TRIP REPORT
DOE/NRC TECHNICAL MEETING
ALTERNATIVE CONCEPTUAL MODELS OF THE
GROUNDWATER SYSTEM AT YUCCA MOUNTAIN
LAS VEGAS, NEVADA
APRIL 11-14, 1988

NUCLEAR WASTE CONSULTANTS INC.

U.S NUCLEAR REGULATORY COMMISSION
DIVISION OF HIGH LEVEL WASTE MANAGEMENT

TRIP REPORT
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ALTERNATIVE CONCEPTUAL MODELS OF THE GROUNDWATER SYSTEM AT YUCCA MOUNTAIN
LAS VEGAS, NEVADA
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TECHNICAL ASSISTANCE IN HYDROGEOLOGY
PROJECT B - ANALYSIS
RS-NMS-85-009

MAY 18, 1988

May 18, 1988

009/1.3/WWL.012
RS-NMS-85-009
Communication No. 263

U.S. Nuclear Regulatory Commission
High-Level Waste Management
Technical Review Branch
OWFN - 4H3
Washington, DC 20555

Attention: **Mr. Jeff Pohle, Project Officer**
Technical Assistance in Hydrogeology - **Project B (RS-NMS-85-009)**

Re: **Trip Report - DOE/NRC technical meeting on "Alternative Conceptual Models of the Groundwater System at Yucca Mountain"**

Dear Mr. Pohle:

This letter transmits the trip report of Mr. Tom Sniff of Water, Waste and Land, Inc. (WWL) concerning DOE/NRC technical meeting on "Alternative Conceptual Models of the Groundwater System at Yucca Mountain". The meeting was held in Las Vegas, Nevada on April 11 through 14, 1988. The trip report has been reviewed by Mark Logsdon of NWC and was prepared under the quality assurance requirements of WWL as controlled by the NWC QA Manual.

Mr. Sniff's report is very detailed. In addition to providing a comprehensive review of the material covered in the meeting, the trip report provides comment on a number of points of concern to NWC. DOE presented a very generalized conceptual model, the components of which have a wide range of uncertainty. Mr. Sniff points out a concern over how, if at all, the wide range of ideas put forward by Dr. Wilson (USGS) will or could be incoprporated into the site characterization process.

Of particular concern to many of the participants in the meeting is the uncertainty over how to evaluate the role of fractures in the hydrologic system (the REV issue). Additionally, Mr. Sniff points out (p. 15) that the nominal case value of 0.5 mm/yr flux through the unsaturated zone was not defended with new data or even with particular enthusiasm. In light of the evaluations performed by WWL (e.g., TR #2) and the recent reviews of recharge in arid environments (TR #7 and #8), this matter remains a significant concern to the NWC technical team.

NWC has one principal comment on the meeting as reported in the trip report. First, while it is clear that there must be a conceptualization of the flow regime at any site, we are concerned that this not become the sole focus of NRC concerns. After all, DOE has been working at the site for many years now, and a good deal is known about at least the physical framework (e.g., Dr. Sinnock's references to the IGIS graphics modeling). Given the current knowledge of the geometry and physical properties of the site materials there are not, NWC considers, infinite possibilities concerning the flow regime. Indeed, we consider that many, perhaps most of the major alternatives can and have already been articulated:

- o Matrix-dominated flow versus fracture-dominated flow;
- o Vertical flow from the repository to the water table versus (the possibility of) lateral flow;
- o Single-phase versus polyphase fluid flow.

These conceptual issues, particularly as they apply to the likely flow of fluids between the proposed location of the repository and the accessible environment, can only be illuminated by the application of real information. Thus, NWC considers that it is time to move the focus from concern over the most general sorts of issues to concerns over how (and how soon) field programs can be initiated to address matters that likely could affect regulatory decisions. For example, there is overwhelming reason to believe that the physics of flow in the unsaturated zone at Yucca Mountain is controlled by two factors, gravity and moisture content of the matrix of the tuffaceous rocks. Thus, for lateral flow to be or become significant, there must be major discontinuities in instrinsic permeability and/or moisture content. Both of these physical properties (although certainly challenging to address in terms of specific field methods) can and must be addressed with data from the field, if we are to progress towards decisions on licensibility. Similarly, as has been pointed out by WWL (and others), the issue of matrix versus fracture flow is intimately tied to the recharge flux through the unsaturated zone: only defensible data derived from the real world will move the issue toward resolution. In short, we consider that the NRC team should increasingly address specific matters; only as new data are collected we will advance our understanding significantly.

If you have any questions about this letter or the attached material from WWL, please contact me immediately.

Respectfully submitted,
NUCLEAR WASTE CONSULTANTS, INC.

Barbara Basse for MJL

Mark J. Logsdon, Project Manager

Att

cc: US NRC - Director, NMSS (ATTN PSB)
HLWM (ATTN Division Director)
Edna Knox, Contract Administrator
HLTR (ATTN Branch Chief)
D. Chery, HLTR

bc: L. Davis, WWL

Water, Waste & Land, Inc.
CONSULTING ENGINEERS & SCIENTISTS

1102

RECE... MAY 6

May 13, 1988 WWL #4001

Mr. Mark Logsdon
Nuclear Waste Consultants, Inc.
155 South Madison Street, Suite 302
Denver, Colorado 80209

Dear Mark:

Please find attached Water, Waste and Land's trip report for Tom Sniff's attendance at the DOE/NRC technical meeting on "Alternative Conceptual Models of the Ground Water System at Yucca Mountain", held in Las Vegas, Nevada on April 11 through April 14, 1988. If you have any questions about this report, please do not hesitate to contact me.

Sincerely,

WATER, WASTE & LAND, INC.

Tom L. Sniff

Tom L. Sniff
Senior Engineer

TLS:dml
Attachment

Creekside Two Building, 2629 Redwing Road, Suite 200, Fort Collins, Colorado 80526 (303) 226-3535

Trip Report

DOE/NRC Technical Meeting

Alternative Conceptual Models

of the Ground Water System at Yucca Mountain

Prepared by

Thomas L. Sniff
Water, Waste & Land, Inc.

May 13, 1988

Trip Report
DOE/NRC Technical Meeting
Alternative Conceptual Models
of the Ground Water System at Yucca Mountain

1.0 INTRODUCTION

At the request of the Project Officer for Project RS-NMS-85-009, Tom Sniff of Water, Waste & Land, Inc. (WWL) attended a technical meeting entitled "Alternative Conceptual Models of the Ground Water System at Yucca Mountain" which was held in Las Vegas, Nevada during the period from April 11 to April 14, 1988. The participants in the meeting included the Department of Energy (DOE), the State of Nevada (State), and the Nuclear Regulatory Commission (NRC).

The purpose of Mr. Sniff attending this meeting was to observe, listen, and support the NRC Hydrology Staff whom were also attending. The agenda of the conference is attached to this report as Attachment A. Prior to the meeting, Mr. Sniff attended a NRC Caucus at the Las Vegas NRC Field Office, on the afternoon of Sunday, April 10, 1988. This caucus provided an opportunity to preview the NRC positions on the joint meeting and to go over the agenda for the meeting.

2.0 OBJECTIVE OF THE TECHNICAL MEETING

The purpose of the joint meeting was to consider different conceptual models of the ground water system, including geologic, tectonic, hydrologic, geochemical, and climatologic influences in the Yucca Mountain region. In his introductory remarks, Mr. Maxwell Blanchard of the DOE, stated that the meeting was to encourage an exchange of ideas about conceptual models rather than to try to assess whether a particular model and its supporting data are correct.

The goal of the meeting was to analyze salient features of the proposed conceptual models. This analyses was to ensure that the statutory Site Characterization Plan (SCP) contains sufficient detail for data collection to allow an evaluation of the alternative conceptual models. An additional goal was to recognize that by the end of site characterization the data may support more than one conceptual model of the Yucca Mountain ground water system.

Each presentation of a conceptual model was to include the following six items:

- Assumptions supporting the model
- Physical processes and disruptive events incorporated in the model
- Boundary conditions
- Available data supporting the model
- Additional data needed to refine the model and testing proposed to gather the additional data
- Analyses to be performed to evaluate the data and the conceptual model

This trip report concentrates on the hydrologic questions and answers which were brought up during the meeting. The political and administrative discussions, while at times interesting, are not reported. A court legal reporter transcribed the meeting; thus the full text of the meeting is available.

/C

SLIDE--REGIONAL POTENTIOMETRIC-SURFACE MAP AND BASIN BOUNDARIES

SATURATED ZONE--REGION AND SITE

PERTURBATIONS ON HYDROLOGIC REGIMES

- TRANSIENT EFFECTS ON EXISTING SATURATED-ZONE REGIMES

  --WATER-TABLE FLUCTUATIONS CAUSED BY:

  EARTH TIDES
  BAROMETRIC CHANGES
  PRECIPITATION VARIATIONS
  SEISMIC WAVES (UNE, NATURAL)

- EVIDENCE OF PAST HYDROLOGIC CONDITIONS

- POTENTIAL FUTURE EFFECTS

  --CLIMATE CHANGE
  --TECTONICS

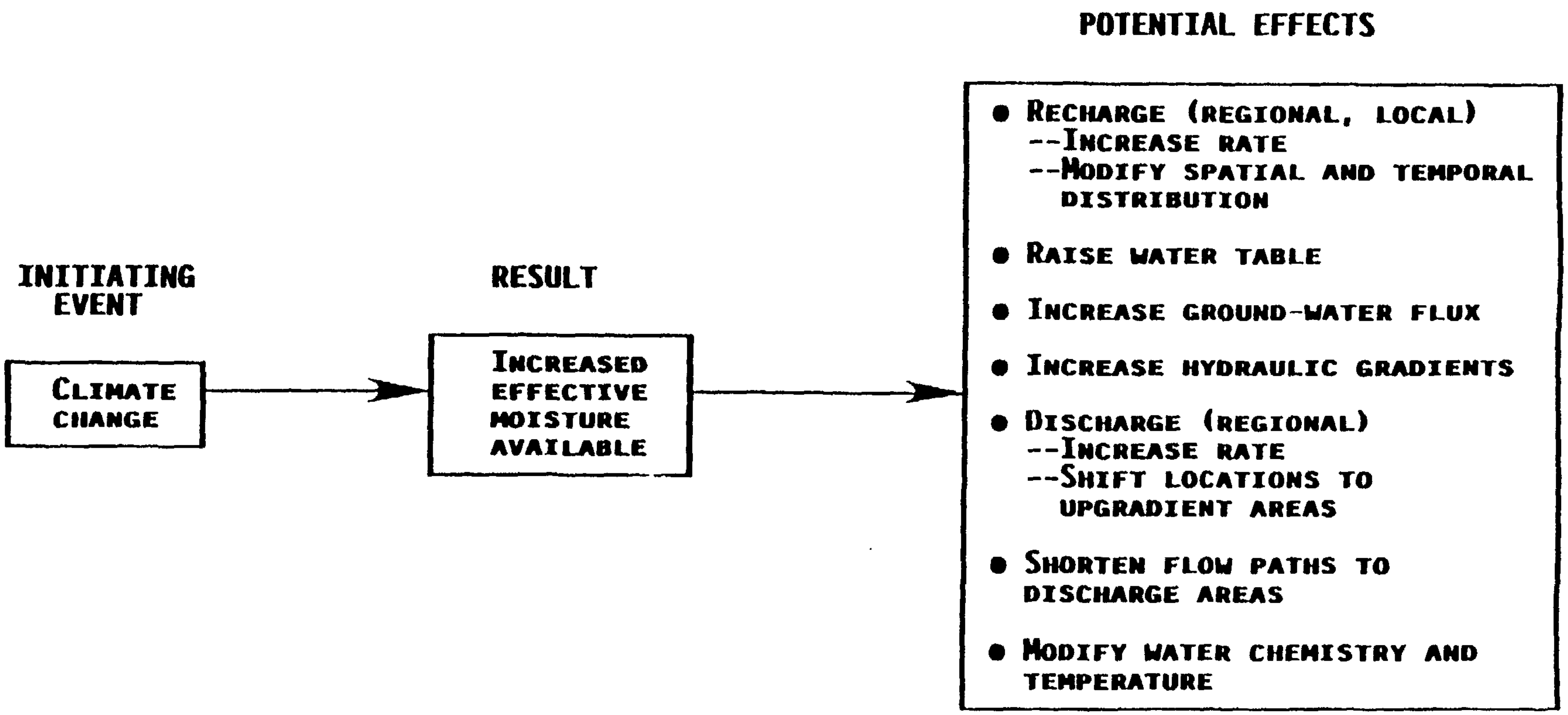
SLIDE--HYDROGRAPH, EFFECTS OF EARTH TIDES

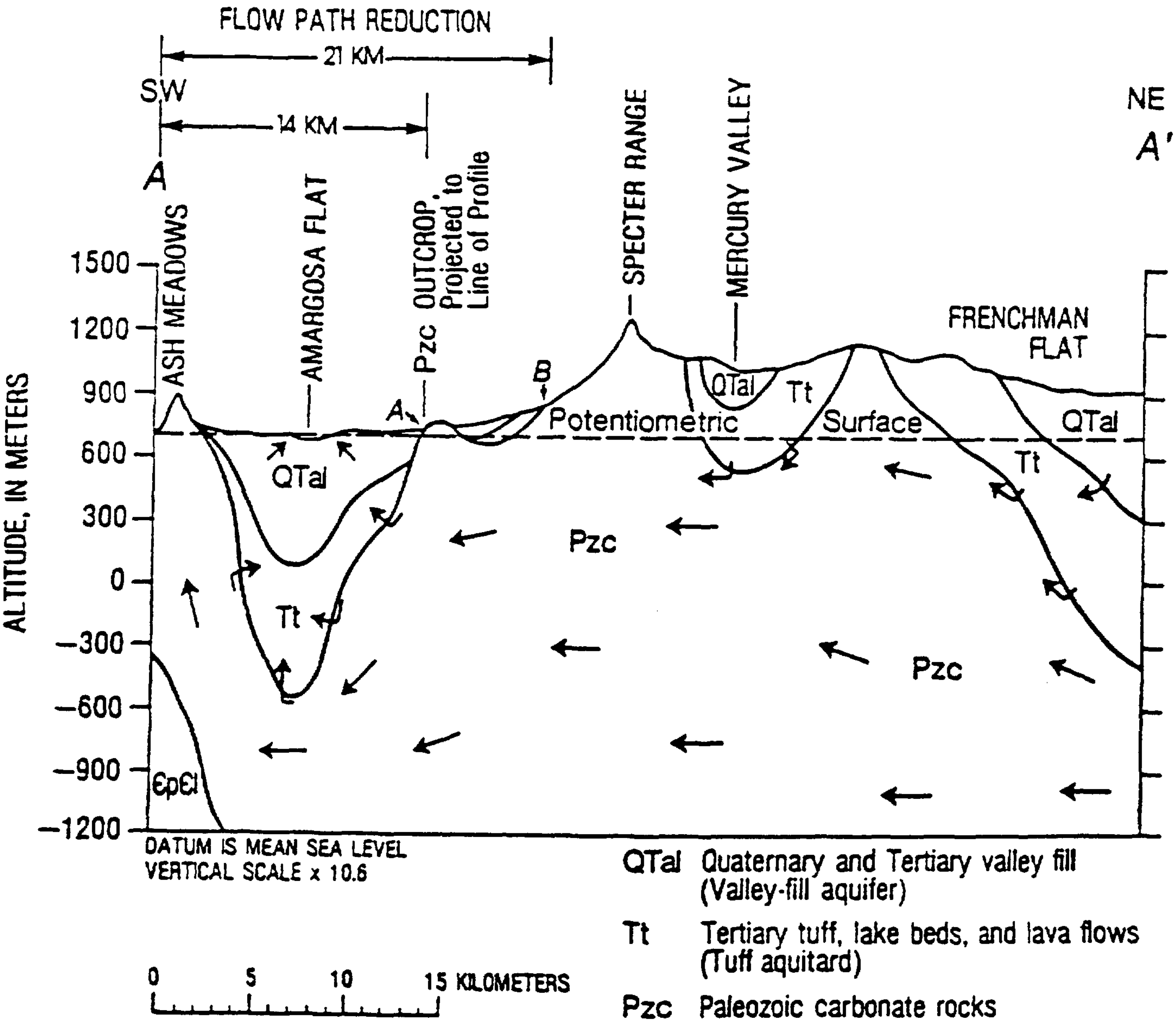
SLIDE--HYDROGRAPH, EFFECTS OF UNE

SLIDE -- VEIN DEPOSITS, FURNACE CREEK WASH

SATURATED ZONE--REGION AND SITE

POTENTIAL EFFECTS OF CLIMATE CHANGE





QTal Quaternary and Tertiary valley fill (Valley-fill aquifer)

Tt Tertiary tuff, lake beds, and lava flows (Tuff aquitard)

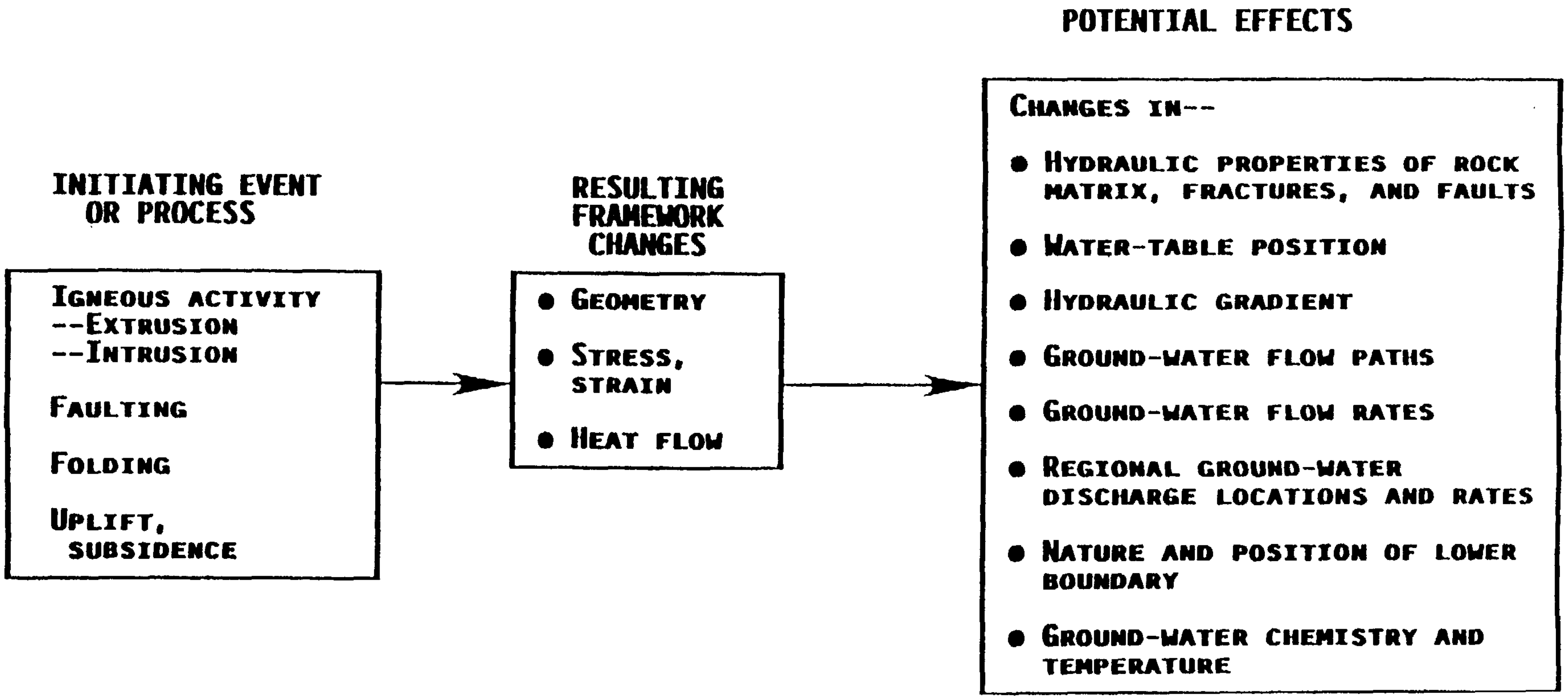
Pzc Paleozoic carbonate rocks (Lower carbonate aquifer)

ЄpЄl Lower Cambrian and Precambrian clastic rocks (Lower clastic aquitard)

(Winograd and Doty, 1980)

SATURATED ZONE--REGION AND SITE

POTENTIAL EFFECTS OF TECTONICS



SATURATED ZONE--REGION
AVAILABLE DATA

- Geologic framework
- Hydraulic properties
- Initial and boundary conditions
- Paleohydrology
- Tectonics
- Climate

SATURATED ZONE--REGION

PRINCIPAL DATA NEEDS	TESTS AND ANALYSES (SCP)
● GEOLOGIC FRAMEWORK --DISTRIBUTION OF HYDROGEOLOGIC UNITS --TEMPORAL AND SPATIAL DISTRIBUTION AND OFFSET OF FAULTS AND LINEAMENTS --GEOLOGY BENEATH FORTYMILE WASH --DATA TO CONFIRM AGE AND ORIGIN OF HYDROGENIC DEPOSITS --OCCURRENCE AND AGE OF PALEODISCHARGE (also recharge! and release times) --REFINEMENT OF HYDROGEOLOGIC UNITS --IN-SITU STRESS DATA --THERMAL PROFILES	--DEEP GEOPHYSICAL STUDIES --EVALUATION OF PAST DISCHARGE AREAS --FORTYMILE WASH RECHARGE STUDY --STUDIES OF CALCITE AND OPALINE SILICA VEIN DEPOSITS --VOLCANIC-ERUPTION STUDIES --REGIONAL HEAT FLOW
● HYDRAULIC PROPERTIES --ESTIMATES OF PROPERTIES OF DISCRETE FEATURES --ESTIMATES OF TRANSMISSIVE AND STORAGE PROPERTIES OF MAJOR UNITS --EFFECTS OF TECTONIC PROCESSES AND EVENTS ON HYDRAULIC PROPERTIES	--REGIONAL HYDROLOGIC MODELING --ANALYSIS OF EFFECTS OF TECTONIC PROCESSES AND EVENTS ON HYDROLOGY

SATURATED ZONE--REGION (CONT.)

PRINCIPAL DATA NEEDS	TESTS AND ANALYSES (SCP)
● INITIAL AND BOUNDARY CONDITIONS	
--DISTRIBUTION OF HYDRAULIC HEAD	--REGIONAL POTENTIOMETRIC-LEVEL STUDIES
--INFILTRATION RATES THROUGH FORTYMILE WASH	--FORTYMILE WASH RECHARGE STUDY
--RATES AND SPATIAL DISTRIBUTION OF EVAPOTRANSPIRATION	--EVAPOTRANSPIRATION STUDIES
--ISOTOPIC AND CHEMICAL ANALYSES OF GROUND WATER	--REGIONAL HYDROCHEMICAL TESTS AND ANALYSES
--CLIMATE DATA (MODERN, PALEO)	--PRECIPITATION AND METEOROLOGICAL MONITORING
--RECHARGE RATES UNDER VARIOUS CLIMATIC CONDITIONS	--STUDY OF MODERN REGIONAL CLIMATE
--PAST WATER-TABLE POSITIONS	--PALEOCLIMATE STUDIES
--PAST LOCATIONS OF DISCHARGE	--REGIONAL HYDROLOGIC MODELING
--FLOW PATHS AND FLOW RATES	--ANALOG RECHARGE STUDIES
	--HISTORY OF MINERALOGIC AND GEOCHEMICAL ALTERATIONS
	--EVALUATION OF PAST DISCHARGE AREAS

SATURATED ZONE--SITE

NEED FOR UNDERSTANDING

- INTERFACE WITH UNSATURATED ZONE; POTENTIAL RISE OF WATER TABLE

- FINAL FLOW PATH TO ACCESSIBLE ENVIRONMENT

SATURATED ZONE--SITE

CURRENT UNDERSTANDING OF EXISTING REGIME

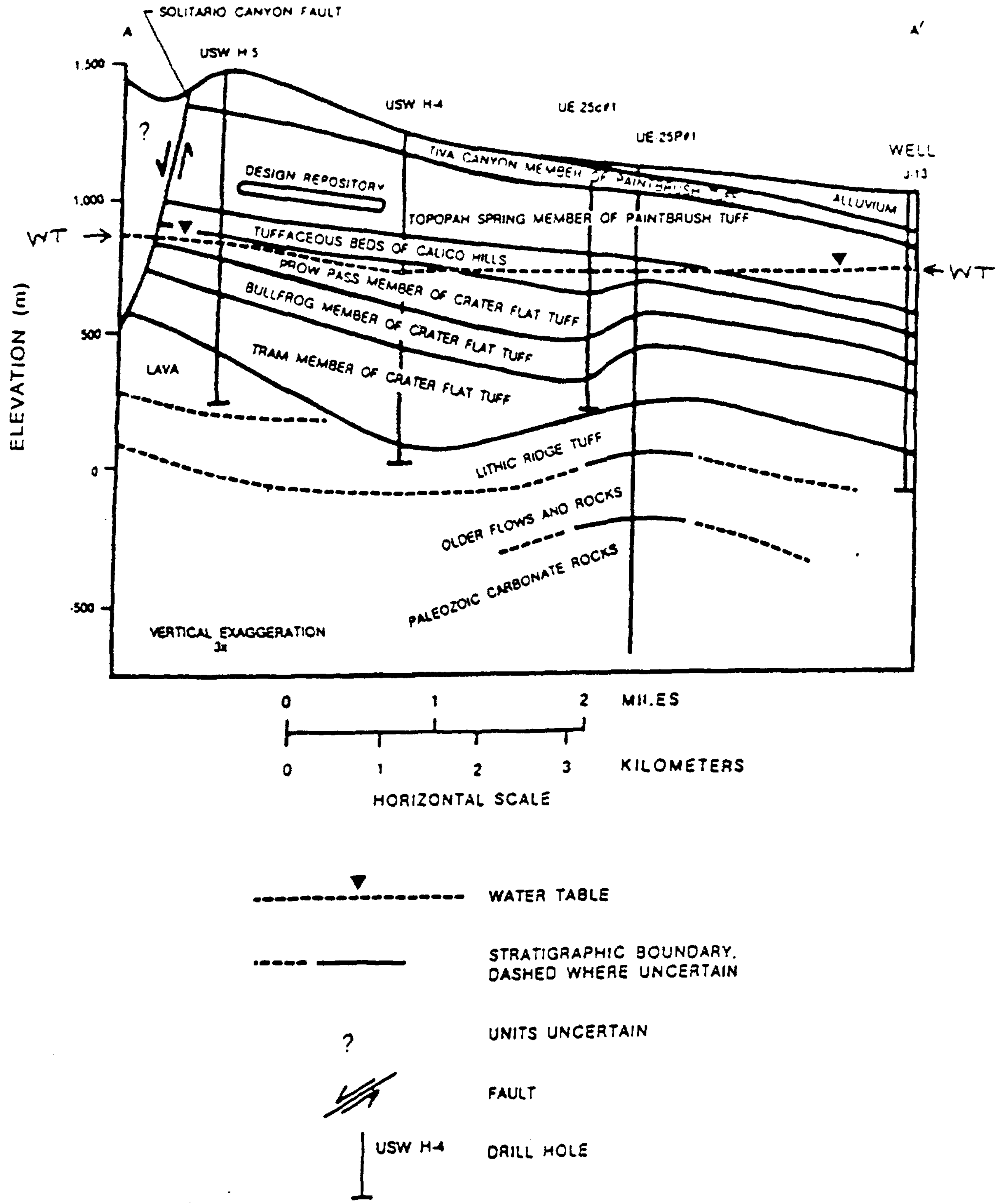
(ASSUMPTIONS, BOUNDARIES, PROCESSES)

- GEOLOGIC FRAMEWORK
  - --STRATIGRAPHY
  - --FRACTURED, POROUS MEDIUM
  - --FAULTS
  - --IN-SITU STRESS
  - --HEAT FLOW

- HYDRAULIC PROPERTIES
  - --TRANSMISSIVE PROPERTIES OF TUFF
  - --FAULTS

- INITIAL AND BOUNDARY CONDITIONS
  - --HYDRAULIC HEAD
  - --HYDRAULIC BOUNDARIES
  - --RECHARGE
  - --HYDROCHEMISTRY

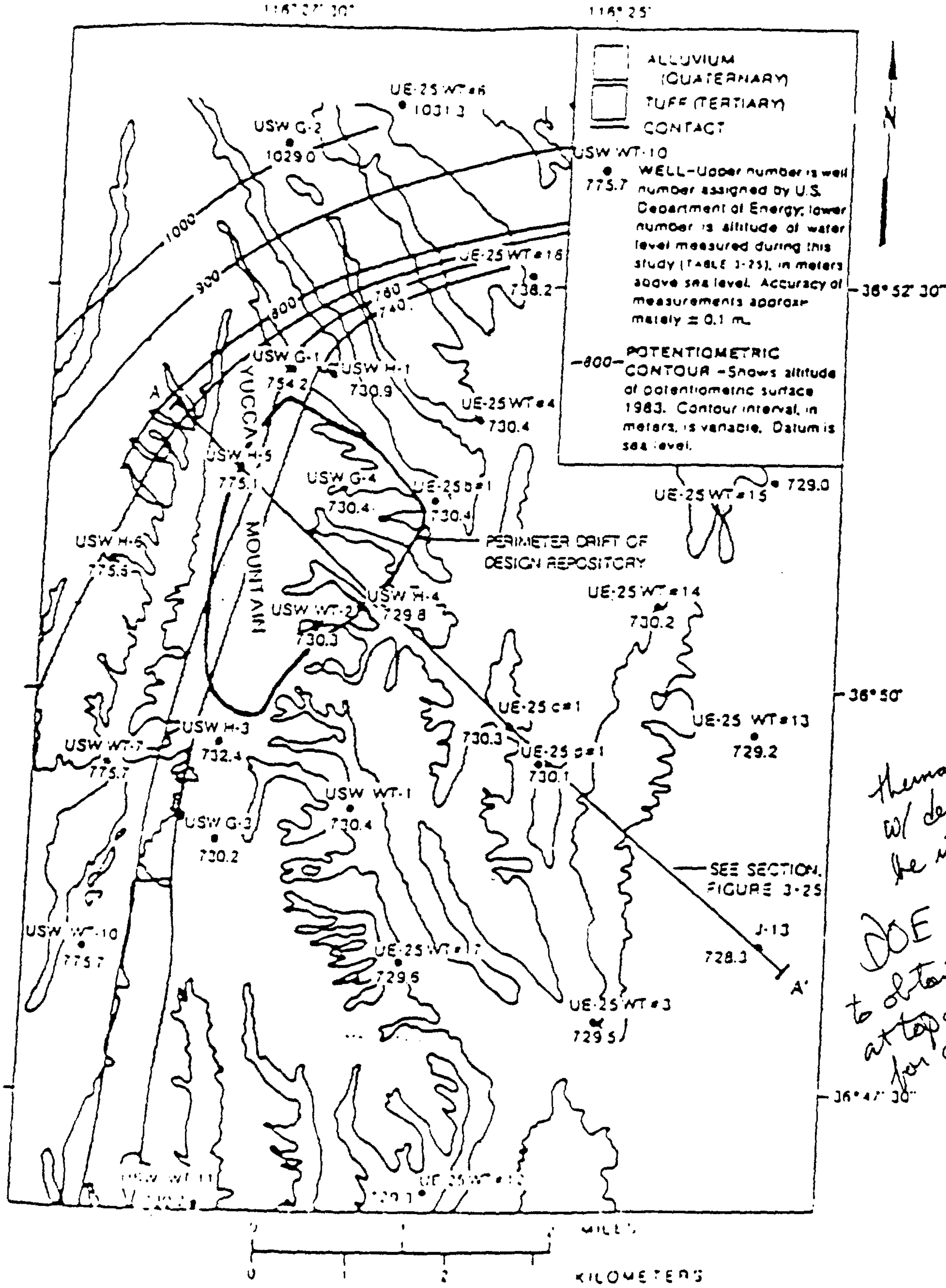
- GROUND-WATER FLOW



SOLITARIO CANYON FAULT
A
A'
USW H-5
USW H-4
UE 25c#1
UE 25P#1
WELL
J-13
1,500
1,000
500
0
-500
ELEVATION (m)
WT
WT
?
DESIGN REPOSITORY
TIVA CANYON MEMBER OF PAINTBRUSH TUFF
ALLUVIUM
TOPOPAH SPRING MEMBER OF PAINTBRUSH TUFF
TUFFACEOUS BEDS OF CALICO HILLS
PROW PASS MEMBER OF CRATER FLAT TUFF
BULLFROG MEMBER OF CRATER FLAT TUFF
TRAM MEMBER OF CRATER FLAT TUFF
LAVA
LITHIC RIDGE TUFF
OLDER FLOWS AND ROCKS
PALEOZOIC CARBONATE ROCKS
VERTICAL EXAGGERATION
3x
0 1 2 MILES
0 1 2 3 KILOMETERS
HORIZONTAL SCALE
WATER TABLE
STRATIGRAPHIC BOUNDARY, DASHED WHERE UNCERTAIN
?
UNITS UNCERTAIN
FAULT
USW H-4
DRILL HOLE

SLIDE--YUCCA MOUNTAIN GEOLOGIC MAP, WITH FAULTS

25



thermal variation w/ depth need to be investigated

DOE is going to obtain water samp at top of sat. zone for age dating

SATURATED ZONE--REGION AND SITE

PERTURBATIONS ON HYDROLOGIC REGIMES

- TRANSIENT EFFECTS ON EXISTING SATURATED-ZONE REGIMES

  --WATER-TABLE FLUCTUATIONS CAUSED BY:

  EARTH TIDES
  BAROMETRIC CHANGES
  PRECIPITATION VARIATIONS
  SEISMIC WAVES (UNE, NATURAL)

- EVIDENCE OF PAST HYDROLOGIC CONDITIONS

- POTENTIAL FUTURE EFFECTS

  --CLIMATE CHANGE
  --TECTONICS

SATURATED ZONE--SITE AVAILABLE DATA

- Geologic framework
- Hydraulic properties
- Initial and boundary conditions
- Paleohydrology
- Tectonics
- Climate

SATURATED ZONE--SITE

PRINCIPAL DATA NEEDS	TESTS AND ANALYSES (SCP)
● GEOLOGIC FRAMEWORK --CHARACTERISTIC OF FRACTURES IN TUFF --GEOMETRY OF FRACTURE NETWORKS --SUBSURFACE GEOLOGY OF AREA OF STEEP HYDRAULIC GRADIENT --TEMPORAL AND SPATIAL DISTRIBUTION AND OFFSET OF FAULTS --STRESS/STRAIN DATA --THERMAL PROFILES	--FRACTURE GEOMETRY AND PROPERTIES --SURFACE FRACTURE NETWORK STUDIES --BOREHOLE EVALUATION OF FAULTS AND FRACTURES --SEISMIC TOMOGRAPHY/VSP --GEOPHYSICAL INVESTIGATIONS --STRATIGRAPHIC-UNIT STUDY --STUDIES TO EVALUATE FAULTS --STRESS-FIELD STUDY IN SITE AREA --EVALUATION OF HEAT FLOW AT YUCCA MOUNTAIN
● HYDRAULIC PROPERTIES --FRACTURED TUFF --FAULTS --EFFECTS OF TECTONIC PROCESSES AND EVENTS ON HYDRAULIC PROPERTIES	--FRACTURE-NETWORK MODELING --ANALYSIS OF PREVIOUSLY COMPLETED HYDRAULIC-STRESS TESTS --SOLITARIO CANYON FAULT STUDY --MULTIPLE WELL INTERFERENCE TESTING --TRACER TESTS --ASSESSMENT OF THE EFFECTS OF TECTONICS ON HYDROLOGIC PROPERTIES OF THE ROCK MASS

SATURATED ZONE--SITE (CONT.)

PRINCIPAL DATA NEEDS	TESTS AND ANALYSES (SCP)
● INITIAL AND BOUNDARY CONDITIONS	
--SPATIAL AND TEMPORAL DISTRIBUTION OF HYDRAULIC HEAD	--SITE AND REGIONAL POTENTIOMETRIC-LEVEL EVALUATIONS
--LATERAL FLUX BOUNDARY CONDITIONS	--SITE AND REGIONAL 2D AND 3D HYDROLOGIC MODELING
--RECHARGE	
--POSITION AND NATURE OF LOWER BOUNDARY	--UNSATURATED-ZONE INFILTRATION AND PERCOLATION STUDIES
--ISOTOPIC AND CHEMICAL ANALYSES OF GROUND WATER IN UPPERMOST PART OF SATURATED ZONE	--SAMPLING AND ANALYSES OF WATER IN UPPER PART OF SATURATED ZONE
--CLIMATE DATA (MODERN, PALEO)	--CLIMATE STUDIES AND MODELING
--FLOW PATHS AND FLOW RATES	--TRACER STUDIES
--EFFECTS OF TECTONICS ON WATER-TABLE ELEVATION	--ANALYSES OF THE EFFECTS OF TECTONIC PROCESSES AND EVENTS ON CHANGES IN WATER-TABLE ELEVATION

SLIDE--AERIAL VIEW OF YUCCA MOUNTAIN

UNSATURATED ZONE--SITE

CURRENT UNDERSTANDING OF EXISTING SYSTEM

(ASSUMPTIONS, BOUNDARIES, PROCESSES)

- GEOLOGIC FRAMEWORK
  - --WELDED AND NONWELDED UNITS
  - --STRUCTURE
  - --IN-SITU STRESS
  - --HEAT FLOW

- HYDRAULIC PROPERTIES
  - --MATRIX
  - --FRACTURES
  - --FAULTS

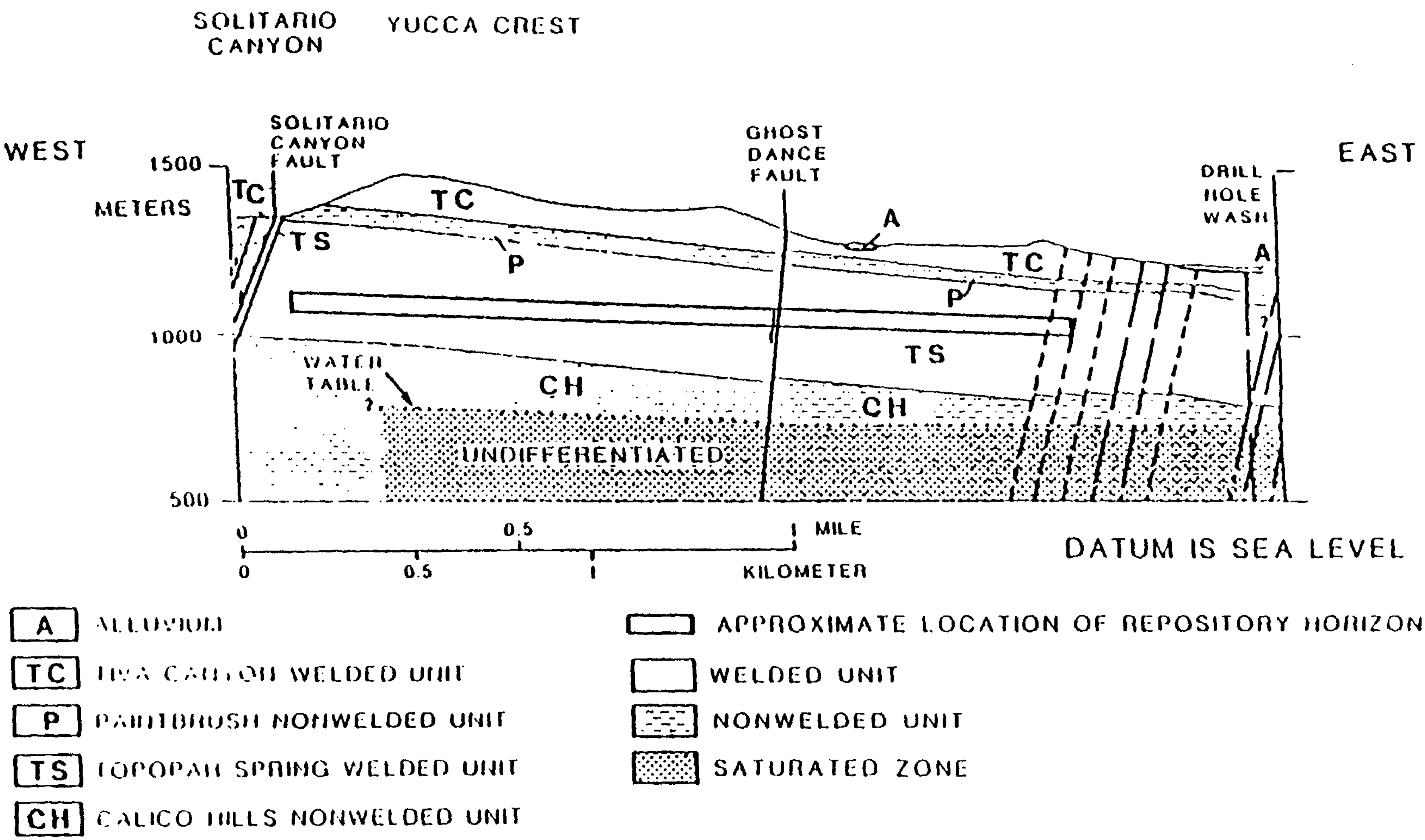
- INITIAL AND BOUNDARY CONDITIONS
  - --INFILTRATION - temporally and spatially variable
  - --MOISTURE CONDITIONS
  - --POTENTIALS – heterogeneity may cause potentials to be spatially distributed
  - --FLUID CHEMISTRY
  - --LOWER BOUNDARY (WATER TABLE)

- MOISTURE FLOW (FLUX)

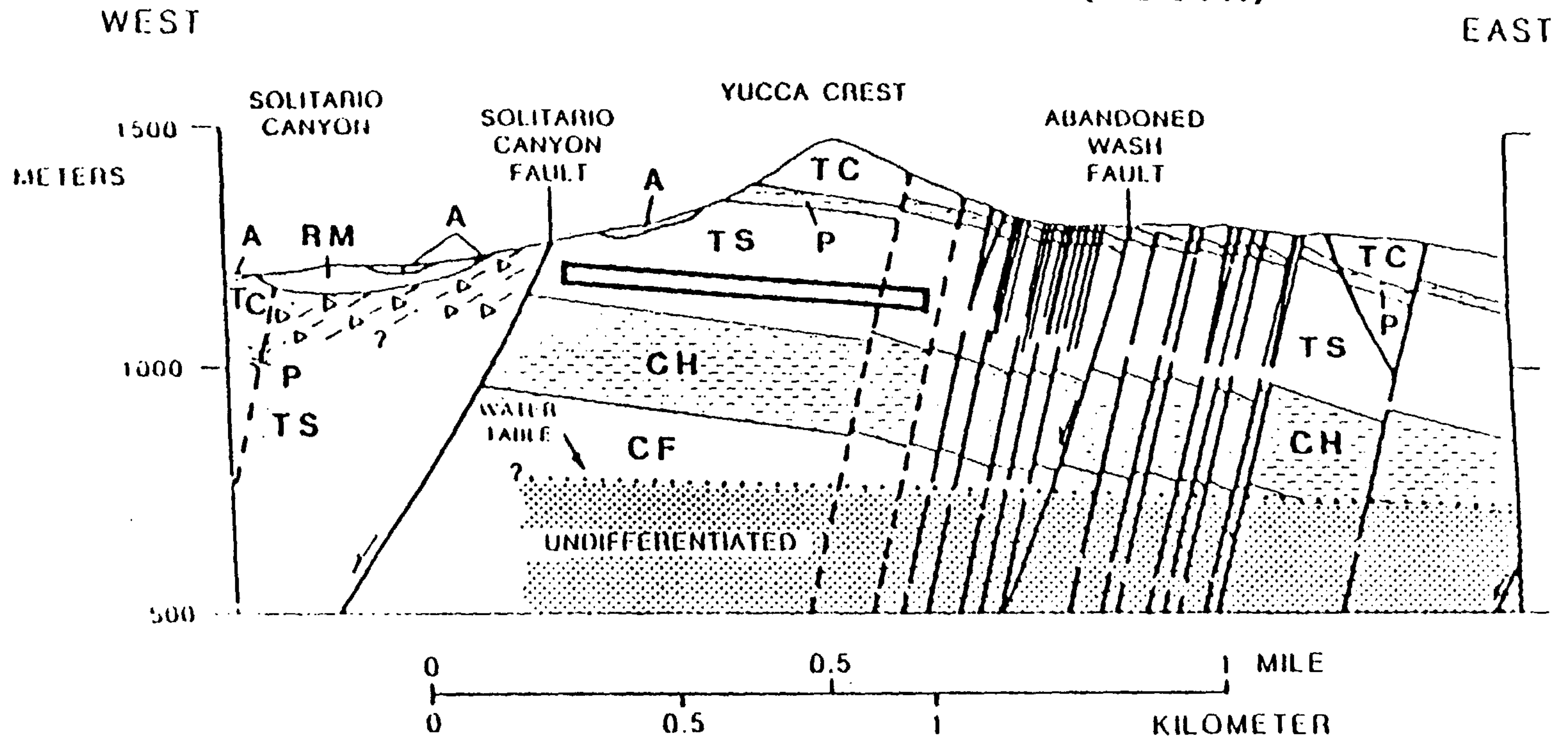
Sass - temp. at Yucca Mtn is lower than surrounding area. Indicative of larger downward flux or upward flux of vapor w/ evaporation.

