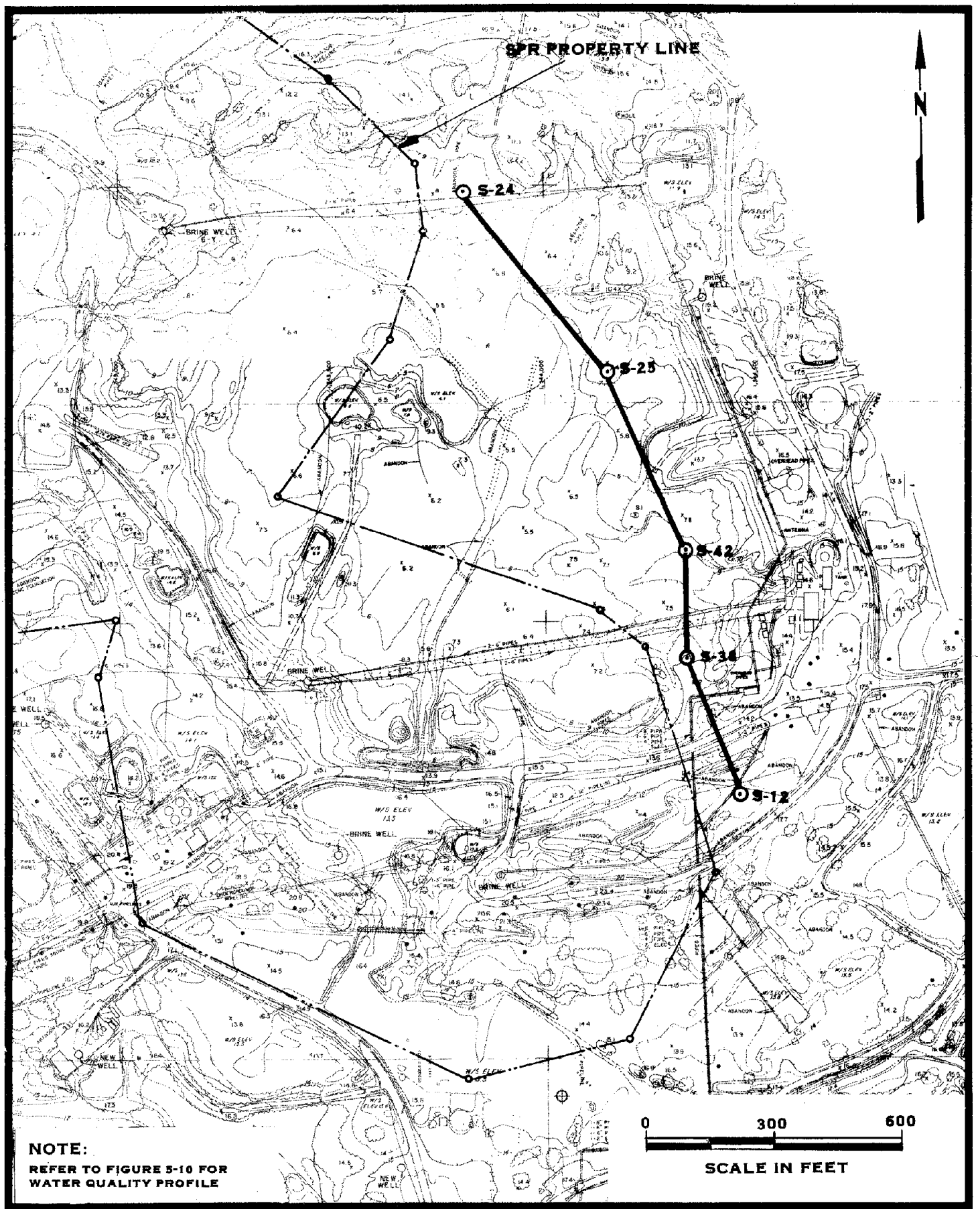
PREPARED BY RAS DATE 5/25/81
CHECKED BY SIF DATE 9/30/80
REVISED BY _____ DATE _____
APPROVED BY LSK DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM

GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME
LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

GENERALIZED HYDROGEOLOGIC CROSS-SECTION THROUGH THE CAPROCK

FIGURE 5-8



NOTE:
REFER TO FIGURE 5-10 FOR WATER QUALITY PROFILE

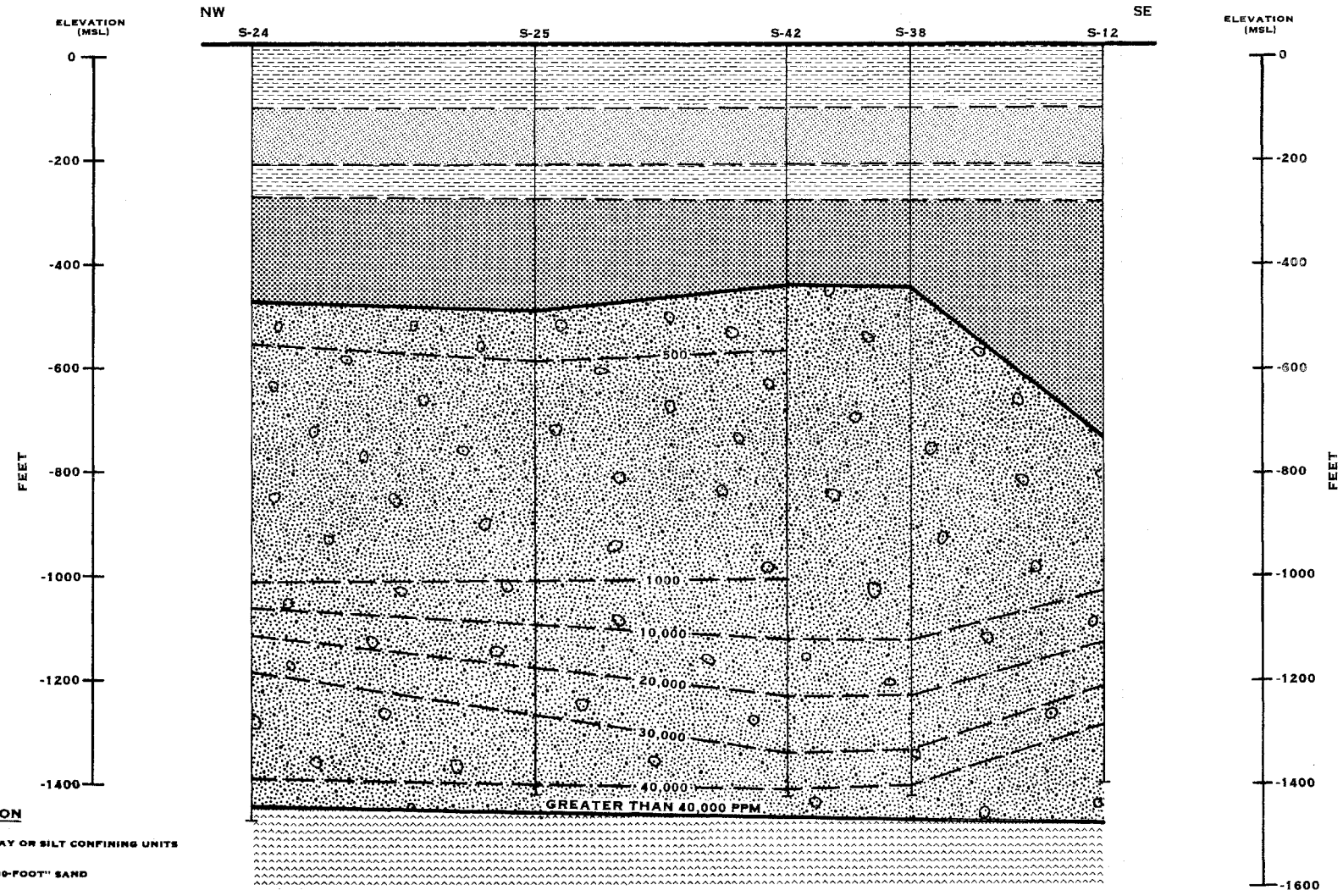
PREPARED BY RMS DATE 9/19/88
CHECKED BY CRS DATE 9/20/88
REVISED BY ____ DATE ____
APPROVED BY LSK DATE 9/19/88

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

LOCATION MAP OF WATER QUALITY PROFILE THROUGH THE CAPROCK

FIGURE 5-9



EXPLANATION

- CLAY OR SILT CONFINING UNITS
- "200-FOOT" SAND
- "500-FOOT" SAND
- CAPROCK
- SALT
- — — 1000 — — CHLORIDES (PPM)

0 200 400
SCALE IN FEET

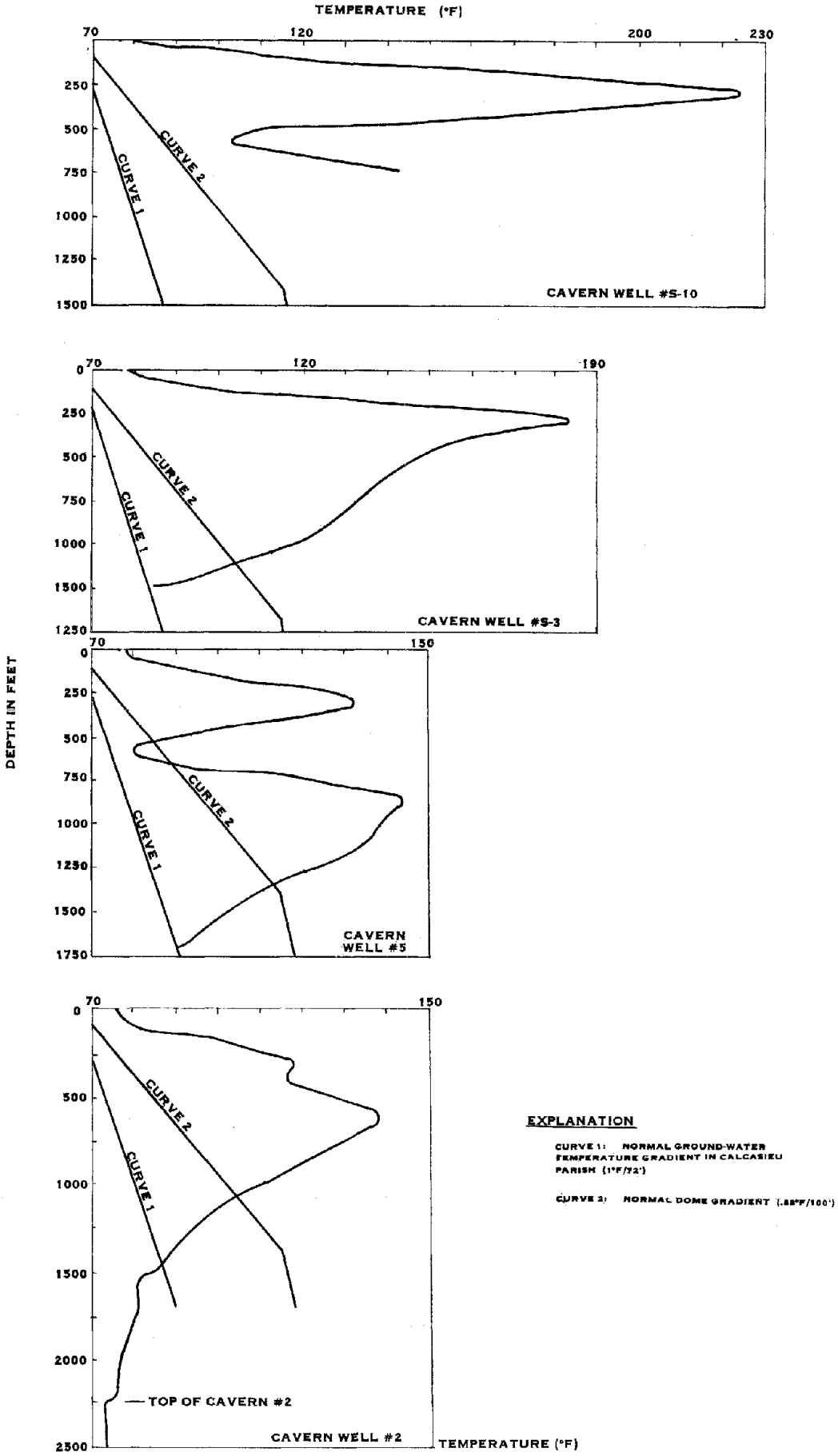
PREPARED BY RAS DATE 9/9/80
CHECKED BY ODS DATE 9/3/80
REVISED BY ____ DATE ____
APPROVED BY ESE DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

GENERALIZED WATER-QUALITY PROFILE THROUGH THE CAPROCK

FIGURE 5-10



PREPARED BY J.J DATE 9/30/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME	THERMAL REGIME WITHIN SULPHUR MINES SALT DOME
CHECKED BY ODS DATE 9/30/80		
REVISED BY ____ DATE ____		
APPROVED BY LSK DATE 10/1/80	LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	FIGURE 5-11

6.0

6.0

6.0 SALT DOME GEOLOGY AND HYDROLOGY

6.1 SALT DOME GEOLOGY

There are over 300 proven salt domes in the Gulf Coast area. They occur both in a coastal and offshore group and in an interior group. Salt domes are located in Alabama, Mississippi, Louisiana, Texas, and Veracruz and Tabasco in Mexico. They occur as far inland as northern Louisiana and offshore on the continental shelves of Louisiana, Texas, and Mexico.

Salt domes are commonly circular and may be as large as 6 miles in diameter at their top. Salt may also occur in long ridges which exist at several miles depth, especially in southern Louisiana. The Sulphur Mines salt dome is located in the Texas-Louisiana coastal salt dome belt. It is a small piercement dome, almost circular in shape and only 1/3 - 1/2 mile in diameter at the -2,000 MSL foot contour interval. The top of the salt occurs at a depth of about 1,470 feet and the salt appears nearly flat-topped.

The few geophysical and drillers logs taken in the salt show the stock to be predominately halite. This data is consistent with the studies of other coastal domes where the salt stocks appear to be 97-99% halite (LETCo, 1980).

The impurities in Gulf Coast salt diapirs are primarily anhydrite. The anhydrite in coastal domes generally occurs as disseminated grains and in bands which may be remnants of original sedimentary layering (Kupfer, 1970). Trace elements found in salt domes include dolomite, calcite, barite, pyrite, quartz, iron minerals, celesite, and sulphur (Halbouty, 1979).

In coastal salt domes, the average dip of the salt and anhydrite bands is very steep, generally 80 to 90 degrees from horizontal. The salt in all domes is commonly highly folded (See Figure 6-1, Muehlberger and Clabaugh, 1968).

The salt in the Sulphur Mines dome is probably similar to the other Louisiana coastal domes since most salt domes have similar lithologies.

6.1.1 Growth History of Salt Domes

The origin of salt domes has been debated among geologists since 1860 (Murray, 1961). Most experts now agree that the domes formed by salt-flowage from large salt beds at depth. However, there is still debate as to the thickness of the sedimentary load and the mechanism necessary to initiate flow.

Several recent models have been proposed to explain salt dome development. Implicit in all of these models is the recognition of stages in the development of the salt structure. The models differ as to whether the salt movement occurred as a single surge or pulse, in a series of pulses, or continuous in time at a constant or variable rate.

In the Gulf Coast, most current workers in the field believe isostatic (halo kinetic) forces are responsible for the movement of salt and the resulting formation of salt domes. In general, most geologists agree on three points concerning the origin of salt structures:

- Salt in diapiric structures is derived from a sedimentary salt bed.

- Salt moved into diapiric structures by means of plastic deformation.

- Density differences between the salt and the overlying sediments and down-building due to sediment loading around the diapiric structure are sufficient to cause dome development.

It is important to note buoyancy and sediment loading are nontectonic. A recent concept of dome development in the basin is presented by Kehle (1978). Kehle suggests that uneven sediment loading occurred so rapidly that buoyancy or density contrast effects are not discernible and therefore the main contrast is that of sediment loading.

Most models of salt dome formation assume an initial horizontal stage of movement when the salt mobilizes into pillow-like structures. Then follows a diapiric stage as the salt migrates upward as a vertical stock. The salt flowing into the dome from the surrounding bed causes the formation of sinks or rim synclines around the dome as the original salt pillow is depleted. As the salt migrates upward, the surrounding "strata may be arch-arched gently or steeply, they may be ruptured and pierced by the salt, they may be complexly faulted, or they may be deformed by various combinations of these" (Murray, 1961).

The salt does not always migrate upwards in a single mass but sometimes as separate spines. At the interface between two spines, "boundary shear zones" and anamalous areas in the salt are likely to occur (Kupfer, 1976). These zones are often 2 to 30 feet thick and can extend in a straight line for 150 to 300 feet. These sections often contain "dirty salt", and sediment inclusions from the country rock and liquid and gas inclusions are common. These zones occur near the edges of the dome more commonly than in the center. In salt mines, they are very carefully avoided because anomalous zones are often areas of leaks, slabbing, and gas blowouts.

6.1.2 Formation of Sulphur Mines Salt Dome

Two periods of salt growth have been defined at Sulphur Mines salt dome. The early stage is the development of a broad salt pillow structure. Whether the salt pillow is connected at depth to the mother salt bed is not definitely known. However, the gravity interpretation does show the salt pillow to continue to a depth of 20,000 feet and the data itself allows speculation that the salt pillow does connect with the mother salt bed. Available well and seismic data show the pillow structure was still growing during Vicksburg deposition (Early Oligocene) as Vicksburg sediments thicken, then thin approaching the salt pillow, suggesting the existance of a rim syncline adjacent to the salt pillow. Additionally, seismic reflectors of horizons below the Vicksburg show similar affects of pillow development by the presence of rim

synclines. As the salt pillow developed, the rim syncline for each successively younger unit migrated closer to the salt pillow and the older underlying units collapsed due to salt withdrawal. The presence of Lower Frio sands pinching out adjacent to the pillow structure suggests that during Middle Oligocene, the pillow was still growing and was a positive feature. Further evidence for this includes thick sand sequences which developed in the Hackberry sands southwest and east of the dome that correspond to the rim syncline area.

The second period of growth is piercement salt dome development of Sulphur Mines salt dome from the salt pillow. The presence of Late Middle Oligocene to Miocene age sands developed adjacent to the salt dome indicate pillow development had stopped. Development of the Sulphur Mines salt dome would have withdrawn salt from the pillow structure, causing areas adjacent to Sulphur Mines salt dome to subside, thus increasing sediment thickness in these Late Middle Oligocene and younger units. Well and seismic data show this to have occurred. Major withdrawal areas of salt for dome development appear to be just west of the dome. A trough within the salt pillow and a persistent syncline is developed throughout the entire post-Nodosaria section to the surface. As dome development continued, the withdrawal of salt from the pillow structure caused collapse of sedimentary units above the salt pillow withdrawal area. Some Pleistocene sediments adjacent to and over Sulphur Mines salt dome also show the effects of dome growth during and after deposition. The Williana Formation thins and is warped up over the dome suggesting erosion due to positive relief of the dome after or contemporaneous with deposition. Younger Pleistocene units show less noticeable signs of dome growth. Thicknesses of Recent sediments, up to 27 feet thick (as defined by shallow borings drilled off the west dome flank), show dome growth was active into Recent times. Further, the thickness of Recent deposits thin westward away from the dome. Confirming that fairly recent dome growth has occurred is the positive relief developed at the surface over the dome prior to surface subsidence.

The internal structure and mineralogy of Sulphur Mines salt dome is inferred from a comparison to other Gulf Coast domes and by a few driller's and electric logs from wells drilled into Sulphur Mines salt dome. As is typical for other Gulf Coast domes, the structure of Sulphur Mines salt dome is inferred to be locally complex and highly folded with vertical axes that resemble the folds in window drapes. The folding is thought to be the result of dome growth, where the salt flows laterally and then vertically into the uplift. In some coastal domes, the vertical salt movement occurs as spines rather than a single plug (Kupfer, 1976). Between the spines are vertical shear zones which contain clay, water, sand, gas or other impurities.

The small size of Sulphur Mines salt dome makes it doubtful that separate spinal growth occurred. However, other anomalous surface and subsurface conditions suggest it could have occurred. As discussed earlier in this report, a topographic irregularity, caprock elevation variations, and the presence of a radial fault in sediments adjacent to the dome, all located in the northeast

quadrant of the dome and trending northeast, tend to suggest spinal movement. Further, PPG production and work-over records for Brine Well Number 1 suggest the presence of a fault intersecting the brine cavity between a depth of 2,600 to 3,000 feet. This well is located in close proximity to the surface and subsurface anomalies in the northeast quadrant of the dome. The trend of the suspect shear zone between the spines would be northeast-southwest passing through Brine Well No. 1 and then eastward either toward Brine Well No. 7 or between Brine Well No. 7 and No. 2.

Confirmation of a shear zone in the vicinity of Brine Wells No. 7 and 2 is not possible as driller's or electric logs do not exist. Electric logs for Brine Source Well No. 13, located between Brine Wells 2 and 7, do not show any anomalous areas in the salt. However, initial testing of the well by DOE determined that it would not hold pressure and it generates gas. The coincedence of these conditions to a linear trend is not sufficient to prove the existance of a shear zone.

The salt in the dome is characteristically banded. White (corresponding to fairly pure salt) and gray to black (corresponding to impurities in the salt, chiefly anhydrite) bands predominate. The bands are on the order of an inch to tens of feet thick with contacts between layers being gradational. At Sulphur Mines salt dome, the few driller's sample logs define the salt as clear to white granular aggregates of halite crystals with some anhydrite impurities. No other impurities or salt types have been recognized. Although the composition of the salt may change from place to place in the dome, the average amount of anhydrite is estimated between 2 and 5 percent by volume at a depth of 2,000 to 5,000 feet. This is based on a visual examination by others of cuttings from Brine Source Wells No. 13 and 14 and the volume of anhydrite sand accumulated in Brine Wells No. 1 and 3. PPG records report the presence of anhydrite rich layers being encountered in the drilling of Brine Well No. 5. No documentation of the layers positions in the well exist. Evaluation of geophysical logs (bulk density) of Brine Wells No. 13 and 14 suggest the presence of anhydrite layers and indicate anhydrite concentrations varying from 19 to 32 percent in 2 to 4 foot thick sections separated vertically by 50 to 150 foot sections of relatively pure salt (5 percent or less anhydrite). Since the layering is believed to be near vertical, the actual true thickness of the anhydrite layers will be somewhat less than that defined by the bulk density log.

In salt mines, the edge of the domes are avoided because anomalous zones are often areas of leaks, slabbing, gas blowouts, and higher percentages of impurities in the salt. No logs of wells penetrate deep enough into the salt at the dome flank to determine variations in salt lithology. Most of these wells were drilled for oil and only penetrate a few feet into the salt.

6.1.3 Salt Dome Geometry

The modelling of Sulphur Mines salt dome was performed to determine the geometry of the salt mass in order to provide further

data to define the proximity of the flank and top of the salt dome to the storage cavities. Additionally, definition of the geometry allowed for the development of ideas regarding its growth history as discussed in Section 6.1.2. The modelling is based on gravity surveys performed over and in the vicinity of Sulphur Mines salt dome. Two sources for the gravity data were utilized.

1. Purchased proprietary data from Exploration Techniques, Inc.;
2. Existing SPR data performed by Tidewater Exploration, Inc. for Gulf Interstate Engineering Company in 1977.

Support data and direction for the modeling was provided by Law Engineering Testing Company. The support data included:

1. Base maps;
2. Caprock and salt elevations based on well logs;
3. Seismic reflection lines;
4. Density and velocity logs over and adjacent to the dome.

The distribution of gravity stations utilized in the modelling is shown in Figure 6-2.

Three steps were required to model the Sulphur Mines salt dome because of its small size and thick caprock. These were:

1. Define, model and remove the effects of the large salt pillow from which Sulphur Mines Dome grew;
2. Define, model and remove the effects of the thick caprock over Sulphur Mines salt dome;
3. Define and model the shape of the Sulphur Mines salt dome.*

It should be noted that all three steps were performed separately, but concurrently, to allow for the best fit to the gravity anamoly.

Restraints were placed on the interpretation on the top of the caprock by the number of wells which penetrated the caprock. Control for the top of the salt above the -2,000 foot elevation amounted to 19 wells, however, between -2,000 and the -5,000 foot elevation tight restraints were placed on the gravity interpretation by the numerous wells which penetrated the salt as a result of oil exploration. Below elevation 5,000 feet, well control was lacking and gravity augmented by seismic data only was used. Overall the accuracy of the model is very good ($\pm$ 10% by volume). In the area near Brine Wells No. 6 and 7 where gravity data density and well control is good, the gravity interpretation

*Initially the effect of storage caverns was thought to significantly influence the modelling and thus the shapes of the caverns were used as input to the modelling. However, upon modelling, the effect of the caverns on the gravity anomaly was determined to be only 0.05 millgal at the ground surface which does not effect the dome shape.

confirms the position of the edge of the salt determined by well control only.

6.1.3.1 Analysis of Salt Dome Shape

The Sulphur Mines salt dome, as shown on Figures, 6-3, 6-4 and 6-5, is fairly circular shaped. It extends some 12,500 feet from a much larger east-west trending salt pillow at depth to within about 1,500 feet of the ground surface. Where well control is good (around edge of dome between -2,000 to -5,000 feet) and in the area of the denser gravity stations (west side of dome) the sides of the dome are somewhat irregular. This of course is the result of data density showing undulations and small overhang development.

Four small overhangs in the salt are present on the east and southwest side of the dome near elevation -3,500 feet. The overhang extends back under the salt 100 to 200 feet. The general slope of the salt surface between -2,000 to -6,000 feet is 60 degrees, however slopes as gentle as 45 degrees and as steep as 80 degrees are present. Below -6,000 feet slopes on the salt approach vertical. Above -1,500 feet the salt is relatively flat with the average elevation being -1,475 $\pm$ 20 feet.

Even with the good control utilized in defining the shape of the dome, irregularities of the salt face causing horizontal variations of $\pm$ 50 feet can be expected. This is exemplified by some wells evaluated on the western side of the dome showing a few feet of salt being encountered followed by 10 or 20 feet of limestone, shale or sand, followed by more salt where the well is terminated. In this well and others that only encounter salt and then terminate, it is not known whether the major salt mass was encountered.

These small irregularities of the edge of the dome may be the result of salt erosion during deposition of adjacent sediments or dissolution of the salt because of the proximity of the salt to adjacent fresh or salt water aquifers. These effects are not presently known.

6.1.4 Brine Production and Storage In Brine Caverns

Since the 1940's, brining operations have supplied local (Lake Charles area) industry with brine as a raw material for processing various products. Since the 1950's, some of the cavities created by the brining have been utilized for LPG storage and will shortly be utilized in the SPR program. Further production of brine from Sulphur Mines Dome is very likely, however, suitable space for brining activities is declining. Figures 6-6 through 6-20 illustrate the various brine caverns with respect to depth, to each other and to dome flanks. Additionally, this data is tabulated in Table 6-1 for the SPR caverns.

6.1.4.1 Brining

Brining operations began at the Sulphur Mines salt dome with the completion of Southern Alkalies No. 1 Brine Well in 1946.

Southern Alkali went on to drill Brine Well No. 2, No. 3, and No. 4 during the next few years. In 1951, Southern Alkali became Columbia Southern Chemical Corporation a subsidiary of Pittsburgh Plate Glass Company. Since then, Brine Wells No. 5, 6 and 7 were drilled in 1953, 1955 and 1957, respectively. In 1977, PPG drilled Brine Well 12(1-A) and in 1979 the DOE drilled Brine Source Wells 13, 14 and 15. The skip in brine well numbers 8 through 11 is due to wells being permitted or attempted and then abandoned. All total at Sulphur Mines, 11 brine wells have been drilled, two drilled and abandoned before reaching salt, and two permitted but not drilled. The status of these wells is shown in Table 6-2 and discussed further in this section.

The brining process at Sulphur Mines salt dome requires a well to be drilled to the desired depth and steel casing is cemented into the caprock and salt leaving an open hole below the casing depth. A string of tubing (generally 4 inch diameter) is placed into the casing and open hole so that fresh water can be injected through the annular space between the casing and tubing at the upper part of the open hole which is to be the top of the solution cavity. To prevent the dissolving of the salt around the casing and to regulate the shape of the cavity, an inert blanket of gas or oil is maintained in the top of the solution cavern. As the injected water becomes almost saturated (about 26 percent salt) it migrates by gravity or differential pressure to the bottom of the cavity where it flows or is pumped to the surface through the tubing. This method is termed top injection. An alternative to top injection is bottom injection where a three-quarter inch diameter tubing is placed within the 4-inch tubing and fresh water is injected out of the tubing. This method is sometimes used to widen the lower portion of the cavity. As of December 1979, the total production of salt was approximately 9.1 million tons. The production records for each brine well are shown in Table 6-2. According to PPG, there are two stages to brining at Sulphur Mines, cavern development and production brining. Cavern development occurs first at a pumping rate of approximately 500 gpm. Until the cavern has enough exposed salt area to completely saturate the water introduced to the cavern at this pumping rate, it is termed cavern development stage. In the development stage the under saturated brine (weak-brine) is recirculated or introduced to a production brine cavern to complete saturation.

During either brining stage, the salt is dissolved, leaving the insoluble residue which is predominantly anhydrite. Anhydrite usually falls to the bottom of the cavity where it accumulates and is sometimes termed sand. As the brining process continues, the 4-inch discharge tubing is generally raised higher from the cavern floor to prevent picking up anhydrite sand which accumulates. Additionally, the tubing and oil or gas blanket is sometimes raised or lowered in an attempt to regulate the shape of the cavern. Except for Brine Wells No. 6 and 7, the single well brining method was utilized. In Brine Well No. 6 and 7, a dual well operation was utilized to solution mine with one well injecting fresh water and the other recovering brine. The brine recovery wells are designated 6-X and 7-B and the injection wells

6-Y and 7-A. Brining operations are still continuing for caverns 2-4-5, 6, 14 and 15. Brine Wells No. 14 and 15 are still in the development stage and introducing their weak brine into cavern 6 and 2-4-5 respectively. Brine cavern 7 is being reworked by DOE and 13 is to be reworked because it does not hold pressure and is generating gas. The remaining three caverns are being or will be utilized for LPG storage.

The shape and location of the brine caverns relative to each other at specific elevations and relative to the edge of the salt dome are shown in Figures 6-13 through 6-20, based on the most recent sonar calipar surveys available. The irregular diameters of the caverns are attributable mainly to the brining program and also structure of the salt. Since the salt bedding is believed nearly vertical, the widening of the caverns at specific levels must be due only to brining technique because anomalies and bedding in the salt do not usually lie in a horizontal plane. The elongation or nonsymmetry of the caverns could, however, be attributed partly to faster solutioning of the salt along its bedding planes. Thin, interbedded, vertical layers of anhydrite rich salt could also account for this elongation. PPG reports the elongation may be along stress lines in the salt. The direction of cavern elongation is fairly consistent with depth, reflecting the bedding strike direction. The direction of elongation at similar levels has resulted in three of the caverns coalescing and forming a common cavern. These are caverns 2 joining cavern 5 in 1954 and 4 joining cavern 5 in 1956. Additionally, caverns 7 and 6 may eventually coalesce, since they are separated by only 20 feet at elevation -3,100 feet MSL (Figure 6-15). The following table demonstrates the correlation of the depth of cavern widening and cavern elongation direction for SPR storage caverns no. 2,4,5,6 and 7.

SPR Storage Cavern Number	Depth of Center of Cavern Widening (ft)	Elongation Direction
2	2,450	South
	2,850	South-Southeast
	2,950	Southeast
	3,050	Symetric
4	2,800	Symetric
	2,950	Northwest
	3,075	Symetric
5	2,450	North-Northwest
	2,800	North-Northwest
	2,950	North
6	2,975	North
	3,075	North and East-Northeast
	3,225	South
7	2,850	North
	3,075	Northwest

No caverns have been identified as breaching the side or top of the salt mass. SPR Cavern 4 is presently the closest to the salt dome flanks (Figures. 6-16 and 6-17). It is within 185 feet of the flank at elevation -2,900 feet MSL. SPR Cavern 7 (Figures 6-14 and 6-18) is second closest with 160 feet separation at 3,020 feet MSL. The potential for cavern breach, coalescence, and collapse is discussed in Section 6.1.5.

