NUREG/CR-2613

Identification of Characteristics Which Influence Repository Design Domal Salt

Final Report (Task 1)
June 8, 1981-March 12, 1982

Prepared by G. Rawlings G. Antonnen, M. Chamness, R. Hofmann,
W. Roberds, C. Soto, C. Welden, J. Rowe, F. Marinelli, K. Jones

Golder Associates

Prepared for
U.S. Nuclear Regulatory
Commission

Availability of Reference Materials Cited in NRC Publications

Most documents cited in NRC publications will be available from one of the following sources:

1. The NRC Public Document Room, 1717 H Street, N.W.
   Washington, DC 20555
2. The NRC/GPO Sales Program, U.S. Nuclear Regulatory Commission,
   Washington, DC 20555
3. The National Technical Information Service, Springfield, VA 22161

Although the listing that follows represents the majority of documents cited in NRC publications, it is not intended to be exhaustive.

Referenced documents available for inspection and copying for a fee from the NRC Public Document Room include NRC correspondence and internal NRC memoranda; NRC Office of Inspection and Enforcement bulletins, circulars, information notices, inspection and investigation notices; Licensee Event Reports; vendor reports and correspondence; Commission papers; and applicant and licensee documents and correspondence.

The following documents in the NUREG series are available for purchase from the NRC/GPO Sales Program: formal NRC staff and contractor reports, NRC-sponsored conference proceedings, and NRC booklets and brochures. Also available are Regulatory Guides, NRC regulations in the *Code of Federal Regulations*, and *Nuclear Regulatory Commission Issuances*.

Documents available from the National Technical Information Service include NUREG series reports and technical reports prepared by other federal agencies and reports prepared by the Atomic Energy Commission, forerunner agency to the Nuclear Regulatory Commission.

Documents available from public and special technical libraries include all open literature items, such as books, journal and periodical articles, and transactions. *Federal Register* notices, federal and state legislation, and congressional reports can usually be obtained from these libraries.

Documents such as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings are available for purchase from the organization sponsoring the publication cited.

Single copies of NRC draft reports are available free upon written request to the Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at the NRC Library, 7920 Norfolk Avenue, Bethesda, Maryland, and are available there for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from the American National Standards Institute, 1430 Broadway, New York, NY 10018.

GPO Printed copy price: $5.50

NUREG/CR-2613
813-1162A

Identification of Characteristics Which Influence Repository Design Domal Salt

Final Report (Task 1)
June 8, 1981 - March 12, 1982

Manuscript Completed: March 1982
Date Published: April 1984

Prepared by
G. Rawlings, G. Antonnen, M. Chamness, R. Hofmann,
W. Roberds, C. Soto, C. Welden, J. Rowe, F. Marinelli, K. Jones

Golder Associates
2950 Northup Way
Bellevue, WA 98004

Prepared for
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN B6983
Under Contract No. NRC 02-81-037

ABSTRACT

This report represents the results of Task 1, Subtask 1.1 of NRC Contract NRC-02-81-037, "Technical Assistance for Repository Design."

The purpose of the complete project is to provide NRC with technical assistance for the following reasons:

- To enable the focused, adequate review by NRC of the aspects related to design and construction of an underground test facility and final geologic repository, as presented in DOE Site Characterization Reports (SCR)
- To ascertain that the DOE site characterization program will provide, as far as possible, all the information necessary to permit a review to be conducted by NRC of a license application for construction authorization.

The results of that part of the study presented in this report cover the identification of characteristics which influence design and construction of a geologic repository in domal salt. Much of the report is therefore media-specific and the results are then applied to the repository sites being considered by DOE in domal salt in Louisiana and Mississippi.

In order to satisfy the performance criteria (EPA and NRC), certain issues related to the design and ultimate construction of a geologic repository in domal salt must be addressed during an SCR review. This report has identified five key issues, i.e., constructability, thermal response, mechanical response, hydrological response, and geochemical response. These issues involve both short-term (up to closure) and long-term (post-closure) effects.

The characteristics of domal salt and its environment are described under the general headings of stratigraphic/structural, tectonic, mechanical, thermal and hydrologic. Characteristics have been separated into those which can be quantified and measured (parameters) and those which can only be described qualitatively (factors).

The characteristics are subjectively ranked in terms of their influence on the key issues as critical, major, minor or insignificant. This ranking took into account the following attributes of each characteristic: availability and suitability of conservative design/construction techniques, uncertainty in model and the model sensitivity to characteristic, and finally, potential for reducing uncertainty in characteristic.

Thus, recommendations are provided for a focused, adequate SCR review by NRC of the design and construction aspects of a nuclear waste repository in domal salt.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

LIST OF FIGURES

LIST OF FIGURES (Cont.)

LIST OF TABLES

LIST OF TABLES (Cont.)

EXECUTIVE SUMMARY

1. INTRODUCTION

1.1 This report represents the results of Task 1, Subtask 1.1 of NRC Contract NRC-02-81-037, "Technical Assistance for Repository Design."

The purpose of the complete project is to provide NRC with technical assistance for the following reasons:

- To enable the focused, adequate review by NRC of the aspects related to design and construction of an underground test facility and final geologic repository, as presented in DOE Site Characterization Reports (SCR)

- To ascertain that the DOE site characterization program will provide, as far as possible, all the information necessary to permit a review to be conducted by NRC of a license application for construction authorization.

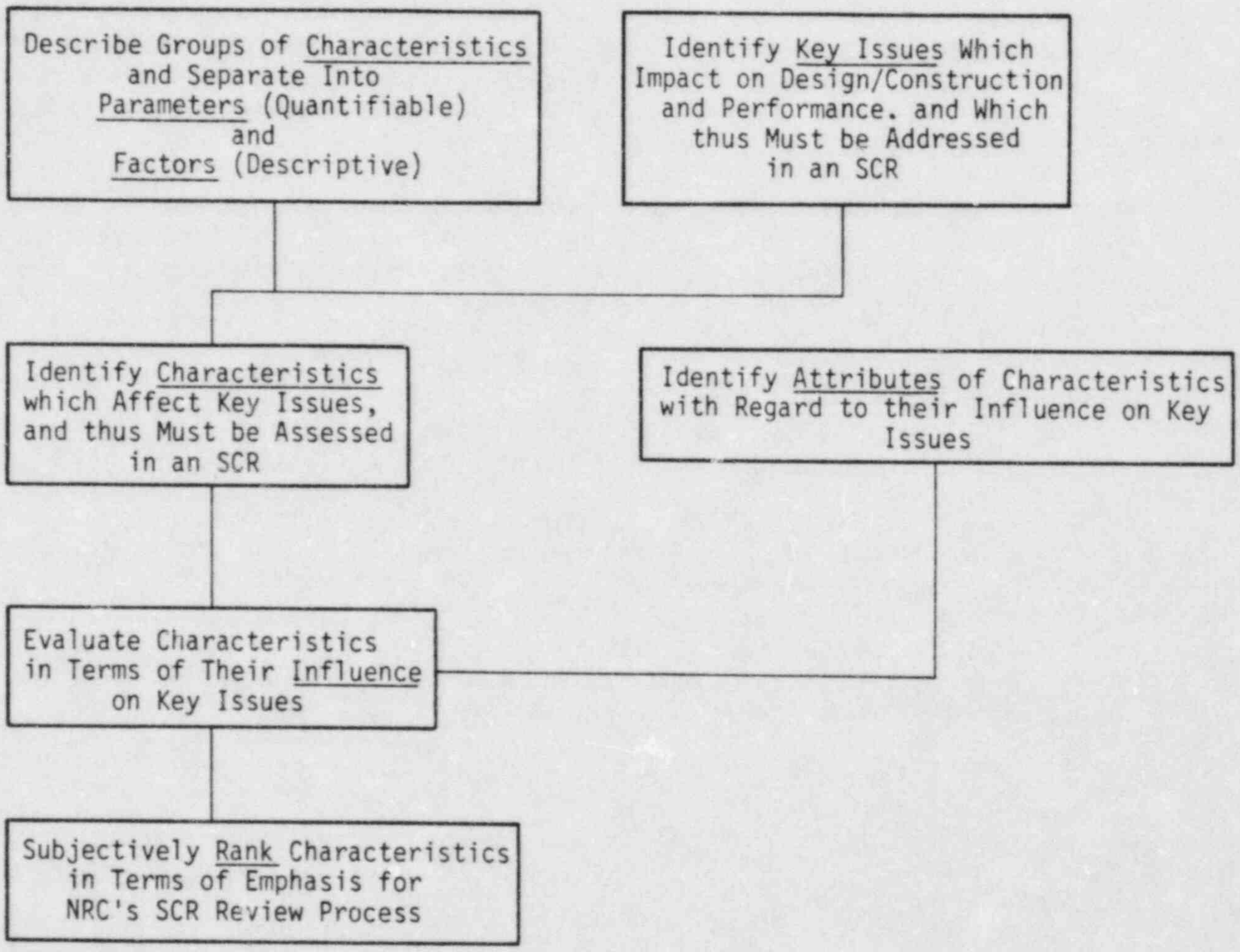
1.2 The results of that part of the study presented here cover the identification and ranking of characteristics which influence design and construction of a geologic repository in domal salt. It is a companion report to the two previous Golder Associates' reports on bedded salt and granite/basalt (1979 a and c, respectively) and a similar report which considers characteristics for a repository located in tuff (Subtask 1.2 of this study). Much of this report is directed towards generic aspects of domal salt at sites in the Gulf Coast region of Louisiana and Mississippi, and the conclusions from that part of the study are applied to selected salt domes, Richton and Cypress Creek, Mississippi and Vacherie, Louisiana, being studied by DOE.

2. STUDY PROCEDURES

2.1 Figure 1 shows a flow chart which represents the process used during the study to identify the priority of characteristics to be emphasized in the NRC's review of an SCR. The components of the process are discussed individually below.

2.2 In order to satisfy the performance criteria (EPA and NRC), both short-term construction/operation and long-term containment/isolation, certain issues related to the design and ultimate construction of a geologic repository in domal salt must be addressed. During an SCR review it will be necessary to evaluate the level of information presented in the SCR about a particular characteristic; i.e., is the information presented sufficient to answer the following five questions or key issues.

TASK 1- ACTIVITY FLOW CHART **Figure 1**



- Constructability. Can the facility be constructed in a timely and safe fashion, and so that it will not jeopardize the long-term containment and isolation capability of the facility? The construction of the facility will entail the unavoidable creation of a disturbed zone of rock around underground openings and the construction of engineered barriers, both of which will have an effect on the response of the repository.

- Thermal Response. Can the temperature field be adequately predicted as a function of time to use as input to the mechanical, hydrological and geochemical models?

- Mechanical Response. Can the stability and deformation of underground openings be adequately predicted for the periods of short-term construction/operation and long-term containment/isolation?

- Hydrological Response. Can an adequate prediction be made regarding the resaturation time of the repository (post-closure) and of the groundwater flow through the repository over the long-term? Of lesser importance is the question of the amount of inflow into the repository during operation, i.e., over the short-term.

- Geochemical Response. Can an adequate prediction be made of the extent and effect of geochemical alteration of the engineered barriers and the rock where there is a potential for radionuclide migration to occur? Can the quantity and rate of migration of specific radionuclides over the long-term be adequately predicted?

2.3 The characteristics of domal salt which must be assessed in order to address the above key issues were divided into five groups:

- Stratigraphic/structural
- Tectonic
- Mechanical
- Thermal
- Hydrologic.

The characteristics which could be quantified and measured are referred to as "parameters," and those which can only be qualitatively described are termed "factors."

2.4 These characteristics (i.e., parameters and factors) were subjectively evaluated in terms of their influence on each of the key issues in design and construction. Based on past experience, this evaluation has taken into account the following categories of attributes:

- Availability of design and construction techniques which allow for a conservative assumption of the value of the characteristic

- Uncertainty in the representation of the real world by the performance prediction model, and sensitivity of that model to characteristic value

- Cost effectiveness and scheduling limitations in potentially reducing the uncertainty in the assessment of characteristic values.

Certain combinations of the above attributes for a characteristic indicate that the characteristic should have the highest priority during NRC's review of an SCR; such a characteristic is termed critical. Similarly, other combinations of attributes suggest lower priorities during SCR review; such characteristics are termed, in decreasing order of priority, major, minor, and insignificant. The combinations of attributes which comprise each priority level have been subjectively assessed based on our experience.

Thus, recommendations are provided for the level of emphasis to be placed on each characteristic in domal salt during the SCR review process. This will allow for a focused, adequate review by NRC of the design and construction aspects of a nuclear waste repository in domal salt.

2.5 The domal salt sites at NTS currently being studied in detail by DOE were reviewed on the basis of the characteristics identified during the project.

3. CONCLUSIONS

3.1 The relative influence of each characteristic of domal salt on the resolution of the key issues has been subjectively assessed, based on the cumulative practical experience and judgement of Golder Associates personnel in the design and construction of underground openings, the modeling of the physical processes involved, and the difficulty of assessing the characteristics. This assessment and the recommended priority of each characteristic in NRC's review process of an SCR in domal salt are summarized in Table 1. It is recommended that those characteristics which have the most significant influence on the key issues (i.e., designated as critical) have the highest priority in NRC's review of DOE submitted SCR(s) for site(s) in domal salt. Similarly, those designated as major, minor, and insignificant should have decreasing priority in NRC's SCR review. This prioritization of characteristics will allow for a focused, adequate review by NRC and, although subjective, the process by which it has been achieved is exposed and trackable.

TABLE 1

RECOMMENDED PRIORITIES IN THE REVIEW
BY NRC OF AN SCR IN DOMAL SALT

	CRITICAL CHARACTERISTICS FOR REVIEW	KEY ISSUES WHICH IMPACT ON DESIGN AND CONSTRUCTION				
		CONSTRUCTABILITY	THERMAL RESPONSE	MECHANICAL RESPONSE	HYDROLOGICAL RESPONSE	GEOCHEMICAL RESPONSE
STRATIGRAPHIC/ STRUCTURAL	Lithology/Mineralogy	Major	Major	Major	Critical	Major
	Stratigraphic Sequence	Major			Critical	Major
	Folding				Minor	
	Faulting/Shearing	Major		Major	Major	Major
	Inclusions	Minor	Minor	Minor	Minor	Minor
	Solutions	Critical	Critical	Critical	Critical	Critical
TECTONIC	Seismicity	Minor	Minor	Minor	Minor	Minor
	Crustal Instability			Minor	Minor	
	Diapirism/Volcanism			Minor	Minor	
	Faulting	Major		Major	Critical	Critical
	Regional Stress	Major		Major		
MECHANICAL	Rock Mass Strength	Major		Major	Minor	
	Deformation Moduli	Major	Minor	Major		
	Creep/Plasticity/Fusing	Major	Minor	Critical	Minor	
	Discontinuities	Major		Major	Major	Major
	Density			Minor		
	Moisture Content		Major	Major	Minor	Major
	In Situ Stress	Major		Major		
	Solubility	Minor		Minor	Minor	Major
THERMAL	In Situ Temperature			Major	Minor	
	Thermal Conductivity		Critical	Critical	Major	Major
	Heat Capacity		Minor	Minor	Minor	Minor
	Thermal Expansion		Critical	Critical		Major
HYDROLOGIC	Hydraulic Conductivity	Major			Major	Major
	Hydraulic Gradient	Major	Minor		Major	Major
	Porosity	Minor				Major
	Specific Storage				Minor	
	Dispersivity					Minor
	Adsorption					Major
	Pore Fluid Composition	Major				Major

KEY:*

- Critical
- Major
- Minor
- Insignificant or not relevant

*For definitions see Section 2.4, and Section 1.3.5 and Table 1.1 in the text

3.2 The relative importance of each characteristic to each issue does not change when going from the generic study (i.e., Gulf Coast salt domes) to the site specific study (i.e., Richton, Cypress Creek, and Vacherie Domes).

3.3 To some extent, the impact of the currently perceived adverse characteristics of domal salt can be decreased by appropriate design and construction strategies. Mitigating measures which should be considered include:

- Leaving a buffer zone between the repository and the dome margin
- Avoiding shearing/faulting zones in the dome interior
- Optimizing repository geometry to include possibly widely separated multiple levels
- Selecting excavation methods to limit the disturbed zone
- Selecting tunnel lining and support systems to reduce stress concentrations
- Selecting the waste package emplacement to limit temperatures
- Selecting the room spacing and design to control creep rates
- Selecting appropriate engineered barriers to complement the adsorption properties of the surrounding sediments
- Designing a suitable ventilation/cooling system
- Controlling inflows by seals, plugs, grouting, freezing and pumping
- Limiting extraneous boreholes and excavations in the dome and caprock
- Controlling hydraulic gradients by drainage.

Specific mitigating strategies can be selected using information from the in situ testing and monitoring program.

1. INTRODUCTION

1.1 TERMS OF REFERENCE

This report represents the results of Task 1, Subtask 1.1 of NRC Contract NRC-02-81-037, "Technical Assistance for Repository Design."

The purpose of the complete project is to provide the U.S. Nuclear Regulatory Commission (NRC) with technical assistance for the following reasons:

- To enable the focused, adequate review by NRC of the aspects related to design and construction of an underground test facility and final geologic repository, as presented in DOE Site Characterization Reports (SCR)
- To ascertain that the DOE site characterization* program will provide, as far as possible, all the information necessary to permit a review to be conducted by NRC of a license application for construction authorization.

The results of that part of the study presented here cover the identification and ranking of characteristics which influence design and construction of a geologic repository in domal salt. By identifying and ranking these characteristics, suitable emphasis can be placed in NRC's review of DOE submitted SCR(s) and license application(s) for site(s) in domal salt. This ensures an NRC review process which is focused (and thus efficient) and yet still sufficient.

Much of this report is directed towards generic aspects of domal salt in the Mississippi and Louisiana Gulf Coast region, and the conclusions from that part of the study are applied to three domal salt sites currently under serious consideration by DOE, specifically Richton and Cypress Creek, Mississippi and Vacherie, Louisiana. It is a companion report to the two previous Golder Associates' reports on bedded salt and granite/basalt (1979 a and c, respectively)** and a similar report which considers characteristics for a repository located in tuff (Subtask 1.2 of this study).

1.2 SITE CHARACTERIZATION PROCESS

The site selection process weights site suitability criteria to permit rational choices to be made. The suitability of any site for potential use as a nuclear waste repository is addressed by a Site Characterization Report (SCR) submitted by the DOE to the NRC. The primary requirement of such a report is to identify and assess those characteristics of a site which will have a significant influence on the ability

---

*Technical terms and those terms with a particular significance in waste disposal parlance are defined in the Glossary, Section 8.

**For references see Section 9.

of a site to meet the established performance criteria formulated by EPA and NRC for waste storage (both the short-term construction/operation and the long-term containment/isolation). In addition, the SCR will contain a conceptual repository design and an in situ testing plan for the completion of detailed characterization.

Characterization is generally performed by a combination of investigation methods: surface, borehole, laboratory and in situ tests. The simpler and cheaper methods are generally utilized in earlier phases of characterization when site selection is at issue. More accurate and expensive methods, especially in situ test methods, will be utilized to provide the more detailed characterization required to plan, design and construct the repository such that the performance criteria are satisfied. This detailed characterization will also serve to help verify the earlier characterization for site selection. However, because of the concentration of effort within the repository horizon and access shafts, verification of the far-field characterization is not generally achieved by site characterization for design and construction.

It will be necessary for the NRC to review DOE submitted SCR(s) and evaluate whether the characterization is, or will be subsequent to in situ testing, sufficient to establish that the performance criteria will be satisfied.

1.3 RATIONALE FOR EMPHASIS IN SCR REVIEW

1.3.1 Rationale Process

Figure 1.1 is a flow chart which represents the process used during the study to identify the priority of characteristics to be emphasized in NRC's review of an SCR. The components of the process, which are discussed individually in the following sections, include primarily:

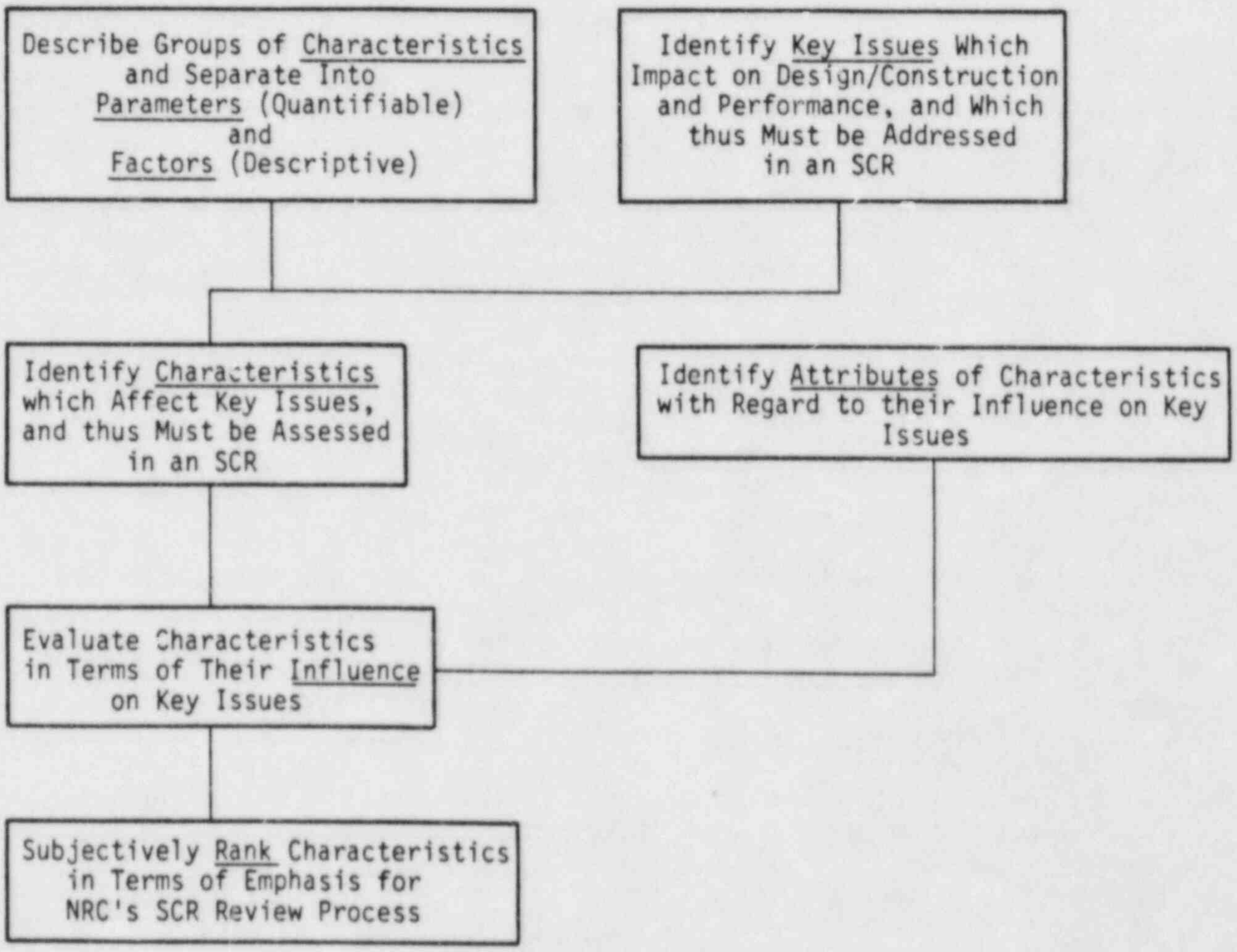
- Identification of key issues related to the design and construction of a repository in domal salt
- Identification of characteristics of domal salt which influence key issues
- Evaluation of the influence of characteristics of domal salt on key issues
- Ranking of characteristics of domal salt in terms of their influence on the key issues.

1.3.2 Key Issues

In order to satisfy the performance criteria (EPA and NRC), both short-term construction and operation and long-term containment and

TASK 1 - ACTIVITY FLOW CHART

Figure 1.1



isolation, certain considerations related to the design and ultimate construction of a geologic repository in domal salt must be addressed and ultimately resolved. These considerations can be summarized by the following five key issues:

- Constructability. Can the facility be constructed in a timely and safe fashion, and so that it will not jeopardize the long-term containment and isolation capability of the facility? The construction of the facility will entail the unavoidable creation of a disturbed zone of rock around underground openings and the construction of engineered barriers, both of which will have an effect on the response of the repository.

- Thermal Response. Can the temperature field be adequately predicted as a function of time to use as input to the mechanical, hydrological and geochemical models?

- Mechanical Response. Can the stability and deformation of underground openings be adequately predicted for the periods of short-term construction/operation and long-term containment/isolation?

- Hydrological Response. Can an adequate prediction be made regarding the resaturation time of the repository (post-closure) and of the groundwater flow through the repository over the long-term? Of lesser importance is the question of the amount of inflow into the repository during operation, i.e., over the short-term.

- Geochemical Response. Can an adequate prediction be made of the extent and effect of geochemical alteration of the engineered barriers and the rock where there is a potential for radionuclide migration to occur? Can the quantity and rate of migration of specific radionuclides over the long-term be adequately predicted?

During an SCR review it will be necessary to evaluate the level of information presented in the SCR, especially as it pertains to the above key issues.

1.3.3 Characteristics

The satisfactory resolution of each key issue identified in Section 1.3.2 will necessitate the adequate assessment of certain characteristics. A full suite of characteristics was drawn up which covered all potential aspects of domal salt and its environment. The previous Golder Associates' reports on bedded salt (1979a) and granite/basalt (1979c) were used for guidance in this effort. This list of characteristics has been divided into five groups as follows:

- Stratigraphic/structural
  - lithology/mineralogy
  - stratigraphic sequence
  - folding
  - faulting/shearing
  - inclusions
  - solution

- Tectonic
  - seismicity
  - crustal instability
  - diapirism/volcanism
  - faulting
  - regional stress

- Mechanical
  - rock mass strength
  - deformation moduli
  - creep/plasticity/fusing
  - discontinuities
  - density
  - moisture content
  - in situ stresses
  - solubility

- Thermal
  - in situ temperature
  - thermal conductivity
  - heat capacity
  - thermal expansion

- Hydrologic
  - hydraulic conductivity
  - hydraulic gradient
  - porosity
  - specific storage
  - dispersivity
  - adsorption
  - pore fluid composition.

The characteristics which can be quantified and measured are referred to herein as "parameters," and those which can only be qualitatively described are termed "factors."

1.3.4 Influence

Each of the characteristics identified in Section 1.3.3 has some influence on each of the key issues, although in some cases this influence may be insignificant. Certain attributes of characteristics can be identified and utilized to evaluate the level of influence of each characteristic on each key issue. Based on past experience, these attributes have been divided into the following three categories.

- Availability of design and construction techniques which allow for a conservative assumption of the value of the characteristic:

a) reasonable techniques are not available (i.e., high cost impact)
b) some techniques are available, but at moderate cost impact
c) reasonable techniques are available (i.e., little cost impact)

- Uncertainty in the representation of the real world by the performance prediction model, and sensitivity of that model to characteristic value:

  d) model has low uncertainty (i.e., is very representative) and has high sensitivity to characteristic
  e) model has moderate uncertainty and moderate sensitivity
  f) model has high uncertainty or low sensitivity

- Cost effectiveness and scheduling limitations in potentially reducing the uncertainty in the assessment of characteristic value:

  g) uncertainty can be significantly reduced in a cost-effective and timely manner (i.e., prior to NRC review of an SCR)
  h) uncertainty can be reduced, but only during in situ testing
  i) uncertainty cannot be significantly reduced in a cost-effective or timely manner (i.e., prior to NRC review for construction authorization).

The influence of each characteristic on each key issue can thus be evaluated by assessing the characteristic's attributes in each of the above three categories; for example:

- In the first category, if a conservative assumption can be made for a characteristic value with little cost impact (i.e., repository design/construction techniques are available which allow for the performance criteria to be met, even with a conservative value of the characteristic - attribute c) then the characteristic has little influence. Conversely, if a conservative assumption for a characteristic value results in a high cost impact (i.e., repository design/construction techniques are not readily available which allow for the performance criteria to be met with a conservative value of the characteristics - attribute a), then the characteristic has significant influence.

- In the second category, if the model used to represent the real world is very poor (regardless of the uncertainty in the characteristics used as input) or if the model is very insensitive to a characteristic (i.e., attribute f), then that characteristic has little influence on the resolution of key issues. Conversely, if the model represents the real world relatively well (not taking into account the uncertainty in the characteristics used as input) and if the model is very sensitive to a characteristic (i.e., attribute d), then that characteristic has significant influence.

- In the third category, if the uncertainty in a characteristic cannot be significantly reduced in a cost-effective or timely manner (i.e., the characteristic has an inherent uncertainty which has little potential for being reasonably reduced prior to construction and operation of a repository - attribute i), then that characteristic has little influence in resolving the key issues during NRC's SCR and construction authorization review process. Conversely, if the uncertainty in the characteristic can be significantly reduced in a cost-effective and timely manner (i.e., the characteristic has an inherent uncertainty that can be reduced using available surface, borehole, or laboratory tests prior to SCR submittal - attribute g), then that characteristic may have significant influence in resolving the key issues during NRC's SCR review process.

1.3.5 Ranking

Certain combinations of the above attributes for a characteristic indicate that the characteristic would have a significant influence on the key issues and thus should have the highest priority during NRC's review of an SCR; such a characteristic is termed critical. Similarly, other combinations of attributes suggest less influence and thus lower priorities during SCR review; such characteristics are termed, in decreasing order of priority, major, minor, and insignificant.

For example, if a conservative assumption of a characteristic value has high cost impact (attribute a), if the model utilized is very representative of the real world and is very sensitive to that characteristic (attribute d), and if the uncertainty in the characteristic can be significantly reduced cost effectively prior to SCR submittal (attribute g), then clearly that characteristic will have a very significant influence on the resolution of key issues. Such a critical characteristic should thus have highest priority in NRC's SCR review process. Conversely, if a conservative assumption of a characteristic value has little or no cost impact (attribute c), if the model utilized is not representative of the real world or is insensitive to that characteristic (attribute f), and if the uncertainty in the characteristic cannot be significantly reduced prior to repository construction (attribute i), then clearly that characteristic will have an insignificant influence on the resolution of key issues. Such an insignificant characteristic should thus have lowest priority in NRC's review process.

Between the above two extreme examples are various combinations of attributes, each with a certain level of influence. The combinations of attributes which comprise each level of influence, and thus each recommended priority level, have been subjectively assessed, as presented in Table 1.1. Although, due to the subjective nature of this assessment there may be some disagreement in the rankings, it is felt that priority levels will not vary by more than one level. For example, if a characteristic has been assessed as insignificant, it is not likely

TABLE 1.1
PRIORITY LEVELS OF CHARACTERISTIC AS A FUNCTION OF THEIR ATTRIBUTES

	Availability of Conservative Design/Construction Techniques	Uncertainty in Model and its Sensitivity to Characteristic	Potential for Reducing Uncertainty in Characteristic
Critical	a	d	g
	a	d	h
	a	d	i
	a	e	g
	b	d	g
Major	a	e	h
	a	e	i
	a	f	g
	b	d	h
	b	d	i
	b	e	g
	b	e	h
	b	f	g
	c	d	g
Minor	a	f	h
	a	f	i
	b	e	i
	b	f	h
	b	f	i
	c	d	h
	c	d	i
	c	e	g
	c	e	h
	c	e	i
Insignificant	c	f	g
	c	f	h
	c	f	i

to be critical or even major. Similarly, if a characteristic has been assessed as critical, it is not likely to be insignificant or even minor.

Thus, recommendations are provided for the emphasis to be placed on each characteristic in domal salt during the SCR review process. This will allow for a focused, adequate review by NRC of the design and construction aspects of a nuclear waste repository in domal salt.

1.4 REPORT FORMAT

The report has been organized on the basis of the five groups of characteristics, namely:

- Stratigraphic/structural
- Tectonic
- Mechanical
- Thermal
- Hydrologic.

In each of the five sections the significant characteristics are described from a generic standpoint for domal salt, their importance considered from the point of view of the key issues and a comparative ranking of importance produced. Matrix diagrams summarize the conclusions at the end of the generic part of each section.

Also in each section, an attempt has been made to consider the higher priority characteristics for domal salt, as identified in the text and matrix diagrams, for each site currently being considered by DOE.

2. STRATIGRAPHIC/STRUCTURAL CHARACTERISTICS

2.1 GENERAL

2.1.1 Selection of Characteristics

The stratigraphic/structural characteristics which must be considered for repository design and construction relate to the basic geology of a candidate area. Most of the characteristics may be treated as factors as they cannot be quantified and will require description and geological/geotechnical survey techniques for their assessment. These aspects of the site assessment for design are considered to be fundamental and represent the framework to which all the subsequent parameters are related. Only by a full understanding of the repository site stratigraphic and structural characteristics can the correct perspective be placed on measured data.

Because of the difficulties of obtaining geologic data in domal salt without the risk of disturbing the integrity of the ground and creating ultimate problems of solution, data for repository design prior to the excavation of a test facility is likely to be inadequate. Mapping, assessment, monitoring and sampling will be necessary during any excavation as on-going exercises.

The key issues of design and construction are affected by the stratigraphic/structural characteristics in the following ways:

- Constructability
  - lithology/mineralogy
  - stratigraphic sequence
  - faulting/shearing
  - inclusions
  - solution

- Thermal Response
  - lithology/mineralogy
  - inclusions
  - solution

- Mechanical Response
  - lithology/mineralogy
  - faulting/shearing
  - inclusions
  - solution

- Hydrological Response
  - lithology/mineralogy
  - stratigraphic sequence

- folding
- faulting/shearing
- inclusions
- solution

- Geochemical Response
  - lithology/mineralogy
  - stratigraphic sequence
  - faulting/shearing
  - inclusions
  - solution

Bedding and discontinuities are described in the following sections from a geological point of view but because of their prime importance for the mechanical properties of the rock mass, they have been included in the overall assessments as part of the mechanical characteristics.

The stratigraphic/structural characteristics of domal salt cannot be considered without an understanding of the salt depositional environment and mode of intrusion of the salt diapir. Thus, these peripheral aspects are also covered. This section critically examines the stratigraphic/structural characteristics to assess their relative influence on the key issues in domal salt. A matrix diagram is presented after the generic section summarizing the assessments. The site specific study which follows the generic study assesses the importance of the identified significant characteristics for the three domal salt sites.

2.1.2 Salt Domes

Salt domes form in areas where thick evaporite sequences have been progressively buried by sedimentary deposits; characteristically this situation develops in subsiding environments. Due to the operative conditions of temperature and pressure, and the mechanical properties of salt, salt beds may become mobilized and intrusive into the overlying sedimentary pile. Such intrusive salt bodies are termed diapirs or stocks. The term "salt dome" encompasses the salt itself, the external sheath of deformed material, and the caprock.

Diapiric salt may be found in various parts of the world, but particularly in the Middle East and the Gulf Coast of the United States. The generic study is based primarily on the domal salt characteristics of the latter location because the specific sites being considered for repository suitability are located in that geological province.

The intrusive evaporite sequence generally consists of halite (rock salt) with minor amounts of anhydrite and gypsum, occasionally separated by thin beds of clay or silt. The sequence into which the salt is intruded may comprise a widely mixed sequence of clastic deposits.

Because of their diapiric formation, salt domes have great vertical continuity. The beds are folded and sheared about vertical axes which contrast markedly with the horizontal continuity of the surrounding rocks. The domes may be continuous with the "mother bed" which is present at some considerable depth or, alternatively, they may be well separated from it. The salt becomes progressively more diapiric as the sedimentation increases and results in uplifts and basins during deposition, hence, it may exert an influence on the pattern and nature of the sedimentation itself.

2.2 DOMAL SALT

2.2.1 Lithology, Mineralogy

Salt domes are 70 to 99 percent halite (NaCl); the halite is said to be purest in those domes which have risen the greatest distance (Kupfer, 1968; LETCo, 1980c). Anhdyrite ($CaSO_4$), gypsum ($CaSO_4 \cdot 2H_2O$) and entrapped sediments form the remainder of the deposits. Halite has a hardness of 2.5 (Moh's scale), anhydrite 3, and gypsum 2. In salt mines, halite is found to have a hardness varying with the proportion of anhydrite present; it is readily soluble in fresh water. The halite found in salt domes may be finely to coarsely crystalline; crystals can range up to several feet long where recrystallization has taken place. The anhydrite may be present as discrete lenses within the halite or, alternatively, completely disseminated through the rock mass. Inclusions of gas, brine and other minerals may be found.

The lithology of the domal salt and its environment impact strongly on several key issues. The mineralogy of the salt is comparatively uniform but less so than surrounding beds. Lithology/mineralogy is a critical characteristic for the hydrological response and a major characteristic for constructability and the thermal, mechanical and geochemical response of a repository site in domal salt.

2.2.2 Stratigraphy

2.2.2.1 Sequence

The stratigraphy of domal salt is strongly related to the intrusive history of the dome which includes the nature of the stock, the external sheath, the caprock and the surrounding sedimentary rock. It must also include some consideration of the structure and the development of the dome as that in itself can affect the nature of the sediments surrounding the stock. Therefore, domal salt stratigraphy is highly site dependent.

Table 2.1 shows the regional stratigraphy of the Gulf Coast area of the U.S.A. The salt has originated in the Louann Formation of lower Jurassic age. Diapiric structures have been intruded from that stratigraphic level to various horizons within the geological sequence.

TABLE 2.1

GENERALIZED STRATIGRAPHIC CORRELATION CHART

SYSTEM	SERIES	GROUP OR STAGE	NORTH LOUISIANA BASIN FORMATION	[illegible] BASIN FORMATION	AGE IN MILLIONS OF YEARS
QUATERNARY	RECENT		RECENT	RECENT	11,000 yr. bp
	PLEISTOCENE		[illegible]CE SURFACES AND DEPOSITS [illegible]UT BASINWIDE CORRELATION [illegible] NOT OBVIOUS		SANGAMON (80-100,000 yr. bp)
	PLIO-PLEISTOCENE		MISSING	CITRONELLE (PRE-GLACIAL)	1.8
TERTIARY	PLIO-MIOCENE			PASCAGOULA-HATTIESBURG	5.5
	MIOCENE		IN	CATAHOULA PAYNES HAMMOCK	
	?			CHICKASAWHAY	22.5
	OLIGOCENE			BUCATUNNA	
		VICKSBURG	STUDY	VICKSBURG UNDIFFERENTIATED	
			AREA	FOREST HILL/ RED BLUFF	38
	EOCENE	JACKSON		YAZOO	
				MOODYS BRANCH	42
		CLAIBORNE	COCKFIELD COOK MTN	COCKFIELD COOK MTN	44.5
			SPARTA	KOSCIUSKO (SPARTA)	46
			CANE RIVER	ZILPHA	
				WINONA	
				TALLAHATTA	
			CARRIZO	MERIDIAN	50
		WILCOX	WILCOX UNDIFFERENTIATED	WILCOX UNDIFFERENTIATED	53.5
	PALEOCENE	MIDWAY	MIDWAY UNDIFFERENTIATED	PORTERS CREEK CLAYTON	58
					65
CRETACEOUS	GULFIAN	NAVARRO (Selma in Mississippi)	ARKADELPHIA NACATOCH SARATOGA		71
		TAYLOR (Selma in Miss.)	MARLBROOK		76
			ANNONA OZAN	SELMA UNDIFFERENTIATED	79
		AUSTIN (Selma in Miss.)	BROWNSTOWN TOKIO [illegible]		81
		EAGLE FORD (Eutaw in Mississippi)	EAGLE FORD	EUTAW	92
		WOODBINE (Tuscaloosa in Miss. and in La.)	TUSCALOOSA	UPPER TUSC. MIDDLE TUSC. LOWER TUSC.	100
	COMANCHEAN	WASHITA		DANTZLER	
			WASHITA UNDIFFERENTIATED		
			KIAMICHI		
		FREDERICKSBURG	GOODLAND PALUXY	WASHITA FREDERICKSBURG UNDIFFERENTIATED	104
		TRINITY	RUSK	PALUXY	105
				MOORINGSPORT	106
			FERRY LAKE RODESSA	FERRY LAKE RODESSA	107
			JAMES PINE ISLAND	PINE ISLAND	109
					113
	COAHUILAN (of Mexico)	NUEVO LEON AND DURANGO (of Mexico)	SLIGO HOSSTON	SLIGO HOSSTON	136
JURASSIC	UPPER	COTTON VALLEY	DORCHEAT SHONGALOO SCHULER	COTTON VALLEY UNDIFFERENTIATED	143
		LOUARK	HAYNESVILLE SMACKOVER	HAYNESVILLE BUCKNER SMACKOVER	
			NORPHLET	NORPHLET	
	LOWER	LOUANN [illegible]	LOUANN SALT WERNER	LOUANN SALT WERNER	
TRIASSIC	UPPER		EAGLE MILLS	EAGLE MILLS	

PRE-MESOZOIC

Modified after LETCo,1980c

The stratigraphic sequence is of critical significance to hydrological response and of major significance to geochemical response and constructability, because the shaft must be driven through the sequence of the water-bearing sedimentary deposits above the salt dome. Inflow from these beds into the shaft and repository must be controlled to maintain the integrity of the repository and to prevent the migration of radionuclides out of the repostory.

2.2.2.2 Salt Diapirism

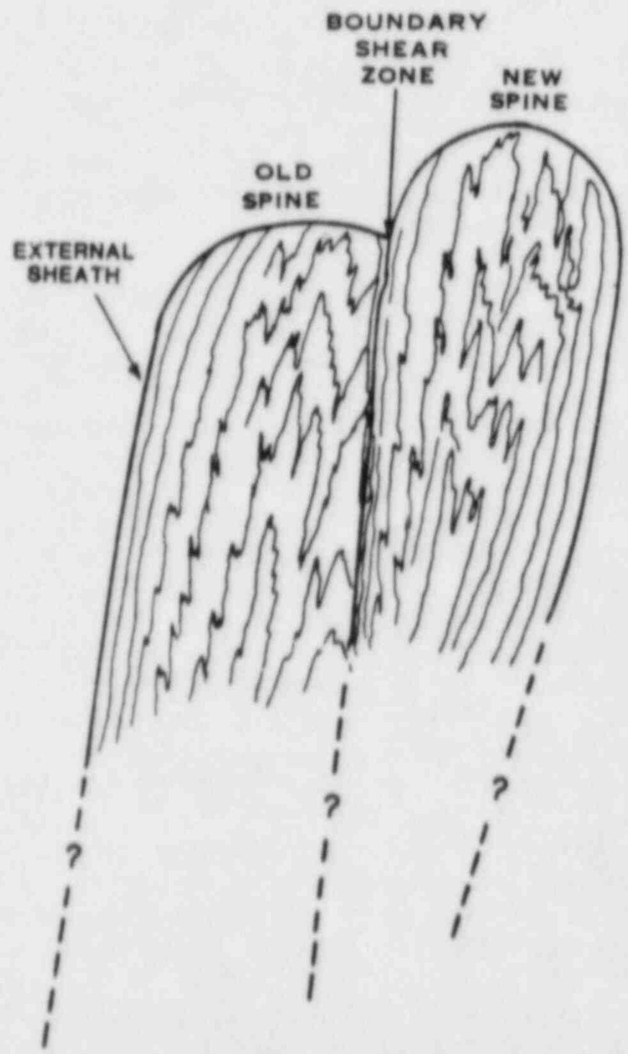
Many theories have been presented to explain how salt diapirism is initiated. Numerous factors are now recognized as controlling salt movement, including the original thickness of the salt, its position in the depositional basin, regional dip, the lithology and temperature of the salt, the rate at which overlying sediments were deposited and the type of basement and tectonic environment.

It is considered that initially the salt moves laterally, forming large pillows or ridges. Diapirs or salt stocks rise from the pillows, or individually from the mother salt bed, moving upward relative to the surrounding strata until stabilization occurs. The growth of domes is thought to be greatest during periods of rapid sedimentation, when uneven loading is more likely and the buoyancy of the salt has a greater effect. LETCo (1980c) reports that domal growth rates in North Louisiana range from 0.001 to 0.027 mm/yr for the Cenozoic, from 0.009 to 0.042 mm/yr for the Lower Cretaceous, and in the East Texas Basin the growth rates range from 0.003 to 0.043 mm/yr in the Tertiary to an average of 0.153 mm/yr in the Jurassic. Netherland, Sewell and Associates (1976) interpreted a growth rate in the East Texas Basin of 0.006 mm/yr (1.9 ft in 100,000 yrs) since the Palco-Eocene Wilcox Formation was deposited. This rate was determined during a period which included the deposition of the thick Eocene Claiborne Formation, when domal growth would have been greater than it has been recently when erosion and minor deposition have been occurring. The salt may eventually reach equilibrium during the waning stages of deposition, or the mother bed may be pinched off by subsidence of the surrounding sediments. The salt can also be extruded on the surface to form salt "glaciers" such as those found in Iran (Gussow, 1968).

Rim synclines form around the dome as salt moves laterally from the mother bed into the salt stock. The relative thickness of the beds in the rim synclines can be used to determine the periods at which the salt movement was taking place. Surveys can be used to determine whether uplift or subsidence of the dome (the latter produced by dissolution of the salt) is now occurring.

Salt rises through the overlying sediments in spines (Figure 2.1). As it moves up, the salt near the exterior of the stock and the sediments surrounding it become sheared and mix together forming an external sheath. When a new spine moves up past an older, immobile spine and its sheath, an internal boundary zone is formed. These internal boundary

SCHEMATIC CROSS SECTION OF SALT STOCK   Figure 2.1



After LETCo, 1980c

zones, or anomalous zones, may be up to 300 feet wide and are characterized by increased inclusions of sediments, brine and gas pockets, and salt that is more impure, coarser grained, and jointed. Impurities in the salt may inhibit the salt's ability to heal joints or fractures. The characteristics of the salt in the anomalous zones could make them undesirable areas for a repository location.

Salt diapirism is not included as a characteristic in this section but is covered more fully in Section 3.5.

2.2.3 Structure

2.2.3.1 Bedding

The presence of bedding is evidenced in salt domes by color banding which varies in various shades of white to black; the darker bands are usually rich in anhydrite. The beds range in thickness from one inch to several feet. Bedding attitudes are usually steep; the coast domes of Louisiana have near vertical bedding, yet those in the north of that state have dips as shallow as 50 degrees (Golder Associates, 1977a). Bedding has a high degree of persistence and, in the salt mines, may be traced from one level to another.

2.2.3.2 Discontinuities

Normally, other than close to excavations, the salt is not naturally jointed or fractured because its physical characteristics (plasticity, low strength, and ease of recrystallization) cause it to heal any joints or fractures that might form. In one documented case of natural jointing in a salt mine, joints spaced 15 to 30 cm (0.5 to 1 foot) apart were found in an area of unusually hard salt (Golder Associates, 1978).