UNSATURATED ZONE

HYDROGEOLOGIC FRAMEWORK (NORTH)



UNSATURATED ZONE
HYDROGEOLOGIC FRAMEWORK (SOUTH)



DATUM IS SEA LEVEL

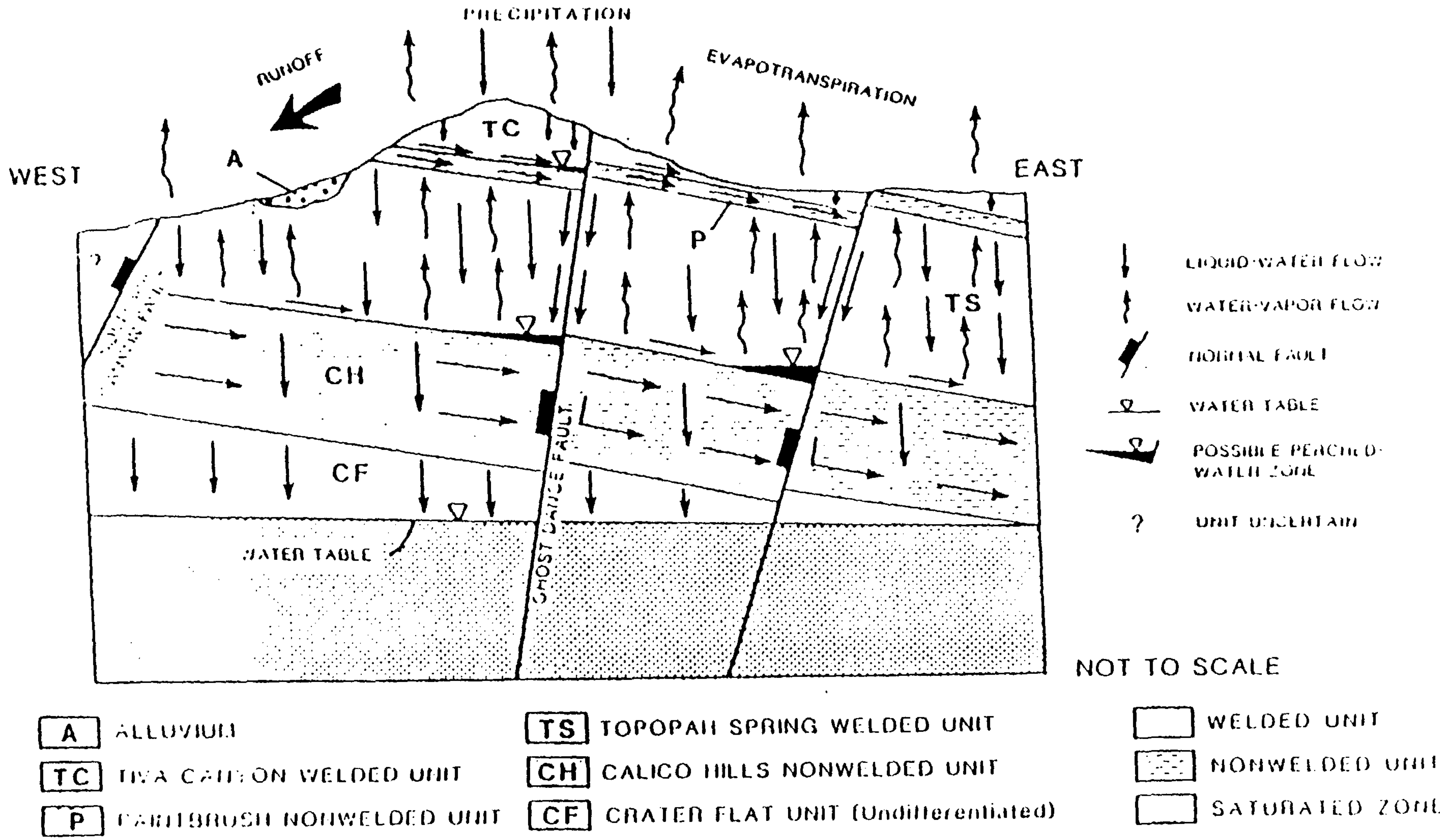
A	ALLUVIUM	TS	TOPOPAH SPRING WELDED UNIT		NONWELDED UNIT
RM	RAINIER MESA UNIT	CH	CALICO HILLS NONWELDED UNIT		SATURATED ZONE
TC	TIVA CANYON WELDED UNIT	CF	CRATER FLAT UNIT (Undifferentiated)		APPROXIMATE LOCATION OF REPOSITORY HORIZON
P	PAINTBRUSH NONWELDED UNIT		WELDED UNIT		

UNSATURATED ZONE--SITE
CURRENT UNDERSTANDING (CONT.)
MOISTURE FLOW

- APPLICABILITY OF CONCEPTS AND THEORY
- LARGE-SCALE AND SMALL-SCALE TESTS
- MULTIPLE HYPOTHESES OF FLOW PROCESSES

  --NET INFILTRATION
  --LATERAL FLOW
  --PERCHED-WATER BODIES
  --FLOW DOWN FAULTS
  --MATRIX VS. FRACTURE FLOW
  --VAPOR FLOW
  --RECHARGE TO SATURATED ZONE

UNSATURATED ZONE
CONCEPTUAL MODEL OF FLOW



UNSATURATED ZONE--SITE

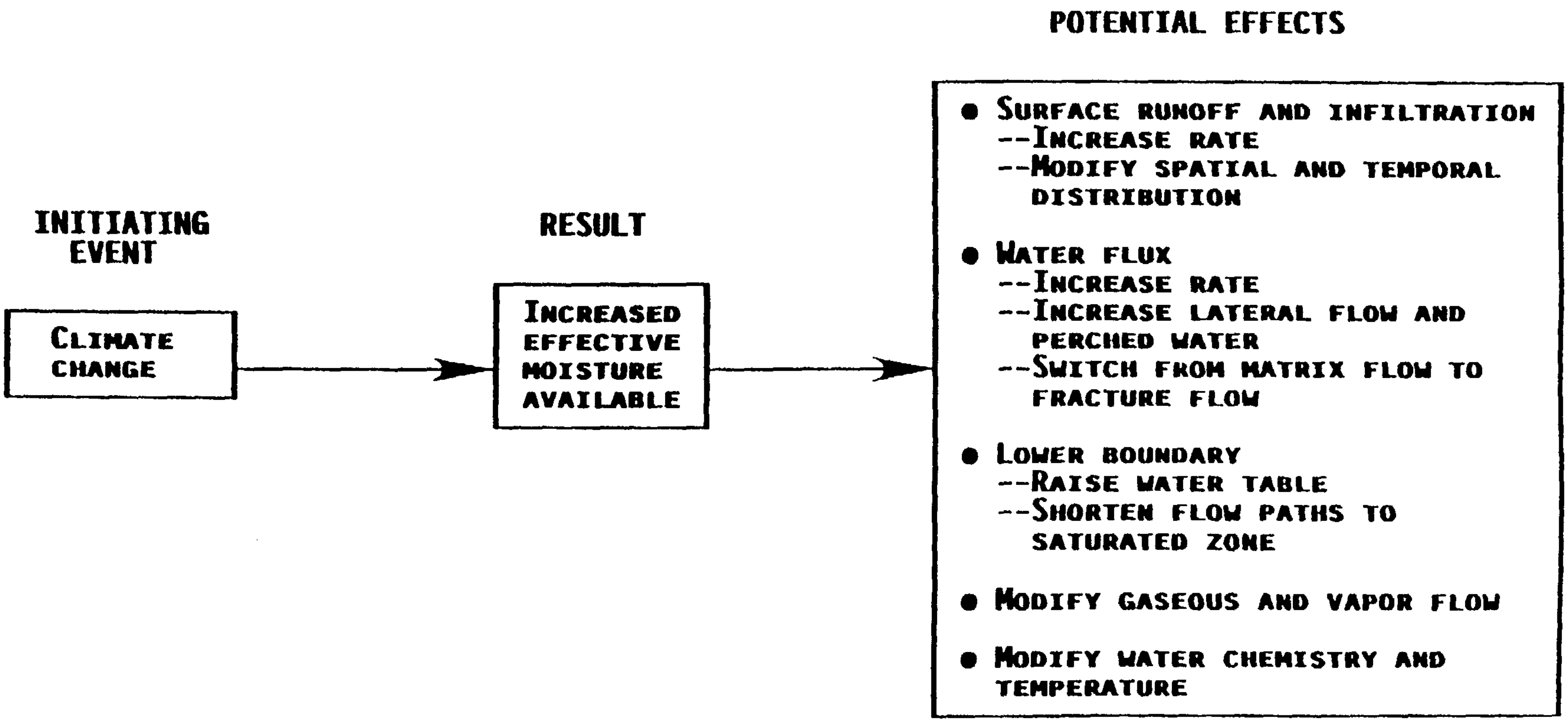
PERTURBATIONS ON HYDROLOGIC REGIME

- TRANSIENT EFFECTS ON EXISTING HYDROLOGIC CONDITIONS
- EVIDENCE OF PAST HYDROLOGIC CONDITIONS
- POTENTIAL FUTURE EFFECTS

  --CLIMATE CHANGE
  --TECTONICS

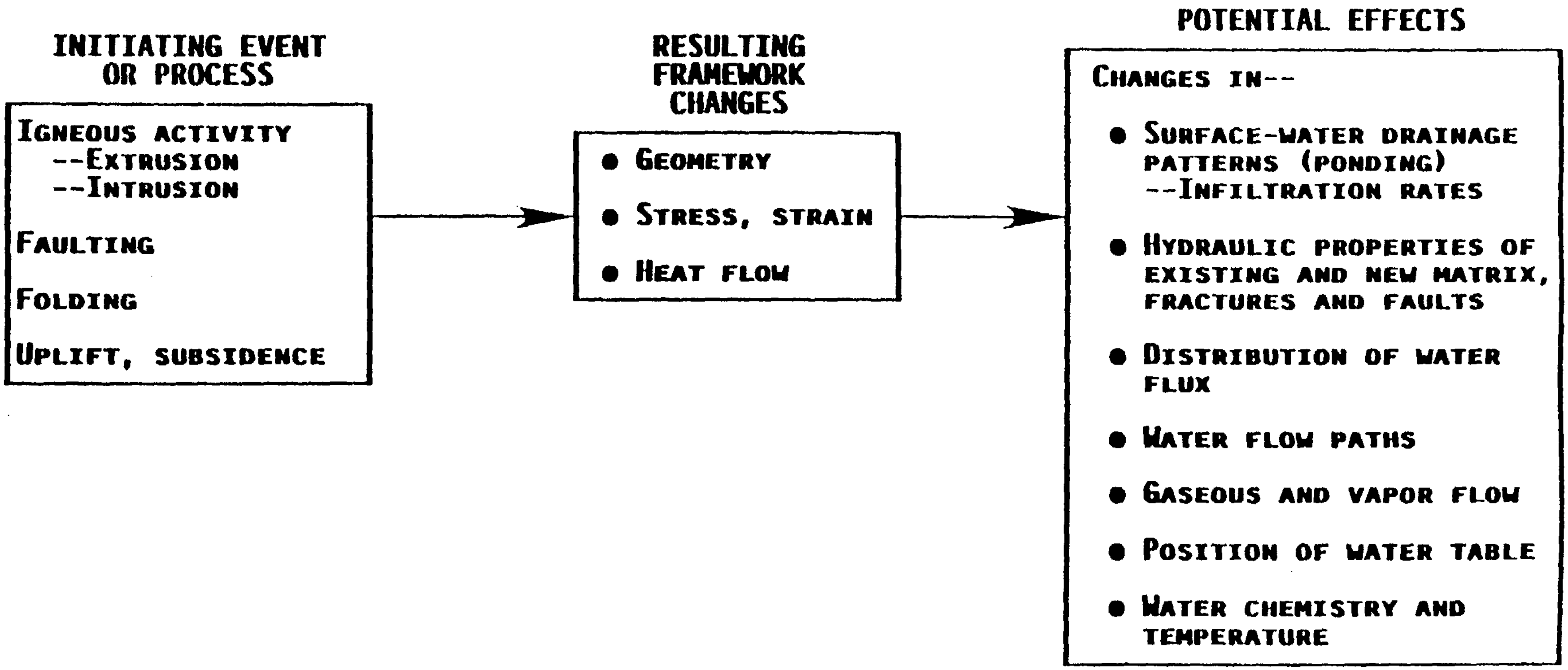
UNSATURATED ZONE--SITE

POTENTIAL EFFECTS OF CLIMATE CHANGE



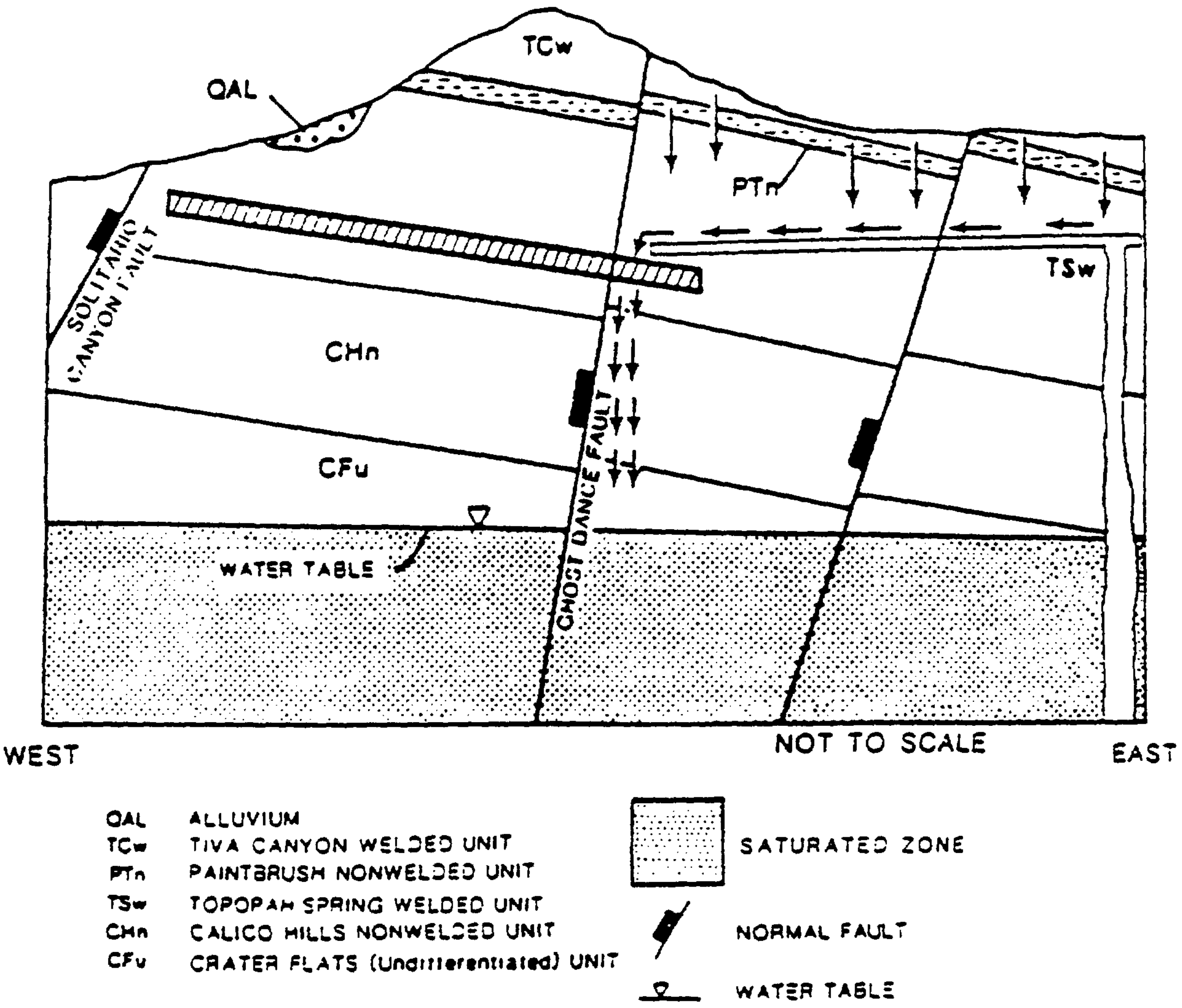
UNSATURATED ZONE--SITE

POTENTIAL EFFECTS OF TECTONICS



HYPOTHETICAL INITIATING EVENT FOR POSTCLOSURE ANALYSIS

IGNEOUS INTRUSION ALTERS FLUX RATES



UNSATURATED ZONE--SITE

AVAILABLE DATA

"space and scanty"

- Geologic framework
- Hydraulic properties
- Initial and boundary conditions
- Paleohydrology
- Tectonics
- Climate

UNSATURATED ZONE--SITE

PRINCIPAL DATA NEEDS	TESTS AND ANALYSES (SCP)
● GEOLOGIC FRAMEWORK --TEMPORAL AND SPATIAL DISTRIBUTIONS AND OFFSETS OF FAULTS --FRACTURE AND MATRIX CHARACTERISTICS OF TUFF UNITS --GEOMETRY OF FRACTURE NETWORKS --DISTRIBUTION OF SURFICIAL INFILTRATION UNITS --REFINEMENT OF HYDROGEOLOGIC UNITS --IN-SITU STRESS DATA --THERMAL PROFILE	--QUATERNARY FAULT STUDIES --DETACHMENT FAULT STUDIES --STUDY OF STRUCTURAL FEATURES, INCLUDING: --EXPLORATORY SHAFT GEOLOGIC MAPPING --SURFACE-FRACTURE NETWORK STUDIES --BOREHOLE EVALUATIONS --SEISMIC TOMOGRAPHY/VSP --INTACT-FRACTURE TESTS --MATRIX PROPERTIES TESTING --SURFICIAL DEPOSITS MAPPING --CHARACTERIZATION OF SURFICIAL MATERIALS DISTRIBUTION --SITE VERTICAL BOREHOLE STUDIES --STRESS-FIELD STUDY --EVALUATION OF HEAT FLOW AT YUCCA MOUNTAIN
● HYDRAULIC AND PNEUMATIC PROPERTIES --MATRIX --FRACTURES --FAULTS --EFFECTS OF TECTONIC PROCESSES AND EVENTS ON PROPERTIES	--HYDROLOGIC PROPERTIES OF SURFICIAL MATERIALS --MATRIX HYDROLOGIC PROPERTIES TESTING --SITE VERTICAL BOREHOLES STUDY --SOLITARIO CANYON HORIZONTAL BOREHOLE STUDY --8 HYDROLOGIC TESTS IN EXPLORATORY SHAFT --CHARACTERIZATION OF GASEOUS-PHASE FLOW --ANALYSIS OF EFFECTS OF TECTONICS ON FRACTURE PERMEABILITY AND EFFECTIVE POROSITY

3.0 PROGRAM

The program as shown on the agenda in Attachment A became modified somewhat as the technical meeting progressed. The primary reason for this modification was the large number of comments and questions addressed to the main DOE presenters by the audience. The following summaries of the presentations are reported in the chronological order in which they occurred at the meeting.

Monday, April 11, 1988, - Morning Session

Introductory remarks were made by the Department of Energy, the State of Nevada, and the Nuclear Regulatory Commission. Dan Galson of the NRC presented a brief history of the performance allocation in the site characterization process and gave a working definition of conceptual model. As defined by Galson, a conceptual model is a pictorial and/or narrative description of the repository system or subsystem that is intended to represent (1) relevant components of a system and/or subsystem, and (2) interactions between the various components and/or subsystems and/or systems. Mr. Galson went on to state that the SCP and performance allocation must consider a full range of alternative conceptual models where uncertainty exists.

The NRC Objection 1 to the CDSCP was reviewed. This objection stated the CDSCP does not address the investigations that would be needed to characterize the site with respect to the full range of alternative conceptual models that are consistent with the existing data. Therefore, all the investigations that are significant to the characterization of the site are not necessarily considered. Consequently, in sequencing investigations, the CDSCP cannot adequately consider whether conducting one investigation would physically preclude conducting another investigation needed to obtain information for licensing.

Mr. Galson provided the following recommendations in context of performance allocations to the DOE:

1. Identify a full range of alternative conceptual models.
2. Identify a full array of information needs and associated investigations in consideration of these conceptual models; consider these conceptual models in sequencing of investigations.

3. Determine which investigations would preclude conducting other investigations important to the characterization program and sequence appropriately.

4. The DOE should specify, through performance allocation, investigations and information needs that will distinguish between alternative conceptual models.

5. Accord high priority to investigations having the greatest potential for resolving issues that could lead to: (1) the site being considered unlicensable, and (2) substantial changes in the characterization program. These investigations should only be done if they do not influence other investigations.

John Trapp of the NRC also addressed the semantics of conceptual model and scenarios. He discussed the fact that testing programs go for known features and perhaps neglect looking for unknown features. Several examples from the CDSCP supporting this point were given.

Mr. Steve Brocoum of the DOE made the following reply to the presentation by the NRC staff:

1. The NRC comments are being reviewed seriously.

2. The definition of a conceptual model presented by Dan Galson is similar to the DOE's conceptual model definition.

3. The DOE agrees that there is a documentation problem regarding the listing of all alternative models and reasons that they were rejected by DOE.

4. A bias toward a conceptual model is not the case and the SCP will include a listing of other models.

5. In reply to Dan Galson's recommendations one through four; the recommendations will be implemented in the SCP.

It must be noted that a direct response was not given by the DOE to recommendation number five.

Monday, April 11, 1988, - Afternoon Session

Maxwell Blanchard (DOE) gave a brief history of the development of conceptual models for Yucca Mountain. Blanchard stated that the conceptual models were developed using open literature published about the geology and hydrology of the Nevada Test Site. Bill Wilson of the USGS then presented "DOE Conceptual Model - The Hydrologic Setting." A copy of Wilson's handout is provided as Attachment B. Wilson defined conceptual model as "a simplified representation of a complex phenomenon or system that is based on observable or measurable processes or conditions." He described the refinement of the model as being an iterative process, with this iterative process being applicable for all submodels and components. The following paragraphs summarize the presentation by Wilson.

In the conceptual model presented by Wilson, the hydrologic regimes were divided into five major types: (1) atmospheric, (2) surface water, (3) saturated zone (regional, and site), (4) site unsaturated zone, and (5) paleohydrology. Wilson concentrated on the regional saturated zone, the site saturated zone, and the site unsaturated zone during the remainder of his presentation. He stated the DOE has recognized that transient effects may be present in the existing saturated zone regimes. Water table fluctuations may be caused by earth tides, barometric changes, precipitation variations, and seismic waves. Evidence exists of past hydrologic conditions different from those present at the site today. Potential future effects on the hydrologic system must also consider climate change and tectonics.

Wilson stated that climate change may result in increased effective moisture being available for infiltration and, subsequently, recharge. This in turn could raise the water table, increase the ground water flux and hydraulic gradients, and ultimately shorten the flow paths to discharge areas. The regional discharge could increase and the discharge areas might be shifted to upgradient areas closer to the repository. The water chemistry and temperature could also be modified by such a climate change.

Wilson also stated tectonics could potentially change the hydrologic flow regime. The results of the tectonic process could be manifested by igneous activity (such as extrusion or intrusion), faulting, folding, uplift, or subsidence. These processes would result in changes in the hydraulic properties of the rock matrix, fractures, and faults. The water table position and the hydraulic gradient could also be significantly altered. This would then alter the ground water flow paths, regional ground water discharge locations and rates, the nature and position of the lower boundary, and the ground water chemistry and temperature.

Regional Saturated Zone

Wilson identified a number of principal data needs for the regional saturated zone which will be addressed in the SCP. The data needs identified for the geologic framework were:

1. Distribution of hydrogeologic units
2. Temporal and spatial distribution and offset of faults and lineaments,
3. Geology beneath Fortymile Wash,
4. Data to confirm age and origin of hydrogenic deposits,
5. Occurrence and age of paleodischarge,
6. Refinement of hydrogeologic units,
7. In-situ stress data, and
8. Thermal properties.

Wilson considered the data needs for the hydraulic properties of the regional saturated zone to be:

1. Estimates of properties of discrete features,
2. Estimates of transmissive and storage properties of major units, and
3. Effects of tectonic processes and events on hydraulic properties.

Finally, the initial and boundary conditions data needs were identified as:

1. The distribution of the hydraulic head,
2. Infiltration rates through Fortymile Wash,
3. Rates and spatial distribution of evapotranspiration,
4. Isotopic and chemical analyses of ground water,
5. Climate data, both modern and paleo,
6. Recharge rates under various climatic conditions,
7. Past water table positions,

8. Past locations of discharge, and

9. Flow paths and flow rates.

Site Saturated Zone

The principal data needs for the site saturated zone geologic framework were identified by Wilson as:

1. Fracture characteristics in tuff,

2. Geometry of fracture networks,

3. Subsurface geology of area of steep hydraulic gradient,

4. Temporal and spatial distribution and offset of faults,

5. Stress/strain data, and

6. Thermal profiles.

The principal data needs for the site saturated zone hydrologic framework are:

1. Hydraulic properties of the fractured tuff,

2. Hydraulic properties of the faults, and

3. Effects of tectonic processes and events on hydraulic properties.

Wilson stated the faults may possibly be modeled as part of the dual porosity system, discretely, or as a portion of the fracture system. Testing during the site characterization process will (hopefully) determine the appropriate assumptions. The upper water of the saturated zone will be evaluated by age dating to further refine the flow regime.

The principal data needs for the site saturated zone initial and boundary conditions are:

1. Spatial and temporal distribution of hydraulic head,

2. Lateral flux boundary conditions,

3. Recharge,

4. Position and nature of lower boundary,

5. Isotopic and chemical analyses of ground water in uppermost part of saturated zone,

6. Climate data, both modern and paleo,

7. Flow paths and flow rates, and

8. Effects of tectonics on water table elevation.

Site Unsaturated Zone

Wilson identified a need for understanding where the site saturated zone interfaces with the unsaturated zone (potential rise of the water table) and the final flow path to the accessible environment. Infiltration may be temporally and spatially variable at the top of the site unsaturated zone. Wilson stated that heterogeneity within units may cause potentials to be spatially distributed. Based on the work of Sass, the temperature at Yucca Mountain is lower than surrounding area. This may be indicative of larger downward flux or upward flux of vapor with evaporation. Wilson concluded that a basic lack of understanding existed for the unsaturated zone. There is also a lack of proven methodology for testing and data acquisition for this zone at Yucca Mountain. The development and confirmation of the theory of flow in an unsaturated matrix/fracture system will be a great challenge. The available data for the site unsaturated zone is sparse and scanty.

According to Wilson, the potential effects increased effective moisture available to the unsaturated zone are increased flux, increased lateral flow and perched water, a switch from matrix only flow to both matrix and fracture flow, and a raising of the water table thus shortening the flow paths to the saturated zone. In addition, climatic change could modify gaseous and vapor flow. Changes would also be expected in the water chemistry and temperature.

The potential effects of tectonics changing the framework of the unsaturated zone geometry, stress-strain relations, and heat flow are complex. Changes could occur in surface water drainage patterns and infiltration rates. The hydraulic properties of existing matrix, fractures, and faults could be altered, changing the distribution of water flux and flow paths. The gaseous and vapor flow systems would change as would the water chemistry and temperature. Ultimately, the results might be a raising or lowering of the water table.

Wilson considered the principal data needs for the geologic framework of the unsaturated zone to be:

1. Temporal and spatial distributions and offsets of faults,
2. Fracture and matrix characteristics of tuff units,
3. Geometry of fracture networks,
4. Distribution of surficial infiltration units,
5. Refinement of hydrogeologic units,
6. In-situ stress data, and
7. Thermal profile.

The hydraulic and pneumatic properties for the matrix, fractures, and faults are also needed, as are the effects which tectonic processes and events have on these properties. As far as boundary and initial conditions, the following were considered by Wilson to be the data needs for the unsaturated zone:

1. Infiltration rates,
2. Moisture conditions,
3. Potentials,
4. Liquid water flux,
5. Isotopic and chemical analyses of water and gases,
6. Nature of flow in fractures,
7. Perched water occurrence,
8. Climate data,
9. Paleohydrologic conditions, including past water table positions, and
10. Effects of tectonics on flux and water table elevation.

Wilson summarized the conceptual model process as initially developing a description of the hydrologic system and the physical processes that cause it to vary over time. Then, a range of multiple alternative hypotheses and scenarios can be included into the description. Ultimately, a consistent, integrated conceptual model will be produced that has an acceptable level of uncertainty.

This participant's thoughts, after hearing the presentation by Wilson, was that the DOE has a basic framework for a conceptual model, but a great deal of uncertainty exists as to the actual details of this model. The presentation showed that the DOE has considered a number of alternative boundary conditions to be possible. Certainly, the presentation by Wilson considered a great number of processes which had only been implicitly considered in the CDSCP conceptual model. The major problem with Wilson's (DOE) presentation was that it provided no framework for incorporation into the SCP. How will the questions, data needs, and uncertainties presented by Wilson be addressed in the SCP? Wilson considered a multitude of possibilities and scenarios which have, could, or may happen in the hydrologic regime surrounding Yucca Mountain.

Following a NRC caucus, Scott Sinnock of Sandia National Laboratories presented "Translation of the Hydrologic Setting to Performance Modeling Applications", a copy of which is provided in Attachment C. The purpose of Sinnock's presentation was to describe how the data and concepts of the hydrogeologic system are being translated into numerical models for ground water flow. Sinnock stated that the numerical models must consider and incorporate the conceptual models described by Bill Wilson and any others that are viable. The numerical models must include the uncertainties in these conceptual models as well as the uncertainties associated with disruption to the system.

For the physical process, Sinnock presented the assumptions with which he is currently working. First, Sinnock assumed Darcy flow was valid and Richard's equation was applicable in the unsaturated zone. The hydraulic conductivity is presumed to be a function of capillary pressure. The capillary pressure is then assumed to be a function of pore size. For fracture-matrix interactions, Sinnock assumed that a pressure equilibrium exists perpendicular to flow and that the effective porosity is equivalent to moisture content. The flow in the unsaturated zone is currently assumed to be isothermal, can be transient or steady state, and only the liquid phase is currently being considered.

For the physical domain, Sinnock stated that the geometry of the hydrologic system can be developed from the IGIS computer graphics model. This model gives the hydrostratigraphy, structure, water table and boundary definitions. The physical domain parameters (e.g. fault permeability, retardation coefficients, rock matrix permeability) can be modified by disruptive scenarios. Sinnock considered that the numerical accommodation of these scenarios can be accomplished by two methods:

1. The unit geometry is selectively altered to account for tectonics or human intrusion scenarios.

2. The physical property distribution can be modified. The modification may be a result of faulting, volcanic activity, climatic change, or human intrusion scenarios.

However, to actually implement the modifications, the magnitude, frequency, and duration of changes provided by tectonic, climatic, geochemical process to the hydrogeologic domain need to be understood. Therefore these processes are data needs which must be addressed in the SCP.

For the baseline case a number of assumptions for the initial and boundary conditions are currently being used by Sinnock. In the unsaturated zone, the upper boundary flux is variable and the lower boundary flux has a capillary pressure of zero. The side boundaries can be no flow or fixed capillary pressure. The gas phase has not yet been integrated into the baseline case.

The current assumptions for the saturated zone baseline case include a variable water table for the upper boundary. The lower boundary is considered to be either a no flow or a transient, specified leakage flux. The side boundary conditions include the potentials from the regional modeling and kriging of known data points. (This implies that a constant flux boundary is not considered).

Sinnock considered that the disruptive scenarios can be accommodated by modifying boundary conditions in the numerical model. This method of numerical experimentation could include a number of mechanisms. The effect of tectonic scenarios such as seismic pumping or volcanism could be accommodated by modifying the water table elevation or lowering the saturated zone head boundary. The effects of climatic change, flooding, or faulting could be accommodated by modifying the surface infiltration flux. These processes could also be modeled by changing the site saturated zone head boundary.

Sinnock stated that the current types of analyses that can be performed vary from simple algebraic equations to the solution of second order partial differential equations for the potential distribution. Sinnock listed two approaches which he thought were available for the determination of the potential distribution: (1) the Wang and Narasimhan method which considers a discrete fracture network, and (2) the Peters and Klavetter method which uses a composite continuum.

If pressure equilibrium is assumed between the matrix and fractures, some simplifying assumptions can be made. One such simplifying assumption is the use of a single porosity continuum for a low flux in the unsaturated zone where the matrix dominates. The fracture porosity would then be used in the saturated zone.

Sinnock pointed out that the tradeoffs between full solutions and the simplified approximations must be recognized. Some of these tradeoffs are the code dimensionality (1D, 2D, or 3D), steady state versus transient conditions, the mesh size-time step convergence criteria, treatment of spatial property variability and uncertainty, and conservatism versus realism. The full solutions may realistically treat the process in the unsaturated and saturated zones. However these solutions may not practically account for transient responses and property variability and uncertainty throughout the domain.

Sinnock pointed out that algebraic solutions may be capable of realistic treatment of the property variability and uncertainly (within limits) but may violate pressure continuity. The use of full solutions of "representative" subdomains may be used to constrain initial and boundary conditions for simplified approximations of flow throughout the full physical domain.

Sinnock stated that to support the performance modeling a number of parameter needs are required from the site characterization. The nominal case is based on measurements and interpretations of current site conditions. For the disruptive scenarios a number of options are available. Performance modeling can be based on the inference of potential changes in parameters defining the nominal case. The SCP modeling will provide some insight into the potential changes by disruptive scenarios. Finally inferences of disruptive scenarios will be drawn in consultation with peer reviewers and performance analysts. The validation of the models will be based on measurements and interpretations of site conditions, laboratory experiments, and natural analogues. Sinnock said this process will be open to outside interpretation through publication of technical reports and periodic peer review.

For the nominal case, Sinnock considered the mathematical basis for modeling to be basically the same for both the saturated and unsaturated zones. The ground water travel time (GWTT) is simply the distance divided by the ground water velocity. The ground water velocity is the Darcy velocity divided by the effective porosity. In the unsaturated zone, the permeability is a function of the matrix and fracture potentials, which in turn are functions of the moisture content (or saturation) of the matrix and fractures.

To determine parameter uncertainty, Sinnock proposed that a sensitivity analysis can be performed to identify the most influential variables. These variables can then be used in an uncertainty analysis where the sensitive input variables are treated as random distributions. A probabalistic prediction of GWTT can then be predicted is by a Monte Carlo or direct stochastic simulation.

Sinnock thought that the treatment of conceptual uncertainty is less amenable to quantification. The conceptual uncertainty can be addressed by consideration of alternative concepts such as weighting by professional judgment, DELPHI, or bounding calculations. In addition, Sinnock stated that extensive dialogue with the State, NRC, and expert consultants will be used. The validation of modeling approaches will occur by calibration with respect to field observations of the parameters, comparison to controlled field observations and laboratory experiments, and periodic formal peer review.

Sinnock summarized the current conceptual concerns for ground water flow in the nominal case to be:

1. Unsaturated zone fracture flow: existence, quantity, and locations
2. Unsaturated and saturated zone "Matrix Diffusion"
3. Scalar Relationships
4. Vapor Flux in the unsaturated zone.

The conceptual concerns for ground water flow in the disruptive scenarios are the magnitude, frequency, duration, and spatial extent of potential changes in material properties and boundary conditions. Specific concerns include tectonic influences (stress-strain changes, thermal variations, intrusive bodies), climatic influences, and human influences.

As Sinnock summarized, the total conceptual model has distinct components, each with its own conceptual basis. Translating the descriptive aspects to numerical representations requires explicit definitions of assumptions in terms of defining parameters for the physical processes, physical geometry, material properties, and boundary conditions. The relation of numerical modeling to data gathering involves an iterative approach. Alternative processes must be considered, evaluated, and eventually selected for analysis. The material properties and boundaries for a nominal case must be characterized as well as the potential for tectonic, climatic, human, and repository induced changes to defining parameters and processes. Finally the potential effects of these changes to the nominal case must be assessed by numerical experiments.

Tuesday, April 12, 1988, Morning Session

This session was dedicated to allowing meeting participants the opportunity to question the DOE regarding the presentation of Wilson and Sinnock. The following hydrogeologic questions (Question #7 was related to geochemistry) were asked by members of the NRC staff in reference to the Wilson and Sinnock presentations. These questions were developed in a NRC caucus Monday night and are presented as they were given in writing to the DOE. In addition, Carl Nelson of the State asked two hydrogeologic questions which are presented, along with the DOE responses, at the end of this section. Wilson and Sinnock deferred some of the questions to members of the audience whom they thought were better able to comment.