6.1.4.2 Storage

Storage in coastal salt domes is not uncommon, the first reported LPG storage was in 1951 in Gibsland Dome, Bienville Parish, Louisiana (Hawkins and Jirik, 1965.) Since then the practice of storage has grown rapidly. Two brine caverns (No. 1 and No. 3, Union Texas designations 1-A and 2) are presently being used for LPG storage by Union Texas Petroleum Company. Three other brine caverns (No. 2-4-5, 6 and 7) are to be used in the near future for crude oil storage by DOE as part of the Strategic Petroleum Reserve Program. PPG anticipates using Brine Well 12 (their number 1-A) for storage in the future.

The latest volume of all caverns at Sulphur Mines Dome is shown in Table 6-2. These capacities do not actually represent total storage potential as a freshwater or brine ballast is needed as a volume displacement agent. Reduction in available space due to this requirement is dependent upon total space and cavern shape. Generally a 10 to 20% reduction in total volume to accommodate the displacement fluid is reasonable.

Filling and withdrawl of the storage product requires the use of either fresh water or brine. If the size of the cavern is to be maintained, brine is used. At the present time, the SPR program plans to use fresh water in the withdrawal process which will result in an increase in the cavern size. The displacement fluids in use by Union Texas Petroleum for caverns No. 1 and 3 is brine supplied by PPG.

6.1.5 Cavern Breach

Breach of the storage caverns is defined as penetration of the cavern through the surface or the side of the salt dome. The breaching would occur only if the existing salt buffer between the top of the cavern and the caprock base or the buffer between the side of the cavern and sediments adjacent to the salt dome are violated. The effects of cavern breach from the surface would more than likely be an initial blow-out followed by rapid surface subsidence as discussed in the previous section on subsidence. A breach from the side to the adjacent sediments would be less noticeable and perhaps go unnoticed. The following section discuss this potential.

6.1.5.1 Potential for Cavern Breach

Cavern breach could result from the continued dissolution of salt to the sediments adjacent to the salt dome, or the caprock above the cavern.

If the solutioning is discontinued, cavern breach is not probable. However, by accidents or unmonitored dissolution of the salt, cavern breach is a significant risk. Additionally, accidental decrease in internal pressure of the cavern, lower than static brine column pressure, could possibly cause cavern breach, as would accidental drilling into the cavern.

The minimum recommended salt thickness between cavern edge and the salt dome flank is 300 feet according to Gulf Interstate's Cavern Certification Report (1977). The only Sulphur Mines SPR cavern to flank spacing greater than 300 feet is Cavern 6 (Figures 6-19 and 6-20). Cavern 4 (Figures 6-16 and 6-17) of the 2-4-5 gallery is the closest SPR cavern to the salt dome flank at 185 feet. The cavern to edge distances for all caverns, including non-SPR caverns is presented in Table 6-1. In some cases these distances differ significantly from the previously reported distances. Continued brining has increased the size of the caverns and the new interpretation of the edge of salt dome is based on additional gravity and well data.

Gulf Interstate's certification reports state the minimum required thickness of salt in the cavern roof as 500 feet and, that as long as the cavern pressure for SPR Cavern 6 and 7 is 1.19 and for 2-4-5 does not exceed 1.27 times the static brine column pressure or is reduced below the static brine column pressure, the usability and integrity of the cavern for storage would be justified. Therefore, the existing salt thicknesses above all caverns is adequate considering the pressure restraints. The minimum thickness is 968 feet based on the present configuration of SPR Storage Cavern 5. The maximum roof thickness is 1,428 feet over SPR Storage Cavern 6.

Of possibly more concern than cavern breach is the thickness of salt above the deepest cemented casing in a cavern. Below this casing there is usually an open hole in which the curtain casing is hung. The hole, which is in salt, varies in diameter from several inches to several feet until the cavern roof is reached where the diameter increases rapidly. The thickness of salt above the deepest cemented casing is shown in Table 6-1. In some cases only a few feet of salt separate the open hole from caprock. The potential for dissolution of the salt to the caprock would depend on keeping an oil or gas pad in the open hole to the cavern roof.

Withdrawal of oil from the caverns utilizing fresh water is expected to increase the size of the caverns further. If an oil blanket is kept at the top of the cavern for protection against further vertical dissolution as recommended by Gulf Interstate, dissolution trends are only expected to continue underlying the oil blanket. A comparison of 1977 and 1979 sonar caliper surveys indicates the cavern volumes have increased 10%, 14%, and 13% for SPR storage caverns 2-4-5, 6, and 7, respectively between 1977 and 1979 (Figures 6-21 through 6-25). The dissolution and elongation trends discussed in Section 6.1.4 have also continued in the same direction. Additional cycling of the oil from the caverns will continue the direction of cavern development in a similar manner although the rate may vary. The cavern to dome edge

distance for SPR caverns 6, 7 and 2-4-5, was decreased by an average of 30, 10, and 30 feet, respectively from 1977 to 1979 due to cavern growth from brining. At this rate, SPR Storage Cavern 2-4-5 may breach the side of the dome within a five year period and Cavern 7 shortly thereafter if brining continues.

Also adding uncertainty to the location of the edge of the dome presented within this report, is the inaccuracy of the data used. The inaccuracies are categorized as follows:

1. Bottom hole locations of wells penetrating salt;
2. Normal undulations in the salt/sediment interface;
3. Sonar caliper survey.

Approximately one-half of the wells used for developing the salt model were directionally drilled using a single shot directional survey for bottom hole location. These surveys should be accurate at these depths to within $\pm$ 20 feet. A more accurate continuous directional survey was used in the other wells which is considered accurate to $\pm$2 feet at these depths. The undulations in the salt dome edge as previously discussed could be $\pm$50 feet. The accuracy of the sonar calipar surveys as stated in the cavern certification reports is $\pm$5 percent of the determined radius. For the radius of the cavern at closest approach to the salt dome edge this could introduce a $\pm$20 foot error. Totalling these inaccuracies, a 100 foot error could be inherent in the resulting interpretation of the distance from salt edge to the cavern side. Therefore, the most conservative approach to assessing the potential for cavern breach may be to reduce the determined edge of salt dome to cavern distances by 100 feet and then assess the adequacy of the separation. In this case all caverns including non-SPR caverns would fall short of the 300 foot minimum separation distance.

The locations of well holes in the salt mass and to the caverns were evaluated to assess the potential for breaching of the caverns through these holes. Holes in the salt from wells would provide a more direct route to the surface if continued development of the caverns reached one of these holes. No wells exist within 250 feet of any of the SPR cavities or the open hole above the caverns. The closest approach of any hole to a cavity would be the brine wells in other cavities.

Another possible circumstance providing for a breached cavern is anomalies in the salt. The salt is considered relatively pure and no anomalies such as sands from adjacent sediments have been identified in the salt mass in the vicinity of the proposed storage caverns. However, an anomaly of unknown nature was identified in Brine Well No. 1 and anomalies within the salt are generally encountered more often towards the edge of the salt dome. SPR Storage Caverns 7 and 4 are in the area where anomalous conditions associated with the salt edge might exist. Therefore, this aspect must be considered as a possible avenue for escape of fluids within the storage caverns although the potential is slim.

6.1.6 Cavern Coalescence

Caverns 2, 4 and 5 have coalesced at Sulphur Mines dome. As stated in the 1977 certification documents for the caverns, the five anticipated cycles of removing oil using fresh water would undoubtedly result in continued development of the storage caverns along similar elongation trends which have occurred in the past. Therefore, some caverns will likely coalesce. However, at this time only one cycle is planned for the storage program. This one cycle will also result in cavern enlargment, but for caverns to coalesence during one cycle will depend on the distance caverns are separated at that time. The potential for futher coalesence of individual caverns is discussed in the following portion of this section.

6.1.6.1 Potential Cavern Coalescence

Based on a statement by Gulf Interstate Engineering Company in the certification of SPR Storage Caverns 6 and 7, coalescence of these caverns together will likely occur during 5 storage cycles. The distance between these caverns at that time was 110 feet, now it is 20 feet. The separation distances for all caverns are shown on Table 6-1. Since only one storage cycle is now proposed a minimal growth of 22 feet in the direction of elongation could occur. Based on the present cavern spacing, the only two caverns which would coalesce are 6 and 7. The assumption and reliability of cavern growth during one storage cycle is speculative as some control may be maintained. The main problem may be the continued brining in some of the SPR caverns prior to oil storage and continued development of non-SPR caverns. Cavern 3 which is a non-SPR cavern lies 350 feet north of SPR Cavern 2. Presently, the non-SPR cavern is being used for LPG storage, and it is not anticipated that rapid cavern development would occur as in the case of a brining operation. The distance between the new Brine Caverns 13, 14, and 15 and other SPR caverns are between 300 to 500 feet. If PPG follows previous development methods at Sulphur Mines salt dome, Cavern 13 which has not been developed, may be expected to coalesce with SPR Cavern 7, if it does not breach the side of the dome first.

Of further significance to the development of the SPR caverns, specifically in 2-4-5 and potentially 6 and 7, is the growth of the passageways at the point of coalescence between the caverns. This will reduce the roof support between these massive caverns and will reduce the safety factor against roof fall. However, it is expected if the cavern pressure is maintained as Gulf Interstate recommended at or above normal static brine pressure the integrity of the cavern will also be maintained.

6.2 SALT DOME HYDROLOGY

Little is known about the actual hydrologic conditions of the salt stock at the Sulphur Mines salt dome. The primary porosity and resulting permeability of salt is extremely low. Secondary porosity is produced along fractures and faults, or along

impurities within the salt. Ground water is normally sealed from a piercement type salt dome by a clay sheath or low permeability sections of caprock.

6.3 IMPACT ON SPR FACILITIES

6.3.1 Salt Dome Geology

The revised shape of the dome brings its flanks closer to several SPR caverns than previously reported. Similarly, the most recent sonar caliper surveys of the coverns show them to have enlarged. Therefore several aspects of future mineral exploitation and oil storage program at the dome may impact the SPR facilities. These are the continued brining operations enlarging caverns and the oil storage program enlarging caverns. Both could lead to SPR cavern coalescence and/or breaching of the salt dome.

Brine cavern collapse could be catastropic, covering a large area, or very minor amounting to a small depression around the wellhead casing at the surface. The latter case would occur where salt is breached around the casing. Both have occurred at Bayou Choctaw where, with the exception of the catastrophic failure, brine caverns have continued to operate. The main mechanism for cavern collapse or roof breach would be dissolution of the salt at the top of the cavern, thus reducing the strength to support overburden pressures. This may amount to overall dissolutionment of the total salt mass or dissolution of the salt along the casing and salt interface. The latter is more probable and less easily detected.

Utilization of the brine cavern as crude oil storage would reduce the probability of cavern collapse occurring as long as an oil or gas blanket is maintained at the top of the cavern to prevent dissolution of the salt. Breach of the caverns at the side of the dome or where encountering anomalies within the salt may initially go unnoticed. Indication of cavern breach in this manner would normally be preceded by pressure reduction within the cavern. If an anomaly such as sandstone is encountered, and it is not connected to the surrounding sediments, a pressure build-up or reduction may occur depending upon the size of and pressure within the included anomaly.

Breach of the side of the salt mass may result in a pressure decrease if a positive pressure is kept within the storage cavern. Collapse of a cavern is unlikely from a side breach phenomena. Cavern pressures do not tend to go below hydrostatic pressure unless local pumping was occurring adjacent to the dome at that point. Breaching of a cavern in this manner has not been documented but may be the reason why some caverns fail to maintain pressure. The major consideration of this impact would be in connection with SPR Caverns 2-4-5 and 7 because they are closest to the dome flank.

Cavern breach at the top of the caverns or openhole above the cavern roof is unlikely since an oil blanket and pressure is to be maintained in the caverns during the oil storage program and open holes are 250 feet or more away from the caverns.

Based on documents obtained from Union Texas Petroleum and PPG and conversations with their personnel, no significant impact occurred during the coalescense of SPR Caverns 2, 4 and 5 although they did occur at separate times. Recognition of cavern coalescense was initially made by pressure fluctuations within the caverns. The coalescense was further documented by sonar calipar surveys. Of these two criteria for recognition, pressure fluctuation would initially be suggestive of some disorder within the cavern. Verification by pressure tests could only be made by monitoring the two caverns though to be involved. Complete verification of the size of the conduit connecting the caverns could only be determined by sonar calipar survey. Mixing of fluids within the caverns that have coalesced is highly likely.

The significance and impact of coalescence of caverns undermining the stability of the roof and causing cavern collapse is similar to that discussed for breach of the cavern top. Similar to cavern coalescence is the failure or breaking off of ledges of salt developed by the erratic development of the caverns. This has not been documented at Sulphur Mines dome, but it has been suggested in some documents obtained during ths study. The impact on SPR facilities would be to the integrity of the piping within the cavern being damaged as a ledge falls to the bottom of the cavern.

6.3.2 Salt Dome Hydrology

There are no known external hydrologic impacts on the salt dome or internal caverns.

TABLE 6-1

STATUS OF BRINE WELL CAVERNS

Brine well Cavern (Permit No)	Closest Approach to Salt Edge (Direction)	Elevation Interval	Salt roof Thickness Above Cemented Casing	Closest Approach to Nearest Cavern (Cavern No)	Elevation Interval
1	220 (ENE)	1,000-2,000	466	410 (15)	2,400-2,600
2-4-5	185 (ESE)	2,800-3,000	110-19-94	350 (3)	2,800-3,000
3	100 (SE)	2,800-3,000	3	350 (2-4-5)	2,800-3,000
6	387 (NW)	3,000-3,200	345	20 (7)	3,000-3,200
7	160 (W)	3,000-3,200	327	20 (6)	3,000-3,200
12	260 (SW)	2,600-2,800	822	190 (13)	2,400-2,600
13	130 (SW)	1,000-2,000	490	190 (12)	2,400-2,600
14	220 (N)	1,000-2,000	510	430 (1)	2,400-2,600
15	710 (ENE)	3,000-3,200	528	400 (3)	2,800-3,000

NOTE: All distances, thicknesses and elevations in feet.

TABLE 6-2

BRINE WELL PRODUCTION AND CAVERN DEVELOPMENT SUMMARY

PERMITTED BRINEWELL NUMBER	OTHER WELL DESIGNATION	ORIGINAL WELL COMPLETION DATE	DATE BRINE OPERATIONS ABANDONED	SALT PRODUCED (TONS)	CAVERN VOLUME AND DATE (BBL)
1	Union Texas Storage Well 1-A	12/46	1954 LPG Storage 1954 to present	182,770	559,905* (1954) 558,252** (12/73)
2	DOE Storage Cavern 2	11/46	Coalesced with Brine Well #5 in 1954	796,720 through 1953	2,440,705* (1953)
3	Union Texas Storage Well No. 2	12/46	1953 LPG Storage 1954 to present	288,840	701,038* (1953)
4	DOE Storage Cavern 4	1949	Coalesced with Brine Well No. 5 in 1954	511,790 through 1955	1,567,838* (1955)
5	DOE Storage Cavern 5	4/47	Coalesced with Brine Well No. 2 in 1954	147,670 through 1953	452,378* (1953)
6X, 6Y, and 6Z	DOE Storage Cavern 6	11/55	Still Operational	1,926,965 through 12/79	5,905,992** (12/79)
7a, 7b and 7c	DOE Storage Cavern 7	1/53	Not Operational (Workover by DOE)	2,067,682 through 12/79	6,333,750** (12/79)
8	None	Not Drilled			
9	None	Not Drilled			
10	None	Plugged & Abandoned 4/75, TD 511'			
11	None	Plugged & Abandoned 5/75, TD 1,443'			

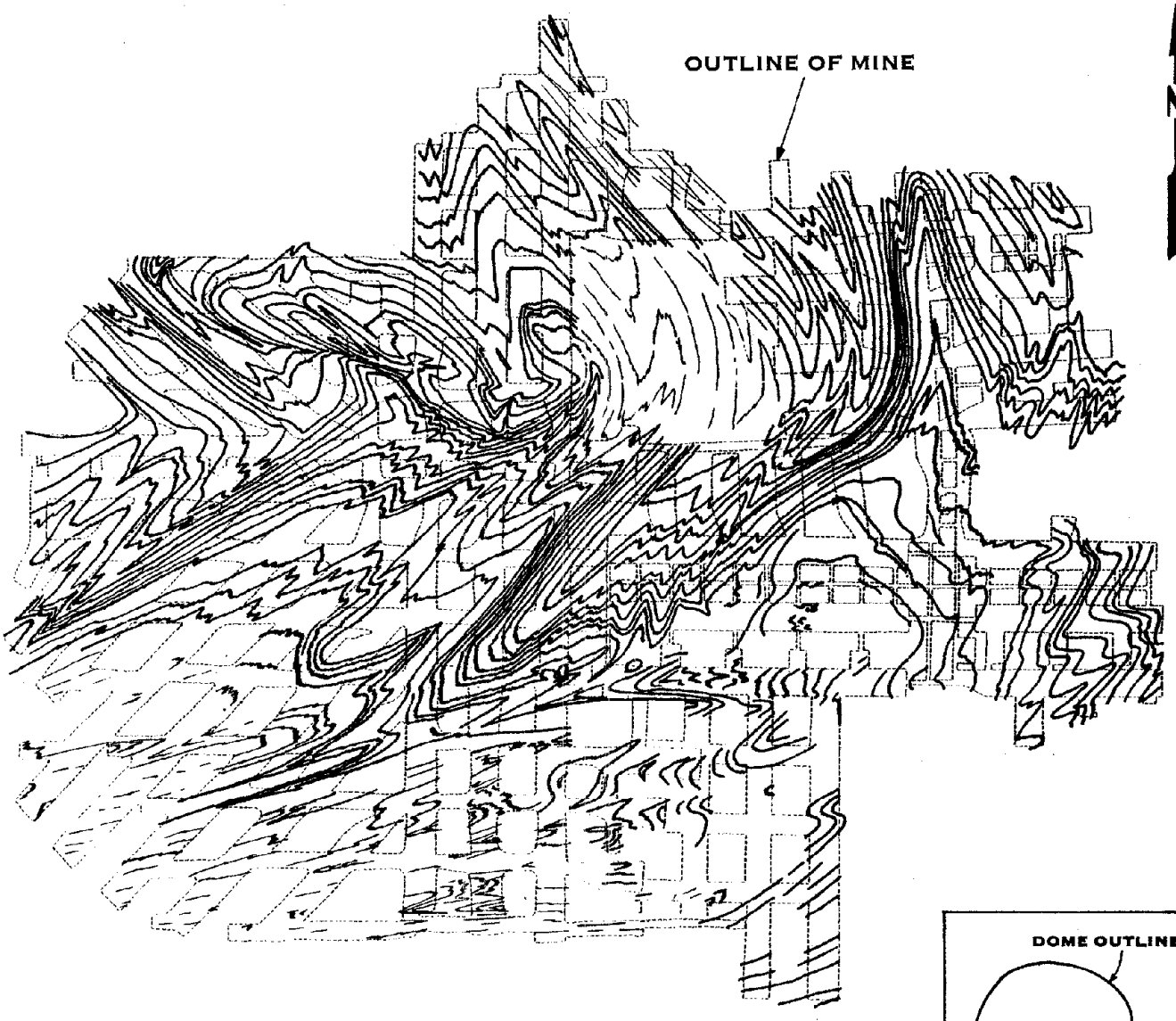
TABLE 6-2

BRINE WELL PRODUCTION AND CAVERN DEVELOPMENT SUMMARY

PERMITTED BRINEWELL NUMBER	OTHER WELL DESIGNATION	ORIGINAL WELL COMPLETION DATE	DATE BRINE OPERATIONS ABANDONED	SALT PRODUCED (TONS)	CAVERN VOLUME AND DATE (BBL)
12	PPG Storage Well 1-A	7/75	9/77 Future LPG Storage	263,045 through 10/77	805,767 (10/77)
13	DOE Brine Source Well 13	7/79	Not Operational	0	No information (assumed size equal to original drill hole size)
14	PPG Brine Source Well 16	6/79	Operational in Development Stage	104,704 through 7/80	320,752** (7/80)
15	PPG Brine Source Well 17	1979	Operational in Development Stage	3,726 through 10/79	11,413** (11/79)
2-5	See 2 and 5	Coalesced in 1954	See 2-4-5	517,470 (1954 through 1955)	See 2-4-5
2-4-5	See 2,4,and 5	2-5 Coalesced with 4 in 1956	Still Operational	2,457,387 (1956 through 12/79)	13,574,255** (12/79)

* Estimate Base on Tone of Salt Produced

** Based on Sonar Caliper Survey



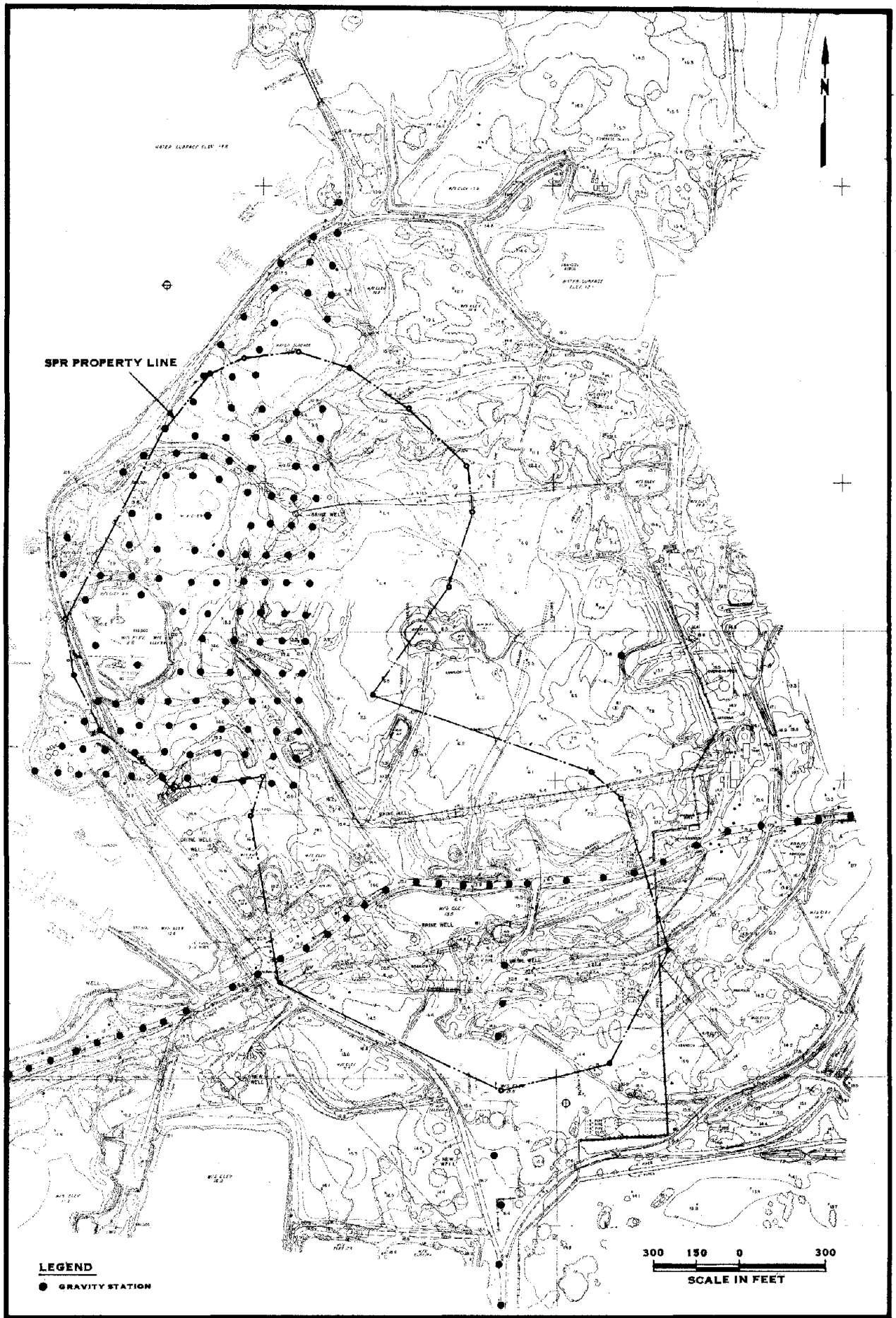
NOTE:

LINES REPRESENT FOLIATIONS MAPPED IN THE MINE ROOF

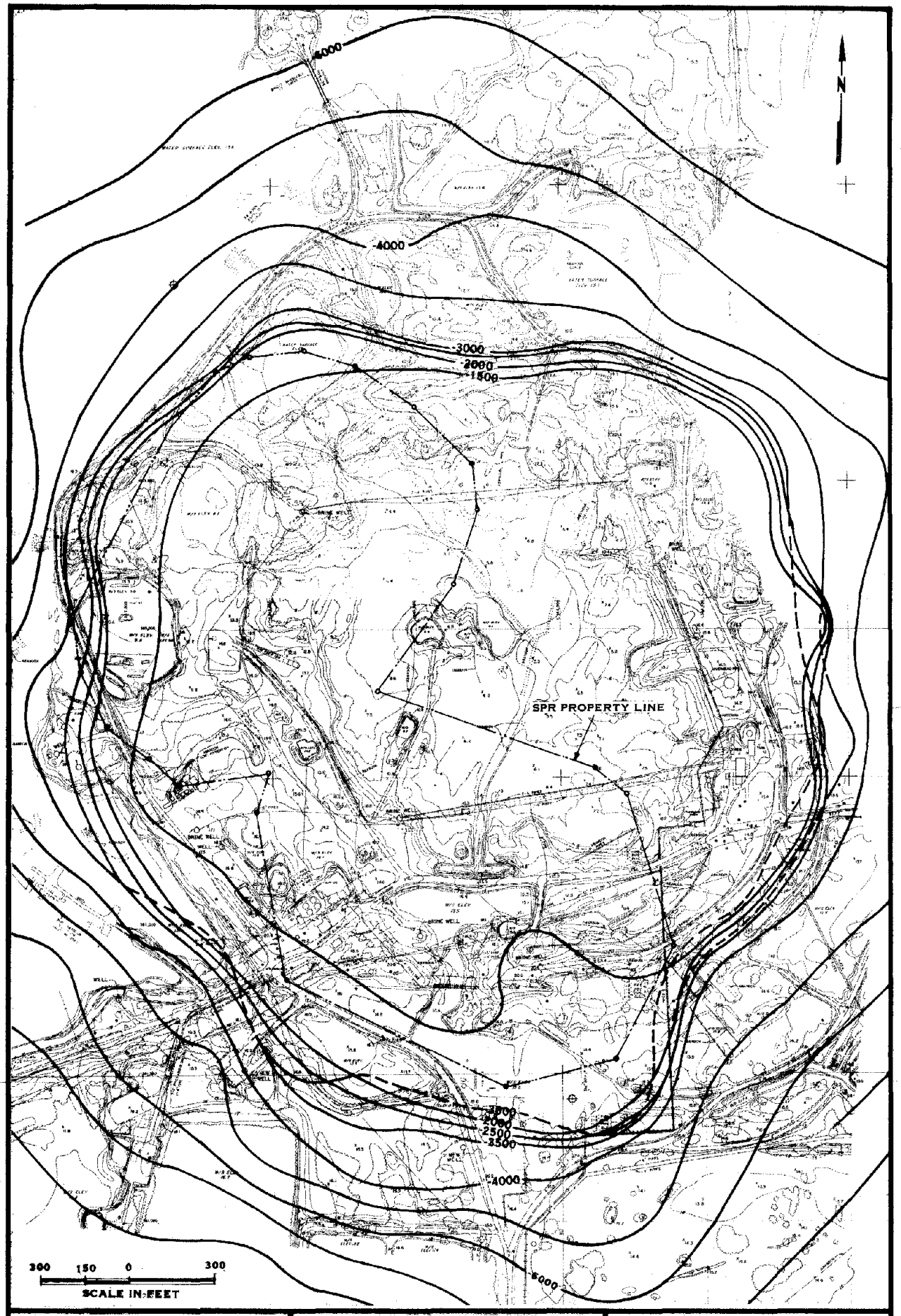
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MUEHLBERGER ET. AL. (1962, P. 274).