Most discontinuities observed in salt excavations have resulted from stress-relief on unloading (the exfoliation fractures of Golder Associates, 1977a), or from blasting. In either case, the planes are believed to be of limited persistence. Golder Associates (1977a) also describes contact fractures between individual mineral grains and cavities or natural pockets which may contain brine or gas. The latter are often found in anomalous zones located near internal boundary zones or at the exterior of the dome. Discontinuities are considered in more detail in Section 4.3.4.

2.2.3.3 Folding

As the salt moves upward, the beds of halite become increasingly deformed and open, or isoclinal folds are formed by plastic flow and ductile faulting. These folds have near vertical axes and range in size from a few inches to thousands of feet in wave length. Parasitic folds may develop on the limbs of larger folds and, in some domes, more than one generation of folds is apparent. Prolate crystals of halite are usually aligned with the long axis parallel to the layering, i.e., near vertical. In the strata surrounding the salt domes, dips are generally away from the dome towards the rim synclines.

Folding has minor significance to the hydrological response of repository site in domal salt.

2.2.3.4 Inclusions

Gas, brine, and non-salt sediments can all form inclusions within a salt stock. These may be primary if they were deposited along with the salt, or secondary if they were incorporated into the salt during domal growth. All three types of inclusions are most commonly found near the external sheath and within the internal boundary zones.

Gas pockets of carbon dioxide and hydrogen sulphide may be encountered within the salt. Pressure pockets are also found in all mines deeper than 305 m (1000 feet) below ground, usually at spine boundaries or near the exterior of the dome. When pressure pockets are encountered, salt may be broken out of the excavation in excess of that planned by the blasting. The relationship between blow-outs and pressure pockets is unknown.

Brines may be found anywhere within the dome, but are most common near ductile fault zones where water was probably trapped within the salt as it pushed through the sediments. Brine flows, which discharge up to 378 m^3 (100,000 gallons) into mines, have been recorded in bedded salt (Golder Associates, 1979a). Brine may also occur as inclusions within halite crystals.

The sediments encased within a dome are usually pod or lenticular shaped. They too are most common near internal boundary zones and the external sheath, but they may be present throughout the dome if they were deposited within the salt.

Although inclusions have provided mining problems in some parts of the world, they have not been shown to be of great significance in the Gulf Coast domes. Inclusions are of minor significance to all the key issues for design and construction in domal salt.

2.2.3.5 Faulting/Shearing

Faulting occurs both within the domal salt and in the surrounding rocks. In the salt, ductile faulting is believed to have occurred where there has been continuous permanent strain without loss of cohesion normal to the fault at the last time of motion (Odom and Hatcher, 1980). Above and adjacent to the stock, brittle faults are formed by the tensional forces created by the uplift during domal growth. Faults may also form in the rim synclines due to subsidence. The whole exterior of the dome may be considered as a ductile fault or shear because of the differential movement between salt and surrounding rocks. Ductile faults may also form within the salt where spines move at different rates and where the beds have become highly attenuated in the fold limbs. The indication of faulting or shearing within the salt is often tenuous and only substantiated by indirect evidence. Open zones created by faulting tend to leak water during the short term, becoming self-sealing in the longer term.

Faulting and shearing are characteristics of major significance to constructability and mechanical, hydrological and geochemical response. Such structures may strongly affect both the strength and hydraulic conductivity of the rock mass.

2.2.3.6 Solution

Rocks present in the Gulf Coast domes are all of high solubility. This aspect is treated in detail in Section 4.3.7. Solution may readily occur under certain hydrologic conditions. When it does occur it could be a progressively deteriorating situation. Various scenarios described from mines in the area are presented in Section 6.2.1. Extreme caution is exercised in mine excavations in salt domes to ensure that known zones of high hydraulic conductivity are avoided. Flooded workings collapse and extreme subsidence can result.

Solution zones, or solution-enlarged discontinuities, are unpredictable other than at the stock margins and in shear zones on the margins of internal spines. Precautionary predictive techniques including drilling ahead of the face and geophysical surveying are employed. It is not possible to predict when such zones might be encountered internal to the dome.

Because of the potentially disasterous consequences, solution of the evaporite or calcareous beds must be considered a critical characteristic for constructability and the thermal, mechanical, hydrological and geochemical response of a repository site in domal salt.

2.3 CAPROCK

All Gulf Coast salt domes are overlain by caprock. The caprock generally has the same configuration as the salt stock and has formed during the intrusive process. It may overhang the salt on all sides. It is normally thicker near the center, while it thins towards the perimeter.

The caprock generally consists of anhydrite, gypsum, calcium carbonate, sand, and traces of clays. Of these, anhydrite and gypsum make up the largest percentage of the material. A typical caprock would consist of an upper calcitic portion interbedded with gypsum. The calcites are subject to dissolution which results in vuggy or fractured zones sometimes filled with water and/or sand and clay. Some limestone may be found towards the perimeter. The lower portion consists mainly of anhydrite containing zones of gypsum and salt stringers. The gypsum is encountered primarily in the zone of probable hydration underlying the water-bearing calcite, where anhydrite has been altered.

The nature of the contact between the caprock and the salt stock is likely to vary from place to place. Conditions range from sharp and tight contacts to possible dissolution cavities.

2.4 DESIGN AND CONSTRUCTION

2.4.1 Generic Stratigraphic/Structural Characteristics Affecting Design and Construction

The stratigraphic and structural characteristics are of importance for design and construction reasons insofar as they represent the framework upon which the mechanical, thermal and hydrological parameters depend. Thus, although these characteristics are not quantifiable and hence are rightly termed factors rather than parameters, techniques need to be specified by which these factors can be described and their influence on the measurable parameters assessed. These factors need to be addressed in the consideration of the integrity of the repository. The matrix in Table 2.2 compares the stratigraphic/structural characteristics and ranks them as to their significance for an NRC review of an SCR in domal salt.

2.4.2 Mitigating Design and Construction Strategies

The adverse stratigraphic/structural characteristics of a deep high-level waste repository sited in domal salt may be mitigated by a variety of design and construction strategies. These include:

- Leaving a buffer zone between the repository and the dome margin
- Avoiding shear zones in the interior of the dome
- Controlling the inflow of water into the repository excavation by pumping, grouting, freezing and seals and plugs
- Limiting drillholes and excavations in the dome and caprock

Specific mitigating measures can be selected using information from the in situ testing and monitoring program.

TABLE 2.2

EVALUATION OF STRATIGRAPHIC/STRUCTURAL CHARACTERISTICS IN TERMS OF THEIR INFLUENCE ON KEY ISSUES

KEY ISSUES	CONSTRUCTABILITY	THERMAL RESPONSE	MECHANICAL RESPONSE	HYDROLOGICAL RESPONSE	GEOCHEMICAL RESPONSE
Lithology/Mineralogy	beh (Major)	beh (Major)	beh (Major)	adh (Critical)	beh (Major)
Stratigraphic Sequence	beg (Major)	cfg (Insignificant or not relevant)	cfg (Insignificant or not relevant)	bdg (Critical)	bfg (Major)
Folding	cfh (Insignificant or not relevant)	cgh (Insignificant or not relevant)	cfh (Insignificant or not relevant)	bfh (Minor)	efh (Insignificant or not relevant)
Faulting/Shearing	aei (Major)	cfi (Insignificant or not relevant)	aei (Major)	aei (Major)	aei (Major)
Inclusions	bei (Minor)	bei (Minor)	bei (Minor)	bei (Minor)	bei (Minor)
Solution	adi (Critical)	adi (Critical)	adi (Critical)	adi (Critical)	adi (Critical)

KEY:*

- Critical
- Major
- Minor
- Insignificant or not relevant

*See Section 1.3.5 and Table 1.1 for definitions of the level of influence

ATTRIBUTES

- availability of design and construction techniques which allow for conservative assumptions for the value of the characteristic:
  - a) reasonable techniques are not available (i.e. high cost impact)
  - b) some techniques are available, but at moderate cost impact
  - c) reasonable techniques are available (i.e., little cost impact)
- uncertainty in the representation of the real world by the performance prediction model, and sensitivity of that model to characteristic value:
  - d) model has low uncertainty (i.e., is very representative) and high sensitivity to characteristic
  - e) model has moderate uncertainty and moderate sensitivity
  - f) model has high uncertainty or low sensitivity
- cost effectiveness and scheduling limitations in potentially reducing the uncertainty in the assessment of characteristic values:
  - g) uncertainty can be significantly reduced in a cost-effective and timely manner (i.e., prior to NRC review of an SCR)
  - h) uncertainty can be reduced, but only during in situ testing
  - i) uncertainty cannot be significantly reduced in a cost-effective or timely manner (i.e., prior to NRC review for construction authorization).

2.5 SITE SPECIFIC STUDY

The features described from the generic viewpoint in the foregoing sections are considered for three sites, the Richton Dome, Mississippi, the Cypress Creek Dome, Mississippi, and the Vacherie Dome, Louisiana, in the following sections. Most of the information is from LETCO (1980a, b, and c).

2.5.1 General

The Gulf Coast salt domes formed progressively during the deposition of sediment into the Gulf Coast Geosyncline between late Triassic and Recent times (Golder, 1977a). The Gulf Coast Geosyncline was built up by the deposition of a series of thick clastic wedges into a shallow transgressive sea in which carbonates and occasional evaporites were accumulating. As each wedge of sediment was deposited into the trough, a changed environment was produced varying from onshore and nearshore deltaic facies through a sandy shelf facies to an offshore marine facies eventually resulting in marine regression. The major tectonic elements operative during this period are described in Section 3.

The total stratigraphic section in Louisiana is estimated to be 12 to 18 km (40,000 to 60,000 feet) thick. Table 2.1 shows the regional stratigraphic sequence. During this period of deposition, the main axis of the geosyncline moved progressively towards the Gulf and the center of deposition moved from south Texas to southeast Louisiana. Subsidence was caused in part by the repeated sedimentary loading which produced movement of the Louann Salt of Lower Jurassic age from near the base of the sequence upwards into the newly deposited sedimentary pile. This movement affected the development of the interior structural basins in which the salt domes are currently located.

It appears unlikely that the Louann Salt was ever buried deeper than 7 kilometers (20,000 feet) without the onset of instability. This is considered to be due to the inability of the salt to remain stable at great overburden pressures. The salt was intruded into the overlying sediments as pillows, stocks, and finally domal uplifts. It seems likely that other factors in addition to superincumbent load also affected salt movement. These factors include the original thickness of the salt, regional dip, position in the depositional basin, lithology and temperature of the salt, sedimentation rate, character of the basement and tectonic environment. The salt moved vertically in relation to the surrounding sedimentary rocks resulting in folding of the salt about vertical axes and the formation of a sheath of sheared sediments surrounding the dome, as described in Section 2.2. The margins of the domes are generally poorly known. The inherent danger of mining or drilling near the boundaries of the salt where influx of fresh water could produce disastrous consequences has resulted in mining developments being concentrated in the central parts of the stocks.

2.5.2 Richton Dome

2.5.2.1 Stratigraphic Location

The Richton Dome lies within the southeastern end of the Mississippi Salt Basin (Figure 2.2) on a large plunging syncline. The stratigraphic sequence at this site is similar to that of the Gulf Coast area as a whole (Table 2.3). Bordering the Mississippi Salt Basin to the north is the Pickens-Gilberton Fault Zone, a series of block faults peripheral to the Gulf Coastal Province, while to the south is the Wiggins Anticline which may have been caused by crustal subsidence and flexure due to sediment loading. The salt basin extends from the Monroe-Sharkey Uplift, of possible plutonic igneous origin, in the west to the Jackson-Mobile Graben to the east.

Any repository would be located within the interior of the salt dome. However, the near-field considerations of this study include not only the salt itself, but also the caprock and the sheath surrounding the dome. Numerous test wells were drilled into the caprock and several into the salt stock of Richton Dome. Caprock, found at depths of 151 to 268 m (497 to 879 feet), ranged in thickness from 6 m (20 feet) near the edge of the dome to a maximum of 65 m (213 feet) near the center (see Figure 2.3). In one DOE borehole, caprock consisted of vuggy limestone, interbedded with calcite near the top, underlain by anhydrite with gypsum-filled veins. Near the base of the caprock, the anhydrite was found to be brecciated and vuggy with gypsum-rich zones (LETCo, 1980b). The caprock-salt contact zone was found to be formed by a 0.9 to 1.5 m (3 to 5 foot) anhydrite sandy zone.

Depth to salt ranged between 220 and 261 m (722 and 857 feet). The DOE core encountered an anhydrite-rich zone near the top of the dome, otherwise the salt was found to be composed of fine-to coarse-grained, equidimensional to prolate halite crystals with anhydrite disseminated throughout or present as inclusions. There were also numerous zones of halite megacrystals present. Halite comprises approximately 90 percent of the core (LETCo, 1980b).

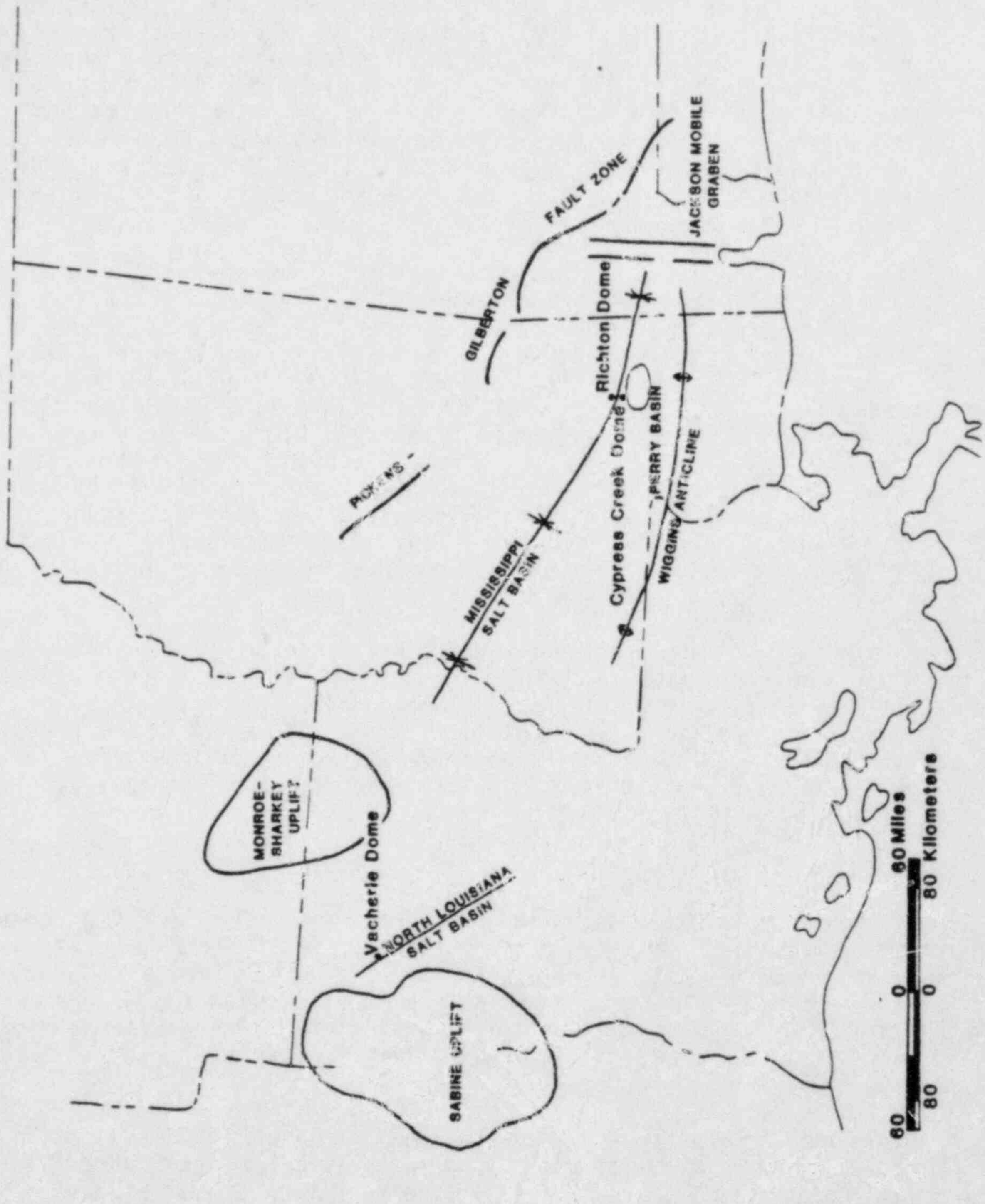
2.5.2.2 Structure

Richton Dome pierces Jurassic, Cretaceous and Early Tertiary sediments and penetrates into Late Tertiary strata (see Figure 2.3). Structural contours on eight Late Cretaceous and Tertiary horizons indicate that the regional strike is generally west-northwesterly. The dome is located on a major northwesterly-trending ridge in Jurassic rocks from which the salt has risen to a higher stratigraphic level (LETCo, 1980b).

The Richton salt body is elliptically shaped, with its long axis parallel to that of the underlying salt anticline (see Figure 2.4). It is approximately 13 km (8 miles) long by 3 km (2 miles) wide at -1800 m (-6000 feet) MSL. Between -4900 and -1200 m (-16,000 and -4000 feet) MSL, the salt column flairs outward on the western flank forming an

STRUCTURAL SETTING
RICHTON AND CYPRESS CREEK DOMES

Figure 2.2



Modified after LETCo, 1980 b

Project No 83/1162 Reviewed KL Date 12/81

TABLE 2.3

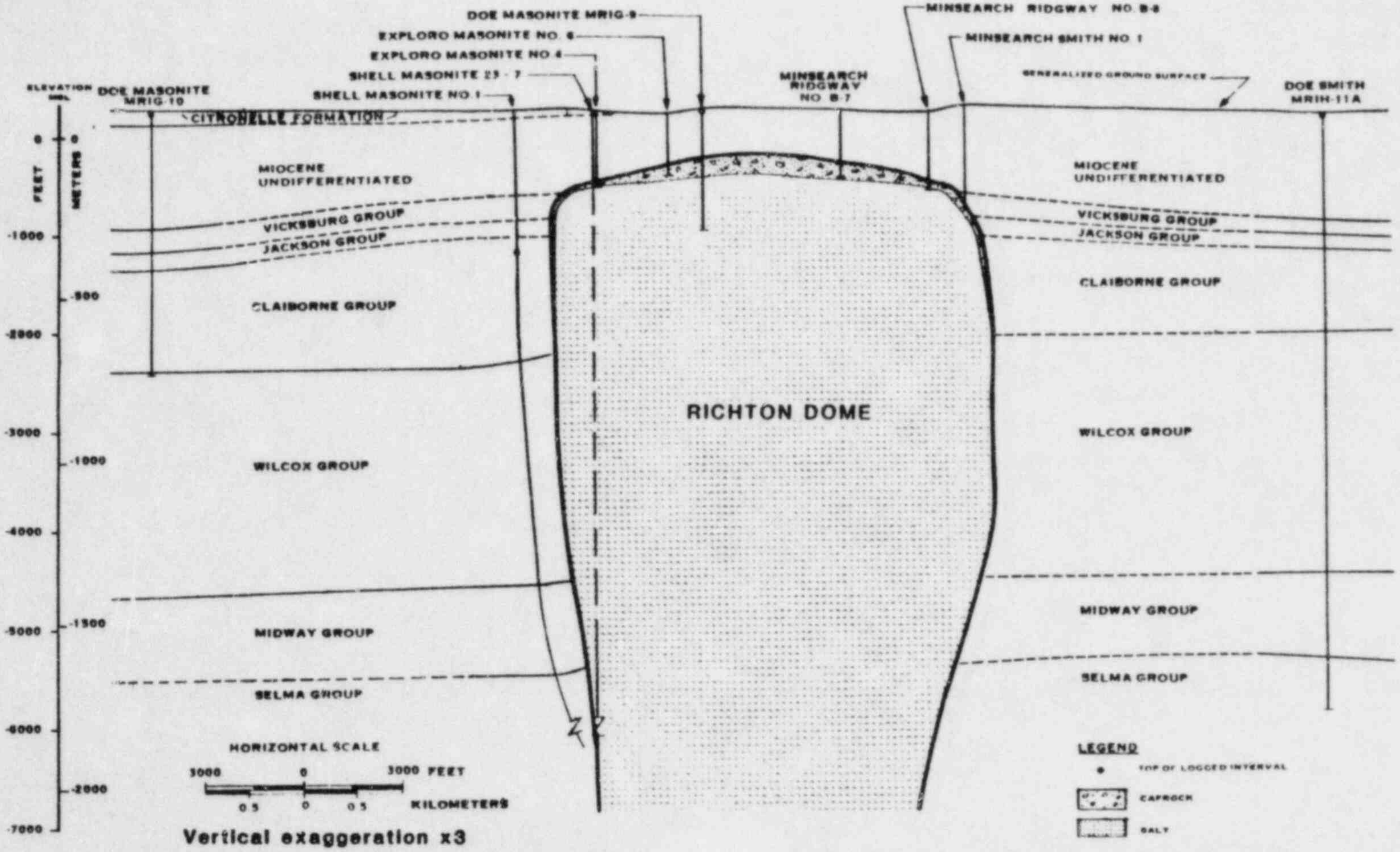
STRATIGRAPHIC SEQUENCE - RICHTON DOME AREA

SYSTEM	SERIES	GROUP OR STAGE	FORMATION	AGE MYBP	THICKNESS FEET STUDY AREA	THICKNESS FEET RICHTON DOME	RICHTON DOME LITHOLOGY
QUATERNARY	RECENT		ALLUVIUM		0-125	—	Interbedded variably sandy and silty clays, variably silty sands, and gravels.
QUATERNARY	?		TERRACE DEPOSITS		0-50	—	Variably clayey quartzose silts with occasional clays and sands.
QUATERNARY / TERTIARY	PLIO-PLEISTOCENE		CITRONELLE	1.8	0-215	0-215	Lenses and interbeds of variably sandy clays, variably silty sands, and gravels.
TERTIARY	MIOCENE		HATTIESBURG AND CATAHOULA UNDIFF.	22.5	849-1991	976-980	Very fine to coarse grained sands, clays, chalky and sandy limestones, and minor shales and siltstones. Includes the <u>Heterostegina</u> zone, a chalky, sandy limestone, clay, and quartz sand unit.
TERTIARY	OLIGOCENE		CHICKASAWHAY		46-215	96-117	Interbedded clays, fine to medium grained sands, and locally very sandy limestones which sometimes grade into limy sands.
TERTIARY	OLIGOCENE	VICKSBURG	BUCATUNNA		11-81	43-76	Interbedded clays, fine to medium grained sands, and occasionally, mudstones
TERTIARY	OLIGOCENE	VICKSBURG	VICKSBURG LIMESTONES UNDIFF.		61-240	61-101	Crystalline, sandy, glauconitic, locally chalky or calcarenitic limestones.
TERTIARY	OLIGOCENE	VICKSBURG	RED BLUFF	36	15-123	42-58	Interbedded clays, chalky limestones, and minor dolomites.
TERTIARY	EOCENE	JACKSON	YAZOO		113-330	122-178	Glauconitic clays, sandy, chalky limestones or chalky, locally sandy marls, underlain by clays and, sometimes, limy shales.
TERTIARY	EOCENE	JACKSON	MOODYS BRANCH	42	10-37	15-18	Locally very sandy, sometimes chalky or glauconitic limestones.
TERTIARY	EOCENE	CLAIBORNE	COCKFIELD		78-295	165-224	Clays and sandy, sometimes chalky or glauconitic, limestone occasionally interbedded with silty, limy, glauconitic shales.
TERTIARY	EOCENE	CLAIBORNE	COOK MOUNTAIN	44.5	112-260	112-150	Chalky, sandy to silty, sometimes crystalline limestones.
TERTIARY	EOCENE	CLAIBORNE	KOSCIUSKO (SPARTA)	48	121-370	151-218	Interbedded clays, silty, limy shales, and, sometimes, sandy, chalky limestones and slightly limy siltstones.
TERTIARY	EOCENE	CLAIBORNE	ZILPHA		45-220	126-170	Clays interbedded with minor limy shales, siltstones, very fine to coarse grained sands and sandy limestones. Abundantly glauconitic.
TERTIARY	EOCENE	CLAIBORNE	WINONA		22-62	33-60	Chalky, sandy, clayey limestones interbedded with limy shales or glauconitic siltstones.
TERTIARY	EOCENE	CLAIBORNE	TALLAHATTA	50	127-500	223-306	Clays, sandy, chalky or silty limestones, and silty, limy shales or limy, glauconitic siltstones.
TERTIARY	— ? —	WILCOX	WILCOX GROUP UNDIFF.	53.5	1,866-4,955	2,200-2,513	Interbedded fine and very fine grained sands, slightly limy siltstones, silty, locally sandy clays, and minor silty shales, sandy limestones, lignites, and bituminous coal.
TERTIARY	PALEOCENE	MIDWAY	PORTERS CREEK		468-1,195	778-870	Interbedded clays, silty sands, poorly fissile shales, and lignites.
TERTIARY	PALEOCENE	MIDWAY	CLAYTON		0-37	12-27	[illegible] limestones, clays, and silty shales.

After LETCo,1980b

GEOLOGICAL SECTION THROUGH RICHTON DOME

Figure 2.3



After LETCo ,1980 b

extensive bulge or overhang. This side of the dome forms a sheer wall from -1200 to -600 m (-4000 to -2000 feet) MSL. Above -600 m (-2000 feet) MSL, the dome is convex and the length of the salt stock decreases. At -300 m (-1000 feet) MSL, the salt dome is approximately 8 km (5 miles) long by 3 km (2 miles) wide.

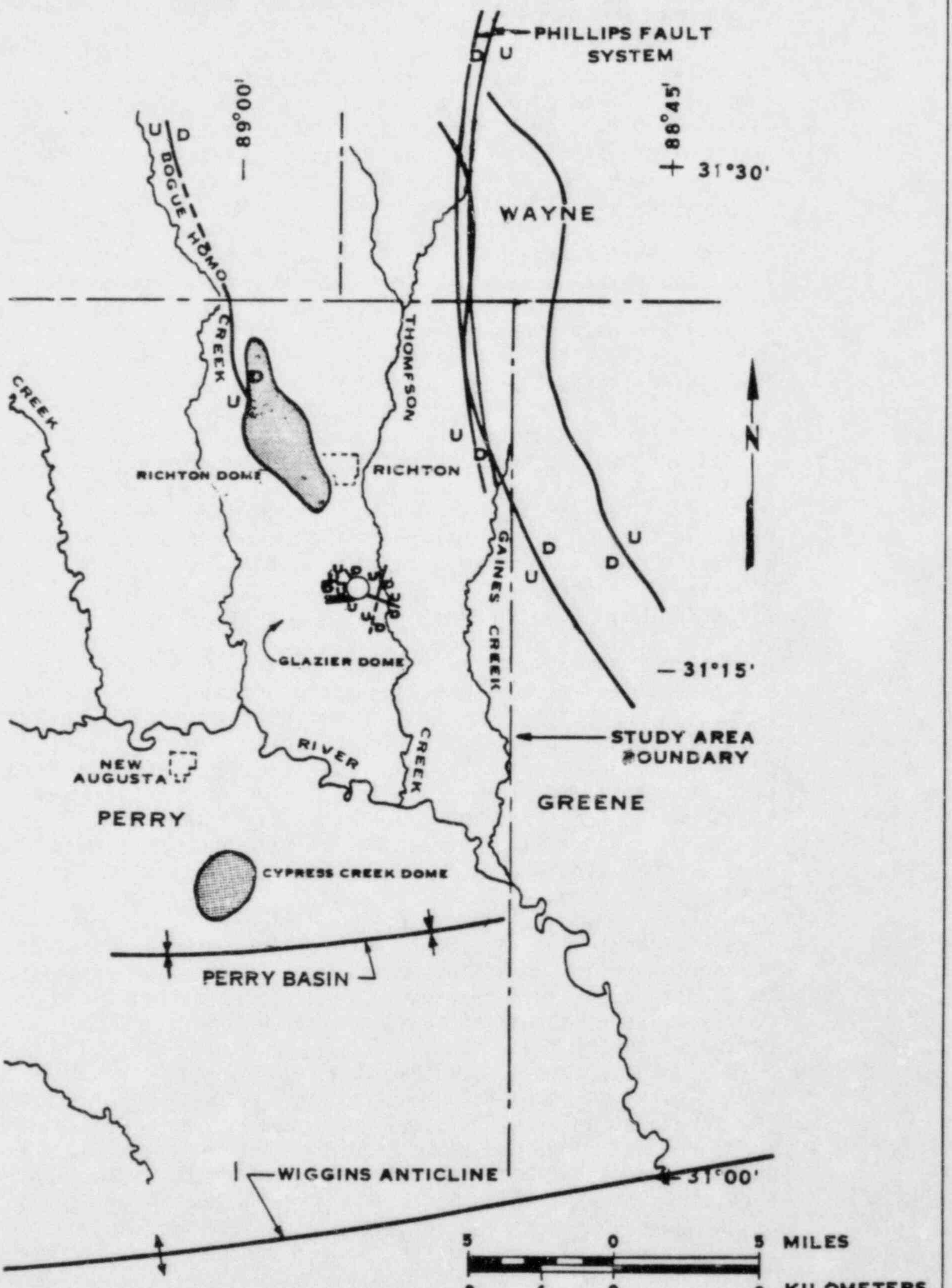
A similar geometry is developed on the eastern flank of the dome with an overhang extending up from -4900 m (-16,000 feet) to approximately -1200 m (-4000 feet) MSL on the southern half of the dome. On the northeastern flank, the overhang extends from approximately -4900 to -600 m (-16000 to -2000 feet) MSL (LETCo, 1980b). Richton Dome is the largest, but shallowest dome currently under consideration.

The dome is located 8 km (5 miles) west of a graben system (Phillips Fault System, Figure 2.4). This graben system is composed of two faults which can be traced in Upper Cretaceous formations. Based on well data, the eastern downthrown block shows approximately 240 m (800 feet) of displacement, while the western downthrown block has almost 210 m (700 feet) of offset on the top of the Lower Tuscaloosa.

Movement of the Richton Dome salt stock has locally disturbed the strata in the surrounding area (Figure 2.3). Seismic data indicate that Early Cretaceous strata are upturned as much as 210 m (700 feet) on the western side of the dome, but structural relief decreases to approximately 60 m (200 feet) on Late Tertiary strata above. On the eastern side of the dome, seismic data shows strata dipping gently towards the dome to within approximately 1.6 km (1 mile) of the domal flank (LETCo, 1980b).

A rim syncline located approximately 6.4 km (4 miles) to the north-northwest of the dome, is mapped on top of the Lower Tuscaloosa Formation. The syncline is bounded along its eastern margin by the northerly trending Bogue Homo Creek Fault which is adjacent to Richton Dome on the western side (Figure 2.4) (LETCo, 1980b). Eocene through Oligocene strata dip away from the dome on the northeastern and western sides, while the strata on the northwestern flank also dip away, but not as steeply, and maximum structural relief is approximately 120 m (400 feet). The strata are faulted with the fault planes dipping toward the dome and displacements approximately 30 to 60 m (100 to 200 feet) down-thrown towards the dome (LETCo, 1980b). Structural analyses of the surficial units indicate domal movement may have occurred as late as the Miocene as evidenced by the presence of faulting in Hattiesburg strata. Two faults over the dome crest have been identified by geophysical log correlations of strata encountered in the Area Characterization shallow borings. One of these faults displaces Miocene strata approximately 20 m (70 feet) over the southwestern portion of the dome crest. The other fault was identified in the center of the dome crest and displaces the strata about 6 m (20 feet). Both apparently have down-thrown blocks to the south. There is no clear evidence that the Hattiesburg-Citronelle contact has been uplifted, nor are there any abnormal terrace elevations above Richton Dome. This, along with a closed depression which may have ben caused by salt dissolution at depth, suggests that there has been no recent uplift of Richton Dome. Lineaments in the area do not appear to be related to domal movement.

LOCAL GEOLOGICAL STRUCTURE- RICHTON DOME Figure 2.4



Modified after LETCo,1980b

Faulting has occurred along the exterior of the dome where it has pushed its way up through the overlying sediments. Richton Dome's external sheath is apparently impermeable, since the dome shows no signs of subsidence. So far, no spines have been recognized at Richton Dome, but detailed mapping during excavation would be needed to show whether such features and the associated internal boundary zones are present.

The thickness and attitude of bedding within the domal salt have yet to be determined and, apparently, no jointing was encountered in the core. These aspects will have to be investigated when excavation begins. Fracturing, due to stress relief on excavation, is likely to be present, although, as stated previously, halite tends to close off such features with time through creep.

2.5.2.3 Design and Construction Aspects at Richton Dome

Because of the purity and homogeneity of the salt in the dome, the design will be relatively insensitive to mineralogical and lithological variations in the repository horizon. However, the design must be flexible enough to cope with any anomalous zones within the dome such as brine or gas pockets, xenoliths or other materials, or the presence of excessive impurities within the halite although none of these have yet been identified. The possibility of finding hydrocarbons in the vicinity of Richton Dome must be considered. Although there are oil and gas fields nearby, all wells at Richton have been dry and the probability of new finds is considered to be low.

The shaft would intersect Miocene beds, caprock and domal salt. The upper beds have been disturbed as the result of the domal uplift, and in situ investigation by drilling would be needed to ensure that the shaft was sunk through intact ground. The sheath rocks are known to only a limited extent, but it should be assumed that they could be weak, highly disturbed, at least of moderate permeability, and likely to prove difficult to seal in the shaft. There has been no evidence of Recent diapiric movement.

Structurally, there is no reason to suppose that the Richton Dome differs much from the generic model. However, investigation in the heart of the dome is sparse and in situ investigation would be required prior to and during construction. Solution is a potential problem but at present has not been shown to have occurred.

2.5.3 Cypress Creek Dome

2.5.3.1 Stratigraphic Location

The Cypress Creek Dome, located approximately 19 km (12 miles) south of the Richton Dome, lies at the southeastern end of the Mississippi Salt Basin. This basin is bordered by the Pickens-Gilberton fault zone on the north, which is peripheral to the Gulf Coastal Province, and by the

Wiggins Anticline, a part of the Wiggins Uplift, on the south. To the east is the Jackson-Mobile Graben and to the west is the Monroe-Sharkey Uplift (Figures 2.2 and 2.4; LETCo, 1980b). Perry Basin, a subbasin to the south of the Cypress Creek Dome, was probably produced by withdrawal of salt into the salt stock (LETCo, 1980b). Perry Basin trends west-northwest and is approximately 39 km (24 miles) long. Deposition occurred in this basin from early Tertiary onwards. The presence of this basin strongly influenced deposition throughout the Tertiary and Quaternary, causing large differences in lithologies and thicknesses from the north to the south side of the dome (LETCo, 1980b). Table 2.4 shows the stratigraphic sequence of the area.

At least 900 m (3000 feet) of structural relief is present in Perry Basin as measured on the surface of the Lower Tuscaloosa, Selma, and Porters Creek Formations, decreasing to 150 m (500 feet) on the top of the Vicksburg Formation. Because of the amount of structural relief present in Perry Basin, LETCo (1980b) suggested that salt from the Cypress Creek stock was actually extruded onto the surface, resulting in the subsidence which formed the basin. By comparing the volume encompassed by Perry Basin on the top of the Porters Creek Formation, the amount of salt presently estimated to be within the stock, and the amount thought to have been dissolved to form the thick caprock, it was found that up to 171 km^3 (41 cubic miles) of salt is missing.

The Cypress Creek Dome is an irregular ellipsoid, with its long axis trending northeast-southwest. A circumferential overhang has formed on the stock between -800 and -1900 m (-2500 and -6000 feet) MSL. This overhang is most prominent on the northeastern flank of the stock and relatively less pronounced on the southeastern side. At -300 m (-1000 feet) MSL, the salt stock encompasses an area of less than 5 km^2 (2 square miles) which increases to 10 km^2 (4 square miles) at -600 m (-2000 feet). The stock then decreases again to 5 km^2 (2 square miles) at -1900 m (-6000 feet), gradually broadening from there until it reaches a maximum of 56 km^2 (22 square miles) at -5500 m (-18,000 feet) MSL (LETCo, 1980b).

As the salt moved up, it pierced Jurassic, Cretaceous and Early Tertiary strata and penetrated into Miocene sediments (Figure 2.5). The piercement and penetration disturbed the overlying and surrounding strata. Sediments pierced by the stock were folded upward near the salt body. Above -900 m (-3000 feet) MSL, strata within 600 m (2000 feet) of the northern flank of the stock are upturned 60 to 150 m (200 to 500 feet). On the southern flank, and below -900 m (-3000 feet) MSL on the northern flank of the stock, strata dip south 40 to 60 m/km (200 to 300 feet per mile) towards Perry Basin (LETCo, 1980b).

Zones of anhydrite, apparently replaced by fine-grained gypsum, are present in the upper portion of the caprock. The lower portion consists of anhydrite, with gypsum present in veins, filling fractures, and as small blebs. The anhydrite grades into granular halite near the salt/caprock contact, and gypsum is absent (LETCo, 1980b). The caprock-salt contact zone is a 0.6 m (2 foot) sandy zone. 62 m (204 feet) of caprock is the maximum thickness proven above the Cypress Creek Dome.

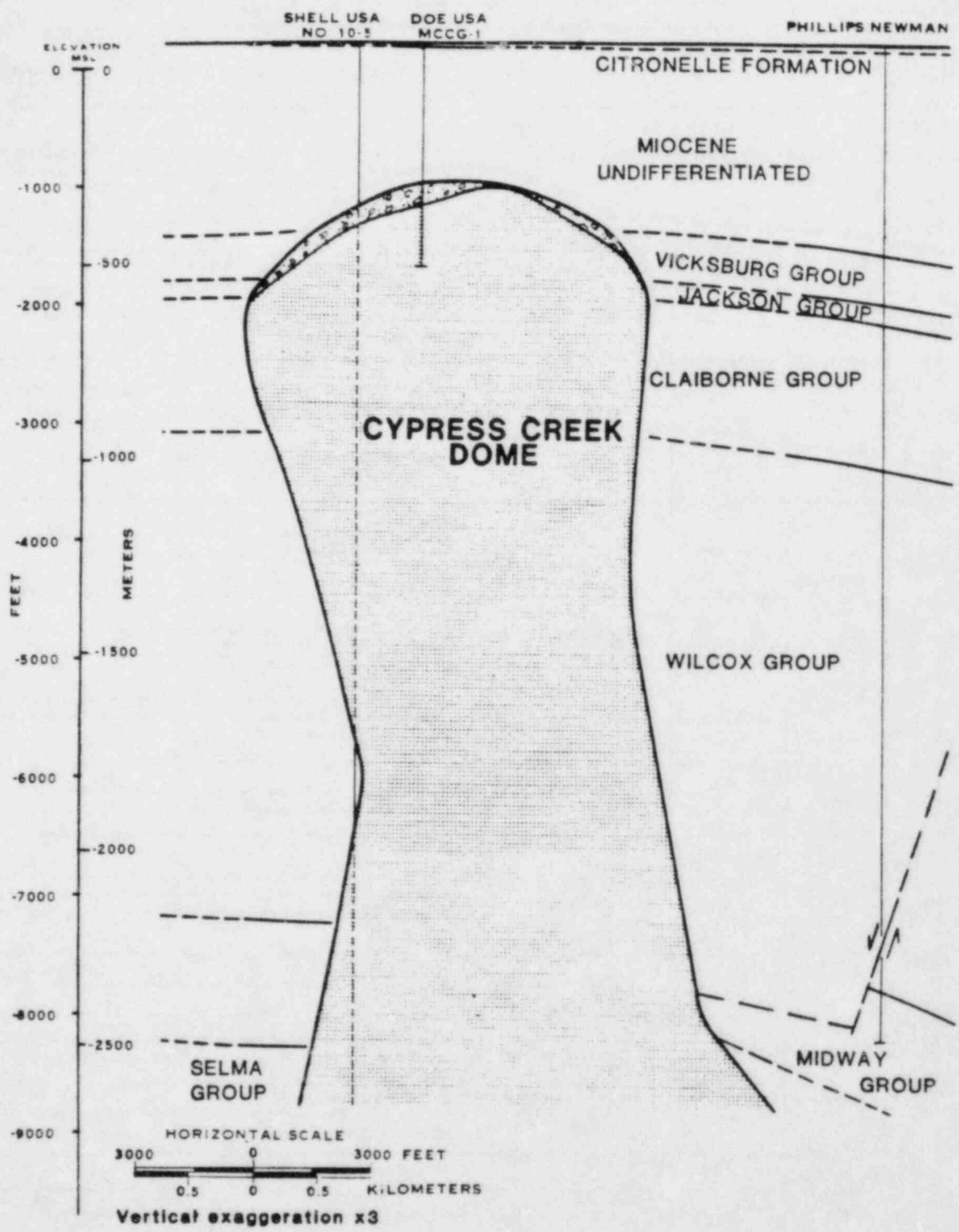
TABLE 2.4

STRATIGRAPHIC SEQUENCE - CYPRESS DOME AREA

SYSTEM	SERIES	GROUP OR STAGE	FORMATION	AGE MYBP	THICKNESS (FEET) STUDY AREA	THICKNESS (FEET) CYPRESS CREEK DOME	CYPRESS CREEK DOME LITHOLOGY
QUATERNARY	RECENT		ALLUVIUM		0 - 125	0 - 50	Interbedded very fine to fine grained silty sands, clays, and silts. A few terrace remnants, lithology unknown, occur in Recent alluvial floodplains.
QUATERNARY	PLIO-PLEISTOCENE		CITRONELLE	1.8	0 - 215	0 - 185	Fine to coarse grained, silty sands, gravelly sands, clayey sands, and clays.
TERTIARY	MIOCENE		HATTIESBURG AND CATAHOULA UNDIFF.	22.5	849 - 1991	1395 - 1991	Interbedded very fine to coarse grained, locally limy sands, highly plastic and locally sandy, partially bentonitic clays, chalky limestones, and, occasionally, lignites. Includes the Heterostegina zone; a chalky limestone and fine to coarse grained sand unit.
TERTIARY	OLIGOCENE		CHICKASAWHAY		46 - 215	114 - 215	Clay, very fine to medium grained sands and chalky, locally calcarenitic, and locally very porous limestones.
TERTIARY	OLIGOCENE	VICKSBURG	BUCATUNNA		11 - 91	50 - 91	Very fine to coarse grained, locally lignitic quartz sands and lignitic clays with traces of limestone.
TERTIARY	OLIGOCENE	VICKSBURG	VICKSBURG LIMESTONES UNDIFF.		61 - 240	161 - 218	Calcarenitic, locally bioclastic, glauconitic limestones, occasionally interbedded with minor sand, clay, mudstone, and dolomite.
TERTIARY	OLIGOCENE	VICKSBURG	RED BLUFF	36	15 - 123	98 - 123	Interbedded limy clays, very fine to medium grained sands, and calcarenitic, locally argillaceous limestones.
TERTIARY	EOCENE	JACKSON	YAZOO		113 - 330	136 - 192	Limy, slightly silty clays with fine and medium grained, limy, glauconitic sands or calcareous claystone with variable amounts of limestone, clay, mudstone, and lignite.
TERTIARY	EOCENE	JACKSON	MOODYS BRANCH	42	10 - 37	25 - 37	Interbedded fine and very fine grained sands, chalky, sometimes glauconitic limestones, and occasional silty, limy mudstones.
TERTIARY	EOCENE	CLAIBORNE	COCKFIELD		76 - 296	180 - 296	Interbedded clays, very fine to medium grained sands, and minor limestones and mudstones to interbedded sandy, abundantly glauconitic limestones, lignites, and fine to coarse grained sands.
TERTIARY	EOCENE	CLAIBORNE	COOK MOUNTAIN	44.5	112 - 280	177 - 280	Occasionally sandy, chalky, calcarenitic limestones interbedded with variable amounts of sand, clay, mudstone and shale.
TERTIARY	EOCENE	CLAIBORNE	KOSCIUSKO (SPARTA)	48	121 370	140 - 158	Interbedded bentonitic, non-calcareous, silty clays and fine and very fine grained, glauconitic, argillaceous, partially limy sands to interbedded limestones and glauconitic shales with thin, fine to coarse grained sands in the lower portion.
TERTIARY	EOCENE	CLAIBORNE	ZILPHA		45 - 220	45 - 85	Glauconitic clay and shale, silty, limy mudstone and limestone.
TERTIARY	EOCENE	CLAIBORNE	WINONA		22 - 62	33 - 50	Interbedded crystalline to microcrystalline limestones and very fine to coarse grained, glauconitic, sometimes limy sands, locally interbedded with clay.
TERTIARY	EOCENE	CLAIBORNE	TALLAHATTA	50	127 - 500	395 - 500	Clays, limy shales, silty mudstones and microcrystalline, locally sandy, glauconitic limestones.
TERTIARY	?	WILCOX	WILCOX GROUP UNDIFF.	53.5	1885 - 4955	2800 - 4955	Interbedded sands and clays of unknown induration.
TERTIARY	PALEOCENE	MIDWAY	PORTERS CREEK		468 - 1195	940 - 1020	Clays underlain by a sand and clay unit; all of unknown induration.
TERTIARY	PALEOCENE	MIDWAY	CLAYTON		0 - 37	15 - 18	Argillaceous limestones.

After LETCo, 1980b

GEOLOGICAL SECTION THROUGH CYPRESS CREEK DOME Figure 2.5



After LETCo,1980 b

Project No. B13116ZC Reviewed KV Date 12-81

Elevation of the salt in the various wells ranged from -316 to -361 m (-1037 to -1184 feet) MSL. Approximately 90 percent of the dome consists of halite, with the remainder composed of anhydrite and xenoliths. The halite occurs as fine- to coarse-grained, equidimensional to prolate crystals. Discrete bands containing up to 25 percent anhydrite are present in the halite (LETCo, 1980b).

2.5.3.2 Structure

A normal fault lies along the axis of Perry Basin, with the northern block down-thrown 500 to 800 m (1700 to 2600 feet). This fault affects Jurassic and Cretaceous strata and may extend beneath the Louann Formation. The relationship of this fault to Perry Basin is unknown, but it is thought that it might have controlled the position of the dome (LETCo, 1980b). Approximately 5.6 km (3.5 miles) south of this is another fault in the Wilcox Group with up to 500 m (1600 feet) of throw. Other faults are present near the dome with displacements between 30 to 90 m (100 to 300 feet). These faults were probably produced by adjustments to the tensional forces associated with domal movement (LETCo, 1980b).

Ductile faulting at the salt stock/sediment contact has not yet been detected, although it is anticipated to be present. No internal ductile faults have been noted in cores of the salt stock, and joints or fractures have not been encountered.

A closed depression is present on the Late Tertiary Hattiesburg-Citronelle contact directly over the Cypress Creek Dome, which has been filled with an unusually thick sequence of Quaternary sediments. This indicates Miocene subsidence of the supradomal sediments caused by dissolution of the salt in the stock (LETCo, 1980). Lineaments in the area generally correlate with stream drainages or other features unrelated to domal movement. There is no evidence indicating uplift of Cypress Creek Dome since at least the Miocene.