NRC Question Number 1:

Is there a dynamic present day relationship between "tectonics" and the hydrologic regime?

a) Does stress influence the present flow regime?
b) Does temperature influence the present flow regime?
c) What is the interrelationship between the tectonic models and the hydrologic models? For example: extension vs. strike or oblique slip.

Max Blanchard of the DOE replied that the conceptual model does include this relationship. However, the DOE is trying to incorporate the various phenomena such as stress and temperature into the mathematical models.

NRC Question Number 2:

What is the "true" flux through the repository horizon?

a) Spatial and temporal variability;
b) How "sensitive" is it to slight changes in boundary conditions, i.e., with slight increase in infiltration what happens;
c) Why .5 (mm/yr)? Why not 5, 10, or 20?

Dwight Hoxie of the USGS replied that given the assumptions of steady state the values are reasonable. The flux cannot be measured at Yucca Mountain. It is a gravity dominated system with a thermal regime perhaps causing upward vapor transfer. Therefore, two phase flow cannot be neglected. Ralph Peters (Sandia) seemed to sum up the problem of determining the actual flux which is occurring at Yucca Mountain by stating "its a very nasty problem."

It was this participant's opinion that the unsaturated flux value of 0.5 mm/yr was not enthusiastically defended by the DOE with any new or field measured data. This parameter is still one of the most important in the program and as of yet very little data from the site is available to justify the DOE's value.

NRC Question Number 3:

Is the ground water system the final means of transport to accessing environment?

a) If lateral flow can occur, why not out at spring or the like at higher elevation?
b) role of "air" transport (vapor)

Bill Wilson (USGS) replied that spring flow would be geometrically difficult at Yucca Mountain, as the repository elevation is lower than the surface elevation around Yucca Mountain. However, vapor transport needs to be investigated.

NRC Question Number 4:

Role of faults.

a) Solitario barrier? Others conduct northwest faults?

Bill Wilson (USGS) stated that the DOE will re-evaluate that portion of the program.

NRC Question Number 5:

How much will construction (ESF) modify the hydrologic regime? If USW UZ-1 was influenced by USW G-1, what is to stop shaft construction from modifying test facilities?

Steve Brocoum of the DOE stated that activities are underway for the SCP to determine ESF impacts with a number of tests currently planned. Ralph Peters (Sandia) stated that very little water will be used in the construction of the shaft and, therefore, the shaft may not modify the hydrologic regime to any great extent. Peters also stated that a number of tests at the G-Tunnel are scheduled such as an air-water-heat test (a prototype test) not referenced in the CDSCP.

NRC Question Number 6:

Scale factors and REV

a) Lab can only test "good" samples and drilling has problem in getting samples. What does lab testing signify? How representative is this data?

The DOE reply was that geostatistics may provide some information. The Navier-Stokes parallel plate theory is still the starting point of fracture characterization in the laboratory. Lab work will provide basic conceptual theory of water moving through fractures. This will then be incorporated into a large scale.

It was this participant's opinion, after listening to the replies by the various researchers, that the determination of the REV is considered by the DOE to be a significant problem in the site characterization.

NRC Question Number 8:

Role of carbonate aquifer and Eleana aquitard.

a) How important?

b) How will program evaluate?

Head difference between carbonate aquifer, therefore the boundary conditions may need to be changed as there is an upward potential to the south. The Eleana (upper clastic aquitard) may act as a basement step and influence the steep gradients in the area.

State Question Number 1:

Will the prototype testing require new technological breakthroughs?

The DOE replied that extensive new technological breakthroughs are not needed and that off-the-shelf technology is available. Measuring the small "changes" in the system is expected to be the problem. Bringing methods which have worked in other disciplines into Yucca Mountain will be somewhat difficult. Prototype testing will determine which methods will work.

State Question Number 2:

The DOE needs to itemize the tests which are going to be addressed. Can the DOE get the characterization done in 7 years?

The DOE responded that the SCP will provide a greater detail on the prototype testing method. The DOE will "have some tight schedules ahead" as far as the characterization process is concerned.

Tuesday, April 12, 1988, - Afternoon Session

Jerry Szymanski of the DOE presented his ideas on possible mechanisms influencing the hydrogeologic regime around Yucca Mountain. A copy of his handout is presented in Attachment D. A review of the conceptual model presented by Szymanski was given in greater detail in the Subtask 1.4 update by WWL (1988). Therefore, only a brief summary will be given in this trip report.

Szymanski concluded that a deforming fractured medium is involved in the flow process. The geologic observations and measurements of contemporary strain indicated that this conclusion is secure beyond a reasonable doubt. At the base of the flow system heat flow is spatially heterogeneous. The volcanic setting, crustal structure, and downhole measurements of the in situ temperature suggest that this conclusion may be proper for the Yucca Mountain site. To sum up, Szymanski said you will not find it unless you look for it.

Max Blanchard asked Szymanski what data would he want if he were king for a day. Szymanski replied that he would like to see the existing hydrographs of the wells on the NTS reviewed, expand the work of Dr. Yang on the chemistry of the pore waters, and do a more detailed examination of the perched waters at the NTS.

This participant considered the presentations by Wilson and Sinnock to have made adequate references to the potential effects which tectonics could have on the hydrologic systems influencing Yucca Mountain. It was not clear, however, if the data needs which Szymanski thought were necessary to determine if his model is valid were specifically addressed. The Szymanski paper is currently undergoing an internal DOE peer review. When this is completed, further definition of the needed testing programs for the conceptual model presented by Szymanski will hopefully be available for independent review.

Wednesday, April 13, 1988, - Morning Session

Alan Dutton of the Bureau of Economic Geology at the University of Texas at Austin presented a chemical hydrologic model. However, the model had nothing to do with the Nevada project and this participant could see little value in the presentation. Following the Dutton presentation, some additional discussion took place concerning the Szymanski model. Szymanski stated that he is not suggesting his model is correct, however the questions which his interpretation bring up need to be addressed.

Wednesday, April 13, 1988, - Afternoon Session

The afternoon session was used as a question and answer period. The following are pertinent hydrologic questions asked by the NRC staff to the DOE scientists.

NRC Question Number 1:

In the unsaturated zone conceptual model presented, how can capillary barriers exist under steady state flow conditions?

Phil Harrold (USGS) stated that capillary barriers only exist under transient conditions. Dwight Hoxie said recent modeling also shows that capillary barriers occur only under transient conditions.

NRC Question Number 2:

How do heterogeneities (permeability) affect water content (flux) distribution in the unsaturated zone conceptual model?

Phil Harrold (USGS) said that heterogeneities could cause the potential distribution to vary within a unit. If 100% saturation occurs, then some fractures could conduct a greater amount of water. This water will move into a new area with less than 100% saturation. The lateral heterogeneities will cause the water to take the path of least resistance and lateral flow will or could occur to a certain extent. Scott Sinnock (Sandia) said the problem is one of micro, macro, and meso scale heterogeneities.

Tom Nicholson (NRC) then asked (in reply to Sinnock's answer): "How do you determine the scale needed for characterization and flux determination?" Scott Sinnock replied that at small scales the heterogeneities may or may not dampen out the large scale effects. Phil Harrold stated that a vertical section from the drillholes will be used for determination of water potential heterogeneities.

It was this participant's feeling that this answer reinforced the idea that the DOE is having a difficult time in determining the testing required to determine what the REV is in the unsaturated zone.

NRC Question Number 3:

> If there is no well-defined systematic variation of matric potential with depth in unsaturated zone hydrogeologic units, then how is it possible to conclude this is consistent with the supposition that the individual hydrogeologic units are relatively homogeneous in the vertical direction and the steady-state vertical moisture flow occurs under unit vertical hydraulic gradient. (page 3-196 CDSCP) (section 3.9.3.1)

Scott Sinnock (Sandia) replied that at the center of a thick unit you will get a possible vertical gradient approaching unity. However, he was not sure as to the effect which microscale heterogeneities have on the overall flow regime. The boundaries between the units may not exhibit a unit gradient.

NRC Question Number 4:

> What is meant by "pressure equilibrium perpendicular to flow"? (page 6, Sinnock presentation)

The DOE replied that a detailed review was given in Water Resources Research in the March, 1988 issue.

NRC Question Number 5:

> How stable is the matrix flow field, in which there is equilibrium between air and water, to perturbations due to the intrusion of more water?

Perturbations can occur and a detailed review is given in Water Resources Research in the March, 1988 issue.

NRC Question Number 6:

The picture on page 25 of Scott Sinnock's presentation shows how fracture flow can evolve from matrix flow. How did the model handle flow from the matrix to the fracture? Additionally, Tom Nicholson asked "How is the characteristic curve for fractures going to be determined and validated?

Phil Harrold (USGS) referred to the exploratory shaft fracture test in Chapter 8 of the CDSCP. The hypothesis at this point in time is that the characteristic curve will work for fractures. Then the question is - can a curve for fracture systems be derived? This cannot be done in a laboratory. Field work will be required. The DOE said it is not yet clear on how to use these curves for GWTT calculations.

NRC Question Number 7:

What is the current understanding of the vapor phase flow system, in particular the effect of the thermally induced repository heat transient on vapor movement including radionuclide vapor releases?

Dwight Hoxie (USGS) replied that the waste heat will drive moisture away as vapor which will condense further out with liquid migrating back eventually forming a convective cell. However this scenario is valid only for a matrix system. With fractures the vapor can perhaps travel for a considerable distance. The convection system will probably be localized.

This participant felt that the DOE investigators were very unsure as to what the actual effects the heat will have on the vapor phase flow system. This is reasonable since the current knowledge of the vapor flow system is minuscule.

Thursday, April 13, 1988

Closing statements were made by the State of Nevada, DOE, and the NRC. After the close of the meeting, a trip was made to the DOE library by this participant and members of the NRC staff. Access was available to the public documents room. Information as to how literature could be made available from the DOE library was obtained.

4.0 EVALUATION OF THE TECHNICAL MEETING

The DOE presented a very general conceptual model, the components of which have a wide range of uncertainty. Wilson identified a number of these uncertainties and data needs. Sinnock discussed the methodology of implementing the conceptual models and the uncertainty in these conceptual models into a numerical framework suitable for calculations and predictions.

This participant was impressed by the frankness of the DOE researchers and their acknowledgement as to the great lack of knowledge which still exists regarding the regional and site flow regimes. The researchers from the USGS and Sandia realize better than anyone that a great deal of work lies immediately ahead in just developing the prototype testing necessary for the site characterization. Examples of this openness were the admission that capillary barriers only exist under transient conditions and determination of the actual flux through the unsaturated zone will be difficult. However, these comments were brought out, more often than not, in the question and answer sessions after the conceptual model presentations.

The DOE seemed anxious to accept recommendations from other parties as to the necessary testing or conceptual model changes which may be appropriate. Therefore, the meeting certainly provided a basis (or a starting point) from which further dialogue can continue on the hydrologic regime at Yucca Mountain.

It would seem that working groups of experts could focus on the various portions of the conceptual model. As a starting point, the regional saturated zone, the site saturated zone, and the unsaturated zone could be considered. Some technical meetings have already been proposed to investigate (to a greater degree of resolution than was possible in this technical meeting) the conceptual model uncertainties and data needs which need be implemented into the SCP to be released in December, 1988. This type of format would (hopefully) avoid the political discussions which took place during this meeting.

Of particular interest, the effects the gas phase in the unsaturated zone has on the water chemistry is largely unknown. Further investigations into this topic may point out testing and data needs which have not been considered in the CDSCP.

5.0 REFERENCES

WWL, 1988. "NNWSI Conceptual Model Update - NNWSI Repository Project, Subtask 1.4"

ATTACHMENT A

DOE-NRC TECHNICAL MEETING

ALTERNATIVE CONCEPTUAL MODELS OF THE GROUNDWATER SYSTEM

YUCCA MOUNTAIN

April 11-14, 1988   Aladdin Hotel, Las Vegas

AGENDA

Meeting purpose is to consider different conceptual models of the groundwater system, including geologic, tectonic, hydrologic, geochemical, and climatologic influences in the Yucca Mountain region. This is to promote open discussion about similarities, differences, and compatibilities of the various conceptual models. Using such information, the DOE will be able to ensure that the SCP contains plans for data collection sufficient to evaluate alternative models. Each presentation of a conceptual model should include the following six items:

- o Assumptions supporting the model
- o Physical processes and disruptive events incorporated in the model
- o Boundary conditions
- o Available data supporting the model
- o Additional data needed to refine the model and testing proposed to gather the additional data (surface-based/ESF)
- o Analyses to be performed to evaluate the data and the conceptual model

Day 1 - Monday, April 11

9:00 - 9:20	DOE Introductory Remarks	
	Purpose and Scope Background	R. Stein, DOE/HQ M. Blanchard, DOE/NV
9:20 - 9:30	State of Nevada Introductory Remarks	R. Loux, State of NV
9:30 - 11:00	NRC Introductory Remarks and Summary of SCP-CD Concerns Relevant to Conceptual Models	
11:00 - 11:30	DOE Response	
11:30 - 1:00	Lunch	
1:00 - 4:00	DOE Conceptual Model	
1:00 - 1:10	Introduction	M. Blanchard, DOE/NV
1:10 - 2:45	The Hydrologic Setting o Include the 6 items identified above	W. Wilson, USGS

2:45 - 3:15	Clarifying questions and commentary from participants	
3:15 - 3:30	Break	
3:30 - 4:30	Translation to numerical models for performance assessment o Include the 6 items identified above	S. Sinnock, SNL
4:30 - 5:00	Clarifying questions and commentary from participants	

Day 2 - Tuesday, April 12

Presentations of other conceptual models:
(Presenters to be arranged)

1 to 3 hrs for each presenter	Description of Alternative Conceptual Model o Include the 6 items identified above
15 to 30 min.	Clarifying Questions from Participants on Description of Conceptual Model

Day 3 - Wednesday, April 13

8:00 - 10:30 Moderator-led Open Discussion of Similarities and Differences Among the Various Conceptual Models

- o Extent to which the alternative conceptual models incorporate the same physical processes and disruptive events and where they differ
- o Extent to which the alternative conceptual models employ the same underlying assumptions and where they differ
- o Extent to which the alternative conceptual models have similar initial fixed and variable boundary conditions and where they differ
- o Extent to which the alternative conceptual models have similar information needs and where they differ
- o Implication of models on ground water travel time and radionuclide transport

10:30 - 11:00	Caucus/Break
11:00 - 12:00	View of Each Participating Organization presented by a Spokesperson from Each Organization
12:00 - 1:00	Lunch

1:00 - 3:00	Moderator-led Open Discussion on Sufficiency of Data Collection Plans in SCP-CD (DOE to provide brief summary/overview of related topics from SCP-CD) o Extent to which the surface-based testing information needs are similar and where they differ o Extent to which the ESF testing information needs are similar and where they differ
3:00 - 3:30	Break
3:30 - 5:00	Discussion on Sufficiency of Data (continued)
5:00 - 5:30	Caucus for Day 4 Wrap-up Statements

Day 4 - Thursday, April 14

8:00 - 9:00	DOE Statement: Discussion Relevant to Szymanski's Draft Report; Wrap-up Statement on Alternative Conceptual Models
9:00 - 9:30	NRC Wrap-up Statement on Alternative Conceptual Models
9:30 - 10:00	State Wrap-up Statement on Alternative Conceptual Models
10:00 - 12:00	Preparation of Draft Meeting Summary
12:00 - 1:00	Lunch
1:00 - 5:00	Discussion and Finalization of Meeting Summary

ATTACHMENT B

4-11-88
1:00 PM

1

DOE CONCEPTUAL MODEL
"THE HYDROLOGIC SETTING"
BY
BILL WILSON, USGS

- INTRODUCTION
  - --PURPOSE
  - --"CONCEPTUAL MODEL"
- HYDROLOGIC REGIMES AND COMPONENTS
  - --SATURATED ZONE, REGION
  - --SATURATED ZONE, SITE
  - --UNSATURATED ZONE, SITE
- EXAMPLE OF STRATEGY USED TO TEST ALTERNATIVE HYPOTHESES
- SUMMARY

(in context of 6 bullets on Prelim. Agenda Sheet)

"CONCEPTUAL MODEL"

- DEFINITION:

  A SIMPLIFIED REPRESENTATION OF A COMPLEX PHENOMENON OR SYSTEM THAT IS BASED ON OBSERVABLE OR MEASURABLE PROCESSES OR CONDITIONS.

- ITERATIVE PROCESS

  1. DESCRIBE SYSTEM
  2. DEFINE RELATIONSHIPS
  3. DEVELOP MULTIPLE HYPOTHESES
  4. TEST HYPOTHESES

- APPLICATION TO YUCCA MOUNTAIN GROUND-WATER FLOW SYSTEM

"These iterative processes are correct for all submodels and components"

HYDROLOGIC REGIMES

TYPES

- Atmospheric
- Surface water
- Saturated zone (Region, Site)
- Unsaturated zone (Site)
- Paleohydrology

4

5

SATURATED ZONE--REGION

NEED FOR UNDERSTANDING

SETTING FOR SITE SATURATED-ZONE REGIME

LATERAL HYDRAULIC BOUNDARIES FOR SITE

REGIONAL EVALUATION OF EFFECTS OF TECTONICS AND CLIMATE CHANGE

SLIDE -- SUBSURFACE RELATIONSHIPS OF HYDROGEOLOGIC UNITS (REGION)

SLIDE -- REGIONAL MAP OF QUATERNARY FAULTS

UNSATURATED ZONE--SITE (CONT.)

PRINCIPAL DATA NEEDS

- INITIAL AND BOUNDARY CONDITIONS

  --INFILTRATION RATES
  --MOISTURE CONDITIONS
  --POTENTIALS
  --LIQUID-WATER FLUX
  --ISOTOPIC AND CHEMICAL ANALYSES OF WATER AND GASES
  --NATURE OF FLOW IN FRACTURES
  --PERCHED-WATER OCCURRENCE
  --CLIMATE DATA
  --PALEOHYDROLOGIC CONDITIONS, INCLUDING PAST WATER TABLE POSITIONS
  --EFFECTS OF TECTONICS ON FLUX AND WATER-TABLE ELEVATION

TESTS AND ANALYSES (SCP)

--EVALUATIONS OF NATURAL AND ARTIFICIAL INFILTRATION
--CHARACTERIZATION OF PERCOLATION
  --SURFACE-BASED AND ES STUDIES
--HYDROCHEMICAL CHARACTERIZATION
--INTACT-FRACTURE, INFILTRATION, AND BULK-PERMEABILITY TESTS IN THE ES
--HISTORY OF MINERALOGIC AND GEOCHEMICAL ALTERATION AT YUCCA MOUNTAIN
--PERCHED-WATER TEST IN THE ES
--HYDROLOGIC NUMERICAL MODELING
--STUDIES OF NATURE AND RATES OF CHANGE IN CLIMATIC CONDITIONS
--QUATERNARY UNSATURATED-ZONE HYDROLOGIC ANALYSIS
--STUDIES OF CALCITE AND OPALINE SILICA VEIN DEPOSITS
--ANALYSIS OF THE EFFECTS OF TECTONIC PROCESSES AND EVENTS ON AVERAGE PERCOLATION AND ON CHANGES IN WATER-TABLE ELEVATION

STRATEGY TO TEST HYPOTHESES

EXAMPLE: SINGLE-FRACTURE, INFILTRATION, AND BULK-PERMEABILITY TESTS IN EXPLORATORY SHAFT

- PROBLEM: HOW TO DETERMINE REPRESENTATIVE VALUES OF PERMEABILITY FOR A FRACTURED ROCK MASS?

- GOAL: DETERMINE WHETHER FRACTURE NETWORK CAN BE TREATED AS EQUIVALENT POROUS MEDIUM (REV APPROACH)

- ALTERNATIVE MODELS

1. NARASIMHAN (1982)

   --REV TOO LARGE TO BE TESTED IN FIELD
   --USE BOTH DISCRETE AND CONTINUUM APPROACHES

2. LONG AND OTHERS (1982)

   --FRACTURE-GEOMETRY PARAMETERS DETERMINE VOLUME OF REV
   --USE CONTINUUM APPROACH

3. NEUMAN (1987)

   --NO GUARANTEE OF REV; DETERMINISTIC APPROACHES REQUIRE TOO MUCH DATA
   --USE STOCHASTIC APPROACH

STRATEGY TO TEST HYPOTHESES
EXAMPLE (CONT.)

- CONDUCT TESTS IN EXPLORATORY SHAFT
  - --TEST AT INCREASING SCALES
  - --ALLOWS EXAMINATION OF ALL SIGNIFICANT FACTORS
  - --INVESTIGATE BOTH DISCRETE AND CONTINUOUS PHENOMENA
  - --PNEUMATIC TESTING OVER A RANGE OF SCALES (BPT) CHECKS FOR REV AND ALLOWS APPLICATION OF STOCHASTIC APPROACH
  - --FROM RESULTS, CAN SELECT APPROPRIATE MODEL OF FLUID FLOW IN UNSATURATED FRACTURED TUFF

SUMMARY

- DEVELOP A DESCRIPTION OF THE HYDROLOGIC SYSTEM AND THE PHYSICAL PROCESSES THAT CAUSE IT TO VARY OVER TIME

- INCLUDE A RANGE OF MULTIPLE ALTERNATIVE HYPOTHESES AND SCENARIOS

- ULTIMATELY, PRODUCE A CONSISTENT, INTEGRATED CONCEPTUAL MODEL THAT HAS AN ACCEPTABLE LEVEL OF UNCERTAINTY

ATTACHMENT C

U.S. DEPARTMENT OF ENERGY

OCRWM

Nevada Nuclear Waste Storage Investigations PROJECT

OGR

Nevada
Nuclear Waste
Storage Investigations Project

U.S. DOE-NRC

WORKSHOP ON "ALTERNATIVE CONCEPTUAL MODELS"

PRESENTED BY

JERRY SZYMANSKI

APRIL 11-15, 1988

United States Department of Energy
Nevada Operations Office/Waste Management Project Office

U.S. DEPARTMENT OF ENERGY

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CONTENT

- CONCEPTUAL MODELS. GENERAL.
- CONCEPTUAL MODEL OF THE DEATH VALLEY GROUNDWATER FLOW SYSTEM
  - CONCEPTUAL UNDERSTANDING OF THE TECTONIC ENVIRONMENT
  - CONCEPTUAL UNDERSTANDING OF FLOW SYSTEM
  - CONCEPTUAL UNDERSTANDING OF FLOW PROCESS IN THE VADOSE ZONE
  - DATA SUPPORTING THE PROPOSED CONCEPTUAL MODEL
- TECHNICAL ISSUES - DATA AND INFORMATION NEEDS

CONCEPTUAL MODEL OF A GEOLOGICAL SYSTEM
WHAT IS IT?

IS A SET OF THOUGHTS OR CONCEPTS WHICH:

1) PERTAINS TO A GEOLOGICAL SYSTEM OR IT'S GIVEN COMPONENT;

2) IS ORGANIZED OR USEFUL; AND

3) RECOGNIZES AND EXPRESSES:

   a) FUNDAMENTAL NATURE OF THE SYSTEM;

   b) CIRCUMSTANCES UNDER WHICH THE SYSTEM OPERATES; AND

   c) COMBINATION OF a) AND b).

GEOLOGICAL SYSTEM

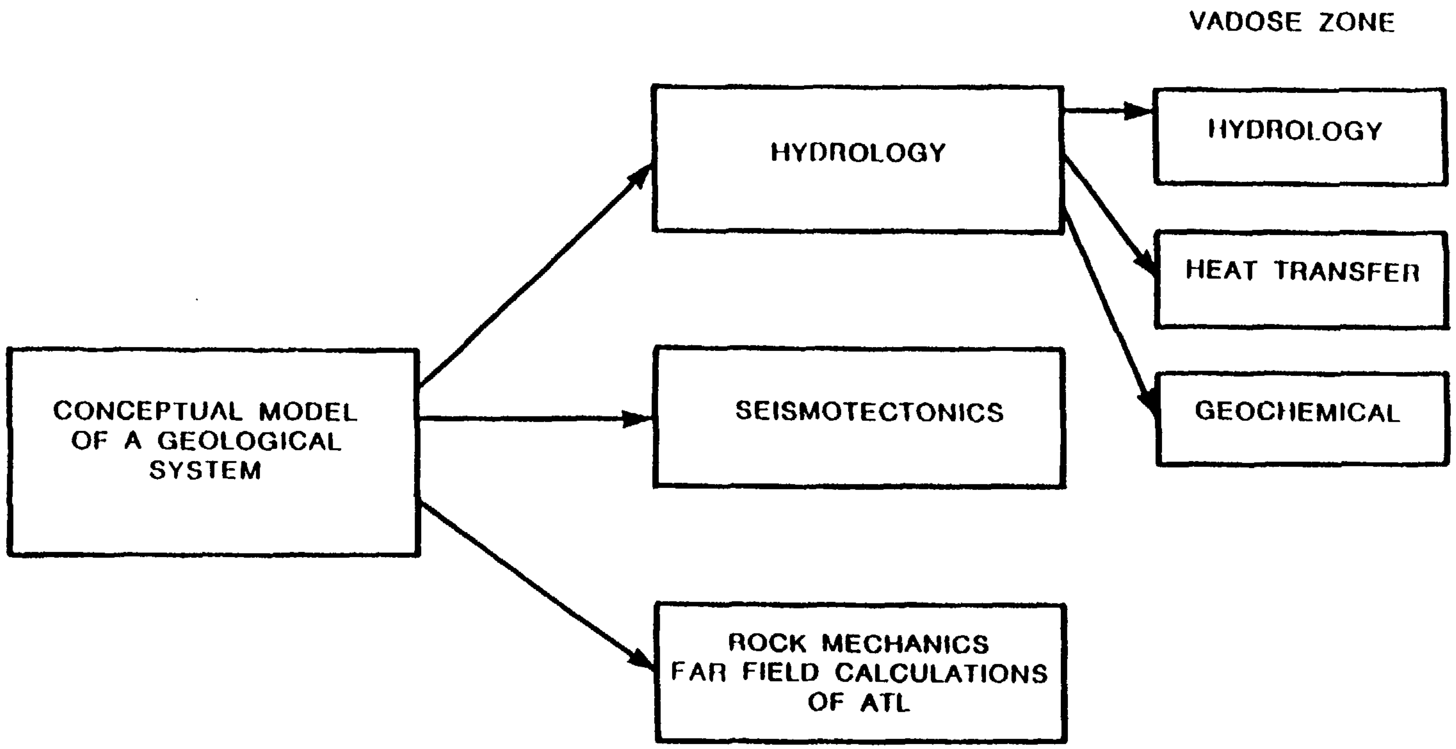
- "A BODY REPRESENTING A PORTION OF EARTH CRUST AND COMPOSED OF INTERACTING AND INTERDEPENDENT PARTS" OR SUBSYSTEM

- SUBSYSTEM "MUST NOT BE TREATED IN ISOLATION FROM THE GEOLOGICAL SYSTEM OF WHICH IS ONLY A PART"

- CHARACTERIZATION OF GEOLOGICAL SYSTEMS. "RECOGNITION TAT WE CANNOT EXPECT TO DEFINE ALL THE PARTS OF A SYSTEM AS COMPLEX AS THE GEOLOGICAL SYSTEM WITHIN WHICH DISPOSAL OF WASTE IS TO BE CARRIED OUT. THE OVERALL OBJECTIVE MUST BE TO GAIN A KNOWLEDGE OF THEOSE PROCESSES PERTINENT TO CONTAINMENT WITHIN THE SYSTEM WHICH IS SUFFICIENT TO RATIONALIZE THE POTENTIAL FOR WASTE/SYSTEM INTERACTION".

HARPER AND SZYMANSKI 1980. "A PERSPECTIVE OF GEOLOGICAL CHARACTERIZATION REQUIRED FOR SUBSURFACE NUCLEAR WASTE DISPOSAL". STOCKHOLM, SWEDEN

INTERDEPENDENCE OF CONCEPTUAL MODELS



CONCEPTUAL MODEL OF A SUBSYSTEM <u>MUST</u> <u>NOT</u> BE TREATED IN ISOLATION FROM THE GEOLOGICAL SYSTEM OF WHICH IT IS ONLY A PART.

CONCEPTS MUST BE USEFUL

i.e., ORGANIZED WITHIN A SPECIFIC FRAMEWORK AS DICTATED BY THE REQUIREMENTS OF THE MATHEMATICAL MODELS

- GOVERNING EQUATION
  - CONSERVATION (MASS, THERMAL ENERGY , MOMENTUM)
  - STATE (STEADY; TRANSIENT)
  - CONSTITUTATIVE RELATIONSHIP, EQUATIONS OF STATE
  - COUPLING, COUPLING MECHANISMS
- BOUNDARY CONDITIONS
  - i.e., MASS AND/OR ENERGY INPUT INTO THE SYSTEM
- INITIAL CONDITIONS
- SPACE AND TIME DEPENDENCE OF CONSTANTS RELATING WORK AND ENERGY

  $K_f; K_h(x; y; z; t)$

CONCEPTS RECOGNIZE AND EXPRESS FUNDAMENTAL NATURE OF THE SYSTEM

EXAMPLE

- BEDDED SALT
  - GRAVITATIONALLY UNSTABLE (BIOT, 1961; BARROWS, 1983)
  - CONTAINS FLUID INCLUSIONS
  - YIELD STRENGTH IN NEGLIGIBLE

    CONCEPTUAL MODEL - HYDROLOGY
    = PRESSURE GRAD. INDUCED BRINE MIGRATION.
    BEHAVIR OF MIXTURE OF TWO FLUIDS WITH VERY DIFFERENT MAXWELL RELAXATION TIME AND SUBJECTED TO $[\sigma; \tau]$ CONTAINING DISEQUILIBRIUM COMPONENT

- GRANITE BODY
  - CONTAINS DISTRIBUTED HEAT SOURCES (RADIOGENIC HEAT)

    CONCEPTUAL MODEL - HYDROLOGY MUST INCLUDE:
    STEADY - STATE CONVECTION; OR
    TRANSIENT CONVECTION.

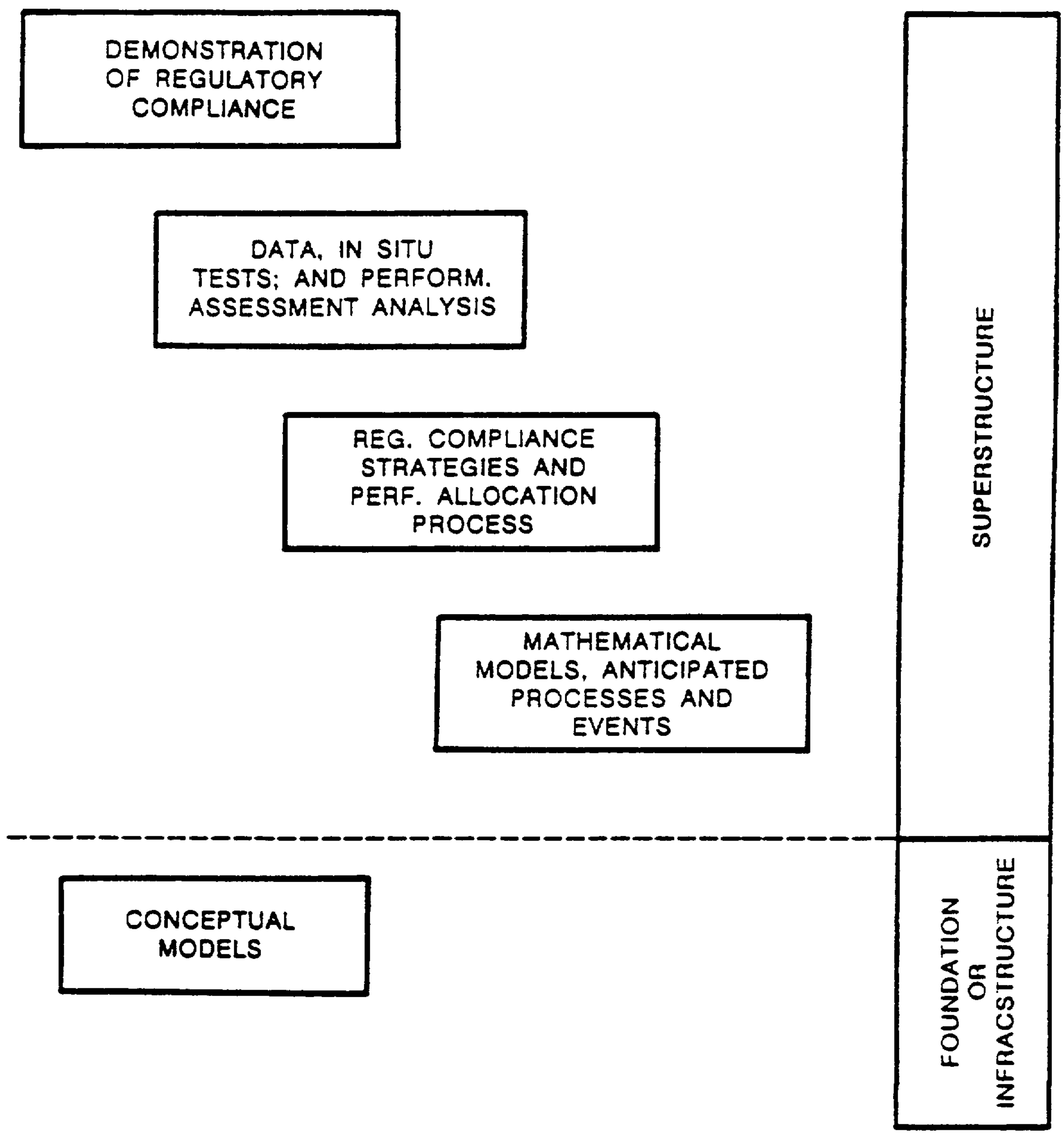
    $\frac{\partial \phi}{\partial t}; \frac{\partial a}{\partial t}$

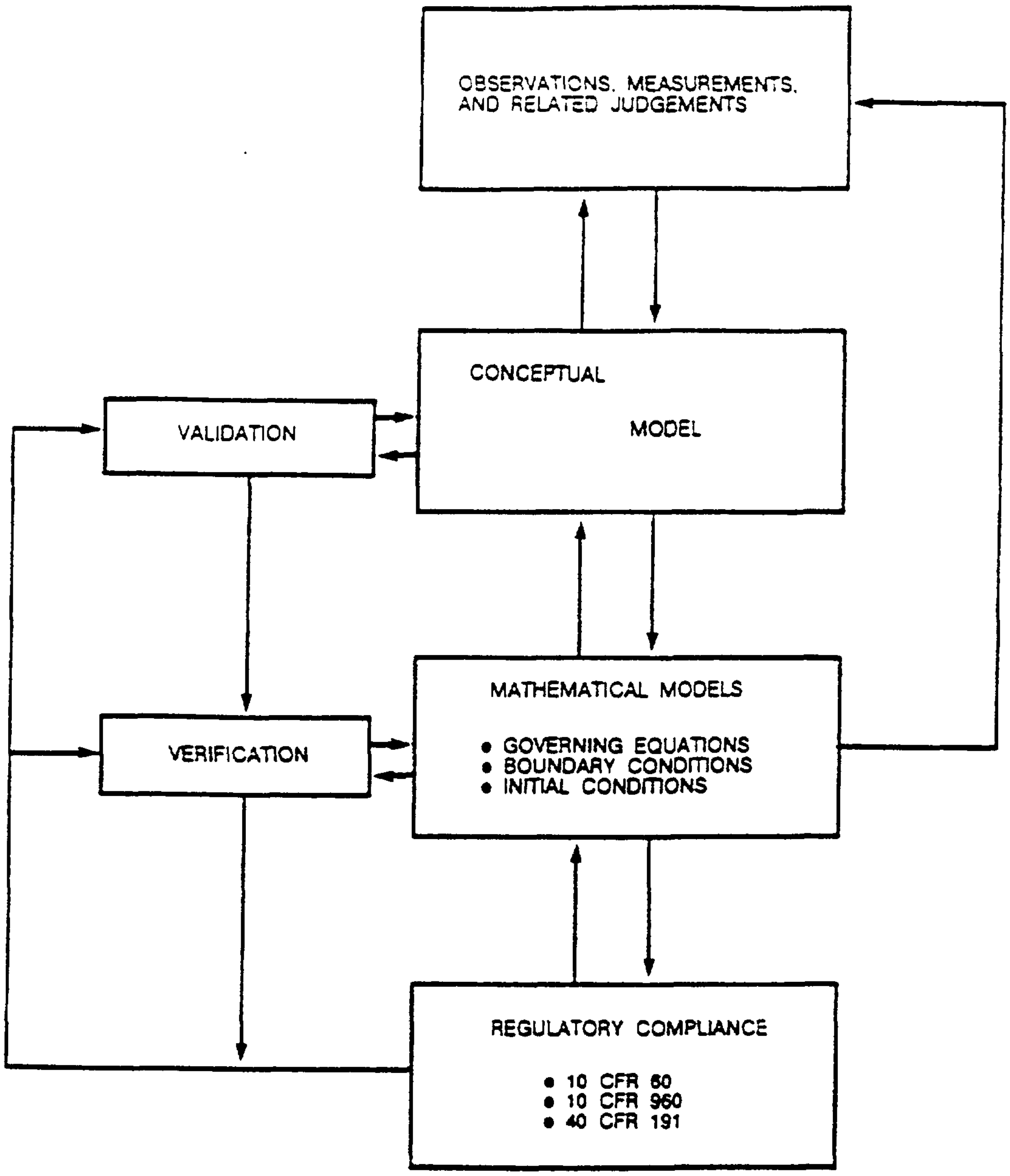
CONCEPTS RECOGNIZE AND EXPRESS CIRCUMSTANCES UNDER WHICH THE SYSTEM OPERATES

- **TECTONIC SETTING WHICH INCLUDES ACTIVE, i.e., EPISODIC, FAULTING AND ALKALINE, i.e., MANTLE DERIVED, VOLCANISM**
  - **STRAIN ENERGY VARY IN TIME AND SPACE, i.e.,** $\frac{\partial^2(\sigma_{zz};\tau_{zy})}{\partial t \cdot \partial z} \neq 0$
  - **HEAT FLOW IN "HIGH" AND/OR HETEROGENOUS IN A PLANER SENSE, i.e.,** $R^* > R_{cr}$ **AND/OR** $\frac{\partial temp}{\partial y} \neq$ **CONST.;** $\frac{\partial temp}{\partial z} \neq$ **CONST.**

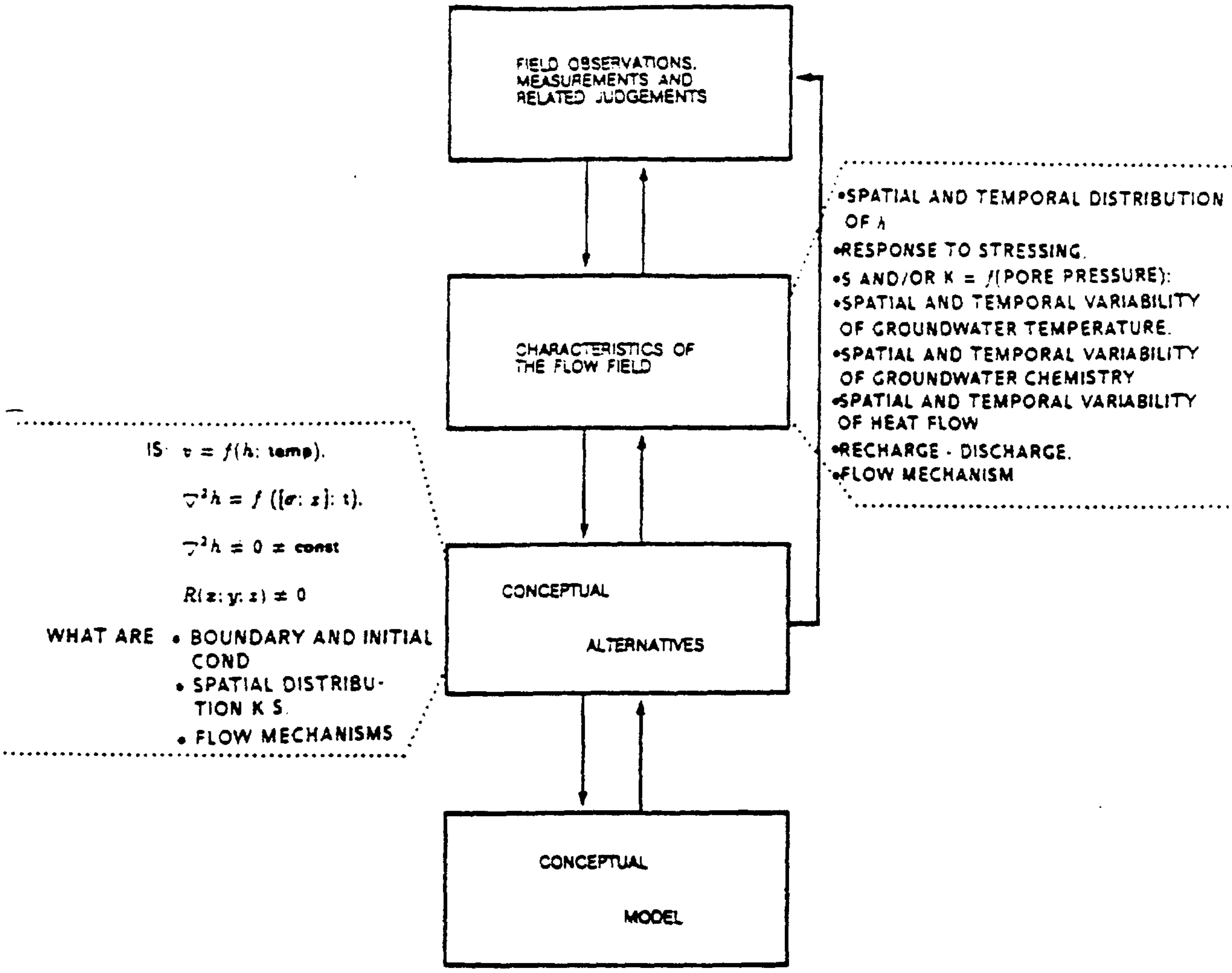
- **CONCEPTUAL MODEL OF HYDROLOGICAL SYSTEM MUST, THEREFORE, RECOGNIZE:**
  - **TIME-DEPENDENCE OF THERMAL AND HYDRAULIC PARAMETERS OF THE MEDIUM** $K_f; K_h; S; D$
  - **CONNECTIVE ASPECTS OF THE FLOW PROCESS;**
  - **TRANSIENT NATURE OF THE FLOW FIELD, i.e.,** $\nabla^2 h \neq 0 \neq$ **CONST.**

IMPORTANCE OF CONCEPTUAL MODELS





Role of mathematical and conceptual models.