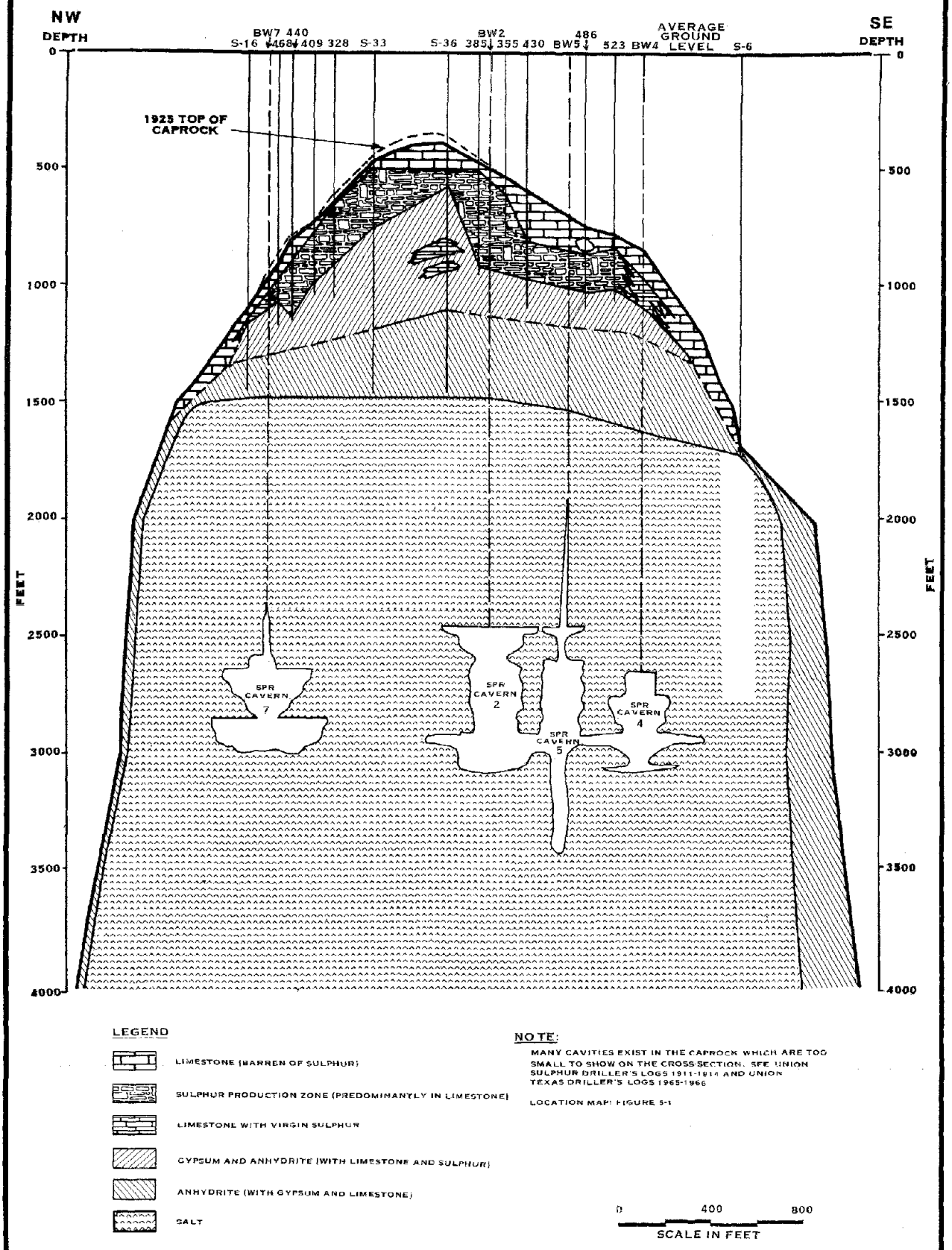
PREPARED BY SLE DATE 2/2/82 CHECKED BY ___ DATE ___ REVISED BY ___ DATE ___ APPROVED BY ___ DATE ___	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	INTERPRETATION OF SALT STRUCTURE, MORTON SALT CO. MINE, GRAND SALINE SALT DOME. FIGURE 6-1



PREPARED BY JSR DATE 8/28/80 CHECKED BY [illegible] DATE 9/30/80 REVISED BY ____ DATE ____ APPROVED BY [illegible] DATE 10/1/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	GRAVITY STATION LOCATION MAP FIGURE 6-2



PREPARED BY JSB DATE 8/25/80 CHECKED BY ODS DATE 9/30/80 REVISED BY ____ DATE ____ APPROVED BY LSK DATE 10/1/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	TOP OF SALT CONTOURS (ELEVATION MSL) FIGURE 6-3



LEGEND

- LIMESTONE (BARREN OF SULPHUR)
- SULPHUR PRODUCTION ZONE (PREDOMINANTLY IN LIMESTONE)
- LIMESTONE WITH VIRGIN SULPHUR
- GYPSUM AND ANHYDRITE (WITH LIMESTONE AND SULPHUR)
- ANHYDRITE (WITH GYPSUM AND LIMESTONE)
- SALT

NOTE:

MANY CAVITIES EXIST IN THE CAPROCK WHICH ARE TOO SMALL TO SHOW ON THE CROSS-SECTION. SEE UNION SULPHUR DRILLER'S LOGS 1911-1914 AND UNION TEXAS DRILLER'S LOGS 1965-1966

LOCATION MAP: FIGURE 5-1

0 400 800
SCALE IN FEET

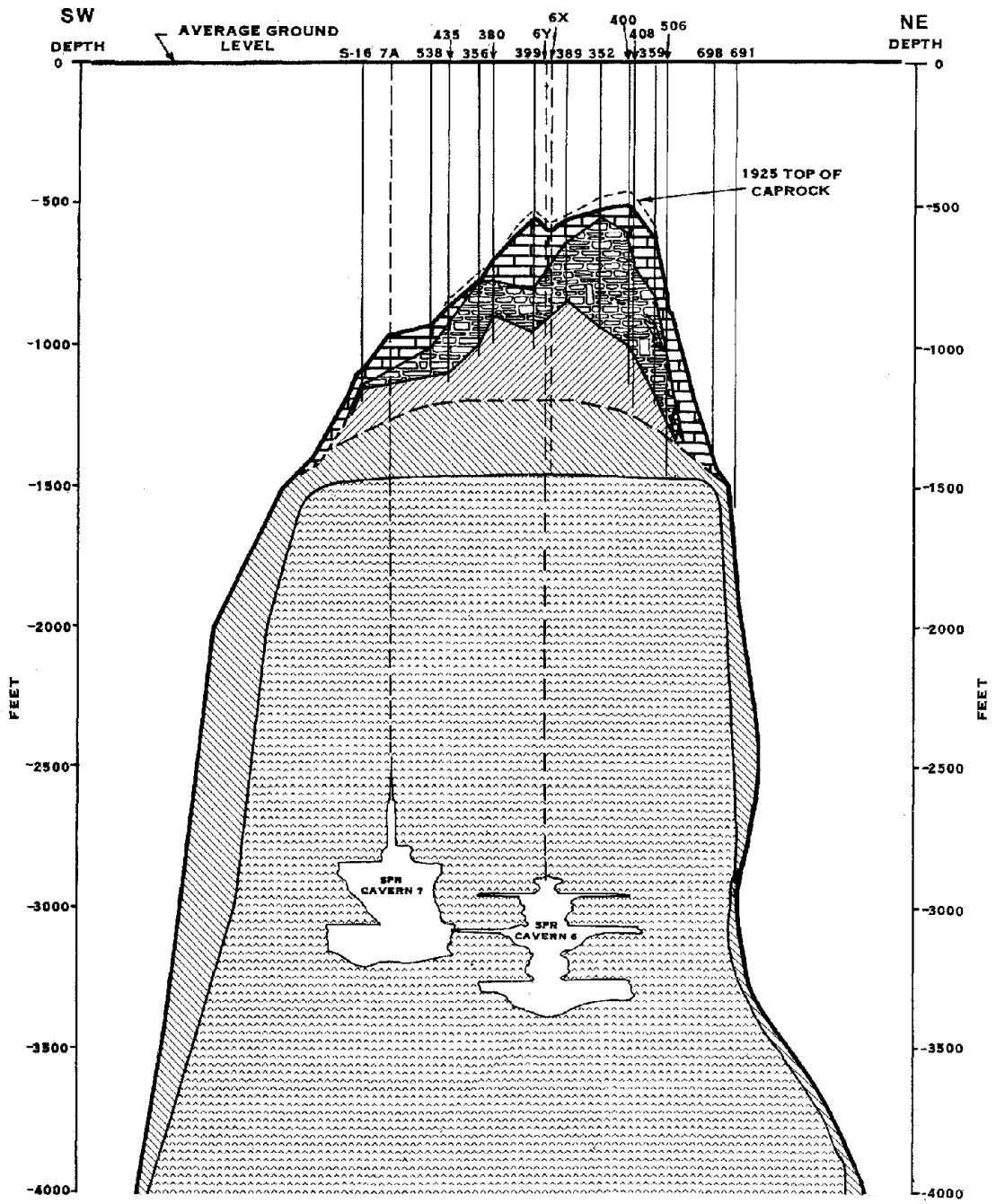
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CHECKED BY CFS DATE 9/30/80
REVISED BY ____ DATE ____
APPROVED BY LSK DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

NW - SE SALT DOME CROSS-SECTION
THROUGH BRINE WELLS
7, 2, 5 AND 4

FIGURE 6-4



LEGEND

- LIMESTONE (BARREN OF SULPHUR)
- SULPHUR PRODUCTION ZONE (PREDOMINANTLY IN LIMESTONE)
- LIMESTONE WITH VIRGIN SULPHUR
- GYPSUM AND ANHYDRITE (WITH LIMESTONE AND SULPHUR)
- ANHYDRITE (WITH GYPSUM AND LIMESTONE)
- SALT

NOTE:

MANY CAVITIES EXIST IN THE CAPROCK WHICH ARE TOO SMALL TO SHOW ON THE CROSS-SECTION. SEE UNION SULPHUR DRILLER'S LOGS 1911-1914 AND UNION TEXAS DRILLER'S LOGS 1965-1966

LOCATION MAP: FIGURE 5-1

0 400 800

SCALE IN FEET

PREPARED BY SLF DATE 8/25/80
CHECKED BY ODS DATE 9/26/80
REVISED BY _____ DATE _____
APPROVED BY LSK DATE 10/1/80

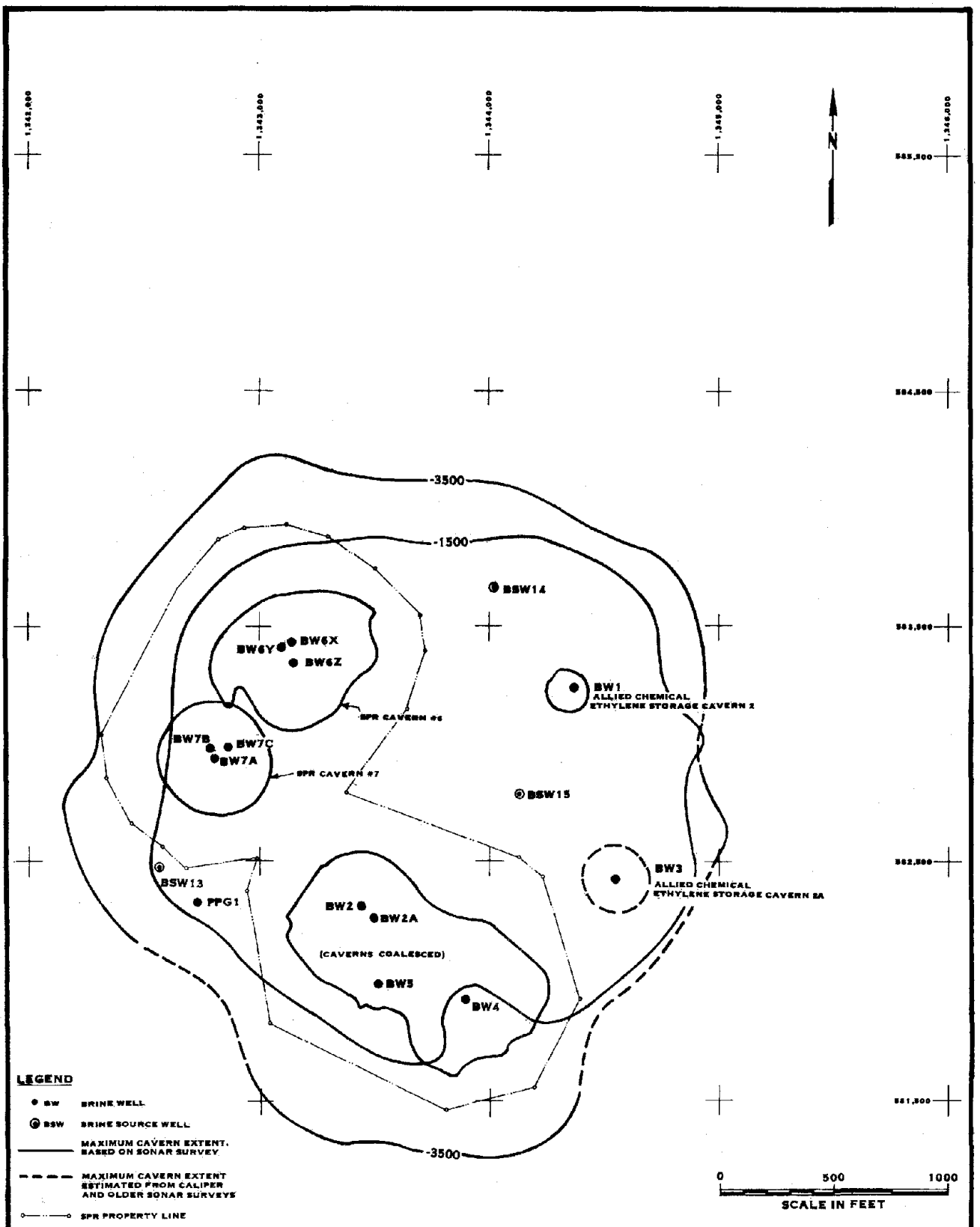
STRATEGIC PETROLEUM RESERVE PROGRAM

GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SW-NE SALT DOME CROSS-SECTION
THROUGH BRINE WELLS
7 AND 6

FIGURE 6-5



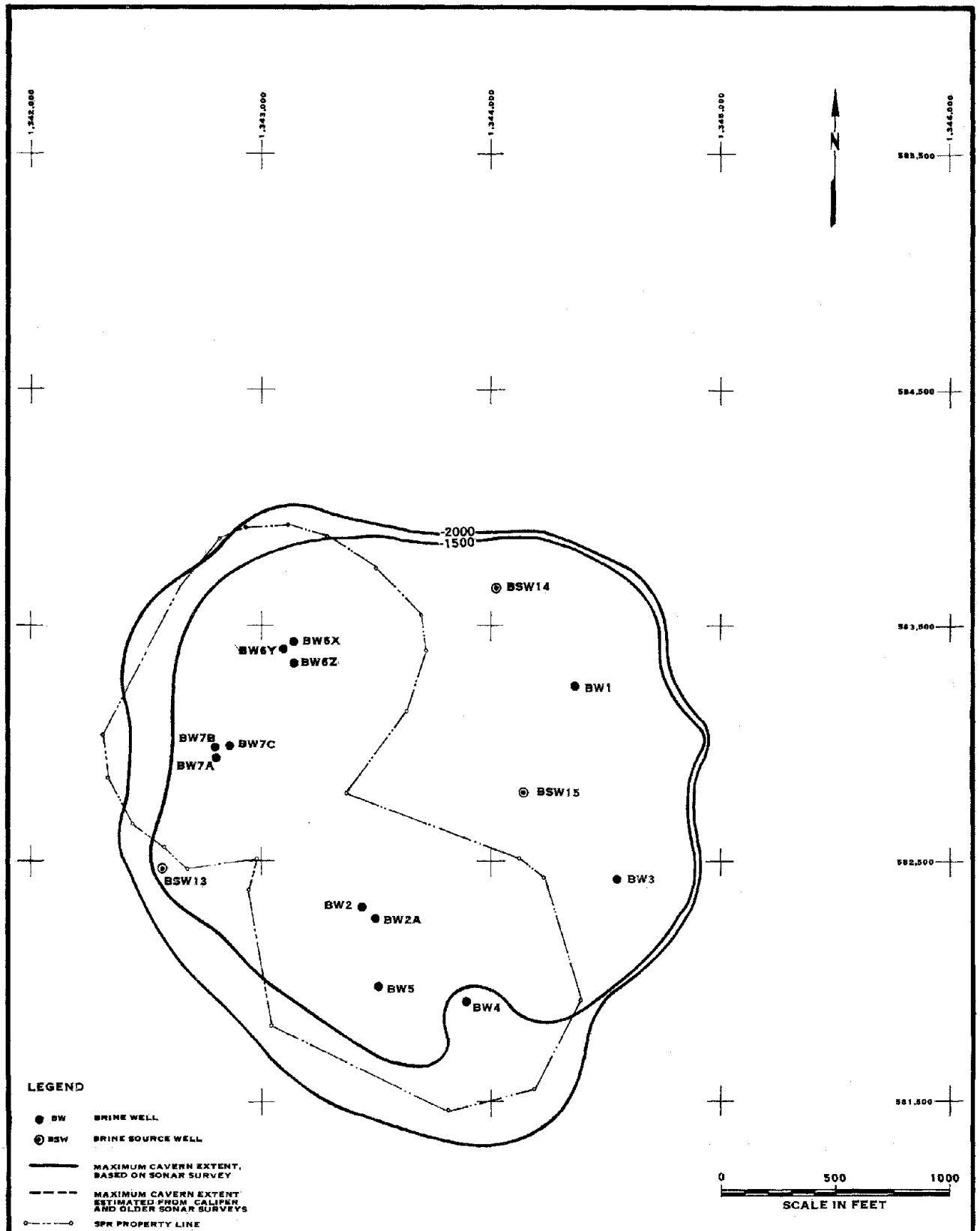
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APPROVED BY LSK DATE 10/1/91

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

MAXIMUM CAVERN EXTENT & SALT CONTOURS
1000' - 3400' DEPTH INTERVAL

FIGURE 6-6



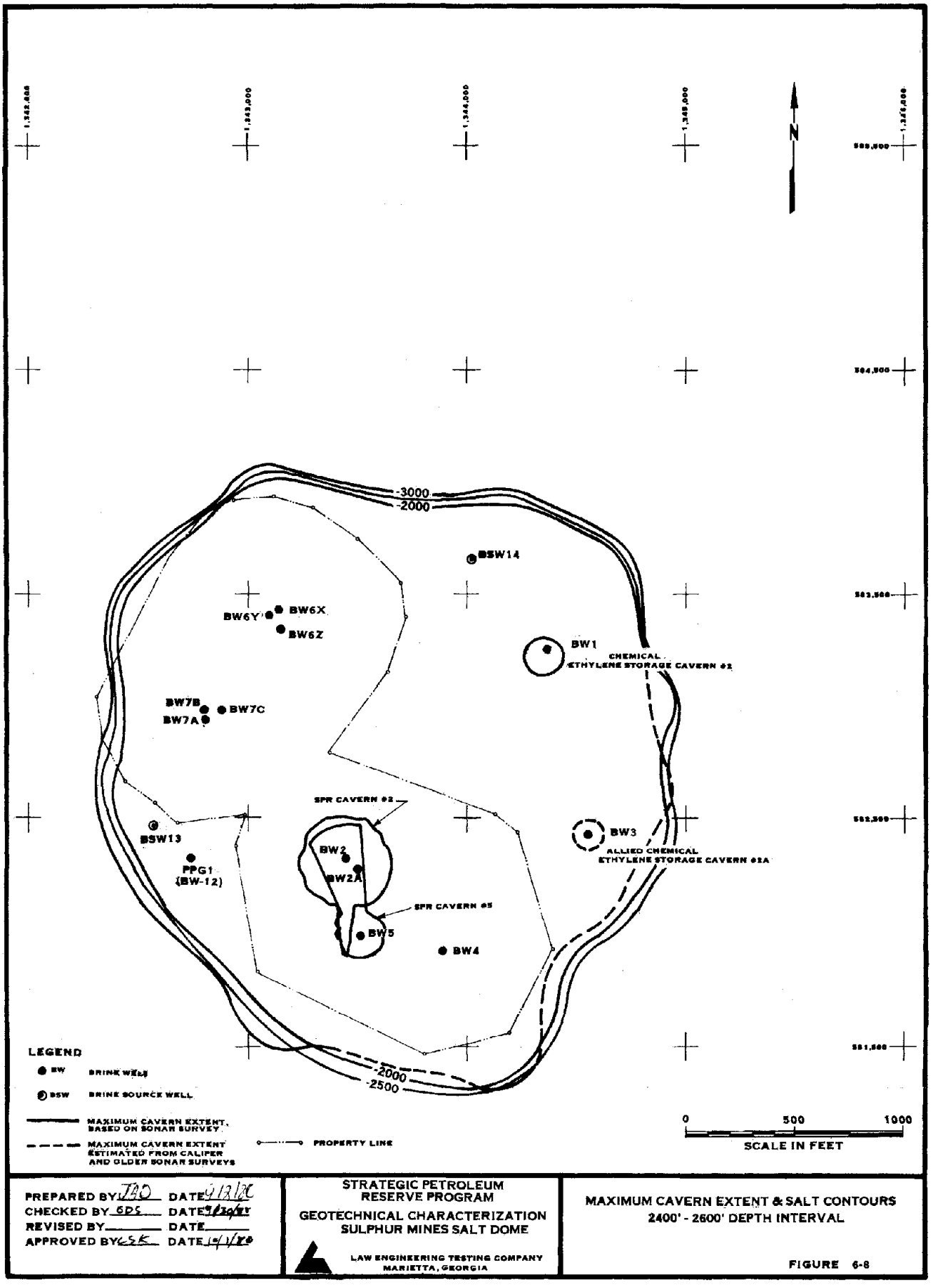
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REVISED BY _____ DATE _____
APPROVED BY CSK DATE 6/1/89

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

MAXIMUM CAVERN EXTENT & SALT CONTOURS
1000' - 2000' DEPTH INTERVAL

FIGURE 6-7



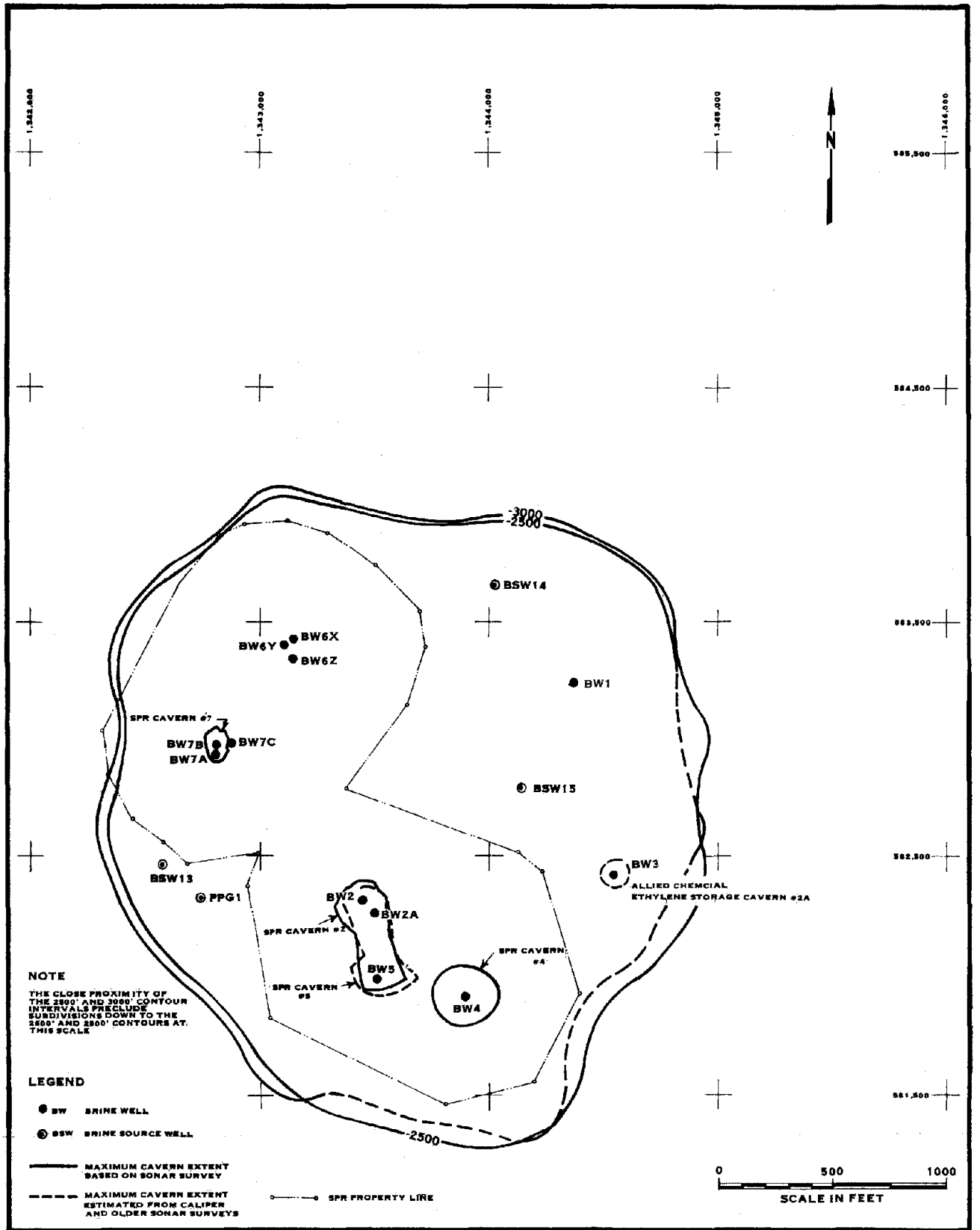
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APPROVED BY CSK DATE 10/1/88

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

MAXIMUM CAVERN EXTENT & SALT CONTOURS
2400' - 2600' DEPTH INTERVAL

FIGURE 6-8



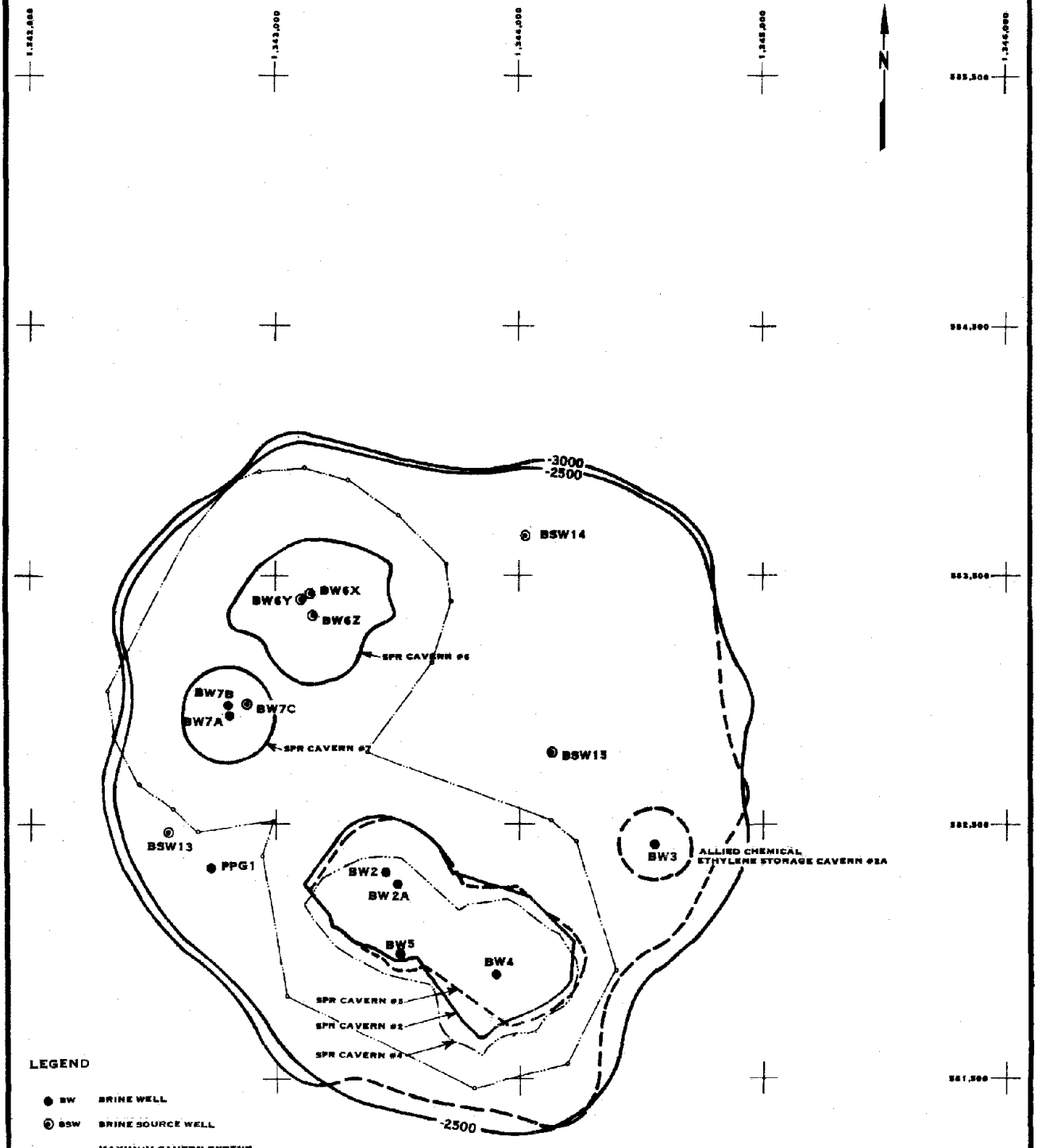
PREPARED BY JHC DATE 6/26/80
CHECKED BY ODS DATE 9/30/80
REVISED BY ____ DATE ____
APPROVED BY USK DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

MAXIMUM CAVERN EXTENT & SALT CONTOURS
2600' - 2800' DEPTH INTERVAL

FIGURE 6-9



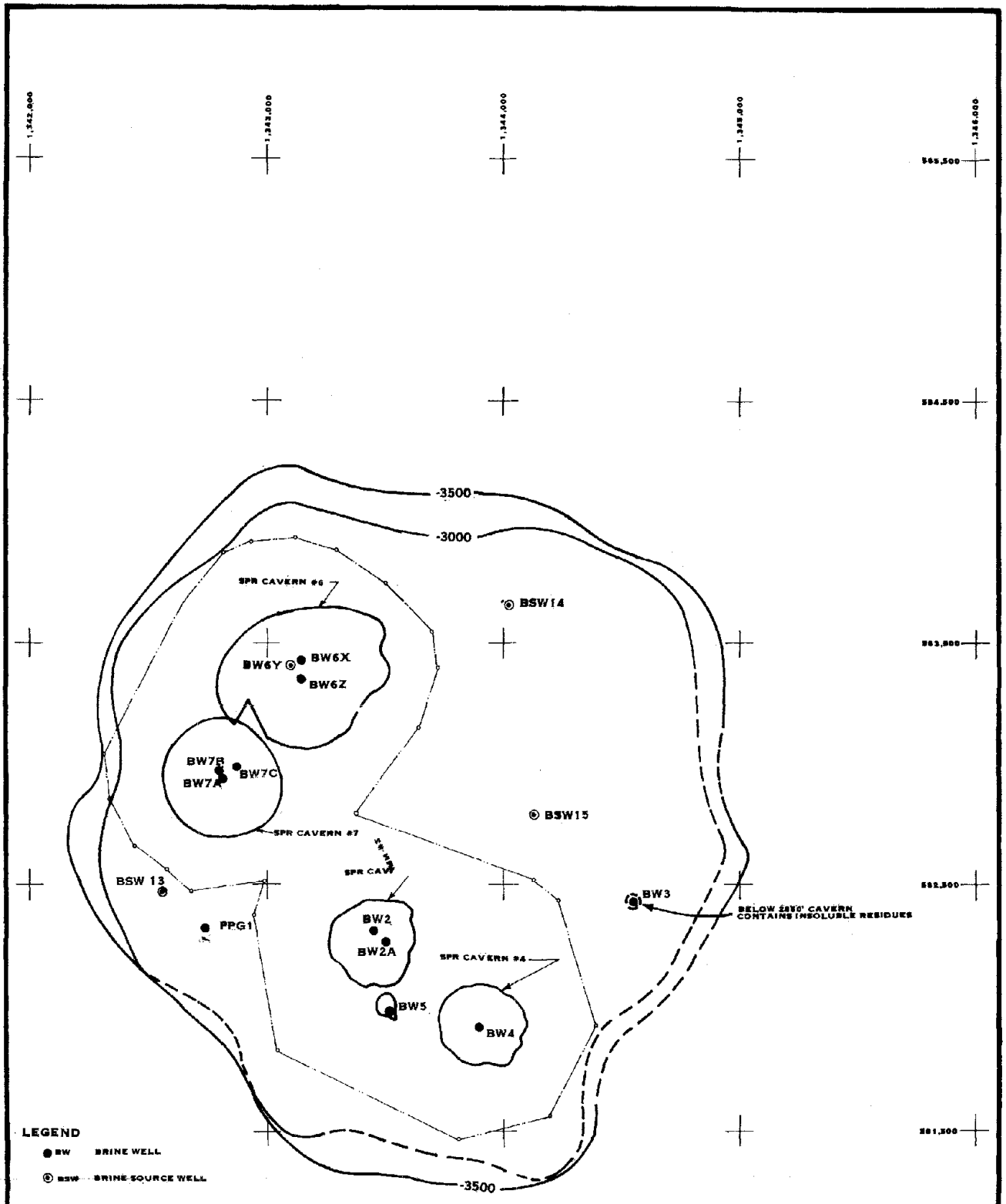
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CHECKED BY GDS DATE 9/20/88
REVISED BY ____ DATE ____
APPROVED BY GDS DATE 10/1/88