Bedding thicknesses and attitudes within the salt have not yet been determined. Estimates might be made by noting the attitude of the long axes of the prolate crystals, which are often parallel to the bedding. Exact measurements could be made during excavation.

2.5.3.3 Design and Construction Aspects at Cypress Creek Dome

The lithology and mineralogy of the dome are relatively uniform and there is no reason to suppose that they will differ substantially from the generic model. Mapping would be required during shaft and test facility construction to verify this. Detailed studies would be required to prove that the pre-Quaternary subsidence is not still continuing.

Although faulting beyond the margins of the dome is widespread, there is no current evidence to show that faulting within the stock is likely to affect design or construction.

A shaft into the dome would intersect the weak Hattiesburg Formation (Table 2.4), the caprock and the salt. If subsidence of the materials overlying the dome has occurred, some disturbance of the beds is likely with possible faulting. High hydraulic conductivity in the caprock should be anticipated.

Solution is a potential problem but at present has not been shown to have occurred.

2.5.4 Vacherie Dome

2.5.4.1 Stratigraphic Location

Vacherie Dome lies within the Vacherie Subbasin of the Minden Basin, in the northern half of the Northern Louisiana Salt Basin, which is a large southeasterly plunging syncline (Figure 2.6). The Lake Bistineau Structural Bridge separates the Minden Basin from the southern half of the Northern Louisiana Salt Basin. The salt basin is bounded on the southwest by the Sabine Uplift, and on the northeast by the Monroe-Sharkey Uplift (Figure 2.2). The latter shows some surface expression, and both are thought to be of plutonic igneous origin (LETCo, 1980a).

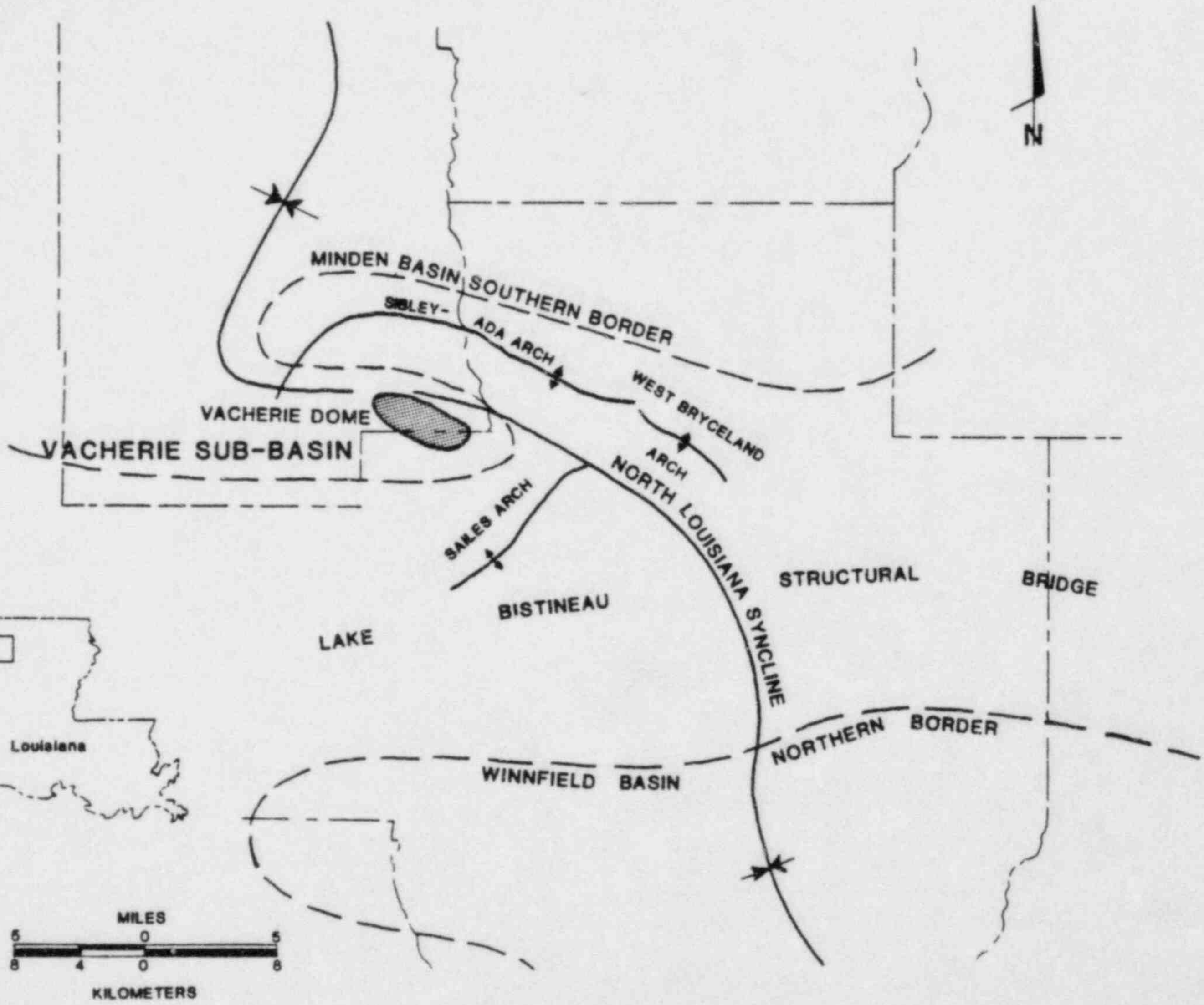
Four minor arches, the Sailes, Sibley-Ada and West Bryceland Arches, partially surround the Minden Basin. These arches probably are residual highs isolated during the nearby withdrawal of salt. The Vacherie Sub-basin is thought to be a salt withdrawal basin or large rim syncline.

Of the rim sycnlines surrounding the dome, the most prominent are those on the southeast and northwest flanks of the dome. Golder Associates (1977a) concluded that development of the synclines, and of the dome, was greatest during the Late Jurassic and Early Cretaceous and continued at a lesser rate through the Early Tertiary. As the Vacherie salt stock moved upward, it pierced Jurassic and Cretaceous sediments and penetrated Early Tertiary strata (Figure 2.7). These strata were deformed by this upward movement. The Lower Cretaceous Sligo Formation shows dips of 30° to 35° as far as 900 m (3000 feet) from the salt stock. Upper Cretaceous and Tertiary sediments show a decreasing amount of dip (LETCo, 1980a). Although hydrocarbons may be trapped in these upturned sediments, to date all wells at Vacherie Dome have been dry; the probability of finding oil is thought to be low. Table 2.5 shows the Tertiary and Quaternary stratigraphic sequence for this area.

The Eocene Sparta Formation is the youngest Tertiary unit found at Vacherie dome, thus Late Tertiary movement of the dome is difficult to assess. Quaternary terraces found near the dome give no indication of Quaternary movement, although there is an unusually thick accumulation of Quaternary sediments in an area directly above Vacherie Dome. More work needs to be done to determine the age of the most recent movement.

STRUCTURAL SETTING, VACHERIE DOME

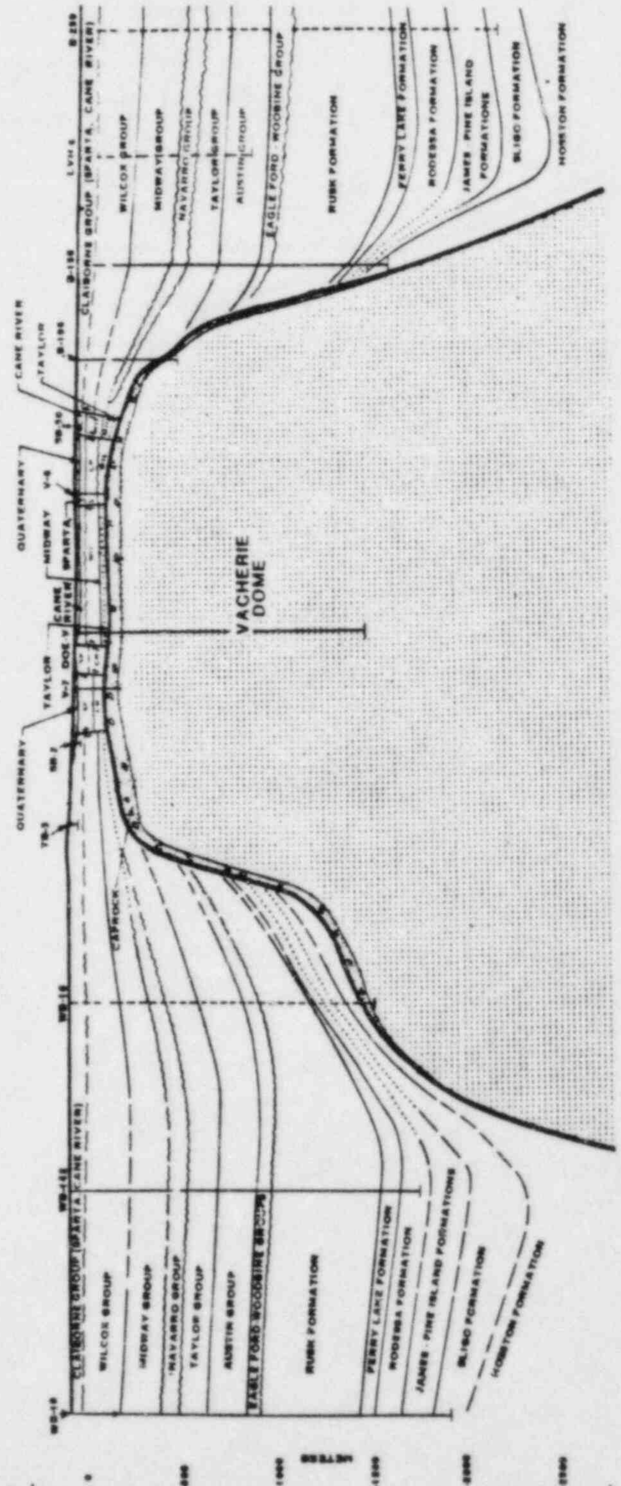
Figure 2.6



Modified after LETCo,1980a

Project No. 83-1162 Reviewed KJ Date 12-81

GEOLOGICAL SECTION THROUGH VACHERIE DOME   Figure 2.7



Vertical exaggeraton x2

After LETCo,1980a

Project No 83-1162 Reviewed KJ Date 12-81

TABLE 2.5

STRATIGRAPHIC SEQUENCE, VACHERIE DOME AREA

		SERIES	STAGE/GROUP	FORMATION	THICKNESS RANGE (FEET)	LITHOLOGY
CENOZOIC	QUATERNARY	RECENT		ALLUVIUM	10-25	GRAVELS, SANDS, SILTS AND CLAYS.
		PLEISTOCENE		TERRACE DEPOSITS	50-125	FLUVIAL SEQUENCES OF GRAVEL, SAND, SILT AND CLAY.
	TERTIARY	EOCENE	CLAIBORNE	COCKFIELD	10-40	MASSIVE TO CROSS-BEDDED, GLAUCONITIC AND NON-GLAUCONITIC QUARTZ SANDS WITH INTERBEDDED SILTS AND CLAYS, FOSSILS, AND PLANT MATTER.
				COOK MOUNTAIN	60-300	FOSSILIFEROUS, GLAUCONITIC, CLAY IRONSTONE INTERBEDDED WITH CHOCOLATE BROWN CLAY AND SILTY SANDS.
				SPARTA	300-610	MASSIVE, FINE GRAINED, CROSS-BEDDED SANDS INTERBEDDED WITH SANDY CLAYS, CONTAINS OCCASIONAL LIGNITES, FOSSILS AND DISULFIDES.
				CANE RIVER	120-465	LOWER, KAKHI-COLORED, INTERBEDDED SILT AND CLAY UNIT; MIDDLE GLAUCONITIC, FOSSILIFEROUS MARL; AND AN UPPER CLAY WITH SILT AND SANDY SILT
				CARRIZO	50-150	FINE TO COARSE GRAINED, FELDSPATHIC, GLAUCONITIC, MASSIVE SANDS WITH MINOR AMOUNTS OF CLAYS, SILTS AND LIGNITES.
			WILCOX	UNDIFFERENTIATED	490-1146	DELTAIC SEQUENCE OF SANDS, SILTS, CLAYS AND LIGNITES WITH INTERBEDDED MARINE SANDS AND CLAYS. COMMONLY CONTAINS GLAUCONITE.
		PALEOCENE	MIDWAY	UNDIFFERENTIATED	420-945	DARK GRAY TO BLACK, PLATY, MICACEOUS, FOSSILIFEROUS, LIGNITIC, CARBONACEOUS SHALE GRADING UPWARD INTO SAND.
MESOZOIC	CRETACEOUS	GULFIAN (UPPER)	NAVARRO	ARKADELPHIA	20-225	PREDOMINANTLY A CHALKY MARL WITH A LARGE AMOUNT OF INTERBEDDED SHALES AND CLAYS.
				NACATOCH	55-500	MARLS AND CHALKS GRADING UPWARD INTO MARLS AND MASSIVE, GLAUCONITIC CALCAREOUS SANDS WITH A FEW SHALE BEDS.
				SARATOGA	30-120	TWO WHITE TO GRAY, FOSSILIFEROUS, SLIGHTLY ARENACEOUS AND ARGILLACEOUS GLAUCONITIC CHALK BEDS SEPARATED BY A THIN SHALE BED.
			TAYLOR	MARLBROOK	95-580	GRAY, CHALKY CLAY INTERBEDDED WITH MARL AND SHALE.
				ANNONA	35-185	WHITE TO GRAY, CALCAREOUS, FOSSILIFEROUS CHALK WITH SOME INTERBEDDED CALCAREOUS, MICACEOUS SHALE.
				OZAN	80-285	PREDOMINANTLY A LIGHT GRAY TO BROWN GRAY MARL WITH SOME INTERBEDDED SHALE.
			AUSTIN	BROWNSTOWN	650-970	MASSIVE, FINE TO MEDIUM- GRAINED SANDSTONES WHICH ARE SOMETIMES INTERBEDDED WITH GRAY SHALES.
				TOKIO		CHALKS AND MARLS GRADING UPWARD INTO MARLY, SILTY SHALES; SANDS, AND SOMETIMES CHERT GRAVELS.
			EAGLEFORD/EAGLEFORD	EAGLE FORD	20-75	DARK GRAY, MICACEOUS, SILTY SHALE WITH THIN LENSES OF FINE-GRAINED SANDSTONES, CONTAINS THIN INTERBEDDED LIMESTONES TO THE SOUTH.
			WOODBINE/TUSCALOOSA	TUSCALOOSA (UPPER, MIDDLE, AND LOWER)	100-600	MASSIVE SANDSTONE OVERLAIN BY A DARK, CALCAREOUS SHALE UNIT AND AN UPPER INTERBEDDED SANDSTONE AND SHALE UNIT.
		COMANCHEAN (LOWER)	WASHITA	UNDIFFERENTIATED	300-1800	MEDIUM TO DARK GRAY SHALES, FLAGGY LIMESTONES, INTERBEDDED SHALES AND LIMESTONES, AND MINOR AMOUNTS OF SAND.
			FREDERICKSBURG	GOODLAND	100-400	CHALKY, WHITISH LIMESTONE ALTERNATING WITH CALCAREOUS CLAY AND SHALE; SOMETIMES CONTAINS SAND; BECOMES LESS CLASTIC, MORE CALCAREOUS UPWARD.
				PALUXY	40-500	RED, BROWN AND GRAY SHALES WITH A FEW INTERBEDDED MASSIVE PINK, GRAY, AND WHITE SANDSTONES.
			TRINITY	RUSK FM. — GREENWOOD MEMBER	400-1500	FINE GRAINED, GRAY TO BROWN SHALES AND SANDSTONES WITH A FEW INTERBEDDED LIMESTONES INCREASING IN ABUNDANCE SOUTHWARD.
				RUSK FM. — MOORINGSPORT MEMBER		GRAY TO BROWN, DENSE TO FINELY CRYSTALLINE, LIMESTONE INTERBEDDED WITH SMALL AMOUNTS OF DARK GRAY TO BLACK SHALE AND STRINGERS OF MICACEOUS SANDSTONE.
				FERRY LAKE	100-650	GENERALLY A WHITE, MASSIVE ANHYDRITE WITH SMALL AMOUNTS OF SHALE AND DOLOMITIC LIMESTONE.
				RODESSA	300-700	WHITE TO DARK GRAY, FOSSILIFEROUS LIMESTONE WITH OOLITIC ZONES; INTERBEDDED WITH MEDIUM TO COARSE GRAINED SANDSTONE AND DARK GRAY CALCAREOUS SHALE.
				JAMES	300-600	GRAY TO BROWN LIMESTONES WITH INTERBEDDED GRAY TO BLACK SHALE. CONTAINS A MASSIVE OOLITIC, COQUINOID OR EARTHY LIMESTONE FACIES IN SOME AREAS.
				PINE ISLAND	75-160	DARK GRAY TO BROWNISH BLACK SPLINTERY SHALE WITH THIN BEDS OF LIMESTONE AND LIMY SHALE.
			COAHUILA	SLIGO	300-600	LIGHT TO DARK GRAY AND BROWN, FOSSILIFEROUS SHALES, LIMY SHALES, AND SANDY, ARGILLACEOUS OR OOLITIC LIMESTONES.
				HOSSTON	1550-3570	LOWER SANDSTONES INTERBEDDED WITH GRAY SHALES; MIDDLE INTERBEDDED RED SHALES AND SILTS; UPPER GRAY SHALES AND SANDS.
	JURASSIC	UPPER JURASSIC	COTTON VALLEY	DORCHEAT	1000-1700	MASSIVE SANDS INTERBEDDED WITH DARK SHALES; LIMESTONES; VERY FOSSILIFEROUS THINLY BEDDED LIMESTONES, SANDS, AND SHALES; AND CALCAREOUS SANDSTONES AND SHALES.
				SHONGALOO	900-1200	DARK GRAY LIMESTONES, SHALES, AND SANDSTONES.
				BOSSIER	300-900	DARK GRAY TO BLACK SHALES WITH LENSES OF DARK GRAY, THIN-BEDDED LIMESTONE.
			LOUARK	HAYNESVILLE FM. — UPPER HAYNESVILLE MEMBER	350-900	LAYERS OF DARK-GRAY SHALE AND FINE TO MEDIUM GRAINED, SILTY TO SHALY, WHITE, LIGHT GRAY, AND TAN SANDSTONE, AND SILTSTONE.
				HAYNESVILLE FM. — BUCKNER MEMBER		LAYERS OF GRAY SHALE WITH GRAY, FINE TO MEDIUM GRAINED, ARGILLACEOUS, BASINAL LIMESTONES.
				SMACKOVER	600-1000	DARK GRAY SHALE INTERBEDDED WITH A THIN, DARK GRAY, SILTY TO ARGILLACEOUS LIMESTONE, AND OCCASIONALLY, CALCAREOUS SANDSTONE OVERLAIN BY A CLEAN LIMESTONE.
				NORPHLET	15-150	PRIMARILY REDBEDS WITH SOME GRAY, LACUSTRINE OR LAGOONAL SANDSTONES WITH A FEW THIN DOLOMITES AND SHALES.
		LOWER TO MIDDLE JURASSIC	LOUISIANA	LOUANN SALT	500-3600	WHITE, SMOKY GRAY OR CLEAR, COARSELY CRYSTALLINE HALITE WITH THIN BEDS OF ANHYDRITE.
				WERNER	150-480	LOWER CLASTIC MEMBER OVERLAIN BY AN ANHYDRITE MEMBER WITH MINOR AMOUNTS OF CARBONATE.
	TR	UPPER TRIASSIC		EAGLE MILLS	200-7000	RED AND WHITE SANDSTONES; RED AND BROWN SILTSTONES; RED, GREEN AND GRAY SHALES; AND VARICOLORED NODULAR DOLOMITES.

After LETCo,1980a

The salt stock itself forms a ridge, with the long axis trending northwest-southeast. Above -3000 m (-10,000 feet) MSL, the flanks of the stock have a slope of 60°, while below -3000 m (-10,000 feet) MSL they are vertical. At a depth of -900 m (-3000 feet) MSL, the stock encompasses an area of 10.8 km^2 (4.2 square miles) (LETCo, 1980a).

Depth to caprock at the Vacherie Dome ranges from 166 to 459 m (543 to 1506 feet) and the thickness of caprock varies from 24 to 83 m (79 to 273 feet). Caprock consists of three zone, which indicates a certain maturity for the caprock. The upper zone contains fine-grained calcite, with sparry calcite in fractures and some xenoliths of limestone. Beneath this is a thin zone of fine-grained gypsum that grades into anhydrite. The lower zone of anhydrite is fine- to coarse-grained and forms a sharp, well-cemented contact with halite in the stock (LETCo, 1980a).

Halite comprises approximately 90 percent of the salt body and occurs as thin bands of relatively pure material, which alternate with bands containing anhydrite. The crystals of halite are coarse-grained, equidimensional and subhedral up to 200 m (700 feet) below the caprock/salt contact. Below this point, the crystals are medium-grained and prolate. Depth to the top of the salt ranges from 244 to 483 m (799 to 1585 feet) (LETCo, 1980a).

2.5.4.2 Structure

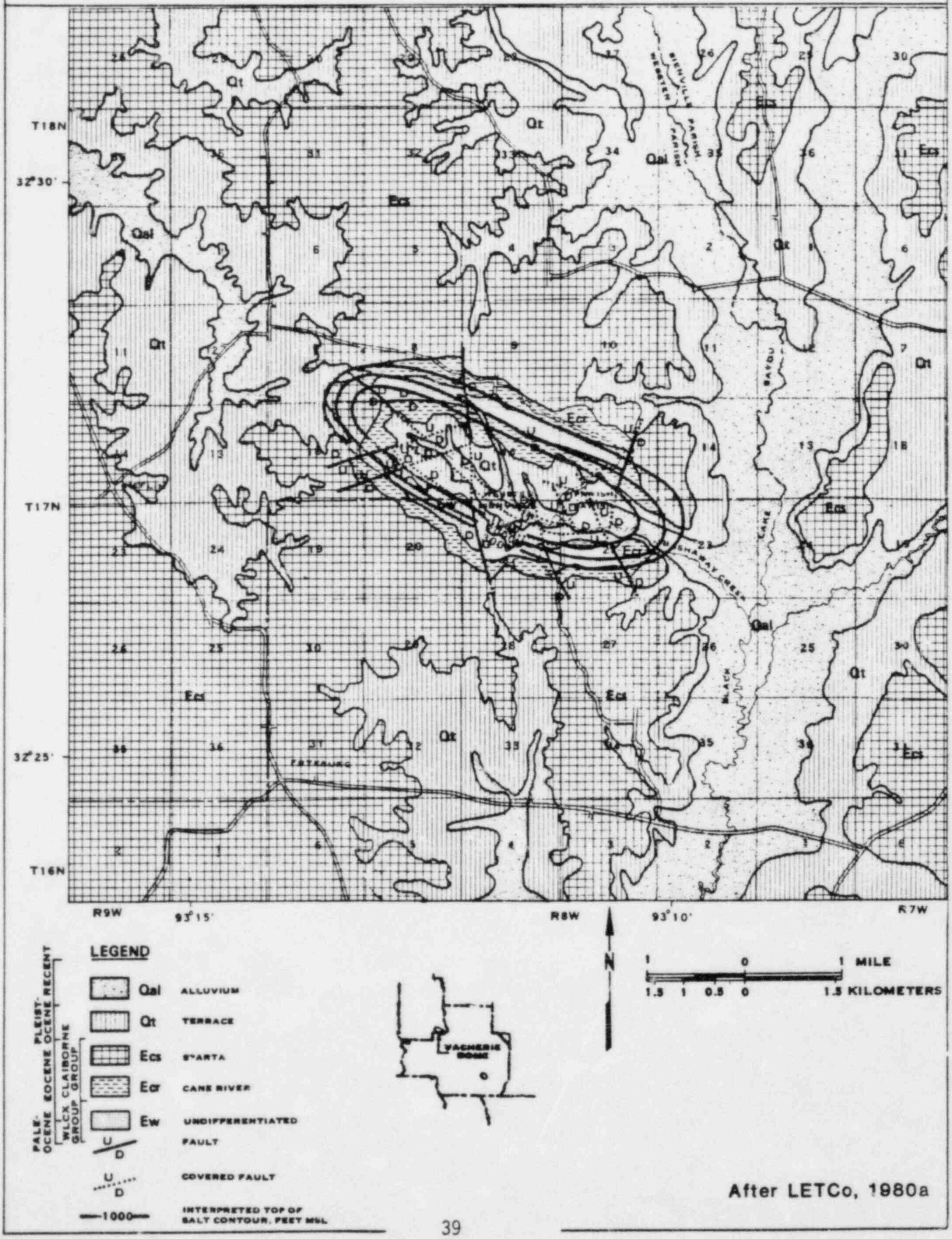
There are faults in the vicinity of, and directly over, Vacherie Dome. The faults above the dome are associated with movement of the salt. These faults appear to be normal faults caused by tensional forces produced by uplift. Faults nearby are usually associated with other structural highs, such as the Sailes and Ada Arches. The amount of offset along these normal faults, which are thought to be due to the movement of salt, appears to be no greater than approximately 100 m (330 feet). There is no evidence of faulting in Quaternary sediments (LETCo, 1980a; Figure 2.8).

No ductile faulting has yet been encountered at Vacherie but is likely to be present. Since the salt stock shows no evidence of massive dissolution, an external sheath is probably present around Vacherie Dome. Internal ductile faults may be present within the stock where the salt spines have moved at different rates. This type of faulting could occur between an inactive spine of salt and a mobile one. Jointing has not been encountered to date.

As the domal salt moves upward, layering in the salt becomes folded and highly contorted. At Vacherie Dome the bands of halite and anhydrite have been isoclinally folded. The limbs of these folds are approximately 0.6 m (2 feet) apart. Fold axes range from 5° to 20° from the vertical (LETCo, 1980a). The exact nature and extent of folding can only be determined by mapping during actual excavation.

GEOLOGICAL MAP- VACHERIE DOME

Figure 2.8



After LETCo, 1980a

Project No 83 1628 Reviewed KJ Date 12/81

2.5.4.3 Design and Construction Aspects at Vacherie

In common with the other salt domes being considered, Vacherie appears to be composed of predominantly uniform soluble materials. Although variations such as gas pockets, brine pockets and xenoliths are to be expected, they cannot be located in advance and can only be investigated during construction. Faults have not, as yet, been located in the stock but the overlying beds are considerably faulted and predominantly weak. They could pose problems for shaft sinking and sealing unless they are well investigated in advance.

Solution is a potential problem but at present has not been shown to have occurred.

2.5.5 Characterization of Site Specific Domes

The investigations carried out by DOE on the three salt domes described above have been for site selection purposes. It is to be expected that the level of detail is insufficient for characterization for design and construction requirements. It will be necessary to employ techniques of geological/geotechnical mapping and surveying during shaft sinking and underground excavation to gain more information on the significant stratigraphic/structural characteristics. As the other characteristics to be measured are dependent on the geological framework, the critical stratigraphic/structural characteristics are regarded as of prime importance.

3. TECTONIC CHARACTERISTICS

3.1 GENERAL

Tectonic activity refers to the large-scale disruption of the earth's crust by means of seismicity, volcanism, faulting/ folding and uplift/downwarp. Many of these processes are confined to well delineated zones within the crust as the result of lithospheric plate movements. However, even outside the major zones, tectonic activity is present in varying degrees and must be considered as a group of potential disruptive processes which could have effects on the design and construction of a nuclear repository.

Although tectonic activity is considered primarily during the site selection stage of site characterization, it also has importance for design and construction. Particular aspects treated here are seismicity, potential for further crustal instability, regional stress, diapirism and faulting.

The key issues of design and construction are affected by these four tectonic characteristics in the following ways;

- Constructability
  - seismicity
  - regional stress
  - faulting

- Mechanical Response
  - seismicity
  - crustal instability
  - regional stress
  - diapirism
  - faulting

- Hydrological Response
  - seismicity
  - crustal instability
  - diapirism/volcanism
  - faulting

- Geochemical Response
  - seismicity
  - faulting.

The following sections critically examine the tectonic characteristics to assess their significnace to these key issues in domal salt. A matrix diagram is presented after these sections summarizing the assessment. The site specific studies which follow the generic study assess the importance of the identified significant characteristics for the three domal salt sites.

3.2 SEISMICITY

3.2.1 Background

Domal salt generally occurs near the periphery of present or former depositional basins which have within their geological sequences thick beds of salt. This generic study considers salt domes near the Gulf Coast, where high rates of sediment deposition have occurred in the geologic past, or are still occurring (see Section 2). Salt domes in the Gulf Coast have generally formed landward of the zones of deposition, with ongoing mud diapirism predominating offshore. Where sediment loads over salt are less than about 900 m (3000 feet) (Kupfer, 1974a), salt movement may occur and salt anticlines may form, but not the tall piercement domal structures being considered in the site specific studies.

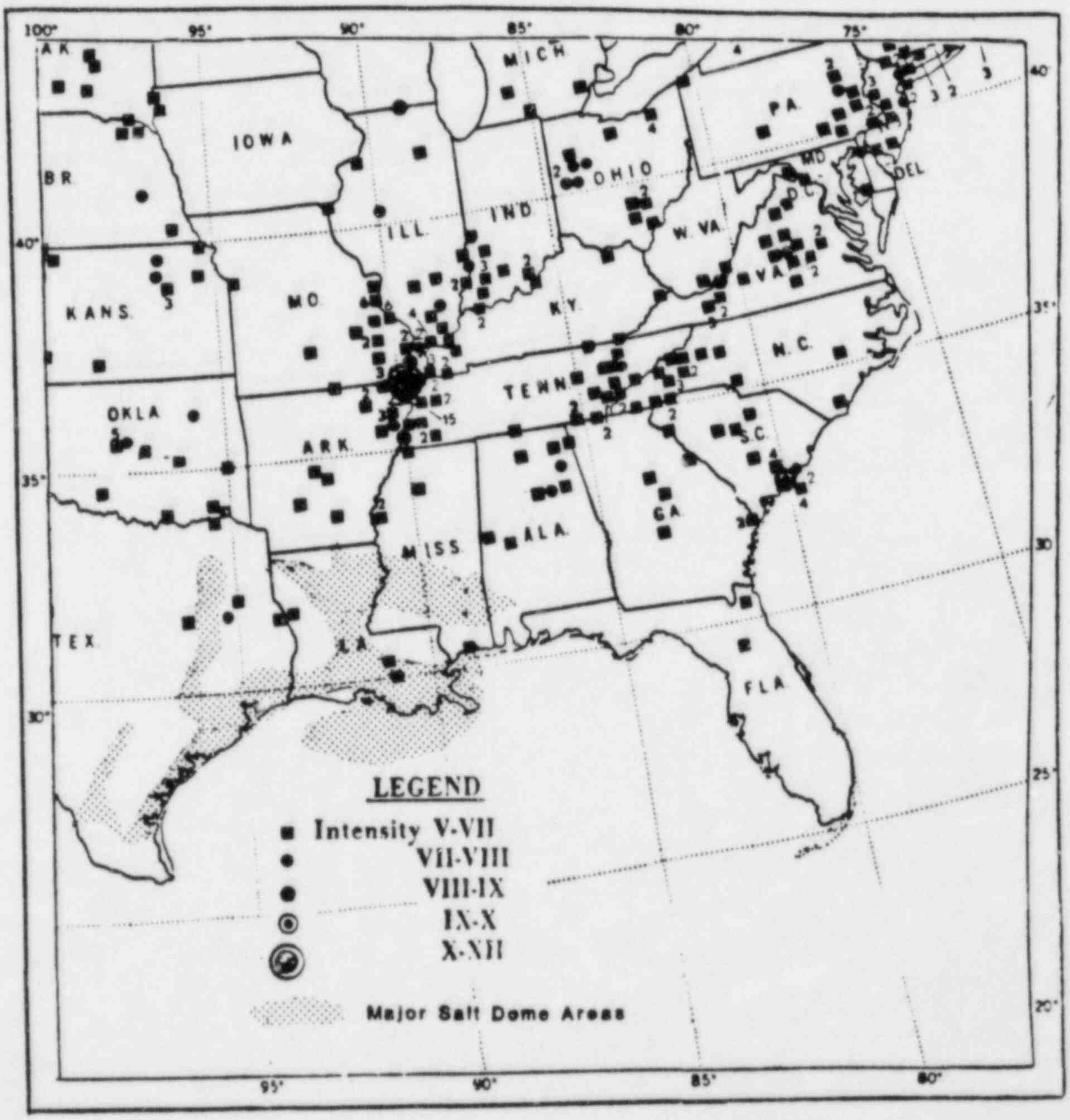
Such areas of high deposition and subsidence are also characterized by growth faults parallel to the shoreline; they occur both on land and offshore. Faulting in adjacent material is also caused by salt and mud diapirism (see Section 2.2.2), and faults surrounding the dome and within the stock are commonly present. Internal faults within the intrusive salt stock may be difficult to recognize. External faults in the sheath surrounding the stock are commonly comprised of salt and the adjacent rock material. Faults within or adjacent to salt domes are not known to cause "felt" or damaging earthquakes.

3.2.2 Seismic Sources

The Gulf Coast areas have not experienced strong earthquakes in recorded history nor do similar depositional environments in other places throughout the world have high levels of seismicity in the absence of known tectonic faulting. Seismically active areas are sometimes associated with deposition offshore from major deltas. Maximum magnitudes, however, are usually less than M=6.5. Exceptions are few and questionable and are in areas of tectonic instability. These zones of seismicity, where detectable, are 160 or more km (100 or more miles) offshore and, therefore, shaking from such zones would not affect repositories in salt domes on land.

Figure 3.1, after Coffman and Von Hake (1973), shows earthquakes in the Gulf Coast states. Principal areas of the U.S. containing salt domes are shaded. None of the earthquakes, in the area of salt domes, exceeds a peak Modified Mercalli damage intensity of VIII. There are two large earthquakes located outside the area of salt domes which have caused substantial shaking within parts of the salt dome area; they are the 1811-1812 New Madrid, Missouri and 1886 Charleston, South Carolina earthquakes. Contours of damage intensity are shown on Figures 3.2 and 3.3, respectively. The Charleston earthquake appears to have generated no more than intensity V in the principal salt dome area, and the New

GULF COAST SEISMICITY 1900 TO 1970 Figure 3.1

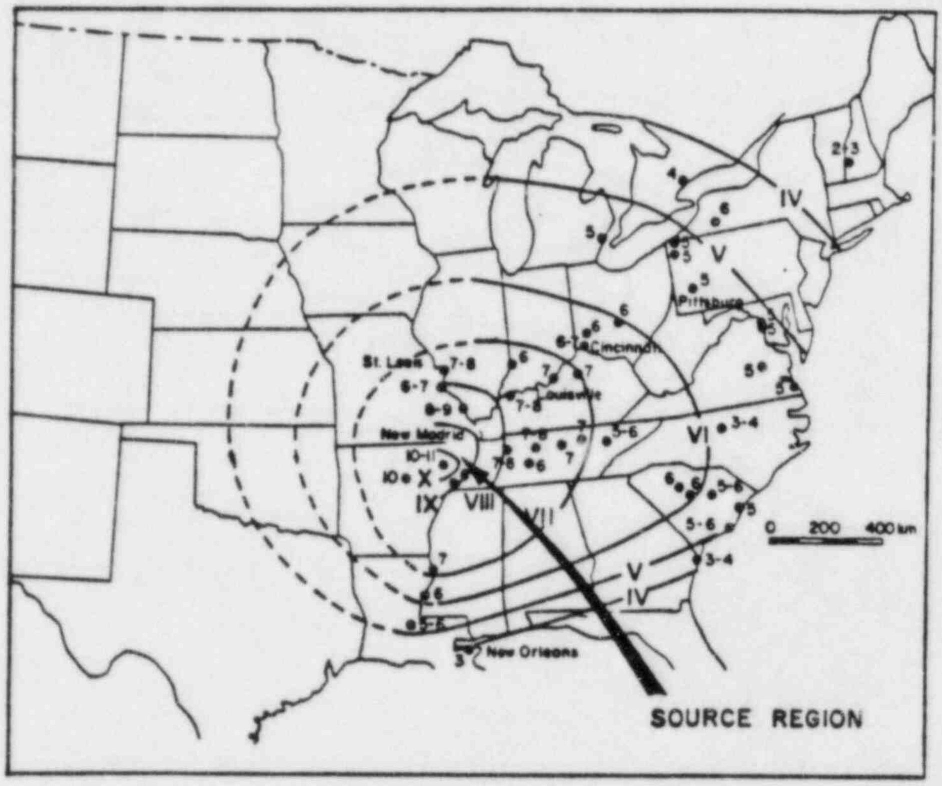


Salt dome areas from Hawkins and Jirik (1966), and Ver Weibe (1952)

Project No 813-1162P Reviewed_____ Date_____

ISOSEISMALS FROM THE 1811-1812 NEW MADRID, MISSOURI EARTHQUAKE

Figure 3.2

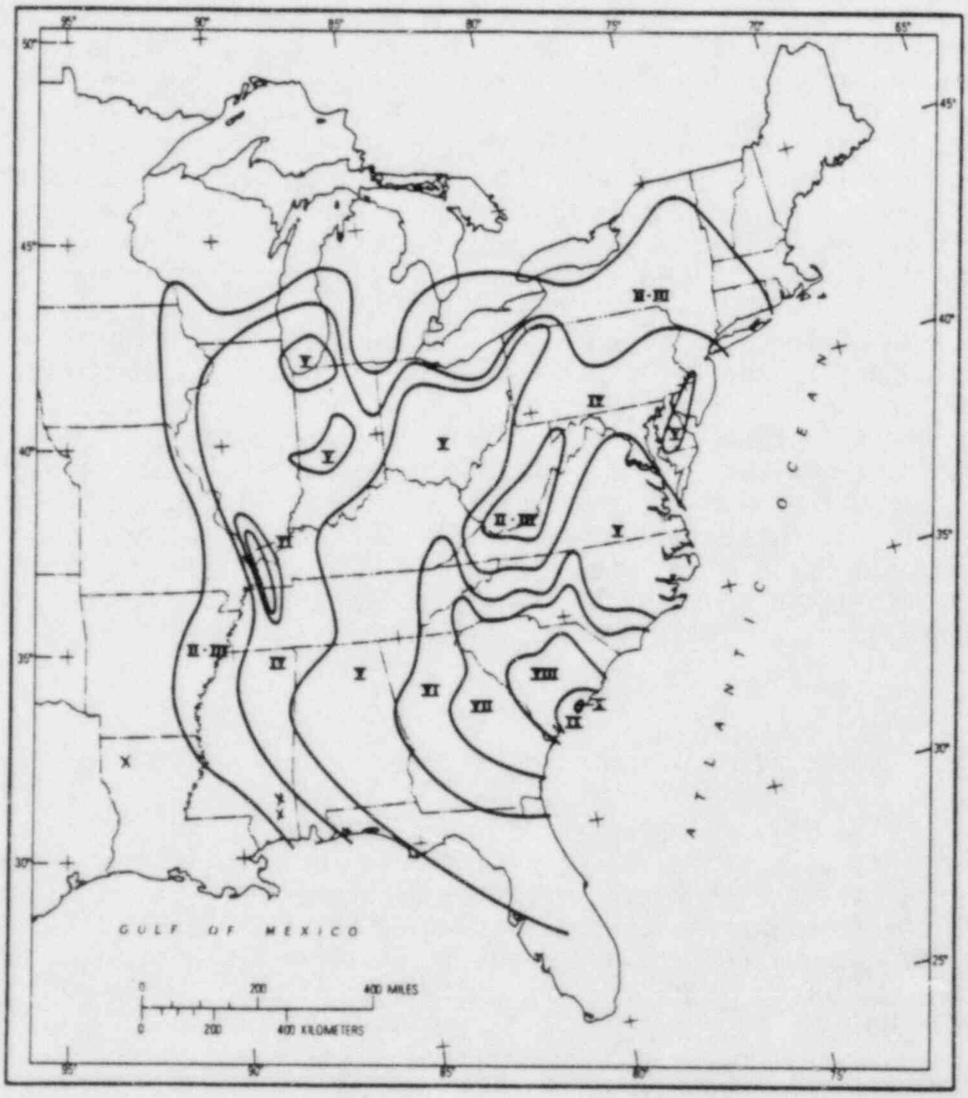


After Nuttli, 1973

Project No. 813-1162B Reviewed ______ Date ______

ISOSEISMALS FROM THE 1846 CHARLESTON, SOUTH CAROLINA EARTHQUAKE

Figure 3.3



From Bollinger, 1977

Project No. 813-1162 B Reviewed ______ Date ______

Madrid shock no more than VIII, although restudies of these two earthquakes are ongoing and some changes may result. Duration of shaking from events like these will be larger than from smaller, closer earthquakes producing similar accelerations. There are other sources of seismic information which may be of value in assessing the seismic hazard at particular salt dome repository sites. For earthquakes large enough to be felt by people Docekal (1970), Nuttli (1979), and Barstow et al (1981) provide updated summaries for the Gulf Coast area.

Design accelerations (SSE) for nuclear power plants in Gulf Coast states have been 0.2 g or less. Such values, however, appear to be under constant re-evaluation. Because a high level nuclear waste repository must perform its function for a longer period of time than a nuclear power plant, the determination of a design acceleration may reasonably be a higher level effort than that for nuclear power plants. However, design and construction and the period of operation and retrievability is when the greatest opportunity for repository disruption by earthquakes is likely. This period of time appears to be of about the same as the operational lifetime of a modern nuclear power plant.

In conclusion, damaging level earthquakes are generally small and infrequent in the principal U.S. area of domal salt, however, because of the long term over which a high level nuclear waste repository should operate effectively, seismic effects must be taken into account in design. The maximum level of shaking possible should be estimated based on historic seismicity, potential active faulting, and from research underway to better understand the sources of large, older historic earthquakes. For these reasons seismicity is considered a characteristic of minor influence on constructability and mechanical, hydrological and geochemical response of a repository site in domal salt.

3.2.3 Application of Seismic Information to Repository Design

Consideration of seismicity is necessary to demonstrate that the integrity of surface structures, shafts, hydrologic seals and canister storage wells will not be affected by seismic events. Design safeguards will be necessary to ensure that acceptable factors of safety against structural failure are achieved. In addition, it must be proven that the proposed repository would have a low risk of being disrupted by faulting.

There are four general approaches necessary:

- Dynamic finite element analysis of the mined excavation. This requires source to site modeling to obtain traveling wave displacements and accelerations. Results provide stress, strain and possible failure points within the excavation. Knowledge of in situ stresses is required to construct the finite element model.

- Probability studies of seismic shaking to set or affirm the level of shaking anticipated. It is necessary to select a distance from the site that a randomly occurring earthquake should be allowed to occur for design purposes.

- Probability of potential new faulting which might affect the repository.

- Conventional seismic analysis of plant, equipment and buildings during the operational and retrievable stages of the repository.

Recent eyewitness accounts of the 1980 (M=7.9) earthquake in China (Evert Hoek, personal communication) tell of the massive surface destruction in which nearly one million people (by some accounts) are said to have perished, and the almost total lack of damage in the underground coal mines close by. This is a demonstration of the substantially lower accelerations which develop at depth below the free surface during shaking, particularly in areas of low velocity surficial sediments.

3.3 CRUSTAL INSTABILITY

Areas of domal salt appear to have been, at some point in geologic time, deep basins in a continental interior. Some connection with an ocean is required, at least intermittently, to provide a continuing supply of water for evaporation. In support of this concept, Figure 3.4 illustrates depositional facies about the Gulf Coast. The Gulf Coast area of U.S. salt domes was considered to be an opening ocean rift during the Mesozoic (Kupfer, 1974a). He suggests that sediment and evaporite loading into the rift caused isostatic imbalances. Further drifting apart of the land masses, which were to become separate continents, enlarged the basin (Figure 3.5). Later deposition caused some salt in very thick beds to be displaced upward and seaward from the depressed basins over the site of the original rift. During the time of rifting, the Louann Salt sequence was deposited with thicknesses up to 15,000 feet. In Cretaceous time, the open Gulf of Mexico formed and the once-continuous salt deposits were split apart and scattered (Kupfer, 1974a).

The trailing edges of continents that have rifted apart are generally of low seismicity and tectonic activity unless they are currently colliding with other tectonic plates. Examples are the eastern coast of the U.S. and South America and the western coast of Australia. The U.S. Gulf Coast also fits this generalization.

Following separation of Africa, the Yucatan and northern parts of South America from the Gulf Coast rift, uplift in the Rocky Mountains began to feed large quantities of sediment into the Gulf Coastal Plain. A high level of sediment deposition continues to the present time.

LOCATION OF CLASTIC, CARBONATE, AND SALT IN THE GULF COAST

Figure 3.4

A. Early to Middle Jurassic

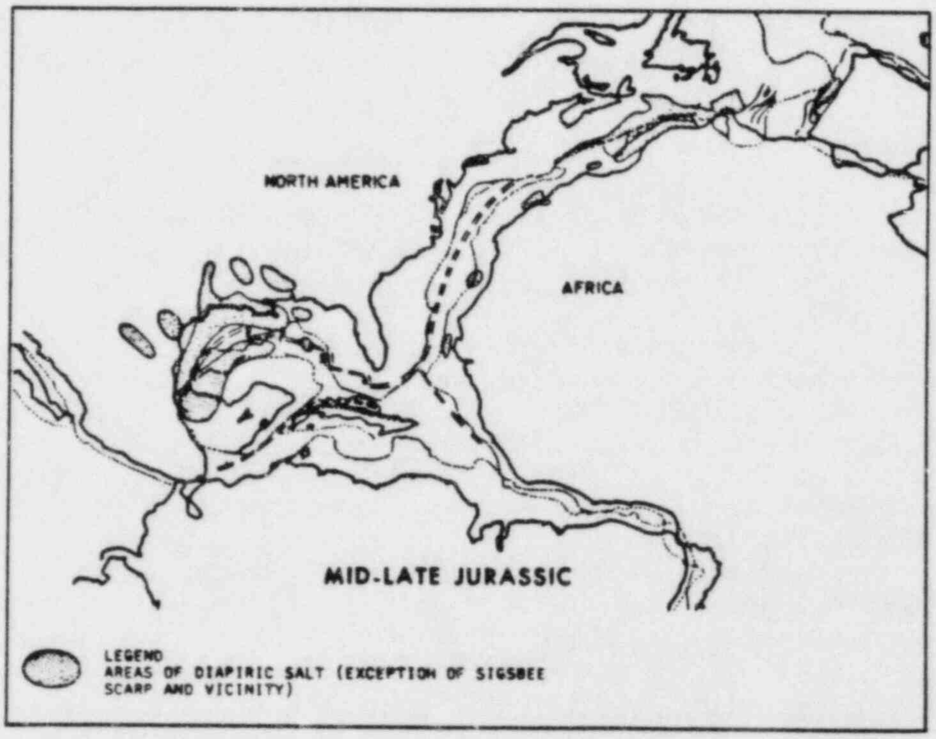
B. Late Jurassic and Cretaceous

C. Cenozoic

After Kupfer, 1974a

Project No. 813-1162 B Reviewed ____ Date ____

JURASSIC GULF COAST RECONSTRUCTION Figure 3.5



After Humphris, 1973

Project No. 813-1628 Reviewed ______ Date ______

The vertical instabilities, observed in historic time and described above, may be attributed to isostatic downwarping, sediment compaction, salt movement, and mud diapirism. Holdahl and Morrison (1974) summarize results of geodetic leveling surveys; their summary figure for the Gulf Coast is reproduced in Figure 3.6. Anomalous subsidence at Houston and at New Orleans is at least partially caused by withdrawal of ground water. The contours may be used to estimate the elevation of a proposed repository in this area for future spans of years.