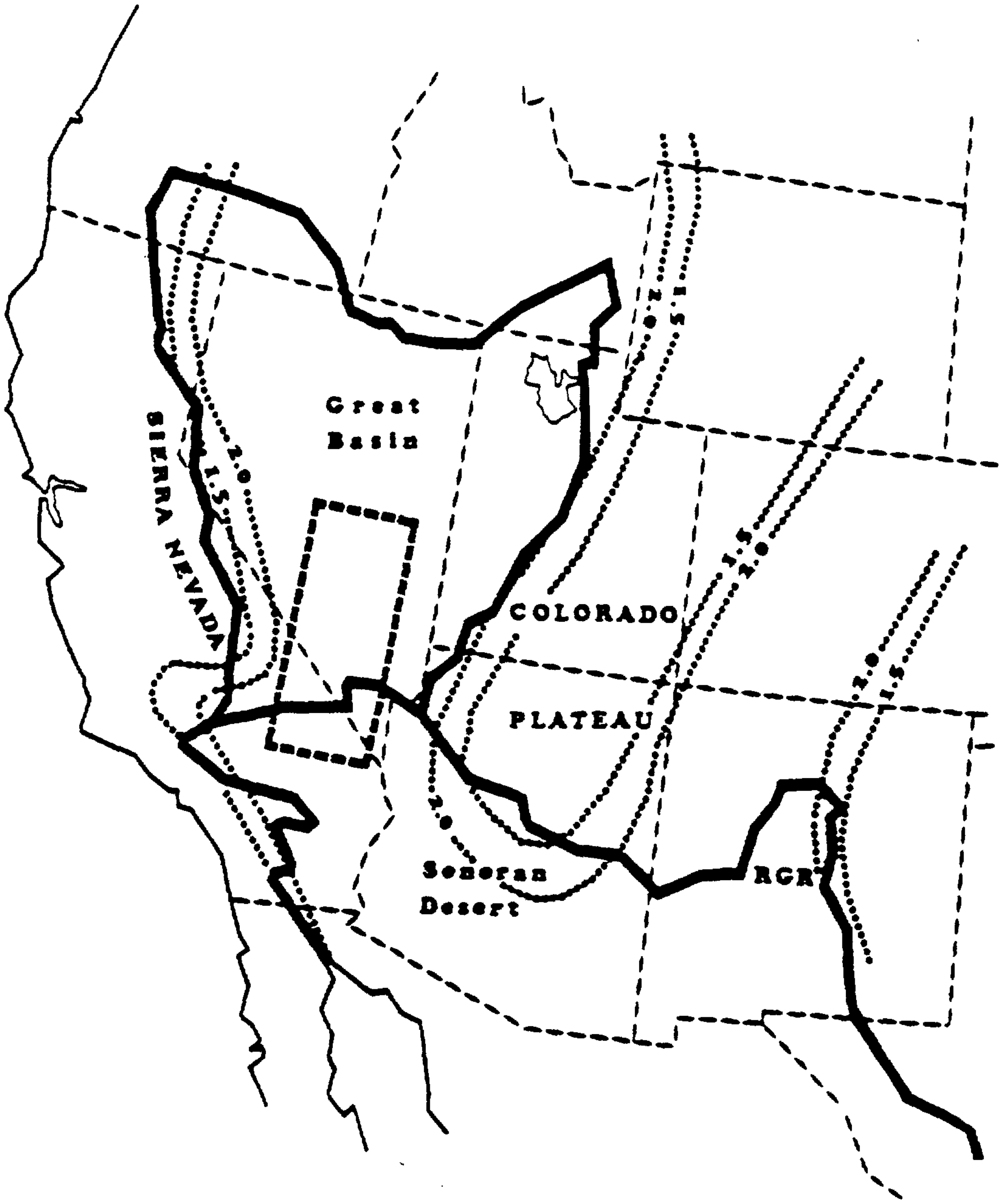


Conceptual model of groundwater flow system.

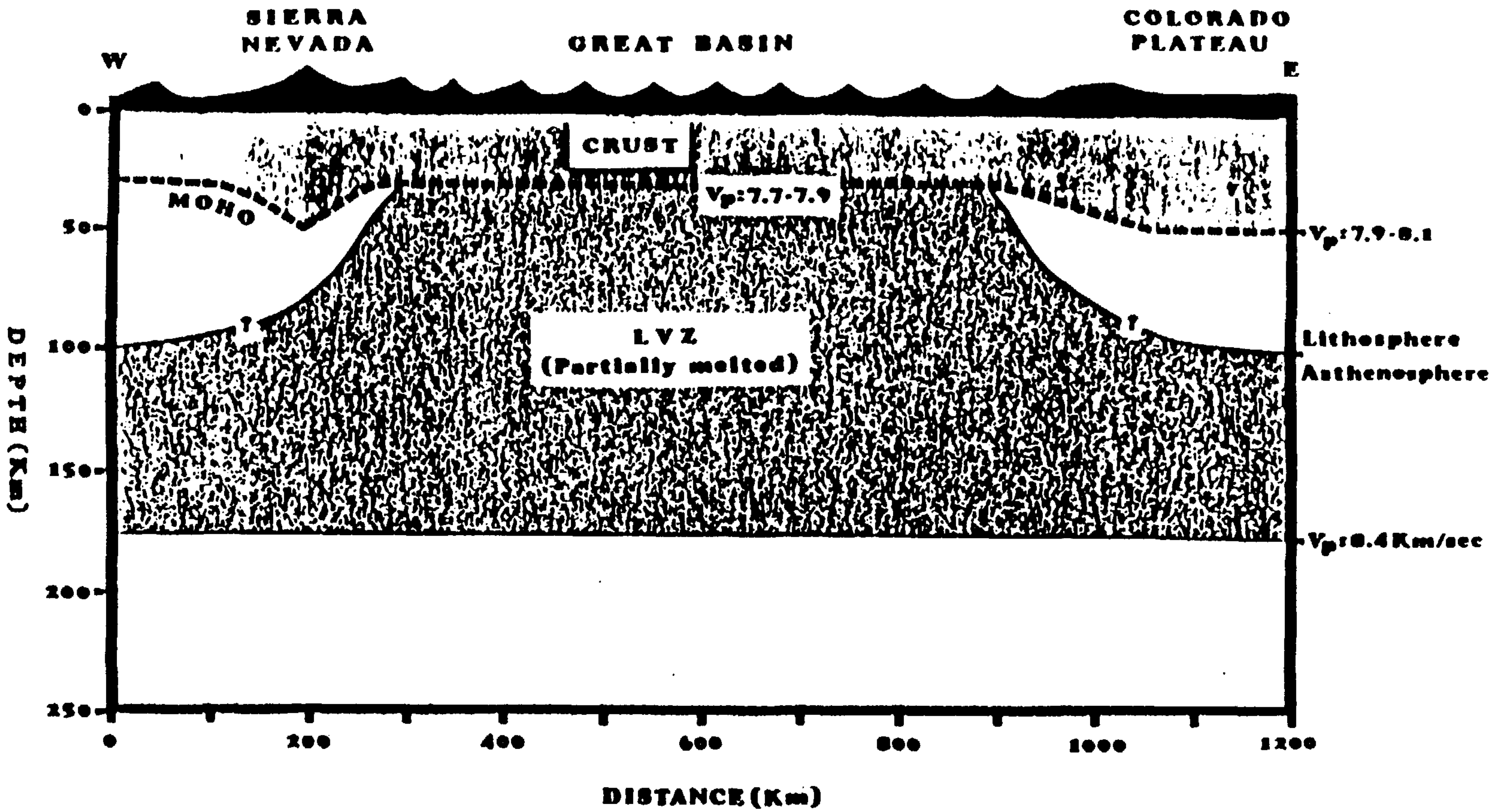
CONCEPTUAL UNDERSTANDING OF TECTONIC ENVIRONMENT OF THE YUCCA MOUNTAIN SITE

- REGIONAL TECTONIC SETTING
- LOCAL CHARACTERISTICS
  - FAULTING; STRAIN STATE; AND
  - VOLCANISM; CRUSTAL STRUCTURE; HEAT FLOW
- SYNTHESIS
  - CONCEPTUAL MODEL OF THE TECTONIC ENVIRONMENT

REGIONAL TECTONIC SETTING



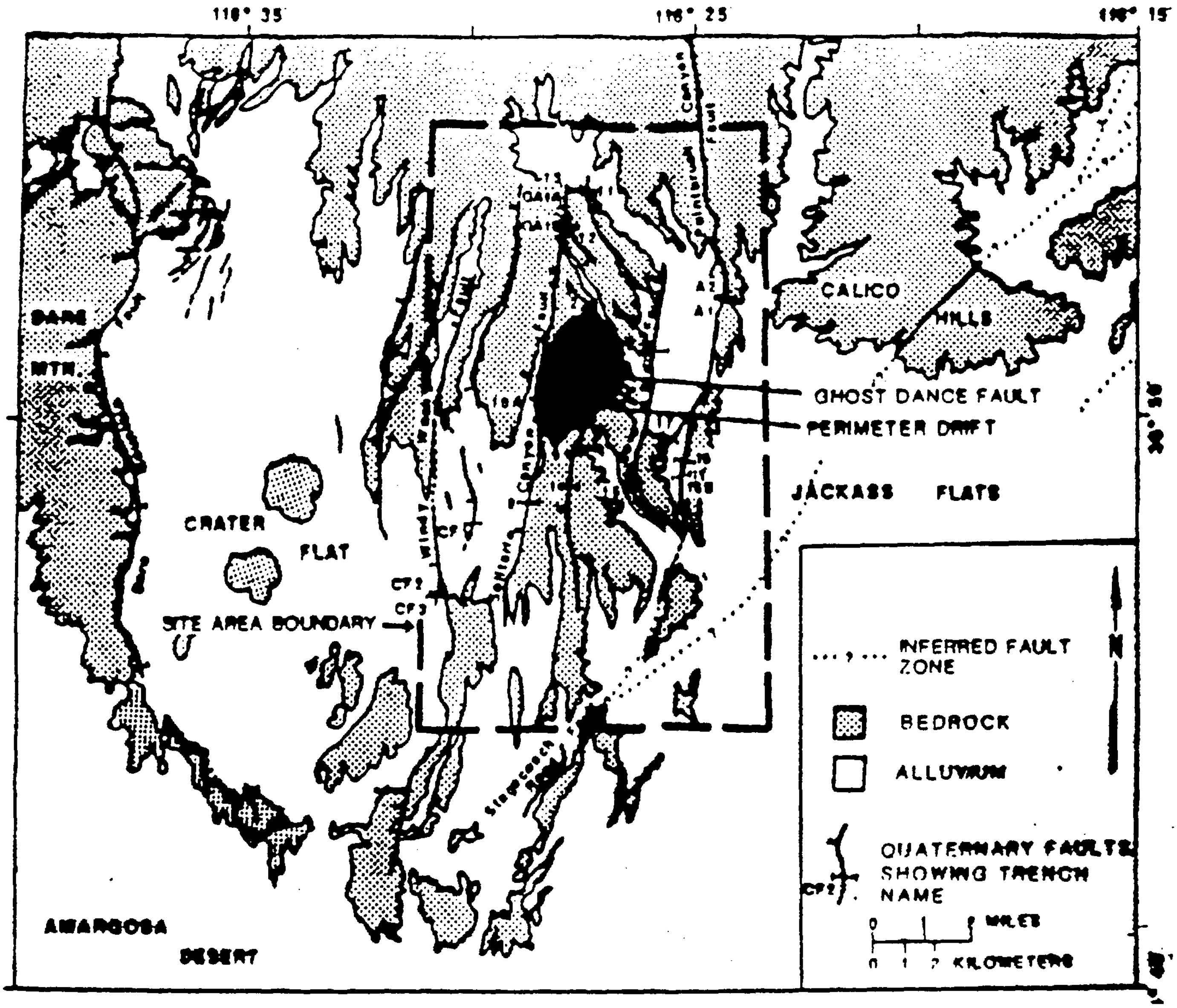
Map of the Basin and Range physiographic province, showing the Great Basin and Sonoran Desert subprovinces, the Rio Grande Rift (RGR), and bordering provinces. The boundaries (bold) are from Fenneman (1931). The fine dotted lines are surface heat-flow contours (in HFU), from Thompson and Burke (1974). The region enclosed by the heavy dotted line is the study area of this thesis, which is shown in greater detail in Figures 5 and 7.



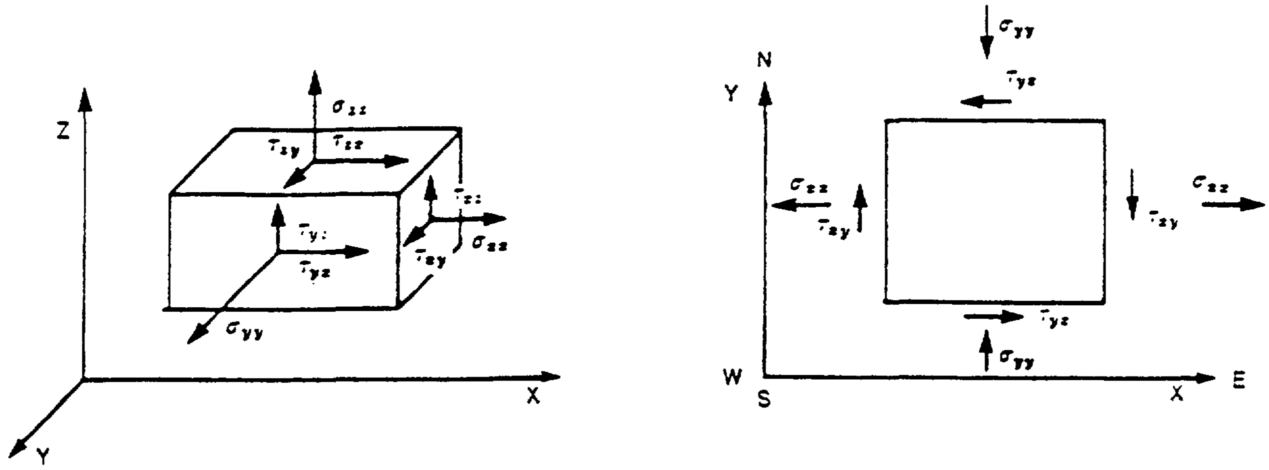
Schematic section through the central Great Basin, after Scholz et al. (1971).

LOCAL CHARACTERTISTICS

- FAULTING; AND
- STRAIN STATE
  - LONG TERM
  - SHORT TERM
  - VERY SHORT TERM



Quaternary faults near proposed repository site. Modified from Maldonado, 1985



STRAIN COMPONENT	STRAIN RATE OR STRAIN ACCUMULATION	SOURCE
ϵ_{xx}	$\dot{\epsilon}_{xx} = 0.07 \times 10^{-6}$/per year	WERNICKE et. al. 1982.
	$\dot{\epsilon}_{xx} = 0.08 \times 10^{-6}$/per year	SAIC. 1984.
	$\dot{\epsilon}_{xx} = 2 \times 10^{-8}$/per year	GREENSFELDER et. al. 1980.
ϵ_{yy}	$\dot{\epsilon}_{yy} = -0.10 \times 10^{-6}$/per year	SAIC, 1984
γ_{xy}	$\gamma_{xy} = \int_0^{12\times10^6}\int_0^{25} \gamma_{xy(y)}\,dy \cdot dt$ $= \tan 30°$ in 25 km in $\approx 12 \times 10^6$ years	SCOTT AND ROSENBAUM, 1986.
γ_{xy}	$\gamma_{xy} = 3 - 7 \times 10^{-3} in$ 3×10^6 years	CARR, 1984.

Summary of strains rates and of accumulated shear strain for the region of Death Valley groundwater basin.

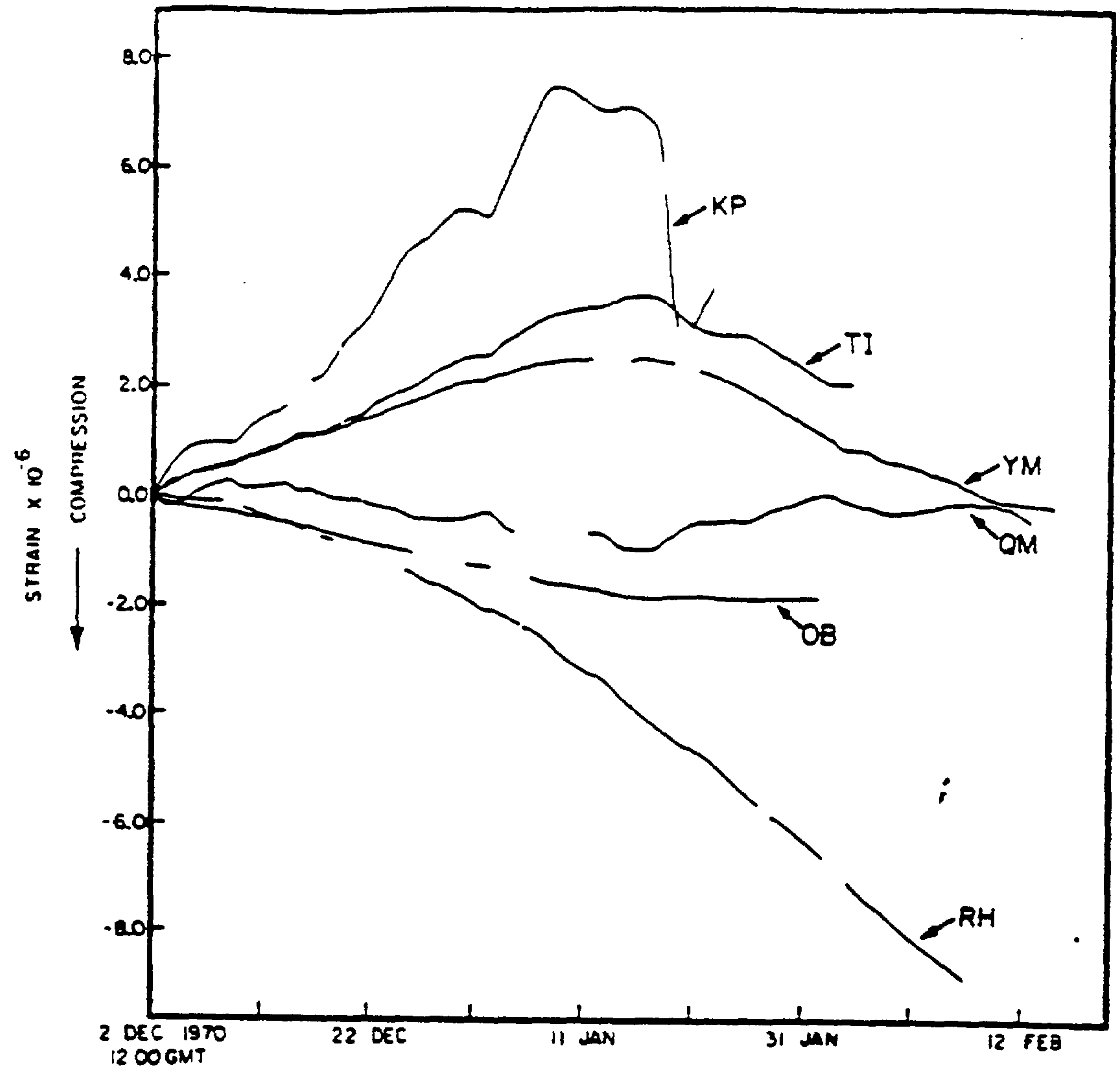


Fig. 3. Long-period part of the observed strain data.

to observe some features common to more than one site by observing Fig. 3. Attention is called to three particular times; December 9 when a variation common to QM and KP occurred: January 2nd when a variation common to KP, TI and QM occurred; and finally January 18 when a very large change occurred in KP accompanied by a change in a major trend of strain at TI, YM, QM and OB. These three episodes will be discussed in more detail in a next section when a best-fit regional strain field is calculated. At this point, we note only that the episodes on December 9 and January 2nd are rather sudden departures from the long-term trend in the strain appearing almost as interruptions with duration of a day to several days after which the main trend is resumed. The episode on January 18 is remarkable in that the sign of the trend in strain changes on all stations except RH and KP showed such an unusual strain change that special attention was paid to it to determine if any instrument malfunctions had occurred. These investigations convinced us that the instrument was working properly during this time and that no unusual conditions existed at this site.

correlation coefficients, a very weak common field, or the field changes significantly after dropping one station or adding another one. This is true for the period from the beginning of the data until about January 18, when the observed change in the trend of all stations, except RH, occurs (Fig. 3). At this time the observed common field breaks down fairly rapidly because of the rapid change at KP. All station combinations which include KP show strong effects. However, station combination 8, which excludes RH and KP, shows generally the same behavior, although at a lower rate. This is another indication that this particular event at KP is real. The least-square strain field for all stations except RH on January 8, 1971, 00.00 G.M.T. is shown in Fig. 6. The extensional principal axis of this field is oriented N 48° W and its maximum value is about $1.3 \cdot 10^{-5}$. The maximum value of the compressional principal axis is about $5.8 \cdot 10^{-6}$. This field does not increase uniformly. Several smaller temporary reversals of the general trend occur at times, when in the raw data (Fig. 3) peaks are observed. After about the middle of January another field emerges, which includes RH. At the end of the data, however, the build-up of this new field is not yet finished. At this time *Ey* has already the same magnitude as in the previously observed field, but continues to rise. *Ex* has still a much lower value and α has

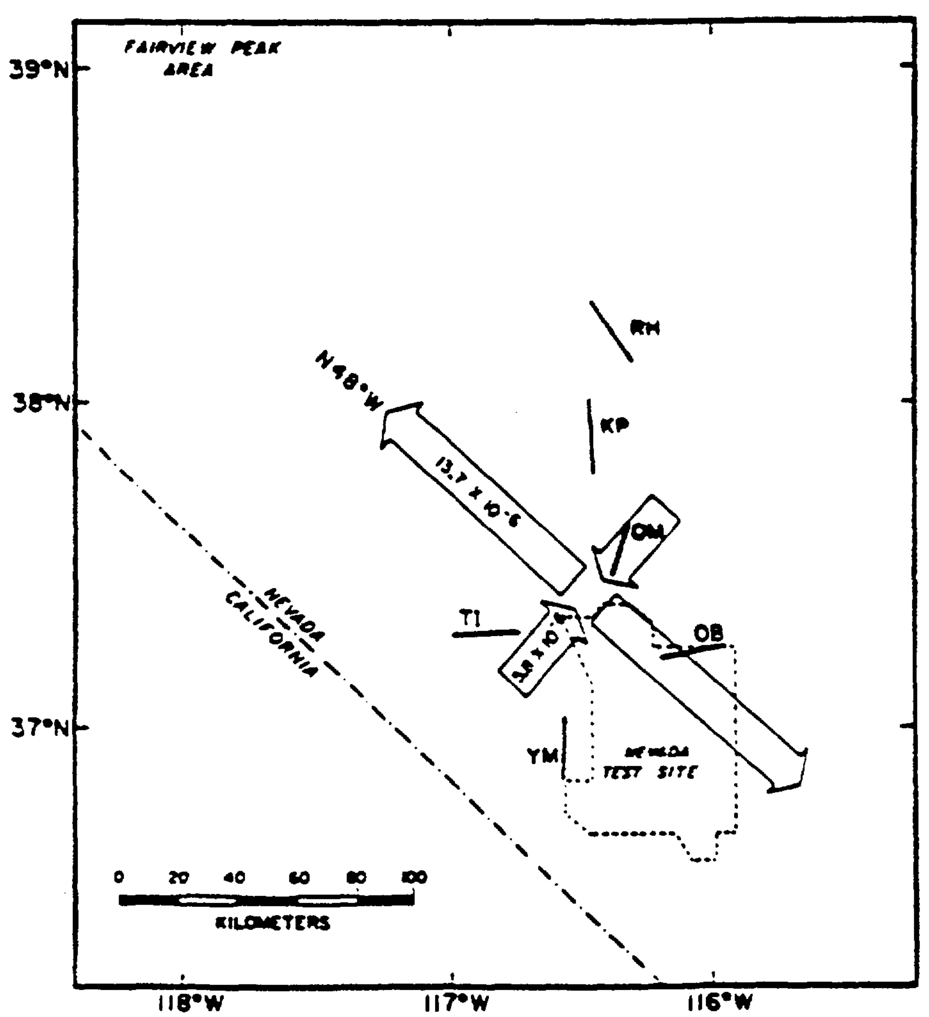
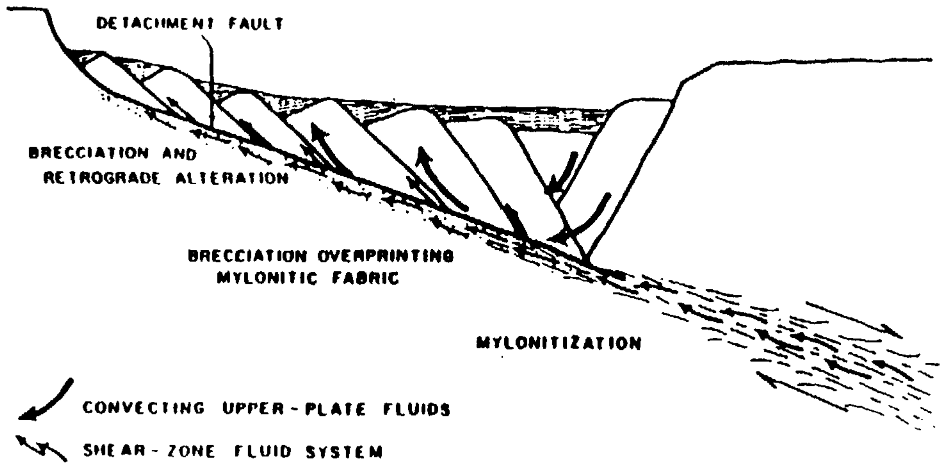


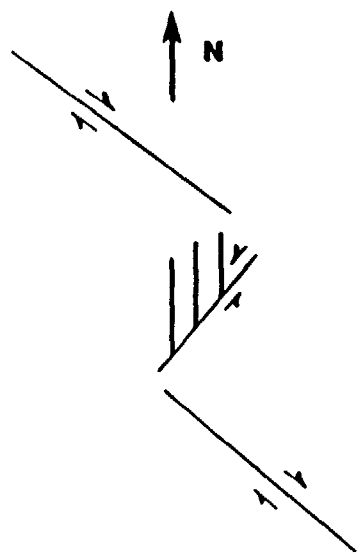
Fig. 6. Location and orientation of strainmeters and least-square strainfield for all stations except RH at January 8, 00.00 G.M.T.

TWO TECTONIC MODELS

a) DETACHMENT FAULTING

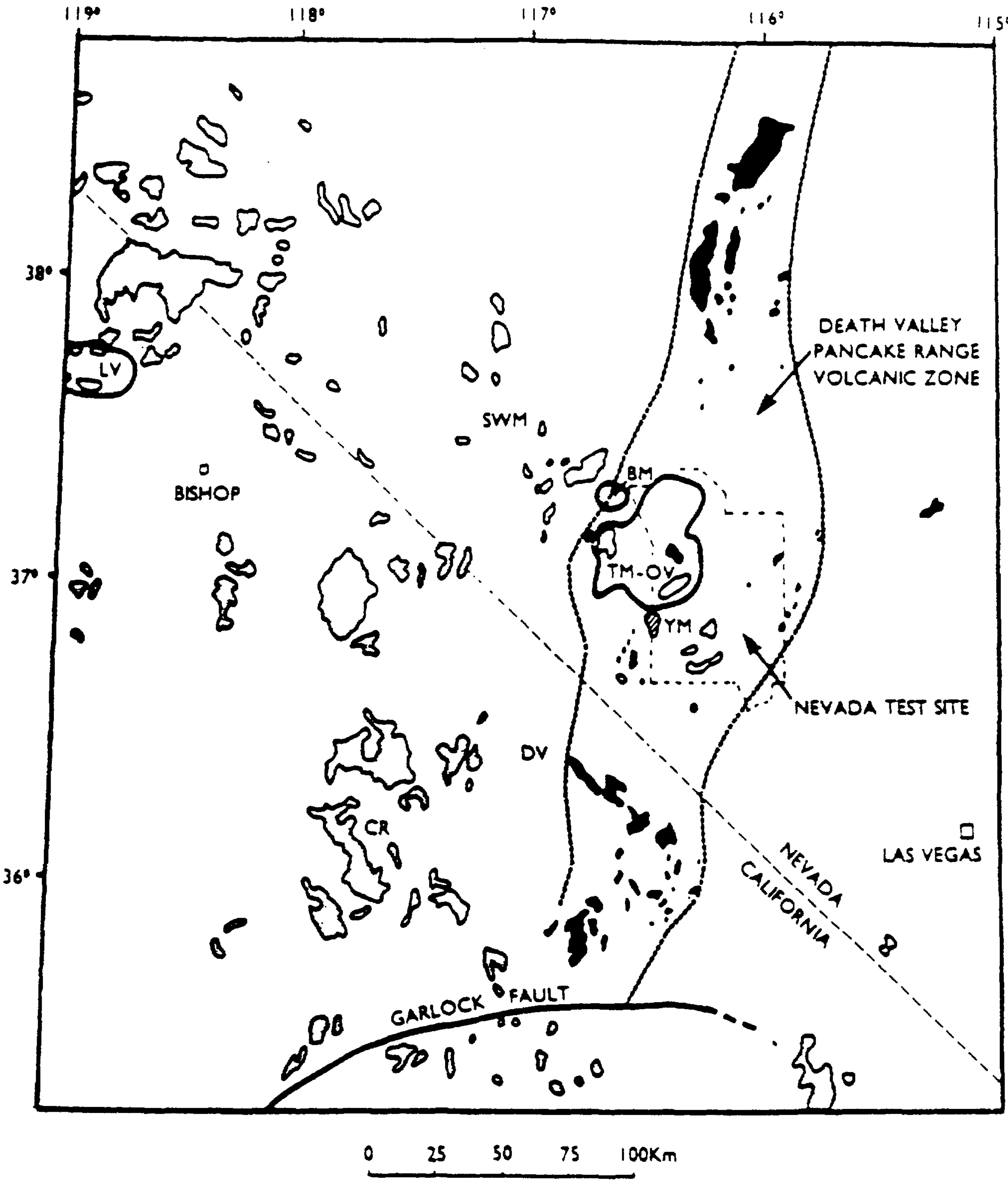


b) DEXTRAL WRENCH SYSTEM. LOCAL STRUCTURE - RIGHT STEP OR DIVERGENT RIFT STRUCTURE



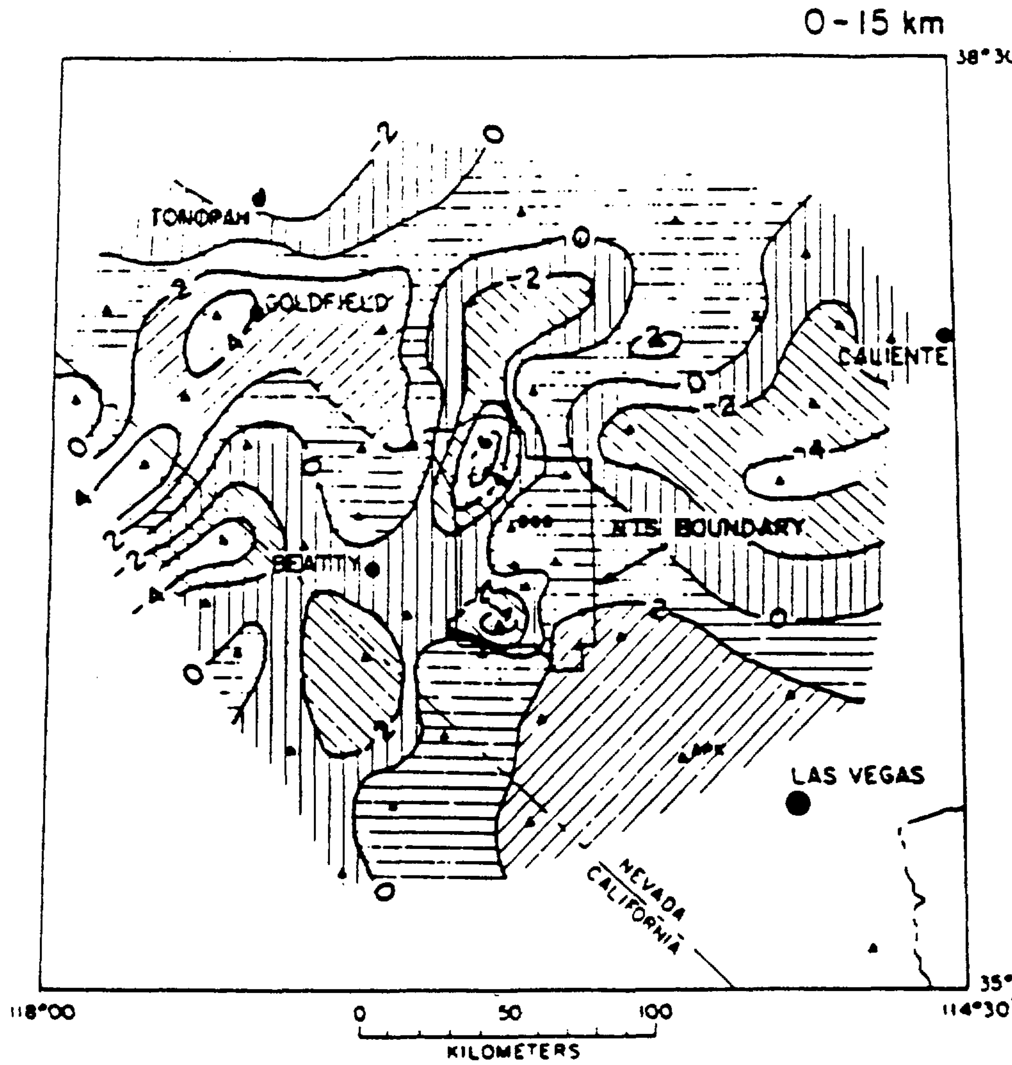
LOCAL CHARACTERTISTICS

- VOLCANISM;
- CRUSTAL STRUCTURE
  - P-WAVE RESIDUALS
  - GRAVITY
- HEAT FLOW

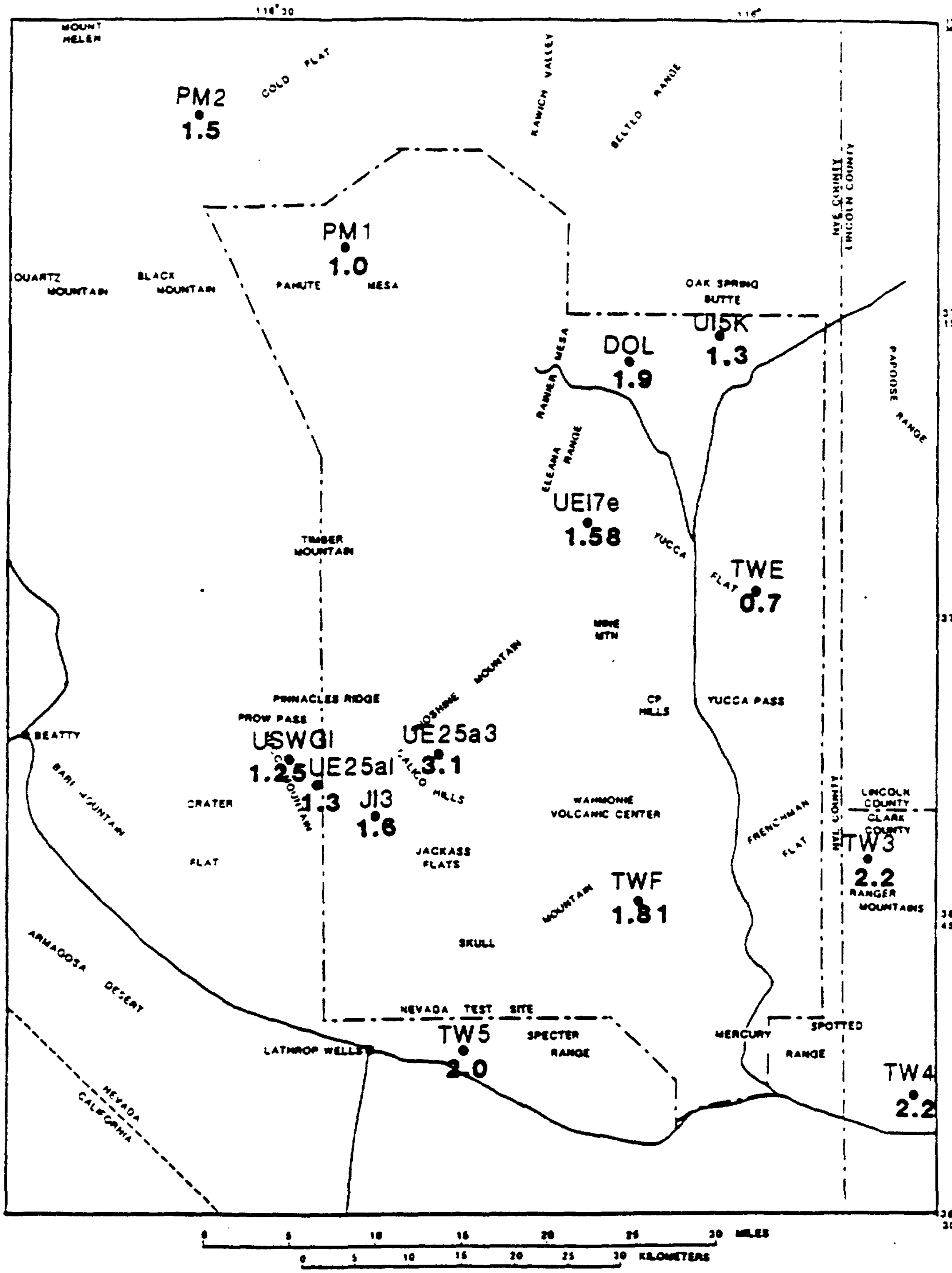


Explanation. SWM Stonewall. BM Black Mountain; TM-OV Timber Mountain-Oasis Valley caldera complex; YM Yucca Mountain exploration block; LV Long Valley; DV Death Valley; and CR Coso Range. Black-shaded areas are volcanic rocks of the DV-PR volcanic zone. light-shaded areas are part of the western Cordillera rift zone.