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

MAXIMUM CAVERN EXTENT & SALT CONTOURS
2800' - 3000' DEPTH INTERVAL

FIGURE 5-10



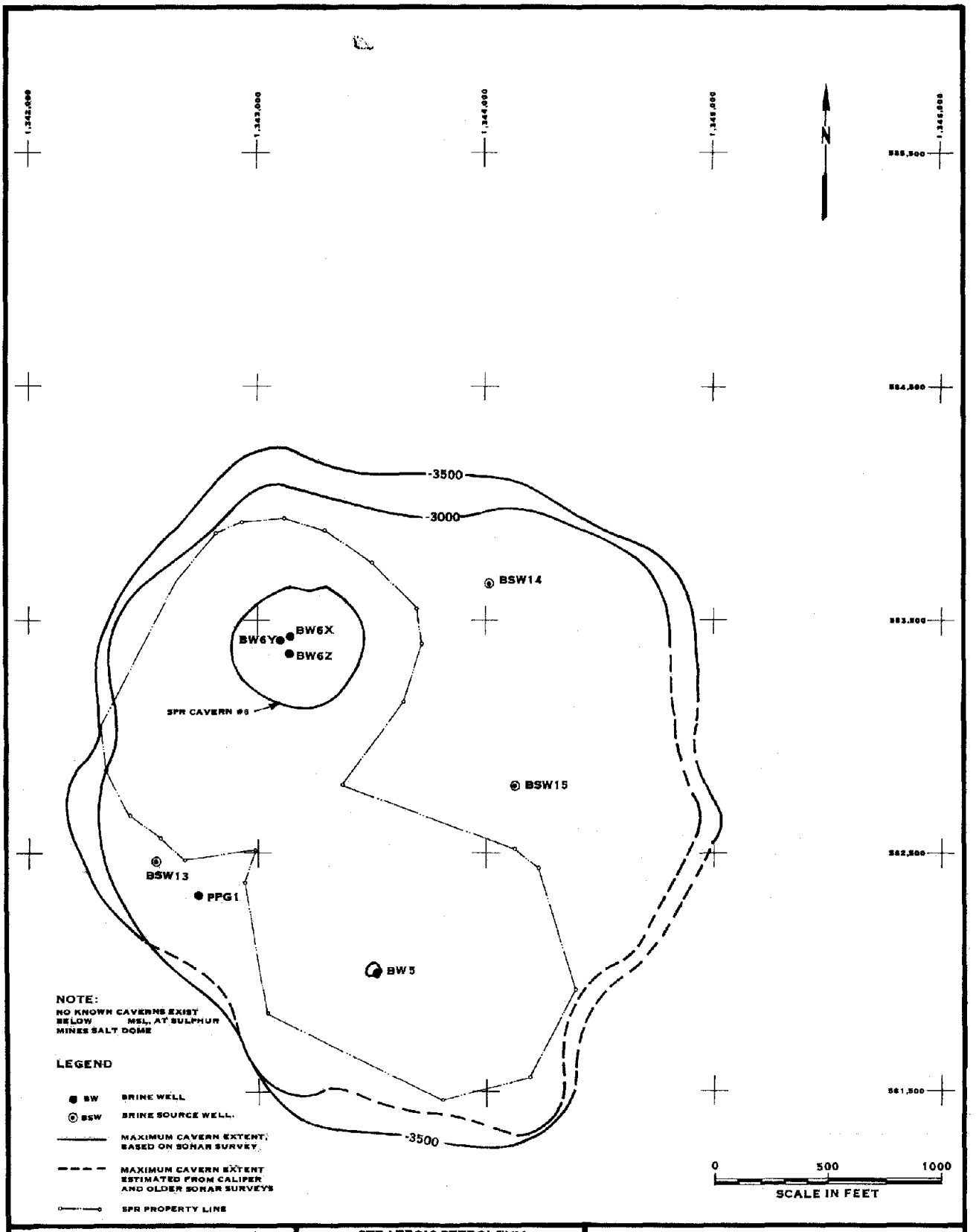
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CHECKED BY CTS DATE 9/30/91
REVISED BY _____ DATE _____
APPROVED BY CTS DATE 10/1/91

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

MAXIMUM CAVERN EXTENT & SALT CONTOURS
3000' - 3200' DEPTH INTERVAL

FIGURE 6-11



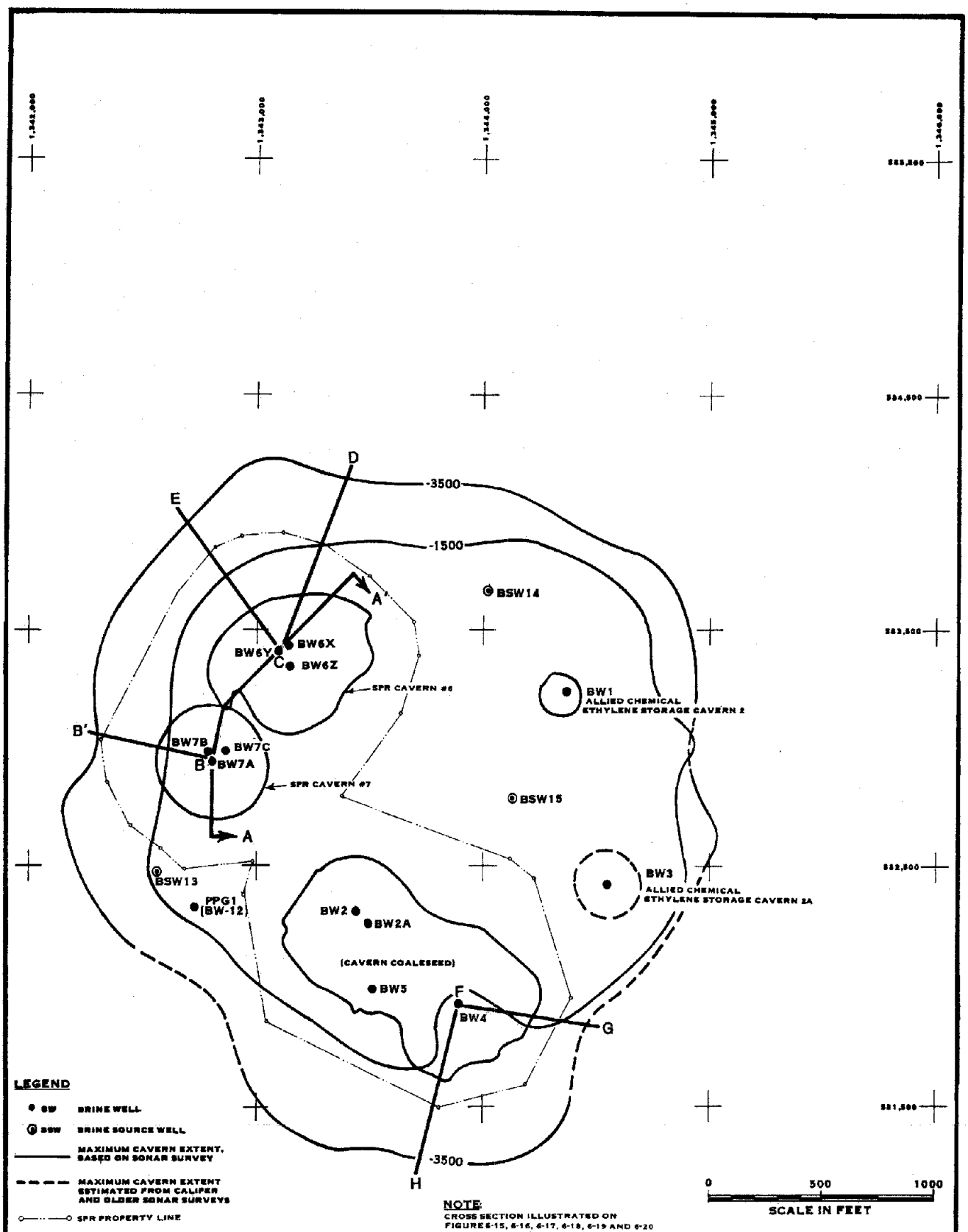
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CHECKED BY OPS DATE 9/30/80
REVISED BY _____ DATE _____
APPROVED BY LSK DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

MAXIMUM CAVERN EXTENT & SALT CONTOURS
3200' - 3400' DEPTH INTERVAL

FIGURE 6-12



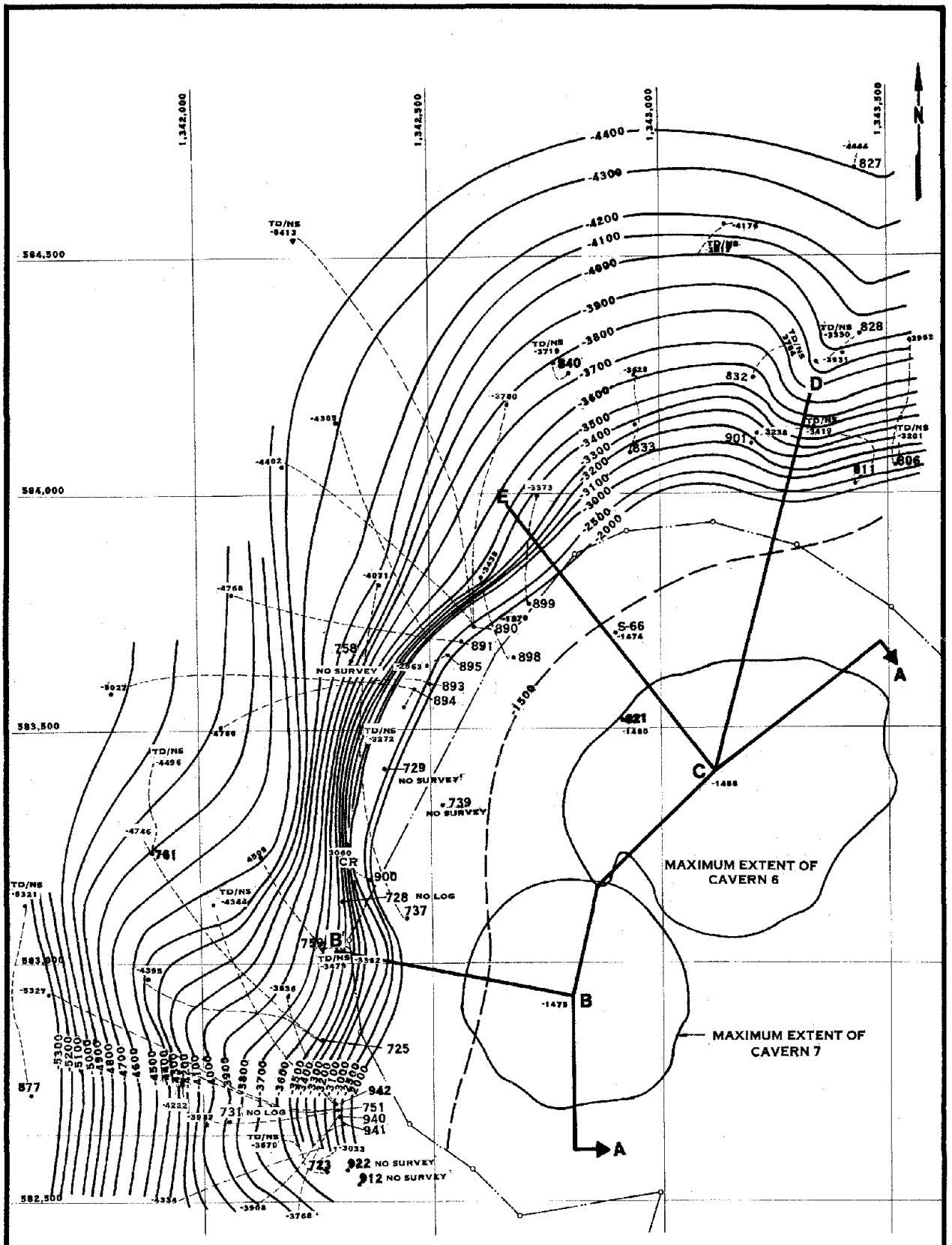
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REVISED BY ____ DATE ____
APPROVED BY [illegible] DATE [illegible]

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SITE CROSS-SECTION LOCATION MAP

FIGURE 6-13



NOTE:

DEPTHS MEASURED TO TOP OF SALT EXCEPT THOSE MARKED TD/NS (TOTAL DEPTH OF HOLE, NO SALT ENCOUNTED) AND CR (DEPTH TO CAPROCK)

LEGEND

SPR PROPERTY LINE

0 100 200 400

SCALE IN FEET

PREPARED BY SLF DATE 9/8/86
CHECKED BY [illegible] DATE [illegible]
REVISED BY [illegible] DATE [illegible]
APPROVED BY [illegible] DATE [illegible]

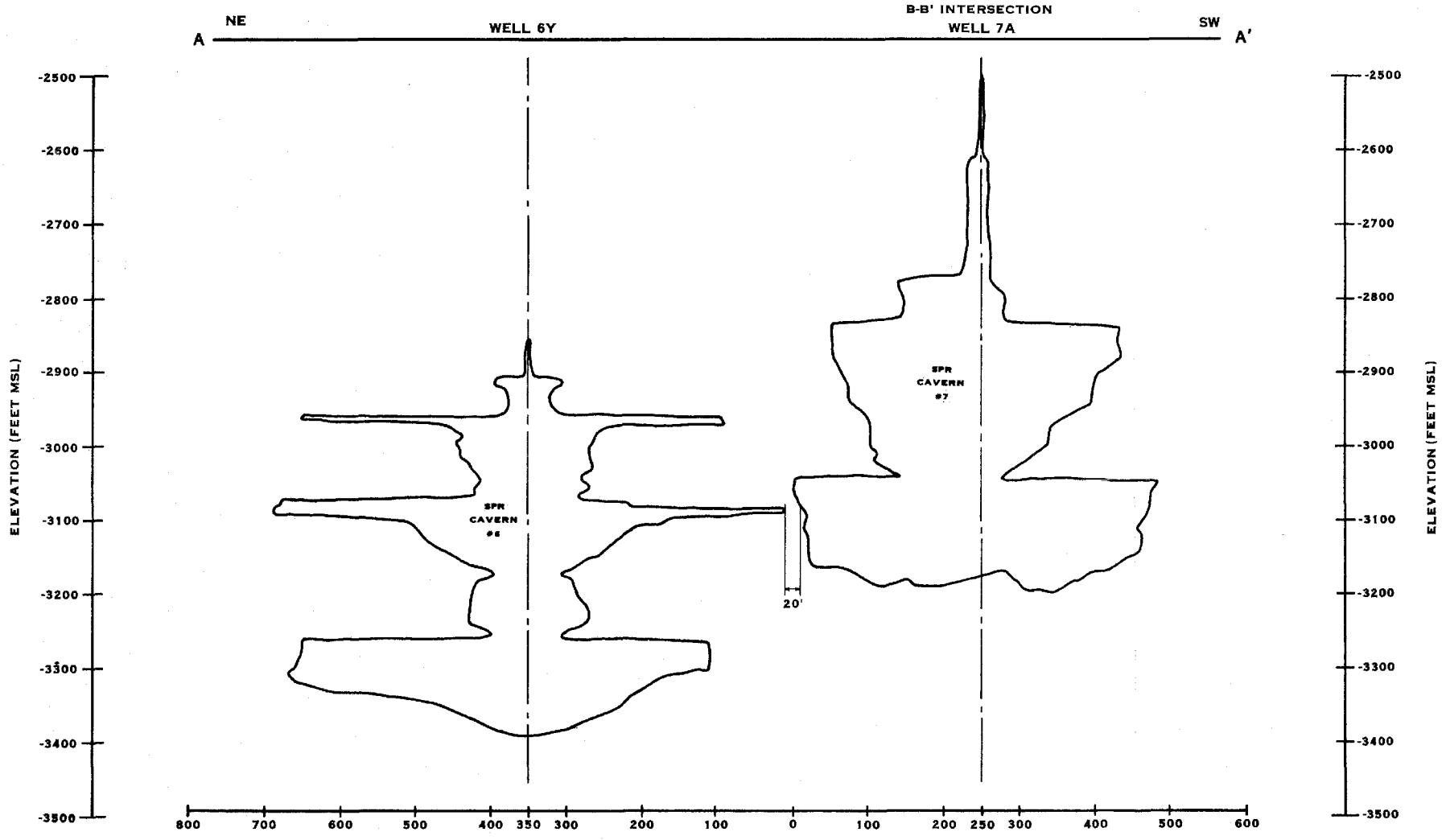
STRATEGIC PETROLEUM RESERVE PROGRAM

GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA

SALT CONTOUR MAP (NW QUADRANT) WITH SPR CAVERNS 6 AND 7

FIGURE 6-14



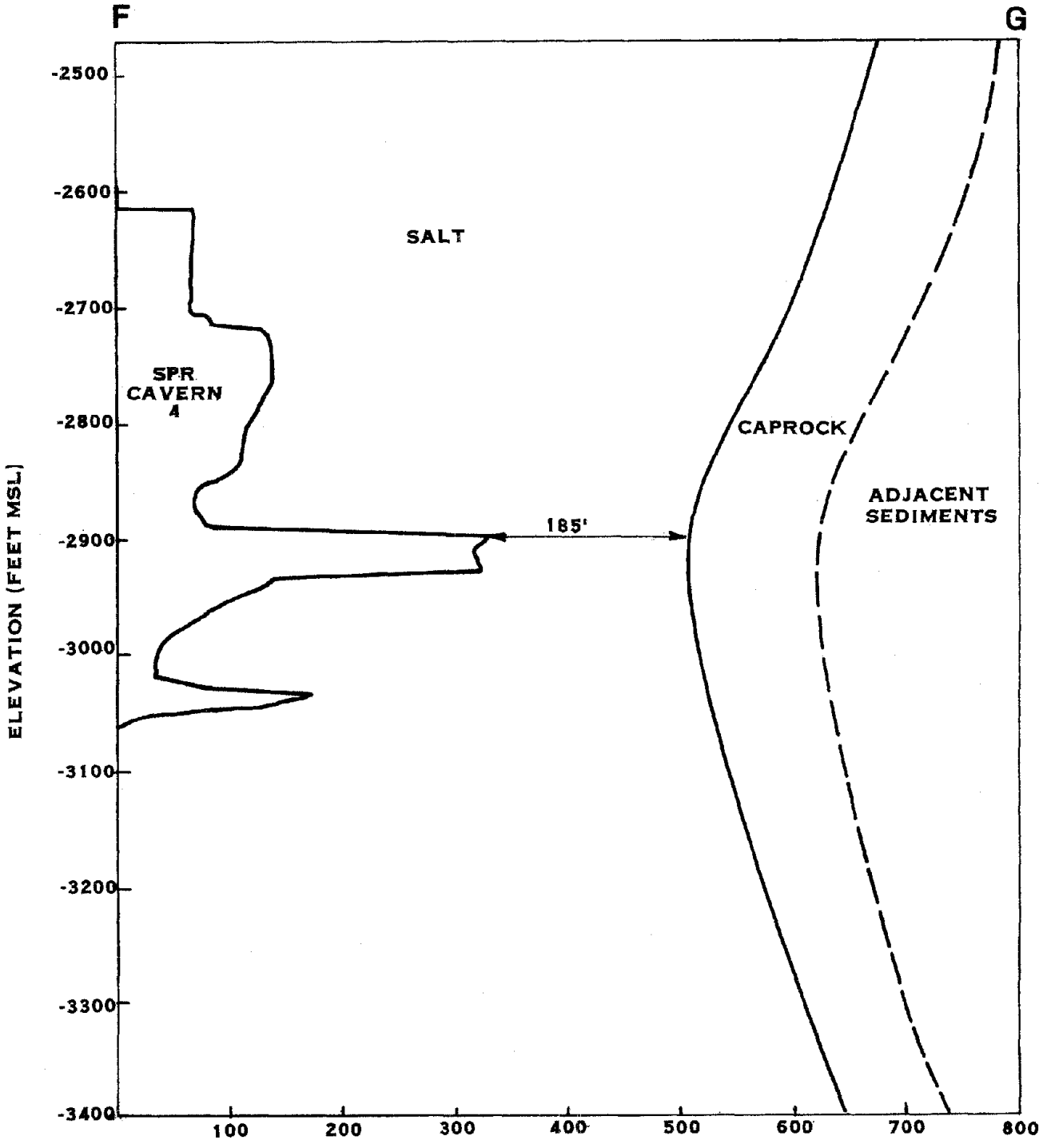
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REVISED BY	DATE
APPROVED BY ESC	DATE 10/1/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

CAVERNS 6 & 7 SHOWING CROSS-SECTION ALONG A - A'

FIGURE 6-15



PREPARED BY SIF DATE 9/18/80
CHECKED BY DRS DATE 9/26/80
REVISED BY SMM DATE 12/19/80
APPROVED BY GSIC DATE 10/1/81

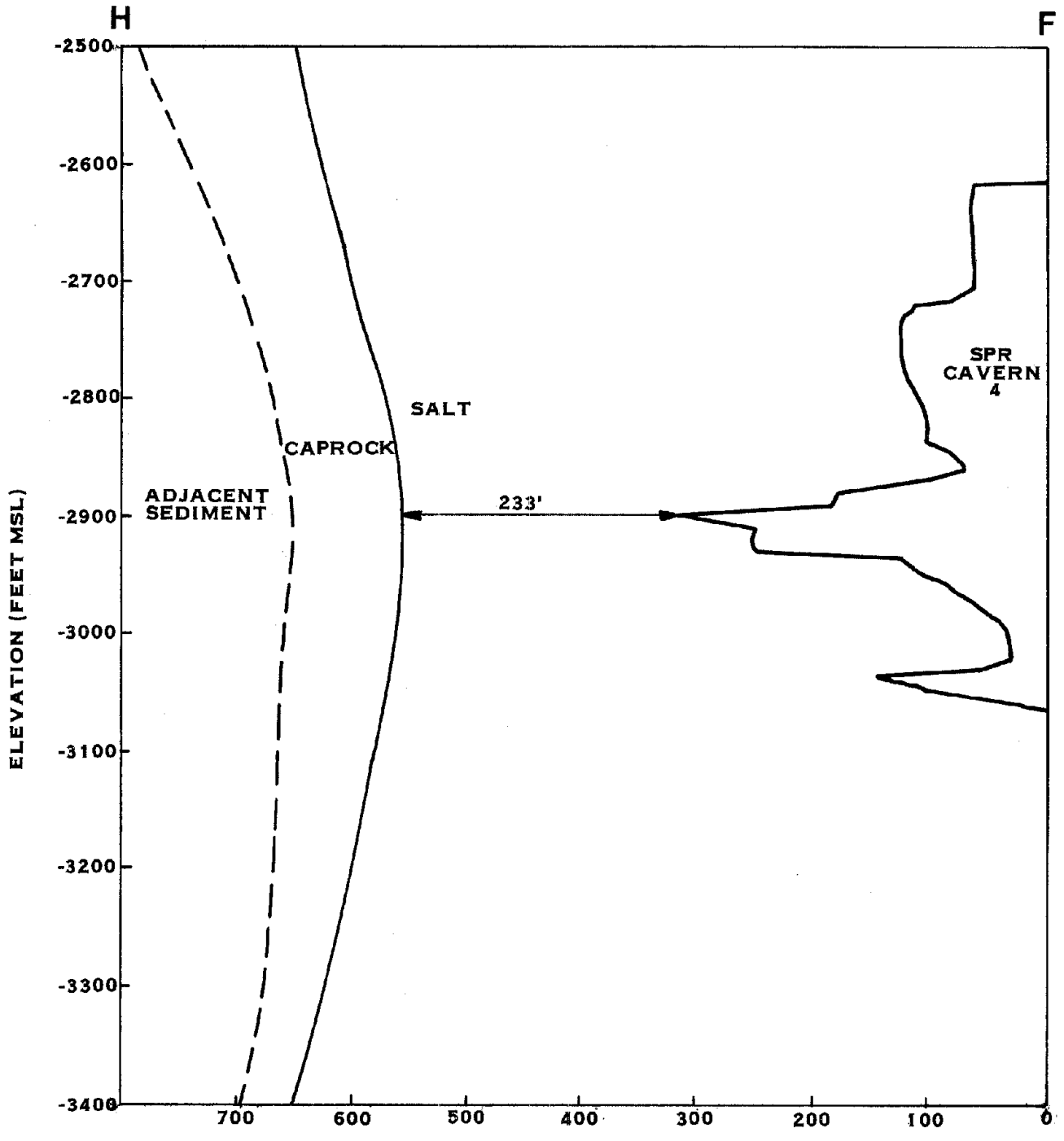
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GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

CAVERN 4

DOME EDGE CROSS-SECTION F-G

FIGURE 6-16



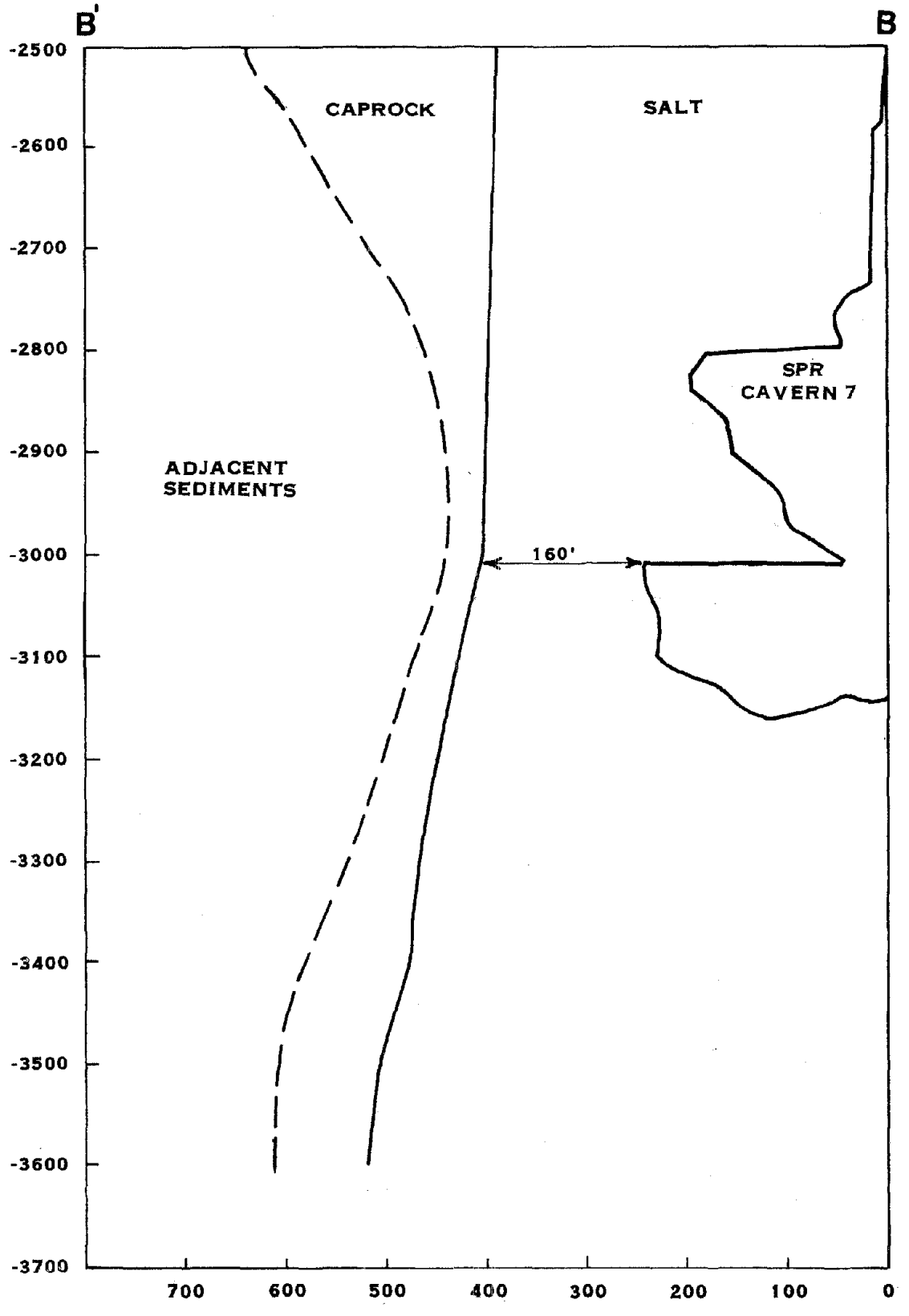
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LAW ENGINEERING TESTING COMPANY
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CAVERN 4
DOME EDGE CROSS-SECTION H-F

FIGURE 6-17



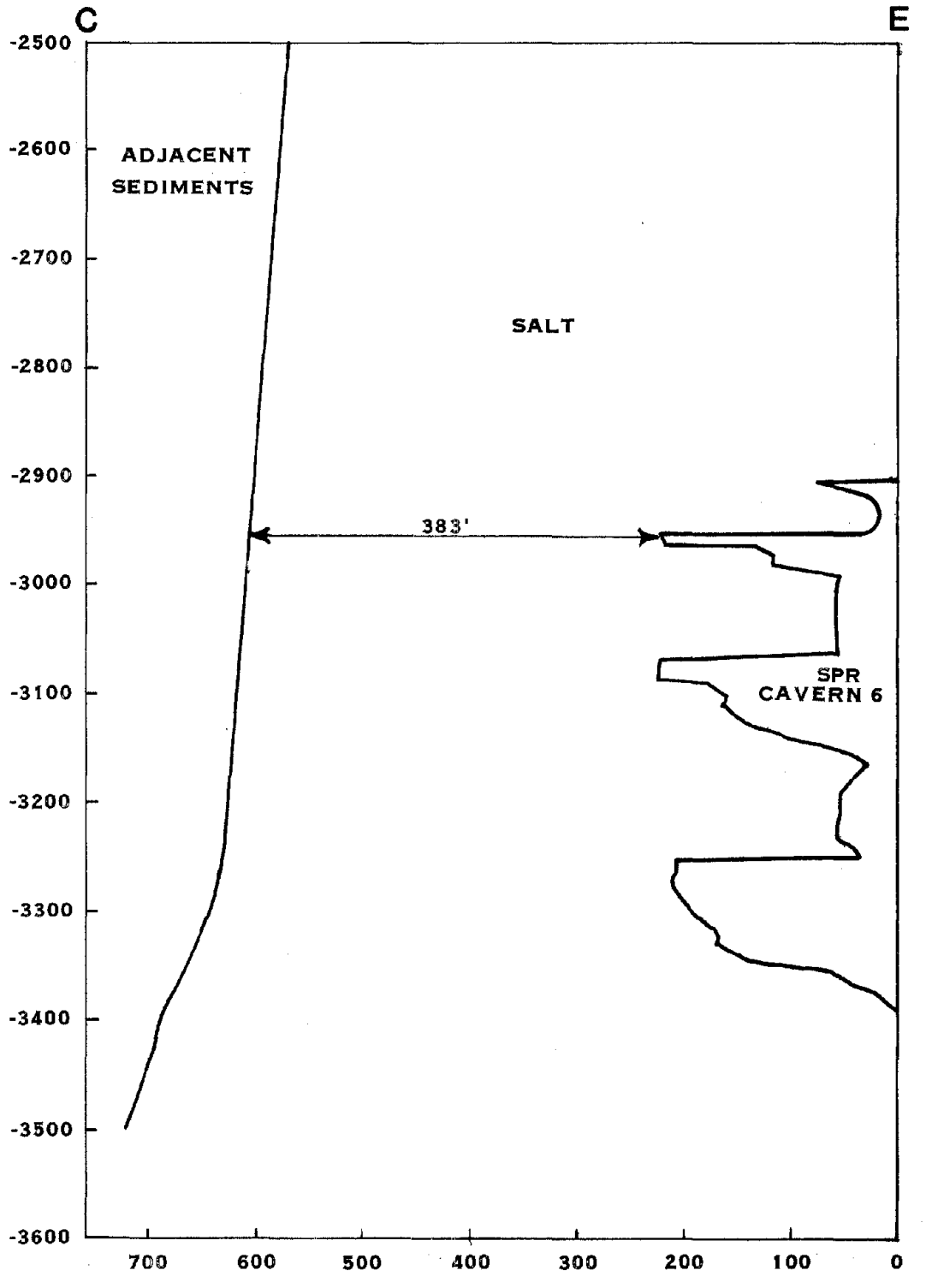
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CAVERN 7
DOME EDGE CROSS-SECTION B'-B