Crustal instability is of minor significance to the mechanical response and hydrological response of a repository site in domal salt.

3.4 REGIONAL STRESS

Regional stress is the in situ stress state of the rock mass prior to any excavation. It is a function of the overburden weight and any tectonically induced stresses.

The pre-existing state of ground stress must be determined before the stress distribution around any man-made excavation can be calculated. Various theoretical attempts to determine the state of stress in virgin ground have been made, but they have been shown to be of limited use as a result of the simplifying assumptions which bear little relation to the complex geologic processes. Recognizing this fact, recent developments have therefore concentrated on the measurement of in situ stress rather than upon its theoretical determination. A variety of instruments have been developed for this purpose, the most useful of which provide the complete three-dimensional state of stress from a single location. Friedman and Heard (1974), for example, have attempted to assess principal stress ratios in Texas Gulf Coast limestones. They show examples of calcite twin gliding which indicates a critical resolved shear stress of over 10 MPa (1500 psi). This factor is largely independent of confining pressure, which must also be considered with regard to hole closure.

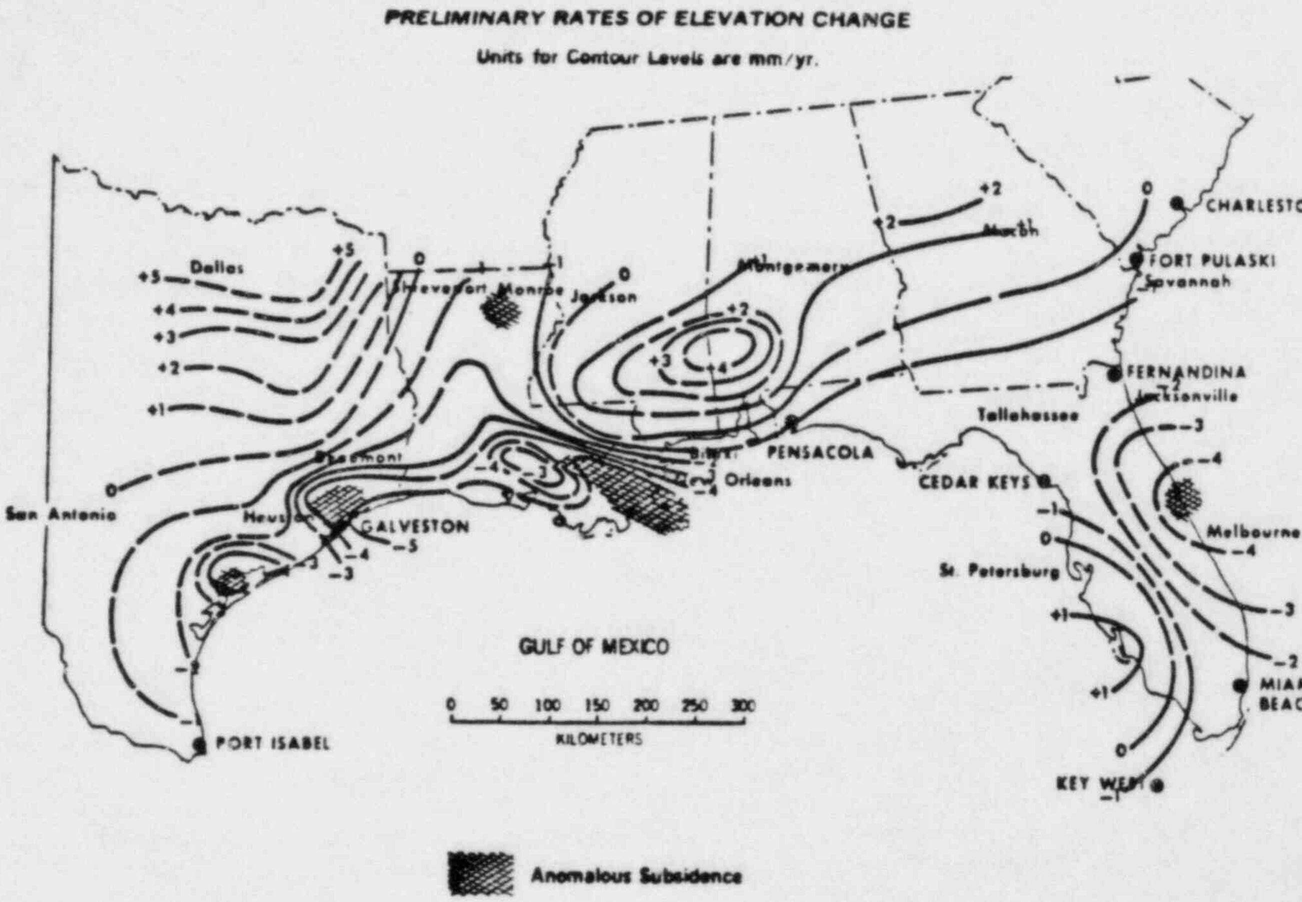
High in situ stresses, in addition to causing cavern closure, may cause additional overbreak in cavern excavation. Finite element modeling of the mined cavity using appropriate elastic and inelastic rock properties will identify areas of potentially high stress concentrations. The effects of high stress or low rock strength may be minimized by suitable design, but it is a characteristic of major influence on constructability and mechanical response and requires detailed consideration for design. The role of in situ stress in design and construction is considered in more detail in Section 4.3.7.

3.5 DIAPIRISM/VOLCANISM

Both sedimentary (salt and mud) and volcanic diapirism have occurred in the U.S. Gulf Coast. On land, most sedimentary diapiric activity has ceased; offshore, both mud and salt diapirism continue to some degree.

PRELIMINARY RATES OF ELEVATION CHANGE
IN THE GULF COAST

Figure 3.6



Based on Leveling and Mareograph Data taken from 1910-1973.
(From Holdahl and Morrison, 1974)

Far offshore in the Sigsbee deep, because the sedimentary overburden is less than for onshore areas, salt movement is comparable to the salt anticline formations of Europe, rather than the near-shore Gulf Coast salt domes.

Ver Weibe (1952) has identified three igneous intrusions in Mississippi. They are the Jackson Dome, the Midnight structure northwest of the Tinsley pool in Humphris County and the Cary structure west of the Tinsley Pond. There is also the cryptovolcanic Kilmichael structure in West Central Montgomery County. These processes cannot really be separated from regional uplift.

Continued diapiric activity of salt domes has been addressed by several investigations. Kupfer (1974), states that "the main salt diapirism of the inner belt of Texas and Louisiana was large in the Cretaceous and Eocene but by the Miocene the movements had nearly stopped. However, in south Louisiana the salt was still clearly moving in the Miocene". Kupfer (1970) feels "that most of the stocks are now stabilized and this appears to be confirmed by the internal structures within the salt, geomorphology and some elevation changes." "Still further south on the continental shelf and slope there is no doubt that the salt is currently very active." Kupfer (1974) also points out that Gera (1972) presents an opposing view. Gera cites examples of evidence of diapiric salt movement in the Gulf coastal zone, offshore islands and in Europe. Ledbetter et al (1975) conclude "what little evidence there is for present dome drowth is restricted to coastal area sites of currently active sedimentation." Also, regarding current rates of growth, Ledbetter et al (1975) state "What have been measured are rates of compaction not rates of dome growth" LETCo (1980c) states "Cessation of regional sedimentation in the Gulf interior region has eliminated motivity for salt dome movement. This occurred 40 million years ago in the Eocene in East Texas and North Louisiana and at least 10 million years ago in the Miocene in South Mississippi." They also point out that terraces formed by fluvial fluctuations accompanying past glacial cycles appear undeformed at Vacherie and Richton Domes.

Perhaps most important are the estimates of domal growth even though the measurements for the growth estimates could as well be attributed to compaction of recent sediments. The worst such estimated are on the order of several hundred feet (600 to 800) per million years (LETCo, 1980c). If a salt repository is constructed at depths of 2000 to 3000 feet, the worst case assumptions would require more than two million yers for exhumation. More reasonable estimates of less than 30 feet per million years require exhumation periods of 100 million or more years. There periods are beyond those of concern for residual radioactivity. They are also beyond a period from which current tectonic forces and geometries may reasonably be extrapolated for salt domes or other currently proposed sites.

LETCo (1980c) concludes "although the evidence for domal stability is not absolute, no convincing evidence for domal instability has been cited." Hart et al (1981) conclude "generally, it is believed that the domes under study stopped growing as long as 30 million years ago." "From numerous lines of evidence it appears that the domes under study are not growing and are in a stable system. However, it will be difficult to prove lack of present or future growth for each dome, due to lack of direct evidence."

There are uncertainties in a conclusion that all inner belt salt domes have ceased diapiric activity. However, the degree of uncertainty is not such that it leads to a conclusion that domal growth is a serious problem in the use of such domes for a nuclear waste repository. Therefore, diapirism/volcanism is a characteristic of minor significance to the mechanical and hydrological response of a repository in domal salt.

3.6 FAULTING

Some Holocene faulting has been identified in Texas, but it is far enough from the proposed sites to not be of consequence. The presence of growth faulting, however, should be considered. Such faults, although not capable of generating earthquakes, could provide a barrier or zone of conduction to water through a repository until the salt healed.

The nature of existing identifiable growth faults, with respect to existing salt diapirs, should be investigated and taken into account for design. Detailed geological mapping and careful stratigraphic and structural evaluation are required. Therefore, faulting is of critical significance to the hydrological and geochemical response of the repository site and of major significance to constructability and mechanical response.

3.7 DESIGN AND CONSTRUCTION

3.7.1 Generic Tectonic Characteristics Affecting Design and Construction

Table 3.1 summarizes the influence of the tectonic characteristics on the key issues for design and construction. The seismicity level would be determined in the site selection process, but choice of the maximum credible earthquake for the repository site and its application to the proposed design would still be necessary. Recent past history of the Gulf Coast area does not indicate uplift to be a critical or major problem. In situ stress must be measured for any major planned excavation and will have a major influence on constructability and mechanical response. Diapirism would require measurement but is considered a minor characteristic over the time span of the repository. The repository ideally would be sited to avoid faults and the potential activity of nearby faults should be investigated. Faulting is a critical characteristic for hydrological and geochemical response and a major characteristic for constructability and mechanical response.

TABLE 3.1

EVALUATION OF TECTONIC CHARACTERISTICS IN TERMS OF THEIR INFLUENCE OF KEY ISSUES

KEY ISSUES	CONSTRUCTABILITY	THERMAL RESPONSE	MECHANICAL RESPONSE	HYDROLOGICAL RESPONSE	GEOCHEMICAL RESPONSE
Seismicity	cei (Minor)		bei (Minor)	afi (Minor)	afi (Minor)
Crustal Instability	cfi		cei (Minor)	cei (Minor)	cfi
Diapirism/Volcanism	cfi		cei (Minor)	cei (Minor)	cfi
Faulting	bfg (Major)		beg (Major)	aeg (Critical)	aeg (Critical)
Regional Stress	bdh (Major)		bdh (Major)	cfh	

KEY:*

- Critical
- Major
- Minor
- Insignificant or not relevant

*See Section 1.3.5 and Table 1.1 for definitions of the level of influence.

ATTRIBUTES

- availability of design and construction techniques which allow for conservative assumptions for the value of the characteristic:

  a) reasonable techniques are not available (i.e. high cost impact)
  b) some techniques are available, but at moderate cost impact
  c) reasonable techniques are available (i.e., little cost impact)

- uncertainty in the representation of the real world by the performance prediction model, and sensitivity of that model to characteristic value:

  d) model has low uncertainty (i.e., is very representative) and high sensitivity to characteristic
  e) model has moderate uncertainty and moderate sensitivity
  f) model has high uncertainty or low sensitivity

- cost effectiveness and scheduling limitations in potentially reducing the uncertainty in the assessment of characteristic values:

  g) uncertainty can be significantly reduced in a cost-effective and timely manner (i.e., prior to NRC review of an SCR)
  h) uncertainty can be reduced, but only during in situ testing
  i) uncertainty cannot be significantly reduced in a cost-effective or timely manner (i.e., prior to NRC review for construction authorization).

3.7.2 Mitigating Design and Construction Strategies

The adverse tectonic characteristics of a deep high-level waste repository sited in domal salt may be mitigated by a variety of design and construction strategies. these include:

- Avoiding shear and fault zones in the interior of the dome

- Leaving a buffer zone between the repository and the dome margin

- Selecting excavation methods to limit the extent of the disturbed zone around underground openings

- Siting the repository at the greatest depth consistent with other requirements

- Selecting repository geometry and the shape of underground openings to reduce stress concentrations.

Specific mitigating measures can be selected using information from the in situ testing and monitoring program.

3.8 SITE SPECIFIC ASPECTS

The following paragraphs consider the most significant tectonic characteristics for design, which were identified in the previous sections, for each of the three salt dome sites.

3.8.1 Vacherie Dome

Vacherie Dome is in Northern Louisiana where the largest historic earthquake was MMI VI in 1930. The largest historic earthquake in the Gulf Coast region is of Intensity VII-VIII which Richter (1958) roughly correlates with magnitude 6.

In past licensing practice, as of 1978, design accelerations for nuclear power plants in the Gulf Coast were assessed considering conditions in the area of the plant. Of the seven plants that could be considered to be in the Gulf Coast Region, six were assigned 0.10 g for the SSE and one, Grand Gulf, 0.15g. Grand Gulf is somewhat closer to the 1811 and 1812 epicentral area than the others. Vacherie Dome lies on about the Intensity IV contour of the 1811-1812 New Madrid, Missouri earthquake and was beyond the area for the Charleston, South Carolina earthquake of 1846, Figures 3.2 and 3.3.

Intensity VI correlates with a design acceleration of about 0.05 g. NRC's minimum design acceleration for nuclear power plants is an SSE of

0.1g. An event of about this size is likely to be required to be assumed for the design of surface facilities of a repository at Vacherie Dome. Accelerations are theoretically lower at depth away from the free surface of the earth. Qualitative evidence is also available to support theory. Therefore design accelerations should be less at the repository depth.

Hart et al (1981) state that the only Holocene fault in the Gulf Coast region is the Mt. Enterprise fault zone in Texas. This fault is about 100 miles from Vacherie Dome and hence does not appear to control design acceleration. Figure 3.7 from Law Engineering Testing Company (1980a) depicts the fault zone and low intensity earthquakes in the vicinity.

Vacherie Dome is near a zero contour for rate of elevation change, Figure 3.6, and hence appears to be in the most stable locale with regard to uplift of the three domes under consideration. It is traversed by Bashaway Creek and its two terraces. Non-defromation of the terraces has been used to establish dome stability since the last glacial epoch (LETCo, 1980c).

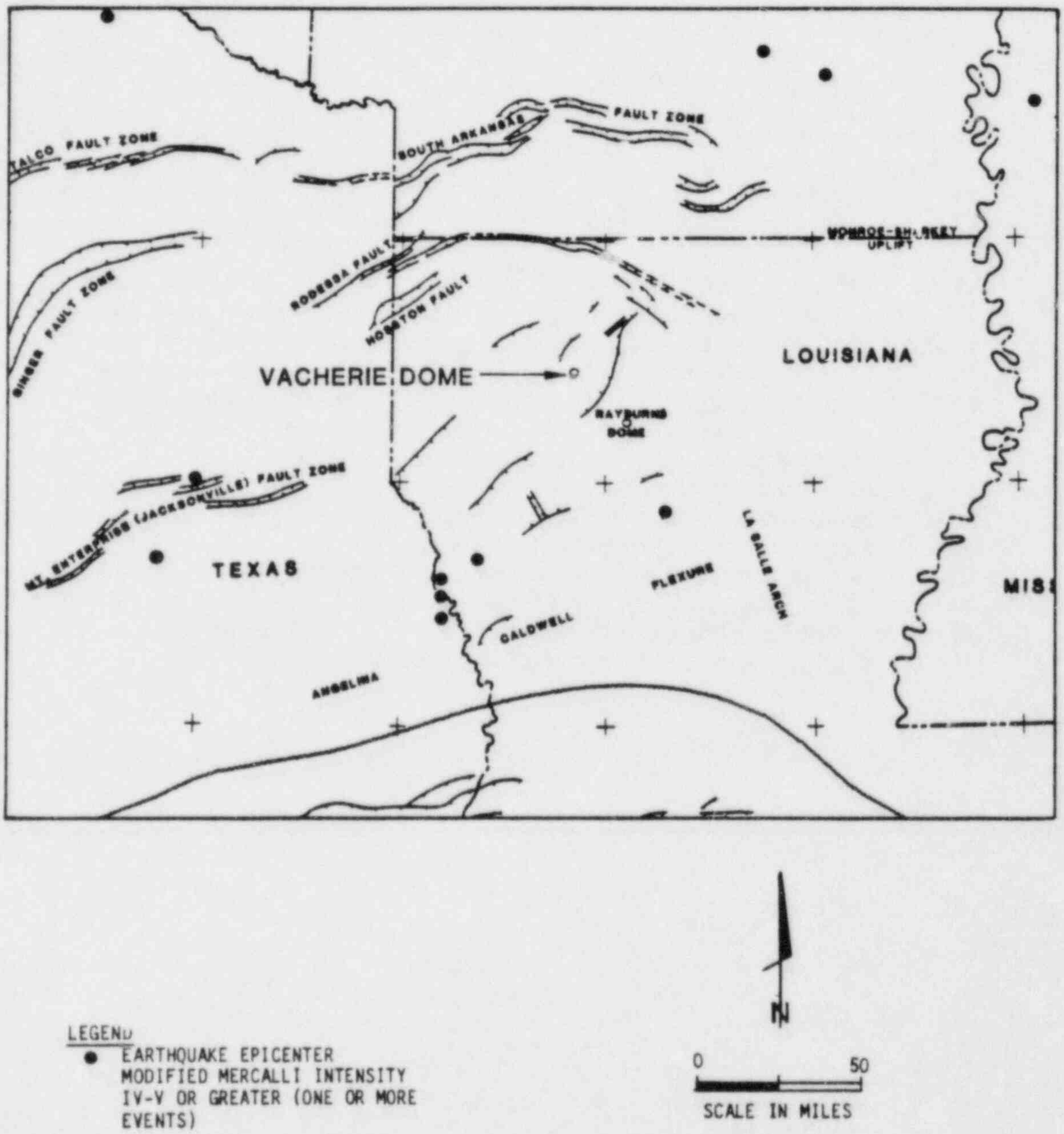
3.8.2 Richton Dome

Richton Dome is in southeastern Mississippi. The largest historic earthquake in Mississippi was MMI VII-VIII in 1931 (Coffman and Von Hake, 1973) and occurred in Northern Mississippi. The affected area is east and north of Greenville and technically not in the Gulf Coastal region. Other Mississippi earthquakes are of Intensity VI or less, typical of Gulf Coastal experience. The evolving NRC dockets for the Grand Gulf, River Bend, Waterford and Farley Nuclear Power Plants should be examined for current information if this site is to be developed as a waste repository. Microearthquakes were recorded for various spans of time by several projects in the Gulf Coastal area. For example, TVA reviewed microearthquakes recorded by the McMinnville Air Force seismic array station for its Yellow Creek nuclear power plant in Mississippi. Other data may be available through the Mississippi test facility at Picayune. Design accelerations would be expected at the same level as for Vacherie Dome (see Section 3.8.1).

Richton Dome is at the highest historic level of uplift, Figure 3.6, in the Gulf Coast region. The 4mm/yr (0.2 in/yr) indicated there, if extrapolated for 1000 years, is 4 meters (13 ft), or for 100,000 years is 400 meters(1300 ft). Assuming erosion kept pace with uplift, much of the repository overburden could be excavated. Consequently a detailed investigation and critique of leveling data in the vicinity of this site would be necessary. LETCo (1980c) states that lack of deformation of terraces at Richton Dome, indicates a lack of domal growth since the last glacial epoch.

An extrapolation of the trend of igneous intrusions, reported by Ver Wiebe (1952), to the northwest passes near Richton and Cypress Creek Domes. Locations of two uplifts thought to be caused by igneous

FAULTS AND EARTHQUAKES NEAR VACHERIE DOME Figure 3.7



After LETCo, 1980a

Project No. 813-1162 B Reviewed ______ Date ______

intrusions are on Figure 3.8. Although there is little likelihood that the presence of such intrusions would affect safety or operational aspects of a repository at Richton Dome, igneous intrusions also lie along the midcontinental geophysical anomaly in Kansas. This anomaly appears to have some increase in seismicity associated with it. Some effort to identify the extent, age, and associated microseismicity of the underlying igneous body below these uplifts, thought to be of igneous origin, might be necessary.

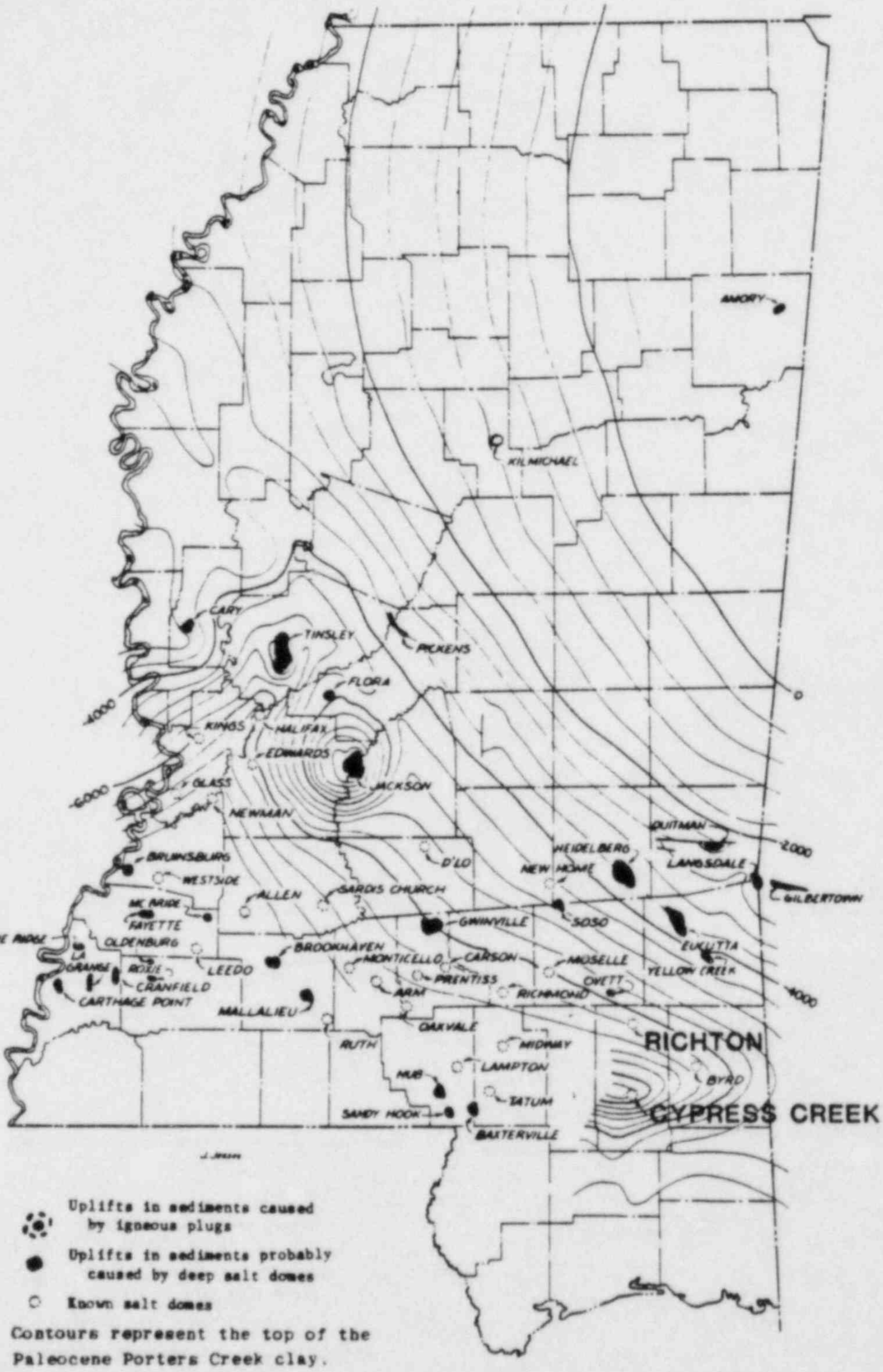
3.8.3 Cypress Creek Dome

Cypress Creek Dome lies a few miles south of Richton Dome. Except that Historic uplift is thought to be about half that for the area near Richton Dome. There is no known difference in tectonic setting, historic earthquake shaking or seismic acivity between the two domes.

LETCo (1980c) states that 3.5 cubic miles of vertical salt movement occurred since Vicksburg Time. If this were all attributed to salt evacuation rather than to sediment compaction, an average 0.25 mm/yr or 792 feet/million years would result. It is noted, however, that the entire amount of apparent vertical salt movement could be attributed to sediment compaction in the rim syncline surrounding the dome. In this situation, the dome would not be extruded on the surface in future years bu several hundred feet of new sediments would be deposited in the rim syncline with older sediments undergoing compaction. Ground level would remain approximtely the same. Stream valleys and terraces traverse Cypress Creek Dome. Lack of movement since the last glacial epoch at other domes has been established by evidence of non deformation However, the terraces at Cypress creek are too poorly preserved or insufficiently mapped to provide that data (LETCo 1980c).

DOMAL STRUCTURE IN MISSISSIPPI

Figure 3.8



After Ver Wiebe, 1952

Project No. 813-1126-B Reviewed____ Date____

4. MECHANICAL PROPERTIES

4.1 GENERAL

In this section, the mechanical properties of domal salt are examined to identify the most important characteristics in the design and construction of a repository. It is only through an adequate knowledge of the mechanical properties of the rock mass, and an understanding of its behavior, that its response to excavation can be satisfactorily assessed for design and construction purposes. The mechanical behavior of a rock mass is dependent not only on the properties of the intact rock material (i.e., the basic substance comprising a cohesive assemblage of minerals), but also on the characteristics of the structural discontinuities such as joints, faults, bedding, and foliation which intersect the rock, and together constitute the rock mass. In addition, the rock mass may be subjected to a number of processes, such as groundwater activity, weathering, and thermal effects arising from the operation of the repository. The mechanical behavior of the rock mass is also dependent on the in situ stress field.

In general, the mechanical properties of salt material (i.e., intact rock) are determined by performing laboratory tests on small samples which contain few irregularities or discontinuities. The results of these tests, while giving reasonable estimates of the mechanical properties of the rock material, usually differ from those obtained by either larger scale laboratory tests or in situ testing. Tests on samples large enough to represent the entire rock mass, including the discontinuities, result in values more representative of the true mechanical properties of the rock mass. The most reliable tests, therefore, are generally those conducted in situ. Only by conducting these tests can the effects of the discontinuities in the rock mass be accurately portrayed in the resulting mechanical properties. An additional advantage of in situ testing is that it often greatly reduces the effects of sample disturbance which results from the handling required to obtain and prepare a laboratory specimen for testing. The minimization of these uncertainties results in values of mechanical properties which have a higher degree of reliability.

Unlike previous Golder Associates' reports, the present study addresses jointly the rock material and the rock mass for each mechanical property considered. The reason for this is four-fold. Firstly, it is the mechanical properties of the rock mass which are most important for the ultimate objective of specific site characterization, and this necessitates an evaluation of rock material properties only as a first approximation. Secondly, as discussed above, the degree of representativeness of the test results for the rock mass characterization increases with specimen scale, i.e., for the same fundamental property the passage from "rock material" measurement to "rock mass" measurement occurs progressively rather than at an arbitrary point. Thirdly, although a great deal of information has been examined for the present domal salt study,

study, it is not felt that this is sufficient to warrant the development of separate characterizations for salt material and domal salt mass at this time; and fourthly, in a self-healing medium like salt, often the mass and the material may be indistinguishable.

The study has broadly separated domal salt, caprock and the surrounding sedimentary rocks. Most of the data for the stock in which the tunnels/caverns would be excavated relate to halite or a mixture of halite and anhydrite. The proportion of the other minerals or rock materials (gypsum, anhydrite, clays, etc.) has not usually been identified, as it is small. Thus, where the text refers to "salt", the data may actually refer to a mixture of materials.

4.2 DEFORMATIONAL PATTERNS

With regard to the behavior of the rock material under a given state of stress and a given mode of application, there are two basic patterns. The first pattern, linear elastic behavior, implies linearity between the applied stress and resulting strain. Although this condition is seldom met by actual rock materials, departure from such behavior is, in many cases, only slight. In a practical approximation, this theory may be applied only when other factors, such as temperature, remain constant. However, all materials will exhibit, at different stress levels, a point at which this linear relationship clearly breaks down, when the resulting strain begins to increase at a much greater rate than the applied stress. This point, referred to as the elastic limit, denotes the onset of the second deformational pattern, which is generally termed plastic behavior. Within the plastic stage, the stress achieves or approaches a peak value at which fracturing or large strains occur. This stress level is referred to as the strength. Once the rock material enters the plastic stage, other factors will usually assume a controlling role. The particular case when, under a constant state of stress, the material will continue to strain as a function of time is referred to as time-dependent or creep behavior. A further complication is introduced in the case of some sedimentary rocks, particularly halite, in which temperature has marked effects on the deformational behavior.

This passage from elastic to plastic behavior, and the particular stress conditions at which it occurs, is critically important in the suitability evaluation of nuclear waste repository sites in salt, for which a high degree of structural integrity is necessary. In fact, this dual behavior gives rise to two fundamental sets of problems:

- The short-term (i.e., instantaneous and during construction) behavior of the repository excavation where the deformational pattern is essentially independent of time and may be characterized in a first approximation, through elastic theory, provided that the site conditions are appropriate and that factors such as temperature remain constant. Elastic theory is generally appropriate for salt because the size of the discontinuities present in salt is generally small compared to the dimensions of the rock mass being considered (Stagg and Zienkiewicz, 1968). In this context, the development of instability leading to discrete failures must be investigated.

- The long-term (i.e. post-construction) behavior of the repository excavation where factors such as time and temperature assume a critical role in deformation. Time-dependent deformational processes are of a very complex nature and may ultimately lead to creep rupture. Increasing temperature may lead to a general degradation of mechanical properties and increased thermal stresses.

With respect to the short-term behavior of the repository excavation, provided that a wide choice is available for a particular site, it is considered that the rock salt material may be characterized approximately by visco-elastic theory and some of the corresponding parameters discussed in the following sections. In this context, it must be borne in mind that a plastic zone of limited extent may be formed around the openings.

The long-term repository performance, however, poses far more complicated problems than the comparatively simple short term "mining" problems. This is compounded by the fact that there is insufficient experimental data on the behavior of such excavations in rock salt over long periods of time. Some limited studies have been carried out to indicate that deformations of pillars, floors and roofs in salt mines which have been observed for many years can ultimately lead to complete closure. Obviously this type of behavior in a repository would greatly affect its containment ability and the retrievability.

The problems associated with design of repository excavations for long term performance are further complicated by the fact that "failure" of the excavation will be measured, not in terms of collapse or closure, but in terms of loss of containment of radionuclides. Therefore, the integration of rock deformation, thermal, and hydrogeologic mass transport models is an essential step in the performance evaluation process.

4.3 DOMAL SALT

The mechanical properties of domal salt may be anisotropic and scale dependent, although these effects are probably slight in view of the self-healing nature of this medium, and are generally dependent on:

- Confining pressure
- Magnitude of stress difference
- Stress rate application
- Temperature
- Radiation
- Grain size

- Extent and nature of impurities
- Moisture.

It is widely accepted that domal salt and bedded salt have similar properties. Also some artificially prepared salt samples appear to give test results similar to those of natural samples. All pertinent test results are included in this summary and where possible, each test result is identified as to the type of material used.

4.3.1 Strength*

The strength of salt is difficult to determine because it varies greatly with temperature, pressure and the rate of loading. In addition, salt is a plastic material subject to large strains under a constant load. Therefore, in order to describe the strength of salt, a complete knowledge of the environmental conditions must be obtained.

Dreyer (1972) performed strength tests on artificial salt samples which clearly show that the strength of salt increases as its confinement increases (Figure 4.1).

Gera (1972) studied the effects of both temperature and pressure on the strength of single halite crystals (Figure 4.2). These results clearly indicate that temperature has a pronounced effect. Other tests conducted by Bradshaw et al (1968) on domal salt from Grand Saline, Texas, determined that an increase in the temperature from 20°C (68°F) to 200°C (392°F) resulted in a loss of 35 percent in its unconfined compressive strength. Hansen and Carter (1980) carried out compression tests on 50 mm (1.97 inch) diameter cores of bedded and domal rock salts at temperatures from 24°C (75°F) to 200°C (392°F) under triaxial stress conditions.

The effects of strain rate on the strength of salt was investigated by Heard (1972) who performed tests on artificial salt samples. (Figure 4.3 a and b). These tests clearly indicate that the strength of salt decreases as the rate of strain is decreased.

Hansen and Carter (1980) concluded that the strengths of natural rock salt were remarkably consistent despite appreciable differences in fabric, grain size, and impurity content (Figure 4.4).

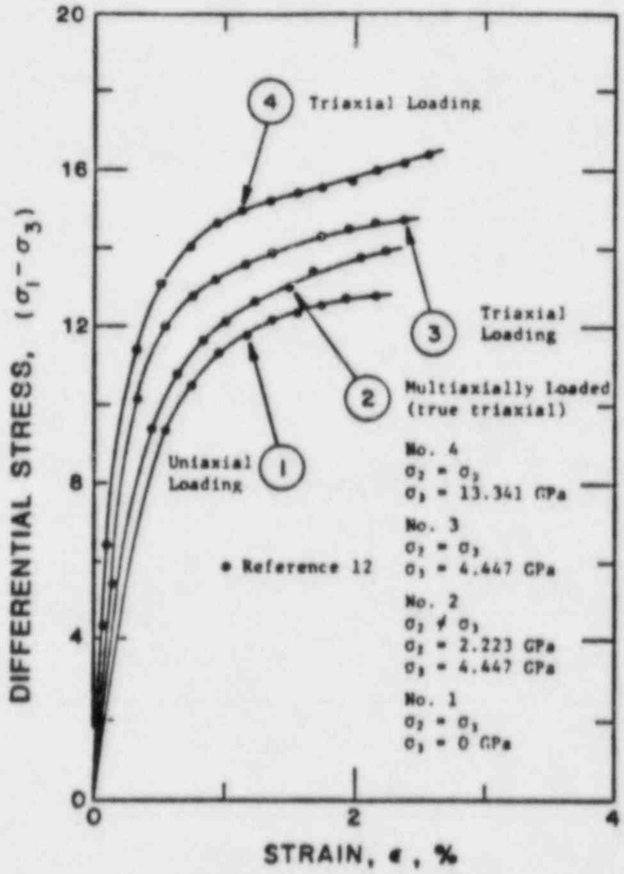
The effect of radiation on domal salt from Grand Saline, Texas, has been studied by Bradshaw et al (1968). They found that compressive strength of domal salt at 20°C (68°F) exposed to 5×10^8 rad is 30 to 40 percent less than for unexposed domal salt. This is a significant reduction in strength, though it will affect only the immediate vicinity of the waste canister due to the shielding properties of salt. Integrated salt doses as high as 5×10^8 rad would not accumulate at distances of more than 0.3 m (1 foot) from the waste containers. If they are stored in the floor, which will not have to support overburden pressures, radiation should not be expected to affect the structural stability of the rooms.

---

*For definitions see Golder Associates (1979b)

DIFFERENTIAL STRESS-STRAIN BEHAVIOR OF ROCK SALT FOR DIFFERENT TEST CONDITIONS

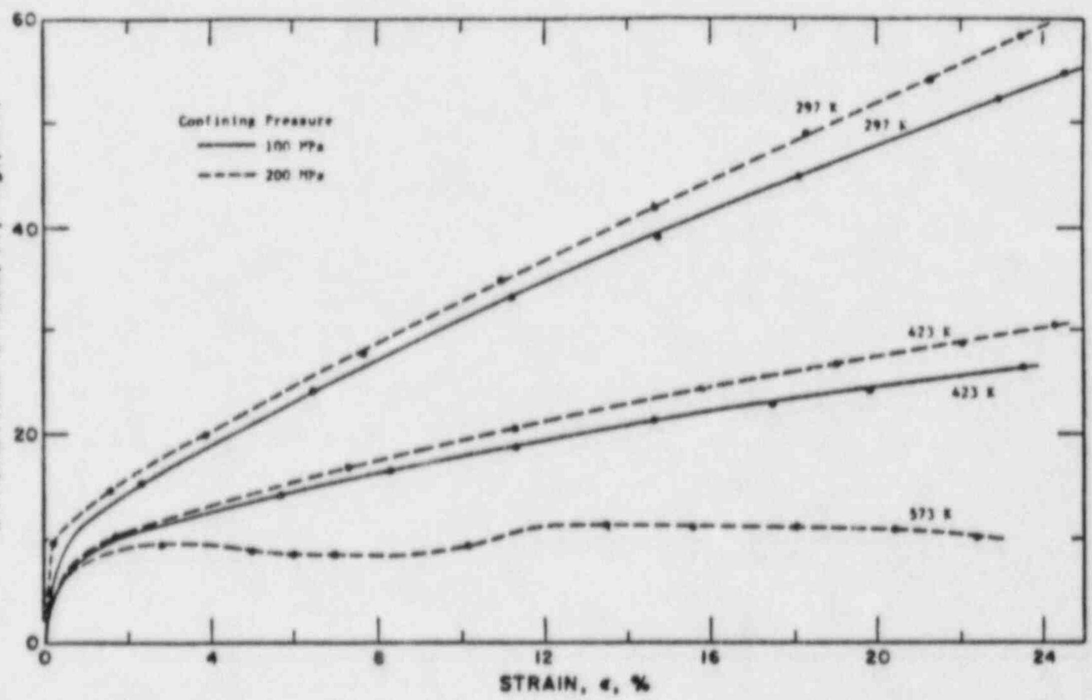
Figure 4.1



After Dreyer, 1972

DIFFERENTIAL STRESS-STRAIN RELATIONSHIP AT SEVERAL TEMPERATURES AND DIFFERENT CONFINING PRESSURES

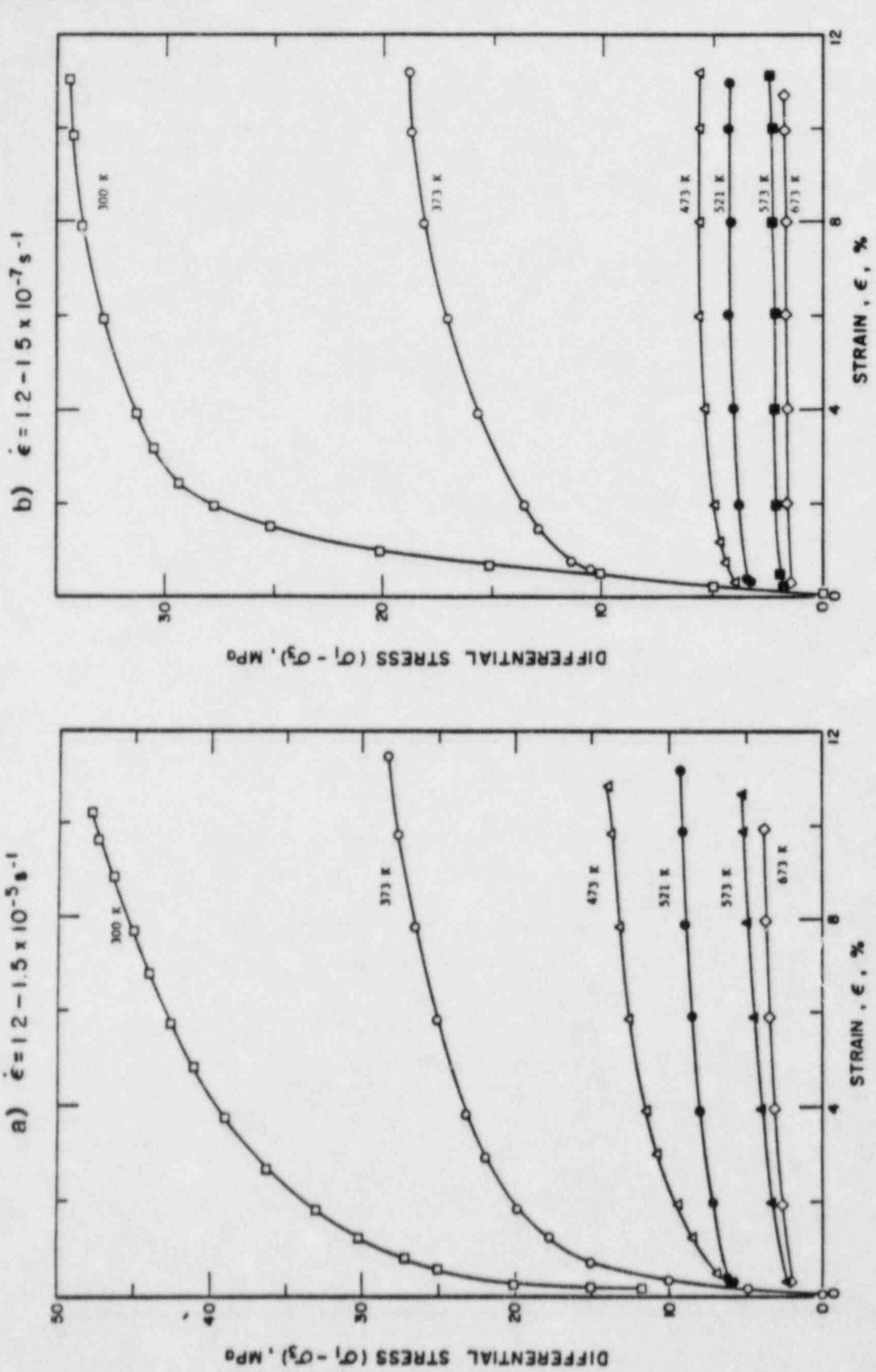
Figure 4.2



After Gera, 1972

DIFFERENTIAL STRESS-STRAIN CURVES FOR POLYCRYSTALLINE HALITE AT TEMPERATURES FROM 300 TO 673 K

Figure 4.3

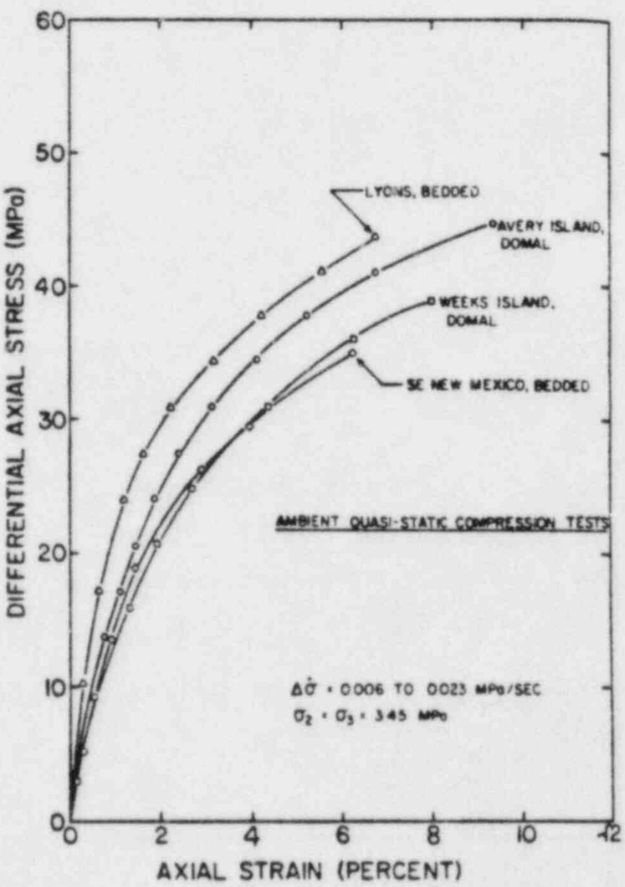


After Heard, 1972

Project No 83-1162 Reviewed KJ Date 12-81

DIFFERENTIAL AXIAL STRESS VERSUS AXIAL STRAIN FOR AMBIENT QUASI-STATIC COMPRESSION TESTS ON FOUR NATURAL ROCKSALTS

Figure 4.4



After Hansen and Carter, 1980

Project No 83-4162 B Reviewed KL Date 12-81

Moisture may reduce the strength of the rock mass with time by:

- Erosion of softer materials by flowing water
- Dissolution of the more soluble minerals
- Expansion or contraction due to wetting and drying
- Increase of pressure
- Affecting frictional characteristics.

The most notable effect would be deterioration of rock surfaces. The contribution of moisture to deterioration of a repository in domal salt is expected to be insignificant.

The effect of a temperature increase on the strength of salt with intergranular water is significant. Samples of domal salt, as well as bedded salt, were heated to temperatures up to 400°C (752°F) by Bradshaw et al (1968). It was found that the bedded salt fractured with considerable violence (decrepitated) at temperatures between 250°C (482°F) and 380°C (716°F). Domal salt, however, was not affected. The rate of heating reportedly had little effect on this phenomenon. It was concluded that the major cause of fracturing was pressure generated by expansion of water contained within the salt. They recommended that a conservative upper allowable temperature for salt is about 200°C (392°F). Jenks (1972) utilized a 250°C (482°F) criterion for decrepitation in his calculation of brine migration. Science Applications, Inc. (1976) recommends as a repository thermal design criterion that not more than 1 percent of the salt volume in a unit cell exceed 250°C (482°F). It was also stated that additional research into the consequences of local effects might eliminate the need for this criterion.

The extent of this decrepitation is linked to the degree of confinement of the salt. Thus, small samples would be expected to shatter completely, while large samples might spall at the edges. This spalling would continue progressively for an unconfined sample. For a confined or partially constrained sample, the extent of spalling would be related to the contained vapor pressure and the strength of the rock. It is considered unlikely that sufficient pressure would be generated to cause fracturing to any great depth in the rock. The rock in the vicinity of the canister, however, could fracture around the emplacement hole if heated to a high enough temperature.