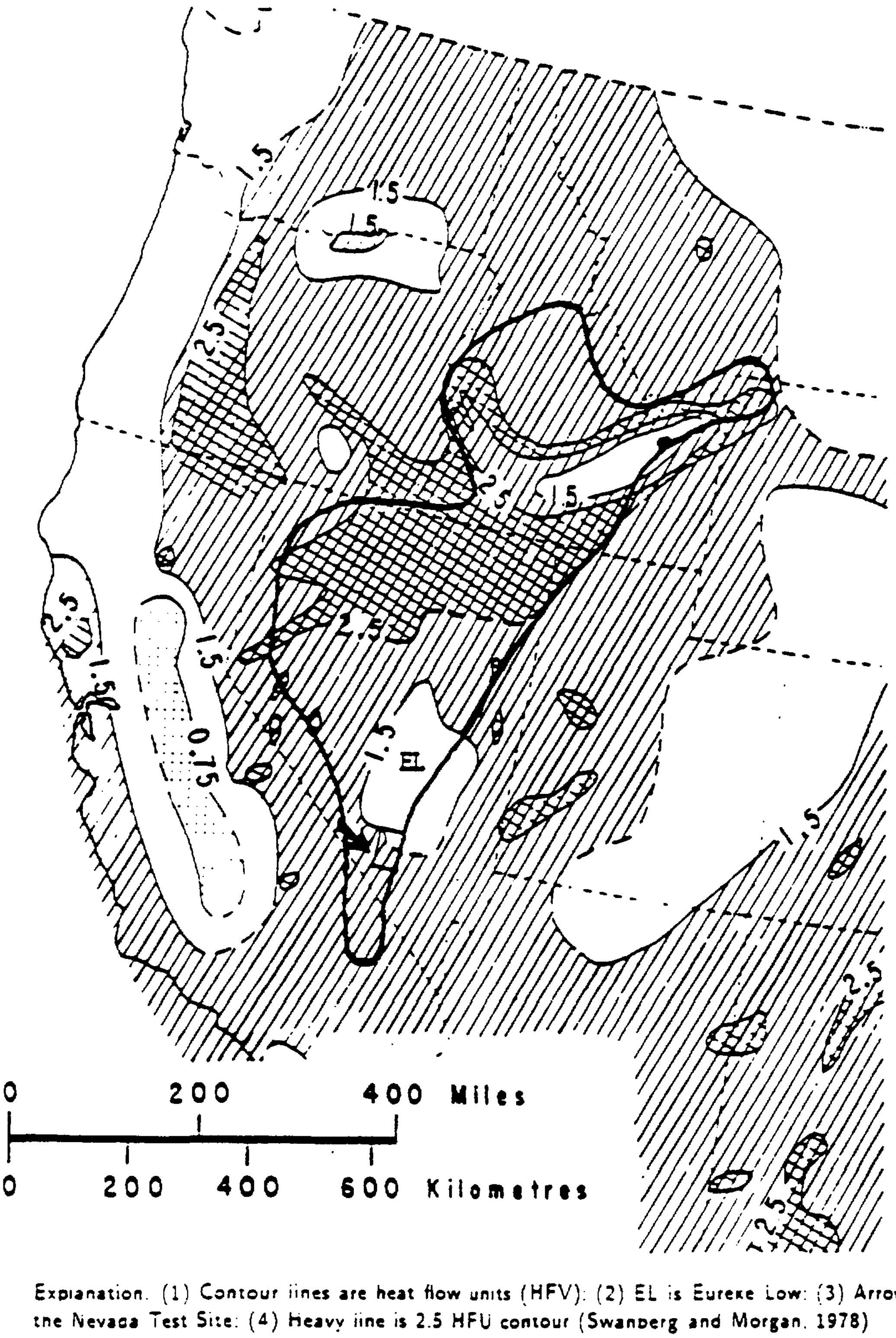
Generalized geologic map of the Death Valley Pancake Range Volcanic Zone. Crowe et. al. 1986



Seismic velocity structure of the upper crust from teleseismic P-wave residuals for the region of southern Nevada. Monfort and Evans, 1982

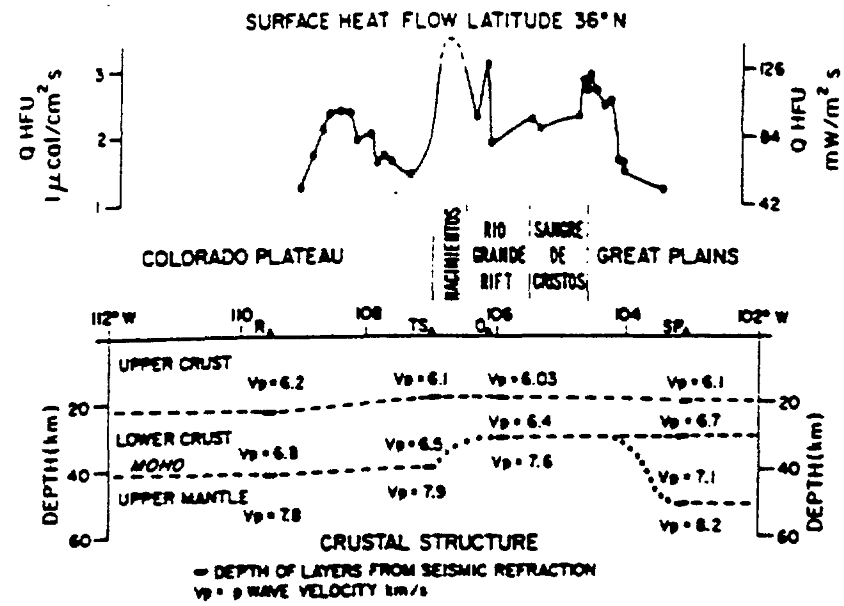


Intensities of heat flow in near ground surface rocks at the Nevada Test Site. From Sass and Lachenbruch (1982)



Explanation. (1) Contour lines are heat flow units (HFV); (2) EL is Eureke Low; (3) Arrow indicates outline of the Nevada Test Site; (4) Heavy line is 2.5 HFU contour (Swanberg and Morgan, 1978)

Map of Western United States showing intensities of heat flow. From Sass and Lachenbruch (1982).



Surface heat flow and seismic crustal structure for the Rio Grande rift and associated physiographic provinces of the North American Continent. Bridwell R.J. and Potzick, 1981.

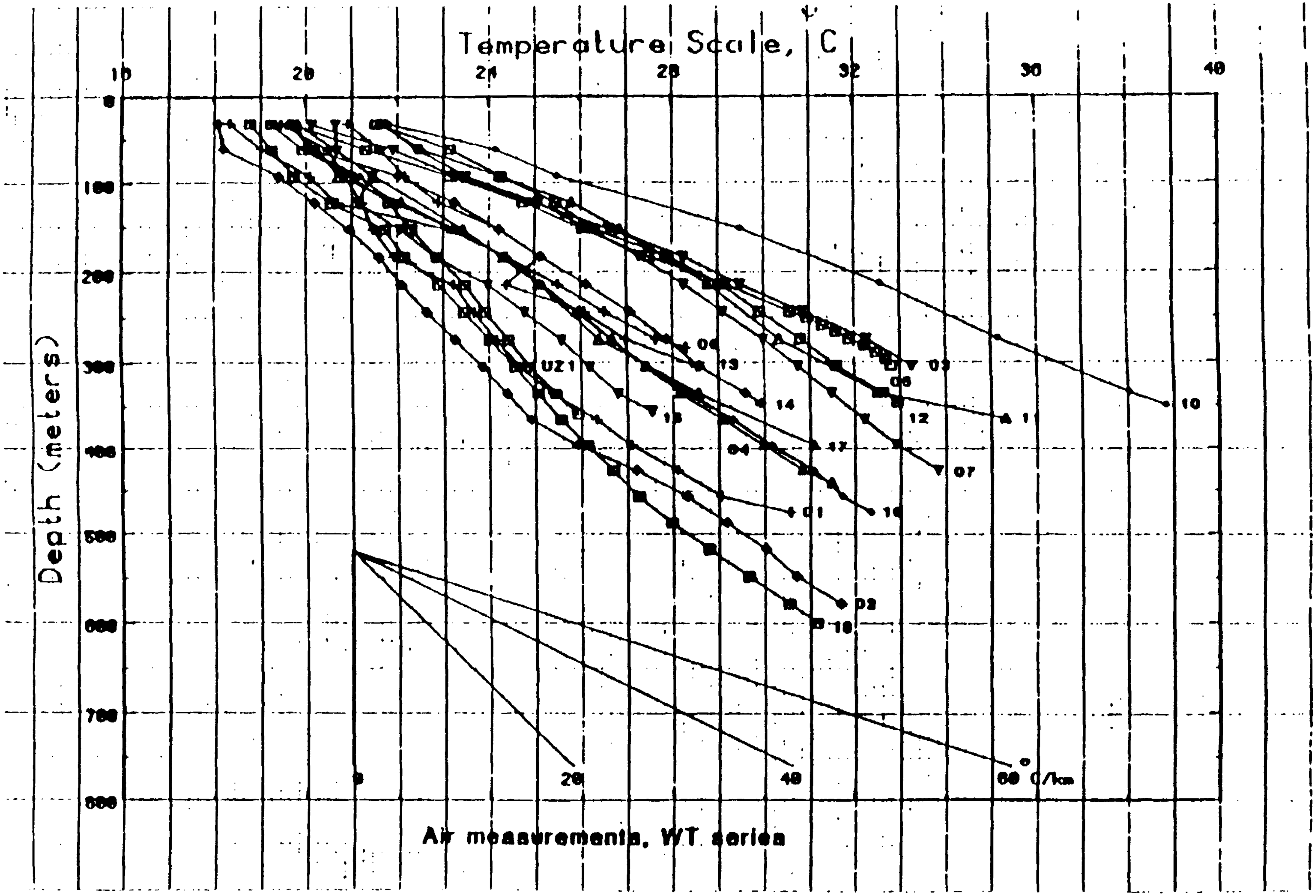
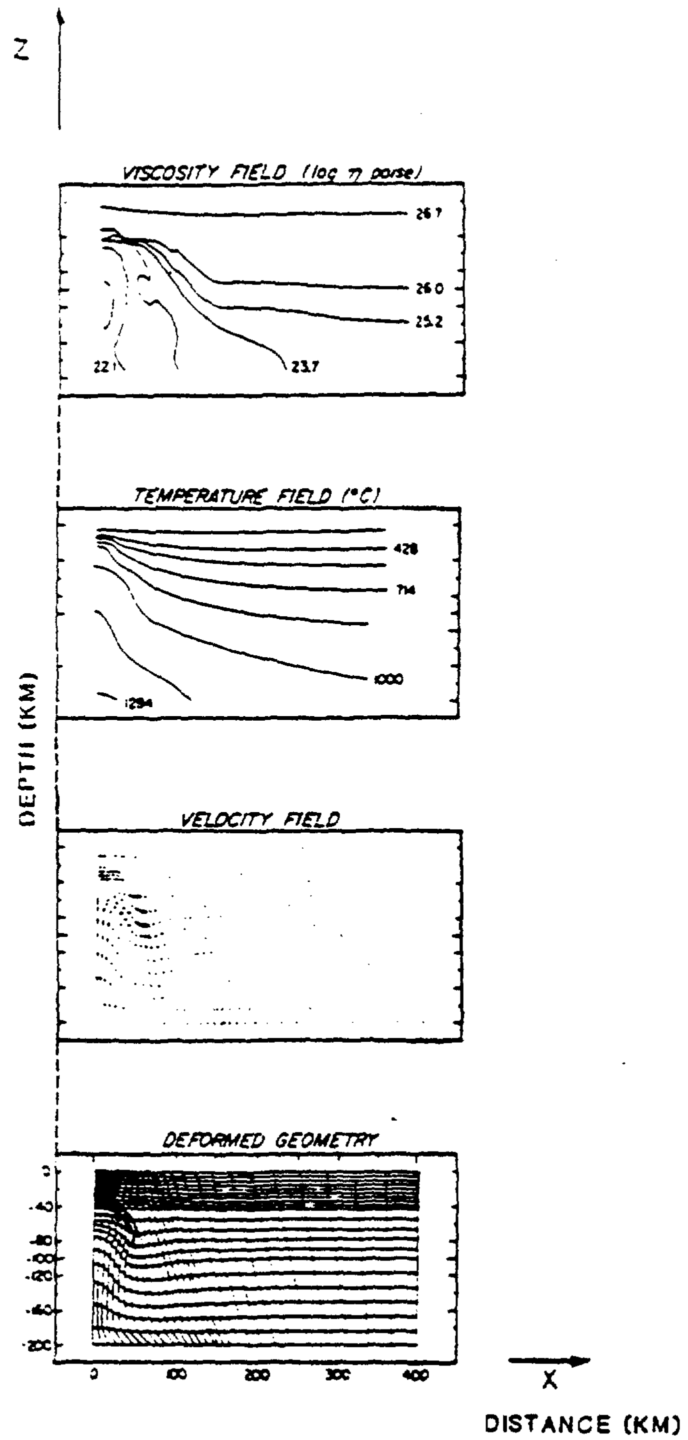


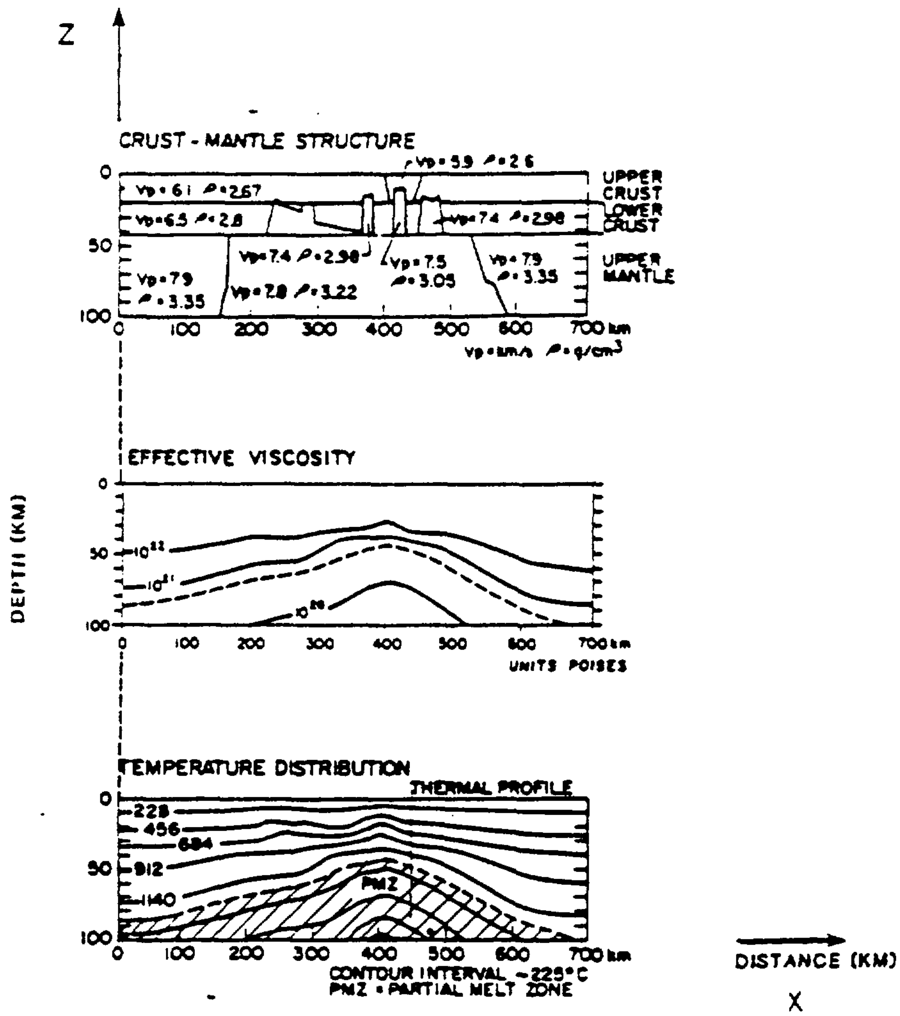
Figure 10. Temperature profiles from WT series wells (see Appendix 2 for individual profiles).

SYNTHESIS

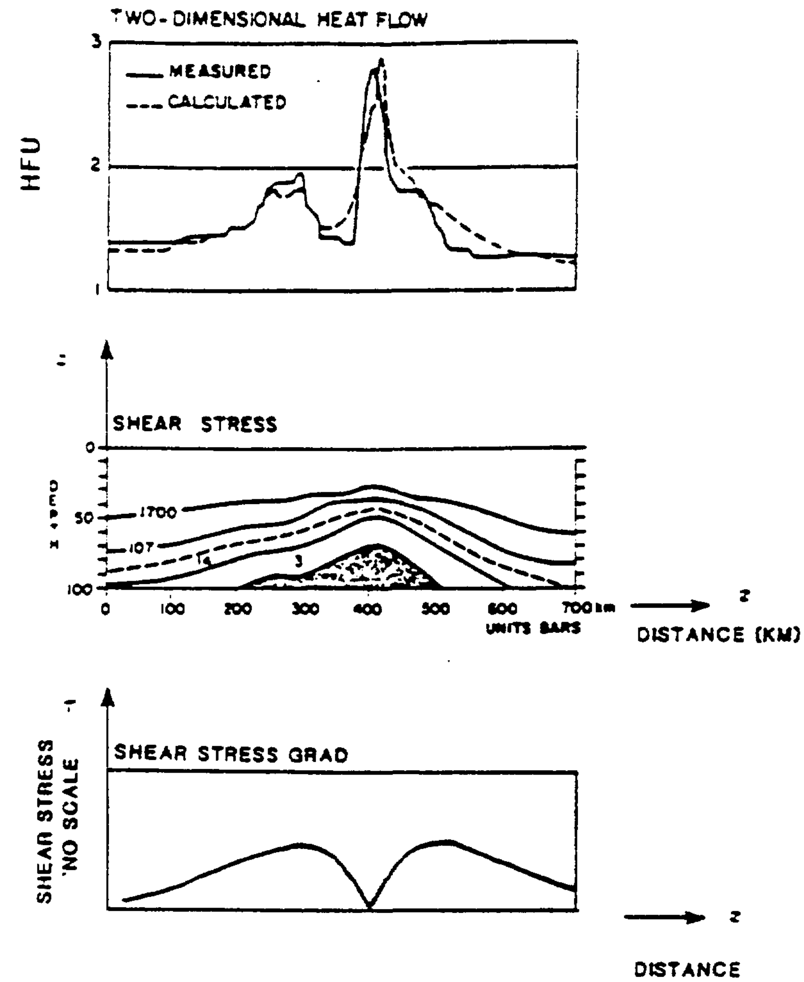
- CONCEPTUAL MODEL OF TECTONIC ENVIRONMENT



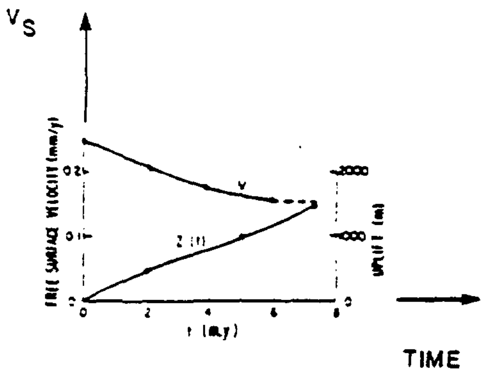
Numerical analysis of a process of upwelling of asthenospheric materials into lithosphere for the Rio Grande Rift
Bridwell R J Potzick 198.

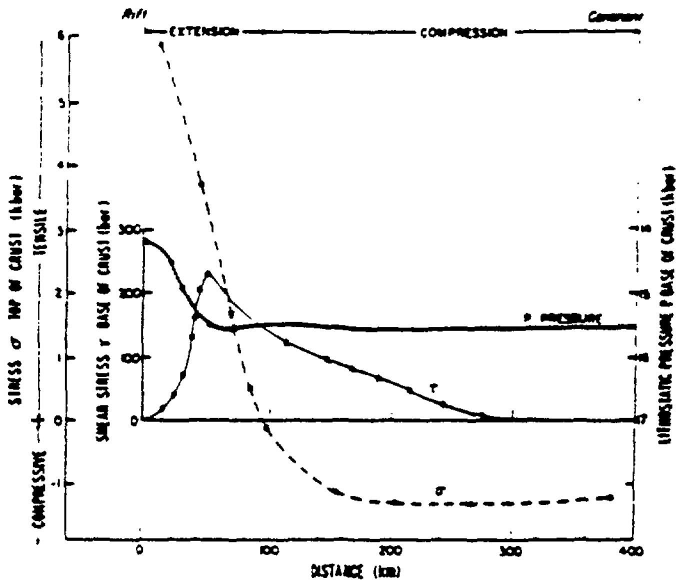


Effect of a mantle upwelling on lithospheric structure. Bridwell R.J 1978



Surface heat flow and shear stresses in upper mantle and lower crust resulting from convective flow of heat and mass in the upper mantle Bridwell R J , 1978





Continuum crustal stresses and surface uplift resulting from convective flow of heat and mass in the upper mantle
Bridwell R.J Potzick. 1981

SUMMARY

CONCEPTUAL UNDERSTANDING OF THE TECTONIC ENVIRONMENT OF THE YUCCA MOUNTAIN SITE LEADS TO TWO IMPORTANT CONCLUSIONS

- **CONCLUSION I**

  - DEFORMING FRACTURED MEDIUM IS INVOLVED IN THE FLOW PROCESS, I.e., $\frac{\partial w}{\partial t} \neq 0 \neq$ CONST.

    GEOLOGIC OBSERVATIONS, MEASUREMENTS OF CONTEMPORARY STRAIN INDICATE THAT THIS CONCLUSION IS SECURE BEYOND A REASONABLE DOUBT

- **CONCLUSION II**

  - AT THE BASE OF THE FLOW SYSTEM HEAT FLOW IS SPATIALLY HETEROGENOUS, I.e., $\frac{\partial t}{\partial x} \neq$ CONST., AND $\frac{\partial t}{\partial y} \neq$ CONST.

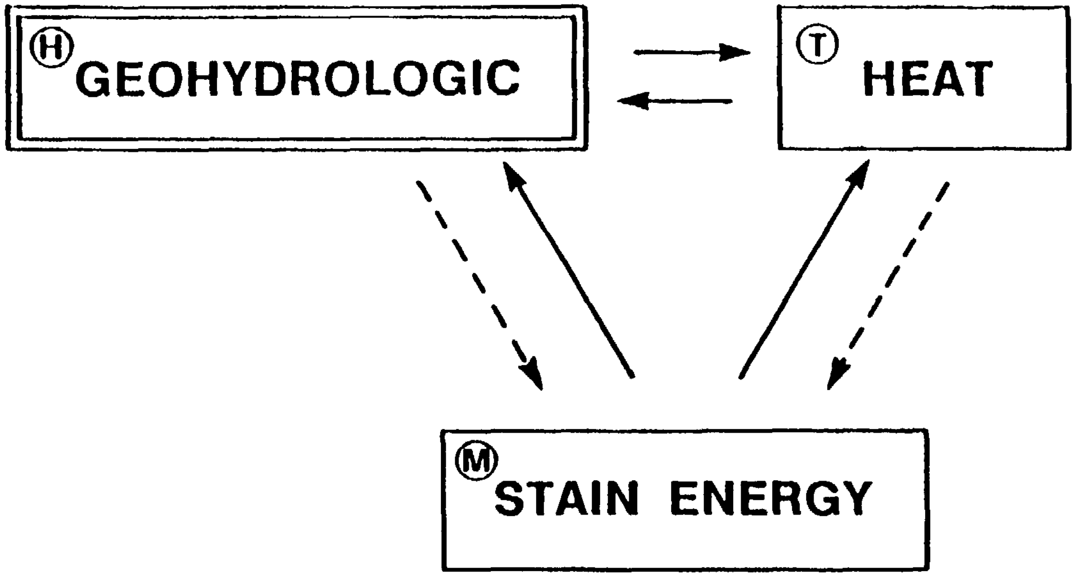
    VOLCANIC SETTING, CRUSTAL STRUCTURE, AND DOWNHOLE MEASUREMENTS OF THE IN SITU TEMPERATURE SUGGEST THAT THIS CONCLUSION MAY BE PROPER FOR THE YUCCA MOUNTAIN SITE

CONCEPTUAL UNDERSTANDING OF FLOW SYSTEM OPERATING AT THE YUCCA MOUNTAIN SITE

- **ASSUMPTIONS** mechanical energy
  - FACTORS (H; M; T);
  - COUPLING MECHANISMS

- **SYNTHESIS**
  - CONCEPTUAL MODEL OF FLUID - HEAT FLOW FIELD DEVELOPED IN THE DEFORMING FRACTURED MEDIUM

FACTORS



- $\frac{\partial^2 temp}{\partial t \partial x}$; $\frac{\partial^2 temp}{\partial t \partial y}$ - **INSIGNIFICANT;**
- $\frac{\partial Q}{\partial t}$ - **INSIGNIFICANT; AND**
- $\frac{\partial [\sigma ; \tau]}{\partial t}$ - **CONTROLLING FACTOR**

M-H AND M-T - COUPLING MECHANISM

$a = f([\sigma; \tau])$;

$[\sigma; \tau] = f(time)$; - DEFORMING FRACTURED MEDIUM.

K_f; K_h; S; D $= f(a) \rightarrow f(t)$.

WHERE:

a - APERTURE;

$[\sigma; \tau]$ - STRESS TENSOR;

K_f - BULK HYDRAULIC CONDUCTIVITY;

K_t - BULK THERMAL "CONDUCTANCE";

S - FLUID STORATIVITY; AND

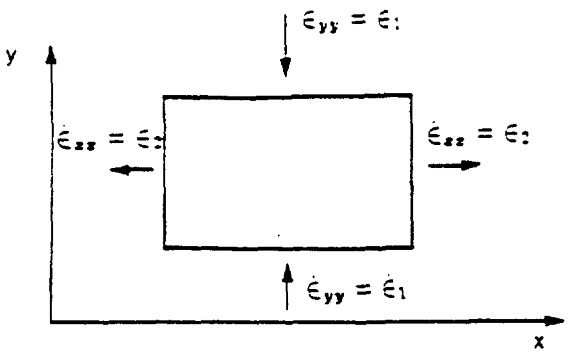
D - BULK THERMAL DIFFUSIVITY.

LOG TIME →

<table>
<tr><td colspan="5">COMPLETE TECTONIC CYCLE</td></tr>
<tr><td>PHASE I</td><td colspan="4">PHASE II</td></tr>
<tr><td></td><td>DILATANT STAGE</td><td>INCLUSION STAGE</td><td>CLOSURE STAGE</td><td>GROWTH STAGE</td></tr>
<tr><td>SLOW BUILD-UP OF TECTONIC STRESS

NORMAL AND SHEAR STRESSES EXHIBIT TIME-DEPENDENCY</td><td colspan="4">RATE OF LOCAL TECTONIC STRAINING INCREASES. INHOMOGENEITIES IN THE STRESS FIELD (NORMAL AND SHEAR STRESS GRADIENTS) BECOME MORE PRONOUNCED WITH TIME. AT THE END. LARGE AND FAST CHANGES IN THE CUMULATIVE STRAIN ENERGY OCCUR IN ASSOCIATION WITH A SEQUENCE OF SEISMIC EVENTS.</td></tr>
<tr><td>MORE OR LESS HOMOGENOUS STRAIN</td><td colspan="4">NON-HOMOGENOUS STRAIN</td></tr>
<tr><td>$\frac{\delta(\sigma_{zz}, \tau_{zy})}{\delta t} \neq 0$
$\frac{\delta(\sigma_{yy}, \tau_{yz})}{\delta t} \neq 0$</td><td colspan="4">$\frac{\delta(\sigma_{zz}, \tau_{zy})}{\delta t} \neq 0 \neq$ const. time-dependence of stress
$\frac{\delta(\sigma_{yy}, \tau_{yz})}{\delta t} \neq 0 \neq$ const
$\frac{\delta(\sigma_{zz}, \tau_{zy})}{\delta z} =$ const stress gradients
$\frac{\delta(\sigma_{yy}, \tau_{yz})}{\delta y} =$ const
$\frac{\delta^2(\sigma_{zz}, \tau_{zy})}{\delta t \cdot \delta z} \neq 0$ time dependence of stress gradients
$\frac{\delta^2(\sigma_{yy}, \tau_{yz})}{\delta t \cdot \delta y} \neq 0$</td></tr>
</table>

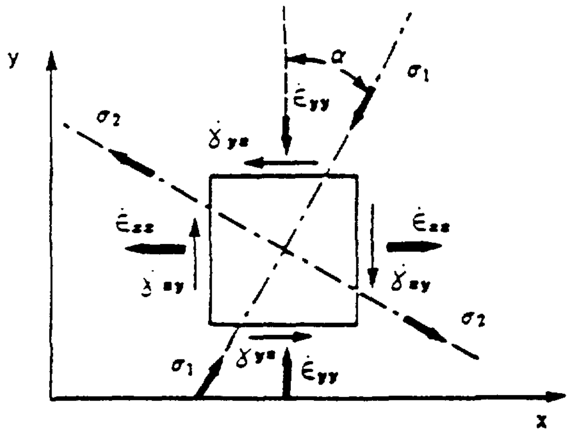
Idealization of tectonic cycle for an individual strain domain



HOMOGENOUS STRAIN

$$\frac{\delta\sigma_1}{\delta t} \neq 0; \text{ and}$$

$$\frac{\delta\sigma_2}{\delta t} \neq 0.$$



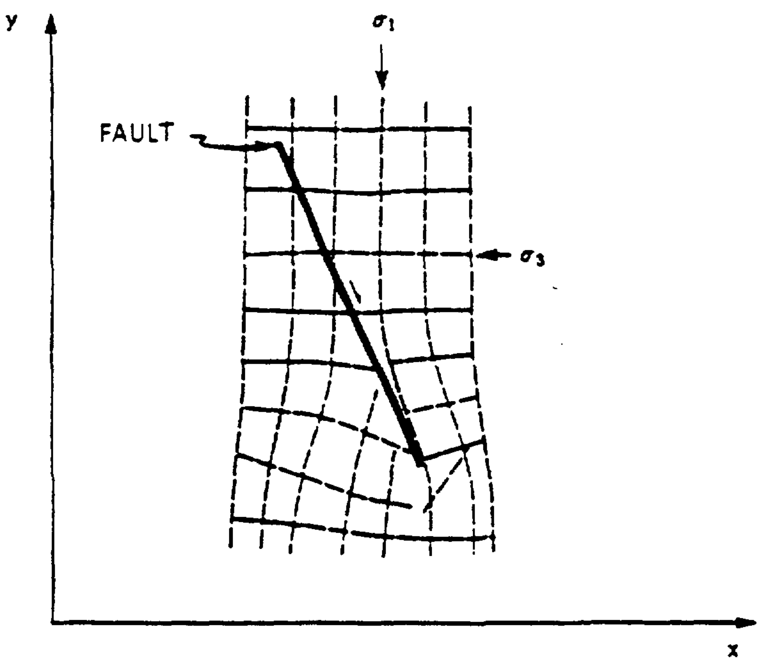
HOMOGENOUS STRAIN

INCLUDES SHEAR COUPLE

$$\frac{\delta\sigma_1}{\delta t} \neq 0;$$

$$\frac{\delta\sigma_2}{\delta t} = 0; \text{ and}$$

$$\frac{\delta\alpha}{\delta t} = 0.$$



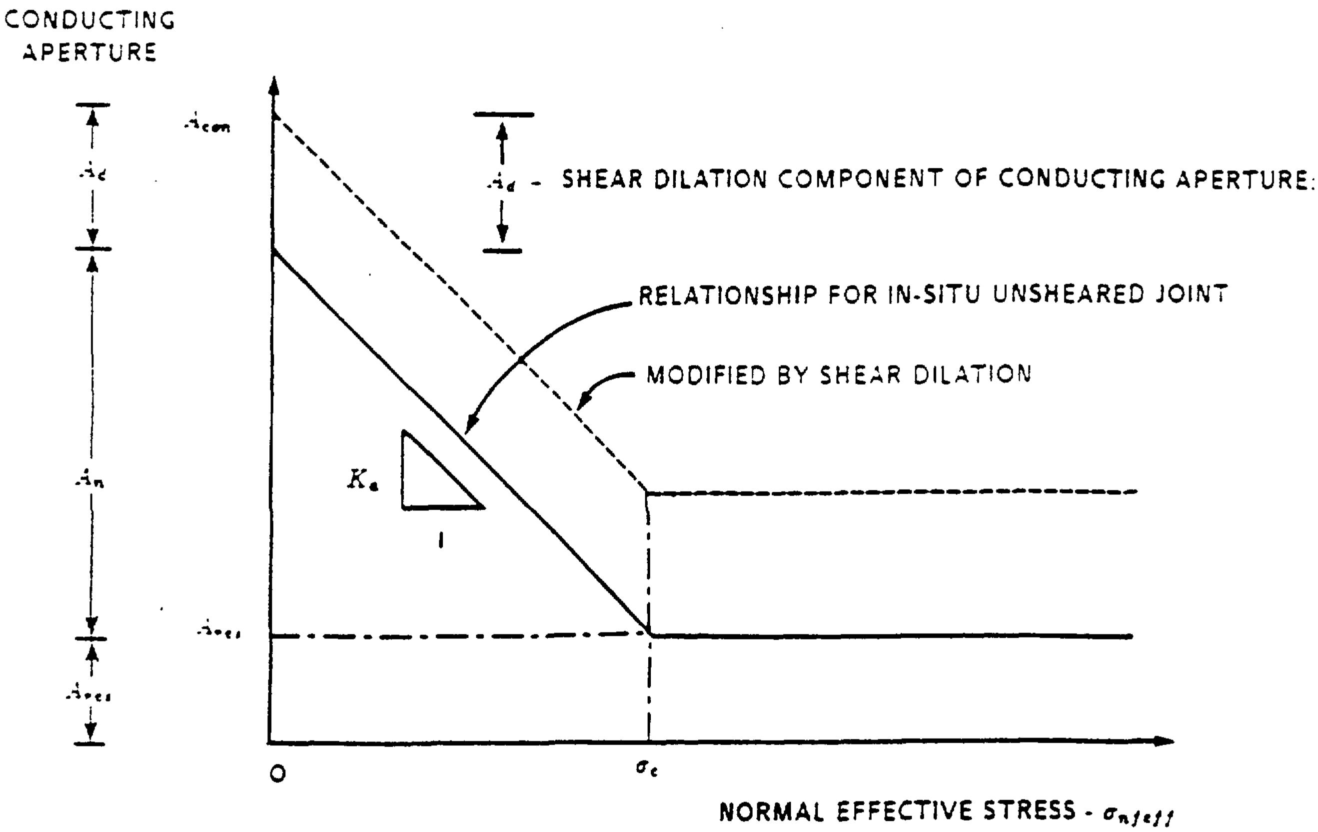
NON-HOMOGENOUS STRAIN

$$\frac{\delta^2(\sigma_{xx}, \tau_{xy})}{\sigma z \sigma t} = 0; \text{ and}$$

$$\frac{\delta^2(\sigma_{yy}, \tau_{yx})}{\sigma z \sigma t} \neq 0.$$

Idealization of changes in stress field during tectonic cycle.

plate 3.2.2-4



$$A_{con} = A_{res.} - r\sigma_{nfeff} \cdot K_e - A_d$$

$r = 1$ if $0 < \sigma_{nfeff} < \sigma_c$

OTHERWISE

$r = 0$

WHERE:

A_{con} – FRACTURE CONDUCTING APERTURE.