FIGURE 6-18



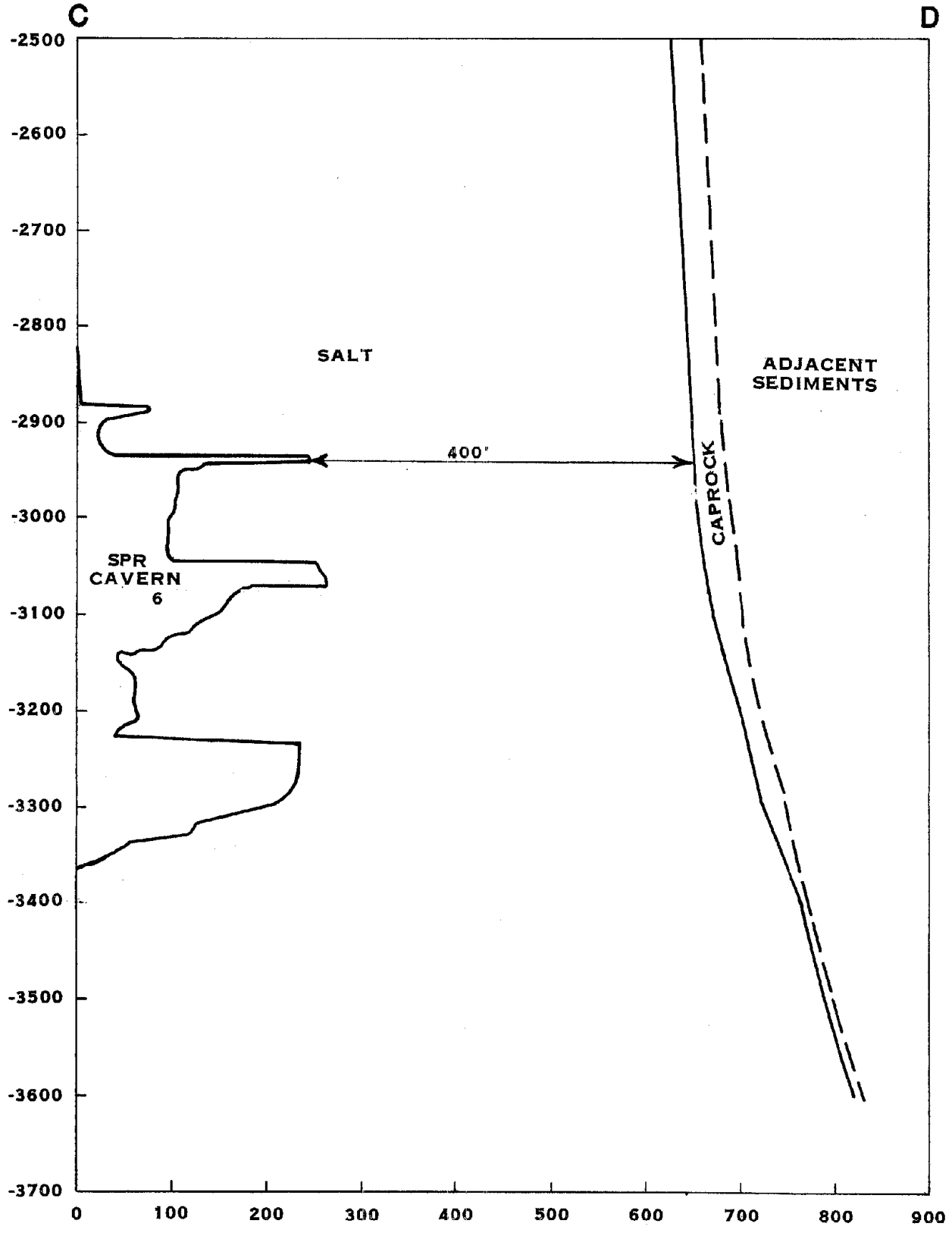
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CAVERN 6
DOME EDGE CROSS-SECTION C-E

FIGURE 6-19



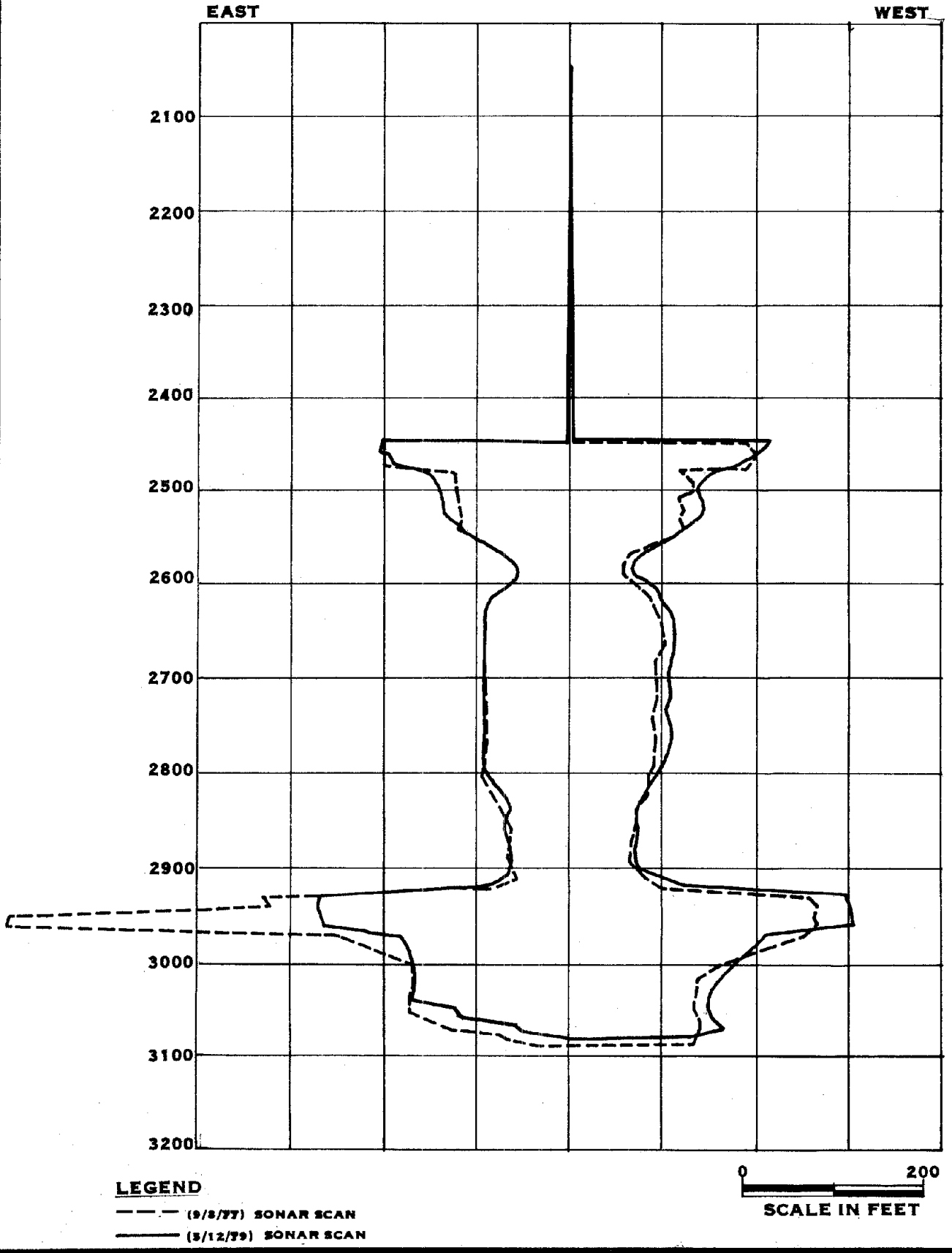
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CAVERN 6
DOME EDGE CROSS-SECTION C-D

FIGURE 6-20



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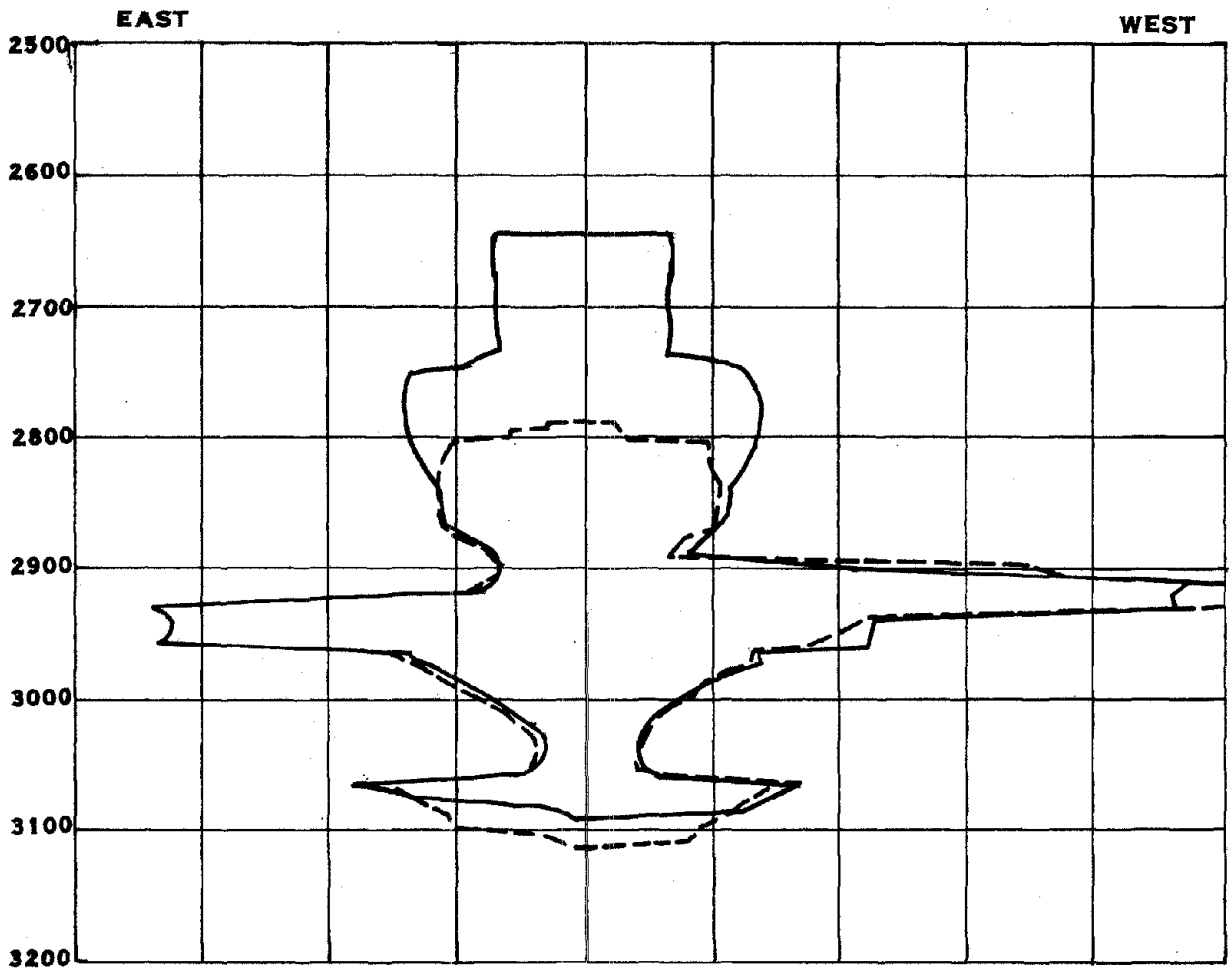
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SPR STORAGE CAVERN 2,
GROWTH RELATIONSHIPS

FIGURE 6-21

AF 12338A



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— — — (8/30/77) SONAR SCAN

——— (5/16/79) SONAR SCAN

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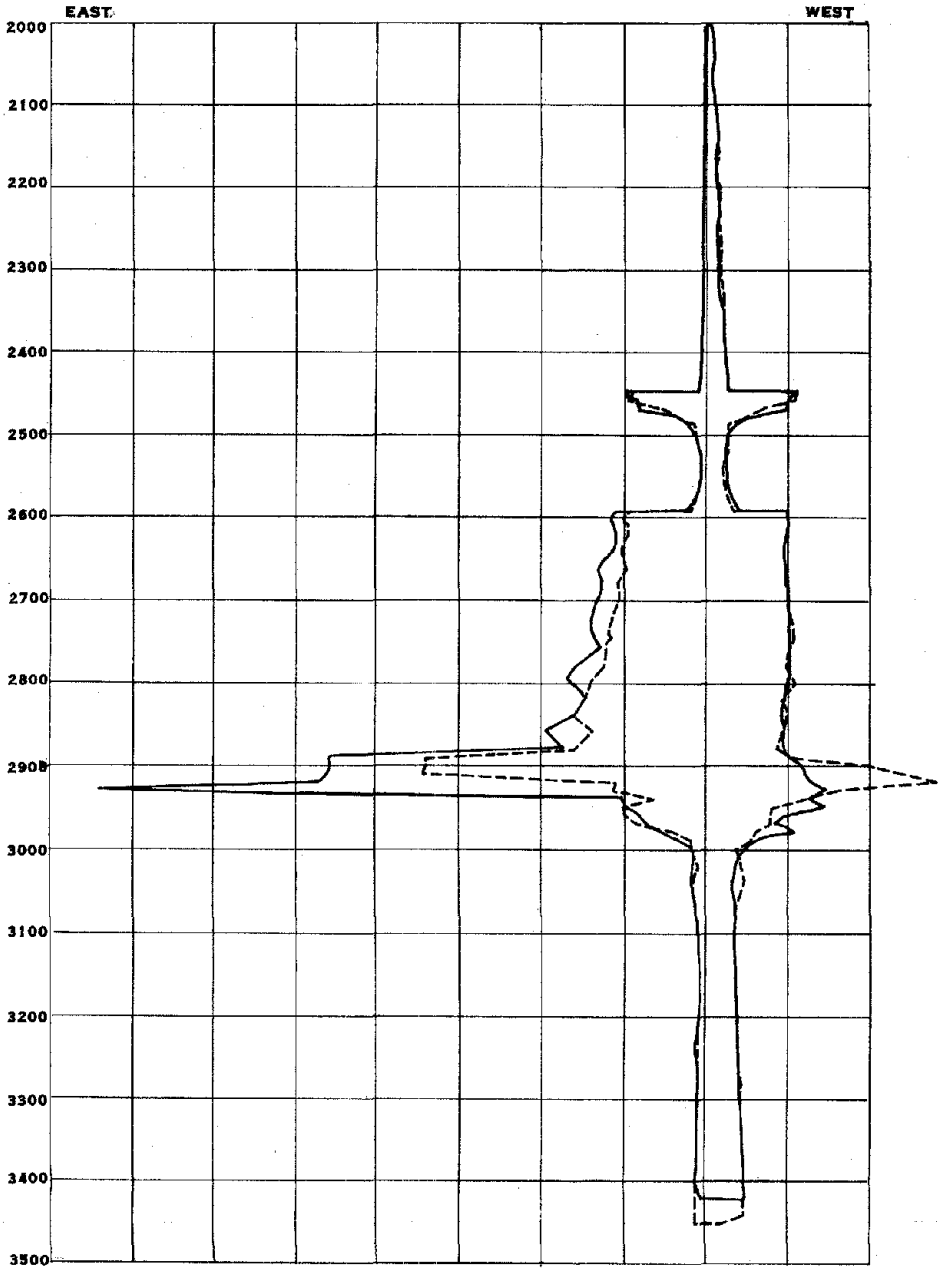
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STRATEGIC PETROLEUM RESERVE PROGRAM
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SULPHUR MINES SALT DOME

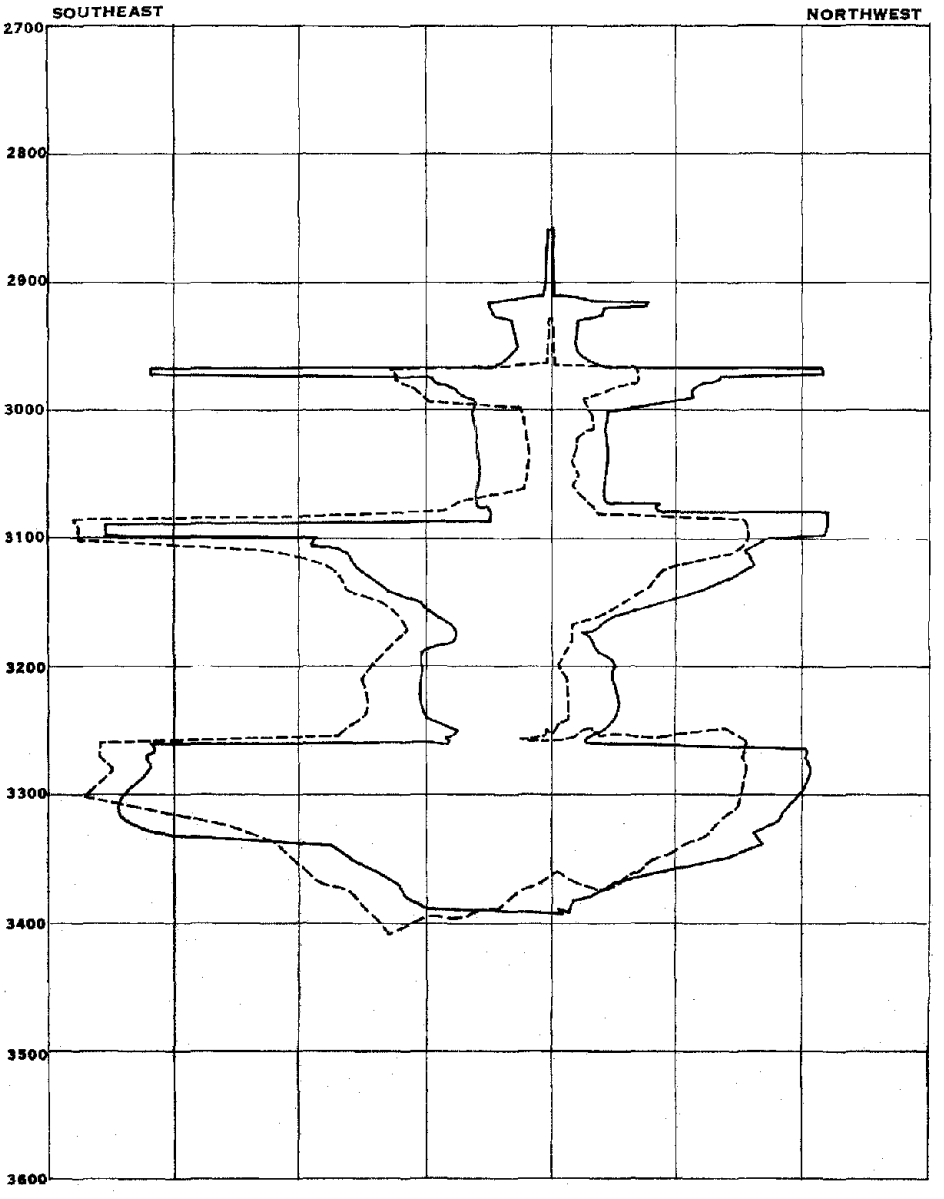
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SPR STORAGE CAVERN 4, GROWTH RELATIONSHIPS

FIGURE 6-22



PREPARED BY JAR DATE 9/29/80 CHECKED BY DDS DATE 9/30/80 REVISED BY ____ DATE ____ APPROVED BY CSK DATE 10/1/80	STRATEGIC PETROLEUM RESERVE PROGRAM GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA	SPR STORAGE CAVERN 5, GROWTH RELATIONSHIPS FIGURE 6-23



LEGEND

– – – – (12/24/77) SONAR SCAN

——— (9/27/79) SONAR SCAN

NOTE:

SONAR SCAN CROSS-SECTIONS WERE DERIVED FROM TWO DIFFERENT CAVERN ENTRY WELL LOCATIONS (6X AND 6Y). THEREFORE, THIS CROSS-SECTION SHOULD ONLY BE USED FOR VOLUME RELATIONSHIPS.

0 200

SCALE IN FEET

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STRATEGIC PETROLEUM RESERVE PROGRAM

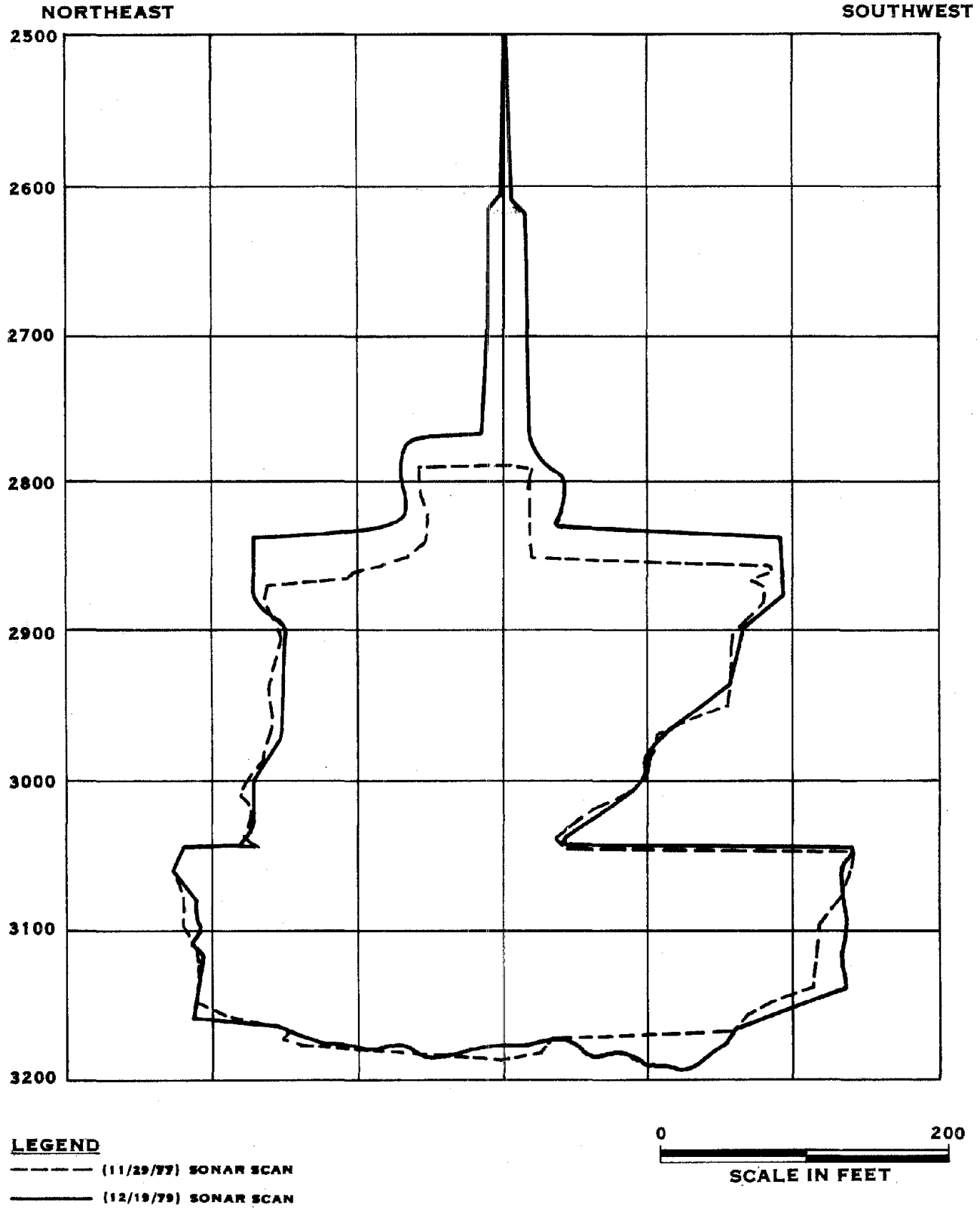
GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA

SPR STORAGE CAVERN 6, GROWTH RELATIONSHIPS

FIGURE 6-24

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APPROVED BY LSIC DATE 10/1/81

STRATEGIC PETROLEUM RESERVE PROGRAM
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SULPHUR MINES SALT DOME
LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SPR STORAGE CAVERN 7,
GROWTH RELATIONSHIPS

FIGURE 6-25

7.0

7.0

7.0 GEOLOGIC AND HYDROLOGIC HAZARDS

Four potential geologic and hydrologic hazards have been identified which could adversely impact the integrity of the SPR storage facility. These are subsidence, faulting, earthquakes, and flooding. The previous chapters of this report have discussed geologic and hydrologic conditions, and history of the region and site area. They provide the evidence and our views and opinions from which predictions of the potential, nature and mechanics of a hazard are developed. From this the impact of such hazards on the SPR facilities are identified.

7.1 SUBSIDENCE

The historic evidence and mechanism for subsidence of the ground surface above the dome has been discussed in Chapter 5.1 as related to caprock collapse and consolidation of the soils overlying the caprock. The following paragraphs of this section discusses these hazards further.

7.1.1 Subsidence Potential

Ground surface subsidence at the Sulphur Mines Dome has occurred and is expected to continue for the foreseeable future at a rate of approximately one inch per year due to caprock collapse. The area of concern can generally be defined by the area encircled by the -2,000 foot caprock contour. This area includes surface facilities associated with caverns 2-4-5, 6 and 7.

The potential for more rapid surface subsidence occurring at noticeable rates measured in hours, days or even weeks is not considered as probable as the continued slow subsidence over the entire caprock area unless sulphur mining is resumed. Although a mud filling program could be instigated with renewed sulphur mining, effectiveness of this method for reducing subsidence at Sulphur Mines is very questionable due to the existing cavities within the caprock. It would be extremely difficult to verify that the mud filling was displacing the sulphur being mined and not migrating to other portions of the caprock.

Excluding the resumption of sulphur mining, the potential for more rapid surface subsidence resulting from caprock collapse is difficult to assess. There has been no documentation of rapid caprock collapse since the termination of sulphur mining. The monitoring of surface subsidence by PPG has only been ongoing for 11 years and only at a few stations over the dome. Thus, areas of more rapid surface subsidence may have gone unnoticed or unrecorded.

Based on sulphur mining reports of rapid caprock collapse at Sulphur Mines, the mechanism would involve the sudden collapse of existing cavities in the caprock. The surface expression would depend upon the size of the cavity. This would probably be a depression on the order of a few tens of feet in diameter although a surface depression of 100 feet in diameter could result, based on reports of a previous collapse.

Based on the 11 year PPG monitoring program, the future potential of slow surface subsidence is almost certain. The potential for rapid surface subsidence resulting from collapse of existing cavities in the caprock is uncertain, but what is certain is that cavities still exist within the caprock and some mechanism is still causing the caprock to collapse, possibly from intergranular creep or dissolution.

7.1.2 Impact of SPR Facilities

The continuing but slow surface subsidence will effect surface facilities within the -2,000 foot caprock contour equally and result in the following:

1. General lowering of ground surface elevation;
2. Slight changes in surface drainage;
3. Lowering of structures founded in near surface soils;
4. A relative rise in wellhead structures;
5. Differential tilting of structures bounding subsidence areas and non-subsidence areas;
6. Differential tilting of structures founded partly on natural soils and connected to wellhead structures;
7. Breaking or bending of well casings.

Rapid surface subsidence resulting from collapse of cavities within the caprock would have a similar affect as the slow subsidence except that it would occur more rapidly and over a localized area. Therefore, differential movement of the surface and within the subsurface soils would result from soil masses sliding into the collapsed area. This could result in casings being bent and possibly sheared as had occurred in the past during sulphur mining. Neither slow nor rapid caprock collapse is expected to affect the integrity of brine caverns, but may effect the integrity of connecting piping to the surface.

7.2 FAULTING

Growth faults and radial faults have been identified at and in the vicinity of the Sulphur Mines salt dome. The projection of subsurface faults to the surface identified by subsurface studies are shown in Figure 4-13. The impact of this faulting and its potential is discussed in the following paragraphs.

7.2.1 Faulting Potential

Movement of radial faults resulting from renewed movement of Sulphur Mines salt dome is highly unlikely. However, movement along these faults could and may be occurring in response to caprock collapse and decrease in pore fluid pressure by the extraction of oil from the flanks of the dome. Maximum movement of these faults would be overshadowed by the effects of ground surface subsidence already occurring over the dome. Movement of the faults adjacent to the dome in response to reduction in pore fluid pressure would be on the order of an inch or less per year at the current rate of oil production. Further, the lithology of

the reservoirs being produced (consisting mostly of fairly massive permeable sands) does not lend itself to a significant potential for consolidation thus subsidence followed by movement along the faults.

Further movement along growth faults in the site vicinity, specifically those bounding the northern and southern edge of the dome is likely. At this time, major movement would not be in response to the general nontectonic subsidence of the Gulf Coast area, but due to withdrawl of subsurface fluids.

Recent movement on faults has been documented in the Baton Rouge, Louisiana, Houston and Corpus Christi, Texas areas as a result of extraction of groundwater and other subsurface fluids. The potential for extraction of fluids from the subsurface and thus reactivation or increased movement along faults identified in the site vicinity is a very real potential. The use of groundwater in the Lake Charles area indicates a decline in groundwater level and increase in the area effected by the pumping, both of which are expected to continue to increase. The dewatering of shallow aquifers results in an increase in effective stress on subsurface units causing consolidation of interbedded clay layers as the pore pressures are reduced. In response to the consolidation, movement occurs along the fault planes. Movement on faults in the Houston area has been reported to occur at rates of up to one inch of vertical movement per year. Continuous data is not available to verify any historic movement of faults in the vicinity of the site resulting from groundwater withdrawal.

7.2.2 Impact on SPR Facilities

The impact of movement of radial faults is minimal and would be overshadowed by subsidence over the dome. The movement associated with growth faults in the vicinity of the site as a result of general basin subsidence of the Gulf Coast is negligible. Movement of these faults resulting from groundwater withdrawal is presently undeterminable, however, rates of vertical movement up to one inch per year could occur if groundwater pumping in the vicinity of the site results in lowering of the groundwater level. At the present, this is minimal and effects from groundwater withdrawal would go unnoticed. Similarly, the effects of extraction of hydrocarbons which cause movement along growth faults is assessed as being negligible to insignificant based on rates of production in the vicinity of the faults. New production in shallow sands in the vicinity of Sulphur Mines could result in renewed movement or increased movement along the growth faults. Only facilities off the south flank of the dome could be effected.

Deep subsurface formations in the vicinity of Sulphur Mines dome may be potential reservoirs to provide geothermal energy. Reduction in subsurface formation pressures resulting from geothermal wells could cause surface subsidence in a more limited area. At the present time, one well located in Cameron Parish south of Calcasieu Parish is being drilled for a geothermal test. This should have no effect on the Sulphur Mines dome. Only geothermal wells located in the close vicinity of the Sulphur

Mines dome should be considered as having an affect on the SPR facilities.

7.3 EARTHQUAKE

The history and mechanisms for earthquakes in this region are discussed in Section 3.1.6. The following sections describe the potential for, and impact of future seismicity at or near the site.

7.3.1 Earthquake Potential

The probability of a damaging earthquake at the site is very low. The maximum anticipated ground motion equates to a Modified Mercalli Intensity VI or an acceleration of 0.06g.

7.3.2 Impact on SPR Facilities

The impact of an intensity VI MMI event would be minimal. No liquefaction or major damage would be anticipated under normal operating conditions. Particle velocity will decrease with depth, thus the effect on the caverns would be about 1/3 that on the surface.

7.4 FLOODING

The Sulphur Mines SPR site is located outside the limits of detailed analysis in the Flood Insurance Study. The Army Corps has indicated that accoring to preliminary hydrologic investigations, floods with return frequencies of once in 50 years and 100 years would produce stages on 17.0 and 18.0 feet National Geodetic Vertical Datum of 1929 (NGVD) in the vicinity of the site. Hurricane surge affects are not believed to extend as far inland as the Sulfur Mines site. Hurricane surge studies for Cameron and Vemillion Parishes are currently underway, but no data from these studies are available.

7.4.1 Impact on SPR Site

The impact of potential flooding on the SPR site is dependent on the severity of flooding. Due to inadequate drainage on and around the site, severe thunderstorm activity, such as occurred on 16 May 1980, may cause localized flooding creating operating problems and limiting access to the site. Although all the facilities on the site have been constructed above the 100 year flood elevation, the occurrence of this flood would effect operations by limiting access to the site. Hurricane surges are not believed to affect the site, but associated weather conditions could disrupt operations and potential cause damage to buildings and other structures on the site.

APPENDIX
A

APPENDIX
A

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MAPS & LOGS

USGS Topo Maps

15 min.

Starks Quad. 1959 (67PR)
Delinquency Quad. 1956
Moss Bluff Quad. 1957
Sulphur Quad. 1960
Lake Charles Quad. 1955
Orange Quad. 1955

5 Ft. Contour Interval

7 1/2 min.

Brimstone Quadd. 1956 (75PR)
Buhler Quad. 1956 (75PR)
Sulphur Quad. 1955 (75PR)
West Lake Quad. 155 (75PR)

7 1/2 min.