The increased temperatures surrounding a waste canister might also have an indirect effect on rock strength. Pockets of moisture within the salt tend to migrate in the direction of increasing temperatures. The brine migration combined with the increased solubility of the salt at higher temperatures could reduce the strength of rock near canisters. These effects are discussed at length by Stewart (Golder Associates, 1979a), who stated that "more than a few percent of fluid would very greatly constrain the thermal and mechanical stresses that could be tolerated for the interval of retrievability". There exists insufficient in situ data to either confirm or deny this effect. Consequently, the design should space the canisters to keep salt temperatures below an acceptable decrepitation limit [200°C (392°F) to 250°C (482°F)].

Table 4.1 contains a summary of the strength values for domal salt found in the literature. It is apparent from previous work that the strength of domal salt is mainly a function of:

- Temperature (this effect is compounded by moisture)
- Confining pressure
- Loading rate
- Radiation
- Discontinuities.

Strength will have a major significance to constructability and mechanical response, and a minor influence on the hydrological response of a repository sited in domal salt.

4.3.2 Elastic/Deformational Moduli

Although linear elastic theory is not appropriate for predicting the long-term deformational behavior of a repository excavation, it does provide a first approximation to the short term deformational response of domal salt to the elevated rock temperatures and the state of in situ and induced stresses in the vicinity of a waste canister and along the access adits and tunnels.

Generally, five elastic constants are defined; the modulus of elasticity (Young's modulus) E, Poisson's ratio ν, the bulk modulus K, the modulus of rigidity G, and Lame's constant λ. Only two of these are independent for an isotropic material. The two most commonly determined are Young's modulus and Poisson's ratio.

Young's modulus is often determined in the laboratory from intact core samples. The results of such tests usually establish the upper bound of the modulus of the rock mass. Tests which are performed on larger volumes of the rock mass result in a lower modulus of elasticity, sometimes referred to as the deformation modulus. The deformation modulus not only accounts for the elastic behavior of the intact rock but also includes the effects of discontinuities found within the rock mass. In the case of domal salt, however, the deformation modulus should be only slightly lower than the modulus of elasticity determined in the laboratory since few discontinuities exist.

Table 4.2 gives elastic moduli determined by various investigators. The results of experiments Bradshaw et al (1968) performed on bedded and domal salt to investigate the effect of radiation on Young's modulus are shown in Figure 4.5(a). It appears that radiation may slightly increase elastic moduli. Isherwood (1981) reports that elastic moduli for salt are relatively unaffected by temperatures below 150°C (300°F), although she and others have reported changes above this temperature. Adachi in Isherwood (1981) has found that increases in temperature reduce Young's modulus while slightly increasing Poisson's ratio (Figure 4.5(b)).

TABLE 4.1

SUMMARY OF DOMAL SALT STRENGTH PROPERTIES

SOURCE	LOCATION	UNCONFINED COMPRESSIVE STRENGTH (PSI) [MPa]	TENSILE (PSI) [MPa]	TRIAXIAL	COMMENTS
Bradshaw, et al (1968)	Grand Saline, Texas	5600±100 [38.6 ± .7]			Six Tests
Hansen, F.D., in Golder Associates (1977)	Cote Blanche, La.	3650 [25.1]	280 [1.93]		
Bureau of Reclamation in Dames & Moore (1979)	Tatum Dome, Miss.			Ø = 63° c = 564 [3.89] psi at normal stress = 0 Ø = 36° c = 1700 psi [11.7] at normal stress range from 1000 [6.89] to 2000 [13.78] psi.	Depths of core (4 15/16" [125 mm] diameter) ranged from 1650 [494 m] to 2700 ft. [823 m]. 18 specimens tested. Based on maximum load obtained, corrected for area.
Hansen, F.D. (1977)	Jefferson Island, La.	3420 [23.6]	225 [1.55]	Ø = 33° c = 1700 psi at normal stress range from 2000 [13.78] to 3000 [20.67] psi.	
	Avery Island, La.	3370 [23.2]	170 [1.17]		
Mogharrebi (1981)	Rayburn Dome, La.		196 [1.35]		
	Vacherie Dome, La.		151 [1.04]		
Hansen and Carter (1980)	Avery Island, La. Weeks Island, La.				See Figure 4.4

Note: All results based on tests conducted at room temperature, at natural moisture content and unirradiated.

TABLE 4.2

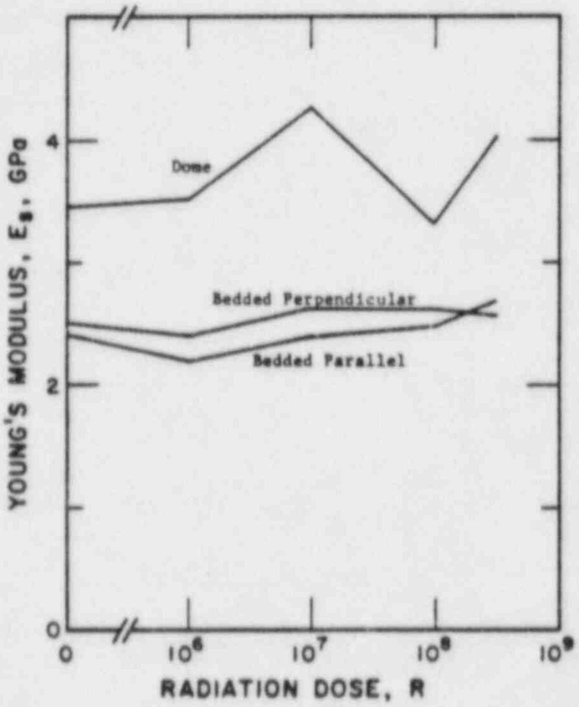
ELASTIC MODULI FOR DOMAL SALT

SOURCE	LOCATION	YOUNG'S MODULUS (PSI) [GPa]	BULK MODULUS (PSI) [GPa]	SHEAR MODULUS (PSI) [GPa]	POISSON'S RATIO	COMMENTS
Dames & Moore (1978)	Various Domal Salt Areas of Texas, Louisiana & Miss.	$0.2 - 0.6 \times 10^6$ [1.4 - 4.1]	6.67×10^5 [4.60]	222×10^5 [1.53]	0.35	
Bradshaw et al (1968)	Grand Saline, Texas	0.5×10^6 [3.4]				Tangent Modulus
Hansen (1977)	Jefferson Island La.	1.0×10^6 [6.9]				Tangent Modulus Stress Range 2000 - 3000 psi 13.8 - 20.7 MPa
Gevantman (1981)	Winnfield Dome La.	$5.2 \times 10^6 \pm 4.5\%$ [35.6]	3.34×10^6 [23.0]		$0.241 \pm 6.1\%$	Surface Geophys Technique
Christenson (1966)	Tatum Dome, Miss.	5.09×10^6 [35.1]	4.45×10^6 [30.7]	1.94×10^6 [13.4]	0.31	3-Dimension Velocity Log
Hansen in Golder Associates (1977)	Cote Blanche, La.	0.4×10^6 [2.8]				Stress Range 400 - 2000 psi 2.76 - 13.8 MPa
		3.3×10^6 [22.7]				Unloading Modulus
		1.1×10^6 [7.6]				Unloading Modulus

VARIATION OF YOUNG'S MODULUS OF ROCK SALT WITH RADIATION DOSAGE

Figure 4.5 a

(Salt from Hutchinson,Kansas and Grand Saline,Texas)

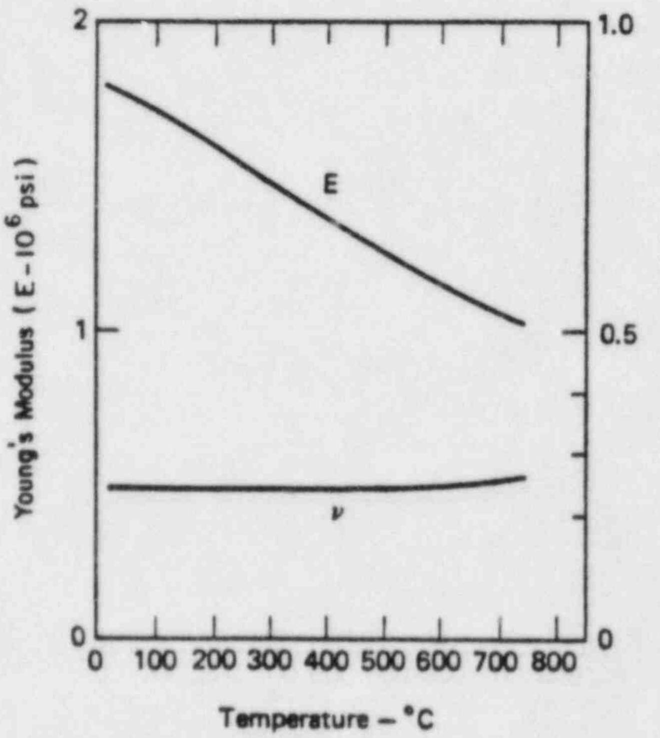


After Bradshaw et al, 1968

Project No. 831/1620 Reviewed KU Date 12-81

TEMPERATURE DEPENDENCIES OF YOUNG'S MODULUS AND POISSON'S RATIO FOR HALITE

Figure 4.5b



After Isherwood, 1981

Project No. 83-1162B Reviewed KL Date 12-81

Therefore, the design of the repository should account for the short-term elastic response of the salt surrounding the waste canisters to prevent the chance of localized failure or abnormal pressures on the waste package. It must also account for the overall deformation of all underground openings (shafts, tunnels, etc). The evaluation of such response under varying thermal conditions may be particularly critical.

The elastic/deformational moduli of domal salt are predominantly a function of:

- Temperature
- Discontinuities.

These moduli will have a major influence on constructability and the mechanical response of a repository sited in domal salt.

4.3.3 Creep Deformation

It has been found experimentally that the deformational pattern of rock salt is not elastic but rather exhibits plastic behavior even at relatively low stress levels. As discussed previously in Section 4.2, this behavior is critically important to the physical integrity of underground excavations.

The term "creep" is customarily used to denote time-dependent effects which are observed to some extent in all rock materials, but are most obvious in rock salt formations. The ultimate goals in the study of creep phenomena are, firstly, to find laws by which postconstruction behavior of underground excavations can be predicted (particularly in terms of strain and strain rate), and secondly, to arrive at the formulation of creep "failure" criteria that may be incorporated in stability analyses for final design. The critical parameters for creep are the applied stresses and temperature, both of which strongly influence the deformational pattern.

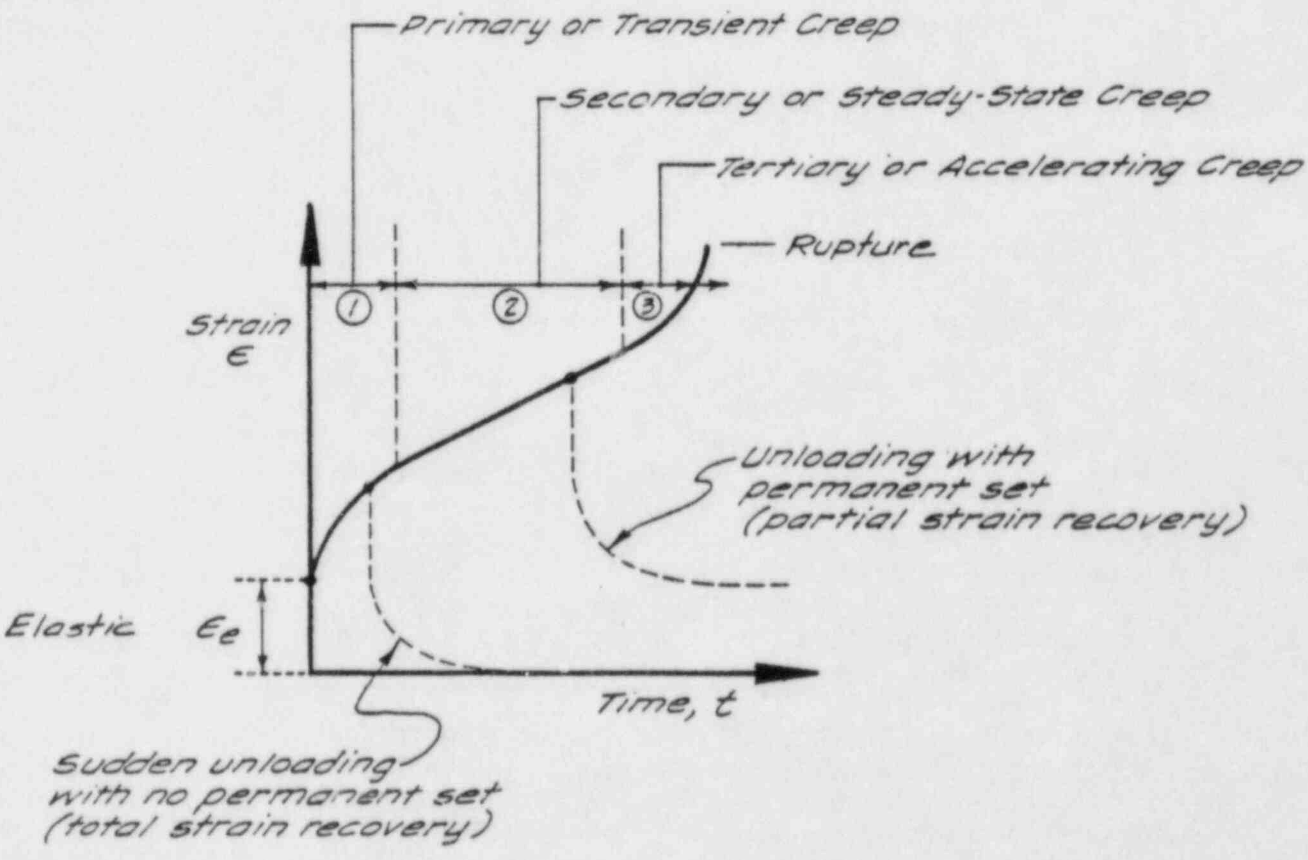
Creep deformation can be divided into three stages as shown in Figure 4.6. The first stage is transient creep, when on unloading the sample will recover all the induced strain with time. The second stage is a steady state creep, when on unloading there is only partial strain recovery. The third stage is characterized by accelerating creep which leads to failure.

Much effort has been exerted by researchers to establish mathematical relationships between creep strain, temperature, stress state, and time. These are the main parameters which will determine the amount of rock salt deformation around the storage cavern.

In creep experiments on Avery Island domal salt and southeastern New Mexico bedded salt, Hansen and Carter (1980) fit 40 and 46 test results, respectively, to an empirical power law describing transient creep. These tests were conducted on 50 mm (1.97 inch) diameter rock salt core

IDEALIZED CREEP CURVE AND STRAIN RECOVERY FOR A ROCK MATERIAL

Figure 4.6



under constant stress triaxial conditions. Results from tests at both sites were similar, despite the appreciable differences in fabric, grain size and impurity content. The creep tests were performed over a temperature range from 24°C (75°F) to 200°C (392°F). The equation which describes the transient creep in the Avery Island specimens over this temperature range and as a function of differential axial stress is as follows:

$$\varepsilon_1 = (1.34 \times 10^{-37}) \; t^{0.45} \sigma_1^{3.3} T^{11.4}$$

where
- σ_1 = differential axial stress (MPa)
- ε_1 = axial strain
- t = time (seconds)
- T = absolute temperature (°K)

The stress in the rock mass in the vicinity of the repository will depend on the repository design as well as on its depth. Temperature will depend on the waste package and room design as well as on the conductivity and thermal capacity of the rock salt.

At high temperatures [100°C (212°F) to 200°C (392°F)], both transient and steady state creep are likely to be very important. Hansen and Carter (1980) have also developed empirical equations which more accurately describe high temperature transient and steady state creep based on limited data from Avery Island. Figure 4.7 shows the strains predicted by these equations for transient and steady state creep at temperatures of 100°C (212°F) and 200°C(392°F), stresses from 1 to 10 MPa (145 to 1450 psi), and times from 10^5 sec (1.16 days) to 10^{11} sec (317 years). It can be seen that at 10 MPa (1450 psi) appreciable creep strains may be expected in the time interval 1 to 100 years. Other creep laws for rock salt with different functional dependencies on stress, temperature and time have been proposed by Pfeifle et al (1981), Obert and Duvall (Burgers Model) (1967), and Stagg and Zienkiewicz (1968). It should be noted that these are all laboratory based approximations and computer simulations and the actual creep behavior will have to be determined by site specific in situ tests.

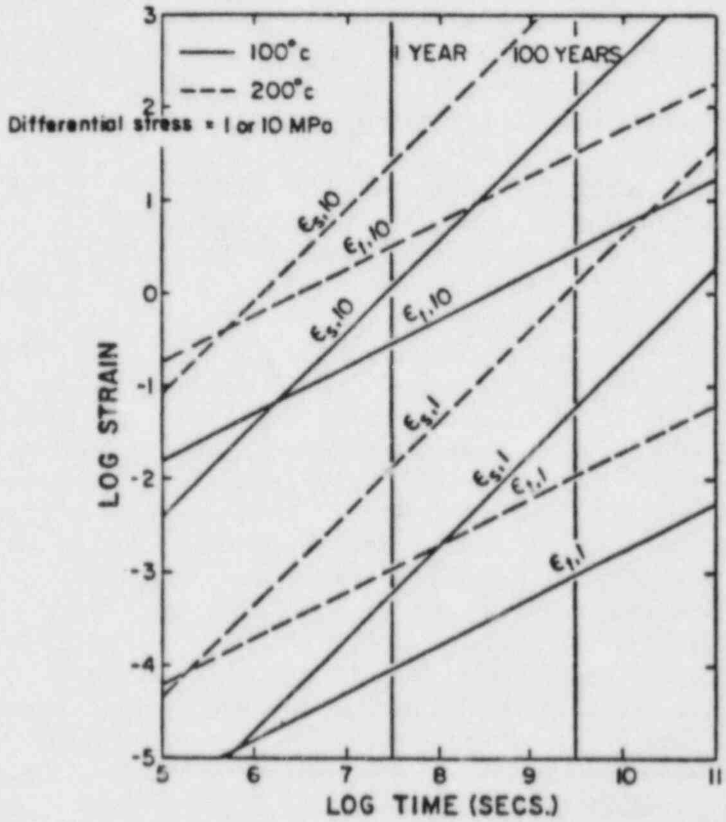
Bradshaw et al (1968) performed creep tests on both domal and bedded salt subjected to radiation. Figure 4.8 shows the result for bedded salt, which indicates a reduction in creep with radiation. According to Bradshaw, the domal salt showed less reduction in creep than the bedded salt shown here. However, due to the shielding properties of salt, the effects of radiation on the creep properties of salt will not be significant in the design process.

To summarize, creep deformation in domal salt is predominantly a function of:

- Stress difference
- Time
- Temperature.

EXTRAPOLATION IN LOG STRAIN-LOG TIME SPACE OF HIGH-TEMPERATURE TRANSIENT CREEP AND STEADY STATE CREEP EQUATIONS

Figure 4.7



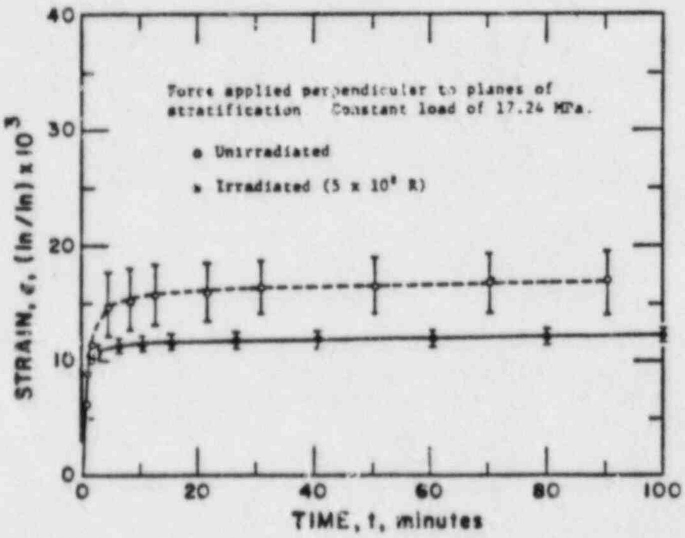
ϵ_s = Steady state creep

ϵ_t = Transient creep

After Hansen and Carter, 1980

Project No. 813/1620 Reviewed KV Date 12.81

EFFECT OF RADIATION ON THE CREEP OF ROCK SALT Figure 4.8



After Bradshaw et al,1968

Creep is a characteristic of critical significance to the mechanical response, major significance to constructability, and minor significance to the thermal and hydrological response of a repository site in domal salt.

4.3.4 Discontinuities

A discontinuity can be defined as any natural or induced fracture or plane separation in the rock mass; as such it includes bedding planes, joints and faults likely to be present in domal salt. In addition, it may be any plane of weakness marking the interface between rocks of different geological or geotechnical characteristics. The presence of discontinuities within the rock mass markedly affects the strength of the mass and may affect many other properties, such as the hydraulic conductivity.

4.3.4.1 Fractures and Joints

Domal salt is not usually naturally fractured or jointed. The visco-plastic nature of salt and its ease of recrystallization causes all such natural fractures to heal almost as soon as they form. However, salt in mine excavations is highly fractured and most salt used in laboratory tests is partially disaggregated and friable. The processes of mining develop a jointing that is easily identifiable and extends back into the salt for several tens of feet; how far this effect progresses has not been determined.

Joints in domal salt are of two origins; artificial joints or blast fractures which result from the excavation process, and exfoliation joints which are caused by stress relief. Blast fractures form at the time of blasting, or shortly thereafter, and do not appear to penetrate more than some 12 inches (30 cm) into the salt. Most are vertical, relatively short and open no more than a fraction of an inch (a few millimeters). Exfoliation joints are generally larger, more continuous, and more open than blast fractures. Most form several feet (approximately one meter) behind the working faces. They extend as far as 15 to 20 feet (5 to 7 meters) back from the face. At these distances, the openings may be up to 1/2 inch (12 mm) wide and extend over the width of the workings 25 to 75 ft (8 to 20 meters). They have been observed in the walls, ceilings and floors.

Some salt, when it is broken out of the wall, has a tendency to break apart into individual grains; this tendency is called friability. Kupfer (Golder Associates, 1977c) considers that friability is a function of several factors including composition of the salt, its movement history, and perhaps mining depth.

4.3.4.2 Inclusions

Liquids and gases occur in salt. These include brine, oil, methane, carbon dioxide, and hydrogen sulphide (Hart et al, 1981). The character of the openings that contain these materials within the salt is unknown. It may be that they are contained in numerous contact fractures which completely surround each grain of salt. More than likely, however, they are contained in some sort of cavity which may also be responsible for pressure pockets (see Section 2.2).

The effect of depth on pressure pockets is not known or understood. They are uncommon at shallow depths [less than 700 feet (210 m)], but occur in all mines of greater than 1000 feet (300 m) depth. The largest have been observed at 1300 feet (400 m). Most commonly they occur in the vicinity of dark, anhydrite-rich salt or near gaseous zones, but they are not confined to these areas.

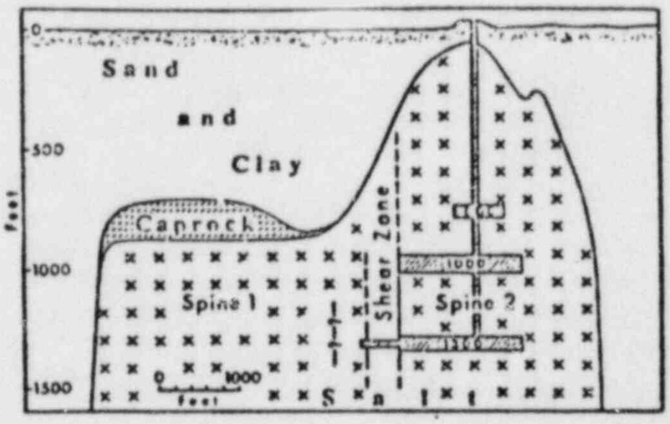
4.3.4.3 Shear Zones

Not all salt within the stock moves at the same rate (see Section 2.2). The compression or squeezing of salt masses, as observed by marked thinning of salt layers, implies differential movement and shearing; these are shear zones on a small scale. It is also known (Kupfer, 1974 b and c) that large masses of salt move past each other in separate spines, with boundary shear zones in between (Figure 4.9). Associated with these much larger shear zones are lenticular layers in the salt that are vague and subparallel to the shear zone. These boundary shear zones separate spines of salt movement and commonly extend completely across the salt stock. They are easily recognized within the salt stock because they contain trapped sediments.

In addition, shear zones are formed around the outer edges of the salt stock as a sheath as it pushes its way to the surface. These have been little explored and almost nothing is known about them. Mine operators never operate less than 90 m (300 feet) from the edge of the salt dome, due to the danger of opening a passageway for water to enter the mine. The petroleum industry generally avoids these zones also, due to problems encountered when drilling, including caving, sticking, geopressuring, and blowouts. Kupfer states in Golder Associates (1977c), that he believes that the sheared salt sheath is generally 400 to 1000 feet (120 to 300 m) thick for most salt domes. He also believes that there is a comparable shale sheath adjacent to the edge of the dome as a result of the movement of the dome up through the deep sedimentary beds of the Gulf coast. Thus, a wide cylindrical fault or shear zone is believed to surround most salt stocks on all sides.

Shearing also takes place between smaller salt masses (Figure 4.10) and is much more difficult to recognize. Such shears are generally only a few feet wide (less than a meter) and can be traced for a few hundred feet (approximately 60 m). It is in these shear zones that most of the foreign inclusions, including sand, clay, carbonate and other clastic

CROSS-SECTION THROUGH JEFFERSON ISLAND SALT DOME   Figure 4.9

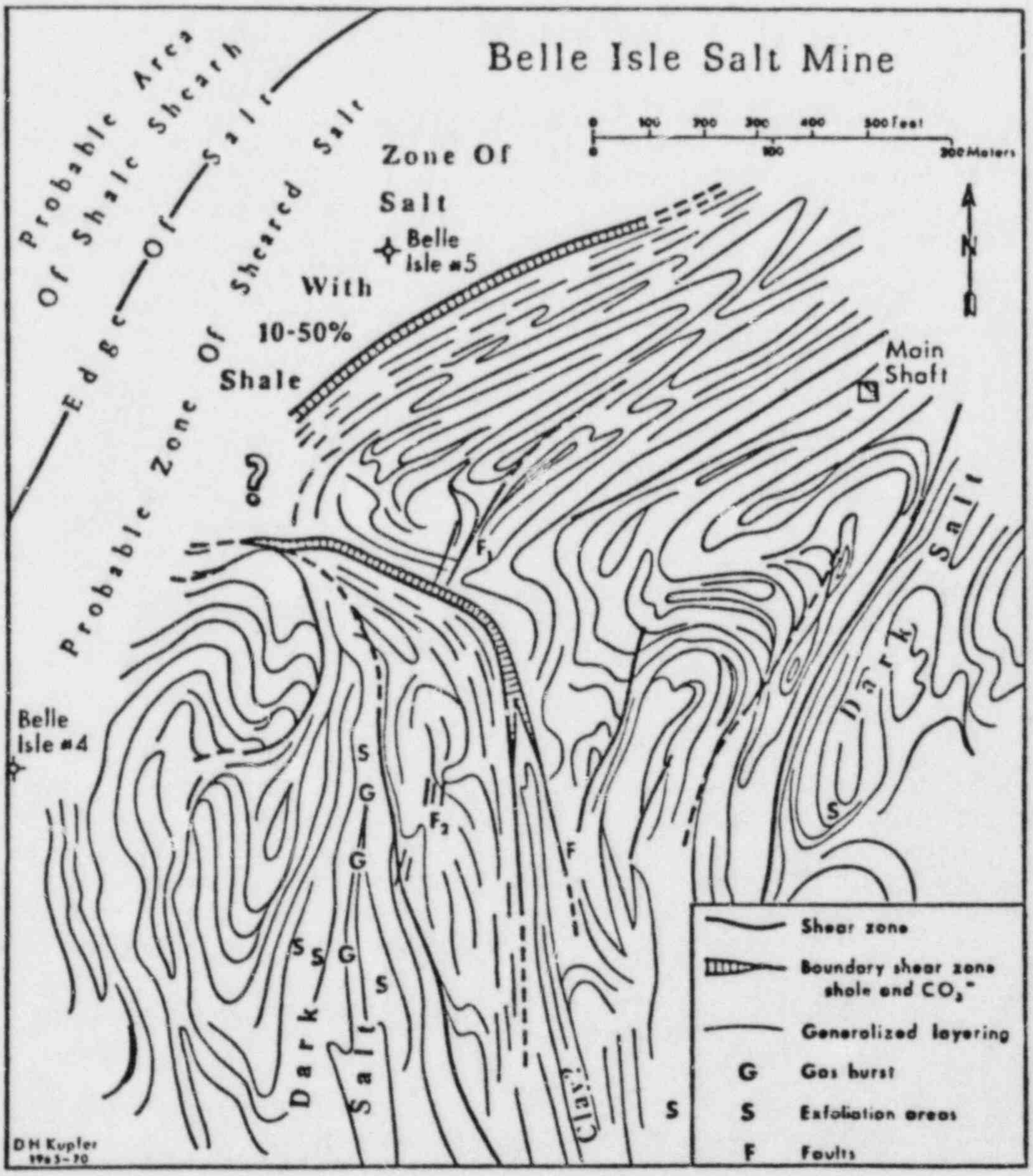


After Kupfer,1974b

Project No. 83-11628 Reviewed KU Date 12-81

BOUNDARY SHEAR ZONE AND OTHER INTERPRETED SHEAR ZONES, BELLE ISLE SALT MINE

Figure 4.10



After Kupfer in Golder, 1977 c

sedimentary materials, liquids, and gases, are found. These inclusions are of primary and secondary origin. Secondary inclusions are most likely to be associated with true boundary or edge shear zones and, thus, are more likely to pose major problems during mining operations.

Discontinuities are of major significance to constructability and the mechanical, hydrological and geochemical response of a repository sited in domal salt.

4.3.5 Density

The most important consideration in relation to the rock mass density is the buoyant force exerted on an embedded container of waste when temperatures in the immediate vicinity of the canisters are sufficient to cause plastic behavior. Under these circumstances, there will be a tendency for the waste canister to migrate upwards or downwards, depending on the relative densities of the waste package and the repository rock. In the case where retrieval of waste packages is an objective, this type of behavior is not desirable.

In Golder Associates (1977c), Kupfer states that the salt contained in the Gulf Coast salt domes is 90 to 95 percent pure halite (density = 2.15 g/cm^3) and 5 to 10 percent anhydrite (density = 2.90 g/cm^3). Salt from northern Louisiana and Texas is less pure.

Table 4.3 shows densities of domal salt measured by various investigators. Gussow (1968) has compiled data on salt density versus the temperature, as shown in Figure 4.11. The possibility that the density of the salt may change due to radiation has not been determined, but it seems unlikely to be a significant factor.

The repository design should space waste packages to keep the adjacent salt temperatures below the threshold value where movement initiated by density changes may occur. The design requirement is to ensure that temperatures in the vicinity of the canisters do not result in significant or excessive loss of shear strength in the adjacent rock. The temperatures should be limited to values which will enable the rock to maintain the waste packages in their correct location.

The density of domal salt will have a minor influence on the mechanical response of a repository sited in domal salt.

4.3.6 In Situ Stresses

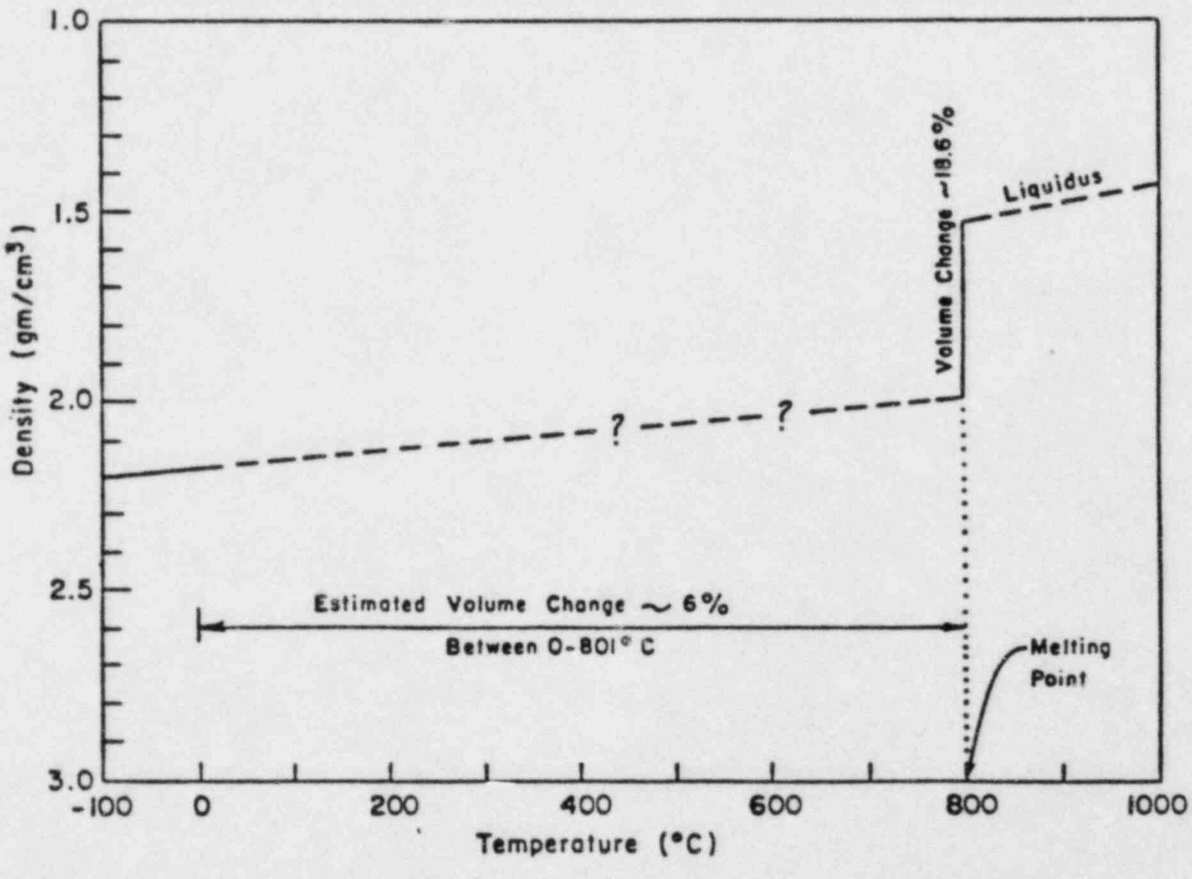
Also known as virgin stresses, geostatic stresses, lithostatic stresses and field stresses, the in situ stresses constitute the stress state in the rock mass prior to any excavation. The behavior of a repository will be affected both by the in situ stresses and the stresses induced during excavation. The relationship between in situ stresses and past tectonic activity in the Gulf Coast area is treated in Section 3.

TABLE 4.3

MEASURED VALUES FOR DENSITIES OF DOMAL SALT

SOURCE	TYPE	LOCATION	DENSITY gm/cm^3
Gevantman (1981)	Clear Salt	Grand Saline, Texas	2.13 - 2.16
	Dark Salt	Grand Saline, Texas	2.22 - 2.25
	Salt	Winnfield, La	2.17
	Salt	Hockley, Texas	2.15 - 2.21
	Salt	Avery Island, La	2.14
Reynolds & Gloyna (1960)	Salt	Grand Saline, Texas	2.14

SALT DENSITY AS A FUNCTION OF TEMPERATURE Figure 4.11



After Gussow, 1968

Project No. 83-1162 0 Reviewed KU Date 12-81

Theoretical predictions of in situ stresses are not generally accurate and field measurements are required to generate the six tensor components which fully define the stress state. It is usual to record the in situ stresses in an orthogonal axis system with one axis vertical. The components would then be three normal stresses (σx, σy and σz), and three shear stresses (τxy, τyz and τzx) derived by symmetry. Alternatively, the stress state may be defined by the orientation and magnitude of the principal stress system, whereby the orientation of orthogonal axes is chosen so that there are no shear stresses.

In situ stresses arise from a combination of:

- Gravitational stresses, due to the weight of overlying material
- Stresses due to orogenic effects (mountain building)
- Stresses resulting from regional uplift and erosion of superincumbent material
- Stresses due to thermal and chemical effects
- Stresses resulting from the diapiric intrusion of the salt dome.

In situ stresses may vary locally in the vicinity of a proposed excavation, especially in the proximity of any major discontinuity; for example, there may be a major variation in stress due to a fault. However, due to the highly visco-plastic nature of salt, it is widely believed that the stresses in domal salt are hydrostatic (due solely to the weight of the overburden). Analyses of geostorage cavities are typically based on this assumption (Martinez et al, 1979). On the other hand, highly anisotropic stress conditions should be anticipated in the rocks surrounding the salt, into which the stock has been intruded and through which the shafts will be sunk.

The design of the waste repository should take into account in situ stresses so as to prevent the creation of excessive differential stresses around any excavation. In particular, the excavation shape and layout must be chosen so as to minimize unfavorable stress concentrations.

To summarize, in situ stresses in domal salt have major significance to constructability and the mechanical response of the repository site.

4.3.7 Solubility

Experienced gained in salt mining generally indicates that free water is uncommon in underground salt excavations. Any seepage water is held in the vapor phase and removed by the mine ventilation system. There are reports, however, of detrimental effects due to solution of the salt, for instance caused by percolation of groundwater from an overlying aquifer. Solution cavities have been observed in many instances, although their development during mining has rarely been the cause of loss of structural integrity of an underground opening.

Small water seeps have often been found to heal, with saturated brine solutions depositing halite within the seepage zone. Larger flow rates would prevent crystallization from the saturated solution and, in the extreme, allow for solution and erosion of the margins of the seepage zone. Additional solution would only take place if the supply of solvent was not saturated, as would be the case for an inflow of fresh water.

Solubilities of rock salt and halite in water given by Weast (1977), range from 3.57 gm/l at 0°C (32°F) to 3.91 gm/l at 100°C (212°F). The effects of water flow and pressure will add an attrition factor which would increase dissolution rates, but not solubility. For siting a high level waste repository, a rock salt of lower solubility would be considered more stable than one of higher solubility.

The solubility of domal salt has a major significance to geochemical response and a minor significance to the constructability, mechanical response, and hydrological response of a repository site in domal salt.

4.4 CAPROCK AND SURROUNDING SEDIMENTS

The majority of the caprock (70 to 80 percent) is expected to be anhydrite. Lesser, though significant, amounts of gypsum and calcium carbonate appear. Also small amounts of sand and clay will be found in thin stringers in some locations. A general description of Gulf Coast salt dome caprocks is contained in Section 2.3.

Drilling operations conducted by Louisiana State University, Law Engineering Testing Co., and others report loss of circulation in zones which contain significant amounts of calcium carbonate. Being highly subject to dissolution by circulating groundwater, these zones are vuggy and will tend to form voids which often fill with sand. These areas will require special attention during shaft sinking to ensure that any circulating water would not be allowed access to the repository level.

4.5 DESIGN AND CONSTRUCTION

4.5.1 Generic Mechanical Characteristics Affecting Design and Construction

Many of the mechanical factors are of major significance for design and construction because the structural stability of the underground excavations is so dependent on them. Creep is of critical significance as it is highly sensitive to both stress and temperature and determines the closure rate of underground excavations. The response of the rock mass to stress and temperature will permit an assessment of its suitability for long-term waste containment. Although the mechanical, thermal and hydrological factors are considered separately in this report, it must be stressed that for repository design purposes, the interaction of these factors must be taken into account. Table 4.4 identifies the significance of the mechanical factors affecting the key issues in design and construction.

4.5.2 Mitigating Design and Construction Strategies

The adverse mechanical characteristics of a deep high-level waste repository sited in domal salt may be mitigated by a variety of design and construction strategies. These include:

- Leaving a buffer zone between the repository excavation and the dome margin
- Avoiding shear zones within the dome
- Choosing the repository geometry and excavation shapes to reduce stress concentrations
- Sizing pillars, designing rooms and selecting tunnel and shaft linings to reduce creep
- Selecting room spacings and canister spacings to control temperatures generated in the rock mass.

Specific mitigating measures can be selected using information from the in situ testing and monitoring program.

4.6 SITE SPECIFIC STUDY

4.6.1 General

Site specific data on mechanical properties of domal salt are sparse. One of the requirements for a potential repository is that it has experienced a minimum of disturbance, thus, the sites described at Richton, Cypress Creek, and Vacherie have had few exploration holes drilled in them.

Exploratory wells have been drilled recently by Law Engineering Testing Co. and Louisiana State University for the purpose of retrieving high quality core for inspection and testing related to repository siting. These rock mechanics tests are still ongoing and the results have not yet been published. However, initial results do indicate that the salt taken from these three sites do fall within the range of expected values for domal salt. In fact, domal salt appears to closely resemble bedded salt in many of its mechanical properties. It would appear, therefore, that mechanical properties of domal salt reported in Section 4.3 represent good initial estimates for design purposes.

TABLE 4.4

EVALUATION OF MECHANCIAL CHARACTERISTICS IN TERMS OF THEIR INFLUENCE ON KEY ISSUES

KEY ISSUES	CONSTRUCTABILITY	THERMAL RESPONSE	MECHANICAL RESPONSE	HYDROLOGICAL RESPONSE	GEOCHEMICAL RESPONSE
Rock Mass Strength	bdh (Major)	cfh (Insignificant)	beh (Major)	bfh (Minor)	cfh (Insignificant)
Deformation Moduli	bdh (Major)	bfh (Minor)	beh (Major)	cfh (Insignificant)	cfh (Insignificant)
Creep/Plasticity/ Fusing	bdh (Major)	ceh (Minor)	adh (Critical)	afh (Minor)	cfh (Insignificant)
Discontinuities	aei (Major)	cfi (Insignificant)	aei (Major)	aei (Major)	aei (Major)
Density	cfi (Insignificant)	cfi (Insignificant)	bfi (Minor)	cfi (Insignificant)	cfi (Insignificant)
Moisture Content	cfh (Insignificant)	beh (Major)	beh (Major)	afh (Minor)	aeh (Major)
In Situ Stress	bdh (Major)	cfh (Insignificant)	beh (Major)	cfh (Insignificant)	cfh (Insignificant)
Solubility	cdi (Minor)	cfi (Insignificant)	bei (Minor)	afi (Minor)	aei (Major)

KEY: *

- Critical
- Major
- Minor
- Insignificant or not relevant

*See Section 1.3.5 and Table 1.1 for definitions of the level of influence.

ATTRIBUTES

- availability of design and construction techniques which allow for conservative assumptions for the value of the characteristic:

  a) reasonable techniques are not available (i.e. high cost impact)
  b) some techniques are available, but at moderate cost impact
  c) reasonable techniques are available (i.e., little cost impact)

- uncertainty in the representation of the real world by the performance prediction model, and sensitivity of that model to characteristic value:

  d) model has low uncertainty (i.e., is very representative) and high sensitivity to characteristic
  e) model has moderate uncertainty and moderate sensitivity
  f) model has high uncertainty or low sensitivity

- cost effectiveness and scheduling limitations in potentially reducing the uncertainty in the assessment of characteristic values:

  g) uncertainty can be significantly reduced in a cost-effective and timely manner (i.e., prior to NRC review of an SCR)
  h) uncertainty can be reduced, but only during in situ testing
  i) uncertainty cannot be significantly reduced in a cost-effective or timely manner (i.e., prior to NRC review for construction authorization).

4.6.2 Richton Dome

Richton Dome is the largest and shallowest piercement dome in the Mississippi Salt Basin. It has had 31 wells drilled into the caprock with 9 of them extending into the salt. A description of the caprock as deduced from these wells is given in Section 2.5.2. Undisturbed core from one of these wells is currently being tested by RE/SPEC, Inc. in Rapid City, South Dakota under the direction of Battelle Memorial Institute in Columbus, Ohio. Test results including strength and creep, are not available.

Initial results of these tests, according to M. Wigley of Battelle Memorial Institute, indicate that salt from Richton Dome has similar mechanical properties to most domal salt and many bedded salt samples. A strength of 55 MPa (7800 psi) was measured for the salt at room temperature under 10 MPa (1450 psi) confining pressure. At 200°C (392°F) a reduction in strength of approximately 30 percent was evident with the relationship between strength and temperature being fairly linear. Elastic constants determined from these tests are Young's Modulus (unloading/reloading) of 30 GPa (4.35×10^6 psi) and Poisson's Ratio of 0.35. These are approximately the same as reported for bedded salt. All of these results are preliminary in nature, however, they do indicate that Richton Dome does not appear to differ significantly in mechanical properties from other Gulf Coast domes.

4.6.3 Cypress Creek Dome

Cypress Creek has had 7 wells drilled into the caprock, all of them extending into the salt. A description of the caprock as derived from these wells is given in Section 2.5.3.

No rock mechanics test results of Cypress Creek salt are available. Based on the results of the other domes, including Vacherie and Richton, it seems likely that mechanical properties for generic domal salt will give reasonable initial estimates for Cypress Creek.

4.6.4 Vacherie Dome

Vacherie Dome has had 10 wells drilled into the caprock with 9 of them extending into the salt. A description of the caprock based on information from these wells is given in Section 2.5.4. Samples from one of these wells are currently being tested by RE/SPEC, Inc. of Rapid City, South Dakota under the direction of Battelle Memorial Institute in Columbus, Ohio. Test results, including strength and creep, are not yet available.

M. Wigley of Battelle Memorial Institute reports that initial tests of Vacherie core indicate that it behaves much the same as most other domal salts and many bedded salts. He reports a strength of 57 MPa (8300 psi) at room temperature under 10 MPa (1450 psi) confining pressure. Similar to the results from Richton Dome, salt from Vacherie loses approximately 30 percent of its strength as it is heated to 200°C. The relationship between strength and temperature is approximately linear. He reports elastic constants for Young's Modulus (loading/unloading) of 30 GPa (4.35 x 10^6 psi) and Poisson's Ratio of 0.35. These are approximately the same values that are reported for other domal and bedded salts.

Mogharrebi (1981) reports a tensile strength for Vacherie salt of 1.04 MPa (151 psi) based on 12 samples tested by means of the Brazilian test. These tests results are also preliminary and subject to change as data are refined. However, they do indicate that Vacherie Dome appears to have similar mechanical properties to other Gulf Coast domes.

5. THERMAL CHARACTERISTICS

5.1 GENERAL

In addition to the influence of high temperatures on the mechanical properties of rock masses (reduced strength, increased ductility and deformability), thermally induced stresses will develop as a result of the restrained expansion of the rock mass in a relatively confined environment. The nature of the thermal stress distribution will depend upon the geometrical layout of the underground repository, the magnitude and distribution of the developed temperatures, and the thermal and mechanical properties of the rock.