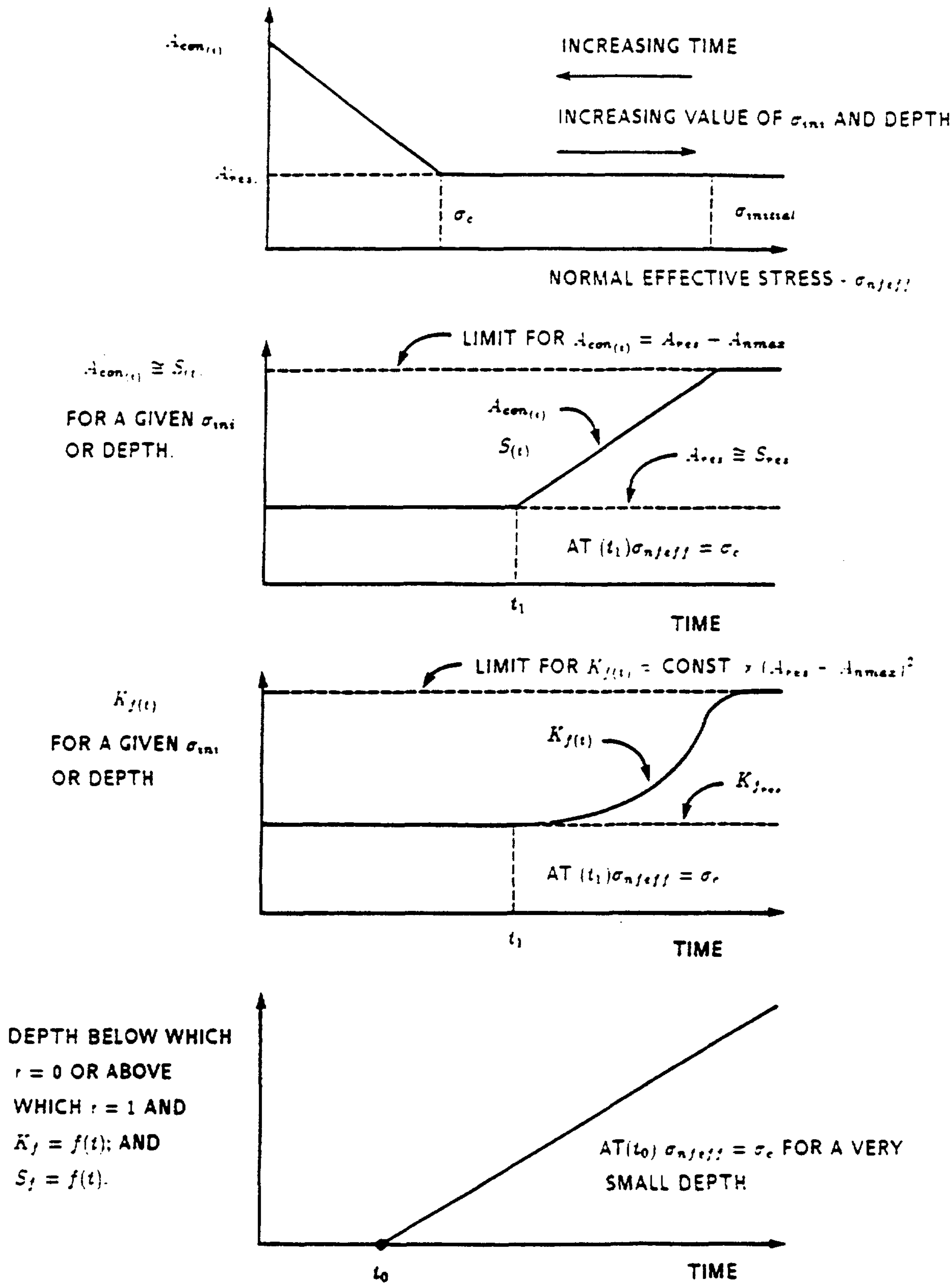
$A_{res.}$ – FRACTURE RESIDUAL APERTURE:

A_d – SHEAR DILATION COMPONENT OF CONDUCTING APERTURE

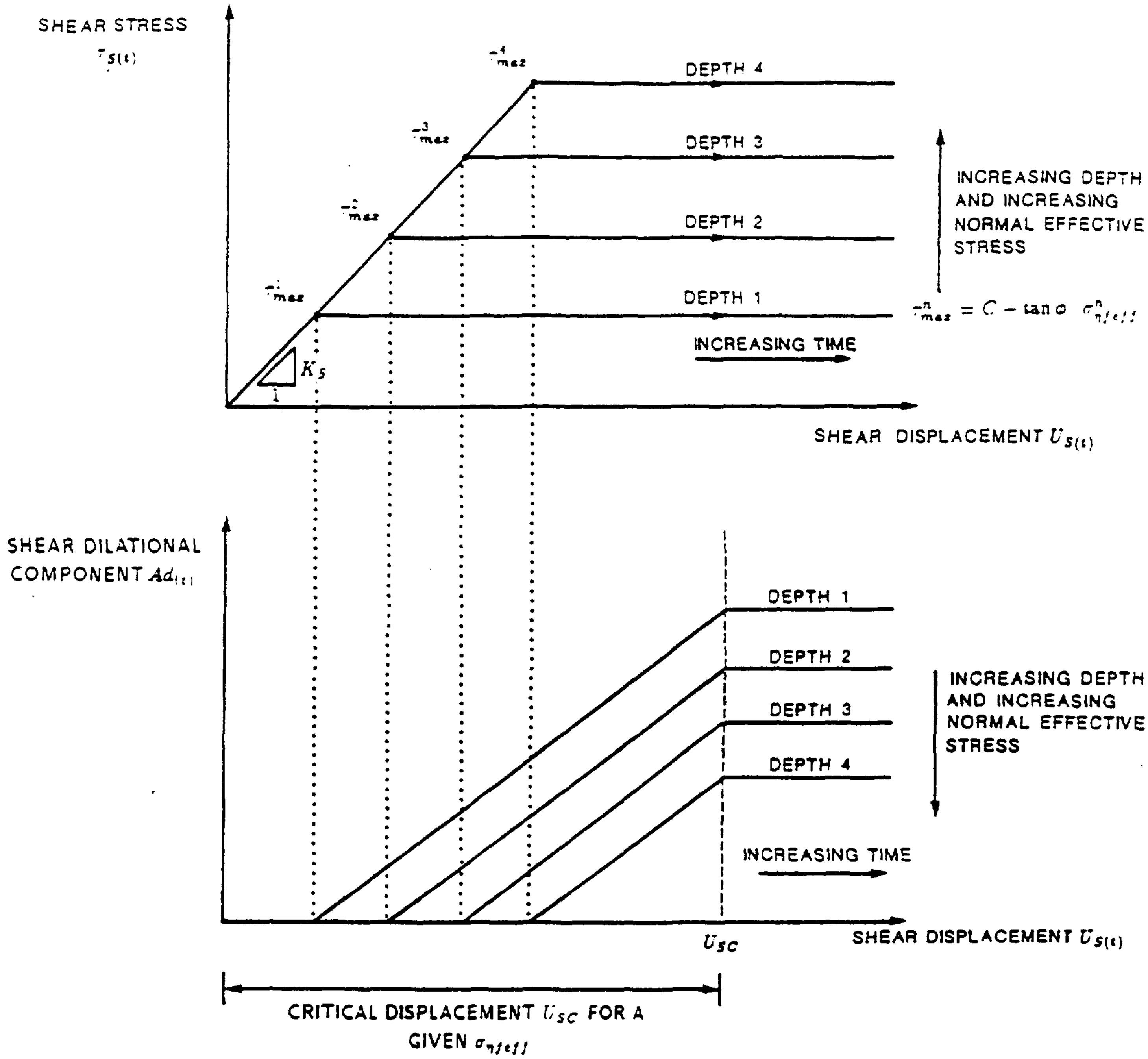
$r\sigma_{nfeff} K_e = A_n$ – NORMAL DILATION COMPONENT OF CONDUCTING APERTURE: AND

K_e – COMPLIANCE

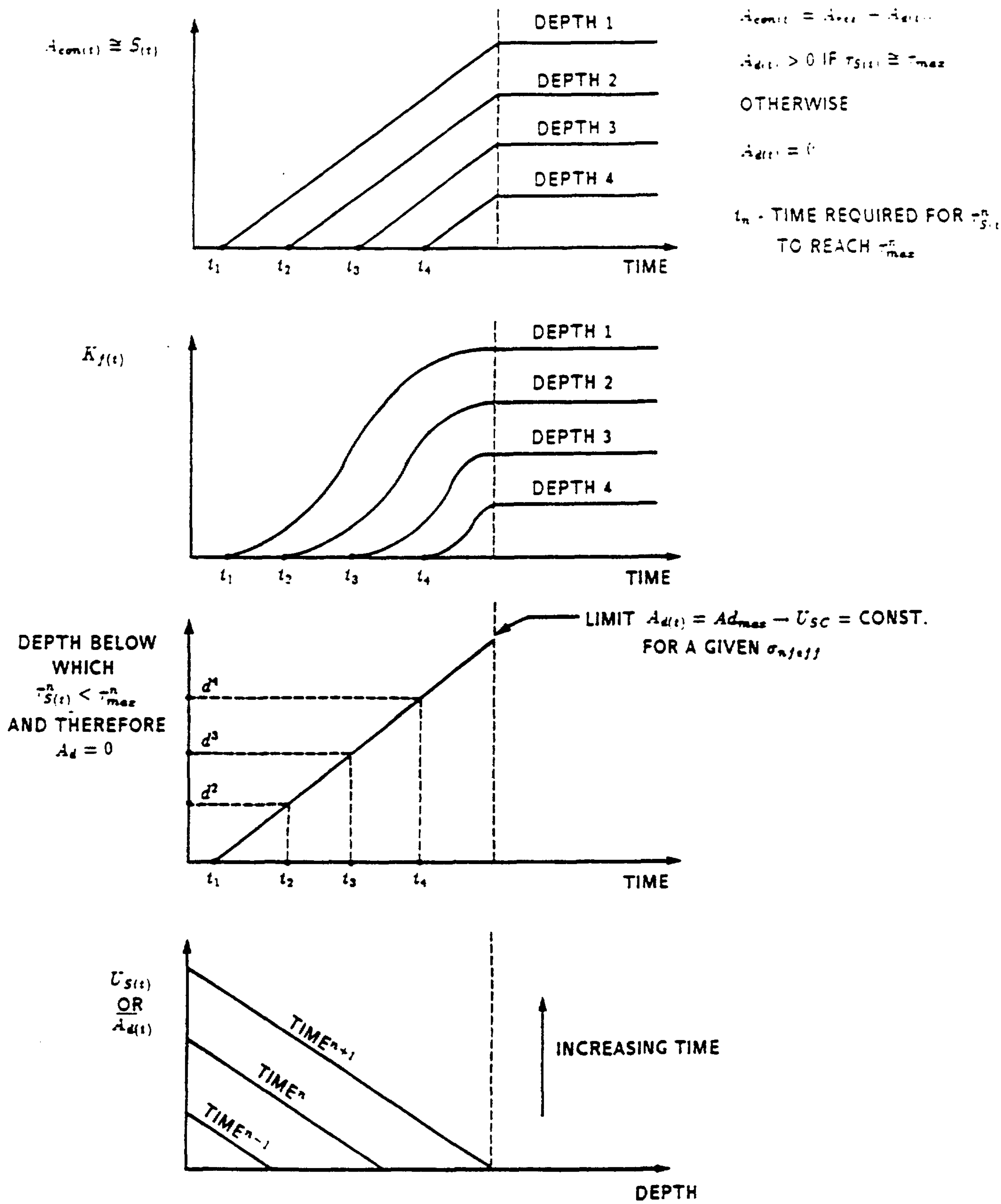
Joint conductive aperture model Harper T R. and Last H C.. 1987



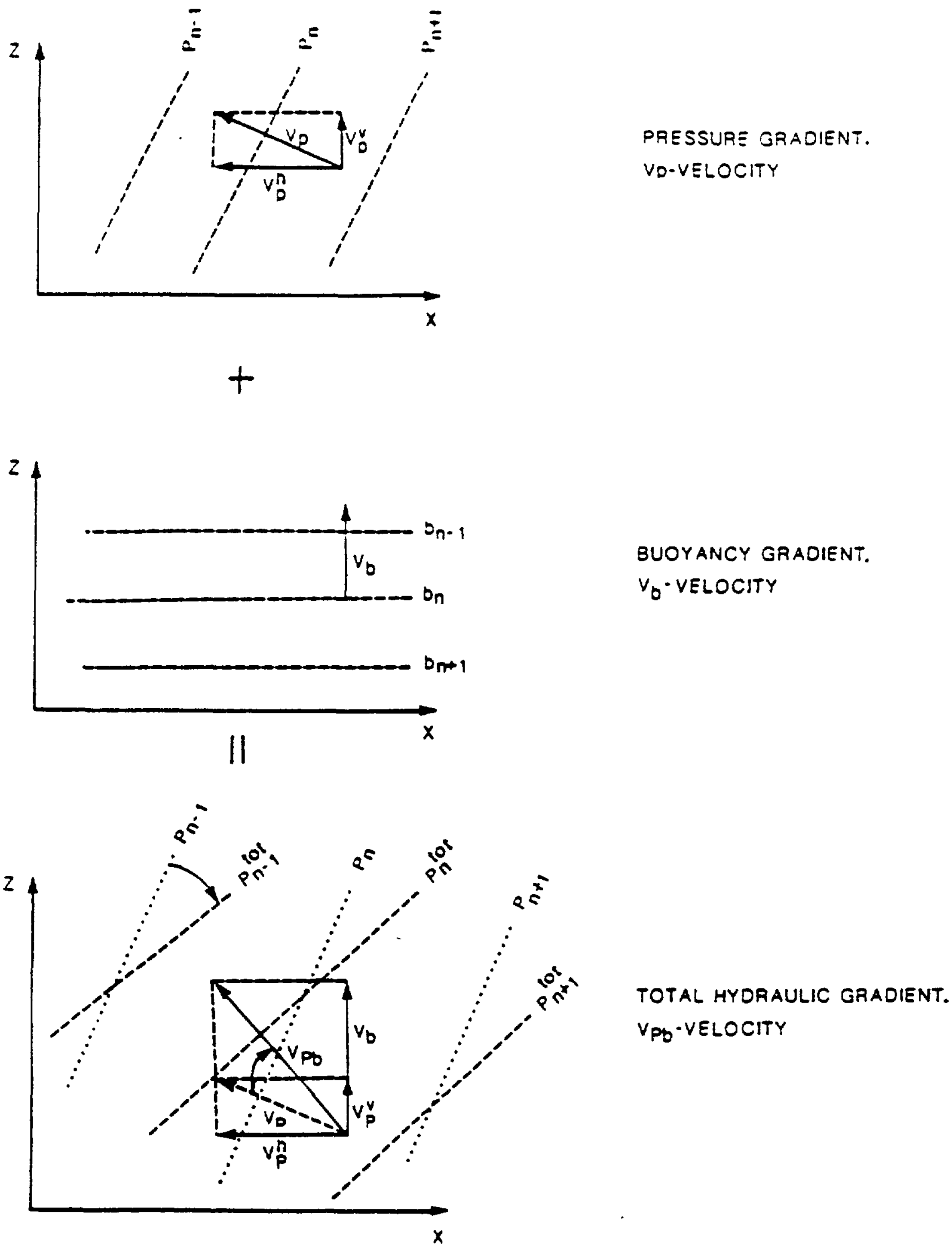
Relationships between time and hydraulic parameters caused by reduction in σ_{nfeff}.



Idealized joint response during shear displacement. Modified from Harper T R. and Last N.C.. 1987.



Relationships between time and hydraulic parameters caused by increase in τ_f



Total hydraulic gradient combines buoyancy and pressure gradient

plate 3.3.2-1.

GOVERNING EQUATIONS

CONSERVATION OF FLUID MASS:

$$\phi\rho^f(c^f - c^*)p_{,t} - \phi\rho^f\beta T_{,t} - \left(\rho^f \frac{k}{\mu}ij(p_{,j} - \rho^f g_j)\right)_{,i} = 0; \quad \text{AND}$$

CONSERVATION OF THERMAL ENERGY:

$$((\rho C)^* T)_{,t} - (\lambda^* T_{,i})_{,i} + \left(\rho^f C^f \left(\frac{k}{\mu}ij(p_{,j} - \rho^f g_j)\right)T\right)_{,i} = 0.$$

EQUATIONS OF STATE

$$\rho^f = \rho^f(p, T), \quad \mu^f = \mu^f(p, T).$$

Note. For explanation of symbols used see plate 3.3.2-4.

Mathematical model for of simultaneous flow of heat and fluid. Thunvik R. and Braester C., 1982

T-H COUPLING - STABILITY CRITERION, CHARACTER OF THE FLOW FIELD

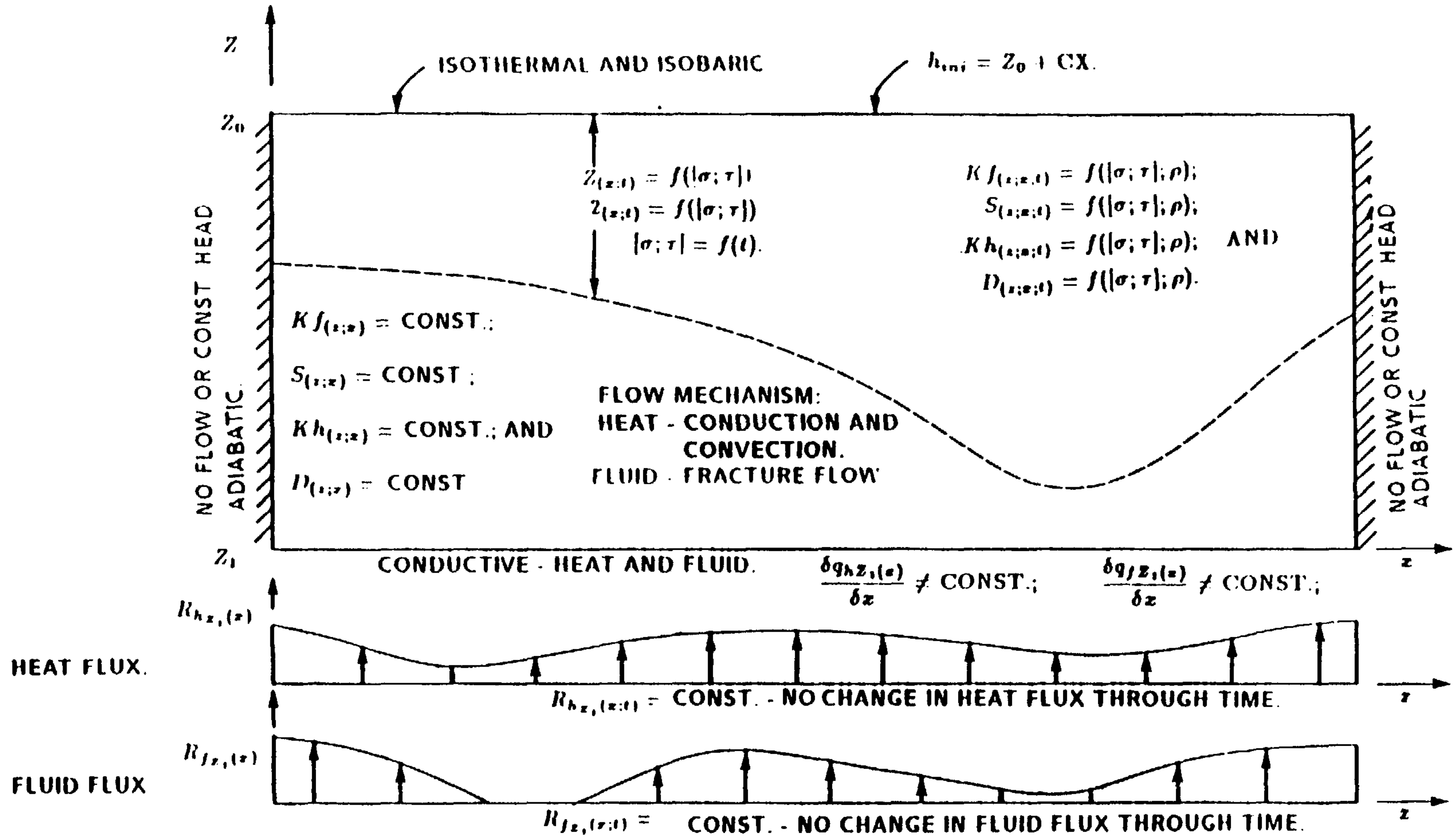
- NUMERICAL ANALYSIS BY CATHLES (1977), FEHN et. al (1978) AND STUDIES OF GEOHYDROLOGY OF CARNMENELLIS GRANITE BY DURRANCE et. al (1982) AND GREGORY AND DURRANCE (1987) HAVE SHOWN THAT QUITE SMALL $\frac{\partial HFU}{\partial x(y)}$ ARE REQUIRED FOR RAYLEIGH - BENARD CONVECTIVE CIRCULATIONS IN A POROUS MEDIUM WITH PERMEABILITY RANGING FROM 10mD TO 50mD

- STUDIES OF CONVECTION OF FLUIDS IN FRACTURES BY MURPHY (1979) DEMONSTRATED THAT THE PROCESS IS TRANSIENT (GROWTH RATE AND GEOMETRY OF THE CELL)

$$\frac{\omega h^2}{K_m} = f(\phi; \frac{1}{a^3})$$

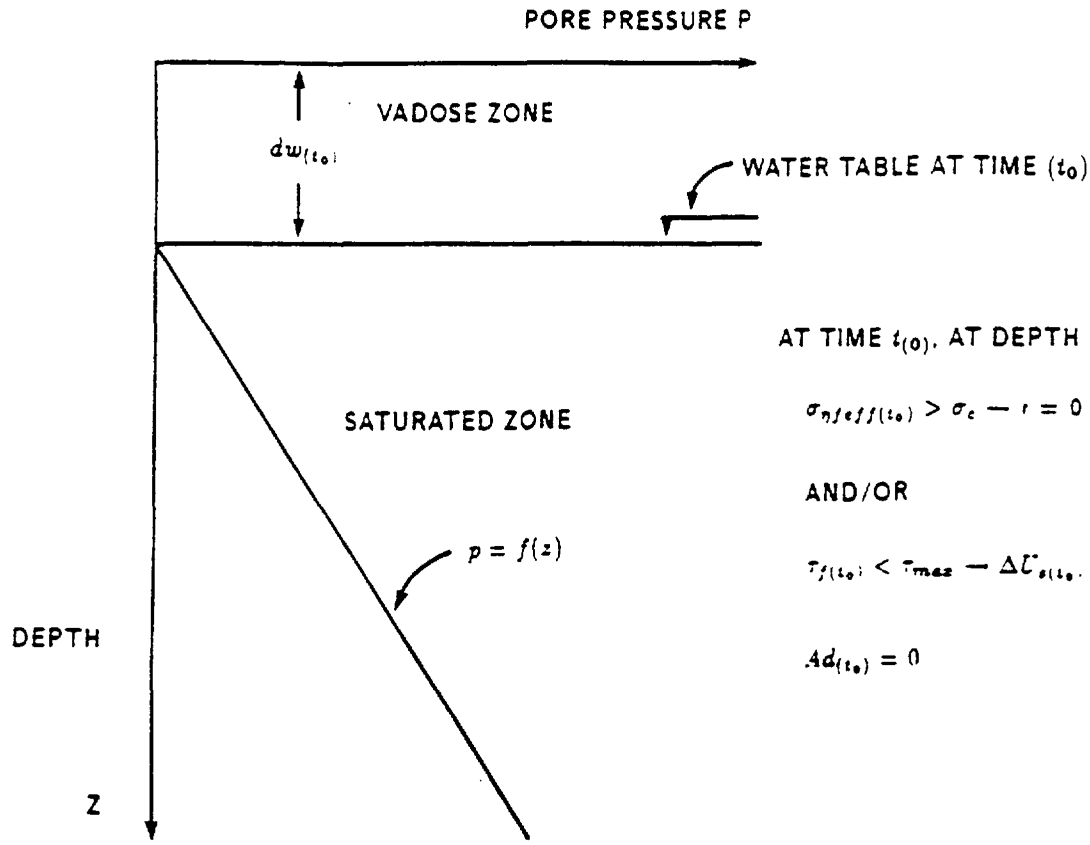
WHERE

ϕ - HEAT TRANSFER FUNCTION; AND
a) - APERTURE



Conceptual model of two phase, heat-fluid coupled, flow field developed in the deforming fractured medium

$t_{(0)}$ - START OF TECTONIC DEFORMATION



AT TIME $t_{(0)}$, AT DEPTH — 0 AND BELOW:

$\sigma_{nfeff(t_0)} > \sigma_c - t = 0$ and $An_{(t_0)} = 0$

AND/OR

$\tau_{f(t_0)} < \tau_{max} - \Delta U_{s(t_0)} = 0$ AND

$Ad_{(t_0)} = 0$

$A_{con(t_0)} = A_{res.} =$ CONST.

$S^{Uz}_{(t_0)} = S^{Sz}_{(t_0)}$

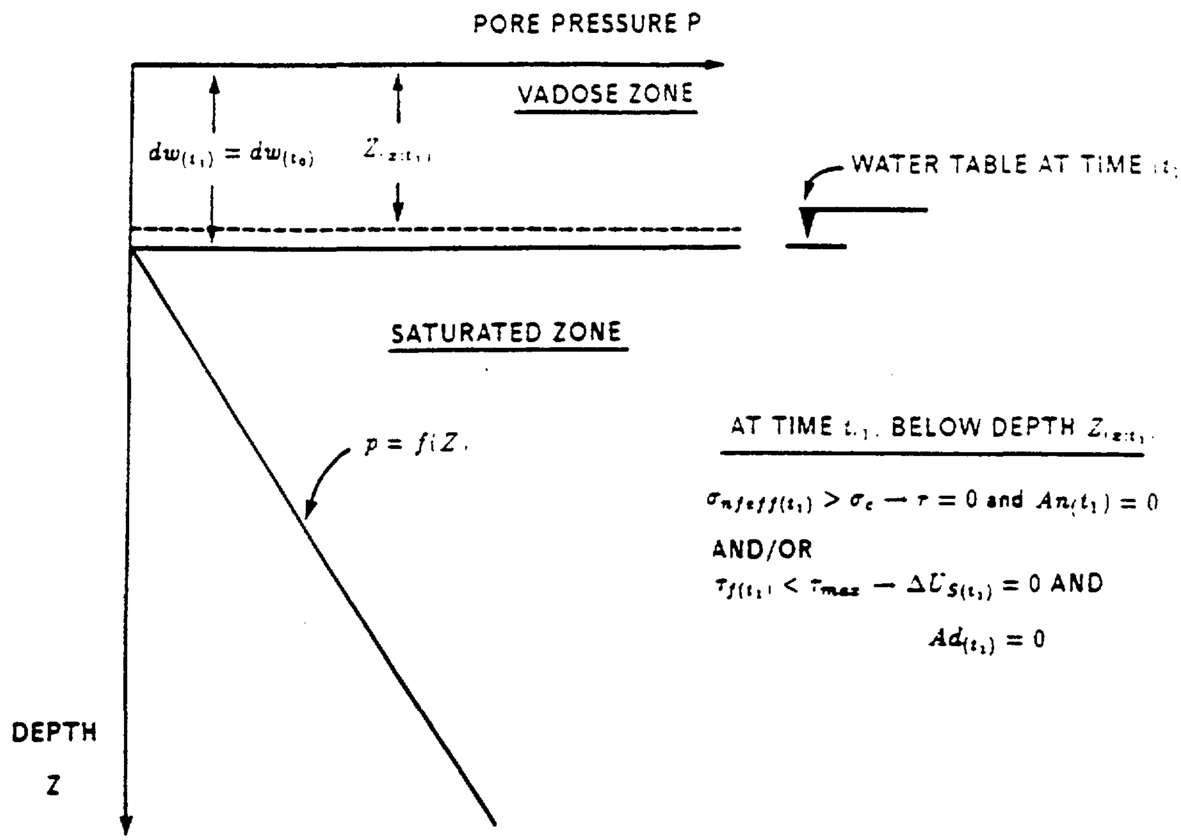
$K^{Uz}_{(t_0)} = K^{Sz}_{(t_0)}$

$Kz_{(t_0)} = Ky_{(t_0)}$

Deforming fractured medium - idealized history of changes in hydraulic potential.

Plate 3.2.4-2

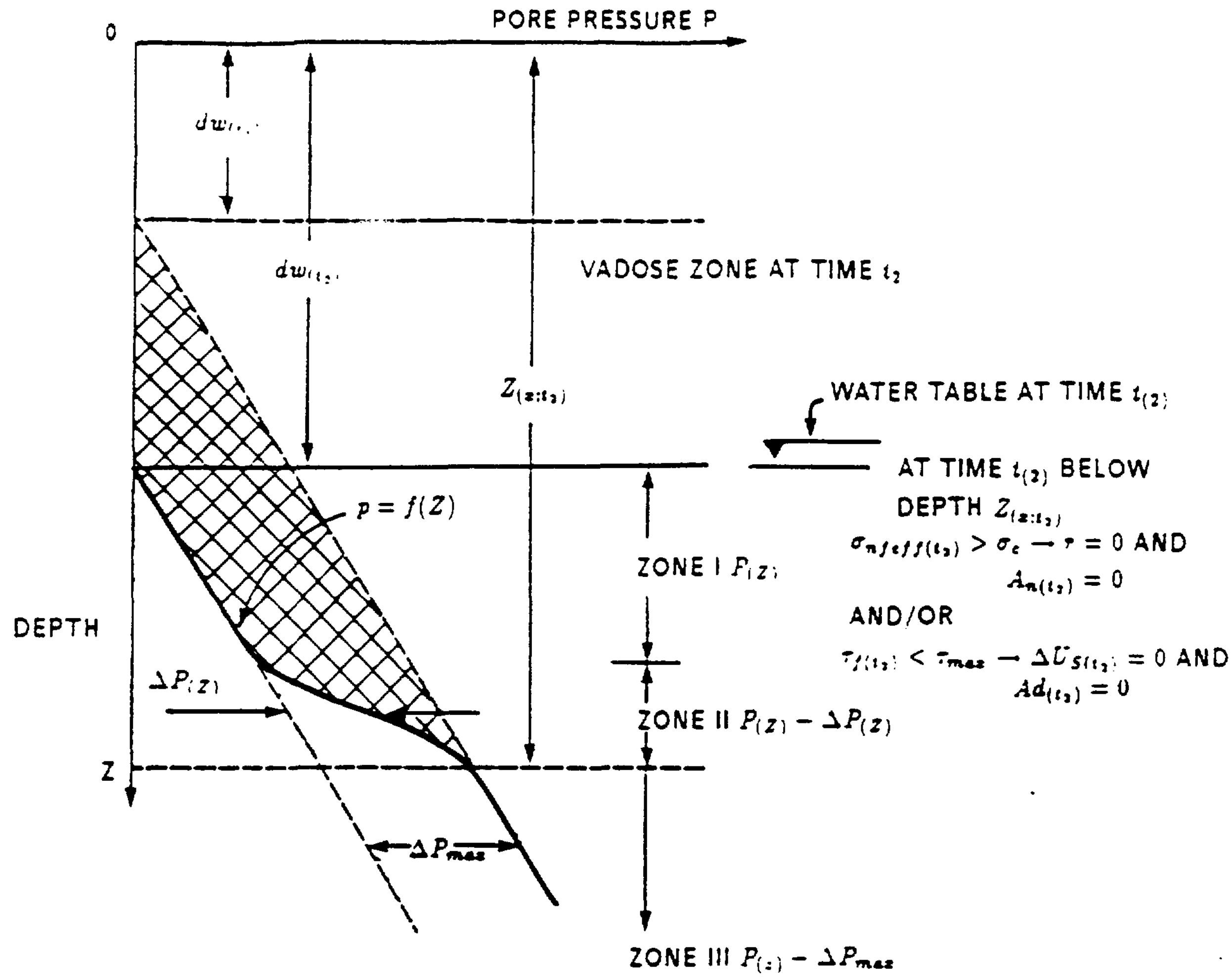
t_1 - EARLY STAGES OF TECTONIC DEFORMATION



ABOVE DEPTH $Z_{(z:t_1)}$	BELOW DEPTH $Z_{(z:t_1)}$
$A_{con(t_1)} = A_{res} - A_{n(t_1)} - Ad_{(t_1)}$	$A_{con} = A_{res} =$ CONST.
$S^{Uz}_{(t_1)} = S^{Uz}_{(t_0)} - \Delta S^{Uz}_{(t_1)}$	$S^{Sz}_{(t_1)} = S^{Sz}_{(t_0)}$
$K^{Uz}_{(t_1)} = K^{Uz}_{(t_0)} + \Delta K^{Uz}_{(t_1)}$	$K^{Sz}_{(t_1)} = K^{Sz}_{(t_0)}$
$K_x \neq K_y$	$K_x = K_y$

Deforming fractured medium - idealized history of changes in hydraulic potential.

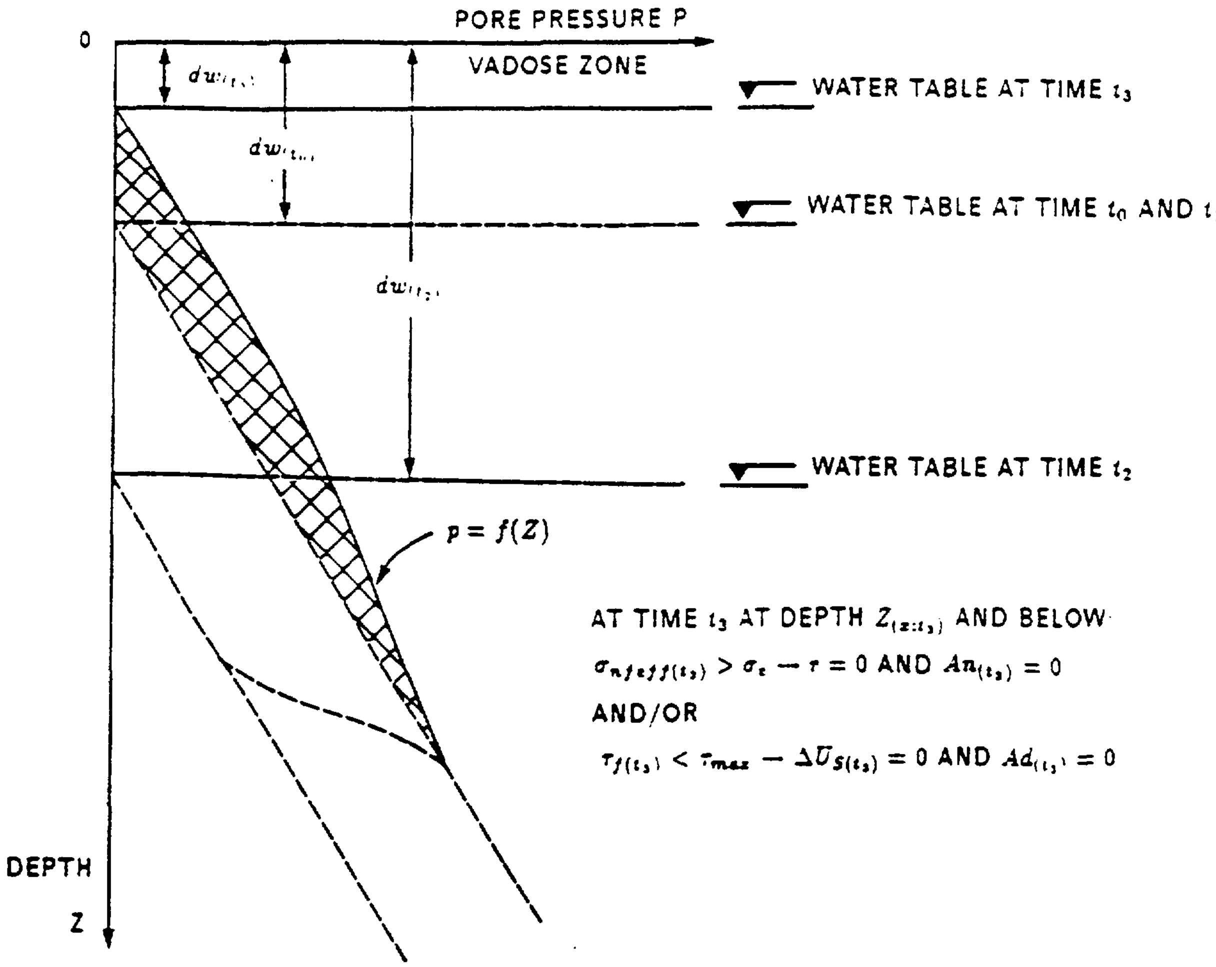
t_2 - ADVANCED STAGES OF TECTONIC DEFORMATION



ABOVE DEPTH $Z_{(z:t_2)}$	BELOW DEPTH $Z_{(z:t_2)}$
$A_{con(t_2)} = A_{res} - An_{(t_2)} + Ad_{(t_2)}$ $S^{Uz}_{(t_2)} = S^{Uz}_{(t_0)} - \Delta S^{Uz}_{(t_1)} + \Delta S^{Uz}_{(t_2)}$ $S^{Sz}_{(t_2)} = S^{Sz}_{(t_0)} + \Delta S^{Sz}_{(t_1)} - \Delta S^{Sz}_{(t_2)}$ $Kf^{Uz}_{(t_2)} = Kf^{Uz}_{(t_0)} - \Delta Kf^{Uz}_{(t_1)} + \Delta Kf^{Uz}_{(t_2)}$ $Kf^{Sz}_{(t_2)} = Kf^{Sz}_{(t_0)} + \Delta Kf^{Sz}_{(t_1)} + \Delta Kf^{Sz}_{(t_2)}$ $K_x \neq K_y$ FRACTURE FLOW	$A_{con(t_2)} - A_{res} = $ CONST $S^{Sz}_{(t_2)} = S^{Sz}_{(t_0)}$ $K^{Sz}_{(t_2)} = K^{Sz}_{(t_0)}$ $K_x = K_y$

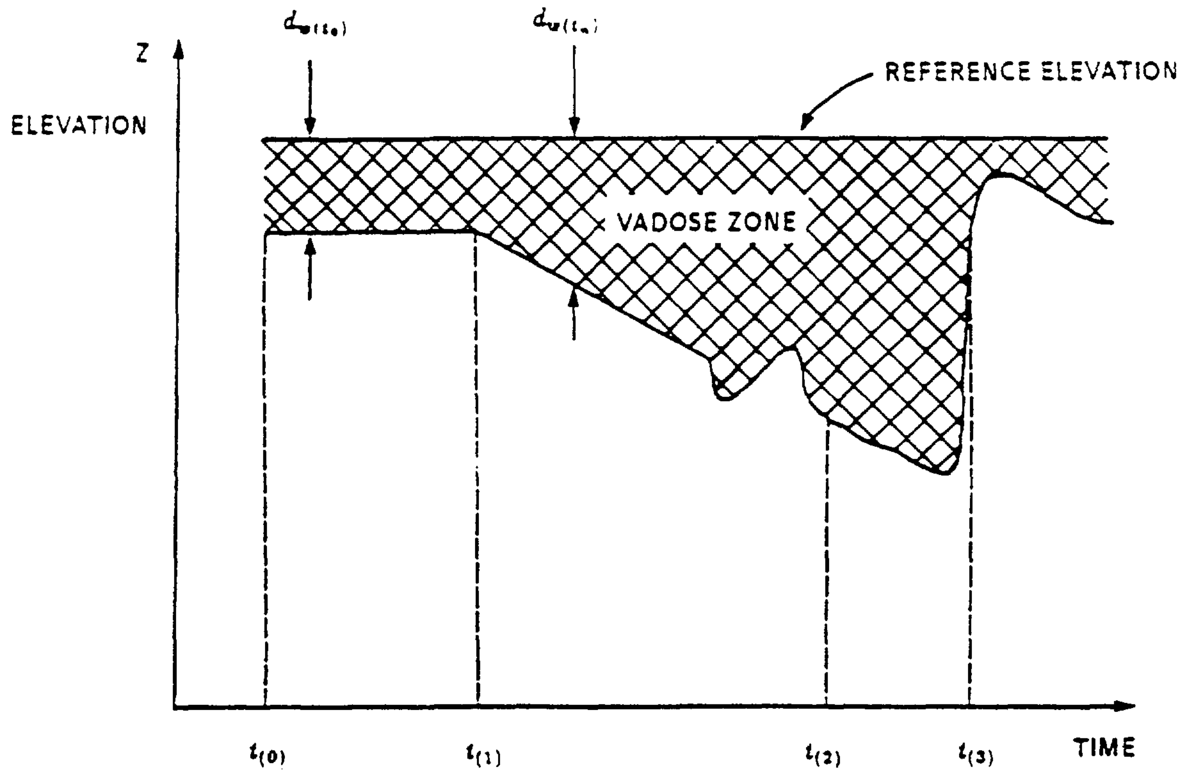
Deforming fractured medium - idealized history of changes in hydraulic potential.

t_3 - END OF THE TECTONIC CYCLE



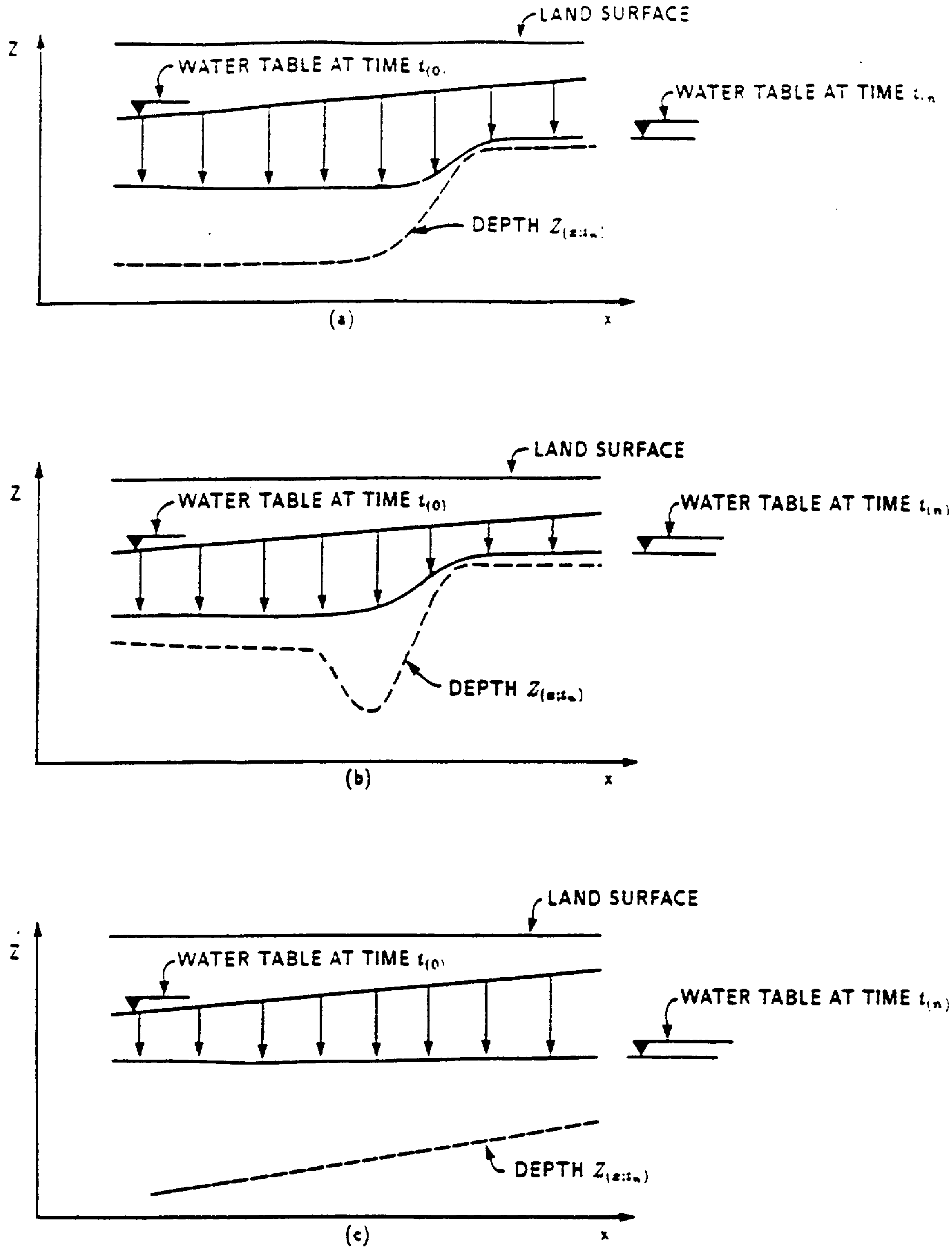
AT DEPTH $Z_{(z:t_3)}$ AND BELOW
$A_{con(t_3)} = A_{res}$
$S^{Uz}_{(t_3)} = S^{Uz}_{(t_0)} < S^{Uz}_{(t_2)}$
$S^{Sz}_{(t_3)} = S^{Sz}_{(t_0)} < S^{Sz}_{(t_2)}$
$Kf^{Uz}_{(t_3)} = Kf^{Uz}_{(t_0)} < Kf^{Uz}_{(t_2)}$
$Kf^{Sz}_{(t_3)} = Kf^{Sz}_{(t_0)} - < Kf^{Sz}_{(t_2)}$
POROUS OR EQUIVALENT FLOW

Deforming fractured medium - idealized history of changes in hydraulic potential.



Note: The drawing is diagramatic - no relationship between initial thickness of the vadose zone and magnitude of tectonic lowering of the water table is implied.

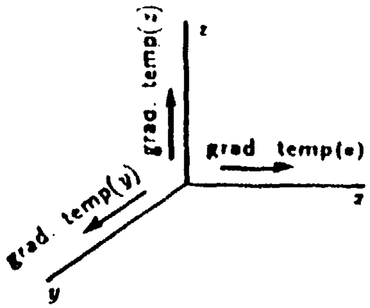
Idealized history of the position of the water table for a single point P(x,y)



Non-homogeneous strain - it's relationship to configuration of the water table.