Sulphur Quad. 1932
Buhler Quad. 1935
Sulphur Mines Quad. 1935
West Lake Quad. 1932

B & W Aerial Photos

5 mile radius around dome:

1:69,000	1975	8 photos
1:40,000	1969	22 photos
1:24,000	1967	34 photos

site specific:

1:400	1977	2 photos

Well Location Maps

La. 401 — 1 inch = 1 mile — 1979 — From Kelly Map Co. (PROPRIETARY)

La. 402

Tobin Ownership Map

No. B-220 (PROPRIETARY)

1:24000 — 5 mile radius

Exploration Techniques: Bouguer Gravity Maps

scale 1' = 4000' (PROPRIETARY)

Contour Interval - 2GU Below - 20
1GU Below - 20

Geologic Maps (Subsurface)

Geomap: Strip maps of Southwest Louisiana
Nos. 1-24 1" = 4000'

21 Cross sections of Southwest Louisiana
(Coordinated with maps - Vertical scale 1':400'
(PROPRIETARY)

Geologic Map (Surface)

Unpublished map by USGS
1:250,000 sheet

Geophysical Logs

Cambe Geological Services - 305 Electric Logs from a 5 mile radius surrounding the dome plus completion cards.

Soils Map

General Soil Map of Calcasieu Parish, La.
USDA Soil Conservation Service No. 4-R-28741-B,
1' = 4 miles, 1972

APPENDIX
B

APPENDIX
B

LIST OF CONTACTS

ORGANIZATION	LOCATION	PERSON(S) CONTACTED
AMOCO	New Orleans	Gordon Greve
		Ed Williamson
AMOCO	Houston, TX	
C. H. BURT, Inc.	Houston, TX	Doug Henderson
CAMBE	Lafayette, LA	Sydney Domes
		Sandy Touchet
CAMBE	Houston, TX	
CORPS OF ENGINEERS	New Orleans	Ed Nachman
		Don Athey
		Doris Cox
D'APPOLONIA	Albuquerque, NM	Peter Kelsall
	Houston, TX	Richard Cunningham
DAWSON EXPLORATION	Houston, TX	Ross Dawson
D.O.E./SPRPMO	New Orleans	Gary Vincient
		Bob Mazurkiewitz
		Bill Smollen
	Sulphur, LA	Allen Fruge
DOWELL-DIVISION-DOW CHEMICAL	Houston, TX	Rex Carmichael
DEPARTMENT OF ARCHIVES	Washington, DC	
EXPLORATION TECHNIQUES	Houston, TX	Wes Pustejovsky
		Gene Greene
		Richard O'Donnell

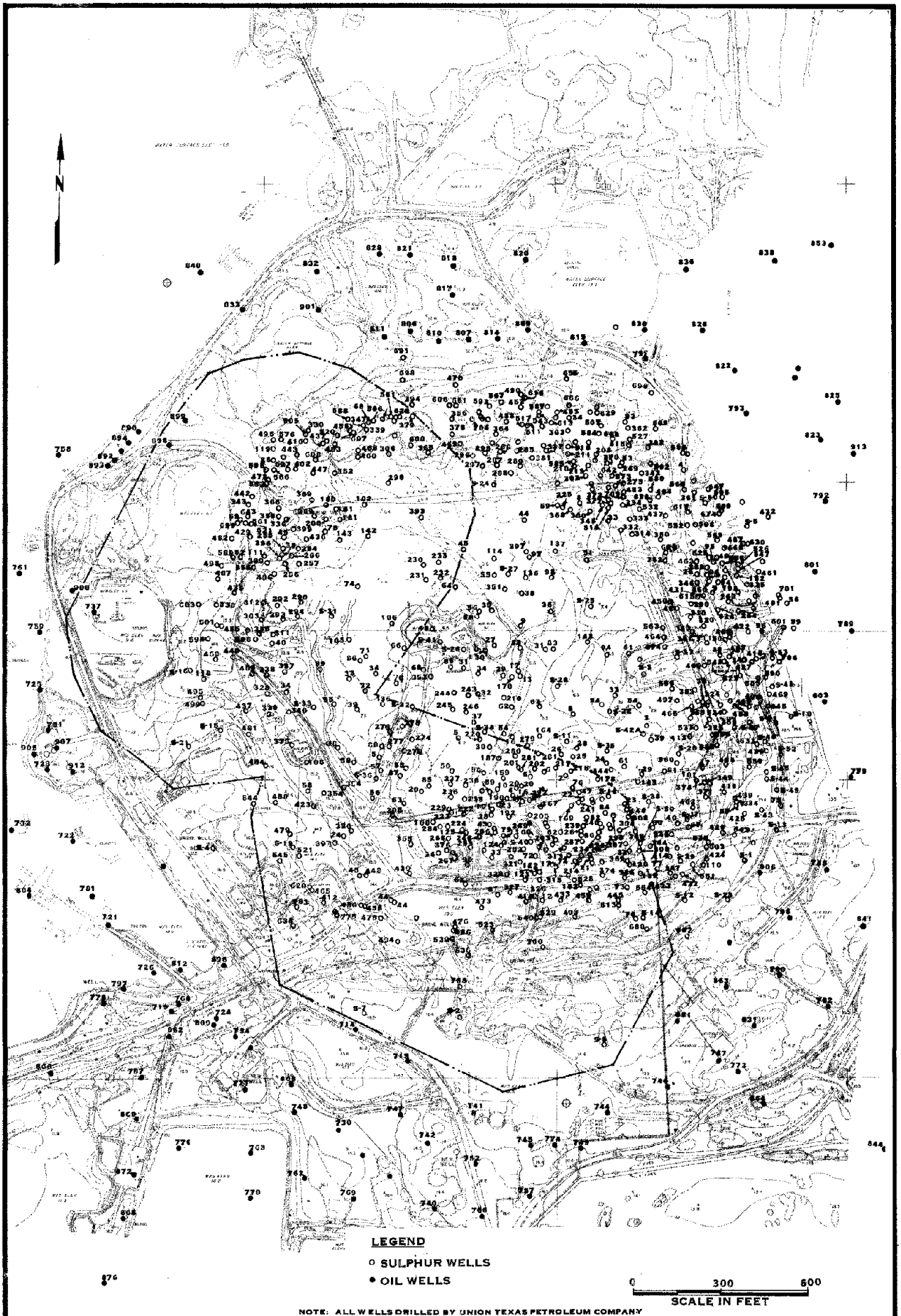
ORGANIZATION	LOCATION	PERSON(S) CONTACTED
FRASCH MUSEUM	Sulphur, LA	Librarian
FREEPORT SULPHUR	New Orleans	Nelson Chisolm
		Ray Young
GEO-MAP	Houston, TX	Lydia Vogelsang
GULF INTERSTATE ENGINEERING CO.	Houston, TX	John Baker
		Bob McDaniels
M.T. HALBOUTY EXPLOR.	Houston, TX	Tom Barber
INEXCO	Houston, TX	Mat Kirkland
	Lafayette, LA	Ed Norwood
		Carl Miller
LOUISIANA DEPT. CONSERVATION	Baton Rouge, LA	Calvin Thomas
		Bob Bates
LOUISIANA GEOLOGICAL SURVEY	Baton Rouge, LA	Don Bebout
		Dave Pope
		Dave Kesel
LOUISIANA SOIL CONSER-VATION SERVICE	Alexandria, LA	Jim Driessen
	Lake Charles, LA	A. J. Roy
LAW ENGINEERING TESTING COMPANY	McLean, VA	Joe Shuffleton
OAO	Hanahan	Penny Keller
PPG	Sulphur	Jim Bourgoise
	Lake Charles	Ron Bennefield
		Hugh Olliff
	Sulphur	Robin Richard
		Leon Cook

ORGANIZATION	LOCATION	PERSON(S) CONTACTED
PEPPARD - SOUNDERS	Houston	Mr. Perilloux
		Jim Morgan
		Phillip Robinson
PB/KBB	Houston, TX.	
PARSONS - GILBANE		
PETROPHYSICS	Houston, TX	Sara Herr
PYBURN & ODOM	Baton Rouge	Roy Odom
RE/SPEC	Rapid City, SD	Paul Senseny
TEXAS BRINE	New Orleans	Jerry Thompson
		John Gabrial
		Frank Whelply
	Houston	Neil VanFossen
TOBIN AIRESEARCH	San Antonio	Malcolm McLeod
	Houston, TX	Joe Vizza
UNION TEXAS/ALLIED CHEMICAL	Lafayette, LA	Mary Whitten
		Ralph Dozier
		Jean Lormand
		Howard Perdue
		Will Kanagy
	Houston, TX	Wayne Jones
		Ben Williams
		John Sutherland
		C. D. Porter
		G. B. Robinson
		Burt Roe

ORGANIZATION	LOCATION	PERSON(S) CONTACTED
UNION TEXAS/ALLIED CHEMICAL Con't	Breaux Bridge	John Bailey
	Lafayette, LA	Glen Gilbreath
SANDIA LABORATORIES	Albuquerque	Richard Beasley
		J. T. Henderson
		Robert G. Hogan
		J. F. Ney
		Terry Ortiz
		Ruth Patterson
		Joseph R. Tillerson
		Glen Whiting
	Harahan, LA	R. J. Hart
		H. Clyde Walker
U.S.G.S.	Alexandria	Jim Rogers
	Bay St. Louis	Hank Svelak
WILLIAMS-STACKHOUSE	S.A.	Mr. Sinclair
WILLISCO	Houston	Dave Grissett
	New Orleans	Glenn Boudoin
CONSULTANT	Baton Rouge	Paul Jones

APPENDIX
C

APPENDIX
C



NOTE: ALL WELLS DRILLED BY UNION TEXAS PETROLEUM COMPANY

PREPARED BY SJE DATE 10/1/80
CHECKED BY _____ DATE _____
REVISED BY _____ DATE _____
APPROVED BY LSK DATE 10/3/80

STRATEGIC PETROLEUM RESERVE PROGRAM

GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

SULPHUR MINES SPR SITE
WELL LOCATION MAP

APPENDIX C

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
1	LP&C CO.*	-	1,230	333	Oil	-
2	ASM Co.**	-	552	344	Oil	-
3	ASM Co.	-	625	-	Oil	-
4	ASM Co.	-	525	-	Oil	-
5	ASM Co.	-	603	-	-	-
6	ASC ***	-	613	-	-	-
7	ASC	-	598	-	-	-
8	ASC	-	596	-	-	-
9	ASC	-	860	-	-	-
10	ASC	-	430	-	-	-
11	ASC					
12	ASC	1893	1,131		-	-
13	ASC	-	-	-	-	-
14	ASC	1896	542	349	Sulphur	2,071
15	ASC	1896	598	400	Sulphur	150
16	ASC	-	-	-	-	-
17	ASC	1897	-	-	Sulphur	2,458
18	ASC	1898	-	-	Sulphur	36
19	ASC	1900	-	-	Sulphur	2,245
20	ASC	1901	-	-	Sulphur	1,108
21	ASC	1902/1903	-	-	Sulphur	2,988
22	ASC	-	-	-	Sulphur	-
23	ASC	1902	-	-	Sulphur	2,855
24	ASC	1902	-	-	Sulphur	944
25	ASC	-	-	-	-	-
26	ASC	1903	605	-	Sulphur	3,075
27	ASC	1903	590	480	Sulphur	4,390
28	ASC	1903	602	-	Sulphur	713
29	ASC	1903	595	-	Sulphur	1,159
30	ASC	1903	566	-	Sulphur	980
31	ASC	1903	600	-	Sulphur	1,065
32	ASC	1903	596	360	Sulphur	7,380
33	ASC	1903	600	355	Sulphur	60
34	ASC	1903	598	365	Sulphur	1,305
35	ASC	1903	630	391	Sulphur	-
36	ASC	1913	578	425	Sulphur	3,925

* Louisiana Petroleum & Coal Oil Co.
** American Sulphur Mining Co.
*** American Sulphur Company

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
37	ASC *	1904	598	377	Sulphur	3,990
38	ASC	1903	603	414	Sulphur	1,345
39	ASC	1904	602	418	Sulphur	307
40	ASC	1904	616	345	Sulphur	365
41	ASC	1904	598	433	Sulphur	650
42	ASC	1904	600	420	Sulphur	1,340
43	ASC	1904	567	385	Sulphur	7,210
44	ASC	1904	635	395	Sulphur	2,630
45	ASC	1904	635	395	Sulphur	50
46	ASC	1905	657	446	Sulphur	11,315
47	ASC	1904	612	410	Sulphur	935
48	ASC	1904	593	380	Sulphur	2,570
49	ASC	1904	592	372	Sulphur	4,985
50	ASC	1904	601	411	Sulphur	23,255
51	ASC	1904	700	461	Sulphur	2,530
52	ASC	1904	591	360	Sulphur	4,500
53	ASC	1904	621	376	Sulphur	11,820
54	ASC		620	420	Sulphur	-
55	ASC	1904	610	462	Sulphur	1,265
56	ASC			450	Sulphur	-
57	ASC	1905	603	355	Sulphur	10,085
58	ASC	1905	731	536	Sulphur	3,120
59	ASC	1905	631	473	Sulphur	60
60	ASC	1905	565	398	Sulphur	1,695
61	ASC	1904	607	391	Sulphur	1,360
62	ASC		428	350	Sulphur	-
63	ASC	1904	544	397	Sulphur	2,875
64	ASC	1904	597	410	Sulphur	300
65	ASC		394	336	Sulphur	-
66	ASC	1905	619	385	Sulphur	965
67	ASC	1905	897	531	Sulphur	4,745
68	ASC		540	540	Sulphur	-
69	ASC	1904	636	361	Sulphur	730
70	ASC	1905	599	384	Sulphur	32,070
71	ASC		633	385	Sulphur	-
72	ASC	1905	609	390	Sulphur	22,590
73	ASC	1905	790	438	Sulphur	20,390
74	ASC	1905	713	364	Sulphur	30
75	ASC		900	-	Sulphur	-

* American Sulphur Company

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
76	ASC *		685	-		-
77	ASC	1905	784	438	Sulphur	5,965
78	ASC		440	344	Sulphur	-
79	ASC		580	348	Sulphur	-
80	ASC		600	333	Sulphur	-
81	ASC	1906	582	427	Sulphur	175
82	ASC	1905	756	410	Sulphur	1,970
83	ASC	1905	610	393	Sulphur	3,115
84	ASC	1906	610	387	Sulphur	4,110
85	ASC		455	333	Sulphur	-
86	ASC		485	376	Sulphur	-
87	ASC		335	335	Sulphur	-
88	ASC	1905	624	395	Sulphur	11,660
89	ASC	1905	629	350	Sulphur	27,700
90	ASC	1905	622	431	Sulphur	41,145
91	ASC	1905	647	404	Sulphur	9,870
92	ASC		644	474	Sulphur	-
93	ASC	1906	744	435	Sulphur	65
94	ASC	1906	767	420	Sulphur	185
95	ASC	1905	865	526	Sulphur	5,495
96	ASC	1906	818	616	Sulphur	175
97	ASC	1907	618	422	Sulphur	6,385
98	ASC	1907	639	428	Sulphur	4,420
99	ASC		694	430	Sulphur	-
100	ASC	1905	622	390	Sulphur	15,745

* American Sulphur Company

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
101	ASC	1906	610	444	Sulphur	500
102	ASC	1907	870	406	Sulphur	5,940
103	ASC	1906	672	372	Sulphur	4,025
104	ASC	1906	840	542	Sulphur	6,200
105	ASC		425			
106	ASC	1906	681	365	Sulphur	1,315
107	ASC	1906	661	393	Sulphur	650
108	ASC	1906	773	496	Sulphur	810
109	ASC		1,471	1,254	Sulphur	
110	ASC		718	556		
111	ASC	1907	1,007	615	Sulphur	4,405
112	ASC		695	564	Sulphur	
113	ASC	1907	1,035	658	Sulphur	1,515
114	ASC		694	411	Sulphur	5,025
115	ASC	1906	661	343	Sulphur	1,785
116	ASC		830		Sulphur	
117	ASC		560	472	Sulphur	
118	ASC		987	950	Sulphur	
119	ASC		942	844	Sulphur	
120	ASC	1906	694	370	Sulphur	5,230
121	ASC	1906	637	352	Sulphur	3,960
122	ASC	1906	622	393	Sulphur	2,255
123	ASC	1906	578	352	Sulphur	16,240
124	ASC	1906	591	350	Sulphur	1,415
125	ASC	1906	628	362	Sulphur	38,020
126	ASC		605	343	Sulphur	54,955
127	ASC		386	343	Sulphur	
128	ASC		890	844	Sulphur	
129	ASC		620	392	Sulphur	
130	ASC		620	374	Sulphur	
131	ASC		603	350	Sulphur	
132	ASC		619	346	Sulphur	
133	ASC	1906	610	350	Sulphur	36,525
134	ASC	1906	634	370	Sulphur	37,550
135	ASC	1906	603	348	Sulphur	4,145
136	ASC	1906	599	346	Sulphur	25,620
137	ASC	1907	648	450	Sulphur	5,695
138	ASC	1907	618	415	Sulphur	4,780
139	ASC	1906	794	435	Sulphur	3,530
140	ASC	1906	636	350	Sulphur	7,315

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
141	ASC	1907	788	381	Sulphur	3,330
142	ASC	1907	790	375	Sulphur	4,625
143	ASC	1907	820	398	Sulphur	2,260
144	ASC	1906	620	358	Sulphur	4,410
145	ASC	1906	618	370	Sulphur	2,695
146	ASC	1906	676	351	Sulphur	13,095
147	ASC	1906	618	361	Sulphur	10,470
148	ASC	1907	602	395	Sulphur	675
149	ASC	1907	774	544	Sulphur	225
150	ASC	1907	721	500	Sulphur	
151	ASC	1907	794	508	Sulphur	1,895
152	ASC	1907	836	565	Sulphur	940
153	ASC	1907	645	380	Sulphur	1,000
154	ASC	1907	613	442		
155	ASC	1907	666	439	Sulphur	598
156	ASC	1907	662	437	Sulphur	120
157	ASC	1907	640	368	Sulphur	1,819
158	ASC	1907	660	388	Sulphur	1,910
159	ASC	1907	603	348	Sulphur	40,385
160	ASC	1907	609	380	Sulphur	22,565
161	ASC	1907	614	373	Sulphur	7,250
162	ASC	1907	592	370	Sulphur	9,211
163	ASC	1907	583	370	Sulphur	1,890
164	ASC	1907	600	352	Sulphur	5,765
165	ASC	1907	592	351	Sulphur	17,455
166	ASC	1907	600	342	Sulphur	9,145
167	ASC	1907	638	364	Sulphur	
168	ASC	1907	624	371	Sulphur	
169	ASC	1908	627	365	Sulphur	3,240
170	ASC	1907	595	364	Sulphur	
171	ASC	1907	613	377	Sulphur	
172	ASC	1907	616	370	Sulphur	15,375
173	ASC		460	408		
174	ASC	1908	618	377	Sulphur	3,605
175	ASC	1907	642	354	Sulphur	27,820
176	ASC	1907	620	362	Sulphur	14,685
177	ASC		652	370	Sulphur	
178	ASC		570	390	Sulphur	
179	ASC	1907	718	429	Sulphur	40,245
180	ASC	1907	724	395	Sulphur	17,195

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
181	ASC	1907	744	388	Sulphur	71,920
182	ASC	1908	615	371	Sulphur	25,425
183	ASC	1908	615	373	Sulphur	5,620
184	ASC		492	370	Sulphur	
185	ASC		610	372	Sulphur	16,405
186	ASC					
187	ASC	1908	626	384	Sulphur	44,020
188	ASC	1908	505	376	Sulphur	4,855
189	ASC	1908	625	393	Sulphur	20,765
190	ASC	1908	607	388	Sulphur	7,095
191	ASC	1908	631	385	Sulphur	43,630
192	ASC	1908	620	376	Sulphur	10,005
193	ASC	1908	604	370	Sulphur	5,195
194	ASC	1908	1,458	360	Sulphur	
195	ASC	1908	777	544	Sulphur	22,760
196	ASC	1908	747	515	Sulphur	12,730
197	ASC	1908	719	542	Sulphur	10,385
198	ASC	1908	767	550	Sulphur	7,975
199	ASC		635	538	Sulphur	
200	ASC		477	395	Pumping mud,sand & caly fill	
201	ASC	1908	628	380	Sulphur	895
202	ASC	1908	640	372	Sulphur	16,120
203	ASC	1908	631	385	Sulphur	12,490
204	ASC	1908	639	380	Sulphur	12,285
205	ASC	1909				
206	ASC					
207	ASC	1908	687	471	Sulphur	160
208	ASC	1908	677	471	Sulphur	4,570
209	ASC	1909	842	463	Sulphur	6,680
210	ASC	1908	723	470	Sulphur	5,700
211	ASC	1908	733	461	Sulphur	11,565
212	ASC	1910	695	463	Sulphur	15,690
213	ASC	1908	860	467	Sulphur	
214	ASC	1909	426	379	Sulphur	
215	ASC	1909	619	377	Sulphur	9,690
216	ASC	1909	619	380	Sulphur	415
217	ASC	1909	619	400	Sulphur	13,940
218	ASC	1909	617	388	Sulphur	4,485
219	ASC	1909	663	365	Sulphur	16,510

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
220	ASC	1909	454	388	Sulphur	
221	ASC	1909	457	389	Sulphur	
222	ASC	1909	678	380	Sulphur	1,235
223	ASC	1909	536	370		
224	ASC	1909	660	365	Sulphur	7,935
225	ASC	1909	638	477	drilled to take mud from sandsucker	
226	ASC	1909	686	388	Sulphur	19,100
227	ASC	1909	668	380	Sulphur	13,920
228	ASC	1909	662	382	Sulphur	2,960
229	ASC	1909	648	370	Sulphur	15,560
230	ASC	1909	690	366	Sulphur	955
231	ASC	1909	646	370	Sulphur	775
232	ASC	1909	630	370	Sulphur	
233	ASC	1909	632	370 1/2	Sulphur	1,980
234	ASC	1909	665	380	Sulphur	45,405
235	ASC	1909	647	375	Sulphur	430
236	ASC	1909	670	388	Sulphur	
237	ASC	1909	662	380	Sulphur	405
238	ASC	1909		382		
239	ASC	1909	668	380	Sulphur	34,800
240	ASC	1909	657	385	Sulphur	21,995
241	ASC	1909	667	382	Sulphur	14,405
242	ASC	1909	676	380	Sulphur	8,200
243	never started					
244		1909	500			
245	ASC	1909	530			
246	ASC	1910	510			
247	ASC	1909	686	405	Sulphur	39,350
248	ASC	1909	689	395	Sulphur	6,530
249	ASC	1910	754	360	Sulphur	15,325
250	ASC	1910	734	382	Sulphur	
251	ASC	1910	763	385	Sulphur	13,305
252	ASC	1910	761	370	Sulphur	17,245
253	ASC	1910	760	400	Sulphur	8,195
255	ASC	1910	957	548	Sulphur	8,445
256	ASC	1910	920	564	Sulphur	8,030
257	ASC	1910	910	557	Sulphur	5,060
258	ASC	1910	812	542	Sulphur	
259	ASC	1910	774	493	Sulphur	
269	ASC	1910	778	504	Sulphur	

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
261	ASC	1910	721	500	Sulphur	-
262	ASC	1910	924	567	Sulphur	2,930
263	ASC	1910	833	545	Sulphur	3,850
264	ASC	1910	857	556	Sulphur	3,835
265	ASC	1910	847	601	Sulphur	670
266	ASC	1910	573	542	Sulphur	-
267	ASC	1910	712	438	Sulphur	1,890
268	ASC	1910	713	427	Sulphur	5,450
269	ASC	1910	979	494	Sulphur	270
270	ASC	1910	1,012	486	Sulphur	2,490
271	ASC	1910	1,069	480	Sulphur	5,075
272	ASC	1910	1,053	487	Sulphur	4,340
273	ASC	1910	1,105	494	Sulphur	4,570
274	ASC	1911	834	339	Sulphur	-
275	ASC	1911	776	342	Sulphur	-
276	ASC	1911	599	358	Sulphur	-
277	ASC	1911	820	356	Sulphur	-
278	ASC	1911	1,031	350	Sulphur	-
279	ASC	1911	768	402	Sulphur	-
280	ASC	1911	736	421	Sulphur	3,755
281	ASC	1911	766	383	Sulphur	625
282	ASC	1911	809	409	Sulphur	8,080
283	ASC	1911	752	409	Sulphur	380
284	ASC	1911	767	430	Sulphur	4,780
285	ASC	1911	800	456	Sulphur	8,585
286	ASC	1911	698	432	Sulphur	6,420
287	ASC	1911	729	404	Sulphur	5,330
288	ASC	1911	804	472	Sulphur	13,675
289	ASC	1911	780	440	Sulphur	-
290	ASC	1911	891	512	Sulphur	-
291	ASC	1911	933	547	Sulphur	5,780
292	ASC	1911	901	553	Sulphur	25,100
293	ASC	1911	965	547	Sulphur	50,315
294	ASC	1911	776	500	Sulphur	-
295	ASC	1911	704	389	Sulphur	2,185
296	ASC	1911	707	381	Sulphur	1,495
297	ASC	1911	704	379	Sulphur	4,795
298	ASC	1911	566	449	Sulphur	-
299	ASC	1911	784	417	Sulphur	6,505
300	ASC	1911	740	490	Sulphur	2,950

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
301	ASC	1911	789	508	Sulphur	-
302	ASC	1911	1,039	485	Sulphur	415
303	ASC	1911	636	613	Sulphur	7,960
304	ASC	1911	725	400	Sulphur	1,805
305	ASC	1911	730	380	Sulphur	80,075
306	ASC	1911	906	443	Sulphur	42,305
307	ASC	1911	848	400	Sulphur	63,480
308	ASC	1911	866	395	Sulphur	-
309	ASC	1911	736	374	Sulphur	16,550
310	ASC	1911	880	497	Sulphur	40,955
311	ASC	1911	822	601	Sulphur	-
312	ASC	1911	966	588	Sulphur	1,470
313	ASC	1911	834	411	Sulphur	12,050
314	ASC	1911	871	420	Sulphur	-
315	ASC	1911	825	424	Sulphur	-
316	ASC	1911	1,037	492	Sulphur	-
317	ASC	1911	1,072	475	Water	-
318	ASC	1911	789	492	Sulphur	-
318A	ASC	1911	801	483	Melting Water	-
319	ASC	1911	963	460	Sulphur	61,660
320	ASC	1911	310	-	Test Sands	-
321	ASC	1911	1,062	442	Sulphur	118,735
322	ASC	1911	887	449	Sulphur	50,754
323	ASC	1911	882	447	Sulphur	29,925
324	ASC	1911	739	465	Sulphur	-
325	ASC	1911	1,050	470		-
326	ASC	1911	1,064	511	Water	-
327	ASC	1911	1,036	505	Sulphur	-
328	ASC	1911	1,036	606		-
329	ASC	1911	220	-		-
330	ASC	1911	970	495		-
331	ASC	1911	850	477		-
332	ASC	1911	866	482		-
333	ASC	1911	867	496		-
334	ASC	1911	853	480	Sulphur	-
335	ASC	1911	941	609		-

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
336	ASC	1911	732	579	Sulphur	-
337	ASC	1911	955	563	Water Well	-
338	ASC	1911	941	610	Water Well	-
339	ASC	1911	847	599	Water Well	-
340	ASC	1911	585	562		-
341	ASC	1911	853	562	Water Well	-
342	ASC	1911	1,056	514	Sulphur	-
343	ASC	1911	231	-	Extract hot water	-
344	ASC	1911	146	-	Hot Water Well	-
345	ASC	1911	559	481	Water Well	-
346	ASC	1912	870	441	Sulphur	-
347	ASC	1912	900	478	Sulphur	-
348	ASC	1912	847	422	Sulphur	31,975
349	ASC	1912	976	455	Sulphur	49,990
350	ASC	1912	1,006	581	Sulphur	9,610
351	ASC	1912	764	417	Sulphur	121,525
352	ASC	1912	953	471	Sulphur	109,980
353	ASC	1912	728	367		-
354	ASC	1912	795	530	Sulphur	62,655
355	ASC	1912	837	531	Sulphur	81,900
356	ASC	1912	1,034	747	Sulphur	89,050
357	ASC	1912	1,229	505	Sulphur	15,425
358	ASC	1912	1,040	509	Sulphur	21,095
359	ASC	1912	1,217	572	Sulphur	43,420
360	ASC	1912	956	545		-
361	ASC	1912	1,113	576	Cold Water Well	-
362	ASC	1912	973	530	Sulphur	19,075
363	ASC	1912	1,029	470	Sulphur	16,600
364	ASC	1912	992	422	Cold Water Well	-
365	ASC	1912	1,058	412	Sulphur	11,060
366	ASC	1912	1,074	524		-
367	ASC	1912	1,073	487	Cold Water Well	-
368	ASC	1912	1,270	494	Water	-
369	ASC	1913	894	404	Sulphur	92,135
370	ASC	1913	893	448	Cold Water Well	60,870

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
371	ASC	1913	1,121	462	Cold Water Well	-
372	ASC	1913	524	494	Cold Water Well	-
373	ASC	1913	988	601	Water/Sulphur	14,800
374	ASC	1913	534	379	Cold Water Well	-
375	ASC	1913	957	554	Water	-
376	ASC	1913	949	473	Cold Water Well	-
377	ASC	1913	1,244	494	Sulphur	7,425
378	ASC	1913	1,275	431	Cold Water Well	14,390
379	ASC	1913	860	305	Sulphur	-
380	ASC	1914	1,027	699	Sulphur	5,350
381	ASC	1915	898	436	Sulphur	-
382	ASC	1914	908	450	Sulphur	105,085
383	ASC	1914	1,038	516	Sulphur	12,405
384	ASC	1914	973	405	Sulphur	82,395
385	ASC	1914	938	443	Sulphur	25,730
386	ASC	1914	1,042	533	Sulphur	65
387	ASC	1914	992	603	Sulphur	3,740
388	ASC	1914	1,062	540	Sulphur	19,365
389	ASC	1914	955	535	Sulphur	68,370
390	ASC	1914	1,043	502	Sulphur	2,570
391	ASC	1914	1,045	552	Water/Sulphur	20,935
392	ASC	1914	1,041	413	Water	925
393	ASC	1914	1,007	381	Water	-
394	ASC	1914	618	-		-
395	ASC	1914	1,168	540		-
396	ASC	1914	1,047	502	Sulphur	29,530
397	ASC	1913	987	673	Sulphur	54,830
398	ASC	1914	712	-		-
399	ASC	1915	1,017	521	Sulphur	4,840
400	ASC	1915	1,156	450		-

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
401	ASC	1915	1,161	593	Water	-
402	ASC	1915	1,206	661	Sulphur	21,405
403	ASC	1915	1,191	498	Sulphur	5,735
404	ASC	1915	1,300	667		-
405	ASC	1915	1,265	416	Sulphur	11,880
406	ASC	1915	1,042	633	Sulphur	62,135
407	ASC	1915	1,128	547	Sulphur	21,975
408	ASC	1915	1,180	468	Sulphur	410
409	ASC	1915	1,039	728	Sulphur	43,010
410						
411	ASC	1915	1,155	589		-
412	ASC	1915	1,235	411	Sulphur	14,855
413	ASC	1915	1,082	491	Sulphur	2,565
414	ASC	1915	992	484	Sulphur	3,320
415	ASC	1915	1,002	564	Sulphur	3,890
416	ASC	1915	1,255	822	Sulphur	6,340
417	ASC	1915	1,219	616	Sulphur	11,630
418	ASC	1915	1,039	547	Sulphur	28,435
419	ASC	1915	1,291	495	Sulphur	12,345
420	ASC	1915	1,343	540	Sulphur	15,125
421	ASC	1915	1,064	497	Sulphur	6,060
422	ASC	1915	1,360	580		-
423	ASC	1916	1,168	585	Sulphur	1,135
424	ASC	1915	1,412	592	Sulphur	34,900
425						
426	ASC	1916	1,159	537	Water Well	3,060
427	ASC	1916	1,177	689	Sulphur	21,815
428	ASC	1916	1,036	614		-
429	ASC	1916	1,172	784	Sulphur	6,425
430	ASC	1916	1,089	599	Sulphur	116,395
431	ASC	1916	632	560	Sand Grouting	-
432	ASC	1916	1,507	670		-
433	ASC	1916	1,283	538	Sulphur	2,130
434	ASC	1916	1,160	569	Sulphur	6,695
435	ASC	1916	1,121	834	Sulphur	7,450
436	ASC	1916	936	497	Sulphur	6,030
437	ASC	1916	1,113	740	Sulphur	-
438	ASC	1916	1,226	525	Sulphur	14,705
439	ASC	1916	762	488	Sanding	-
440	ASC	1916	1,149	785	Sulphur	5,360