5.2 DOMAL SALT

5.2.1 Temperature

The temperature distribution in and around the repository will depend upon the in situ temperatures, the distribution and heat generation of each of the high-level waste packages and the thermal properties of the medium. The convective effects of ventilation (prior to backfilling) and fluids circulating under thermal, hydraulic, or chemical gradients (after backfilling) may also have a significant impact. Heat balance may be significantly altered by phase changes such as water to steam or mineralogical changes within the rock.

For any given distribution of temperature within a repository zone, the thermal stresses developed will depend on the coefficient of thermal expansion and on the parameters describing the stress-strain response of the rock mass and the timing of the backfill. These thermal and mechanical properties of the rock will be dependent upon the temperature and, hence, a nonlinear numerical analysis will be required. Such a procedure will ultimately serve to define maximum permissible temperatures and thermal loading densities which can be tolerated in the repository.

One concern of thermal loading is the possibility that the heating of the dome will result in reactivation of dome movement. Ledbetter (1975) has investigated the possibility, and while admitting that some thermally induced movement in the zone of the repository could occur, dismisses it as unimportant over the time frame being considered. Another consideration is that of brine migration caused by thermal gradients within the salt dome. Martinez et al (1979) have investigated the migration of brine induced by the dissolution and diffusion of salt within very small brine inclusions (up to a few hundred microns in diameter) caused by temperatures gradients (Table 5.1). It appears from these calculations that brine can move several meters over the lifetime of the repository. It is expected that any migration will be more significant from the viewpoint of corrosion of the waste package rather than as a potential vehicle for radionuclide transport.

TABLE 5.1

VELOCITIES OF BRINE MIGRATION IN SALT
(10^{-4} cm/yr)

Thermal Gradient $^{o}C/100m$	Temperature, ^{o}C 100	150	200	250
1	1.2	2.4	5.1	11
2	2.4	4.8	10.2	22
3	3.6	7.2	15.3	33
4	4.8	9.6	20.4	44
5	6.0	12.0	25.5	55

After Martinez et al, 1979

In situ thermal gradients have been measured for various Gulf Coast salt domes (Table 5.2). Martinez et al (1979) report that the temperature in an exploration well varies approximately linearly from 36°C (97°F) to 75°C (167°F) for Rayburn's Dome and from 41°C (106°F) to 78°C (173°F) for Vacherie Dome, over depths ranging from 305 to 1524 m (1000 to 5000 ft).

No information has been obtained on the change in thermal properties of salt due to radiation. Because the volume of salt exposed to radiation will be small, changes in the thermal properties due to radiation would only affect temperatures near the waste canisters. Other factors, such as brine migration, could also affect the thermal conductivity of the salt near the canisters. However, there is no evidence or reason to suggest that any significant changes in thermal properties will occur.

The design must account for the thermal properties of the repository horizon by adjusting the waste package spacing to keep the thermal load below critical levels, both during the operational life (ventilated) and after decomissioning (unventilated) of the repository. Critical thermal loads will be those rock temperatures which endanger the structural integrity of the repository and, hence, impact radionuclide containment.

In summary, the temperature distribution and levels in domal salt will be a function of:

- In situ temperature
- Heat generation and distribution of waste packages
- Thermal properties of the medium
- Convective effects of circulating air, gas, or water
- Phase changes affecting heat balance.

In situ temperature has major significance to the mechanical response and a minor significance to the hydrological response of a repository sited in domal salt.

5.2.2 Thermal Conductivity

For site evaluation of a high level waste repository in domal salt, it will be necessary to establish the temperature change in the rock mass due to the heat output of the nuclear waste. The physical parameters of importance in defining the thermal effects of storing high level nuclear waste in domal salt are the thermal conductivity and the thermal diffusivity, if it is assumed that only conductive heat transfer occurs. Thermal conductivity governs the response in steady-state heating while transient heating is governed by the thermal diffusivity. Their definitions are as follows:

TABLE 5.2

IN SITU THERMAL GRADIENTS (°F/100 ft.) FOR SALT DOMES OF THE GULF COAST INTERIOR BASIN

Salt Dome Depth Range (feet)	Lampton	Richton	Vacherie	Rayburn's	Palestine	Keechi	Oakwood
Surface-200	3.0	6.0	9.0	1.5	6.0	6.5	3.5
200-400	3.0	6.0	3.0	2.5	4.5	9.0	5.5
400-600	3.0	6.0	3.5	1.5	2.0	2.0	2.5
600-800	2.5	1.5	2.0	2.5	1.5	1.5	7.5
800-1,000	3.0	1.5	1.5	2.0	1.5	1.5	1.5
1,000-1,200	3.0	1.0	2.5	2.0	1.5	1.5	1.5
1,200-1,400	3.0	1.0	1.5	2.0	1.5	1.5	1.5
1,400-1,600	3.0	1.5	2.0	2.0	2.0	2.0	2.0
1,600-1,800	2.0	1.0	1.5	2.0	1.5	1.5	2.0
1,800-2,000	1.0	1.0	2.0	2.0	1.5	1.5	1.5
2,000-2,200	1.5	1.5	1.5	2.0	1.5	1.5	1.5
2,200-2,500	1.6	1.0	1.6	1.6	1.6	1.6	1.6
2,500-3,000	1.4	1.2	1.6	1.8	1.6	1.6	1.6
3,000-4,000	1.0	1.2	1.7	1.6	1.7	1.7	1.7
4,000-5,000	1.5	1.2	1.5	1.6	1.6	1.6	1.6
5,000-6,000	1.0	1.2	1.6	1.6	1.6	1.6	1.6

After Martinez et al, 1979

Note: 1° F/100' = 1.8°c/100m

- Thermal Conductivity:

The thermal conductivity, K, is the ratio between the heat flow per unit area and the thermal gradient:

$$K = \frac{\frac{Q}{At}}{\frac{\partial T}{\partial x}} \quad (MLT^{-3}Te^{-1})$$

- Thermal Diffusivity:

The thermal diffusivity, κ, is the ratio between the thermal conductivity, K, and the thermal capacity per unit volume:

$$\kappa = \frac{K}{\rho C_m} \quad (L^2T^{-1})$$

In general, the thermal conductivity of materials is dependent on the grain size, orientation, and composition of the mineral particles, and on the size, orientation, and moisture content of the pores. It may be anisotropic and a function of temperature, stress level, and scale.

The thermal conductivity of domal salt is expected to be close to that of pure NaCl, due to its high purity and homogeneous nature. Tables 5.3 and 5.4 list recommended values of the thermal conductivity and diffusivity for rock salt (Gevantman, 1981). These agree well with values determined in situ from bedded salt (Bradshaw et al, 1968). The degree of jointing within the rock mass will be a significant factor in assessing the thermal conductivity.

The thermal conductivity of domal salt will have critical significance to the thermal and mechanical response of a repository in domal salt. It will have major significance to the hydrological and geochemical response of the repository site.

5.2.3 Thermal Expansion

Thermal expansion is a measure of the unrestricted change in size exhibited by a material in response to change in temperature. It may be anisotropic and a function of temperature, stress level, and scale. The various forms of thermal coefficients commonly used to describe this change are linear expansion or linear strain per degree, and cubical expansion, or volumetric strain per degree (usually assumed as three times the coefficient of linear expansion).

The expansion response of salt following emplacement of waste will enable prediction of incremental compressive stresses during heating of

TABLE 5.3

RECOMMENDED VALUES OF
THE THERMAL CONDUCTIVITY OF ROCK SALT*

(Temperature, T,K; Thermal Conductivity, k, $Wm^{-1}K^{-1}$)

T	k	T	k
0.4	0.95	25	191
0.5	1.78	30	130
0.6	3.13	40	75.0
0.7	4.97	50	54.0
0.8	7.40	75	34.9
0.9	10.0	100	24.3
1	14.0	150	15.0
2	99.3	200	10.9
3	270	250	8.24
4	443	293	6.65
5	595	300	6.57
6	735	400	4.80
7	820	500	3.67
8	880	600	2.98
9	870	700	2.47
10	836	800	2.08
15	502	900	1.85
20	306	1000	1.67

*Those below 100 K are typical values.

TABLE 5.4

RECOMMENDED VALUES OF
THE THERMAL DIFFUSIVITY OF ROCK SALT*

(Temperature, T,P; Thermal Diffusivity, $10^{-4}m^2s^{-1}$)

Solid		Solid	
T	α	T	α
10	301	293	0.0353
15	136	300	0.0349
20	36.7	400	0.0249
25	15.9	500	0.0186
75	0.952	600	0.0149
100	0.192	800	0.0103
150	0.0955	900	0.00915
200	0.0628	1000	0.00827
250	0.0459		

*Those below 100 K are typical values

TABLE 5.5

RECOMMENDED VALUES OF
THE THERMAL LINEAR EXPANSION OF ROCK SALT

(Temperature, T,K; Thermal Linear Expansion, $\Delta L/L_o$,%)

T	$\Delta L/L_o$	T	$\Delta L/L_o$
5	-0.772	600	1.371
10	-0.772	700	1.878
15	-0.772	800	2.430
20	-0.771	900	3.034
25	-0.771	1000	3.699
50	-0.759	1074	4.528
75	-0.722	1100	4.840
100	-0.666	1200	6.057
150	-0.521	1300	7.274
200	-0.352	1400	8.490
250	-0.168	1500	9.707
293	0.000	1600	10.924
400	0.448	1700	12.141
500	0.896	1750	12.750

After Gevantman (1981)

the repository. These expansions need to be considered from the standpoints of stress and deformation. Pillar stresses in intact material would increase on heating unless stress release jointing were in evidence so that some expansion would be taken up in closure of the discontinuities in the pillar.

For the thermal coefficient of linear expansion of rock salt, Gevantman (1981) recommends the values shown in Table 5.5 and Figure 5.1, based on data from various investigators.

Thermal expansion is of critical significance to the thermal and mechanical response of a repository sited in domal salt. It is of major significance to the geochemical response of the repository site.

5.2.4 Heat Capacity

Mass heat capacity is defined as the heat required to warm a unit mass of material through one degree. It may be thought of as the thermal capacity of a unit mass of substance. Ratigan (1976) reports a mass heat capacity for salt of 0.22 Cal/gm °C. A.D. Little (1978) reports that mass heat capacity increases with elevated temperature as shown in Figure 5.2.

The heat capacity of domal salt will have minor significance to the thermal, mechanical, hydrological and geochemical response of the repository site.

5.3 CAPROCK

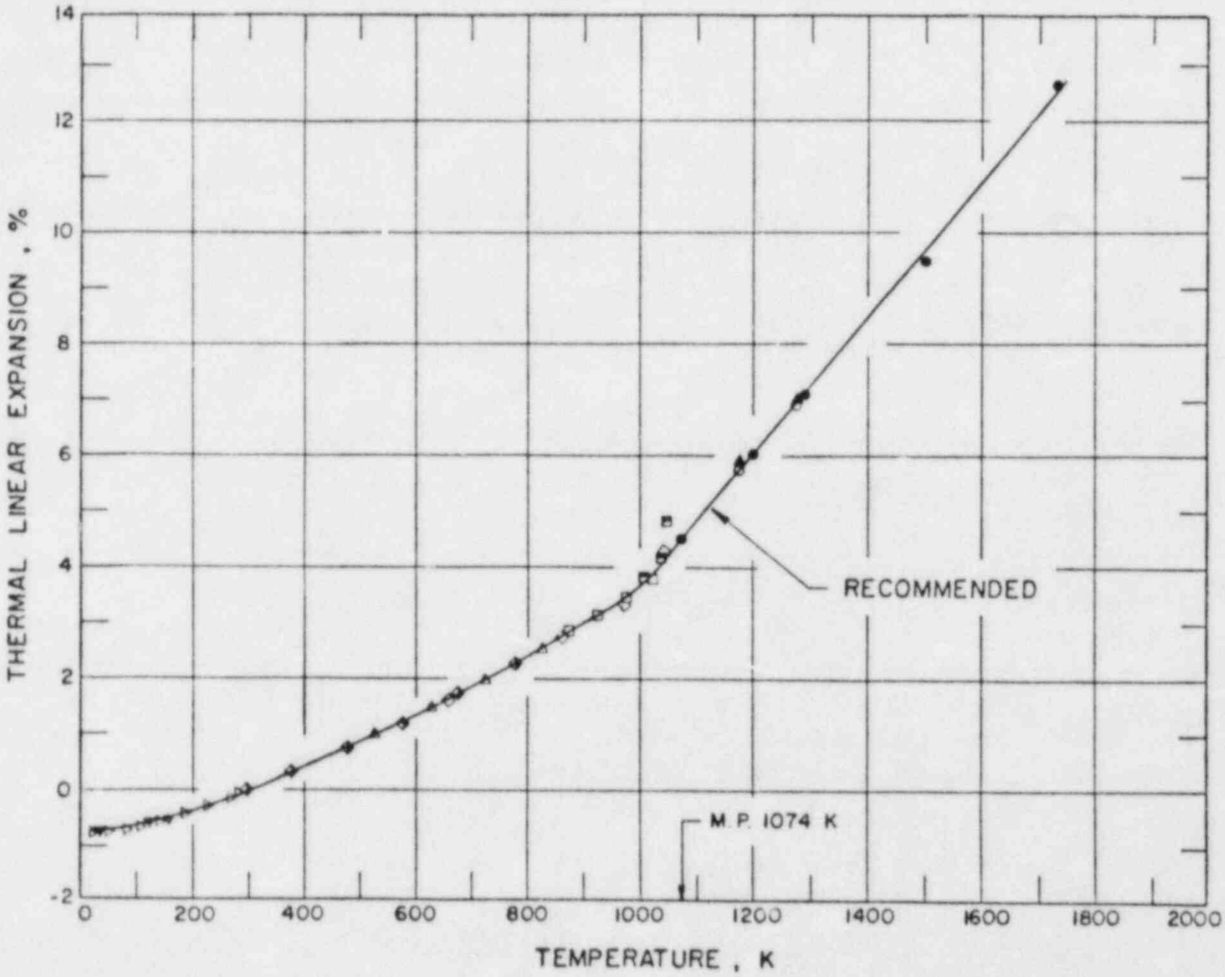
To date there has been no thermal testing of the caprocks overlying Gulf Coast salt domes. Since the thermal effects of the repository on the caprock are expected to be minimal, little effort has been exerted to investigate their thermal properties.

5.4 DESIGN AND CONSTRUCTION

5.4.1 Generic Thermal Characteristics Affecting Design and Construction

A combination of thermal conductivity, heat capacity, and density will yield information required for the characterization of heat flow through the repository site following the emplacement of high level waste. The coefficient of thermal expansion determines thermal stresses induced by the increased temperatures. Table 5.6 summarizes the significance of thermal characteristics in repository design and construction.

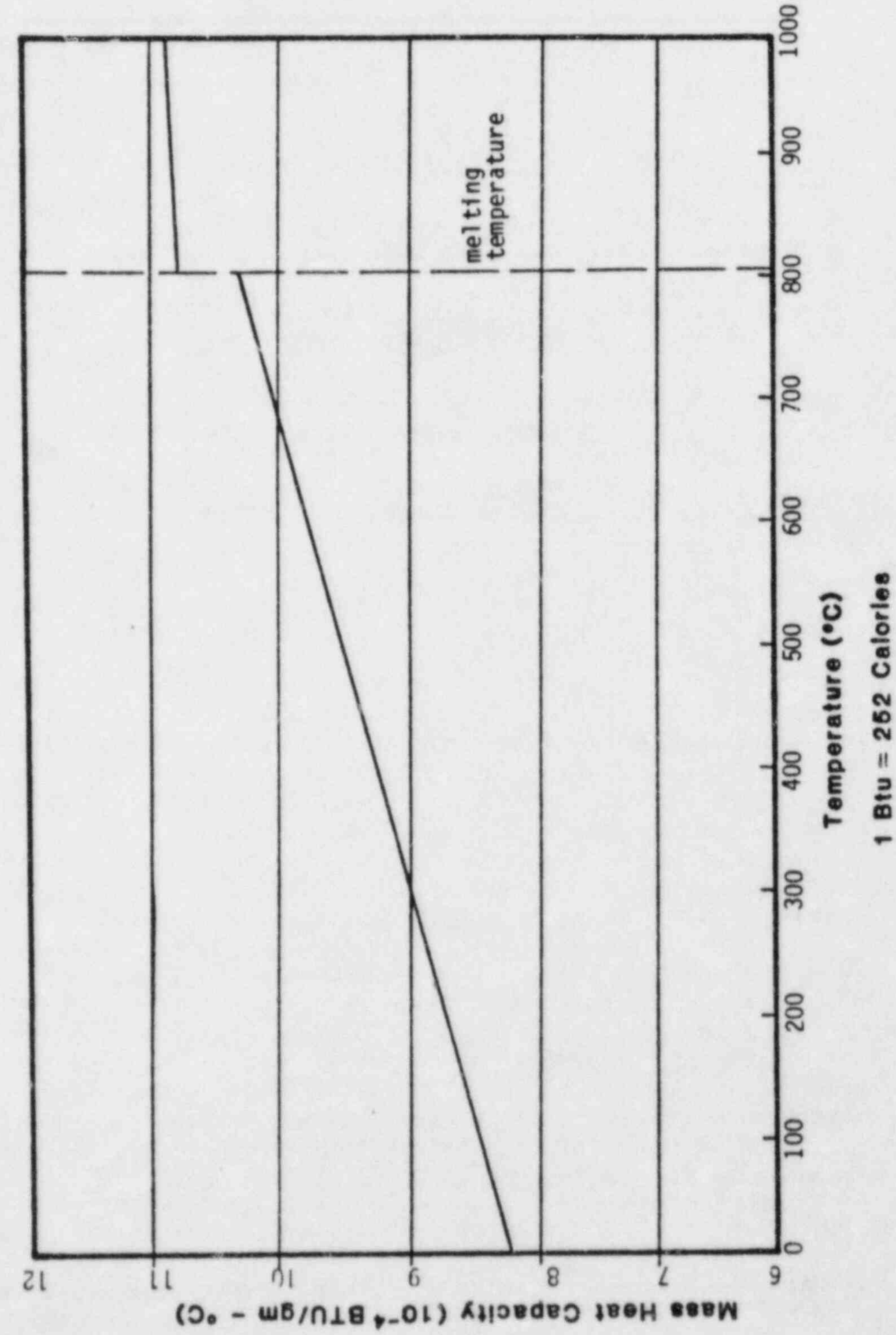
THERMAL LINEAR EXPANSION OF ROCK SALT — Figure 5.1



After Gevantman, 1981

Project No. 413-1162 B Reviewed KJ Date 12-81

SPECIFIC HEAT OF ROCK SALT VS TEMPERATURE Figure 5.2



After Arthur D. Little, 1978

Project No 813-1168B Reviewed KL Date 12-81

TABLE 5.6

EVALUATION OF THERMAL CHARACTERISTICS IN TERMS OF THEIR INFLUENCE ON KEY ISSUES

KEY ISSUES	CONSTRUCTABILITY	THERMAL RESPONSE	MECHANICAL RESPONSE	HYDROLOGICAL RESPONSE	GEOCHEMICAL RESPONSE
In Situ Temperature	cfh (Insignificant)	cfh (Insignificant)	beh (Major)	ceh (Minor)	cfh (Insignificant)
Thermal Conductivity	cfh (Insignificant)	adh (Critical)	adh (Critical)	aeh (Major)	aeh (Major)
Heat Capacity	cfi (Insignificant)	bfi (Minor)	bfi (Minor)	bfi (Minor)	bfi (Minor)
Thermal Expansion	cfh (Insignificant)	adh (Critical)	adh (Critical)	cfh (Insignificant)	aeh (Major)

KEY:*

- Critical
- Major
- Minor
- Insignificant or not relevant

*See Section 1.3.5 and Table 1.1 for definitions of the level of influence.

ATTRIBUTES

- availability of design and construction techniques which allow for conservative assumptions for the value of the characteristic:
  - a) reasonable techniques are not available (i.e. high cost impact)
  - b) some techniques are available, but at moderate cost impact
  - c) reasonable techniques are available (i.e., little cost impact)
- uncertainty in the representation of the real world by the performance prediction model, and sensitivity of that model to characteristic value:
  - d) model has low uncertainty (i.e., is very representative) and high sensitivity to characteristic
  - e) model has moderate uncertainty and moderate sensitivity
  - f) model has high uncertainty or low sensitivity
- cost effectiveness and scheduling limitations in potentially reducing the uncertainty in the assessment of characteristic values:
  - g) uncertainty can be significantly reduced in a cost-effective and timely manner (i.e., prior to NRC review of an SCR)
  - h) uncertainty can be reduced, but only during in situ testing
  - i) uncertainty cannot be significantly reduced in a cost-effective or timely manner (i.e., prior to NRC review for construction authorization).

5.4.2 Mitigating Design and Construction Strategies

The adverse thermal characteristics of a deep high-level waste repository sited in domal salt may be mitigated by a variety of design and construction strategies. They include:

- Sizing pillars, designing rooms and selecting tunnel linings to reduce creep
- Designing the repository and excavations to avoid stress concentrations
- Selecting canister and room spacings to control temperatures generated in the rock mass.
- Designing a cooling/ventilation system.

Specific mitigating measures can be selected using information from the in situ testing and monitoring program.

5.5 SITE SPECIFIC STUDY

As was previously discussed in Section 4.6.1, the amount of testing on samples from the three candidate domes is limited. There are thermal tests now being conducted by Fiber Materials, Inc. of Biddeford, Maine under the direction of Battelle Memorial Institute. These include measuring thermal expansion, heat capacity and thermal conductivity from room temperature to 500°C, where possible. However, these test results are not currently available to Golder Associates.

Based on the similarities in their mechanical properties, it seems likely that the samples of the three candidate domes currently being tested will fall into the range of thermal properties for rock salt in general.

6. HYDROLOGIC CHARACTERISTICS

6.1 GENERAL

Hydrologic considerations for repository design include:

- Groundwater inflow into the excavations
- Sealing the access shaft to prevent vertical groundwater migration
- Resaturation of the backfill
- Assessment of the controlled release of nuclides into the groundwater flow system from the aspects of both containment and isolation.

Since a vertical access shaft is required from land surface to the repository excavation, hydrologic properties of geologic strata overlying and surrounding the salt stock need to be evaluated in addition to those of the repository horizon.

In previous sections the characteristics have been treated jointly for each medium: domal salt, caprock and surrounding sedimentary rocks. In this hydrology section it is more appropriate to treat the three media jointly for each characteristic. The hydrologic properties span all media and it is thus more logical to consider the groundwater regime as a whole.

Consideration of the key design and construction issues identified in Section 1 and the hydrologic characteristics shows that they may be related in the following way:

- Constructability
  - hydraulic conductivity
  - hydraulic gradient
  - porosity
  - pore fluid composition

- Thermal response
  - hydraulic gradient

- Hydrological response
  - hydraulic conductivity
  - hydraulic gradient
  - specific storage

- Geochemical response
  - hydraulic conductivity
  - hydraulic gradient
  - porosity
  - dispersivity
  - adsorption
  - pore fluid composition

The following sections describe the hydrologic characteristics and assess their importance for the design and construction issues from the generic domal salt viewpoint. A matrix diagram is presented at the end of these sections ranking the characteristics in terms of significance for design and construction. The second half of this hydrologic section assesses the three domal salt sites according to the ranking developed within the generic study.

6.2 HYDRAULIC CONDUCTIVITY

Hydraulic conductivity is a proportionality constant relating the Darcy velocity of a fluid (volume flux rate) to the hydraulic gradient as defined by Darcy's law:

$$q_i = -K_i \frac{\partial h}{\partial x_i}$$

where x_i = refers to the principal directions of hydraulic conductivity, i = 1, 2, 3

q_i = Darcy velocity in the i direction (LT-1)

K_i = principal hydraulic conductivity in the i direction (LT-1)

$\frac{\partial h}{\partial x_i}$ = hydraulic gradient in the i direction; rate of change in hydraulic head with distance (dimensionless)

The above equation indicates that hydraulic conductivity is a directional property of the porous medium. In layered sedimentary rocks, the principal directions of hydraulic conductivity are usually perpendicular and parallel to bedding with the former less than or equal to the latter. In fractured media, the directional relationships are much more arbitrary with higher hydraulic conductivities in the preferred directions of fracturing.

Hydraulic conductivity is a measure of the ability of a porous medium to transmit fluid of a particular density and viscosity. It is often convenient to separate the fluid properties from the porous medium properties as follows:

$$K = \frac{k \rho g}{\mu}$$

where K = hydraulic conductivity (LT-1)

k = intrinsic permeability (L2)

ρ = fluid density (ML-3)

g = gravitational acceleration (LT-2)

μ = fluid dynamic viscosity (ML-1 T-1)

Fluid density (ρ) and viscosity (μ) are sensitive to temperature and the composition of pore fluids. Intrinsic permeability (k) is approximately constant and considered a characteristic property of the medium.

The hydraulic conductivity of a formation represents flow between individual grains (interstitial or matrix hydraulic conductivity) and flow through fractures or other secondary openings in the rock (fracture hydraulic conductivity). Hydraulic conductivity values based on laboratory core samples do not generally reflect fracture permeability and, therefore, usually represent a lower bound value. As a consequence, hydraulic conductivity data based on field tests, such as full-scale pumping tests, more adequately reflect the in situ hydraulic conductivity of a rock mass.

Hydraulic conductivity directly or indirectly affects many design and construction issues including:

- Shaft and repository inflow and the design of control measures
- Post-decommissioning resaturation of repository backfill
- Performance of shaft and borehole seals
- Local flow field in the immediate region of the waste package and the repository
- Velocity and direction of nuclide transport from the repository to the biosphere.

Since groundwater velocity is proportional to hydraulic conductivity, the design of backfills and other engineered barriers must consider the hydraulic conductivity of the natural and man-made materials through which contaminated groundwater will flow.

6.2.1 Domal Salt

Permeability tests have been performed on laboratory samples of both bedded and domal salts. Gloyna and Reynolds (1961) concluded that if flow occurs in a rock salt specimen, it must occur through fractures or intercrystalline planes and not through the salt crystals. They measured intrinsic permeabilities for domal salt from effectively zero to 1.5×10^{-9} cm^2 (1 cm^2 is approximately equal to 10^5 cm/sec for pure water at 20°C). These values were increased using a nonreactive fluid (helium or kerosene). Intrinsic permeabilities decreased with increased stress and also with time. Many of the fractures which transmitted fluid initially were thought to be caused by stress relaxation when the samples were removed from the environment. These fractures begin to close with increased pressure and continue to do so over time. Intrinsic permeabilities measured using brine were highly variable, but averaged only 32 percent of the nonreactive fluid permeabilities. Katz and Coats (1968) reported laboratory intrinsic permeabilities of bedded or domal rock salt from effectively zero to 10^{-9} cm^2. It seems possible that overburden pressure will cause permeable channels in salt to heal, resulting in extremely low values of matrix hydraulic conductivity.

Laboratory permeability data indicate that natural groundwater flow in domal salt would probably result from fracture hydraulic conductivity. Kupfer (1974a and b) postulates that a zone of sheared salt containing

10 to 50 percent shale exists along the external boundaries of most salt domes (see Section 4.3.4.3). The geometry and hydraulic conductivity of these shear zones is largely unknown, since excavations avoid the outer regions of the salt stock. Many domes contain internal shear zones which separate spines that have moved differentially. Since the attitudes of internal shear zones are predominantly vertical, they are not readily intercepted by vertical exploration boreholes. Therefore, in situ tests have not been routinely performed in these zones of presumably higher hydraulic conductivity. A planimetric map at the Belle Isle Salt Mine (Figure 4.10) illustrates the important internal structural features in domal salt (see Sections 2.2 and 4.3).

Naturally occurring fractures are rare in domal salt due to plastic flowage over geologic time, but stress relief joints due to mining operations may create fractures which are likely to extend for a limited distance into the salt mass. Such fractures could intercept an existing shear zone and provide a pathway for groundwater flow.

Case studies of salt mines have demonstrated the low in situ hydraulic conductivity of domal salt. Groundwater seepage rates tend to be low and the mines remain dry without large-scale dewatering operations. The movement of groundwater is primarily through fissures and shear zones or inclusions of impure salt. Three types of fluid leaks have been observed in mines in Louisiana salt domes (GAI, November 1978) and a description of these leaks provides qualitative information on the in situ hydraulic conductivity of domal salt. They include:

- Short-Duration Leaks: These leaks are relatively common in Louisiana mines. Typically, brine containing hydrocarbons begins dripping from the ceiling after new workings are opened. Volumes may be significant (i.e., exceed evaporation rate) for several days to a month, after which flow diminishes and generally ceases within six months. The larger and more persistent drips are commonly near shear zones.

  It is felt that these pockets of water were probably introduced into the salt during intrusion into the overlying sedimentary layers and were subsequently sealed by recrystallization. Fracturing caused by mining could intercept the previously isolated brine inclusions.

- Increasing Volume Leaks: These leaks tap water sources from outside the salt dome. Because there is a large source of fresh water in the surrounding sediments, these leaks can rapidly increase in size due to salt dissolution and cause flooding of the mine. Miners carefully seal shafts and avoid the outer regions of domes because of potential flooding hazard.

- Sporadic - Continuing Leaks: These leaks, found in only two Louisiana mines, occur near boundary shear zones. They begin slowly, gradually increasing to a peak discharge rate and then stabilize at a much lower rate. They are normally grouted at this time. However, new leaks commonly develop within several months, and the process is repeated.

The leaks are thought to tap an external water source which is hydraulically connected to the mine by a semipermeable boundary shear zone. If the groundwater is not saturated with respect to sodium chloride, dissolution could locally increase hydraulic conductivity in the shear zone and cause flooding (although this has not actually occurred to date).

6.2.2 Caprock

Indurated, unfractured caprock is expected to have a low hydraulic conductivity, probably less than 10^{-6} cm/s. The upper parts of the caprock are often brecciated or sheared and may contain solution channels so that in situ hydraulic conductivity will be locally higher where these secondary features exist. Furthermore, some caprocks are unconsolidated at the salt-caprock boundary and drillers have experienced circulation losses in what they describe as "loose anhydrite sand." The presence of such zones seems likely to indicate active migration of fluids along the boundary of the salt stock.

Packer tests in the upper caprocks of Richton and Cypress Creek Domes (LETCo, 1980b) measured hydraulic conductivities of 7.8×10^{-4} and 2.1×10^{-5} cm/s, respectively. It is generally believed that groundwater flow in upper caprock is primarily through joints, fractures and solution channels. Straddle packer tests, conducted at the salt-caprock interface of the same domes (LETCo, 1980b), indicated hydraulic conductivities of 7.0×10^{-6} and 1.8×10^{-6} cm/s, respectively. These values suggest a relatively tight contact. In some caprocks, drillers have reported abnormally high hydraulic heads at the salt-caprock interface which suggests that caprock can be a relatively impermeable natural barrier to groundwater flow.

6.2.3 Sedimentary Deposits

Sedimentary deposits of the interior Gulf Coastal Basin are characterized by thick accumulations of interbedded sands, silts and clays. The sediments tend to be poorly lithified near the land surface and become more indurated with depth. Sediment type is the primary factor controlling permeability with consolidation and cementation playing a secondary role. Although the sedimentary formations tend to be characterized by a dominant rock type, horizontal and vertical changes in lithology result in a range of hydraulic conductivity that can exceed two or three orders of magnitude. Since the sediments are subhorizontally stratified and not pervasively fractured, the vertical hydraulic conductivity tends to be less than or equal to that in the horizontal direction. However, there are faults and shear zones in the sediments which can provide significant pathways for vertical flow.

The most reliable measure of hydraulic conductivity is from in situ borehole tests. Such tests are an effective measure of horizontal hydraulic conductivity, but are relatively insensitive to vertical hydraulic conductivity. In Figure 6.1 are the results of the borehole tests conducted in the Mississippi and Louisiana study areas by LETCo (1980, 1981). The values presented are horizontal hydraulic conductivities of the more permeable strata and may be considered upper bounds on vertical hydraulic conductivity. The effect of discontinuities (faultrs or shear zones) on the rate and direction of groundwater flow should be assessed from a discointinuum approach.

The hydraulic conductivity of sedimentary deposits affects:

- Shaft inflow and the design of control measures
- Performance of shaft and borehole seals
- Velocity and direction of nuclide transport from the repository

The sedimentary deposits will be responsible for the major proportion of groundwater inflow into the shaft. Since inflow rates are roughly proportional to the hydraulic conductivity, the design of control measures strongly depends on hydraulic conductivity. Nuclide travel paths from the repository to the accessible environment will include groundwater transport through sedimentary deposits. Such transport may originate at the caprock-sedimentary contact or at some location along the access shaft. Since the velocity of nuclide transport is proportional to hydraulic conductivity, this characteristic is of major importance in predicting nuclide travel times and evaluating shaft seals.

Hydraulic conductivity is a characteristic of major significance to constructability and the hydrological and geochemical response of repository site in domal salt.

6.3 HYDRAULIC GRADIENT

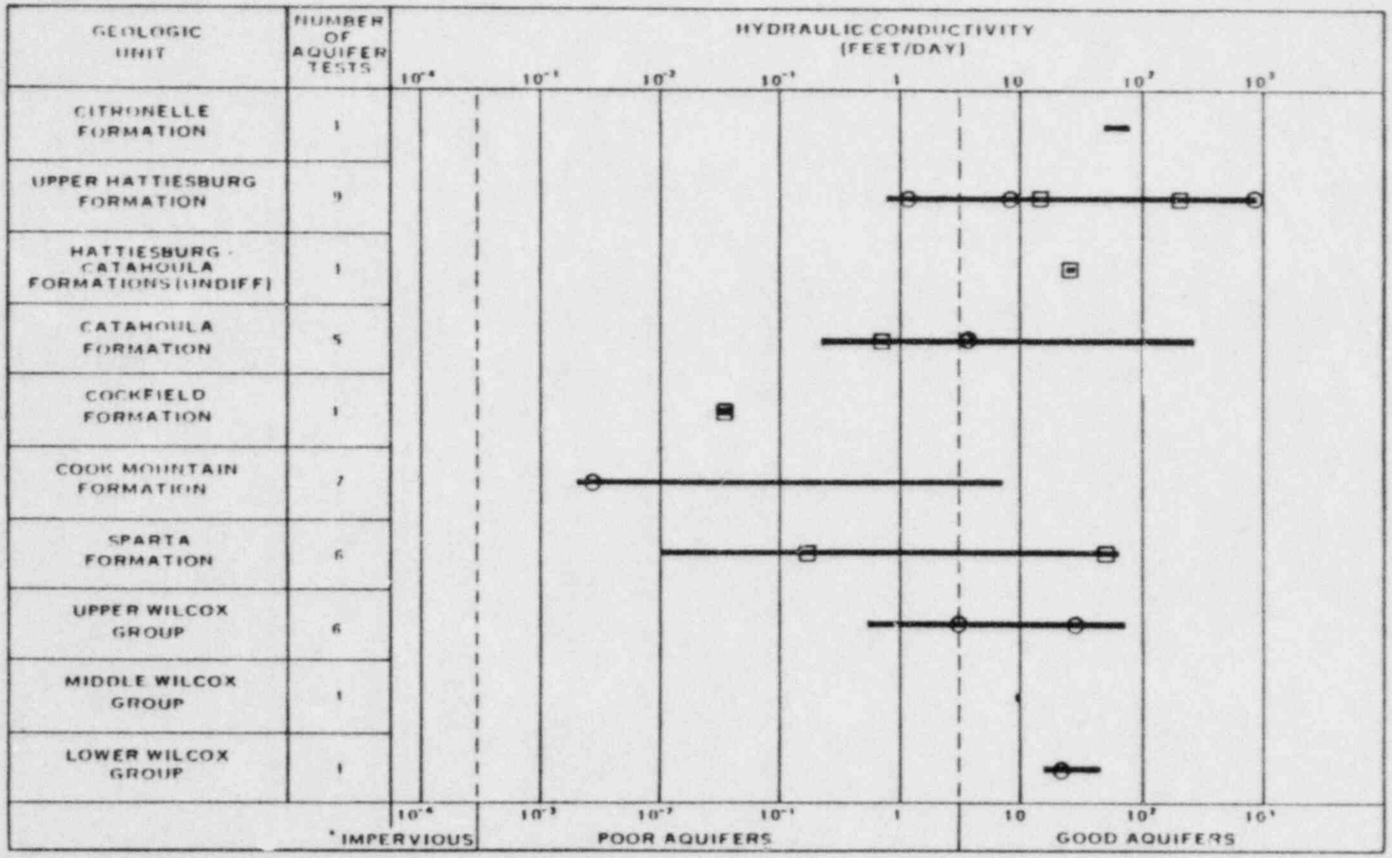
Hydraulic gradient is the rate of change in hydraulic head with distance. In the absence of other gradients (i.e., temperature and chemical) it causes fluid flow according to Darcy's law. Hydraulic gradient will probably be the major force causing fluid flow within salt dome flow systems, although temperature and salinity gradients may be significant at the repository horizon after decommissioning. Hydraulic gradients in natural groundwater systems can be complex, exhibiting three-dimensional variability that generally reflects the natural variations in hydraulic conductivity of the geologic media.

A knowledge of hydraulic gradients is of major importance because they affect the following design considerations:

- The rate of groundwater inflow into the shaft and repository excavation

Project No. 813-1162 B Reviewed ______ Date __________

AQUIFER TEST SUMMARY FOR SELECTED GEOLOGIC UNITS – MISSISSIPPI STUDY AREA



LEGEND

○ Near Richton Dome

□ Near Cypress Creek Dome

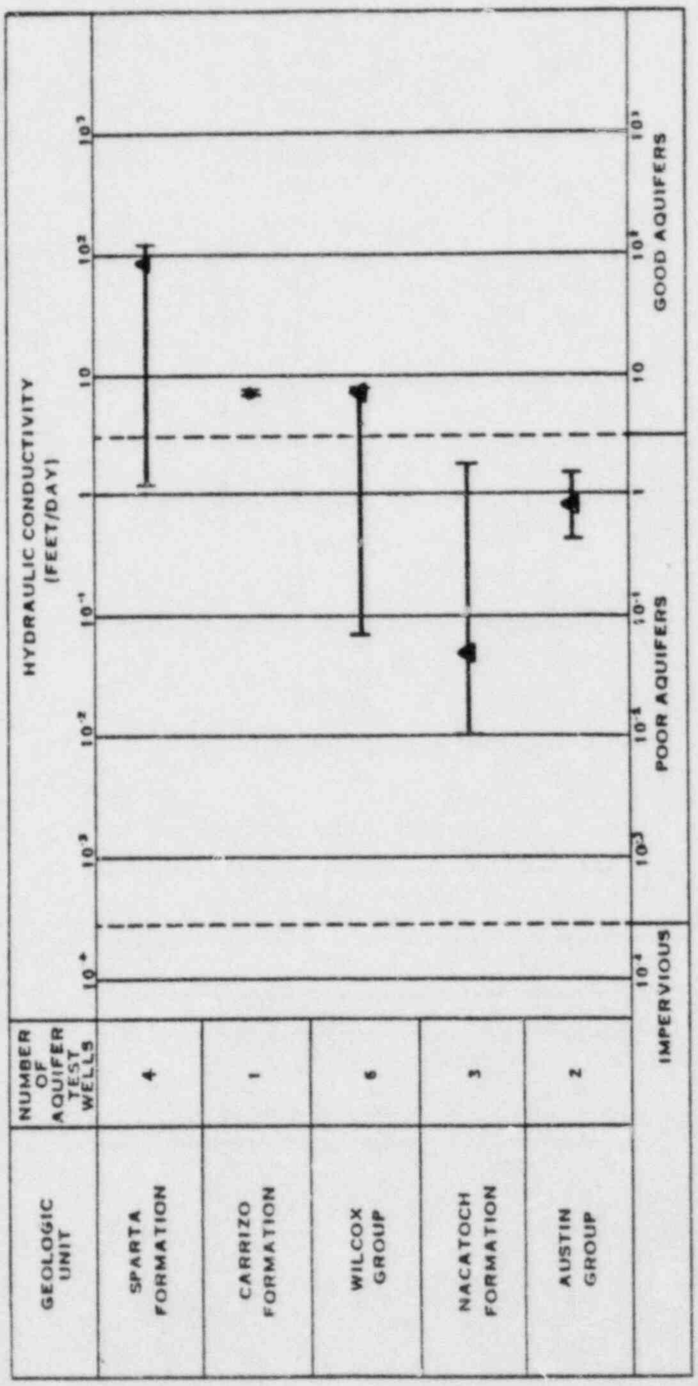
1 foot/day = 3.53 X 10^{-4} cm/sec.

After LETCo, 1980b

Figure 6.1A

AQUIFER TEST SUMMARY FOR SELECTED GEOLOGIC UNITS - LOUISIANA STUDY AREA

Figure 6.1B



1 foot/day = 3.53 X 10^{-4} cm/sec.

LEGEND

▲ Near Vocherle Dome

After LETCo, 1981b

Project No. ______ Reviewed ______ Date ______

- The time required for saturation of the engineered barriers after decommissioning
- The velocity of groundwater carrying nuclides from the repository to the accessible environment.

6.3.1 Domal Salt and Caprock

Little data exists which establishes natural hydraulic gradients within domal salt and caprock. At some Gulf Coast salt domes, drillers have experienced abnormally high hydrostatic pressures at the salt-caprock interface, but this phenomenon has not been reported at any of the candidate domes. No measurements of hydraulic gradient have been made in salt domes.

6.3.2 Sedimentary Deposits

Regional hydraulic gradients of the interior Gulf Coast Basin range from 0.2 to 2.0 m per km in a general southerly direction (LETCo; 1980c, 1981b). The hydraulic gradient in unconfined aquifers is defined by the surface of the water table. Water table contours generally follow the local topography and are much more irregular than the piezometric contours of confined aquifers. The natural gradients can be greatly altered by the effects of groundwater withdrawal (near population centers) and the injection of oilfield brines (in the vicinity of petroleum development). The local hydraulic gradient may also be affected by the presence of the salt dome itself. Antiformal structures in the sedimentary rocks commonly exist above a dome so that deep formations are brought near the land surface or outcrop in the vicinity of the dome. In this way, local groundwater recharge may occur. At Vacherie Dome, the Wilcox Group outcrops around the dome and the piezometric surface indicates groundwater flow that is radially outward from the outcrop area.

Regional vertical gradients suggest a general tendency for upward flow from deeper to shallow formations. However, the vertical gradients may be enhanced or reversed as a result of groundwater withdrawal or injection in specific aquifers. The vertical gradients in the vicinity of a salt dome can be quite complex. The exterior boundary of the salt stock and/or the boundary shear zone may provide a permeable pathway for the upwelling of deep saline waters into shallow freshwater aquifers or recharge above the dome may result in downward vertical flow from the land surface.

Hydraulic gradient is a characteristic of major significance to constructability, hydrological response and geochemical response and minor significance to the thermal response of a repository site in domal salt.

6.4 POROSITY

Total porosity is the ratio of the volume of void space in the rock to the total volume. Primary porosity is formed when the material is deposited and consolidated. Secondary porosity forms after consolidation and results from such features as joints, fractures, and dissolution cavities.

The term effective porosity is often defined as the ratio of void space through which fluid moves (interconnected voids) to the total volume and is, by definition, less than or equal to the total porosity. In terms of solute transport, it is defined as the porosity value which, when divided into the Darcy velocity, gives the true average flow velocity of fluid through porous media. The two definitions above are not necessarily equivalent, particularly in fractured media where a large proportion of the fluid can be carried by a very small proportion of the voids.

No values of effective porosity have been measured in domal salt. However, total porosity measurements by Gloyna and Reynolds (1961) did not exceed 1.71 percent and Katz and Coats (1968) reported porosities in rock salt from 0.6 to 2.0 percent. The use of these measured values as total porosities of the rock mass is questionable because of the stress release experienced by the core samples. Within massive domal salt, it is quite possible that in situ stress causes fractures to heal resulting in extremely low porosity. An exception to this may occur in the boundary and internal shear zones.

Porosity is considered to be a characteristic of major significance to geochemical response and of minor significance to the constructability of a repository in domal salt.

6.5 SPECIFIC STORAGE

The specific storage is the volume of fluid taken into or released from storage in a unit volume of porous medium per unit change in hydraulic head under saturated conditions. It is related to the compressibility of the rock matrix and the pore fluid. For porous media the relationship can be expressed as (Domenico and Mifflin, 1965):

$$S_s = \rho g (n B + a)$$

where
- Ss = specific storage (L-1)
- B = compressibility of pore fluid (LT2 M-1)
- ρ = mass density of the material (ML-3)
- g = acceleration of gravity (LT-2)
- a = compressibility of porous media matrix ($LT^2 M^{-1}$)
- n = total porosity (dimensionless)

The applicability of this equation to media with very low permeability is uncertain.

Specific storage is significant only when transient pressure response in the host rocks is considered, such as during depressurization (excavation) and repressurization (post-decommissioning). Values of specific storage for various geologic materials likely to be encountered in an access shaft are given in Table 6.1. Since deeper sedimentary deposits are more consolidated, the specific storage for a given lithology is likely to decrease with depth. Specific storage will be important in predicting groundwater flow through permeable formations towards the access shaft. It is a characteristic of minor significance to the hydrological response of the repository site.

6.6 DISPERSIVITY

Dispersion describes the spreading of a solute when introduced into a flow field and includes both mechanical dispersion and molecular diffusion. Mechanical dispersion results from the movement of fluid particles along random paths through the porous medium while molecular diffusion results from physiochemical properties of the fluid and the surrounding rock. Molecular diffusion is normally neglected in natural groundwater systems except where the flow velocities are extremely low (Reddell and Sunada, 1970).

Dispersivity (the measure of dispersion) is a length property of the medium which is largely dependent on the scale of the flow region under consideration. Values can range from 10^{-2} cm for laboratory tests to 10^{4} cm for regional systems (Cherry et al, 1975). At the microscopic (laboratory) scale, it is consequence of the tortuosity of the media pore space while at the macroscopic (field) scale, it is primarily due to the divergence of flow paths resulting from heterogeneities in aquifer properties, particularly hydraulic conductivity. Dispersivity varies with direction and is described by a lateral dispersion coefficient (perpendicular to flow direction) and a longitudinal dispersion coefficient (in the direction of flow).

A physical consequence of dispersion theory is that the leading front of a nonreactive contaminant plume travels faster than the average pore fluid velocity. Therefore, the calculation of travel time based on average fluid velocities may overestimate the time required for a nonreactive contaminant to first appear. In regional systems, the error may be severe. In situ measurements may only be valid for near-field considerations.

Dispersivity pertains primarily to the extent and rate of spread of a nuclide plume. It is a characteristic of minor significance to the geochemical response of a repository site in domal salt.