HEAT FLOW FIELD DEVELOPED IN THE DEFORMING FRACTURED MEDIUM WITH $R_{k_{e_1}(x;t)}$ = CONST.
HAS THE FOLLOWING CHARACTERISTICS

THREE DIMENSIONS

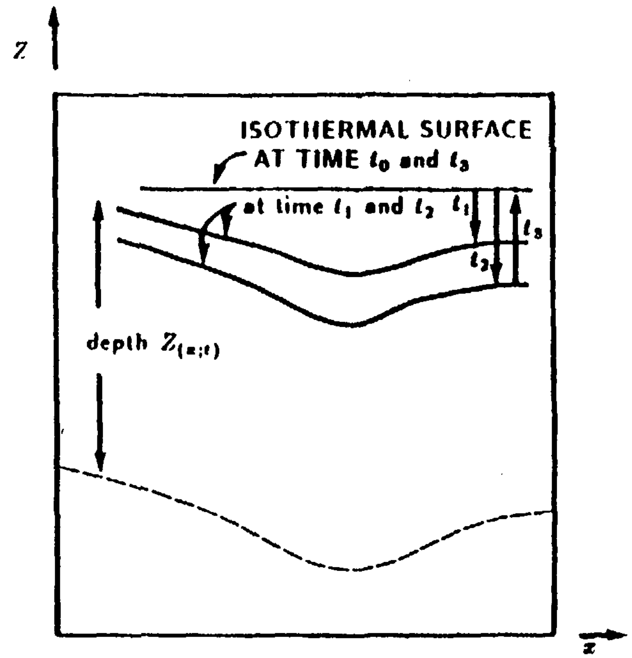


$$\frac{\delta^2 temp.}{\delta x \delta t} \neq 0 \neq \text{const.};$$

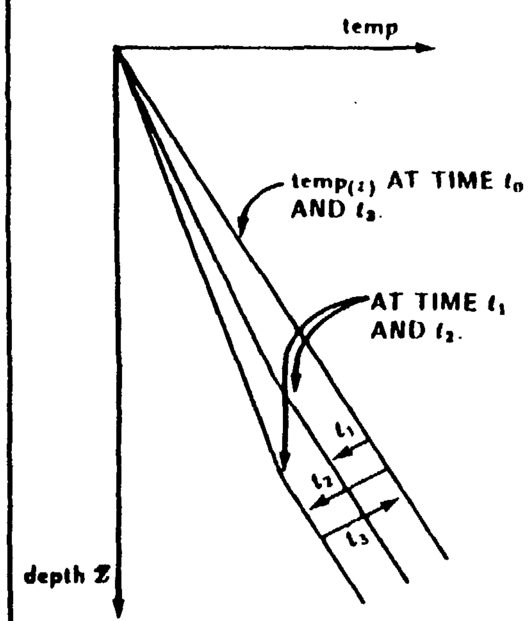
$$\frac{\delta^2 temp.}{\delta y \delta t}; \neq 0 \neq \text{const.}; \text{and}$$

$$\frac{\delta^2 temp.}{\delta z \delta t} \neq 0 \neq \text{const.}$$

TWO DIMENSIONS

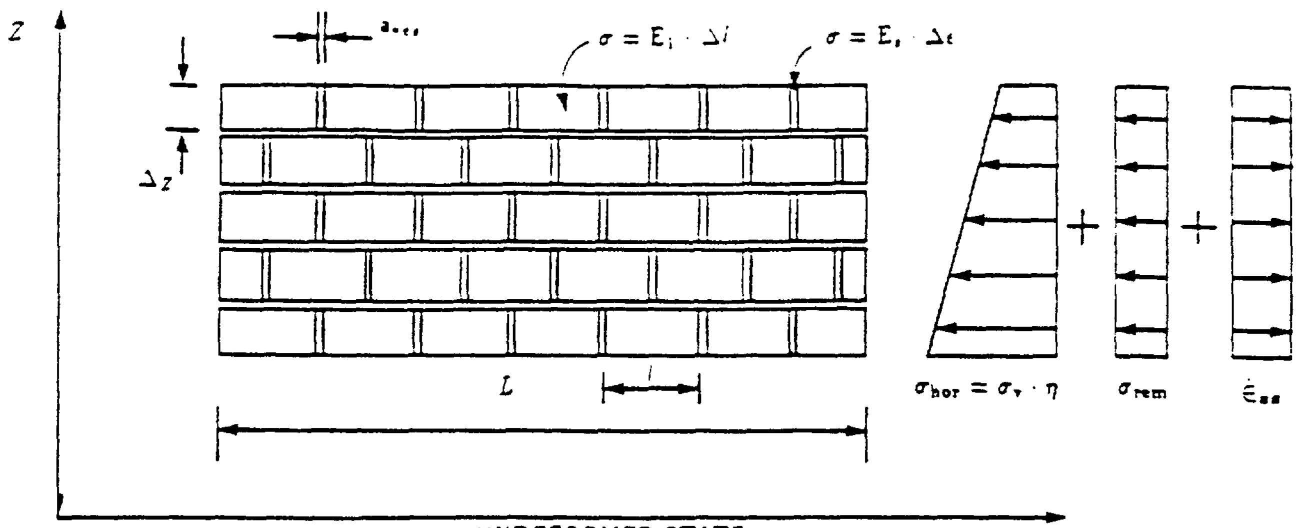


ONE DIMENSION



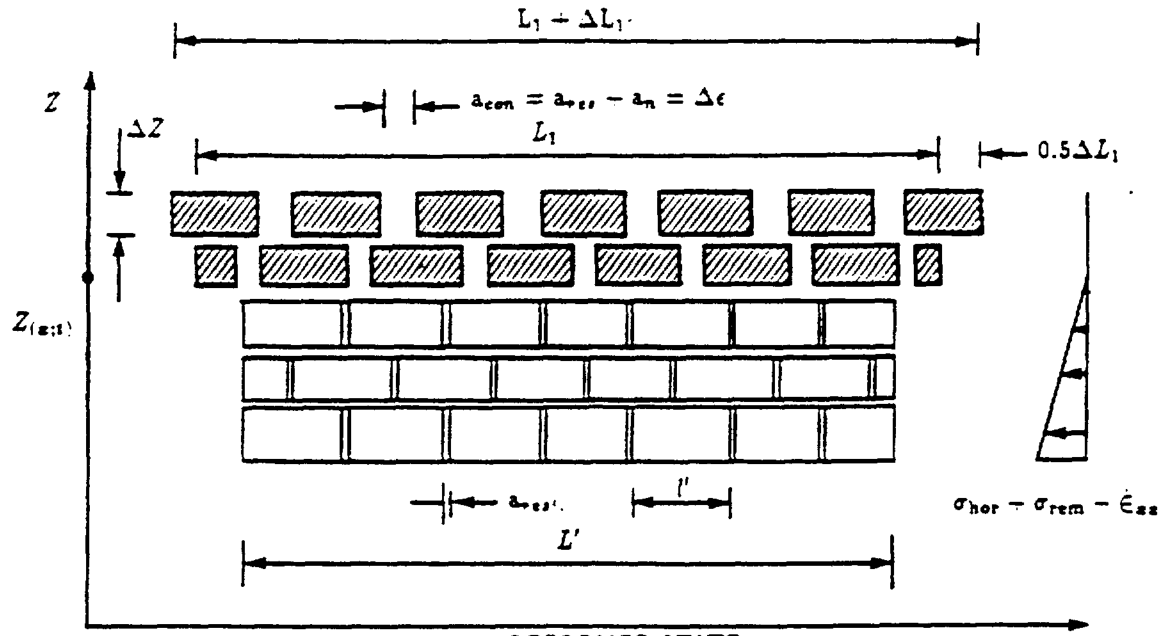
Main characteristics of the heat flow field developed in the deforming fractured medium

DIAGRAM 1



UNDEFORMED STATE.

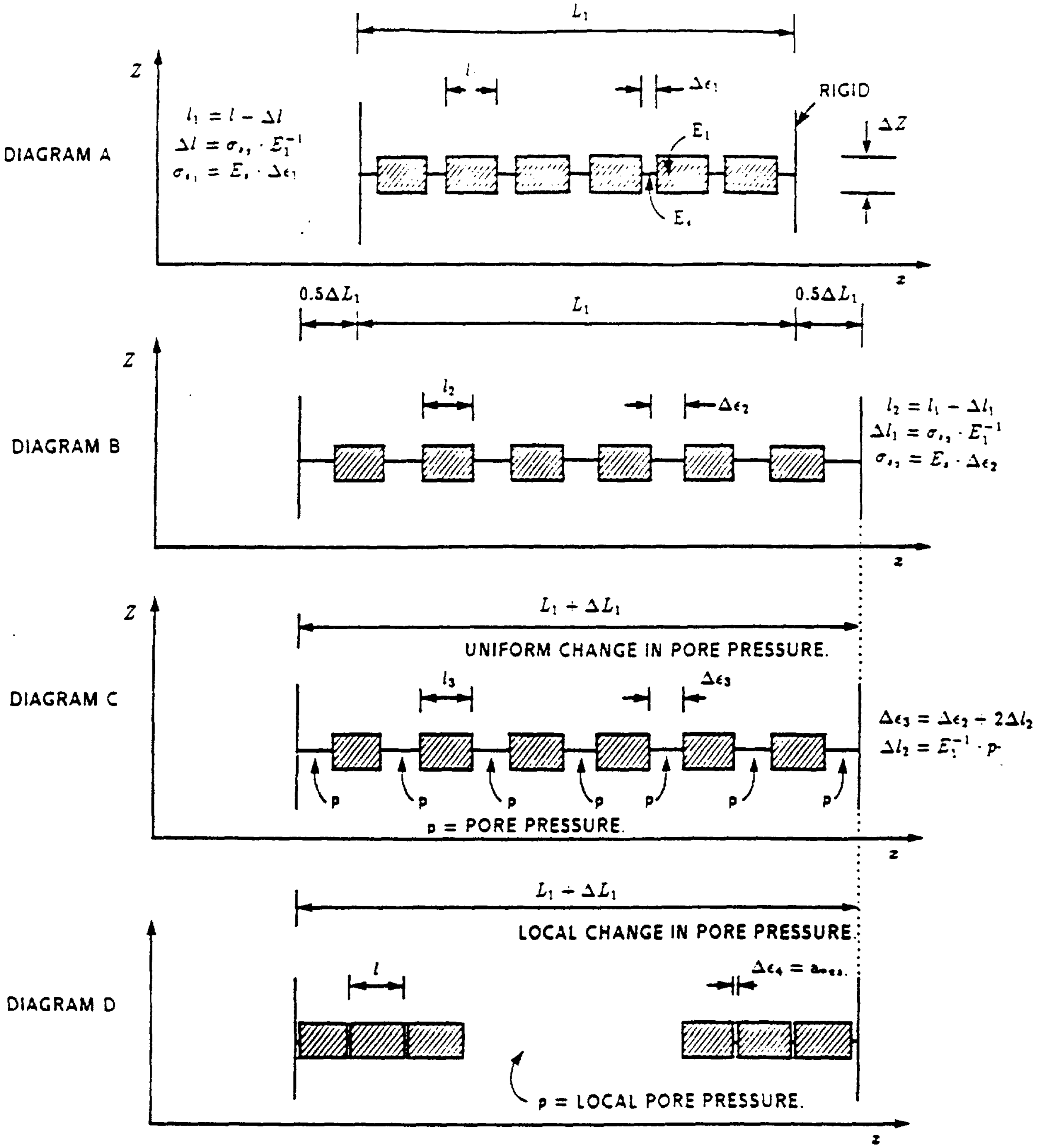
DIAGRAM 2



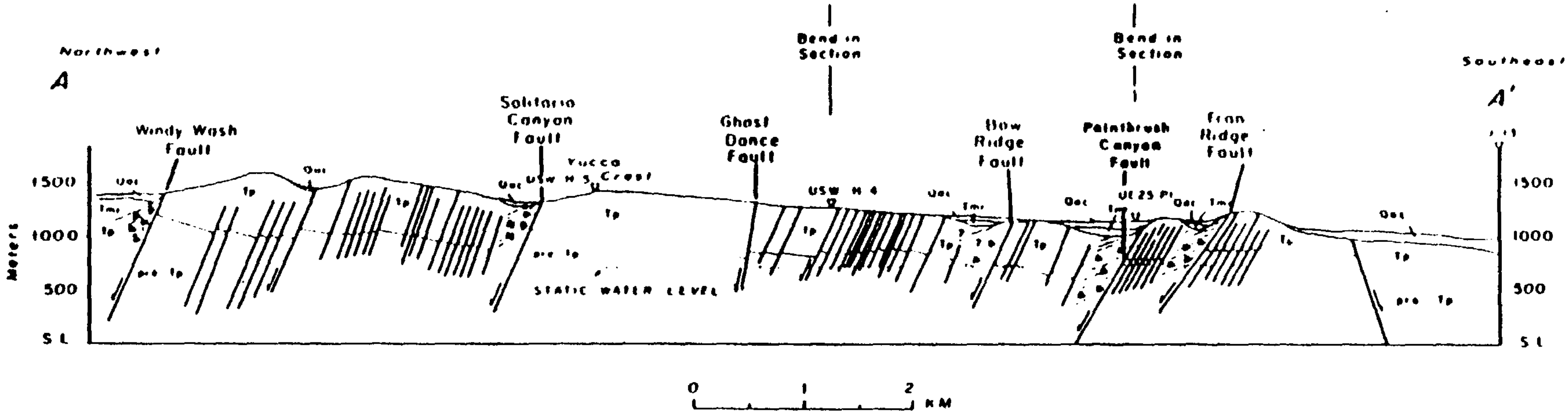
DEFORMED STATE.

Idealized response of the fractured medium during uniform extension

plate 3 4 3--



Idealized response of the dilated fractured medium to sudden changes in pore pressure.



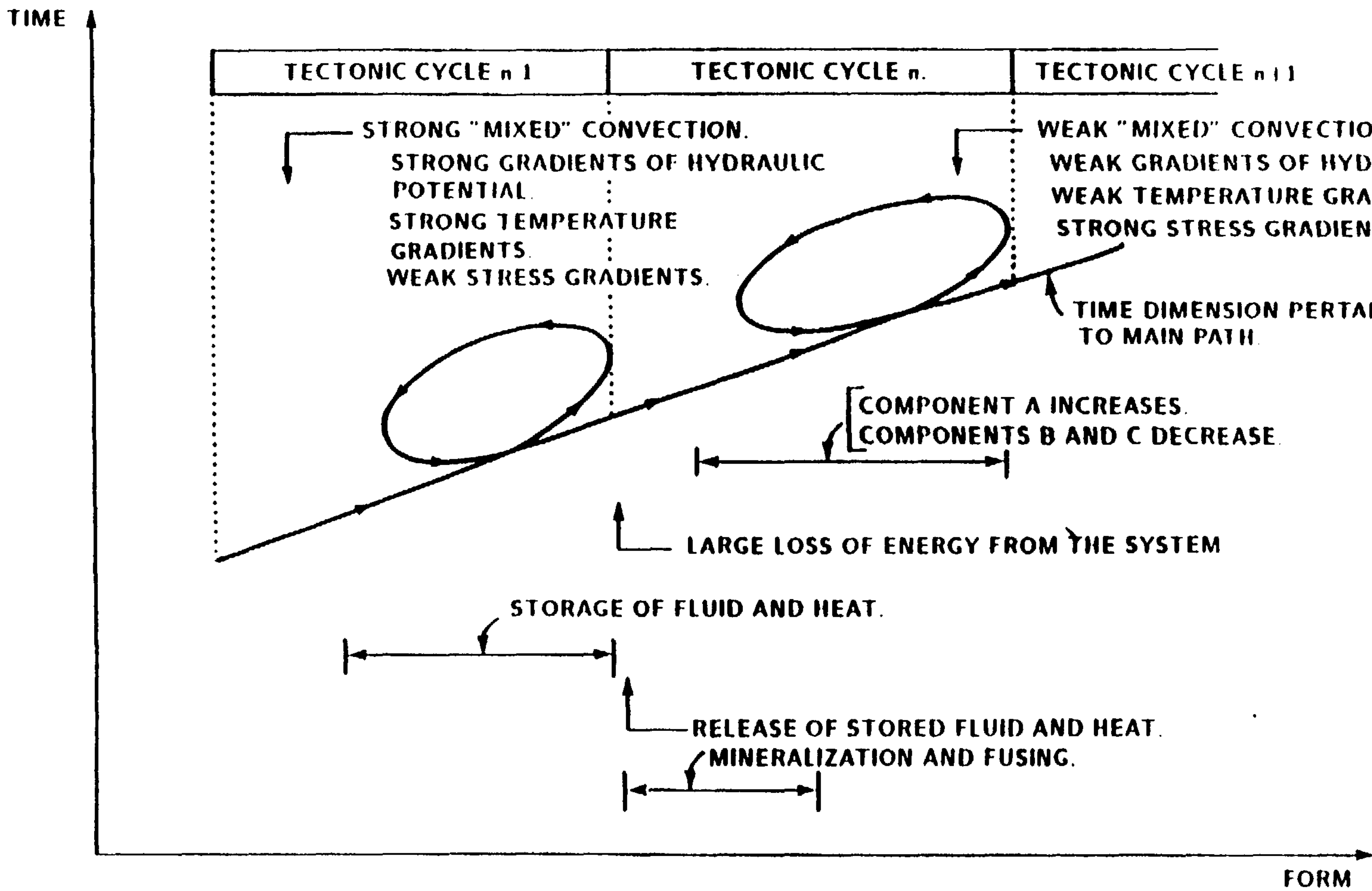
total length – *10km*

$5 \times 500m$ – $2.5km$

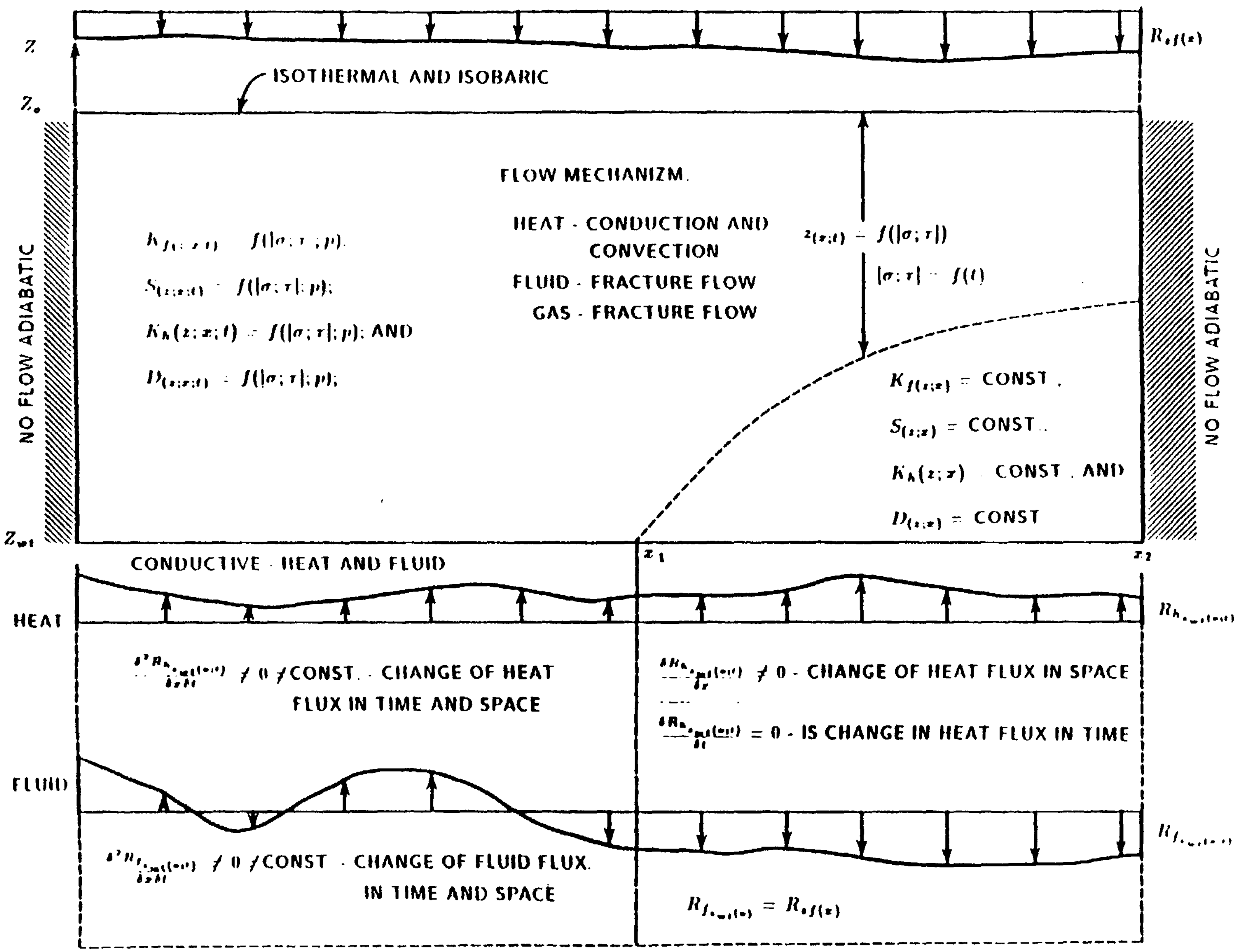
$\frac{\Delta v}{\Delta}$ – 10%

ΔL – $250m$ *in* 10^7 *years*

Geologic section across Yucca Mountain showing location and thicknesses of breccias. From Scott and Bonk (1984)



Evolutionary path of the coupled fluid and heat flow field developed in the deforming fractured medium.



Conceptual model of flow in vadose zone of the two phase, heat-fluid coupled, flow field developed in the deforming fractured medium

plate 3 4 3 2

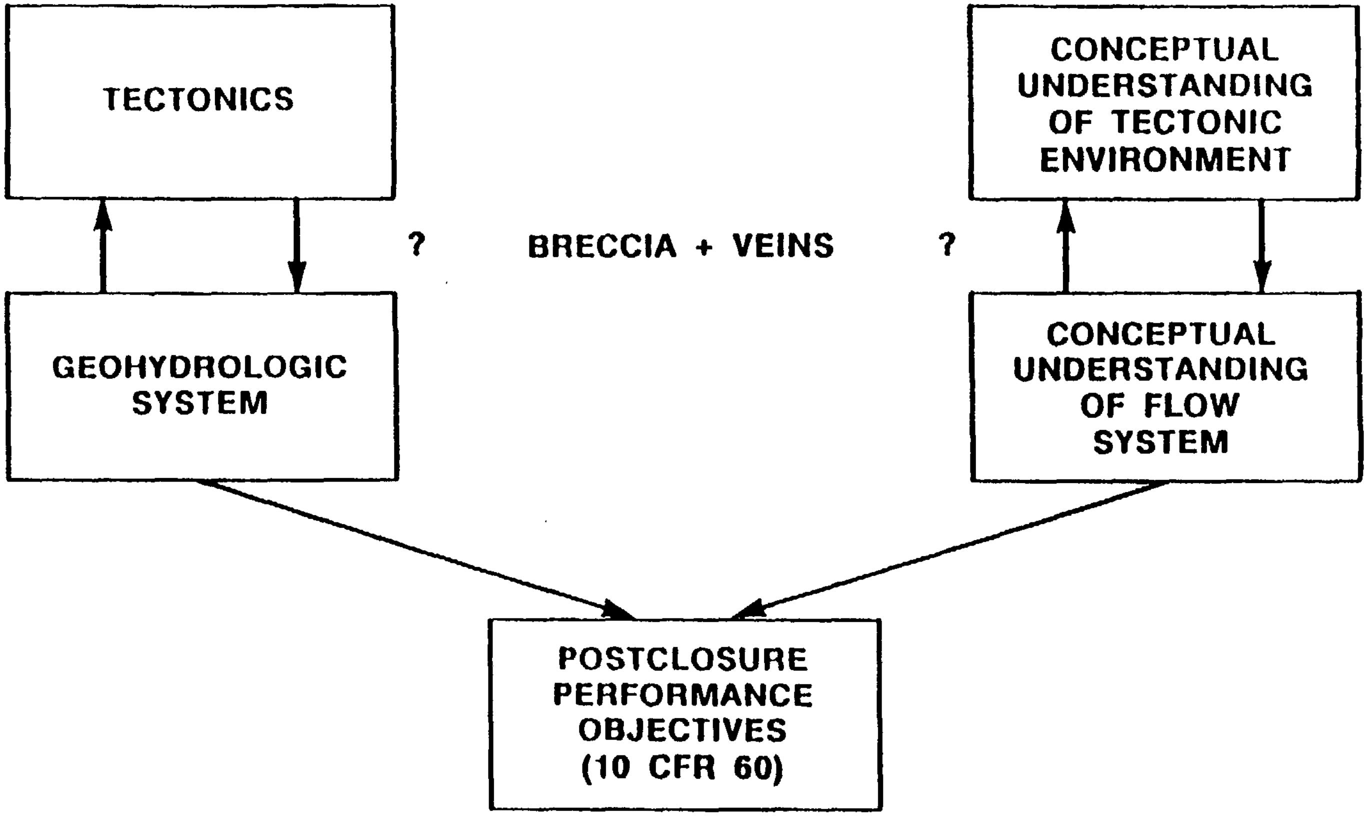
DATA "SUPPORTING" THE PROPOSED CONCEPTUAL MODEL OF THE DEATH VALLEY FLOW SYSTEM

- GENERAL APPROACH;
- ACTUAL DATA
  - PERCHED WATERS;
  - CONFIGURATION OF THE WATER TABLE;
  - 3D DISTRIBUTION OF HYDRAULIC POTENTIAL;
  - STATE OF STRESS;
  - THERMAL HETEROGENEITY (SPACE AND TIME);
  - HYDRAULIC STRESSING; AND
  - GEOLOGICAL MATERIALS

GENERAL APPROACH

- IS IT POSSIBLE? RATHER THAN IS IT TRUE?
- "REASONABLE ASSURANCE" DOES NOT MEAN
  - "ABSOLUTE ASSURANCE THE SITE AND/OR SITE CHARACTERIZATION/SITE SELECTION LOGIC CONTAINS A FATAL FLOW"
- FATAL FLOW
  - "THOU SHALT NOT FIND IT UNLESS THOU LOOKS FOR IT AND KNOWS WHAT IT LOOKS LIKE"

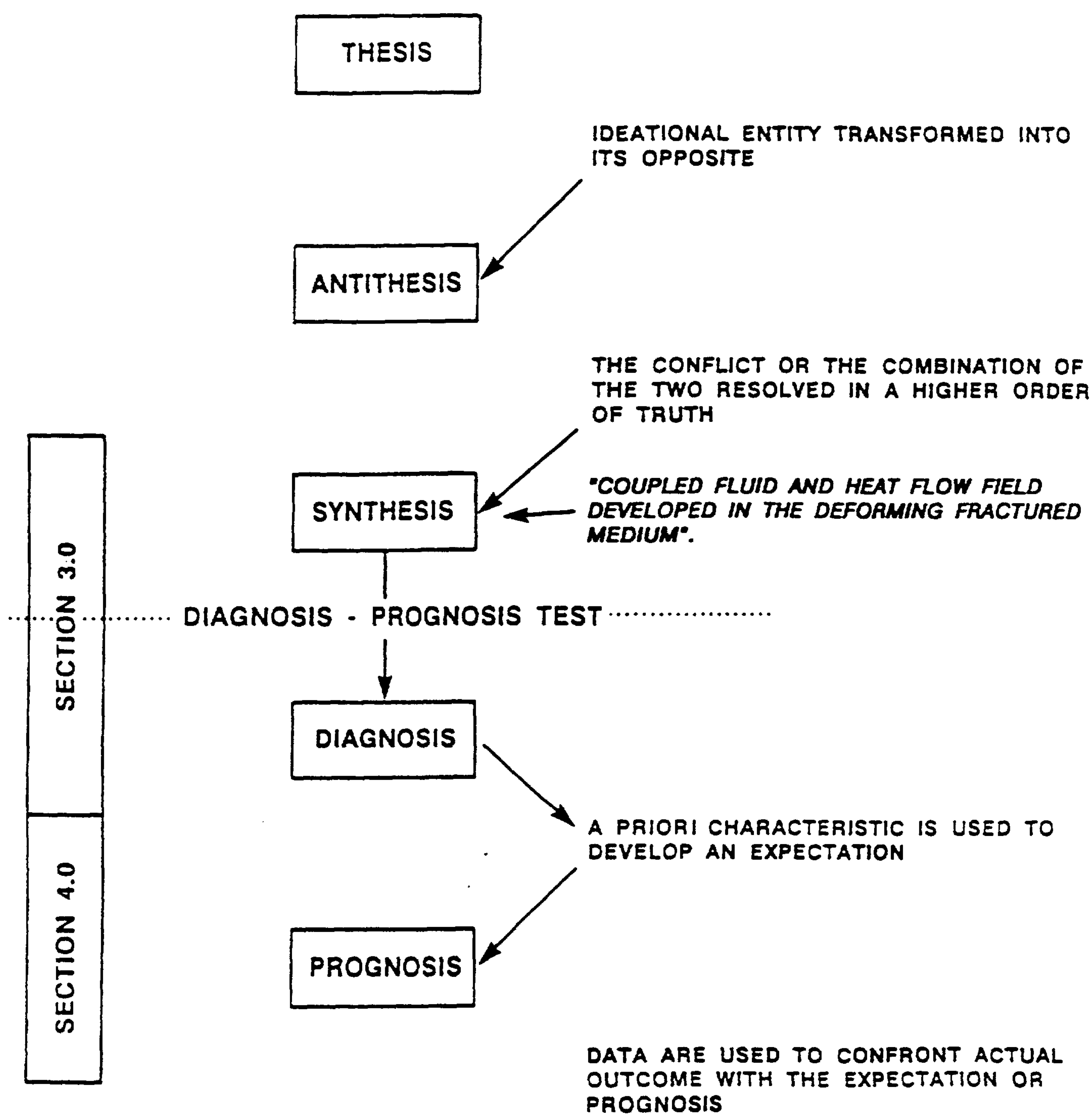
STATEMENT OF THE PROBLEM



DESIRED UNDERSTANDINGS WERE DEVELOPED VIA DIALECTIC REASONING OR HEGELIAN PROCESS OF CHANGE

"CONCEPTUAL CONSIDERATIONS OF THE DEATH VALLEY GROUNDWATER SYSTEM WITH SPECIAL EMPHASIS ON THE ADEQUACY OF THIS SYSTEM TO ACCOMMODATE THE HIGH-LEVEL NUCLEAR WASTE REPOSITORY".

DIALECTIC REASONING



ACTUAL DATA

DIAGNOSIS - PROGNOSIS TEST

LOGIC UTILIZED IN EXAMINING THE DATA BASE PERTAINING TO THE DEATH VALLEY GROUNDWATER SYSTEM

DIAGNOSIS - PROGNOSIS TEST

STEP 1 - IDENTIFY DIAGNOSTIC CHARACTERISTICS OF THE FLOW FIELD - SECTION 3.0

SECTION 4.0

STEP 2 - IDENTIFY SYSTEM SPECIFIC DATA WHICH PERTAIN TO A GIVEN DIAGNOTSIC CHARACTERISTIC

STEP 3 - IDENTIFY "CONCEPTUAL ALTERNATIVES"

STEP 4 - IDENTIFY DATA/INFORMATION NEEDS REQUIRED IN ORDER TO SELECT A CORRECT CONCEPTAL ALTERNATIVE

STEP 5 - EXAMINE THE DATA BASE RELATIVE TO THESE DATA/INFORMATION NEEDS

STEP 6 - REJECT; ACCEPT; OR IDENTIFY FURTHER SPECIFIC DATA/INFORMATION NEEDS

DIAGNOSTIC CHARACTERISTICS - STEP 1

AS IDENTIFIED IN SECTION 3.0 BASED ON CONCEPTUAL CONSIDERATIONS OF TWO PHASE FLOW FIELD OPERATING IN A DEFORMING FRACTURED MEDIUM

- PERCHED WATERS
  - INJECTION FROM BELOW THE WATER TABLE?
- CONFIGURATION OF W. T.
  - STEEP GRADIENTS, MOUNDS OR PERCHED WATERS, AND SINKS - CONTROLLED BY TECTONIC FACTORS (HEAT AND/OR STRESS)?
- HETEROGENEITY IN 3D DISTRIBUTION OF HYDRAULIC POTENTIAL
  - OVERPRESSURE, UNDERPRESSURE, PLANNER DISCONTINUES CONTROLLED BY TECTONIC FACTORS

    ($Z_{(x;tn)}$ AND $R_{h_{x_1}}(x)$ AND $R_{f_{x_1}}(x)$)

DIAGNOSTIC CHARACTERISTICS - STEP 1
(CONTINUED)

- **THERMAL HETEROGENEITY IN SPACE AND TIME**
  - TEMPERATURE GRADIENTS IN 3D, TIME DEPENDENCE OF TEMP GRADIENTS - CAUSED BY TECTONICS FACTORS
    ($K_h(t)$ AND $R_{h_{e_1}}(x)$ AND $R_{f_{e_1}}(x)$)
- **IN-SITU STRESS**
  - LATERAL GRADIENTS OF IN-SITU STRESS, TIME DEPENDENCE OF THESE GRADIENTS LIMIT EQUILIBRIUM - CAUSED BY ONGOING TECTONIC DEFORMATION
- **RESPONSE TO HYDRAULIC STRESSING**
  - $Kf = f(p)$- SMALL CHANGES IN PORE PRESSURE CAUSE LARGE CHANGES IN $Kf \cdot \Delta h \rightarrow \Delta[\sigma;\tau]$ - SCALE
- **TIME - DEPENDENCE OF HYDRAULIC POTENTIALS AS EXPRESSED IN GEOLOGICAL RECORD**
  - LARGE SCALE FLUCTUATION OF W.T. AS EXPRESSED THROUGH GEOLOGIC MATERIALS ORIGIN OF WHICH IS RELATED TO G.W. UPWELLING

SYSTEM SPECIFIC DATA BASE - STEP 2

- ALL SEVEN CHARACTERISTIC IDENTIFIED IN STEP 1
  - PRESENT
- IN MOST CASES, HOWEVER, THE CAUSE IS UNCERTAIN
  - TRADITIONAL APPROACH, i.e., TIME INDEPENDENT 3D CONDUCTIVITY STRUCTURE
    - a) INTERPRETATION IS PERMISSIBLE;
    - b) NOT COMPLETE; AND
    - c) NO DATA TO SUPPORT IT DIRECTLY
- TWO PHASE FLOW FIELD DEVELOPED IN A DEFORMING FRACTURED MEDIUM, i.e., TIME DEPENDENT 3D CONDUCTIVITY STRUCTURE AND "FLOW" (HEAT AND FLUID) BOUNDARY CONDITIONS
    - a) INTERPRETATION IS PERMISSIBLE;
    - b) COMPLETE;
    - c) SOURCE DATA TO SUPPORT IS DIRECTLY; AND
    - d) CIRUMSTANTIAL EVIDENCE

PERCHED WATERS - STEP 3 THROUGH STEP 6

STEP 3 - CONCEPTUAL ALTERNATIVES

- RECENT METEORIC WATER; OR
- INJECTION FROM BELOW THE WATER TABLE

STEP 4 - DATA NEEDS REQUIRED TO SELECT A CORRECT CONCEPTUAL ALTERNATIVE

- CHEMICAL AND ISOTOPIC COMPOSITION;
- $\frac{\delta h}{\delta z}$ – UZ
- $\frac{\delta h}{\delta t}$ – UZ
- THERMAL CHARACTERISTICS;
- LOCATION (OVER AREAS WITH UPWARD FLOW IN SZ OR WHERE $\sigma_{nfeff} > \sigma_c; \tau_{nf} < \tau_{max}$)

STEP 5 - EXAMINE DATA BASE

- WELL 73-68 UZ $\frac{\delta h}{\delta z}$ - up (WINOGRAD AND THORDARSON, 1975 PG. C-58)
- SZ $\frac{\delta h}{\delta z}$ -up (64.5°C TEMP 73-66, 5420PPM TDS 68-69)

STEP 6 - REJECT, ACCEPT.....

- PERMITS SUSPICION

CONFIGURATION OF WATER TABLE - STEEP GRANDIENT

STEP 3 - CONCEPTUAL ALTERNATIVES

- LITHOLOGY CONTROLLED BARRIER;
- IN-SITU STRESS CONTROLLED BARRIER - $Z_{(x;tn)}$; AND
- THERMAL HETEROGENEITY $R_{h_{e_1}(x)}$; $R_{f_{e_1}(x)}$

STEP 4 - DATA NEEDS REQUIRED SO SELECT A CORRECT CONCEPTUAL ALTERNATIVE

- $\frac{\partial Kf}{\partial x}$ - DISTRIBUTION OF LITHOLOGY CONTROLLED HYDRAULIC CONDUCTIVITY ACROSS THE GRADIENT
- $\frac{\partial^2[\sigma;\tau]}{\partial z \cdot \partial x}$ - VARIABILITY OF IN-SITU STRESS WITH DEPTH AND ACROSS THE GRADIENT
- $\frac{\partial^2 temp}{\partial z \cdot \partial x}$ - VARIABILITY OF IN-SITU TEMPERATURE WITH DEPTH AND ACROSS THE GRADIENT

STEP 5 - EXAMINE DATA BASE

- IN-SITU STRESS USWG-2; USWG-1; AND UE25p-1
- IN-SITU TEMP H-4; G-4; G-1; G-2 H-6; H-5; G-4; B1H
  SASS et. al. 1987

STEP 6 - ACCEPT, REJECT .....

- MAYBE (HARD TO TELL)
- PERMITS SUSPICION

3D - DISTRIBUTION OF HYDRAULIC POTENTIAL

(CONTINUED)

STEP 3 - CONCEPTUAL ALTERNATIVES

- LITHOLOGY CONTROLLED 3-D CONDUCTIVITY STRUCTURE
- IN-SITU STRES CONTOLLED 3-D CONDUCTIVITY STUCTURE (TIME DEPENDENT)
- TECTONICALLY CONTROLLED BOUNDARY CONDITIONS (BASE OF THE FLOW SYSTEM - $R_{h_{z,(z)}}$ AND $R_{f_{z,(z)}}$)

STEP 4 - DATA NEEDS REQUIRED TO SELECT A CORRECT CONCEPTUAL ALTERNATIVE

$\frac{\partial[\sigma;\tau]}{\partial x(\partial z)(\partial y)}$ - IN-SITE STRESS HETEROGENEITY

$\frac{\partial temp}{\partial x(\partial z)(\partial y)}$ - IN-SITU TEMP. HETEROGENEITY

$\frac{\partial chem}{\partial x(\partial z)(\partial y)}$ - HETEROGENEITY IN GROUNDWATER CHEMISTRY

STEP 5 - EXAMINE DATA BASE

- PAHUTE MESA (THERMAL AND CHEMICAL HETEROGENEITY; POSSIBLE IN-SITU STRESS LIMIT EQUILIBRIUM)
- YUCCA MOUNTAIN (IN-SITU STRESS LIMIT EQUILIBRIUM)

STEP 6 - ACCEPT, REJECT

- TENTATIVE ACCEPTANCE

IN-SITU STRESS STATE

STEP 3 - CONCEPTUAL ALTERNATIVES

- GRAVITATIONAL
- REMNANT TECTONIC
- ACTIVE TECTONIC, i.e., TIME AND SPACE VARIABLE, LOCALLY LIMIT EQUILIBRIUM $\sigma_{nfeff} \rightarrow \sigma_3$ AND $\tau_f \rightarrow \tau_{max}$

STEP 4 - DATA REQUIRED TO SELECT A CORRECT CONCEPTUAL ALTERNATIVE

$\frac{\partial[\sigma;\tau]}{\partial_z(\partial x)(\partial y)}$ - 3D DISTRIBUTION OF IN-SITU STRESS

$\frac{\partial[\sigma;\tau]}{\partial t}$ - CHANGES IN TIME (GEOLOGICAL OBSERVATIONS, LOGN AND SHORT TERM STRAIN MEASUREMENTS)

STEP 5 - EXAMINE DATA BASE

- LOCAL SETTING
  HISTORY OF FAULT MOVEMENT AND STRAIN ACCUMULATION
- YUCCA MOUNTAIN
  LOCALLY LIMIT EQUILIBRIUM - SLUG TESTS AND HYDROFRACTURE MEASUREMENTS

STEP 6 - ACCEPT, REJECT...

- ACCEPT

IN-SITU TEMPERATURE

STEP 3 - CONCEPTUAL ALTERNATIVES

- LITHOLOGY CONTROLLED 3-D CONDUCTIVITY STRUCTURE, i.e., "FORCED" CONVECTION
- IN-SITU STRESS CONTROLLED 3-D CONDUCTIVITY STRUCTURE, (TIME-DEPENDENT), i.e., ATTENUATED "FORCED" CONVECTION
- IN-SITU STRESS CONTROLLED 3-D CONDUCTIVITY STRUCTURE AND TECTONICALLY CONTROLLED BOUNDARY CONDITIONS AT THE BASE OF FLOW SYSTEM i.e., ATTENUATED "MIXED" CONVECTION

STEP 4 - DATA NEEDS REQUIRED TO SELECT A PROPER CONCEPTUAL ALTERNATIVE

$\frac{\partial temp}{\partial z(\partial x)(\partial y)}$ – THERMAL HETEROGENEITY IN 3-D - MAINLY BASE OF THE FLOW SYSTEM $R^* > R_{cr}$ AND $\frac{\partial temp}{\partial x(\partial y)}$

$\frac{\partial^2 temp}{\partial t \partial z(\partial x)(\partial y)}$ – TIME DEPENDENCE OF THERMAL HETERGENEITY - UPPER PARTS OF THE FLOW SYSTEM

$\frac{\partial^2 h}{\partial t \partial z(\partial x)(\partial y)}$ – 3-D DISTRIBUTION OF HYDRAULIC POTENTIAL AND ITS TIME-DEPENDENCE

STEP 5 - EXAMINE DATA BASE

- REGIONAL SETTING; SILICA CONTENT IN GROUNDWATER
  - HIGH HEAT FLOW AT THE BASE OF FLOW SYSTEM
- IN-SITU TEMPERATURE
  - EUREKA LOW (NEAR SURFACE THERMAL DISTURBANCE)
- PALEOTEMPERATURE
  - POSSIBLE TIME DEPENDENCE

STEP 6 - ACCEPT, REJECT...