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
441	ASC	1916	886	700	Sulphur	14,340
441A	ASC	1917	706	700		-
442	ASC	1916	1,230	827	Sulphur	78,850
443	ASC	1916	1,190	789	Sulphur	4,815
444	ASC	1916	1,049	672	Sulphur	16,375
445	ASC	1916	1,284	566	Sulphur	25,145
446	ASC	1916	1,301	578	Sulphur	12,010
447	ASC	1916	1,110	579	Sulphur	24,655
448	ASC	1916	696	678	Sulphur	-
449	ASC	1916	1,240	556	Sulphur	-
450	ASC	1916	1,041	541	Sulphur	15,095
451	ASC	1916	1,129	695	Sulphur	7,345
452	ASC	1916	1,461	569	Sulphur	25,535
452A	ASC	1917	670	535		-
453	ASC	1916	1,273	425	Sulphur	85,670
453A	ASC	1917	440	425		-
454	ASC	1916	1,453	633	Sulphur	4,065
455	ASC	1917	1,089	800	Sulphur	7,135
456	ASC	1916	1,112	812	Sulphur	8,875
456A	ASC	1917	754	-		-
457	ASC	1916	1,212	705	Water Well	-
458	ASC	1916	1,303	654	Water Well	-
459	ASC	1916	1,244	538	Sulphur	310
460	ASC	1917	1,115	496	Sulphur	39,595
461	ASC	1916	1,371	657	Sulphur	20,155
462	ASC	1916	1,317	455	Water	-
463	ASC	1917	1,395	561	Sulphur	16,260
464	ASC	1917	1,058	504	Sulphur	-
465	ASC	1917	1,084	836	Sulphur	32,195
466	ASC	1917	1,078	526	Sulphur	15,440
467	ASC	1917	1,187	950	Sulphur	35,745
468	ASC	1917	1,169	862	Sulphur	59,435
469	ASC	1917	617	-		-
470	ASC	1917	1,369	975		-

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
471	ASC	1917	875	-		-
472	ASC	1917	1,215	778	Sulphur	83,230
473	ASC	1917	1,211	614	Sulphur	12,520
474	ASC	1917	1,072	520	Sulphur	39,995
475	ASC	1917	1,185	920	Sulphur	-
476	ASC	1917	724	701		-
477	ASC	1917	1,044	774	Sulphur	34,505
478	ASC	1917	1,070	814	Sulphur	25,650
479	ASC	1917	1,145	748		-
480	ASC	1918	1,001	685	Sulphur	140
481						
482	ASC	1917	863	863		-
483	ASC	1917	1,267	508	Sulphur	12,940
484	ASC	1917	1,061	524	Sulphur	35,860
485	ASC	1917	965	597		-
486	ASC	1917	1,083	740	Sulphur	47,140
487	ASC	1917	1,135	658		-
488	ASC	1917	1,008	555		-
489	ASC	1917	1,030	562	Sulphur	97,140
490	ASC	1917	1,343	648	Cold Water Well	-
491	ASC	1918	1,264	652	Water	-
492	ASC	1917	675	576	Cold Water Well	-
493	ASC	1918	1,256	593	Water	-
494	ASC	1917	1,129	844	Cold Water Well	-
495	ASC	1917	1,007	800	Cold Water Well	-
496	ASC	1917	1,134	947	Cold Water Well	-
497	ASC	1917	1,028	516	Sulphur	78,735
498	ASC	1917	950	704		-
499	ASC	1917	1,095	911	Sulphur	12,045
500	ASC	1918	1,019	552	Sulphur	600

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
501	ASC	1918	1,016 A	595	Sulphur	124,585
502	ASC	1918	1,200 A	790	Sulphur	36,360
503	ASC	1918	1,061 A	809	Sulphur	27,115
504	ASC	1918	1,222 A	596	Sulphur	26,970
505	ASC	1918	1,569	886	Sulphur	6,150
506	ASC	1918	1,471	850	Sulphur	4,440
507	ASC	1918	1,227 A	481	Sulphur	23,090
508	ASC	1918	1,275 A	582	Sulphur	450
509	ASC	1918	1,071	628	Sulphur	64,220
510	ASC	1918	1,203 A	496	Sulphur	4,395
511	ASC	1918		-	Sulphur	-
512	ASC	1918	1,146 A	796	Sulphur	48,235
513	ASC	1918	1,062 A	625	Sulphur	85,225
514	ASC	1920	1,025 A	526	Sulphur	24,245
515	ASC	1918	1,024	562	Sulphur	43,045
516	ASC	1918	1,202 A	772	Sulphur	30,455
517	ASC	1918	762 A	486		-
518	ASC	1918	1,137 A	480	Sulphur	42,280
519	ASC	1918	1,226 A	576	Sulphur	42,615
520	ASC	1920	1,424 A	714	Sulphur	89,065
521	ASC	1918	1,105 A	775	Sulphur	55
522	ASC	1918	1,127 A	895	Sulphur	10,135
523	ASC	1918	1,079 A	772	Sulphur	41,805
524	ASC	1920	1,007 A	547	Sulphur	20,265
525	ASC	1918	1,036 A	601	Sulphur	83,925

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
526	ASC	1918	1,150 A	596		-
527	ASC	1918	1,114 A	788	Sulphur	4,080
528	ASC	1918	1,160 A	-	Water	-
529	ASC	1919	A	-		-
530	ASC	1921	1,173 A	524	Sulphur	8,175
531	ASC	1923	1,338 A	542	Sulphur	20
532	ASC	1918	983 A	515	Sulphur	13,690
533	ASC	1920	1,024 A	518	Sulphur	16,280
534	ASC	1918	1,220 A	537	Sulphur	-
535	ASC	1918	1,244 A	533	Water	-
536	ASC	1920	1,086 A	466	Sulphur	99,165
537	ASC	1918	1,215 A	475	Sulphur	48,435
538	ASC	1918	1,125	925	Sulphur	13,455
539	ASC	1921	1,095 A	773	Sulphur	-
540	ASC	1919	1,202 A	623	Sulphur	280
541	ASC	1919	1,215 A	699	Sulphur	1,265
542	ASC	1921	1,337 A	679	Sulphur	44,475
543	ASC	1919	829 A	-		-
544	ASC	1919	1,054 A	833		-
545	ASC	1919	1,133 A	887		-
546	ASC	1919	1,070 A	566	Sulphur	20,565
547	ASC	1920	1,070 A	596	Sulphur	6,975
548	ASC	1920	1,059 A	598	Sulphur	62,785
549	ASC	1920	1,230	601	Sulphur	68,245
550	ASC	1920	1,275	892	Sulphur	33,310
551	ASC	1920	1,345 A	552	Water	33,310
552	ASC	1921	1,066	575	Sulphur	1,375
553	ASC	1921	1,330	475	Water	-
554	ASC	192	1,097 A	572	Sulphur	-

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
555	ASC	1921	1,053 A	623	Sulphur	-
556	ASC	1921	1,320 A	609		-
557	ASC	1921	1,409 A	782	Sulphur	-
558	ASC	1921	1,057 A	519	Sulphur	1,005
559	ASC	1921	1,318 A	576	Sulphur	16,840
560						
561	ASC	1921	1,080 A	801	Sulphur	1,165
562	ASC	1921	1,059	552	Sulphur	7,795
563	ASC	1921	1,046 A	515		-
564	ASC	1921	1,089	500	Sulphur	81,920
565	ASC	1921	565 A			-
566	ASC	1921	1,183 A	859	Sulphur	73,870
567	ASC	1921	1,338	594	Sulphur	16,505
568	ASC	1921	1,306 A	578	Sulphur	105,410
569	ASC	1921	1,250 A	590	Water	165,090
570	ASC	1921	1,396 A	698	Sulphur	-
571	ASC	1921	1,319	533		110,290
572	ASC	1921	1,177 A	527		9,665
573	ASC	1921	1,196 A	513	Sulphur	72,360
574	ASC	1921	1,066 A	482	Sulphur	-
575	ASC	1921	1,012 A	550	Sulphur	-

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
576	ASC	1921	1,188	1014	Sulphur	77,150
577	ASC	1921	1,296 A	540	Water	-
578	ASC	1921	1,344 A	491	Sulphur	45,105
579	ASC	1921	1,344 A	628	Sulphur	5,380
580	ASC	1921	1,201 A	537	Sulphur	78,680
581	ASC	1921	1,208 A	493	Sulphur	100
582	ASC	1921	978 A	-		-
583	ASC	1921	1,318 A	855	Sulphur	36,275
584	ASC	1921	1,234 A	503	Sulphur	57,995
585	ASC	1921	1,200 A	545	Sulphur	51,760
586	ASC	1922	1,342	727	Sulphur	72,175
587	ASC	1922	1,472 A	473	Sulphur	7,910
588	ASC	1922	1,288 A	989	Sulphur	525
589	ASC	1922	1,138 A	855	Sulphur	8,085
590	ASC	1922	1,066	738	Sulphur	455
591	ASC	1922	1,181 A	650	Sulphur	225
592	ASC	1922	1,256	544	Sulphur	76,390
593	ASC	1922	1,283 A	663	Sulphur	54,680
594	ASC	1922	1, ?	917		-
595	ASC	1922	1,301	582	Sulphur	125,710
596	ASC	1922	1,118 A	936	Sulphur	11,815
597	ASC	1922	1,196 A	468	Sulphur	-
598	ASC	1922	1,209 A	899	Sulphur	24,190
599	ASC	1922	1,281 A	834	Water	-
600	ASC	1922	1,304 A	481	Sulphur	-

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
601	ASC	1922	1,157	672	Sulphur	16,265
602	ASC	1922	1,298	440	Sulphur	2,300
603	ASC	1922	1,319	534	Sulphur	121,905
604	ASC	1922	1,240	566	Sulphur	49,395
605	ASC	1922	1,328	667	Sulphur	47,910
606	ASC	1922	1,350	737	Water	-
607	ASC	1922	1,328	687	Sulphur	6,750
608	ASC	1922	1,202	636	Sulphur	-
609	ASC	1922	1,260	600	Sulphur	-
610	ASC	1922		824-829	Sulphur	-
611	ASC	1922	1,398	659	Sulphur	60,395
612	ASC	1922	1,390	520	Sulphur	-
613	ASC	1922	1,393	535	Water	18,070
614	ASC	1922	1,219	884	Water	-
615	ASC	1922	1,326	550	Sulphur	20
616	ASC	1922	1,397	658	Sulphur	63,545
617	ASC	1922	1,358	593	Sulphur	23,180
618	ASC	1922	1,444	650	Water	-
619	ASC	1922	1,398	728	Sulphur	63,325
620	ASC	1922	1,361	698	Sulphur	24,325
621	ASC	1922	1,552	791	Sulphur	-
622	ASC	1922	1,403	653	Sulphur	16,625
623	ASC	1923	1,355	574	Sulphur	-
624	ASC	1923	1,362	602	Sulphur	-
625	ASC	1923	1,402	602	Sulphur	25,760
626	ASC	1923	1,189	835	Sulphur	-
627	ASC	1923	1,451	633	Sulphur	-
628	ASC	1923	1,316	571	Sulphur	10,200
629	ASC	1923	1,409	520	Sulphur	22,270
630	ASC	1923	1,347	670	Sulphur	1,305
631	ASC	1923	1,364	616	Sulphur	11,685
632	ASC	1923	1,403	516	Water	-
633	ASC	1923	1,315	542	Sulphur	17,945
634	ASC	1923	1,303	898	Sulphur	-
635	ASC	1923	1,314	586	Water	20
636						
637	ASC	1924	351		Sulphur	-
638	ASC	1923	1,313	1,112	Sulphur	85,430
639	ASC	1923	1,322	563	Sulphur	18,685

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
640	ASC	1923	1,463	710	Sulphur	-
641	ASC	1923	1,401	652	Sulphur & Water	8,995
642	ASC	1923	1,308	586	Sulphur	15,375
643	ASC	1923	1,368	535	Sulphur	15,890
644	ASC	1923	1,313	1,043	Sulphur	27,770
645	ASC	1923	1,303	574	Sulphur	30
646	ASC	1923	1,172	720	Sulphur	3,135
647	ASC	1923	1,414	656	Water	-
648	ASC	1923	1,325	692	Sulphur	-
649	ASC	1923	1,321	1,066	Sulphur	4,755
650	ASC	1923	1,276	954	Sulphur	-
651	ASC	1923	1,351	733	Sulphur	2,665
652	ASC	1923	1,413	1,019	Water	29,850
653	ASC	1923	1,417	670	Sulphur	-
654	ASC	1923	1,266	757	Sulphur	15
655	ASC	1923	1,500	705	water	
656	ASC	1923	1,336	1,065	Sulphur	
657	ASC	1923	1,277	896	Sulphur	30
658	ASC	1923	1,414	705	Sulphur	480
659	ASC	1923	1,280	1,071	Sulphur	8,125
660	ASC	1923	1,493	586	Sulphur	
661	ASC	1923	1,369	1,002	Sulphur	
662	ASC	1923	1,418	812	Sulphur	17,955
663	ASC	1923	1,464	990	water	24,900
664	ASC	1923	1,435	599	Sulphur	6,540
665	ASC	1924	1,411	537	Sulphur	-
666	ASC	1924	851	490	Sulphur	-
667	ASC	1924	1,502	1,149	water	-
668	ASC	1924	1,340	1,058	Sulphur	27,725
669	ASC	1924	1,304	1,002	Sulphur	17,525
670	ASC	1924	1,416	664	Sulphur	9,560
671	ASC	1924	1,406	562	Sulphur	1,245
672	ASC	1924	1,398	647	Sulphur	0
673	ASC	1924	1,448	623	Sulphur	17,545
674						
675	ASC	1924	1,384	1,011	Sulphur	7,735
676	ASC	1924	1,339	1,028	water	-
677	ASC	1924	1,385	1,154	Sulphur	3,870
678	ASC	1924	1,398	1,046	Sulphur	3.725

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
679	ASC	1924	1,386	778	Sulphur	2,105
680						
681	ASC	1924	1,432	494	Sulphur	9,640
682	ASC	1924	1,308	962	Sulphur	2,675
683	ASC	1924	1,445	883	Sulphur	-
684	ASC	1924	1,427	1,084	Sulphur	2,040
685	ASC	1924	1,436	772	Sulphur	1,610
686	ASC	1924	1,398	1,138	Sulphur	6,405
687	ASC	1924	1,330	935	water	0
688	ASC	1924	1,043	826	Sulphur	-
689						
690						
691	ASC	1924	1,532	931	Sulphur	-
692	ASC	1924	1,342	1,075	Sulphur	-
693	ASC	1924	1,388	1,190	Sulphur	-
694	ASC	1924	1,385	1,100	Sulphur	3,345
695	ASC	1924	1,394	758	water	-
696	ASC	1924	1,404	828	water/sulphur	2,070
697	ASC	1924	1,438	909	Sulphur	5,615
698	ASC	1924	1,449	1,399	Sulphur	-
699	ASC	1924	1,359	900	Sulphur	205
700	ASC	1924	1,224	792	water	-
701	ASC	1924	1,470	1,045	Sulphur	-
702	ASC	1924	1,083	683	Sulphur	-
703	ASC	1924	1,324	952	Sulphur	-
704	ASC	1924	886	616	Sulphur	-
705	ASC	1924	870	667	Sulphur	-
706						
707						
708	ASC	1924	599	599	Sulphur	-
709	ASC	1924	work abandoned			-
Test Well #8	ASC	1922	362			
Oil Well #5	ASC	1916	397	378	oil	-
Water Well 1919 Cottages	ASC	1919	564	-	water	-
Fresh Water Well	ASC	1916	771	2	water	-
Fresh Water Well	ASC	1911	624	-	water	-

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	PURPOSE	TOTAL PRODUCTION (tons)
Boiler Supply Water Well #1	ASC	1917	604	-	Water	-
Boiler Supply Water Well #2	ASC	1918	690	-	Water	-
Boiler Supply Water WEll #3	ASC	1918	521	-	Water	-

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	SALT DEPT (feet)	PURPOSE
721	USC *	1927	3355			Oil
722	USC	1928	3491			Oil
723	USC	1928	3063			Oil
723 WO#1	USC	1933	4340	4245	4273	Oil
723 WO#2	USC	1938	3076	2785	3033 (Actual Depth)	Oil
725	USC	1928	3429			Oil
725 Run#2	USC	1938	4829		4746 (Actual Depth)	Oil
725 Run#5	USC	1943	4458		4395 (Actual Depth)	Oil
727	USC	1928	4045			Oil
728	USC	1928	6081			Oil
729	USC	1929	3201		2593	Oil
730	USC	1928	5700			Oil
731	USC	1928	4849			Oil
732	USC	1928	3262			Oil
733	USC	1929	6104			Oil
734	USC	1938	4870			Oil
737 Run#2	USC	1940	4200	4045 (Actual Depth)	4071 (Actual Depth)	Oil
741 WO#2	USC	1937	3640		3640.	Oil
745 Run #5	USC		3482			Oil
746	USC	1929	4159			Oil
747 WO#1	USC	1929	3155		3755	Oil
748	USC	1929	4059			Oil
756	USC	1938	5366			Oil
757	USC	1937	4359			Oil
757 Run #2	USC	1937	4598			Oil
759 Run#1	USC	1937	4552	4439 (Actual Depth)	4509 (Actual Depth)	Oil
759 Run#2	USC	1939	3507	3418 (Actual Depth)	3479 (Actual Depth)	Oil
759 Run#3	USC	1940	3023		3382 (Actual Depth)	Oil
760 WO#2	USC	1937	5247			Oil
761	USC	1940	4522		4496 (Actual Depth)	Oil
763 Run#2	USC		5265			Oil
766	USC	1940	3434			Oil
767	USC	1936	4547		4547	Oil
769	USC	1937	4775			Oil
773 WO#3	USC		4765		4765	Oil
779 Run#1	USC	1936	3780			Oil
779 Run#2	USC	1938	4154			Oil

*Union Surphur Company

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	SALT DEPT (feet)	PURPOSE
779 Run#3	USC *	1939	3533			Oil
781 Run#1	USC	1936	3689			Oil
481 Run#2	USC	1937	3876	3828	3869	Oil
782	USC	1936	4195			Oil
785	USC	1936	3799			Oil
786	USC	1940	5775			Oil
793	USC	1940	3355			Oil
797 Run#2	USC	1935	4094			Oil
798 (Deepening)	USC	1936	3652			Oil
799	USC		2957			Oil
800 Run#2	USC	1935	2977			Oil
800 Run#3	USC	1935	2974			Oil
800 Run#4	USC	1935	3039			Oil
801	USC	1937	3752			Oil
803	USC	1936	3410		3410	Oil
806 Sidetrack	USC	1936	3226			Oil
806 Run#1	USC	1934	2841			Oil
806 Run#2	USC	1935	3222			Oil
806 Run#4	USC	1937	3290			Oil
806 Run#5	USC	1937	3343			Oil
806 Run#6	USC	1937	3422			Oil
806 Run#7	USC	1939	3034			Oil
806 Run#8	USC	1939	3581			Oil
806 Run#9	USC	1939	4009		3953 (Actual Depth)	Oil
807	USC	1935	3267			Oil
810	USC	1935	2664			Oil
810	USC	1936	2857			Oil
810 Run#2	USC	1936	3120			Oil
810 Run#3	USC	1936	3236			Oil
811 Run#2	USC	1939	3419	3327 (Actual Depth)		Oil
812	USC	1935	4155		4155	Oil
813	USC	1935	5309		5309	Oil
814	USC	1935	3373			Oil
815	USC	1935	2926			Oil

*Union Sulphur Company

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	SALT DEPT (feet)	PURPOSE
815 Sidetrack	USC *	1935	3210		3192	Oil
815 Run#3	USC	1935	2960			Oil
815 Run#4	USC	1936	3413			Oil
816	USC	1935	5333			Oil
816 Sidetrack	USC	1936	5331		5331	Oil
817	USC	1935	2936			Oil
817 Run#2	USC	1940	3675			Oil
818	USC	1936	3805			Oil
818 Run#2	USC	1937	3841			Oil
819	USC	1936	4259			Oil
820	USC	1936	3264			Oil
820 Run#2	USC	1936	3988			Oil
820 Run#3	USC	1936	4266			Oil
820 Sidetrack	USC	1936	3177			Oil
820 Run#5	USC	1939	3834			Oil
821	USC	1936	3391			Oil
821 Run#2	USC	1939	3492			Oil
821 Run#3	USC	1939	4106		4089 (Actual Depth)	Oil
822	USC	1936	3328			Oil
823	USC	1936	3032			Oil
824	USC	1936	4185			Oil
824 Run#2	USC	1936	4315			Oil
824 Run #3	USC	1936	4454			Oil
824 Run #4	USC	1936	3915			Oil
824	USC	1936	3151			Oil
826	USC	1936	3464			Oil
828	USC	1936	3111			Oil
828 Run #2	USC	1936	3358			Oil
828 Run #3	USC	1939	3509			Oil
828 Run #4	USC	1939	3966		3931 (Actual Depth)	Oil
829	USC	1936	4247			Oil
830	USC	1936	3106			Oil
831	USC	1937	4044			Oil
832	USC	1936	3738			Oil
833	USC	1936	2919			Oil
833 Run #3	USC	1938	3665		3628 (Actual Depth)	Oil

*Union Sulphur Company

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	SALT DEPT (feet)	PURPOSE
824	USC*	1936	4464		4444 (Actual Depth)	Oil
834 Sidetrack	USC	1936	4100			Oil
835	USC		4350			Oil
836	USC	1936	4583			Oil
837	USC	1941	4887			Oil
838	USC	1936	4438			Oil
839	USC	1936	3875			Oil
839 Run #2	USC	1936	3940			Oil
839 Run #3	USC	1939	4216		4176 (Actual Depth)	Oil
840	USC	1937	3740		3731 (Actual Depth)	Oil
840 Run #2	USC	1939	3564			Oil
841	USC	1936	4455			Oil
842 Side track	USC	1937	5141			Oil
843	USC	1937	3224			Oil
844 Run #1	USC	1937	5183			Oil
845	USC	1937	4485			Oil
848 Run #2	USC	1945	5192			Oil
848 Run #3	USC	1945	5083			Oil
850	USC	1937	5142			Oil
851 Run #3	USC	1944	5345			Oil
852 Run #5	USC	1938	5171			Oil
854 Run #4	USC	1945	5448			Oil
857 Run #1	USC	1938	6742			Oil
858 Run #1	USC	1938	5005			Oil
860	USC	1938	5736			Oil
861 Run #1	USC	1938	3780			Oil
863 Run #1	USC		3368			Oil
863 Run #2	USC		3482			Oil
864 Run #1	USC	1938	4636			Oil
865 Run #3	USC	1940	6588		6515	Oil
867	USC	1940	6989			Oil
868	USC	1940	6239			Oil
869 Run E1	USC	1940	5826			Oil
870	USC	1940	6478			Oil
871 Run #1	USC	1940	7655			Oil
872	USC	1940	5889			Oil
873 Run #1	USC	1940	6350			Oil

*Union Sulphur Company

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	SALT DEPT (feet)	PURPOSE
874 Run #1	USC	1940	5103		5050 (Actual Depth)	Oil
875	USC	1941	6660			Oil
876 Run #1	USC	1941	6127			Oil
877	USC	1941	5990		5321 (Actual Depth)	Oil
878	USC	1941	7209			Oil
879 Sidetrack	USC	1942	6834			Oil
880 Run #3	USC	1945	7136			Oil
881 Run #1	USC	1941	3447			Oil
882 Run #1	USC	1948	1416			Oil
883 Run #1	USC	1948	4918			Oil
885	USC	1945	5492			Oil
886	USC	1944	7266			Oil
887	USC	1945	6981			Oil
888	USC	1945	5135			Oil
889	USC	1945	5450			Oil
840	USC	1946	5547		5413 (Actual Depth)	Oil
840 Sidetrack#1	USC		4550		4402 (Actual Depth)	Oil
890 Sidetrack#2	USC		3874			Oil
891 Run #1	USC	1946	4413		4305 (Actual Depth)	Oil
841 Run #2	USC	1946	220			Oil
891 Run #3	USC	1946	4842		4767 (Actual Depth)	Oil
892 Run #1	USC	1942	2820		2763 (Actual Depth)	Oil
893	USC	1946	4836		4836	Oil
894 Run #1	USC	1946	5126		5027 (Actual Depth)	Oil
894 Run#2&3	USC	1946	6066		5915 (Actual Depth)	Oil
894 Run #4	USC	1947	2563	2499 (Actual Depth)		Oil
895 Run #1	USC	1947	2636		2592 (Actual Depth)	Oil
896	USC	1947	1625		1570	Oil
896 Sidetrack	USC	1947	3850		3813	Oil
897	USC	1948	5466			Oil
897 Run #2	USC	1948	4988			Oil
899	USC	1947	3429		3378 (Actual Depth)	Oil
898	USC	1947	1907		1870 (Actual Depth)	Oil
900	USC	1948	1946		1878 (Actual Depth)	Oil
900 Run #2	USC	1948	3134			Oil
901 Run #1	USC	1948	3266		3238 (Actual Depth)	Oil
902 Run #1	USC	1948	4872			Oil
903	USC	1948	5974			Oil

*Union Sulphur Company

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	SALT DEPT (feet)	PURPOSE
904	USC*	1949	3305			Oil
905	USC	1949	4403		4334 (Actual Depth)	Oil
907	USC	1949	3824		3768 (Actual Depth)	Oil
908	USC	1949	4640			Oil
909	USC	1950	6012			Oil
909 Sidetrack	USC	1950	6879			Oil
910	USC	1950	5037			Oil
911	USC	1950	4785			Oil
912	USC	1950	3568			Oil
913	USC	1950	4398			Oil
913 Sidetrack	USC	1950	4379			Oil
914	USC	1950	7114			Oil
916	USC	1951	4766			Oil
917	USC	1953	5126			Oil
918	USC	1953	6741			Oil
918 Run #2	USC	1953	6940			Oil
919	UTPC**	1962	6880			Oil
619 Sidetrack	UTPC	1962	6206			Oil
920	UTPC	1966	5088			Oil
921	UTPC	1967	5755			Oil
922	UTPC	1971	5758			Oil
923	UTPC	1971	6250			Oil
925	UTPC	1975	5196			Oil
926	UTPC	1975	5385			Oil
927	UTPC	1975	7138			Oil
928	UTPC	1975	7350			Oil
929	UTPC	1977	4333			Oil
930	UTPC	1977	6368			Oil
931	UTPC	1977	5580			Oil
932	UTPC	1977	5210			Oil
933	UTPC	1977	4827			Oil
934	UTPC	1977	4904			Oil
935	UTPC	1977	4800			Oil
935 Sidetrack	UTPC	1977	4368			Oil

*Union Sulphur Company
**Union Texas Petroleum Company

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	SALT DEPT (feet)	PURPOSE
937	UTPC **	1977	5074			Oil
938	UTPC	1977	3473			Oil
939	UTPC	1977	5261			Oil
940	UTPC	1978	4226		3983 (Actual Depth)	Oil
941	UTPC	1978	4015			Oil
942	UTPC	1978	3896		3836 (Actual Depth)	Oil
943	UTPC	1978	6810			Oil
944	UTPC	1978	7000			Oil
945	UTPC	1978	6822			Oil

**Union Texas Petroleum Company

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	SALT DEPTH (feet)	PURPOSE
S-1	UTPC*	1965	1,490	1,020	1,480	Sulphur Test Well
S-2	UTPC	1965	1,496	1,339	1,474	Sulphur Test Well
S-3	UTPC	1965	1,479	505	1,479	Sulphur Test Well
S-4	UTPC	1965	1,492	1,190	1,486	Sulphur Test Well
S-5	UTPC	1965	1,478	754	-	Sulphur Test Well
S-6	UTPC	1965	1,997	1,614	1,709	Sulphur Test Well
S-7	UTPC	1965	1,459	1,362		Sulphur Test Well
S-8	UTPC	1965	1,401	1,020		Sulphur Test Well
S-9	UTPC	1965	1,488	1,232	1,481	Sulphur Test Well
S-10	UTPC	1965	1,486	712		Sulphur Test Well
S-11	UTPC	1965	1,248	445		Sulphur Exploration
S-12	UTPC	1965	1,426	758		Sulphur Exploration
S-13	UTPC	1965	1,506	896	1,481	Sulphur Exploration
S-14						
S-15	UTPC	1965	1,453			Sulphur Exploration
S-16	UTPC	1965	1,451	1,040		Sulphur Exploration
S-17	UTPC	1965	1,243	464		Sulphur Exploration
S-18	UTPC	1965	1,450	437		Sulphur Exploration
S-19	UTPC	1965	1,450	770		Sulphur Exploration
S-20	UTPC	1965	1,449	491		Sulphur Exploration
S-21	UTPC	1965	1,445	1,048		Sulphur Exploration
S-22	UTPC	1965	1,260	517		Sulphur Exploration
S-23	UTPC	1965	1,452	845		Sulphur Exploration
S-24	UTPC	1965	1,479	500	1,472	Sulphur Exploration
S-25	UTPC	1965	1,447	520		Sulphur Exploration
S-26	UTPC	1965	515	407		Sulphur Exploration
S-27	UTPC	1965	635	450		Sulphur Exploration
S-28	UTPC	1965	1,366	436		Sulphur Exploration
S-29	UTPC	1965	1,377	514		Sulphur Exploration
S-30	UTPC	1965	1,252	495		Sulphur Exploration
S-31	UTPC	1965	1,024	475		Sulphur Exploration

* Union Texas Petroleum Company

WELL NUMBER	DRILLED FOR	DATE DRILLED	TOTAL DEPTH (feet)	ROCK DEPTH (feet)	SALT DEPT (feet)	PURPOSE
S-32	UTPC*	1965	1,440	378		Sulphur Exploration
S-33	UTPC	1965	1,455	462		Sulphur Exploration
S-34	UTPC	1965	1,455	422		Sulphur Exploration
S-35	UTPC	1965	1,451	435		Sulphur Exploration
S-36	UTPC	1965	1,434	400		Sulphur Exploration
S-37	UTPC	1965	1,311	546		Sulphur Exploration
S-38	UTPC	1965	1,450	470		Sulphur Exploration
S-39	UTPC	1965	1,380	1,050		Sulphur Exploration
S-40	UTPC	1965	1,444	537		Sulphur Exploration
S-41	UTPC	1965	1,450	406		Sulphur Exploration
S-42	UTPC	1965	1,451	466		Sulphur Exploration
S-43	UTPC	1965	1,394	914		Sulphur Exploration
S-44	UTPC	1965	848	595		Sulphur Exploration
S-45	UTPC	1965	1,437	604		Sulphur Exploration
S-46	UTPC	1965	1,444	597		Sulphur Exploration
S-47	UTPC	1965	1,421	565		Sulphur Exploration
S-48	UTPC	1965	1,470	738		Sulphur Exploration
S-49	UTPC	1965	1,446	1,110		Sulphur Exploration
S-50	UTPC	1965	1,465	661		Sulphur Exploration
S-51	UTPC	1965	1,461	597		Sulphur Exploration
S-52	UTPC	1965	1,459	695		Sulphur Exploration
S-53	UTPC	1965	1,467	689		Sulphur Exploration
S-54	UTPC	1965	1,467	697		Sulphur Exploration
S-55	UTPC	1965	1,465	1,250		Sulphur Exploration
S-56	UTPC	1965	1,463	1,015		Sulphur Exploration
S-57	UTPC	1965	1,450	1,212		Sulphur Exploration
S-58	UTPC	1965	1,476	770		Sulphur Exploration
S-59	UTPC	1965	1,503	768	1,476	Sulphur Exploration
S-60	UTPC	1965	1,500	790		Sulphur Exploration
S-61	UTPC	1965	1,504	896		Sulphur Exploration
S-62	UTPC	1965	1,463	735		Sulphur Exploration
S-63	UTPC	1965	1,495	752	1,480	Sulphur Exploration
S-64	UTPC	1965	1,485	727	1,480	Sulphur Exploration
S-65	UTPC	1965	1,459	586		Sulphur Exploration
S-66	UTPC	1965	1,501	1,244	1,474	Sulphur Exploration

* Union Texas Petroleum Company

APPENDIX D

APPENDIX
D

APPENDIX D

MODIFIED MERCALLI INTENSITY SCALE OF 1931
(Abridged)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.

IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

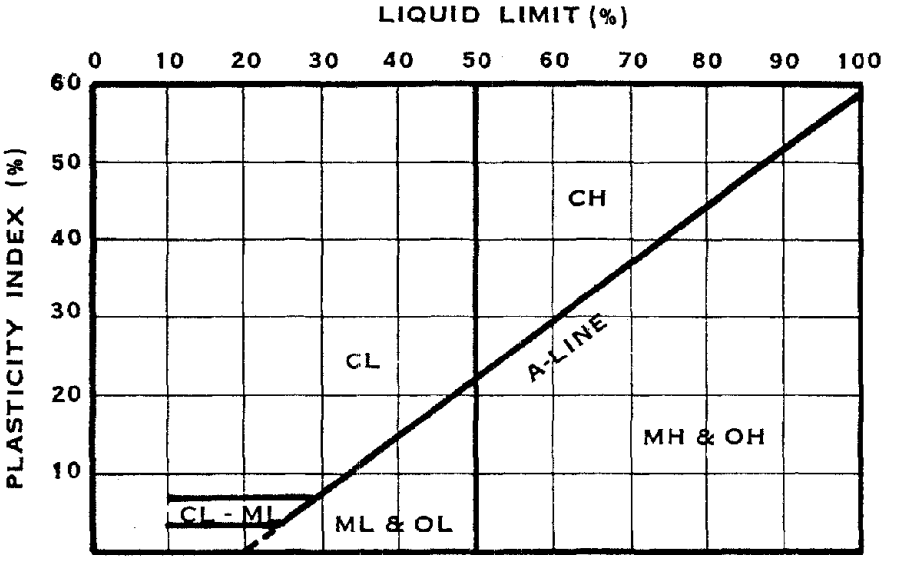
XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

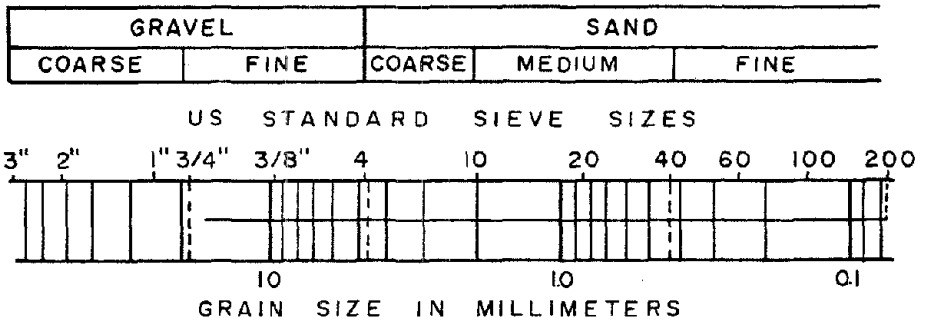
APPENDIX
E

APPENDIX
E

PLASTICITY CHART



PARTICLE SIZE DISTRIBUTION



(SM) SILTY SANDS, SAND-SILT MIXTURES WITH AN APPRECIABLE AMOUNT OF FINES.

(SP) POORLY-GRADED SANDS, GRAVELLY SANDS WITH LITTLE OR NO FINES.

(ML) INORGANIC SILTS AND VERY FINE SANDS, SILTY OR CLAYEY SILTS WITH SLIGHT PLASTICITY.

(MH) INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS.

(CL) INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS.

(CH) INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS.

(OL) ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY.

(OH) ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS.

PREPARED BY LSK DATE 1/86
CHECKED BY GDS DATE 1/86
REVISED BY ____ DATE ____
APPROVED BY LSK DATE 1/86

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME
LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

UNIFIED SOIL CLASSIFICATION SYSTEM

APPENDIX E

APPENDIX
F

APPENDIX
F

APPENDIX F

Detailed Investigation of Dome Flank Proximity to SPR Cavern No. 4

Appendix F was written after the Geological Characterization, Sulphur Mines SPR Site report (Law Engineering, 10/80) was completed. The original report estimated the distance from the edge of SPR Storage Cavern No. 4 to the flank of the salt dome as 155 ±50 feet. This estimate was based on a few well records and a gravity model. The gravity model did not have a close grouping of gravity stations over the southeastern portion of the dome. A closer investigation was proposed for this region, due to the previously limited data base and the potential for breaching at this closest approach of the cavern to the dome flank.

Sandia National Laboratory requested Law Engineering Testing Company perform a supplemental study to refine the salt dome contour map near SPR Storage Cavern No. 4. This was accomplished by ordering, analyzing and plotting additional well information for the southeastern flank of the salt dome. This information included additional geophysical logs, completion cards, drillers' logs, well histories, field notes, and directional drilling surveys (see Table F-1).

The revised contour maps of the southeastern flank (Figures F-1, F-2, F-3) show the closest approach of SPR Storage Cavern No. 4 to the salt dome flank to be 185 ±50 feet. The ±50 feet range of error has not been reduced due to the sparse well control at this closest approach to the dome flank. This error

could be reduced by a test boring drilled from the surface to the exact point in question. Careful directional drilling will be required to execute this test and avoid breaching the cavern and its coalesced neighbors, SPR Storage Caverns No. 2 and 5.

Contouring Procedures

Completion cards, geophysical logs, directional surveys, drillers' logs, well histories, and field notes were obtained for each sulphur and petroleum exploration well in the area of interest. Not every catagory of information was available for each well. The forms of information obtained and the resulting data are recorded in Table F-1.

The top of the salt dome was identified from geophysical logs. When these logs were unavailable, completion cards, drillers' logs, well history reports, or field notes were used to establish the occurrence of salt in a boring. The elevation of the first occurrence of salt, or the bottom of the well when salt was not encountered, was calculated by subtracting the vertical depth correction (given on the directional survey) and the elevation of the kelly bushing (the point from which most logs were measured) from the apparent depth given on the geophysical logs. The surface elevation was obtained from a topographic map of scale 1:1,200 (1"=100') then added to the distance between the ground surface and the kelly bushing to obtain the elevation of the kelly bushing. When not given on the log, the kelly bushing was estimated to be 12 feet above the ground.

The surface locations of the wells were plotted on a base map of scale 1:600 (1"=50') from information given on completion cards, well history reports, well logs, or directional surveys. The actual location of the top of the salt or the bottom of the well was identified from the directional survey and plotted on the base map. Directional surveys were not available for the sulphur exploration wells. As these wells are relatively shallow, they were plotted as vertical holes. The Union Texas Petroleum Company's map of Sulphur Mines Oil Field indicated bottom-hole locations for some deeper wells without directional surveys. However, the elevations in these wells are approximate because no depth corrections are available. Other deep wells without directional surveys were not used in this analysis as they would only introduce errors into the data base.

The elevations of the top of salt was contoured on the data base map considering both top of salt data points and data points where no salt was encountered. The gravity model of the dome was used to modify contour lines where little well control was available. The gravity map is not accurate in all places because more data is now available than was available when the model was constructed.

WELL DATA

WELL#	C.C.	DIR. SURVEY	GEOPHYSICAL LOGS	DRILLER'S LOG	SURFACE ELEV. (FT. MSL)	KELLY BUSHING *(FT.)	DEPTH CORR.	SALT */**	NO SALT */**	REMARKS REFER.
S-1	X			Field Notes	15.5	12		1481/ -1454		TS from field notes
S-2	X		I.E.	Field Notes	15	14.35		1474/ -1445		Caprock at -1309'
S-4	X		C.D. Micro	Field Notes	17	12.75		1478/ -1449		TS from field notes. Caprock at -1158'
S-6	X		I.E.	Field Notes	14.5	12		1709/ -1682		TS from field notes
S-7	X			Field Notes	14.5	12		1455/ -1428		
S-9	X			Field Notes	17.5	12		1481/ -1452		
S-12	X			Field Notes	15.5	12			1426/ -1398	
S-14	X				13.5	12				TD 1451'
S-18	X				8.5	12			1450/ -1422	No Salt from C.C.

Table F-1

WELL#	C.C.	DIR. SURVEY	GEOPHYSICAL LOGS	DRILLER'S LOG	SURFACE ELEV. (FT. MSL)	KELLY BUSHING *(FT.)	DEPTH CORR.	SALT */**	NO SALT */**	REMARKS REFER.
S-19	X			Field Notes	16	12			1450/ -1422	No Salt from field notes. Caprock from -747'
S-36	X			Field Notes	12	12				Caprock at -431'
BW-2					13.69	15.69		1475/ -1446		
BW-2A					16.05	18.55		1482/ -1447		
BW-4					13.25	19.25		1620/ -1588		
BW-5					14.4	1		1464/ -1449		
724 Orig		X		X	16	12	63		4170/ -4079	May Hit Salt
ST							26		3622/ -3584	

Table F-1 (Cont.)

WELL#	C.C.	DIR. SURVEY	GEOPHYSICAL LOGS	DRILLER'S LOG	SURFACE ELEV. (FT. MSL)	KELLY BUSHING *(FT.)	DEPTH CORR.	SALT */**	NO SALT */**	REMARKS REFER.
727 Orig			SP-RES				57.5		5408/ -5321	
1stST	X	X			17	12	25.6		4366/ -4311	Driller's Log at UTP.
2ndST			SP-RES				7.1		3909/ -3873	
734		*	SP-RES							*Edge of Study Area. No Salt
741 Orig							14.9		3556/ -3515	NS from C.C.
ST	X	X	RES		14	12	10.85	3635/ -3598		
745 Orig			SP-RES				49	4972/ -4897		
ST		X	SP-RES		14.4	12	16.6		4812/ -4769	
746 Orig			POR-RES				67.5		4668/ -4574	
ST	X	X	SP-RES		14.5	12	2.5		3438/ -3409	

Table F-1 (Cont.)

WELL#	C.C.	DIR. SURVEY	GEOPHYSICAL LOGS	DRILLER'S LOG	SURFACE ELEV. (FT. MSL)	KELLY BUSHING *(FT.)	DEPTH CORR.	SALT */**	NO SALT */**	REMARKS REFER.
747										
748	X	X	POR-RES		16	12	106		5278/ -5144	
749 Orig							15.74	4479/ -4435		
1stST	X	X	SP-RES	Well History	16.5	12	3.88	4020/ -3988		
2ndST			SP-RES				5.36			Caprock at -4006'
753		X						4577/		UTP Field Map
754								4991/		UTP Field Map
756 1stST	X	X	SP-RES	Well History	16	12	21.4		5366/ -5317	Poss. ledge 10' thick
2ndST			SP-RES				3.3	3894/ -3863		NS from C.C.

Table F-1 (Cont.)

WELL#	C.C.	DIR. SURVEY	GEOPHYSICAL LOGS	DRILLER'S LOG	SURFACE ELEV. (FT. MSL)	KELLY BUSHING *(FT.)	DEPTH CORR.	SALT */**	NO SALT */**	REMARKS REFER.
757 Orig	X	X	POR-RES	Well History	16.5	12	37.3		5267/ -5201	NS from C.C.
1stST			POR-RES				22.4		5227/ -5176	
2ndST			POR-RES				4.2	4357/ -4324		
762 1stST		X	SP-RES		16	12	29		5674/ -5617	
Orig										Insufficient Data
765		X			14	12	5.22	4455/ -4424		TS from Driller's Log at UTP.
766		X	SP-RES, GAMMA		16	12	5		4187/ -4154	Well Extends Deeper
767	X	X	SP-RES; POR		13.5	12	2.6			
773	X	X	SP-RES		14.5	12	14.7	4760/ -4719		

Table F-1 (Cont.)

WELL#	C.C.	DIR. SURVEY	GEOPHYSICAL LOGS	DRILLER'S LOG	SURFACE ELEV. (FT. MSL)	KELLY BUSHING *(FT.)	DEPTH CORR.	SALT */**	NO SALT */**	REMARKS REFER.
774		Partial			14.5	12	6	4206/ -4174		
776 Orig		X			16	12				
1stST			POR-RES				10.2	4872/ -4834		
777		X								
779 Orig		X	POR-RES		13	12	None Given		4150/ -4125	Off Area
ST			SP-RES				4.7	3525/ -3495		
780 1stST					15	12	.52			3502' TD
2ndST	X	X	SP-RES				1.4		3878/ -3850	
3rdST			SP-RES				6.4		4592/ -4559	
782 Orig		X	POR-RES		14	12	18.6		4581/ -4536	
ST			POR-RES				7	4822/ -4789		

Table F-1 (Cont.)

WELL#	C.C.	DIR. SURVEY	GEOPHYSICAL LOGS	DRILLER'S LOG	SURFACE ELEV. (FT. MSL)	KELLY BUSHING *(FT.)	DEPTH CORR.	SALT */**	NO SALT */**	REMARKS REFER.
785					14	12		4267/ -4241 *		UTP Field Map. *Does not include vertical depth correction
786		X	SP-RES		16.5	12	5.8	5762/ -5728		
787	X	X	POR-RES		17	12	22.8	4555/ -4503		
788 Orig			POR-RES		16	12			5894/ -5866 *	*Do not include vertical depth correction
ST			POR-RES					5543/ -5515 *		
794			POR-RES							
795		*	POR-RES						5873/	*Edge of study Area
796										No Survey
798 Orig	X				13.5	12			3652/ -3737 *	*Do not include vertical depth correction
ST			SP-RES						4070/ -4055 *	

Table F-1 (Cont.)

WELL#	C.C.	DIR. SURVEY	GEOPHYSICAL LOGS	DRILLER'S LOG	SURFACE ELEV. (FT. MSL)	KELLY BUSHING *(FT.)	DEPTH CORR.	SALT */**	NO SALT */**	REMARKS REFER.
805	X		SP-RES		16	12		4230/ -4202 *		UTP Field Map *Does not include vertical depth correction
809	X	X	POR-RES		15	12	4.9	3885/ -3853		Hole continues, no log for interval
831 Orig	X	X	POR-RES		13.5	12	208		5512/ -5278	
ST							1	4442/ -4416		TS from C.C
841 Orig	X	X	POR-RES		14.5	12	9.8		4456/ -4420	
ST			POR-RES				8.4		4589/ -4554	
846	X		POR-RES						5389/	
849	X		SP-RES						5634/	

Table F-1 (Cont.)

WELL#	C.C.	DIR. SURVEY	GEOPHYSICAL LOGS	DRILLER'S LOG	SURFACE ELEV. (FT. MSL)	KELLY BUSHING *(FT.)	DEPTH CORR.	SALT */**	NO SALT */**	REMARKS REFER.
852										
1st ST			POR-RES				3.85	5082/ -5050		
2nd ST	X	X			16	12	3	5063/ -5032		
3rd ST			POR-RES				20	5166/ -5118		Off Map
861	X	X	SP-RES		16	12	1.75	3752/ -3722		
863										
Orig			SP-RES				.5		3484/ -3456	
ST	X	X	SP-RES		15	12	1.9	4249/ -4220		
864	X	X	SP-RES		15	12	5.6	5058/ -5025		
866			SP-RES		14	12			5023/ -4997 *	*Does not include vertical depth correction
869	X		SP-RES		16.5	12		5807/ -5778 *		*Does not include vertical depth correction

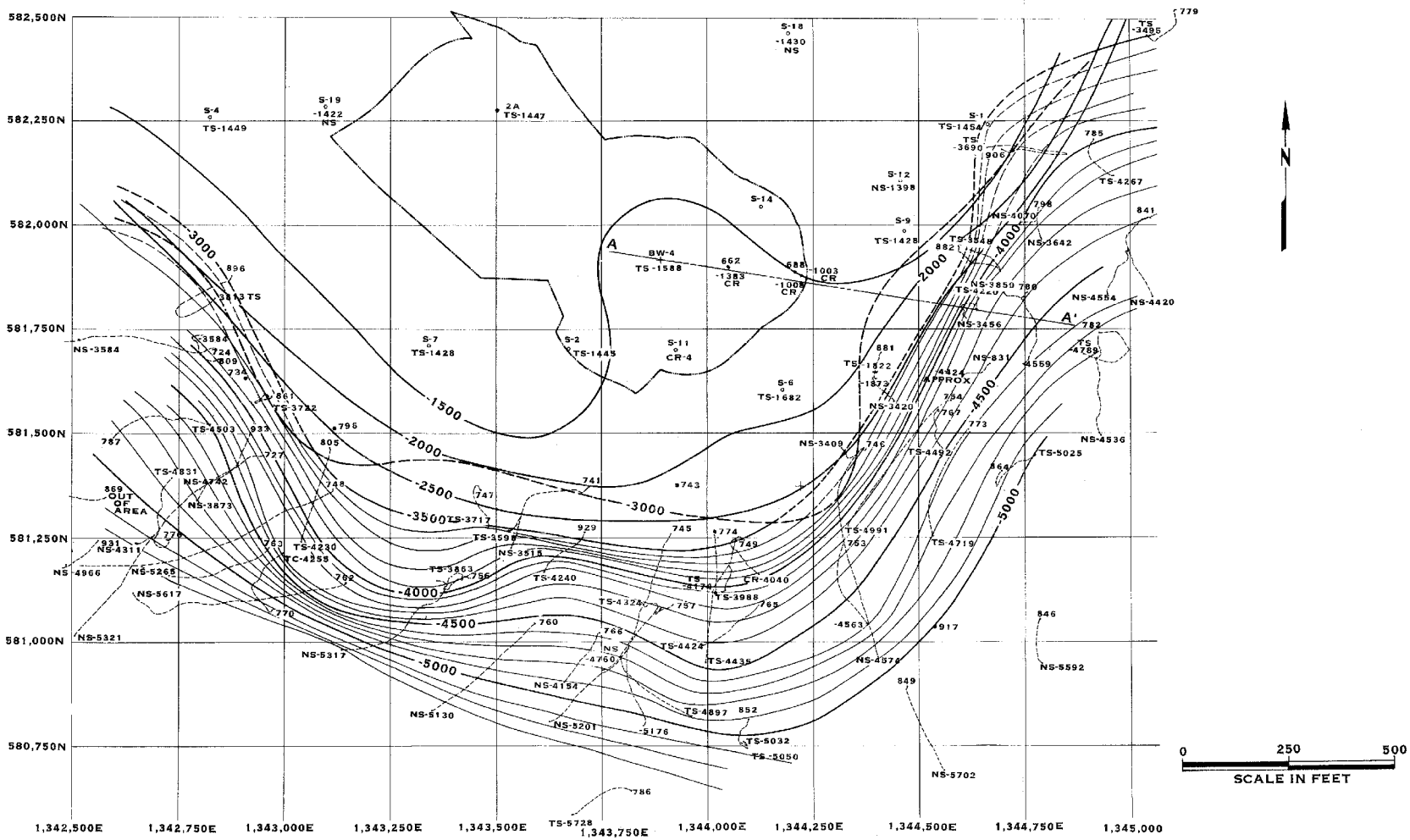
Table F-1 (Cont.)

WELL#	C.C.	DIR. SURVEY	GEOPHYSICAL LOGS	DRILLER'S LOG	SURFACE ELEV. (FT. MSL)	KELLY BUSHING *(FT.)	DEPTH CORR.	SALT */**	NO SALT */**	REMARKS REFER.
881	X	X	SP-RES	Well History	14.5	12	1.1/ 3.99	1850/ -1822	3450/ -3420	Salt ledge from -1822' to -1873'
882 Orig	X	X			15.5	12				TD 1400
ST			SP-RES				10	3585/ -3548		
896	X		SP-RES		18	12		1570/ * -1540 3813/ * -3783		UTP Field Map. *Does not include vertical depth correction
906								3690/ *		UTP Field Map
917			SP-RES					5112/		
929	X	X	SP-RES		15.5	12	3	4270/ -4240		
931	X	X	SP-RES		16	12	15		5560/ -5517	
933	X	X	SP-RES		16.5	12	6	4790/ -4766		

Table F-1 (Cont.)

EXPLANATION FOR TABLE F-1

WELL #	
Orig	Original hole
ST	Sidetracked hole
C.C.	Completion Card
DIR. SURVEY	Directional Survey of well
GEOPHYSICAL LOGS	
C.D.	Compensated density log
GAMMA	Gamma Ray log
I.E.	Induction Electrical log
MICRO	Micro Resistivity log
POR-RES	Porosity Resistivity log
RES	Resistivity log
SP-RES	Spontaneous Potential Resistivity log
KELLY BUSHING	Most logs were measured from the kelly bushing. Unless stated on log, the kelly bushing is assumed to be 12 feet above the ground surface.
DEPTH CORR.	Vertical depth correction obtained from directional survey to correct effects of "wandering" hole.
SALT */**	Apparent depth to salt/Elevation of salt.
NO SALT */**	Apparent depth of well that did not encounter salt/Elevation at bottom of hole.
REMARKS REFER.	
NS	No salt encountered
TD	Total depth
UTP	Union Texas Petroleum



LEGEND

-4500 / -4600	CONTOUR LINE
	LINE OF CROSS SECTION
	CAVERN OUTLINE AT -2930 TO -2960 FEET MSL
787 TS -4503	PLAN VIEW OF BORING TRACE
TS	TOP OF SALT
NS	NO SALT
CR	CAPROCK
S-7	SULPHUR WELL
796	PETROLEUM WELL (NO DIRECTIONAL SURVEY)

NOTE

CONTOUR INTERVAL:
100' BETWEEN -3500' AND -5300'
500' BETWEEN -1500' AND -3500'

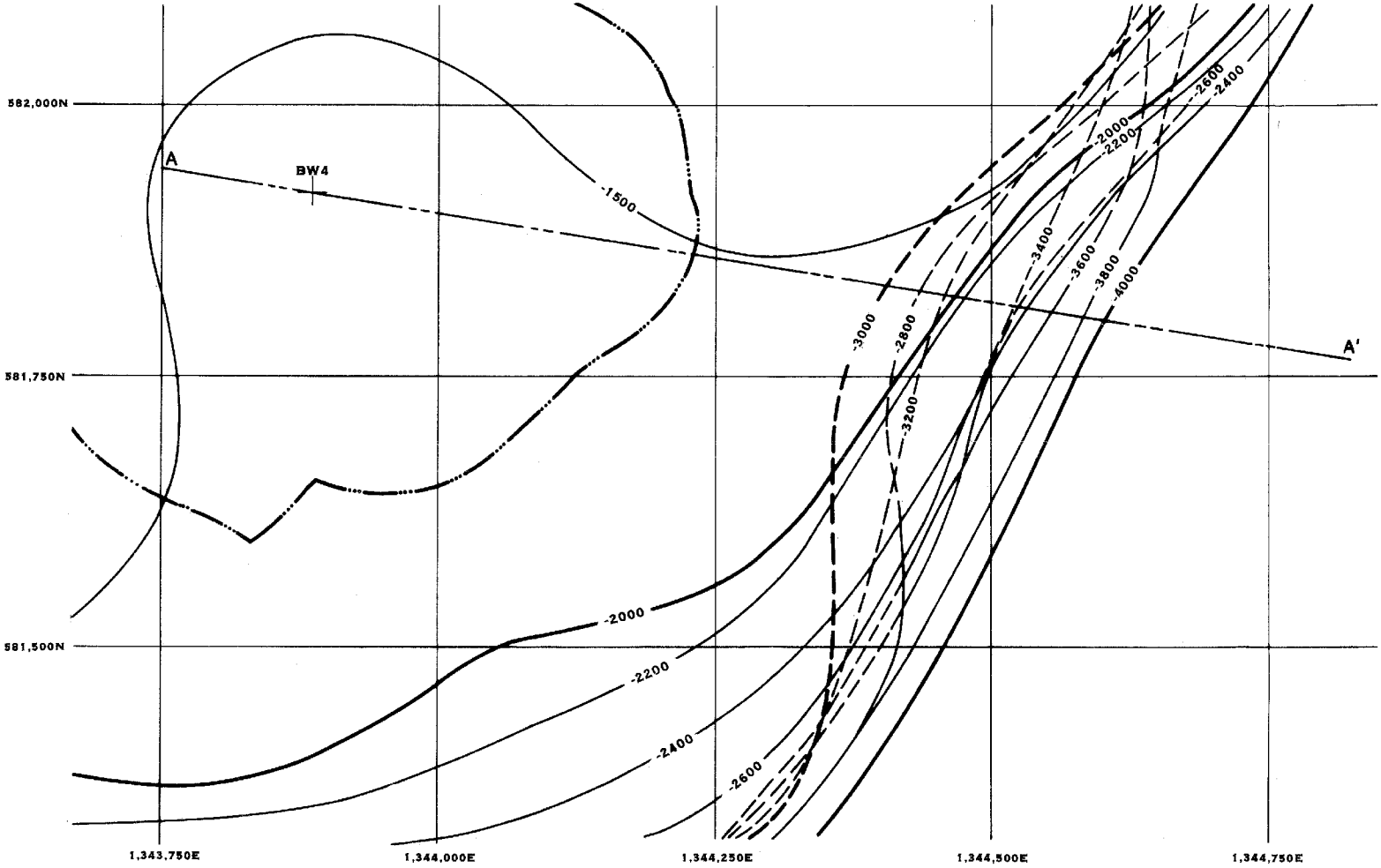
PREPARED	SMM	DATE	12/19/80
REVISED		DATE	
REVISED		DATE	
APPROVED	LSK	DATE	12/19/80

STRATEGIC PETROLEUM RESERVE PROGRAM
GEOTECHNICAL CHARACTERIZATION
SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY
MARIETTA, GEORGIA

TOP OF SALT CONTOURS SOUTHERN PORTION OF SULPHUR MINES SALT DOME

FIGURE F-1



PREPARED	GMM	DATE	12/11/86
REVISED		DATE	
REVISED		DATE	
APPROVED	LSK	DATE	12/12/86

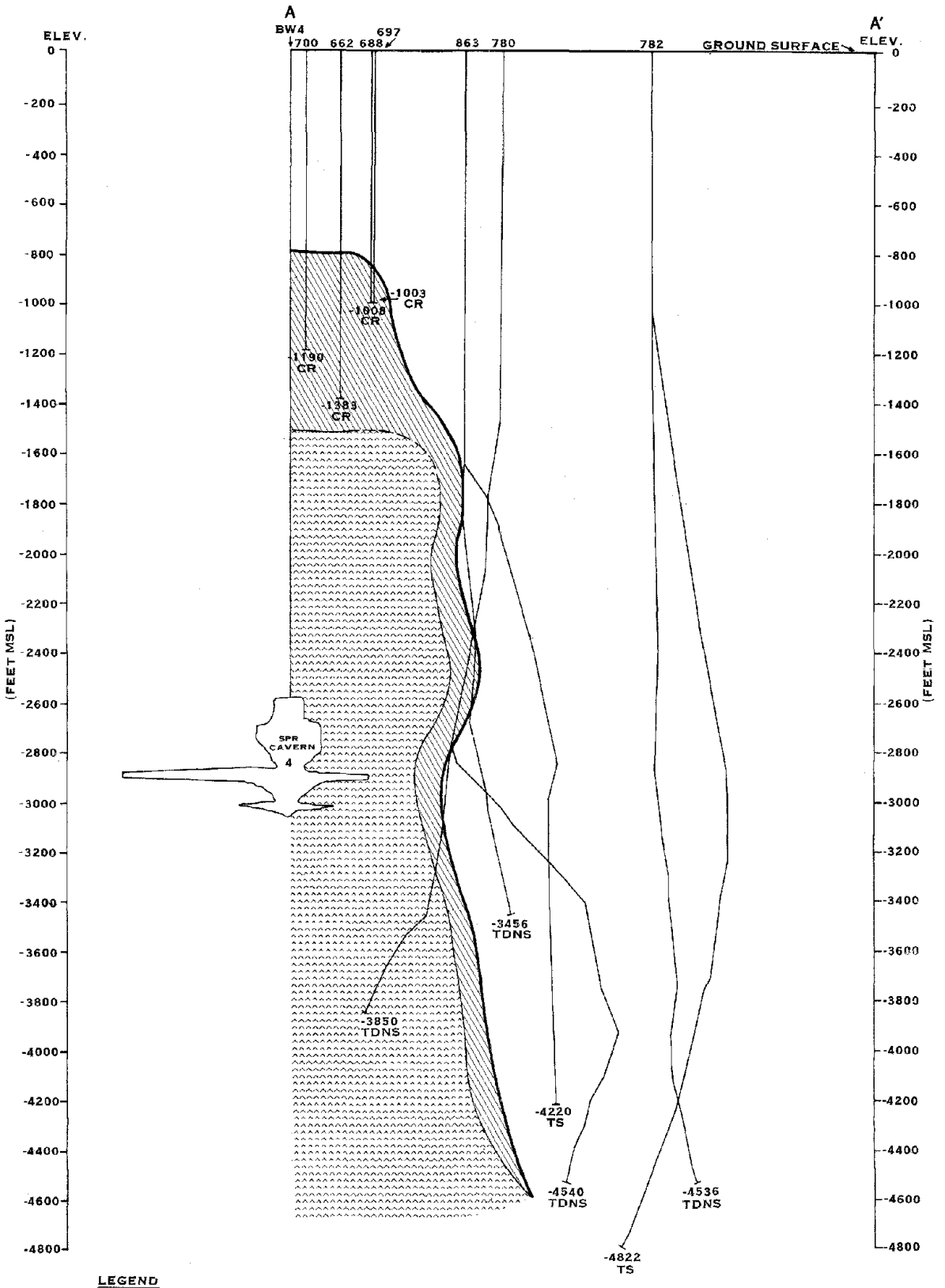
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SULPHUR MINES SALT DOME

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EXPANDED CONTOUR MAP
NEAR SECTION A-A'

FIGURE F-2



LEGEND

SALT DOME

CAPROCK

782 SULPHUR WELL OR PETROLEUM WELL

TS TOP OF SALT

TDNS TOTAL DEPTH - NO SALT

CR CAPROCK

NOTE

WELL TRACES ARE PROJECTED PERPENDICULARLY ONTO THE LINE OF THE CROSS SECTION.

PREPARED SAM DATE 12/19/80

REVISED ____ DATE ____

REVISED ____ DATE ____

APPROVED ____ DATE ____

STRATEGIC PETROLEUM RESERVE PROGRAM

GEOTECHNICAL CHARACTERIZATION SULPHUR MINES SALT DOME

LAW ENGINEERING TESTING COMPANY MARIETTA, GEORGIA

CROSS SECTION THROUGH CAVERN 4 ALONG LINE A-A'

FIGURE F-3

SECTION III

SECTION III

SALT PROPERTIES FOR SULPHUR MINES DOME

NOVEMBER 1980

Section Editor
R. R. Beasley

ABSTRACT

This section is to contain the results of three areas of salt evaluation--mineralogy analyses, mechanical property tests, and geophysical log analyses--and is to cover the materials pertinent to cavern structural analysis. There are no material samples or geophysical logs available that relate to the material properties of the salt. If material properties information becomes available, it will be added in this section.

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