6.7 GEOCHEMISTRY

6.7.1 General

Although the details of geochemical reactions between salt and radionuclides are poorly known, some generalizations can be made on the expected

TABLE 6.1

VARIATIONS IN SPECIFIC STORAGE FOR VARIOUS GEOLOGIC MATERIALS

MATERIAL	Ss (f^{-1})	Ss (cm^{-1})
Plastic Clay	6.2×10^{-3} to 7.8×10^{-4}	2.0×10^{-4} to 2.6×10^{-5}
Stiff Clay	7.8×10^{-4} to 3.9×10^{-4}	2.6×10^{-5} to 1.3×10^{-5}
Medium Hard Clay	3.9×10^{-4} to 2.8×10^{-4}	1.3×10^{-5} to 9.2×10^{-6}
Loose Sand	3.1×10^{-4} to 1.5×10^{-4}	1.0×10^{-5} to 4.9×10^{-6}
Dense Sand	6.2×10^{-5} to 3.9×10^{-5}	2.0×10^{-6} to 1.3×10^{-6}
Dense Sandy Gravel	3.1×10^{-5} to 1.5×10^{-5}	1.0×10^{-6} to 4.9×10^{-7}
Rock, Fissured, Jointed	2.1×10^{-5} to 1.0×10^{-6}	6.9×10^{-7} to 3.0×10^{-8}
Rock, Sound	Less than 1.0×10^{-6}	Less than 3.0×10^{-8}

(adapted from Walton, 1970)

interactions of the host medium and radioactive contaminants. In contrast to other rock types being considered as repository media, salt has almost no sorptive capacity with respect to migrating radionuclides. Presumably a repository in a salt dome would be located in the most stable portion of a dome away from shear zones at the margin of the dome and the margins of individual spines composing the dome. Thus, the repository horizon should be almost pure halite with minor anhydrite. It is expected to be generally free of shale, clay, and other sedimentary inclusions which could provide some sorptive capacity.

In general, natural geochemical barriers do not exist in the repository environment within a salt dome. Engineered barriers (waste package, room backfill and borehole seals) will have to incorporate those materials (clays, zeolites, etc.) which would chemically retard radionuclides. The sedimentary deposits outside the salt dome have some natural adsorption capabilities. The sorption properties of the engineered barriers should be chosen to complement these capabilities.

Adverse aspects of the chemical environment include the presence of brine in the groundwater system. Brine lowers the sorptive capacity of most materials and may increase the general mobility of radionuclides in solution. Thus, the natural groundwater system will to some extent decrease the effectiveness of sorptive materials used in engineered barriers. Little is known about the changes in sorptive capacity in the presence of brine for materials that are candidates for use in engineered barriers, and testing should be undertaken to determine their effectiveness in a salt dome environment.

6.7.2 Adsorption

As discussed above, adsorption of nuclides by the geologic media is a major concern in designing backfill and other engineered barriers. Since the adsorption capacity of a medium varies with the nuclide species, an optimal backfill material should adsorb nuclides which are not strongly retarded by the host rocks. Therefore, an assessment of the in situ adsorption properties is required.

The degree to which radionuclides are retarded depends on the solute species, the geochemical character of the rock and the chemical composition of the pore fluid. Therefore, parameters which describe retardation may not be meaningful unless all geochemical characteristics of the system are specified. For a mixture of reactive contaminants, each species will travel according to its retardation properties and, after a given time, the contaminant plume will segregate into different zones, each advancing at its own rate. If the adsorption reactions of a particular ion are nonreversible, the contaminant is permanently immobilized by the media. Unfortunately, many nuclides have reversible adsorption reactions and thus, a change in the geochemical environment (i.e., decrease in dissolved solute concentration) may cause the contaminant to be remobilized by the groundwater flow system.

The amount of contaminant adsorbed by a porous medium is commonly a function of the dissolved solute concentration. For low to moderate concentrations, the following relationship generally holds (Freeze and Cherry, 1979):

$$S = Kd\, C^b$$

where S = mass adsorbed solute per unit bulk dry mass of the medium (dimensionless)
C = solute concetration; mass of solute per unit volume of fluid (ML^{-3})

Kd and b are experimentally determined coefficients which depend on the contaminant species and the geochemical characteristics of the system. For many contaminants, b is close to unity. Therefore, the above equation may be approximated by:

$$S = Kd\, C$$

which describes a linear adsorption isotherm. Kd is called the equilibrium distribution coefficient of the solute species and is defined as the mass of adsorbed solute per unit dry mass of media divided by the mass of dissolved solute per unit volume of fluid. It has dimensions of (L^3/M) and is normally expressed in (ml/g).

In situ adsorption tests are probably not feasible for all relevant nuclides, since this would require the introduction of potentially harmful contaminants into the natural environment. However, it may be advisable to perform a limited number of in situ tests so that the validity of other methods can be assessed.

Distribution coefficients are normally measured in the laboratory by batch or column tests. In batch tests, a contaminant solution of known initial concentration is mixed with powdered rock. When chemical equilibrium is achieved, the change in dissolved solute concentration is used to calculate the amount of solute adsorbed by the rock particles. Column experiments are similar, except the solution is recirculated through a column of crushed rock until the dissolved solute concentration ceases to change. Column tests give distribution coefficients which are lower and probably more realistic than the less expensive batch tests. In many tests, the reaction rates are very slow so that equilibrium conditions cannot be verified at the end of the test. In this case, the ratio (S/C) is called the sorption ratio (Rd) and is similar to Kd, but does not imply equilibrium conditions. Measured sorption ratios are less than or equal to the equilibrium distribution coefficient.

As previously discussed, adsorption of a specific ion is strongly dependent on the concentration of other ions in solution and on the history of adsorption in the media. Preliminary evaluations by Lawrence Livermore Laboratory indicate that sorption coefficients of some nuclides are several orders of magnitude lower in brines than in fresh water (Golder Associates, June 1977b). In domal salt, the adsorption of many nuclide species will probably be insignificant due to the saline composition of the pore fluids. However, this assumption must be verified by in situ and laboratory tests.

Artificial means of increasing adsorption are possible, for example, by encasing the waste packages in a material which provides good adsorption characteristics. However, any design relying upon nuclide retardation must take into account the saline environment and the resulting potential for contamination of the retardant substance by brine, thus making it less effective. Adsorption is a characteristic of major significance to the geochemical response of a repository site in domal salt.

6.7.3 Composition of Pore Fluids

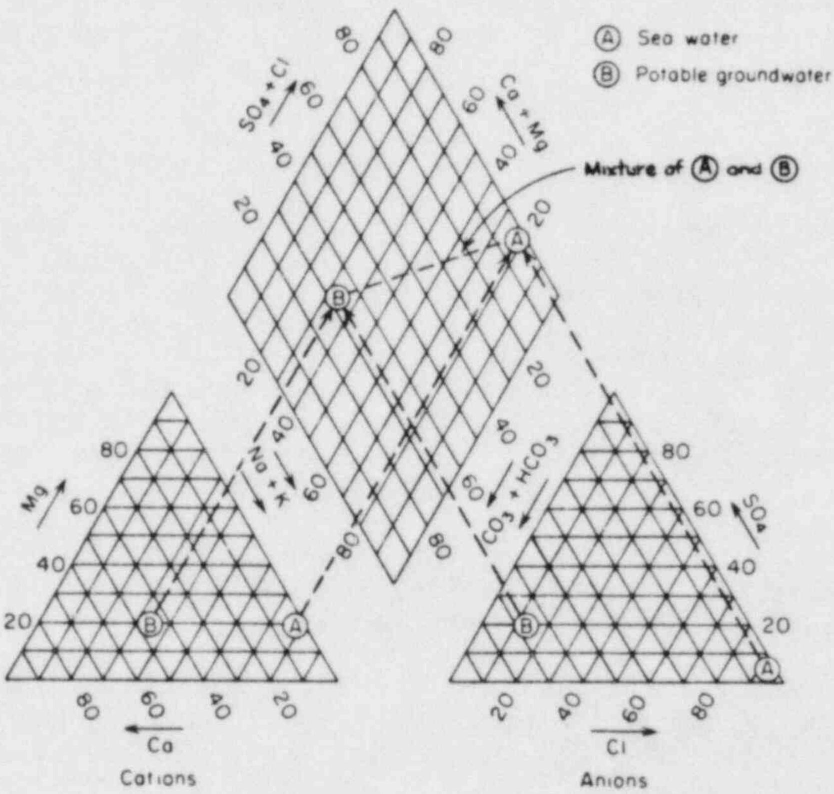
Dissolved salts generally originate from solution of rock materials (primarily associated with sedimentary formations) and from connate waters. Dissolution affects the density of water which may alter ground water gradients and flow rates. Variations in water chemistry can also induce water movement through different ionic pressures. The concentration of dissolved salts has a major effect on the potential of the groundwater to dissolve minerals. This is exemplified by salt formations where the location and growth of dissolution features are strongly influenced by groundwater salinity.

For purposes of this study, the salinity of the groundwater will be a primary consideration relating to groundwater chemistry. The following classification adopted from Robinove (1958) is suggested:

Classification	Dissolved Solids (milligrams per liter)
Fresh	Less than 1000
Slightly Saline	1000 to 3000
Moderately Saline	3000 to 10,000
Very Saline	10,000 to 35,000
Brine	More than 35,000

The final classification of water, however, should be based on the concentrations of major ions. The trilinear diagram (Piper, 1944) is designed to permit chemical compositions of many samples to be represented graphically (Figure 6.2). Since ionic concentrations are expressed as percentages of total milliequivalents, waters with different total concentrations can have identical representations on the diagram. A mixture of two different waters will plot on a straight line joining the points that describe the two water types.

A major concern in repository design is the dissolution of domal salt by unsaturated waters from caprock and sedimentary deposits which migrate downward along the access shaft or exploratory boreholes. The trilinear diagram may be useful in identifying zones where groundwater mixing has occurred. Furthermore, the long-term integrity of the waste canister and backfill are directly related to the near-field hydrochemistry.



Percentage epm (milliequivalents)

NOTE: $\text{epm} = \dfrac{\text{moles of solute x valence}}{10^6 \text{ g of solution}}$

After Freeze and Cherry, 1979

6.7.3.1 Domal Salt

Pore fluids in domal salt are sodium chloride type brines with salinity in excess of 250,000 mg per liter and are essentially saturated solutions of domal material. The solubility of sodium chloride is related to temperature and pressure. Elevated temperatures in the vicinity of high-level-waste package can be expected to increase the solubility of sodium chloride, resulting in some dissolution of domal material and a corresponding increase in the salinity of pore fluids.

6.7.3.2 Caprock

The chemical composition of groundwater in caprock is affected by dissolved components of the caprock itself (calcium sulfate) and the mixing of water from domal salt and/or sedimentary deposits. Depending on the relative importance of each contribution, the caprock pore water may exhibit spatial variability in water chemistry.

In water samples from the upper caprock of Tatum Dome (Mississippi), the USGS reported slightly to moderately saline calcium sulfate type groundwater (Taylor, 1971). Salinity measurements in the caprocks of Richton and Cypress Creek domes by LETCo (1980b) were 11,000 and 16,500 mg per liter, respectively.

6.7.3.3 Sedimentary Deposits

Within the areas being considered, the salinity of ground water in sedimentary deposits tends to increase with depth from fresh water in near surface deposits to brine in the deeper formations. Water chemistry studies by LETCo (1980b, 1981b) at Richton, Cypress Creek and Vacherie domes indicate sodium bicarbonate type fresh water at shallow depths grading to sodium chloride type brines in formations at the repository level. Waters in the vicinity of domes tend to have higher salinity for a given depth than do the regional groundwaters.

LETCo (1980b, 1981b) identified two salinity anomalies in studies of candidate domes. At Richton Dome, an anomalous region of high salinity occurs south of the dome which could suggest dissolution of domal salt by circulating fresh waters. However, saline water could also originate from brine disposal or the upwelling of deep formation water through abandoned boreholes or along the boundary of the salt stock. Another anomaly was recognized near Vacherie Dome where the salinity of water in the Nacatoch Formation was 1.7 times greater than water in the underlying Austin Group.

Pore fluid chemistry is a characteristic of major significance to constructability and to the geochemical response of the repository site.

6.8 DESIGN AND CONSTRUCTION

6.8.1 Generic Hydrologic Characteristics Affecting Design and Construction

All of the hydrologic parameters are of some importance to repository design. Since groundwater flow is a primary concern, it is important that reliable in situ measurements of hydraulic conductivity for the repository horizon and all geologic formations penetrated by the access shaft be obtained. In addition, point measurements of hydraulic head are required so that natural and induced hydraulic gradients can be determined. As groundwater salinity greatly affects the dissolution of salt, a knowledge of the composition of pore fluids in all geologic formations is important. As groundwater pore velocity is directly related to effective porosity its value in domal salt must be assessed. Specific storage in the sedimentary deposits is important because it affects transient groundwater flow toward the access shaft. Adsorption of most nuclides is generally assumed to not occur in an environment of high salinity, but to verify this assumption, in situ and laboratory measurements of adsorption in domal salt are considered necessary. Dispersivity in the sediments surrounding a salt dome is important in evaluating the migration of contaminants to the accessible environment. The significance of the hydrologic parameters to the key issues is summarized in Table 6.2.

The creation of an in situ test facility as part of a repository program will only permit data to be gathered on the near-field factors. Many groundwater considerations involve dimensions which far exceed the near-field scale, yet no knowledge will be accumulated on this aspect from the facility. Thus, verification of hydrologic site suitability is likely to be limited.

6.8.2 Mitigating Design and Construction Strategies

The adverse hydrological characteristics of deep high-level waste repository sited in domal salt may be mitigated by a variety of designa nd construction strategies. These include:

- Leaving a buffer zone between the repository excavation and the edge of the dome
- Avoiding shear zones within the dome
- Controlling hydraulic gradients by drainage
- Controlling inflow into the repository excavation by grouting, pumping, freezing and seals and plugs
- Selecting appropriate engineered barriers to complement the adsorption properties of the sediments surrounding the salt dome
- Limiting extraneous excavations and drill holes in the salt dome.

Specific mitigating measures can be selected using information from the in situ testing and monitoring program.

TABLE 6.2

EVALUATION OF HYDROLOGIC CHARACTERISTICS IN TERMS OF THEIR INFLUENCE ON KEY ISSUES

KEY ISSUES	CONSTRUCTABILITY	THERMAL RESPONSE	MECHANICAL RESPONSE	HYDROLOGICAL RESPONSE	GEOCHEMICAL RESPONSE
Hydraulic Conductivity	bdh Major	cfi		beh Major	aeh Major
Hydraulic Gradient	beh Major	ceg Minor		beh Major	aeh Major
Porosity	ceh Minor	cfi		cfh	beh Major
Specific Storage	cfh	cfi		ceh Minor	cfh
Dispersivity					bei Minor
Adsorption					beg Major
Pore Fluid Composition	beh Major				beg Major

KEY:*

- Critical
- Major
- Minor
- Insignificant or not relevant

*See Section 1.3.5 and Table 1.1 for definitions of the level of influence.

ATTRIBUTES

- availability of design and construction techniques which allow for conservative assumptions for the value of the characteristic:

  a) reasonable techniques are not available (i.e. high cost impact)
  b) some techniques are available, but at moderate cost impact
  c) reasonable techniques are available (i.e., little cost impact)

- uncertainty in the representation of the real world by the performance prediction model, and sensitivity of that model to characteristic value:

  d) model has low uncertainty (i.e., is very representative) and high sensitivity to characteristic
  e) model has moderate uncertainty and moderate sensitivity
  f) model has high uncertainty or low sensitivity

- cost effectiveness and scheduling limitations in potentially reducing the uncertainty in the assessment of characteristic values:

  g) uncertainty can be significantly reduced in a cost-effective and timely manner (i.e., prior to NRC review of an SCR)
  h) uncertainty can be reduced, but only during in situ testing
  i) uncertainty cannot be significantly reduced in a cost-effective or timely manner (i.e., prior to NRC review for construction authorization).

6.9 SITE SPECIFIC STUDY

The significant hydrologic characteristics identified in the generic study are examined for the Richton, Cypress Creek, and Vacherie Domes. In situ hydrologic properties exhibit spatial variability in natural geologic deposits and it is difficult to predict the hydrologic conditions at a particular location unless detailed site specific data are available. In many cases, this site specific data base is lacking, and therefore local or regional descriptions of similar geologic materials must be relied upon. A regional understanding of salt dome hydrology is also useful in evaluating the reliability of existing site specific data.

6.9.1 Richton Dome

6.9.1.1 Hydrologic Framework

Richton Dome is located in the interior Gulf Coastal Basin in southeastern Mississippi. The region is characterized by low relief topography and dendritic surface drainage patterns. Sedimentary strata of hydrologic interest are Quaternary and Tertiary deposits composed predominantly of interbedded sands, silts, and clays, which generally form extensive aquifers and aquitards of regional scale. The sedimentary units dip southwest at 2 to 9 m/km and generally thicken in the direction of dip. The generalized stratigraphy and water-bearing characteristics of geologic units are given in Table 6.3 (from LETCo, 1980b). Above the dome is a highly transmissive aquifer containing the Hattiesburg and Cataboula formations which is pumped extensively for local municipal, industrial, and domestic water supplies. Aquifers located at the flanks of the dome (transmissive formations of the Claiborne and Wilcox Groups) are not important sources of water locally due to high salinities, but may be pumped in other areas, particularly to the north. Important aquitards are the Vicksburg and Jackson Groups, nontransmissive formations of the Claiborne Group, and the Midway Group.

A vertical geologic section through Richton Dome is shown in Figure 2.3. The piercement structure locally affects the strike, dip, and thickness of the geologic strata. Since the geologic section is based on a limited amount of subsurface data, the actual structure above and around the dome is likely to be more complex than shown.

Groundwater recharge occurs by infiltration of precipitation and stream runoff in the outcrop areas of the geologic units. The Citranelle, Hattiesburg, and Cataboula Formations are units which outcrop near the dome, comprising unconfined or semiconfined aquifers that receive local recharge. The deeper aquifers outcrop and receive recharge in areas north of the dome. Groundwater flow in confined aquifers is generally to the south while in unconfined aquifers the flow directions are controlled by local topography.

TABLE 6.3

STRATIGRAPHY AND WATER BEARING CHARACTERISTICS OF GEOLOGIC UNITS NEAR RICHTON AND CYPRESS CREEK DOMES

SYSTEM	SERIES	GEOLOGIC UNIT			DOMINANT LITHOLOGY[1]	WATER BEARING CHARACTERISTICS[2]
QUATERNARY	PLIO-PLEISTOCENE		CITRONELLE FORMATION		UNCONSOLIDATED SAND AND GRAVEL. FINE- TO COARSE-GRAINED QUARTZOSE SAND WITH TRACES OF CHERT AND SOME CLAY.	TRANSMITS SMALL QUANTITIES OF WATER. YIELDS OF WELLS TAPPING THIS AQUIFER ARE GENERALLY SMALL. A FEW WELLS CAN PRODUCE UP TO 200 GPM BUT MOST WELLS YIELD ≤ 25 GPM. AQUIFER USE IS PREDOMINANTLY FOR SMALL DOMESTIC WELLS, ALTHOUGH A FEW WELLS PRODUCE ENOUGH FOR MUNICIPAL NEEDS. CHEMICALLY, WATER IS LOW IN DISSOLVED SOLIDS AND pH.
TERTIARY	MIOCENE		HATTIESBURG AND CATAHOULA FORMATIONS, UNDIFFERENTIATED		INTERBEDDED SAND AND CLAY. SAND IS FINE GRAINED AT THE TOP AND GRADES TO COARSE-GRAINED GRANULAR QUARTZ. PYRITE IS COMMON THROUGHOUT.	A HIGHLY TRANSMISSIVE WATER BEARING FORMATION. AN IMPORTANT SOURCE OF WATER SUPPLY FOR MUNICIPAL, INDUSTRIAL, AND DOMESTIC WELLS IN SOUTHERN MISSISSIPPI. PUMPING RATES VARY FROM 125 TO 850 GPM. CHEMICALLY, WATER IS LOW IN TOTAL DISSOLVED-SOLIDS.
TERTIARY	OLIGOCENE		VICKSBURG GROUP AND JACKSON GROUP	▨	PREDOMINANTLY CLAY, LIMESTONE, AND MARL, MINOR INTERBEDS OF FINE SAND. LIMESTONES VARY FROM CHALKY TO SANDY AND SILTY TO FOSSILIFEROUS.	DOES NOT TRANSMIT WATER READILY. ABUNDANCE OF CLAY PREVENTS MOVEMENT OF WATER.
TERTIARY	EOCENE	CLAIBORNE GROUP*	COCKFIELD FORMATION		CONSISTS OF BEDS OF FINE-TO MEDIUM-GRAINED SAND, SANDY CARBONACEOUS CLAY, AND THIN BEDS OF LIGNITE. BEDS OF INTERBEDDED CLAY AND LIMESTONE OCCUR LOCALLY.	HIGH TRANSMISSIVITIES AND HYDRAULIC CONDUCTIVITIES NORTH OF STUDY AREA, WITH YIELDS DECREASING DOWNDIP IN THE STUDY AREA. BECAUSE OF HIGH DISSOLVED SOLIDS AND EXCESSIVELY COLORED WATER, AQUIFER UTILIZATION IS LIMITED IN THE STUDY AREA.
TERTIARY	EOCENE	CLAIBORNE GROUP*	COOK MOUNTAIN FORMATION	▨	LIMESTONE, VARIABLE, CRYSTALLINE TO FOSSILIFEROUS, CONTAINS SOME SAND AND SILT.	GENERALLY NOT CONSIDERED AN AQUIFER, BUT CAN TRANSMIT WATER LOCALLY. UTILIZATION IS LIMITED IN THE STUDY AREA DUE TO HIGH SALINITY. THIS FORMATION IS USED FOR BRINE DISPOSAL IN SOUTHERN MISSISSIPPI. AQUIFER TESTS CONDUCTED BY LETCO SHOW VERY LOW TRANSMISSIVITIES.
TERTIARY	EOCENE	CLAIBORNE GROUP*	KOSCIUSKO (SPARTA) FORMATION		LIMESTONE, CLAY, AND SAND INTERBEDDED. UPDIP OF STUDY AREA FORMATION IS COMPOSED PREDOMINANTLY OF ROUNDED QUARTZ GRAINS.	GOOD FLUID TRANSMITTING PROPERTIES UPDIP OF STUDY AREA WHERE SPARTA IS EXTENSIVELY UTILIZED FOR PUBLIC AND INDUSTRIAL WATER SUPPLIES. DUE TO HIGH SALINITY AND DEPTH OF THE FORMATION, UTILIZATION IS LIMITED IN THE STUDY AREA. TRANSMISSIVITIES COMPUTED FROM LETCO AQUIFER TESTS SHOW THAT THE SPARTA IS CAPABLE OF TRANSMITTING FLUIDS.
TERTIARY	EOCENE	CLAIBORNE GROUP*	ZILPHA, WINONA, AND TALLAHATTA FORMATIONS	▨	ALTERNATING BEDS OF CLAY AND LIMESTONE WITH SOME BEDS OF SILTSTONE AND SHALE. LIMESTONE IS VARIABLE, BUT GENERALLY GLAUCONITIC AND FOSSILIFEROUS.	DOES NOT TRANSMIT WATER READILY.
TERTIARY	EOCENE		WILCOX GROUP		INTERBEDDED SAND, CLAY AND SILTSTONE, WITH MINOR SHALE, LIMESTONE, AND LIGNITE. SAND IS VERY FINE-TO FINE GRAINED.	CAPABLE OF TRANSMITTING WATER NORTH OF THE STUDY AREA. TRANSMISSIVITY AND HYDRAULIC CONDUCTIVITY OF THIS FORMATION IS REDUCED IN THE STUDY AREA DUE TO THE FINE GRAINED CHARACTER OF THE SANDS. WATER PRODUCED FROM THIS FORMATION IN THE STUDY AREA IS HIGHLY SALINE AND MAY CONTAIN GAS.
TERTIARY	PALEOCENE		MIDWAY GROUP	▨	PREDOMINANTLY CLAY, WITH INTERBEDDED SAND, SHALE AND LIGNITE. LIGNITE, PYRITE, AND GLAUCONITE ARE COMMON THROUGHOUT.	DOES NOT TRANSMIT WATER READILY.

▨ Aquitards   ☐ Aquifers

6.9.1.2 Existing Site Specific Data

In situ measurements of hydraulic conductivity in domal salt at Richton Dome have not been documented. Considering the uniformity of domal salt in most Gulf Coast domes, it is probable that the in situ matrix hydraulic conductivity is similar to the lower range of laboratory values (effectively zero to 10^{-7} cm/s). Higher hydraulic conductivities may occur within shear zones, but this has not been assessed by in situ measurements.

Matrix hydraulic conductivity in caprock is expected to be less than 10^{-6} cm/s. However, groundwater flow in caprock is probably controlled by secondary features such as fractures, shear zones and solution cavities. In situ hydraulic conductivity is therefore expected to be quite variable and may be locally much greater than the matrix value. Two borehole permeability tests were conducted by LETCo (1980b) in the caprock of Richton Dome. A packer test in upper caprock measured a hydraulic conductivity of 7.8×10^{-4} cm/s and a straddle packer test at the salt-caprock interface gave a value of 7.0×10^{-6} cm/s. If in situ hydraulic conductivity is controlled by secondary features, then large variations will occur depending on the location and type of test performed.

Figure 6.1a shows the results of aquifer tests performed in sedimentary units within the area that includes both Richton and Cypress Creek Domes. Of these tests, a total of 8 were performed in wells in the immediate vicinity of Richton Dome. The data suggest that hydraulic conductivity can be quite variable within individual units on the site specific scale.

Site specific hydraulic gradients in domal salt and caprock have not been determined. Furthermore, there is insufficient general data to establish the generic characteristics of hydraulic gradients in Gulf Coast salt domes and caprocks.

Regional hydraulic gradients in sedimentary deposits in the vicinity of Richton and Cypress Creek domes are shown in Figure 6.3 (LETCo, 1980b). The map indicates natural horizontal hydraulic gradients ranging from 0.3 to 1 m/km in a general southerly direction. However, waste water injection near the town of Columbia, Mississippi has created a buildup cone at intermediate depths in the aquifer system which may have some influence on hydraulic gradients at Richton Dome. Figure 6.3 also indicates a regional tendency for upward vertical flow in the sedimentary deposits. In the local vicinity of Richton Dome, horizontal gradients vary from 0.45 to 0.85 m/km and indicate flow in a south to southwest direction. It should be pointed out that flow patterns on a site specific scale are likely to be much more complex than those on the regional scale.

Pore fluids in domal salt are sodium chloride type brines with total dissolved solids (TDS) greater than 250,000 mg/l and represent saturated

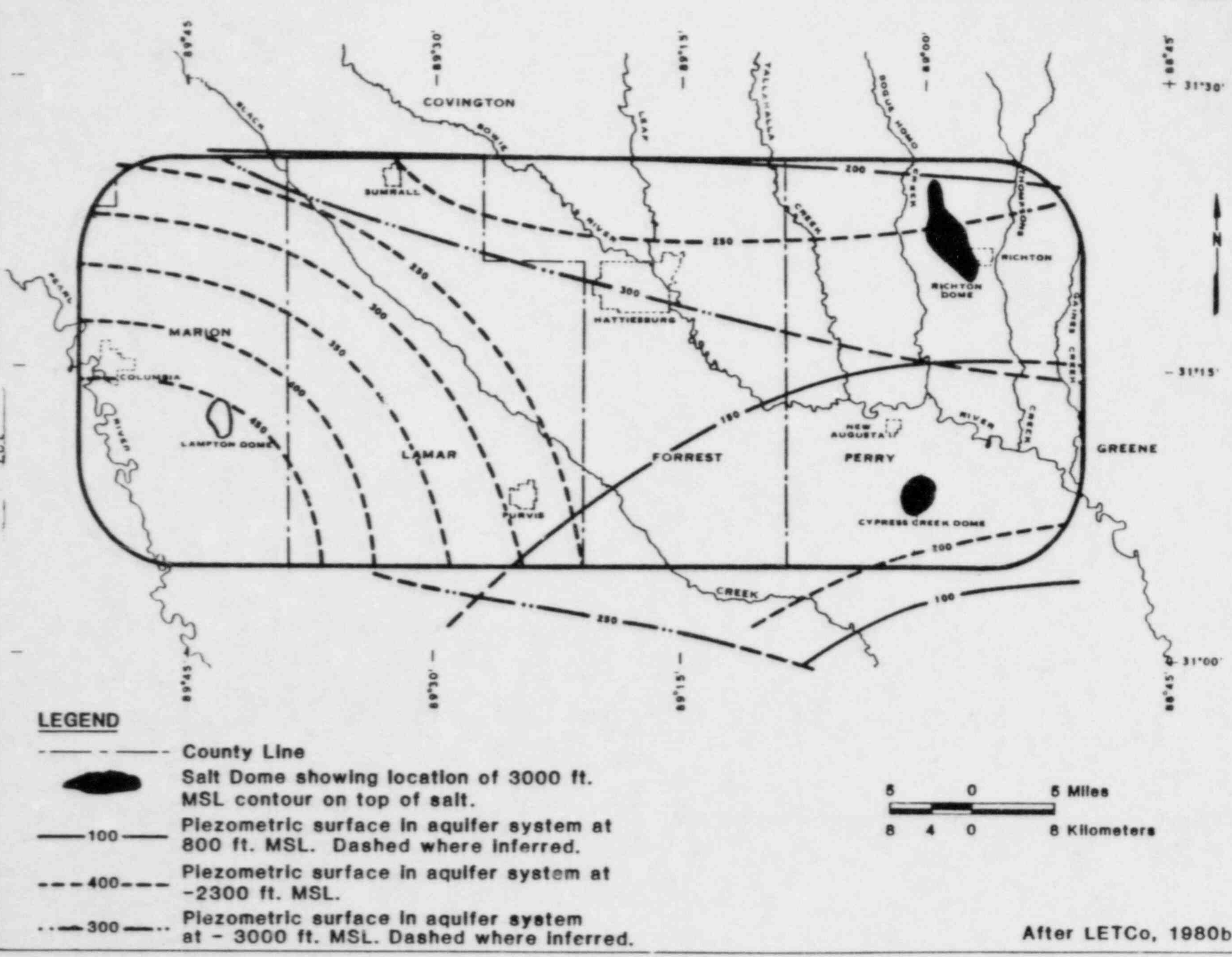


Figure 6.3

PIEZOMETRIC CONTOUR MAPS FOR SELECTED ELEVATIONS NEAR RICHTON AND CYPRESS CREEK DOMES solutions of domal material at in situ temperatures and pressures.

Chemical analyses of pore fluids in caprock have not been documented. Dissolution of caprock material would result in calcium sulfate type water, but caprock pore fluids may be greatly affected by the addition of waters from domal salt and/or the sedimentary deposits. One salinity measurement at Richton Dome by LETCo (1980b) indicated TDS equal to 11,000 mg/l.

Chemical analyses of pore fluids in sedimentary rocks have not been documented. The regional maps in Figures 6.3 and 6.4 show the elevation of the base of fresh water (TDS = 1000 mg/l) and the base of moderately saline water (TDS = 10,000 mg/l). The maps indicate an increase in groundwater salinity near the dome for a given depth and that a saline plume may extent downgradient from the dome. This may indicate dissolution of domal salt, injection of waste water, or the upwelling of deep formation waters.

6.9.1.3 Design and Construction Aspects

A major concern at Richton Dome is the presence of a thick, transmissive, freshwater aquifer extending from caprock to the land surface (see Figure 2.3). During construction, a vertical access shaft could experience large inflow rates, requiring a high capacity dewatering system. Furthermore, downward vertical movement of fresh water between a shaft casing and the formation could result in extensive dissolution of domal material and cause rapid flooding of the underground workings. Since the overlying aquifer is extensively pumped for water supplies, its entire thickness should be considered the "accessible environment." Therefore, design calculations regarding nuclide transport should neglect travel times from caprock to the land surface.

Figures 6.4 and 6.5 show abnormally high groundwater salinities south of Richton Dome. The origin of this salinity high would need to be ascertained.

6.9.2 Cypress Creek Dome

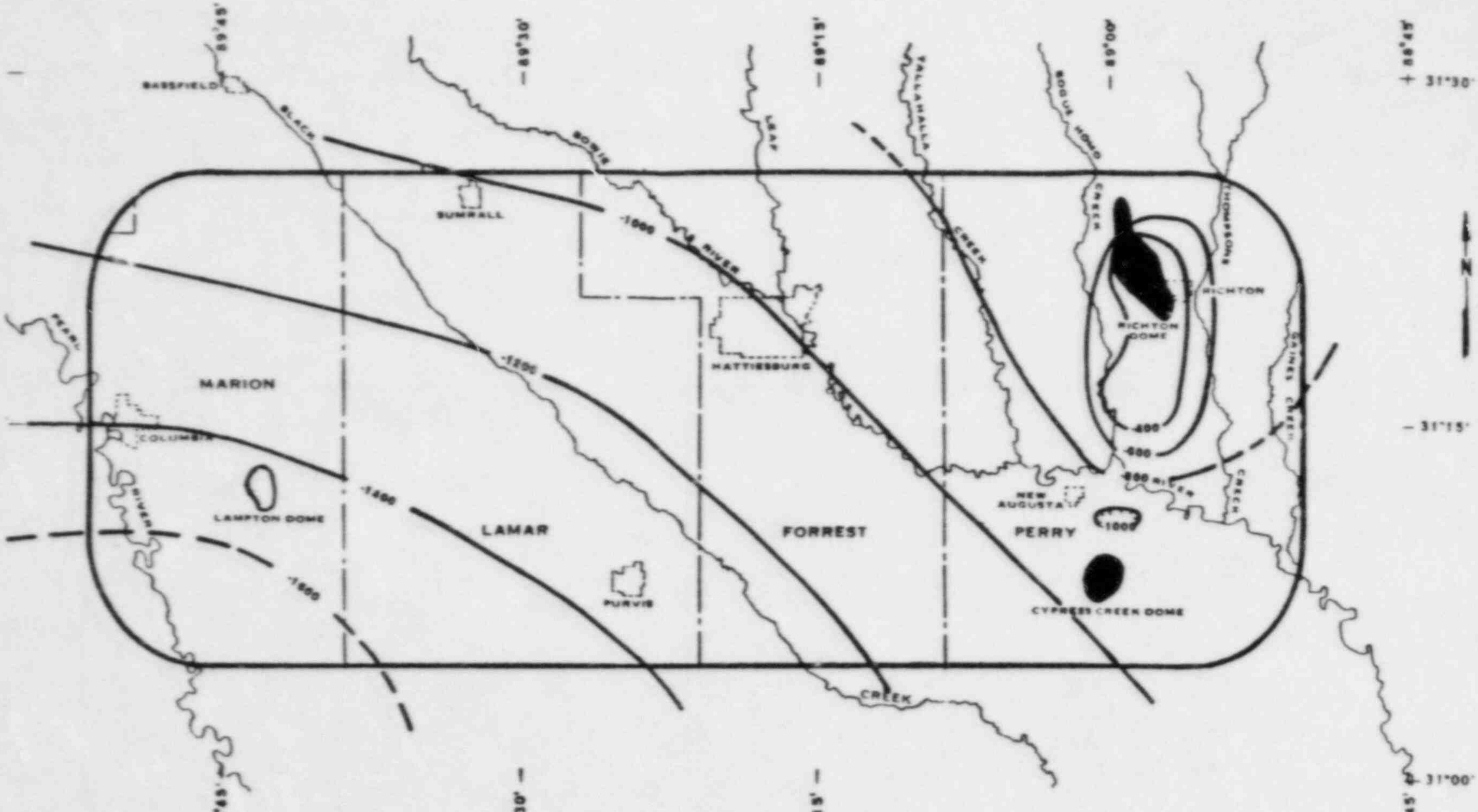
6.9.2.1 Hydrologic Framework

Cypress Creek Dome is located in southeastern Mississippi, approximately 25 km south of Richton Dome. Therefore, the regional hydrologic framework is similar to the discussion for Richton Dome (in Section 6.9.1.1). The generalized stratigraphy and water-bearing characteristics of geologic units are given in Table 6.3 (from LETCo, 1980b) and a vertical geologic section through Cypress Creek Dome is presented in Figure 2.5.

The geologic sections in Figures 2.3 and 2.5 illustrate many similarities between Cypress Creek and Richton domes. An extensive freshwater aquifer (Hattiesburg and Cataboula Formations) lies above Cypress Creek

Project No. 815-1162 B Reviewed ______ Date ______

Figure 6.4 MAP SHOWING BASE OF FRESH WATER (TDS = 1000mg/l)



LEGEND

— - — County Line

Salt Dome showing location of -3000 ft. MSL contour on top of salt.

— -1000 — Base of fresh-water zone. Dashed where inferred. Datum is MSL.

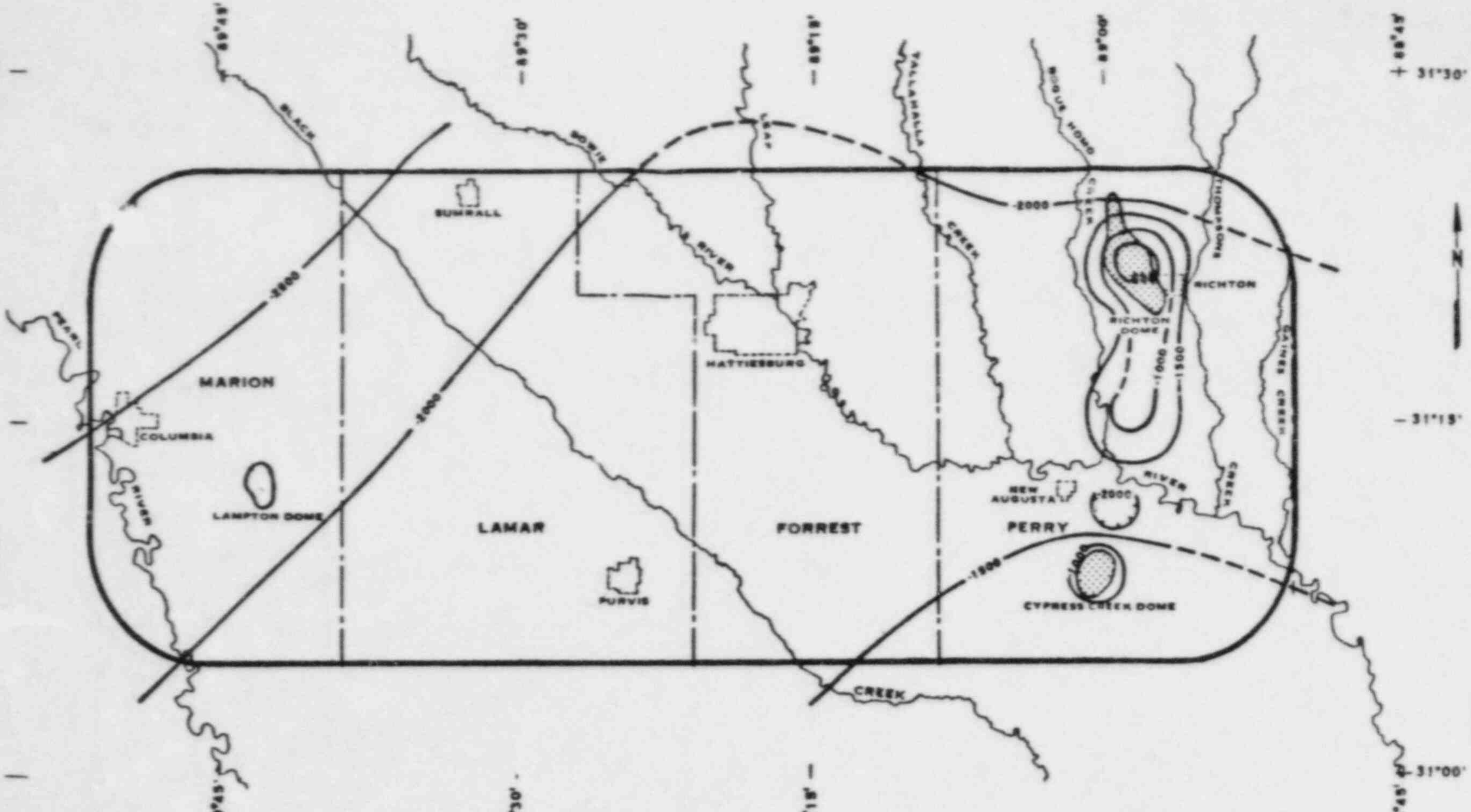
5 0 5 Miles

8 4 0 8 Kilometers

After LETCo, 1980b

MAP SHOWING BASE OF MODERATELY SALINE WATER (TDS=10,000 mg/l)

Figure 6.5



LEGEND

- County Line
- Salt Dome showing location of -3000 ft. MSL contour on top of salt.
- -500 Very Saline-water zone. Contour shows elevation of top of very saline-water zone. Dashed where inferred. Datum is MSL.

5 0 5 Miles
8 4 0 8 Kilometers

After LETCo, 1980b

Dome and numerous saline aquifers (transmissive formations of the Claiborne and Wilcox Groups) lie along the flanks. The dome is characterized by an overhang on its northern flank.

6.9.2.2 Existing Site Specific Data

In situ measurements of hydraulic conductivity in domal salt at Cypress Creek Dome have not been documented. It is probable that in situ matrix hydraulic conductivity is similar to the lower range of laboratory values (effectively zero to 10^{-7} cm/s). Higher hydraulic conductivities may occur within shear zones, but this has not been assessed by in situ measurements.

Matrix hydraulic conductivity in caprock is expected to be less than 10^{-6} cm/s, but in situ hydraulic conductivity is likely to be quite variable due to secondary features. Two borehole permeability tests were conducted by LETCo (1980b) in the caprock of Cypress Creek Dome. A packer test in upper caprock measured a hydraulic conductivity of 2.1×10^{-5} cm/s and a straddle packer test at the salt-caprock interface gave a value of 1.8×10^{-6} cm/s.

Figure 6.1a shows the results of aquifer tests performed in sedimentary units within a regional study that includes both Cypress Creek and Richton Domes. Of these tests, a total of 7 were performed in wells in the immediate vicinity of Cypress Creek Dome. The data suggest that hydraulic conductivity is quite variable within individual units on the site specific scale.

Site specific hydraulic gradients in domal salt and caprock have not been determined. Furthermore, there is insufficient general data to establish the generic characteristics of hydraulic gradients in Gulf Coast salt domes and caprocks.

Regional hydraulic gradients in sedimentary deposits in the vicinity of Cypress Creek and Richton Domes are shown in Figure 6.3 (LETCo, 1980b). The regional hydraulic gradients at Cypress Creek Dome are similar to those discussed in Section 6.9.1 for Richton Dome. In the local vicinity of Cypress Creek Dome, horizontal gradients vary from 0.5 to 0.6 m/km and indicate flow in a south to southeast direction. Site specific flow patterns are probably more complex than those on the regional or local scale.

Pore fluids in domal salt are sodium chloride type brines with total dissolved solids (TDS) greater than 250,000 mg/l and represent saturated solutions of domal material at the in situ temperatures and pressures. Chemical analyses of pore fluids in caprock have not been documented. One salinity measurement at Cypress Creek Dome by LETCo (1980b) indicated a TDS equal to 16,500 mg/l. Chemical analyses of pore fluids in sedimentary deposits have not been documented. The regional maps in Figures 6.3 and 6.4 indicate no significant changes in groundwater salinity down gradient of the dome. A zone of decreased salinity north of the dome has no apparent explanation.

6.9.2.3 Design and Construction Aspects

As with Richton Dome, a major concern is the presence of a thick, transmissive, freshwater aquifer existing from caprock to the land surface (see Figure 2.5). Repository design must consider the significance of this aquifer with regard to the following design issues:

- Access shaft inflows/dewatering requirements
- Dissolution of domal salt due to leakage past the shaft seal
- Nuclide transport and the definition of "accessible environment."

The overhang illustrated in Figure 2.5 may have an impact on repository design due to the corresponding decrease in cross-sectional area of the salt stock. The repository excavation must avoid external boundaries of the dome because of the potential flooding hazard. Furthermore, an oil exploration borehole (Shell U.S.A. No. 10-5) was drilled through the overhang and into sedimentary deposits of the Wilcox Group. Groundwater flow along this abandoned borehole could jeopardize the hydrologic integrity of the repository.

6.9.3 Vacherie Dome

6.9.3.1 Hydrologic Framework

Vacherie Dome is located in the Interior Gulf Coastal Basin in northwest Louisiana. The region is characterized by low relief topography and dendritic surface drainage patterns. Sedimentary deposits of hydrologic interest are Quaternary alluvium and Tertiary to Upper Cretaceous strata. The Tertiary strata consist of a thick sequence of alternating marine clays and terrigenous sands, and the Upper Cretaceous strata are composed of sandstone, shale, marl, chalk, and some limestone. The strata form extensive aquifers and aquitards that dip southeasterly at about 19 m/km and generally thicken in the direction of dip. The generalized stratigraphy and water-bearing characteristics of geologic units are given in Table 6.4 (from LETCo, 1981b). Depending on water quality, transmissive formations of the Claiborne and Wilcox Groups are locally pumped for municipal, industrial, and domestic water supplies. The Austin Group comprises a saline aquifer located at the flanks of the dome. Important aquitards are nontransmissive formations of the Claiborne Group, Midway Group, Navarro Group, Taylor Group, and Eagle Ford Group.

A vertical geologic section through Vacherie Dome is given in Figure 2.7. The piercement dome has formed antiformal structures in the sedimentary strata and complex normal faulting occurs directly above the dome. As a result, regional confined aquifers (Carrizo Formation and Wilcox Group) are brought to the land surface and outcrop around the dome.

TABLE 6.4

STRATIGRAPHY AND WATER BEARINGS CHARACTERISTICS OF GEOLOGIC UNITS NEAR VACHERIE DOME

SYSTEM	SERIES	GEOLOGIC UNIT		DOMINANT LITHOLOGY	WATER TRANSMITTING CHARACTERISTICS
QUATERNARY	Recent		Alluvium	Gravels, sands, silts and clays.	Yields small to large quantities of water to wells regionally. Uses vary from domestic supply to irrigation supply. Hydraulic conductivity ranges from 100 feet/day to 300 feet/day (Hosman, 1978).
	Pleistocene		Terrace Deposits	Fluvial sequences of gravel, sand, silt and clay.	
TERTIARY	Eocene	CLAIBORNE GROUP	Cockfield Formation	Massive to cross-bedded, glauconitic quartz sands with interbedded silts and clays, fossils and plant material.	These formations are capable of transmitting small quantities of water locally. The hydraulic conductivity of the Cockfield Formation ranges from less than 15 feet/day to more than 40 feet/day (Hosman, 1978). These formations are present in only a small portion of the study area.
			Cook Mountain Formation	Fossiliferous, glauconitic, clay ironstone interbedded with brown clay and silty sands.	
			Sparta Formation	Massive, fine-grained, cross-bedded sands interbedded with sandy clays. Contains occasional lignites and fossils.	This formation is capable of transmitting large quantities of water. It is the principal aquifer in northern Louisiana. Hydraulic conductivities of this formation in the study area as determined by LETCo from aquifer tests, ranged from 1.3 feet/day to 124 feet/day.
			Cane River Formation	Interbedded silt and clay basal unit and upper unit. Middle of this formation is a glauconitic fossiliferous marl.	This formation is generally considered to have poor water transmitting properties regionally.
			Carrizo Formation	Fine- to coarse-grained, massive sands with minor amounts of clays, silts and lignites.	The Carrizo Formation is capable of transmitting water regionally. One LETCo aquifer test in this formation resulted in an average hydraulic conductivity value of 7.7 feet/day.
	Paleocene		Wilcox Group	Deltaic sequence of sands, silts, clays and lignites with interbeds of marine sands and clays.	Deposits of the Wilcox Group are capable of transmitting water regionally. Hydraulic conductivities of these deposits in the study area as determined from LETCo acquifer tests, ranged from 0.08 feet/day to 8.2 feet/day.
			Midway Group	Micaceous, fossiliferous, lignitic carbonaceous shale grading upward into sand.	These deposits are generally considered to have poor water transmitting properties regionally.
UPPER CRETACEOUS	Gulfian	NAVARRO GROUP	Arkadelphia Formation	Predominantly chalky marl with interbedded shales and clays.	This formation is generally considered to have poor water transmitting properties regionally.
			Nacatoch Formation	Marls and chalks grading upwards into fine grained sand.	This formation has good water transmitting properties in its outcrop area in southern Arkansas. In the study area, this formation generally has poor water transmitting properties. Results of aquifer testing by LETCo in the study area gave a hydraulic conductivity range of 0.01 to 2.0 feet/day.
			Saratoga Formation	Fossiliferous chalk with thin shale beds.	This formation is generally considered to have poor water transmitting properties regionally.
			Taylor Group	Predominantly chalk, shale, and marl all interbedded.	This formation is generally considered to have poor water transmitting properties regionally.
		AUSTIN GROUP	Brownstown Formation	Fine- to medium-grained sand with shale interbeds.	The Tokio Formation has good water transmitting properties in its outcrop area in southern Arkansas. In the study area, undifferentiated deposits of the Austin Group have fair water transmitting properties. Results of aquifer testing by LETCo in the study area gave a hydraulic conductivity range of 0.5 and 1.7 feet/day.
			Tokio Formation	Calcareous sands and shale, with some chert gravels, basal marls and chalk.	
			Eagle Ford Group	Micaceous silty shale with thin lenses of fine-grained sandstones and limestones.	This formation is generally considered to have poor water transmitting properties regionally.
			Tuscaloosa Group	Interbedded sand and shale with some calcareous beds; and a massive basal glauconitic sandstone.	This Group is capable of transmitting small quantities of water in its outcrop area in southern Arkansas.

☐ Potential Aquifers ▨ Aquitards (Cook Mountain, Cane River, Midway, Arkadelphia, Nacatoch, Saratoga, Taylor, Eagle Ford)

(after LETCo, 1981b)

Groundwater recharge occurs by infiltration of precipitation and stream runoff in the outcrop areas of geologic units and to a lesser extent by vertical leakage through aquitards. The Sparta and Carrizo Formations (Claiborne Group) and the Wilcox Group outcrop around the dome so these aquifers receive local groundwater recharge.

6.9.3.2 Existing Site Specific Data

In situ measurements of hydraulic conductivity in domal salt and caprock have not been documented at Vacherie Dome. In situ matrix hydraulic conductivity in domal salt is probably similar to the lower range of laboratory values (effectively zero to 10^{-7} cm/s), but higher in situ hydraulic conductivities may occur with internal and external shear zones. Matrix hydraulic conductivity in caprock is expected to be less than 10^{-6} cm/s, but in situ values may be locally much higher due to the presence of secondary features.

Figure 6.1b shows the results of aquifer tests performed in sedimentary units within a regional study area. Of these tests, a total of 4 were conducted in a borehole near Vacherie Dome. The data suggest that hydraulic conductivity can be quite variable within individual geologic units.

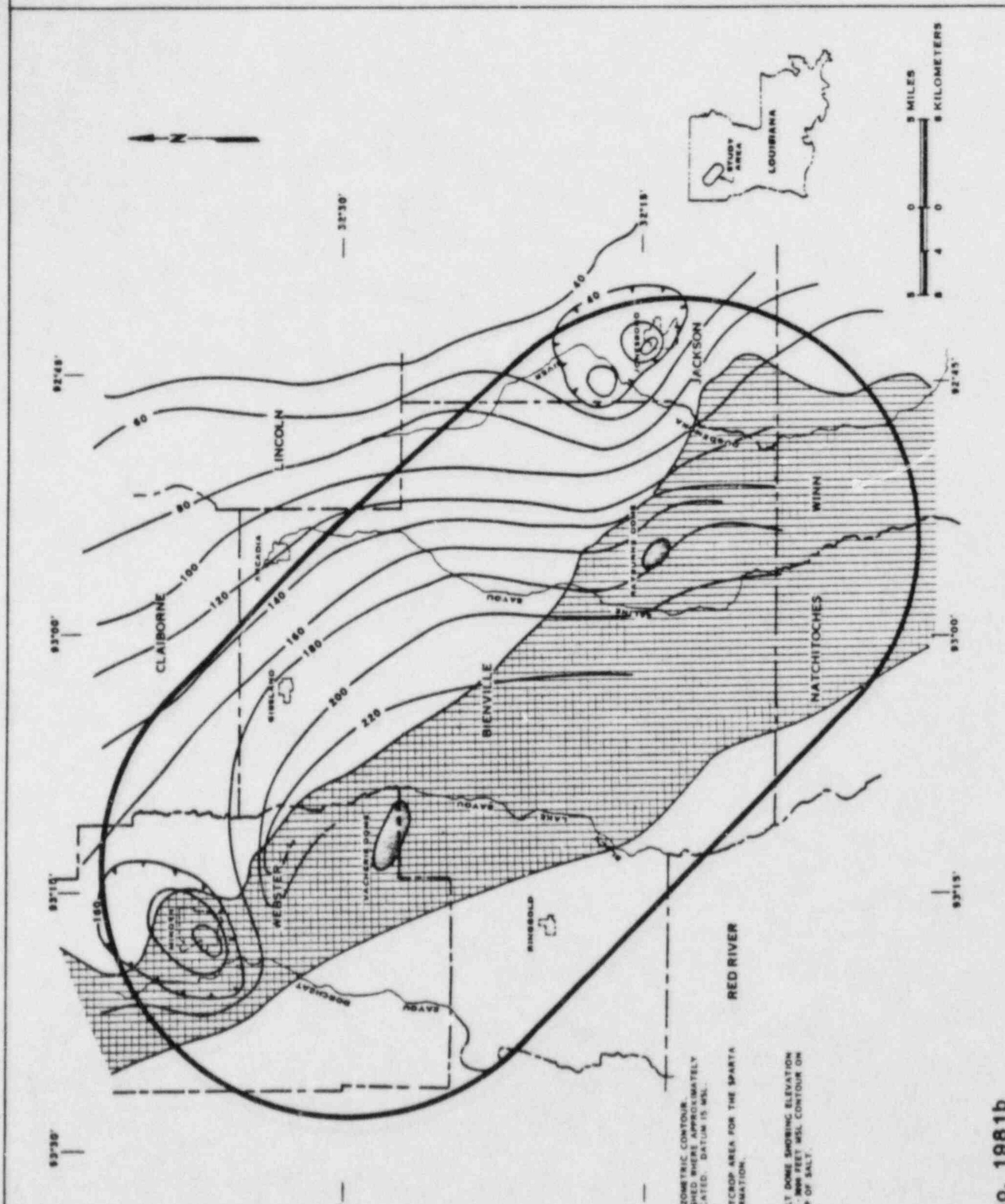
Site specific hydraulic gradients in domal salt and caprock have not been determined. Furthermore, there is insufficient general data to establish the generic characteristics of hydraulic gradients in Gulf Coast salt domes and caprocks.

Regional hydraulic gradients in the Sparta and Wilcox-Carrizo aquifers are shown in Figures 6.6 and 6.7, respectively. The maps indicate groundwater flow away from outcrop areas in a general northeasterly direction. Groundwater withdrawal near the town of Minden has created a depression cone in the Sparta Formation which may have some influence on the hydraulic gradients at Vacherie Dome. The hydraulic gradients indicate groundwater flow which is radially outward from the outcrop (recharge) areas. Measurements by LETCo (1981b) in a well several kilometers south of the dome showed increasing hydraulic head with depth, which would indicate an upward vertical component of flow.

Pore fluids in domal salt are sodium chloride type brines with total dissolved solids (TDS) greater than 250,000 mg/l and represent saturated solution of domal material at in situ temperatures and pressures. Chemical analyses of pore fluids in caprock have not been documented. Pore fluid composition is probably controlled by dissolution of caprock material (calcium sulfate) and the mixing of waters from domal salt and the sedimentary deposits. Numerous groundwater chemical analyses have been performed by the U.S. Geological Survey and LETCo (1981b). Table 6.5 gives a summary of chemical analyses for the major regional aquifers. The chemical character of groundwater changes with increasing depth, from calcium bicarbonate to sodium bicarbonate and then to sodium chloride types. These changes probably result from increased leaching

PIEZOMETRIC SURFACE OF SPARTA FORMATION

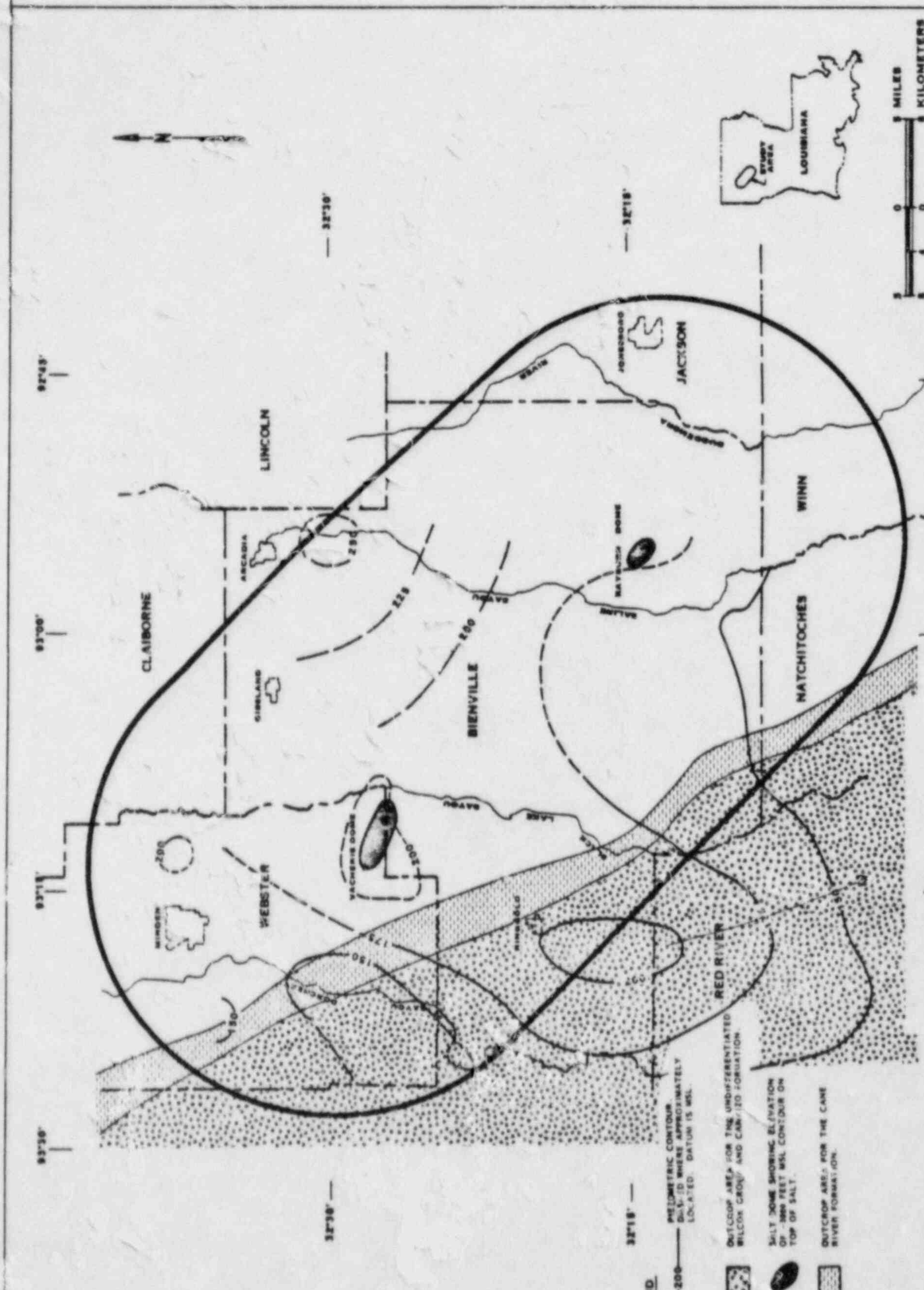
Figure 6.6



After LETCo, 1981b

Project No. Reviewed Date

PIEZOMETRIC SURFACE OF WILCOX-CARRIZO DEPOSITS Figure 6.7



After LETCo, 1981b

TABLE 6.5

SUMMARY OF CHEMICAL ANALYSES FOR WATER FROM SELECTED WELLS

(All values in milligrams/liter except pH as shown)

Geologic Unit	Statistic	pH (S.U.)	Alkalinity (as $CaCO_3$)	Hardness (as $CaCO_3$)	Dissolved Solids (Residue at 180°C)	Sodium Dissolved (as Na)	Chloride Dissolved (as Cl)	Bicarbonate Dissolved (as HCO_3)	Calcium Dissolved (as Ca)	Magnesium Dissolved (as Mg)	Sulfate Dissolved (as SO_4)	Iron Dissolved (as Fe)	Silica Dissolved (as SiO_2)	Potassium Dissolved (as K)
Terrace Deposits	Median	7.1	37	74	145	14	20	45	12	5.2	4.3	0.[illegible]	34	1.4
	Mean	6.8	80	114	156	18	25	93	19	7.0	5.2	0.9	35	1.6
	Range	5.2-8.1	8-279	8-690	35-274	0.2-36	2.5-82	10-340	2.0-62	0.5-23	0.2-21	0-4.4	12-53	0.4-3.3
	No. of Samples	18	16	18	19	19	19	19	19	19	19	18	19	19
Red River Alluvium	Median	7.0	508	510	654	65	52	629	110	54	86	6.1	20	1.8
	Mean	6.9	490	560	764	76	80	598	124	57	105	7.3	19	2.[illegible]
	Range	6.2-7.3	254-674	200-1300	323-2040	17-200	8.0-220	310-822	29-270	19-140	0.7-480	0.3-21	14-27	0.6-4.8
	No. of Samples	14	17	18	17	18	18	18	17	17	18	17	17	17
Sparta Formation	Median	7.2	87	10	173	40	6.8	116	2.2	0.6	12	0.4	25	1.7
	Mean	7.1	94	17	190	54	12.7	120	4.8	1.43	19	0.9	29	2.1
	Range	4.2-9.4	2-271	0-142	29-775	1.2-288	0-226	2-522	0-40	0-20	0-813	0-7.5	0-66	0.2-9.0
	No. of Samples	210	131	197	218	218	219	219	219	219	214	205	214	204
Carrizo-Wilcox Deposits (Undifferentiated) Fresh Water	Median	8.0	237	16.5	311	120	15	264	3.7	1.2	2.0	125	15	1.9
	Mean	7.9	320	36	376	143	41	311	14.5	5.4	3.5	630	19	2.2
	Range	5.6-8.9	3-593	1-320	64-905	7.6-580	2.1-540	11-711	0.1-440	0-200	0-2600	0-12,000	8.2-61	0.3-8.4
	No. of Samples	91	70	92	91	95	93	98	92	93	93	88	92	93
Saline Water	Median	7.8	378	68	2965	1180	1420	411	16	5.5	.1	.35	12	9.5
	Mean	7.8	476	81	3292	1283	1557	514	21	6.0	51	.36	13	9.4
	Range	6.8-8.4	167-1040	16-176	1185-6790	360-3080	19-3690	204-1040	3.8-50	1.7-14	0-590	.03-1.6	7.8-18	6.9-14
	No. of Samples	11	10	11	12	12	12	12	12	12	12	12	12	12
Nacatoch Formation	Median	7.3	151	2770	51600	18750	30800	151	661	230	<1	5.8	9.9	44
	Mean	7.5	138	2980	99590	37360	58700	138	728	234	770	7.9	10.0	147
	Range	7.0-8.3	110-152	1790-4380	29330-217830	10730-82600	16700-128800	110-152	462-1060	128-543	<1-2310	3.2-14.6	6.9-13.1	38-360
	No. of Samples	3	3	3	3	3	3	3	3	3	3	3	3	3
Austin Group	Median	-	-	-	-	-	-	-	-	-	-	-	-	-
	Mean	7.1	130	5070	85060	29130	[illegible]90	130	1300	320	2.6	6.5	9.8	84
	Range	6.6-7.5	128-132	3050-7080	44550-125570	15620-42630	[illegible]850-[illegible]0330	128-132	790-1800	154-484	<1-5.2	6.8-6.1	9.3-10.2	57-110
	No. of Samples	2	2	2	2	2	2	2	2	2	2	2	2	2

(after LETCo, 1981b)

at depth coupled with greater proportions of conate waters. A similar trend is observed with increasing distance from outcrop areas in the lower stratigraphic units. Groundwater salinity in the Wilcox aquifer shows an increase in total dissolved solids above Vacherie Dome which could represent dissolution of domal salt or the upwelling of deep formation waters. A saline anomaly was recognized in a borehole near Vacherie Dome where the salinity of water in the Nacatoch Formation was 1.7 times greater than in the underlying Austin Group (LETCo, 1981b).

6.9.3.2 Design and Construction Aspects

A major concern at Vacherie Dome is the presence of shallow groundwater aquifers and complex faulting above the dome (see Figure 2.7). During construction, the access shaft may experience large inflow rates from the transmissive units and unpredictable inflow rates when fault or shear zones are encountered. Therefore, the dewatering requirements cannot be assessed until the deposits directly above the dome are hydrologically characterized.

7. SUMMARY AND SCR REVIEW RECOMMENDATIONS

This study has identified a complete list of characteristics which could have an impact on repository design and construction in domal salt. These characteristics have been separated into five main groups, namely:

- Stratigraphic/structural
- Tectonic
- Mechanical
- Thermal
- Hydrologic.

This study has examined the influence of each of the identified characteristics on five key issues related to repository design and construction in domal salt. Previous reporting by others has indicated that these key issues can be delineated as follows:

- Constructability: This includes issues related to short-term safety during construction and operation, and the irreversible effects of construction on the long-term containment and isolation capability of a repository. In addition, construction of the repository will influence the design and performance of engineered barriers (such as room plugs and backfill, as well as major shaft seals).

- Thermal Response: The existing temperature field and the associated thermal properties of the rock in which the repository is to be excavated must be assessed so that the effects of waste generated heat can be predicted with time.

- Mechanical Response: Potential instability and deformations induced by excavation and thermal effects must be adequately predicted such that construction/operational safety and waste package retrievability is maintained. However, most importantly, the mechanical effects (such as opening of higher permeability pathways to the biosphere, etc.) must be adequately predicted so that the long-term containment and isolation capability of a repository will be progressively assured with greater certainty at each successive step in repository development.

- Hydrological Response: A potentially effective barrier to the escape of radionuclides from a repository is the resaturation or recharge time after a repository is closed. This is important since no escape can occur until the media through which radionuclides may pass are saturated and hydraulic gradients exist to drive the radionuclides from their source (waste package) to the accessible biosphere. Most of the hydrological issues are therefore long-term, but must be addressed at the time of the SCR with the understanding that they will be progressively refined during subsequent construction and operational phases. Of minor importance would be an assessment of the quantity of inflow of groundwater into the repository during the construction and operational phases since, if this was indeed a sustained quantity, it would imply high hydraulic conductivity which in turn would indicate that the repository would be unlikely to meet performance critiera.

- Geochemical Response: Geochemical characteristics of the engineered barriers and the rock units through which radionuclides may pass after the repository is resaturated must be addressed. This issue is perhaps the most difficult to address in an SCR since little is understood about adsorption, dispersion, retardation, etc., as well as the extent and effect of existing or potential alteration of geologic materials. Also, the plans in an SCR for in situ tests that may be carried out are the subject of considerable debate in the technical community. The coupling of all reponses, (i.e., thermal, mechanical, hydrological, and geochemical) into a mass transport performance model is the ultimate tool for assessing the SCR.

Three categories of attributes of characteristics have been identified and utilized to evaluate the level of influence of each characteristic on each key issue; these categories are:

- Availability of design and construction techniques which allow for a conservative assumption of the value of the characteristic (i.e., cost impact of a conservative assumption)

- Uncertainty in the representation of the real world by the performance prediction model (i.e., "goodness" of model, regardless of the uncertainty in the characteristics used as input), and the sensitivity of that model to characteristic values

- Cost effectiveness and scheduling limitations (i.e., availability prior to SCR or construction authorization review) in potentially reducing the uncertainty in the assessment of characteristic values.

Combinations of attributes in each of the three categories have been subjectively determined for each characteristic, as it relates to each key issue. This subjective evaluation, as discussed in Section 1.3.4, represents the cumulative practical experience and judgement of Golder Associates personnel associated with this task in the design and construction of underground openings, the modeling of the physical processes involved, and the difficulty in assessing characteristics used in those models. Although subjective, this evaluation has been clearly exposed in this report.

A ranking system has been developed which determines the level of influence a characteristic has on a given key issue based on the combination of attributes evaluated for that characteristic. The four levels of influence (in decreasing order of significance) are: critical, major, minor, and insignificant. Again, this ranking system is subjective, based on the experience and judgement of the Golder Associates personnel associated with this task, but is clearly defined.

The results of this process applied to domal salt are summarized in Table 7.1. It is recommended that those characteristics which have the most significant influence on the key issues (i.e., designated as critical) have the highest priority in NRC's review of DOE submitted SCR(s) for site(s) in domal salt. Similarly, those designated as major, minor, and insignificant should have decreasing priority in NRC's SCR review. This prioritization of characteristics will allow for a focused, adequate review by NRC and, although subjective, the process by which it has been achieved is exposed and trackable.

To some extent, the impact of the currently perceived adverse characteristics of domal salt can be decreased by appropriate design and construction strategies. Mitigating measures which should be considered include:

- Leaving a buffer zone between the repository and the dome margin
- Avoiding shearing/faulting zones in the dome interior
- Optimizing repository geometry, to include possibly widely separated multiple levels
- Selecting excavation methods to limit the extent of the disturbed zone
- Selecting tunnel lining and support systems to reduce stress concentrations
- Selecting the waste package emplacement to limit temperatures
- Selecting the room spacing and design to control creep rates
- Selecting appropriate engineered barriers to complement the adsorption properties of the surrounding sediments
- Designing a suitable ventilation/cooling system
- Controlling inflows by seals, plugs, grouting, freezing and pumping
- Limiting extraneous boreholes and excavations in the dome and caprock
- Controlling hydraulic gradients by drainage.

Specific mitigating strategies can be selected using information from the in situ testing and monitoring program.

TABLE 7.1

RECOMMENDED PRIORITIES IN THE REVIEW BY NRC OF AN SCR IN DOMAL SALT

	CRITICAL CHARACTERISTICS FOR REVIEW	KEY ISSUES WHICH IMPACT ON DESIGN AND CONSTRUCTION: CONSTRUCTABILITY	THERMAL RESPONSE	MECHANICAL RESPONSE	HYDROLOGICAL RESPONSE	GEOCHEMICAL RESPONSE
STRATIGRAPHIC/ STRUCTURAL	Lithology/Mineralogy	Major	Major	Major	Critical	Major
	Stratigraphic Sequence	Major			Critical	Major
	Folding				Minor	
	Faulting/Shearing	Major		Major	Major	Major
	Inclusions	Minor	Minor	Minor	Minor	Minor
	Solutions	Critical	Critical	Critical	Critical	Critical
TECTONIC	Seismicity	Minor	Minor	Minor	Minor	Minor
	Crustal Instability			Minor	Minor	
	Diapirism/Volcanism			Minor	Minor	
	Faulting	Major		Major	Critical	Critical
	Regional Stress	Major		Major		
MECHANICAL	Rock Mass Strength	Major		Major	Minor	
	Deformation Moduli	Major	Minor	Major		
	Creep/Plasticity/Fusing	Major	Minor	Critical	Minor	
	Discontinuities	Major		Major	Major	Major
	Density			Minor		
	Moisture Content		Major	Major	Minor	Major
	In Situ Stress	Major		Major		
	Solubility	Minor		Minor	Minor	Major
THERMAL	In Situ Temperature			Major	Minor	
	Thermal Conductivity		Critical	Critical	Major	Major
	Heat Capacity		Minor	Minor	Minor	Minor
	Thermal Expansion		Critical	Critical		Major
HYDROLOGIC	Hydraulic Conductivity	Major			Major	Major
	Hydraulic Gradient	Major	Minor		Major	Major
	Porosity	Minor				Major
	Specific Storage				Minor	
	Dispersivity					Minor
	Adsorption					Major
	Pore Fluid Composition	Major				Major

KEY: *

- Critical
- Major
- Minor
- Insignificant or not relevant

*For definitions see Section 1.3.5 and Table 1.1

8. GLOSSARY

Characteristic: Aspect of ground or environment describing repository site, and being either quantitative (parameter) or qualitative (factor)

Characterization: Assessment of a set of characteristics by testing or measurement

Factor: Nonquantitative characteristic

Key Issue: Influence on design and construction which may affect the ability of the repository to meet the criteria established for safe performance

Parameter: Quantitative characteristic

Scale: Volumetric aspects of repository, as follows (in size order):

- waste package (very near field)
- room (near field)
- repository (3 sq mi underground)
- site (10 sq mi) (far field)
- location (30 sq mi)
- area (1000 sq mi)
- basin
- region (multi state)
- nation (U.S.)

Stage: Distinct period of time during repository life, as follows (in chronological order):

- site selection
- detailed site characterization (followed by submittal of SCR)
- in situ testing
- repository construction (preceded by construction authorization permit)
- repository operation (preceded by operating license)
- waste retrieval (if required)
- decommissioning (preceded by license to decommission)
- post-decommissioning

Variable: Engineering aspect of design or construction which can be altered by the engineer (e.g., size, shape, and orientation of underground openings)

9. REFERENCES

N.L. Barstow, K.J. Brill, Jr., O.W. Nuttli and P.W. Pomeroy, "An Approach to Seismic Zonation for Siting Nuclear Electric Power Generating Facilities in the Eastern United States," NUREG/CR-1557, U.S. Nuclear Regulatory Commission, Washington D.C. 20555, 1981. Available in public technical libraries.

G.A. Bollinger, "Reinterpretation of the Intensity Data for the 1886 Charleston, South Carolina Earthquake," Paper B, pp. 17-32 in Studies Related to the Earthquake of 1886 - A Preliminary Report, U.S. Geological Survey Paper 1028, editor D. Rankin, 1977. Available in public technical libraries.

R.L. Bradshaw, F.M. Empson, W.J. Boegly, H. Kubota, F.L. Parker, E.G. Struxness, "Properties of Salt Important in Radioactive Waste Disposal," Geol. Soc. of America Sp. Paper No. 88, pp. 643-659, 1968. Available in public technical libraries.

G. Brune, Anhydrite and Gypsum Problems in Engineering Geology, Vol. 2, No. 1, 1965. Available in public technical libraries.

J.A. Cherry, R.W. Gilliam, and J.F. Pickens, "Contaminant Hydrogeology, Part 1: Physical Processing," J. Geosci. Can., Vol. 2: 76-81, 1975. Available in public technical libraries.

D.M. Christensen, "The Determination of the In Situ Elastic Properties of Rock Salt with a 3-Dimensional Velocity Log," Second Symposium on Salt; Vol. 2, The Northern Ohio Geological Society, Inc., Cleveland, Ohio, 1966. Available in public technical libraries.

J.L. Coffman and C.A. Von Hake, Earthquake History of the United States, Publication 41-1, U.S. Dept. of Commerce, 1973. Available in public technical libraries.

Dames and Moore, "Technical Support for GEIS: Radioactive Waste Isolation in Geologic Formations, Baseline Rock properties--Salt," prepared under subcontract G24-45701C with Union Carbide Corp., Nuclear Division for the U.S. Department of Energy contract W-7405 eng. 26, 1978. Available in public technical libraries.

J. Docekal, "Earthquakes of the Stable Interior with Emphasis on the Midcontinent" (Volumes 1 and 2), Ph.D. Thesis, The University of Nebraska, 1970. Available from University of Nebraska library.

P.A. Domenico and M.D. Mifflin, "Water from Low-Permeability Sediments and Land Subsidence," Water Resour. Res., Vol. 1: 563-576, 1965. Available in public technical libraries.

W. Dreyer, The Science of Rock Mechanics, Vol. I, Tran. Tech. Publications, pp. 29-164, 1972. Available in public technical libraries.

R. Evans, "The Significance of the Evaporites in the Basins Around the Atlantic Margin", (Abstract) p. 271, Proceedings of the Fourth Symposium on Salt, Volume 1, editor A.H. Coogan, The Northern Ohio Geological Society, Inc., Cleveland, Ohio, 1974. Available in public technical libraries.

R.A. Freeze and J.A. Cherry, Groundwater, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1979. Available in public technical libraries.

M. Friedman and H.C. Heard, "Principal Stress Ratios in Cretaceous Limestones from Texas Gulf Coast", American Association of Petroleum Geologists Bulletin, V. 58, No. 1, 71-78, 1974. Available in public technical libraries.

F. Gera, "Review of Salt Tectonics in Relation to the Disposal of Radioactive wastes in Salt Formation", Geological Society of American Bulletin, 83, 3551-74, 1972. Available in public technical libraries.

L.H. Gevantman, Physical Properties Data for Rock Salt, U.S. Department of Commerce/National Bureau of Standards, Washington, D.C., 1981. Available in public technical libraries.

E.E. Gloyna and T.D. Reynolds, "Permeability Measurements of Rock Salt," J. Geophys. Research, V. 10, No. 10, 3913-3921, 1961. Available in public technical libraries.

Golder Associates, "Report to Gulf Interstate Engineering Co. on Geotechnical Study of Cote Blanche Island Salt Mine: Vol. II - Appendices," Appendix II, June 1977a. Available from Golder Associates.

Golder Associates, "Development of Site Suitability Criteria for the High Level Waste Repository," prepared for Lawrence Livermore Laboratories, June 1977b. Available from Golder Associates.

Golder Associates, "Report to Gulf Interstate Engineering Co. of Geotechnical Study of Cote Blanche Island Salt Mine: Vol. II - Appendices," Appendix X, June 1977c. Available from Golder Associates.

Golder Associates, "Scoping Study of Salt Domes, Basalts and Crystalline Rock as Related to Long Term Risk Modeling for Deep Geologic Disposal of Nuclear Waste," prepared for Lawrence Livermore Laboratory, Nov. 1978. Available from Golder Associates.

Golder Associates, "Geologic, Stratigraphic, Thermal and Mechanical Factors which Influence Repository Design in the Bedded Salt Environment," for Lawrence Livermore Laboratory, December 1979a. Available from NTIS.

Golder Associates, "Derivation of Parameters Necessary for the Evaluation of Performance of Sites for Deep Geological Repositories," for Lawrence Livermore Laboratory, 1979b. Available from NTIS.

Golder Associates, "Geologic, Structural, Thermal, and Mechanical Factors which Influence Repository Design in Granitic and Basaltic Rocks," for Lawrence Livermore Laboratory, 1979c. Available from NTIS.

Gussow, W.C., "Salt Diapirism: Importance of Temperature, and Energy Source of Emplacement," pp. 16-52 in Diapirism and Diapirs, ed. J. Braunstein, Am. Assoc. of Petrol. Geologists, 1968. Available in public technical libraries.

F.D. Hansen and N.L. Carter, "Creep of Rock Salt at Elevated Temperatures," pp. 217-226 in Proceedings 21st Symposium on Rock Mechanics, 1980. Available in public technical libraries.

F.D. Hansen, "Case History Rock Mechanics Examination of Jefferson Island Salt Mine: II Laboratory Evaluation of Strength and Creep Deformation Characteristics of Dome Salt under Confining Pressure," Tech. Memorandum Report RSI-0057, Subcontract Y/OWI/SUB-77/22303/5, 1977. Available in public technical libraries.

P.R. Hart, L. Johnson, T.J. Nicholson, E. Quinn and R.J. Wright, "Survey of Salt Dome Investigations," Internal U.S. Nuclear Regulatory Commission Report of 1/81, 1981. Available from the NRC.

M.E. Hawkins and C.V. Jirik, "Salt Domes in Texas, Louisiana, Mississippi, Alabama and Offshore Tidelands," Survey Information Circular 8313, U.S. Bureau of Mines, 1966. Available in public technical libraries.

H.C. Heard, "Steady-State Flow in Polycrystalline Halite at 2 Kilobars," pp. 191-209, American Geophysical Union Monograph 16, 1972. Available in public technical libraries.

S.R. Holdahl and N.C. Morrison, "Regional Investigation of Vertical Crustal Movements in the U S., Using Precise Relevelings and Mareograph Data", Tectonophysics, Vol. 23: 373-390, 1974. Available in public technical libraries.

C.C. Humphris, "Salt Movement on Continental Slope, Northern Gulf of Mexico" American Association of Petroleum Geologists Bulletin, V. 63, No. 5; 782-798, 1979. Available in public technical libraries.

D. Isherwood, "Geoscience Data Base Handbook for Modeling a Nuclear Waste Repository: Vol. 1, "Univ. of California , Livermore, NUREG/CR-0912, Nuclear Regulatory Commission, Washington, D.C., 1981. Available in public technical libraries.

J.C. Jaeger and N.G.W. Cook, Fundamentals of Rock Mechanics, Chapman and Hall, Ltd., and Science Paperbacks, London, 1971. Available in public technical libraries.

G.H. Jenks, "Radiolysis and Hydrolysis in Salt Brines," ORNL-TM-3717, 1972. Available in public technical libraries.

A.R. Jumikis, Soil Mechanics, D. Van Nostrand Company, Inc. Princeton, N.J., 1962. Available in public technical libraries.

D.L. Katz and K.H. Coats, Underground Storage of Fluids, Ann Arbor, Mich., Ulrich's Books Inc., 1968. Available in public technical libraries.

J.J. Kinsman, "Evaporite Deposits of Continental Margins," Proceedings of the Fourth Symposium on Salt, Volume 1: 255-259, editor A.H. Coogan, The Northern Ohio Geological Society Inc., Cleveland, Ohio, 1974. Available in public technical libraries.

D.H. Kupfer, "Relationship of Internal to External Structure of Salt Domes", pp. 79-89, in Diapirism and Diapirs, ed. J. Braunstein, Am. Assoc. of Petrol. Geologists, 1968. Available in public technical libraries.

D.H. Kupfer, "Mechanism of Intrusion of Gulf Coast Salt," in The Geology and Technology of Salt, Louisiana State University, pp. 25-66, 1970. Available in public technical libraries.

D.H. Kupfer, "Environment and Intrusion of Gulf Coast Salt and its Probable Relationship to Plate Tectonics," pp. 197-213, Proceedings of the Fourth Symposium on Salt, editor A.H. Coogan. The Northern Ohio Geological Society Inc., Cleveland, Ohio, 1974a. Available in public technical libraries.

D.H. Kupfer, "Boundary Shear Zones in Salt Stocks," in Proceedings of the Fourth Symposium on Salt, A.H. Coogan (editor), Northern Ohio Geological Society, Cleveland, Ohio, Vol. 1: 215-225, 1974b. Available in public technical libraries.

D.H. Kupfer, "Shear Zones in the Gulf Coast Salt Delineate Spines of Movement," Gulf Coast Association of Geol. Societies, Trans., V. 24: 197-209, 1974c. Available in public technical libraries.

Law Engineering Testing Company, "Gulf Coast Salt Domes Project - Text North Louisiana Study Area," prepared for Battelle Memorial Institute, Vol. IIIA, Final Draft Area Characterization, 1980a. Available from ONWI.

Law Engineering Testing Company, "Gulf Coast Salt Domes Project - Text Mississippi Study Area," prepared for Battelle Memorial Institute, Vol. IVA, Final Draft Area Characterization, 1980b. Available from ONWI.

Law Engineering Testing Company, "Gulf Coast Salt Domes Project -- Introduction, Background, and Summary", prepared for Battelle Memorial Institute, Vol. I, 2nd Draft Area Characterization, 1980c. Available from ONWI.

Law Engineering Testing Company, "Area Characterization (Second Draft), Volume 1, Introduction, Background, and Summary, Gulf Coast Salt Domes Project," pp. 267-269, for Battelle Memorial Institute, Office of Nuclear Waste Isolation, 1980d. Available from ONWI.

Law Engineering Testing Company, "Area Characterization, Louisiana Study Area, Gulf Coast Salt Domes Project", for Battelle Memorial Institute, Office of Nuclear Waste Isolation, Vol. IIIA, 1981a. Available from ONWI.

Law Engineering Testing Company, "Louisiana Study Area: Final Draft Area Characterization: Gulf Coast Salt Domes Project", prepared for Battelle Memorial Institute Office of Nuclear Waste Isolation, 1981b. Available from ONWI.

J.O. Ledbetter, W.R. Kaiser and E.A. Ripperger, "Radioactive Waste Management by Burial in Salt Domes," EMRL No. 1112, p. 45, 1975. Available in public technical libraries.

A.D. Little, "Draft Report, Assessment of Accidental Pathways," prepared for the Environmental Protection Agency, 1978. Available from EPA.

T.F. Lomenick and R.L. Bradshaw, "Deformation of Rock Salt in Openings Mined for the Disposal of Radioactive Wastes," in Rock Mechanics, Vol. 1: 5-30, 1969. Available in public technical libraries.

R.L. Martinez, et al., "An Investigation of the Utility of Gulf Coast Salt Domes for the Storage or Disposal of Radioactive Wastes", Institute for Environmental Studies, Louisiana State University for U.S. Department of Energy, E511-02500A-1, 1979. Available in public technical libraries.

M. Mogharrebi, "Inelastic Deformation of Deep Boreholes in Salt," Louisiana State University, Master of Science Thesis, 1981. Available from Louisiana State University library.

Netherland, Sewell and Associates, "Geologic Study of the Interior of Salt Domes of Northeast Texas Salt-Dome Basin to Investigate their Suitability for Possible Storage of Radioactive Waste Material," prepared for the U.S. Energy Research and Development Administration, 1976. Available from NTIS.

O.W. Nuttli, "Seismicity of the Central United States," Geological Society of America Reviews in Engineering Geology, Vol. IV: 67-93, 1979. Available in public technical libraries.

L. Obert and W. Duvall, Rock Mechanics and the Design of Structures in Rock, John Wiley and Sons, Inc., New York, 1967. Available in public technical libraries.

A.L. Odom and R.D. Hatcher, Jr., "A Characterization of Faults in the Appalachian Fold Belt," U.S. Nuclear Regulatory Commission, NUREG/CR-1621, 1980. Available in public technical libraries.

T.W. Pfeifle, K.D. Mellegard, P.E. Senseny, "Constitutive Properties of Salt from Four Sites," Topical Report RSI-0165, prepared by RE/SPEC Inc., for Battelle Memorial Institute, 1981. Available from NTIS.

A.M. Piper, "A Graphic Procedure in the Geochemical Interpretation of Water Analyses," Trans. Amer. Geophys. Union, 25: 914-923, 1944. Available in public technical libraries.

Project Dribble, "Triaxial Compression Tests of Salt Rock Cores for the U.S. Atomic Energy Commission," Lab. Report No. C-1043, Division of Engineering Laboratories, Bureau of Reclamation, 1962. Available in public technical libraries.

J.L. Ratigan, "Preliminary Analysis of the Potential for Thermally Induced Rock Fractures Around High Level Waste Containers," RE/SPEC, Inc. Tech. Mem. Rept. RSI-0045, ORNL/-SUB-4269/20, 1976. Available in public technical libraries.

D.L. Reddell and D.K. Sunada, "Numerical Simulation of Dispersion in Groundwater Aquifers," Hydrol. Pap. 41, Colo. State Univ., Fort Collins, 1970. Available in public technical libraries.

T.D. Reynolds and E.F. Gloyna, "Reactor Fuel Waste Disposal Project - Permeability of Rock Salt and Creep of Underground Salt Cavities," prepared for U.S. Atomic Energy Commission, Contract AT-(11-1)-490, 1960. Available in public technical libraries.

C.F. Richter, Elementary Seismology, Freeman and Sons, N.Y., 1958. Available in public technical libraries.

C.J. Robinove, R.H. Langford, and J.W. Brookhart, "Saline-Water Resources of North Dakota," U.S. Geol. Survey Water-Supply Paper 1428, 1958. Available in public technical libraries.

Science Applications, Inc., "The Selection and Evaluation of Thermal Criteria for a Geological Waste Isolation Facility in Salt," Oak Ridge: Office of Waste Isolation, Y/OWE/SUB-76/07220, 1976. Available from NTIS.

K.G. Stagg and O.C. Zienkiewicz (editors), Rock Mechanics in Engineering Practice, John Wiley and Soins, New York, 1968. Available in public technical libraries.

R.E. Taylor, "Geohydrology of Tatum Salt Dome Area, Lamar and Marion Counties, Miss., Vela Uniform Program Project Dribble," U.S. Geological Survey Report No. VUF-1023, 1971. Available in public technical libraries.

W.A. Ver Wiebe, North American Petroleum, University of Wichita, Kansas, Edwards Brothers Inc., An Arbor, Michigan, 1952. Available in public technical libraries.

W. C. Walton, Groundwater Resource Evaluation, McGraw-Hill Book Company, New York, N.Y., 1970. Available in public technical libraries.

N.C. Wardlaw, "Cretaceous Evaporites of Brazil and West Africa and their Bearing on the Theory of Continental Separation," p. 253, Abstract in Proceedings of the Fourth Symposium on Salt, Vol. 1, Editor, A.H. Coogan, The Northern Ohio Geological Society Inc., Cleveland, Ohio, 1974. Available in public technical libraries.

R.C. Weast, Handbook of Chemistry and Physics, C.R.C. Press, Cleveland, Ohio, 57th Ed., 1977. Available in public technical libraries.

Golder Associates

T. Haigh

EDUCATION	B.Sc., Civil Engineering, University of Calgary, Alberta, 1974
AFFILIATIONS	Registered Professional Engineer, Alberta

EXPERIENCE

1981 to date	Senior Engineer, Golder Associates, Kelowna, B.C. Engaged in geotechnical consultation and investigation for residential subdivisions, commercial and institutional buildings, roadways and sewage effluent disposal systems. Involved in design and construction control of tailing dams and building foundations.
1979 - 1981	Project Engineer, Klohn Leonoff Ltd., Calgary, Alberta then Vancouver, B.C. Materials Engineer in Calgary office which involved supervision of technicians on quality control testing of concrete and soil compaction for roadways, bridges and building construction; engineering evaluation of existing concrete structures. Resident Engineer on construction of major dams at an operating copper mine in the interior of British Columbia, which included quality control supervision as well as project management functions of contract negotiations and evaluation of contractors' claims. Geotechnical consulting services were provided for a variety of civil engineering structures during expansion of the mine facilities.
1974 - 1979	Branch Manager, Hardy Associates (1978) Ltd., Lethbridge, Alberta. Responsible for geotechnical investigations for a variety of buildings, bridges, dams, irrigation canals, highways, urban road systems and subdivisions and preparation of engineering reports. Supervisory engineer for materials testing service including concrete, asphalt, soils and aggregate testing. Undertook materials engineering projects which included mix designs for asphalt, concrete and soil-cement; evaluation of existing asphalt pavements and concrete structures; pavement thickness design and evaluation of granular materials.
1959 - 1974	Engineering technician, consulting firms and government agencies. Involved in construction supervision and testing of materials for airports, roadways and buildings in Alberta, the Yukon and Northwest Territories. Carried out geotechnical investigations for the same or similar projects.

11/81

NRC FORM 335 (7-77)

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

1. REPORT NUMBER *(Assigned by DDC)*	NUREG/CR-2613
4. TITLE AND SUBTITLE *(Add Volume No., if appropriate)*	Identification of Characteristics Which Influence Repository Design - Domal Salt
2. *(Leave blank)*	
3. RECIPIENT'S ACCESSION NO.	
7. AUTHOR(S)	G. Rawlings, G. Antonnen, M. Chamness, R. Hofmann, W. Roberds, C. Soto, C. Welden, J. Rowe, F. Marinelli, K. Jones.
5. DATE REPORT COMPLETED	MONTH: March; YEAR: 1982
9. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*	Golder Associates 2950 Northup Way Bellevue, WA 98004-1486
DATE REPORT ISSUED	MONTH: April; YEAR: 1984
6. *(Leave blank)*	
8. *(Leave blank)*	
12. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS *(Include Zip Code)*	Division of Waste Management Office of Nuclear Material Safety and Safeguards U. S. Nuclear Regulatory Commission Washington, D. C. 20555
10. PROJECT/TASK/WORK UNIT NO.	
11. CONTRACT NO.	B-6983
13. TYPE OF REPORT	
PERIOD COVERED *(Inclusive dates)*	June, 1981 - March, 1982
15. SUPPLEMENTARY NOTES	
14. *(Leave blank)*	

16. ABSTRACT *(200 words or less)*

The purpose of the complete project is to provide NRC with technical assistance to enable the focused, adequate review by NRC of the aspects related to design and construction of an underground test facility and final geologic repository as presented by the Department of Energy (DOE).

The study presented in this report covers the identification of characteristics which influence design and construction of a geologic repository in domal salt. This report has identified five key issues, i.e., constructibility, thermal response, mechanical response, hydrologic response, and geochemical response. This report involves both short-term (up to closure) and long-term (post closure) effects.

The characteristics of domal salt and its environment are described under the headings of stragraphic/structural, tectonic, mechanical, thermal and hydrologic. Characteristics are separated into parameters (quantified and measured) and factors (qualitative). The characteristics are then subjectively ranked by their influence on the key issues. This takes into account the availability and suitability of conservative design/construction techniques, uncertainty in model and model sensitivity to the characteristic.

17. KEY WORDS AND DOCUMENT ANALYSIS	17a. DESCRIPTORS
17b. IDENTIFIERS/OPEN-ENDED TERMS	
18. AVAILABILITY STATEMENT	Unlimited
19. SECURITY CLASS *(This report)*	Unclassified
20. SECURITY CLASS *(This page)*	
21. NO. OF PAGES	
22. PRICE	S

NRC FORM 335 (7-77)

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

FOURTH-CLASS MAIL
POSTAGE & FEES PAID
USNRC
WASH. D. C.
PERMIT No. G-67

120555078877 1 IAN
US NRC
ADM-DIV OF TIDC
POLICY & PUB MGT BR-PDR NUREG
W-501
WASHINGTON DC 20555