- PERMISSIBLE, HOWEVER, IN-SITU STRESS CONSIDERATIONS SUGGEST THAT TENTATIVE ACCEPTANCE MAY BE IN ORDER

GEOLOGIC MATERIALS - VEINS, POUD-SEEP DEPOSITES, TUFF MOUNDS

STEP 3 - CONCEPTUAL ALTERNATIVES

- NOT RELATED TO UPWARD DISPLACEMENTS OF W.T. i.e., PEDOGENIC, PERCHED WATERS
- CLIMATE RELATED DISPLACEMENT OF W.T.
- TECTONICALLY CAUSED DESPLACEMENT OF W.T.

STEP 4 - DATA REQUIRED TO SELECT A CORRECT CONCEPTUAL ALTERNATIVE

- COMPOSITION
- AGE
- TEMPERATURE OF FORMATION
- RELATIVE POSITION
- CONCEPTUAL MODEL OF HYDROLOGIC SYSTEM

STEP 5 - EXAMINE DATA BASE

STEP 6 - ACCEPT, REJECT...

- PERMISSIBLE

TECHNICAL ISSUES

- IS "TECTONIC RISE" OF WATER TABLE POSSIBLE AT THE YUCCA MOUNTAIN SITE?
- WHAT IS A MAGNITUDE OF THIS RISE?
- WHAT IS IT'S FREQUENCY OF OCCURANCE AND DURATION?

IS "TECTONIC RISE" OF WATER TABLE POSSIBLE AT THE YUCCA MOUNTAIN SITE?

- H SYSTEM. NO
- H-M SYSTEM. YES
- H-T SYSTEM. YES
- H-T-M SYSTEM. YES

MAGNITUDE OF THE TECTONIC RISE OF THE WATER TABLE FOR H-T-M SYSTEM

SUM OF THREE COMPONENTS, I.e:

- OVERPRESSURE - $\Delta_{P_{max}}$;
- WATER RELEASED FROM STORAGE ($\Delta \frac{\Delta V}{V}$; ΔS CAUSED BY $\Delta[\sigma; \tau]$); AND
- CONNECTIVE COMPONENT
  $GR = f(\phi; \frac{1}{a^3})$.

FREQUENCY AND DURATION OF THE RISE OF WATER TABLE FOR H-T-M SYSTEM

- FREQUENCY
  - FREQUENCY OF LARGE SCALE RESTRUCTURINGS IN THE STRAIN ENERGY FIELD - I.e., FAULTING (M $\approx$ 6.0 - 7.5 RANGE)

- DURATION
  - RATE OF POST-TECTONIC STRAINING ($[\sigma;\tau]$ AT LIMIT EQUILIBRIUM);
  - RATE OF APERTURE CHANGE (SEPARATION, DEPOSITION); AND
  - RATE OF CHANGE IN THE HEAT TRANSFER FUNCTION

DATA AND INFORMATION NEEDS TO:

a) VALIDATE THE CONCEPTUAL MODEL OF FLOW SYSTEM;

b) ESTIMATE THE MAGNITUDE OF "POST-TECTONIC" RISE OF WATER TABLE; AND

c) ESTIMATE PERIODICITY AND DURATION OF THIS RISE.

- BEHAVIOR OF THE FLOW SYSTEM IN THE PAST, SPECIFICALLY DURING THE QUATERNARY PERIOD
  - "FOOT PRINTS"; AND

- CONTEMPORARY CHARACTERISTICS OF THE FLOW SYSTEM.

BEHAVIOR OF THE FLOW SYSTEM IN THE PAST

- SEEP-POND DEPOSITS AND VEINS (SURFACE, SUBSURFACE, BELOW AND ABOVE WATER TABLE)
  - COMPOSITION;
  - ORIGIN; AND
  - AGE
- PERCHED WATERS - WHAT IS THE ORGIN OF FLUIDS COMPRISING THESES FEATURES? (METEORIC OR INJECTION). FROM BELOW THE WATER TABLE
  - COMPOSITION;
  - ORIGIN; AND
  - AGE
- PORE WATER - WHAT IS THE ORIGIN OF FLUIDS RESIDING IN PORES OF ROCKS OF THE VEDOSE ZONE (CONTEMPORARY METEORIC; REMNANT-DISPOSITION OF ROCKS; REMNANT-HYDRAULIC MOUND)
  - COMPOSITION;
  - ORIGIN; AND
  - AGE

CONTEMPORARY CHARACTERISTICS OF THE FLOW FIELD

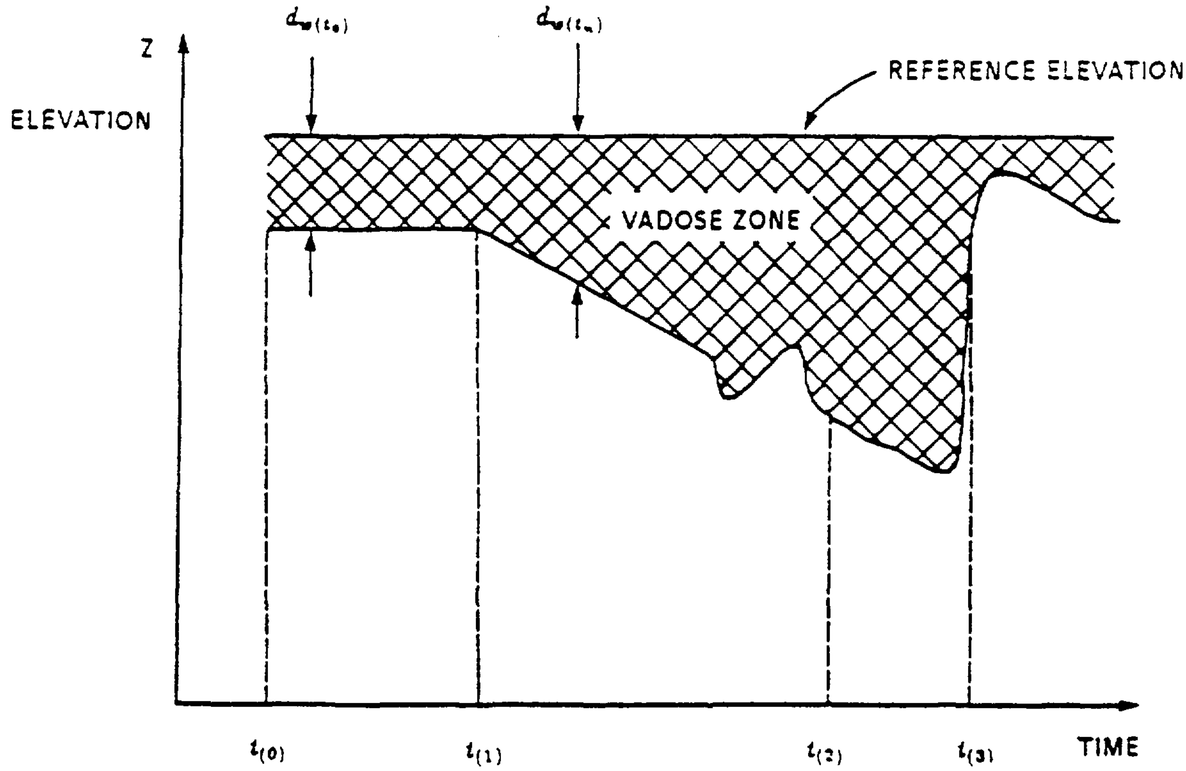
- $\frac{\partial h}{\partial t}$ — TIME DEPENDENCE OF HYDRAULIC PROTENTIALS
  HYDROGRAPHS FROM EXITSTING WELLS
  DRIFT - INCHES PER YEAR; SHORT TERM INSTABILITIES - FT - TEENS OF FT
  EXAMPLE

- $\frac{\partial h}{\partial z}; \frac{\partial[\sigma;\tau]}{\partial z}; \frac{\partial temp}{\partial z}$ — INTERDEPENDENCE BETWEEN: a) IN-SITU STRESS; b) HYDRAULIC POTENTIAL; AND c) IN-SITU TEMPERATURE
  ORIGIN OF OVERPRESSURE WITH DEPTH
  MAGNITUDE OF $\Delta pmax$
  SINGLE BOREHOLE - LOW WATER TABLE
  EXAMPLE

- $\frac{\partial^2 h}{\partial z;\partial x}; \frac{\partial^2[\sigma;\tau]}{\partial z;\partial x}; \frac{\partial^2 temp}{\partial z \cdot \partial x}$ — INTERDEPENDENCE BETWEEN: a) IN-SITU STRESS; b) HYDRAULIC POTENTIAL; AND c) IN-SITU TEMPERATURE
  ORIGIN OF STEEP HYDRAULIC GRADIENT
  BOREHOLES (1 OR 2 ROWS) ACROSS STEEP GRADIENT
  EXAMPLE

- $\Delta \frac{\Delta V}{V} \rightarrow \Delta h$ — RESPONSE OF WATER TABLE TO CHANGES IN VOLUMETRIC STRAIN, i.e., RESPONSE OF WATER TABLE TO NUCLEAR DETONATIONS
  EXAMPLE

$\frac{\partial h}{\partial t}$ — TIME DEPENDENCE OF HYDRAULIC POTENTIALS

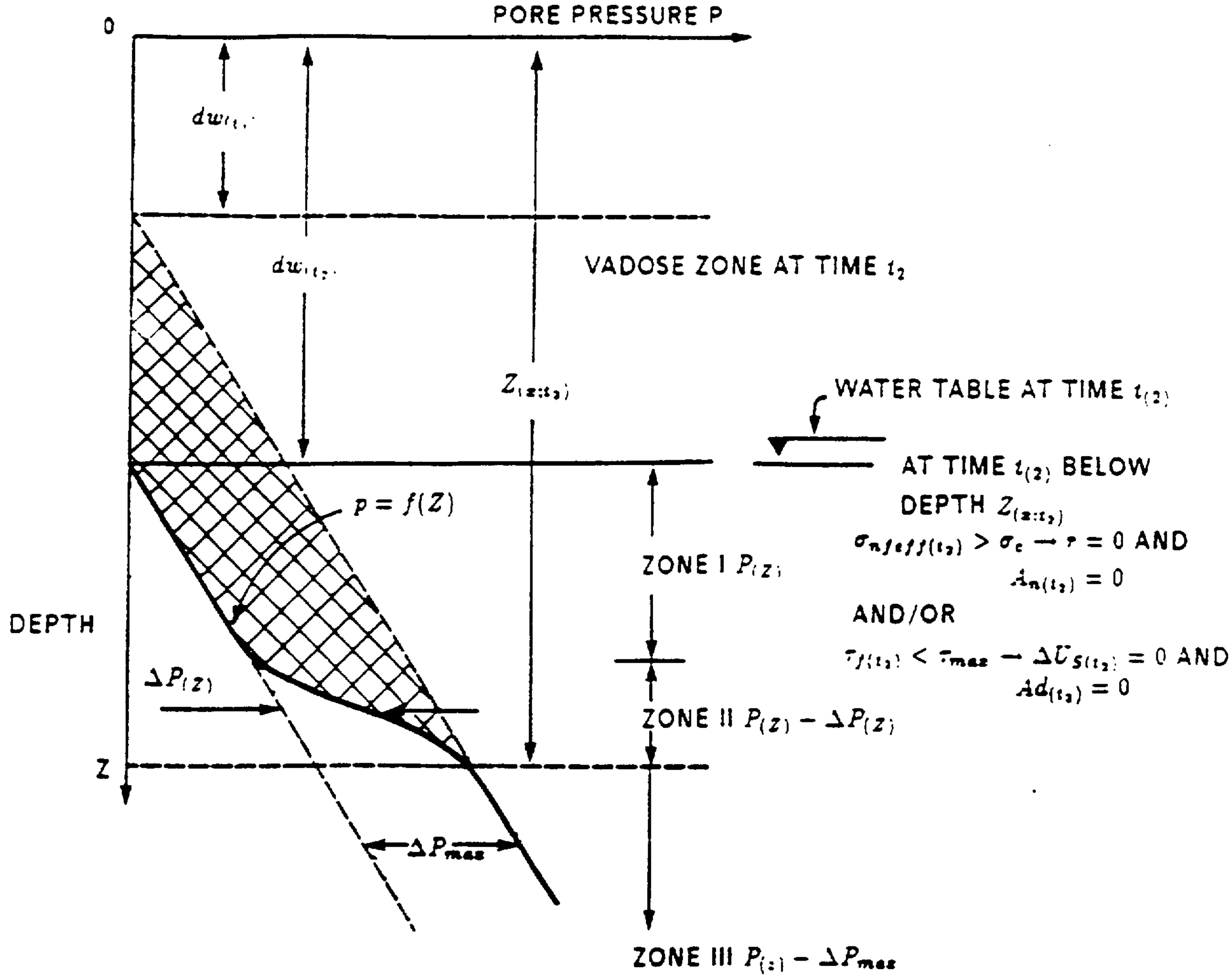


Note: The drawing is diagramatic - no relationship between initial thickness of the vadose zone and magnitude of tectonic lowering of the water table is implied.

Idealized history of the position of the water table for a single point P(x,y).

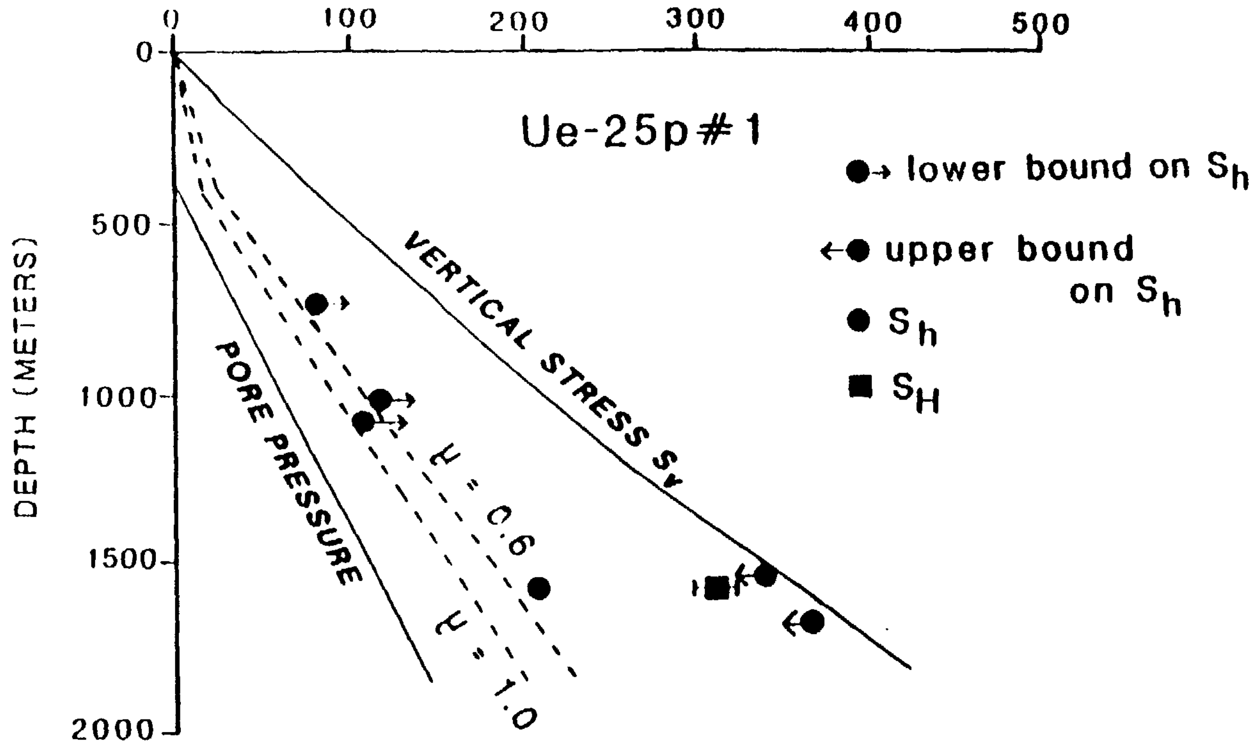
$\frac{\partial h}{\partial z}$; $\frac{\partial[\sigma;\tau]}{\partial z}$; $\frac{\partial temp}{\partial z}$ — INTERDEPENDENCE (WITH DEPTH) BETWEEN: a) IN-SITU STRESS; b) HYDRAULIC POTENTIAL; AND c) IN-SITU TEMP.

t_2 - ADVANCED STAGES OF TECTONIC DEFORMATION



ABOVE DEPTH $Z_{(z:t_2)}$	BELOW DEPTH $Z_{(z:t_2)}$
$A_{con(t_2)} = A_{es} - An_{(t_2)} - Ad_{(t_2)}$ $S^{Uz}_{(t_2)} = S^{Uz}_{(t_0)} + \Delta S^{Uz}_{(t_1)} - \Delta S^{Uz}_{(t_2)}$ $S^{Sz}_{(t_2)} = S^{Sz}_{(t_0)} + \Delta S^{Sz}_{(t_1)} - \Delta S^{Sz}_{(t_2)}$ $Kf^{Uz}_{(t_2)} = Kf^{Uz}_{(t_0)} - \Delta Kf^{Uz}_{(t_1)} + \Delta Kf^{Uz}_{(t_2)}$ $Kf^{Sz}_{(t_2)} = Kf^{Sz}_{(t_0)} + \Delta Kf^{Sz}_{(t_1)} + \Delta Kf^{Sz}_{(t_2)}$ $K_x = K_y$ FRACTURE FLOW	$A_{con(t_2)} - A_{es}$ = CONST $S^{Sz}_{(t_2)} = S^{Sz}_{(t_0)}$ $K^{Sz}_{(t_2)} = K^{Sz}_{(t_0)}$ $K_x = K_y$

Deforming fractured medium - idealized history of changes in hydraulic potential.

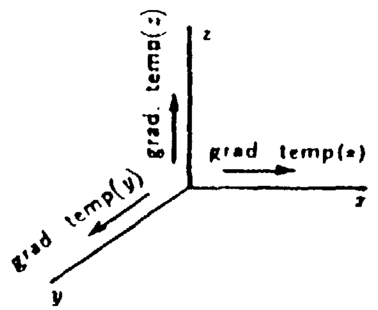
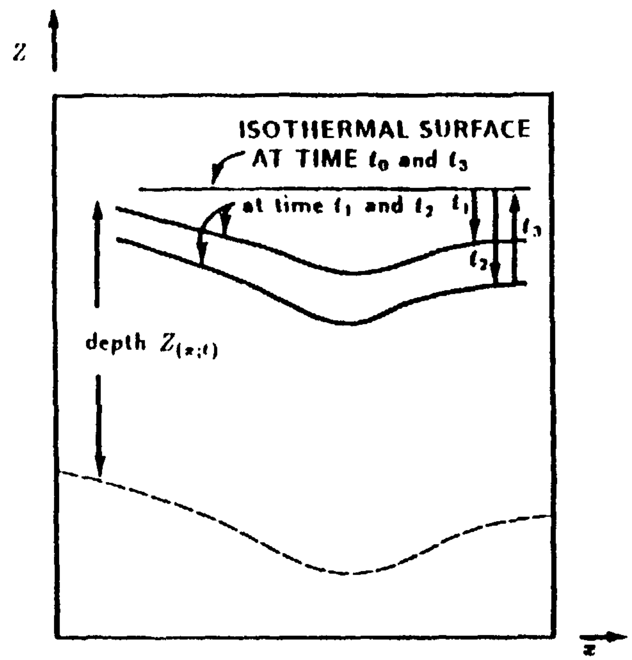
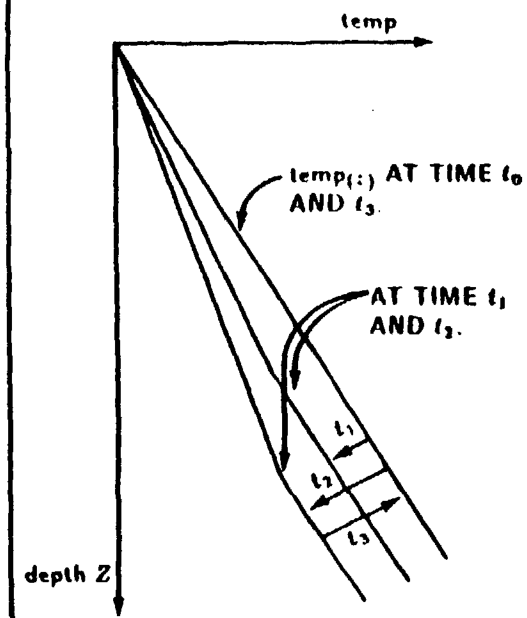


Hole	Logged depth (m)	Breakdown pressure[1] (bars)	Shut-in pumping pressure (bars)	Hydro-static pressure (bars)	Pore[2] pressure (bars)	S_h (bars)	S_v [3] (bars)	T[4] (bars)	S_H (bars)	Comments
P1	1,564	none[1]	337	153	115	337±2	353			Reopening preexisting fracture
P1	1,573	236	207	154	116	207±2	356	41	310±11	
Pa1	1,693	none[1]	366	166	128	365±10	388			Reopening preexisting fracture

1. No clear breakdown pressures seen

Results of in situ stress determination in well Ue-25p#1, Yucca Mountain. From Stock et al. (1986)

HEAT FLOW FIELD DEVELOPED IN THE DEFORMING FRACTURED MEDIUM WITH $R_{h_{e_1}(x;t)}$ = CONST HAS THE FOLLOWING CHARACTERISTICS

THREE DIMENSIONS	TWO DIMENSIONS	ONE DIMENSION
 $\frac{\delta^2 temp.}{\delta x \delta t} \neq 0 \neq$ const.; $\frac{\delta^2 temp.}{\delta y \delta t}$; $\neq 0 \neq$ const.; and $\frac{\delta^2 temp.}{\delta z \delta t} \neq 0 \neq$ const.		

Main characteristics of the heat flow field developed in the deforming fractured medium

$\frac{\partial^2 h}{\partial z \cdot \partial x}$; $\frac{\partial^2 [\sigma;\tau]}{\partial z \cdot \partial x}$; $\frac{\partial^2 temp}{\partial z \cdot \partial x}$ – INTERDEPENDENCE (ACROSS STEEP HYDRAULIC GRADIENT) BETWEEN: a) IN-SITU STRESS; b) HYDRAULIC POTENTIAL; AND c) IN-SITU TEMP.

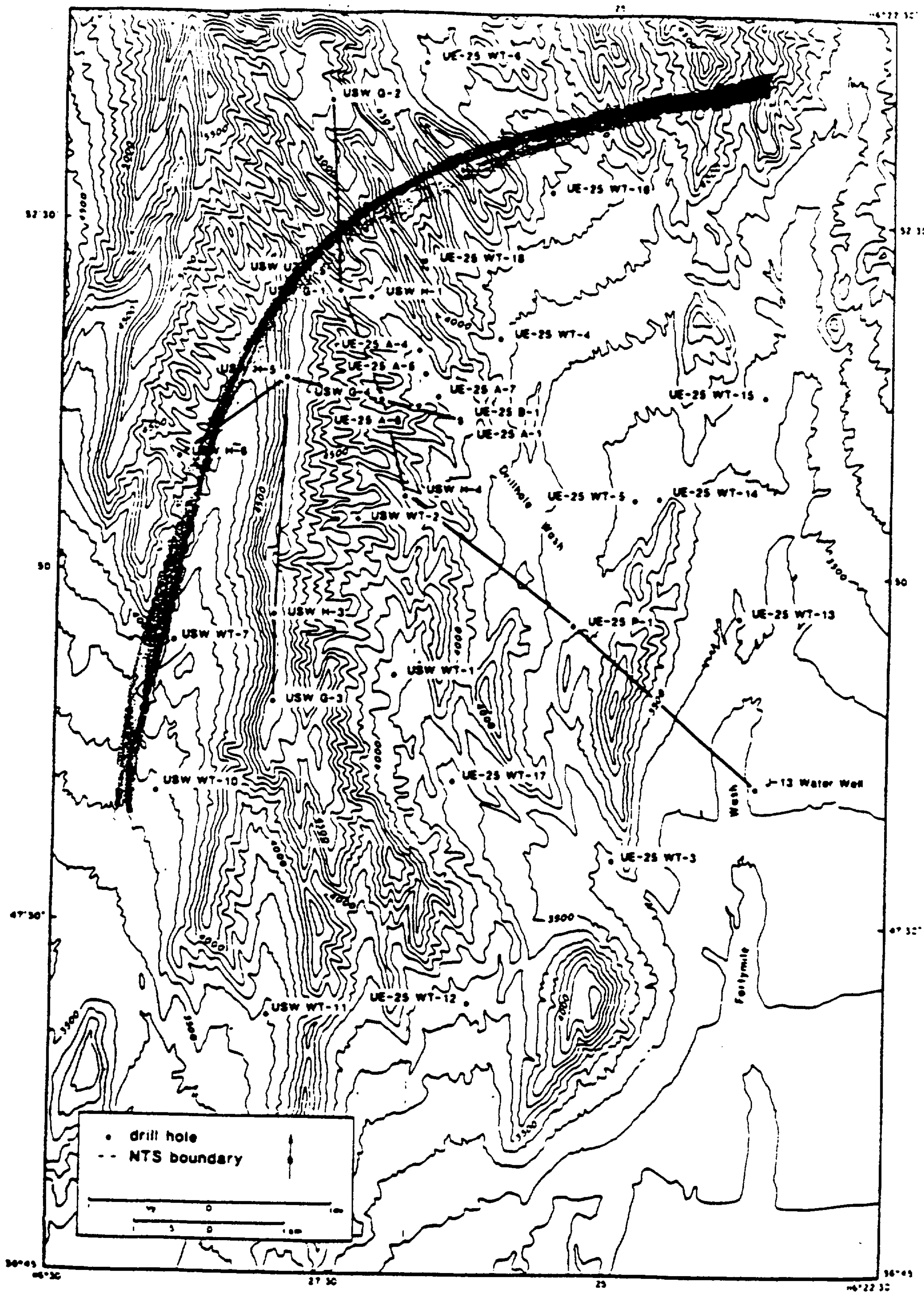


Figure 3. Test wells near Yucca Mountain. Profiles of Figures 4 through 8 are identified by solid lines.

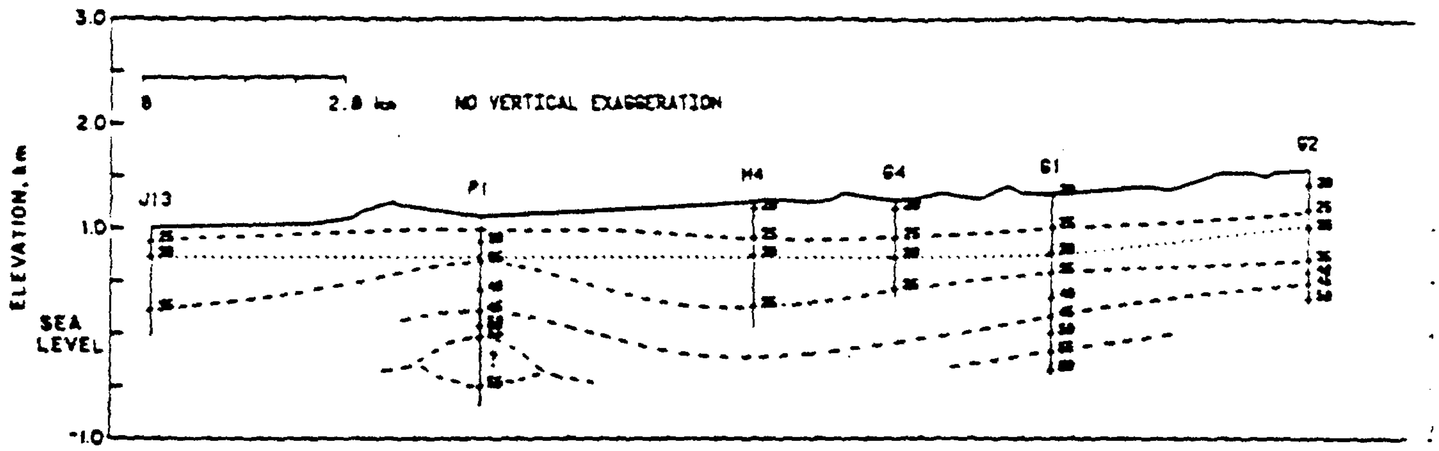


Figure 4. Thermal profile J13-G2 (Figure 3). Temperature profiles are plotted above with common origin. Dashed lines, isotherms; dotted line, static water level.

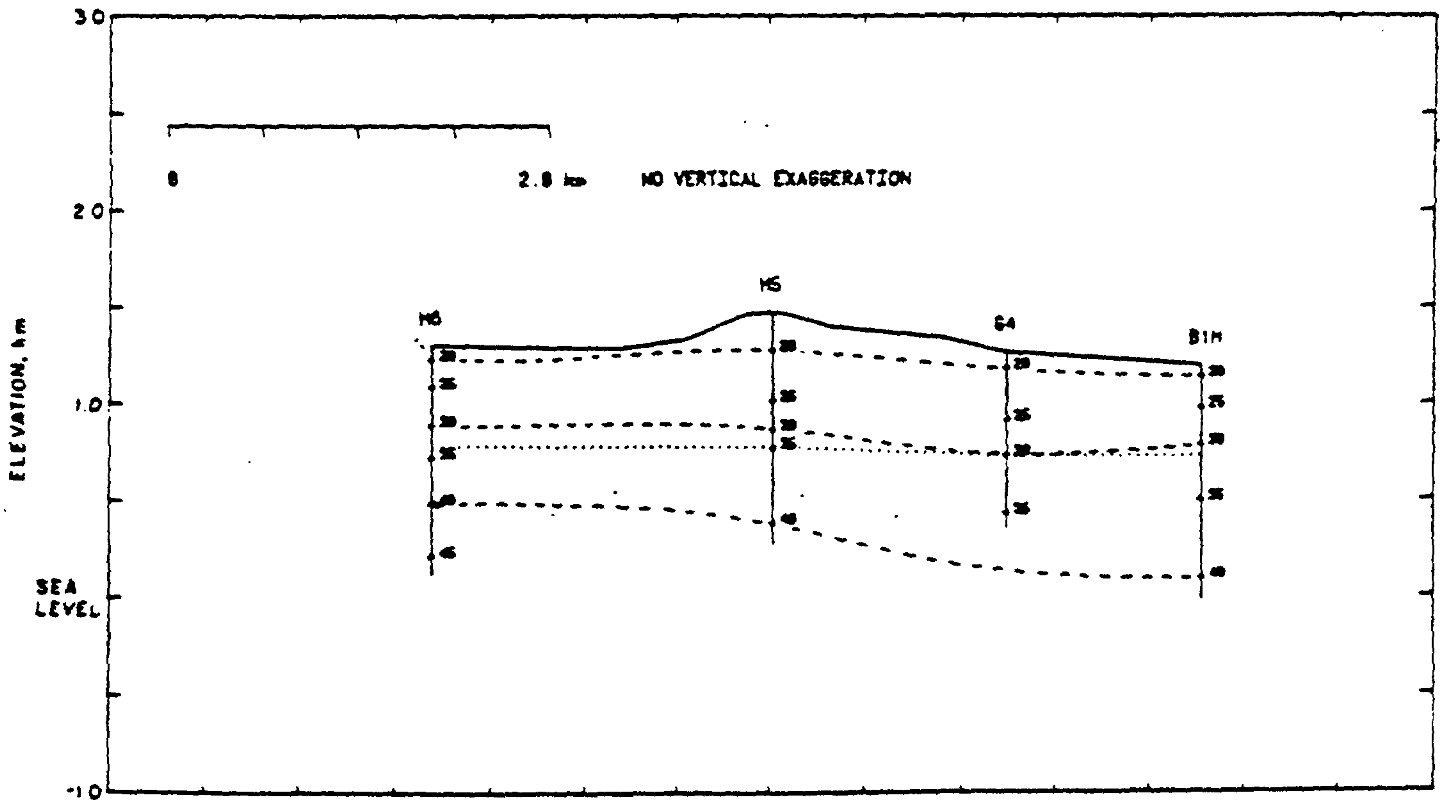
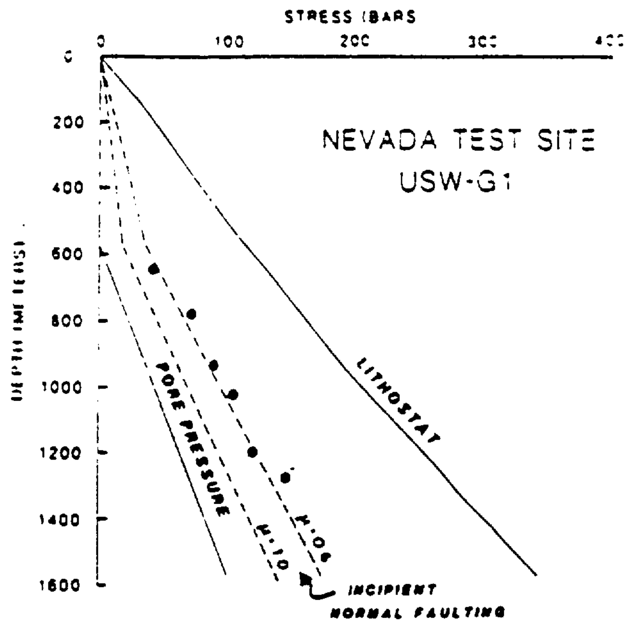
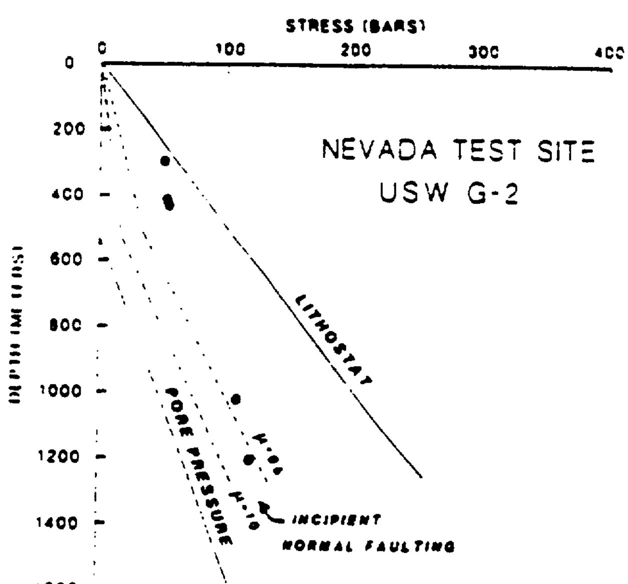
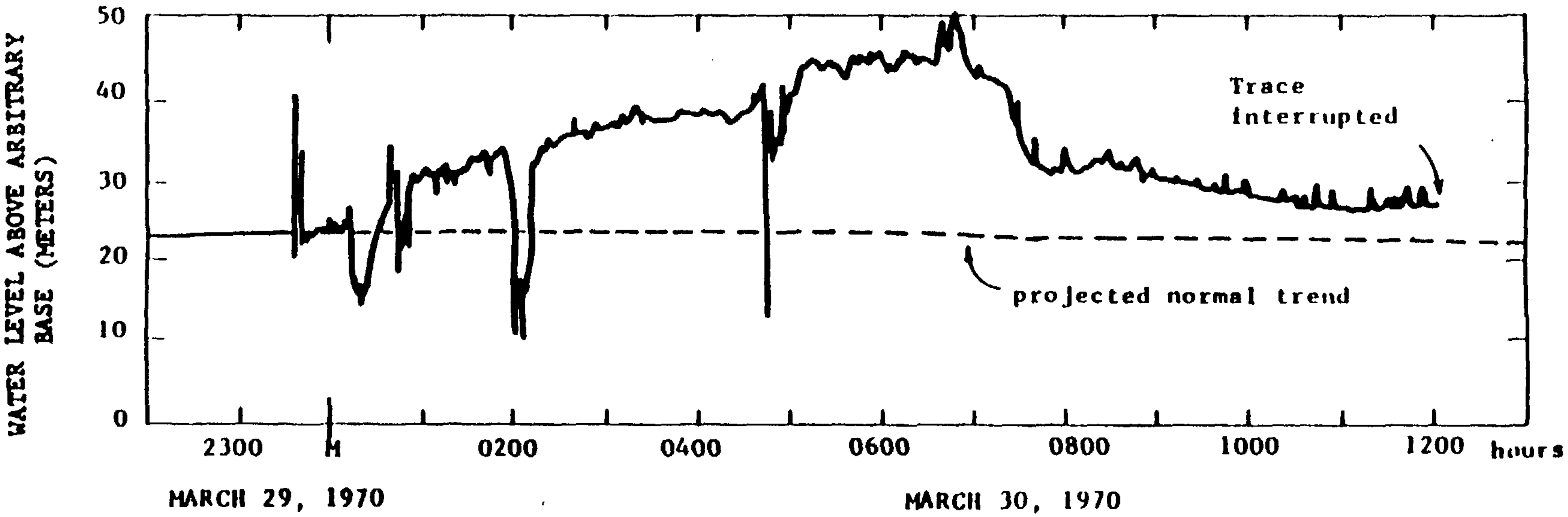


Figure 8. Thermal profile, H6-B1H (Figure 3). Temperature profiles are plotted above with common origin. Dashed lines, isotherms; dotted line, static water level.


STRESS (BARS)
0
100
200
300
400
0
200
400
600
800
1000
1200
1400
1600
NEVADA TEST SITE
USW-G1
LITHOSTAT
PORE PRESSURE
INCIPIENT
NORMAL FAULTING


STRESS (BARS)
0
100
200
300
400
0
200
400
600
800
1000
1200
1400
1600
NEVADA TEST SITE
USW G-2
LITHOSTAT
PORE PRESSURE
INCIPIENT
NORMAL FAULTING

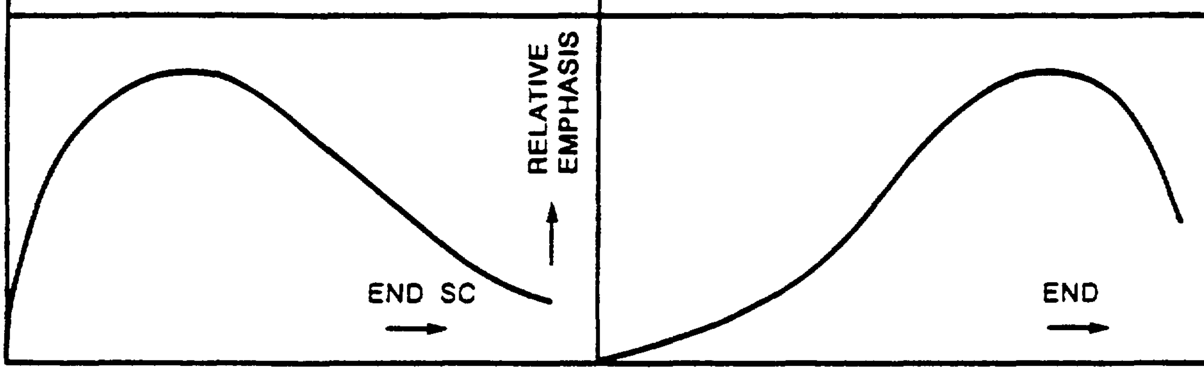
$\Delta \frac{\Delta V}{V} \rightarrow \Delta h$ — RELATIONSHIP BETWEEN CHANGES IN IN-SITU STRESS AND RESULTING CHANGES IN POSITION OF WATER TABLE



Hydrologic response to the Handley Event in well UE-20p. From Dudley et al (1971)

SITE CHARACTERIZATION DATA AND INFORMATION NEEDS

CONCEPTUAL MODEL DATA NEEDS	IMPLEMENTATION DATA NEEDS. PERFORMANCE ASSESSMENT. DESIGN.
• SURFACE-BASED TESTING BOREHOLE GEOPHYSICS TRENCHING MAPPING ETC.	• IN SITU TESTING IN EXPLORATORY SHAFT



QUESTIONS

ATTACHMENT D

4-11-88

TRANSLATION OF THE HYDROLOGIC SETTING TO PERFORMANCE MODELING APPLICATIONS

PRESENTED AT CONCEPTUAL MODEL WORKSHOP

LAS VEGAS, NEVADA

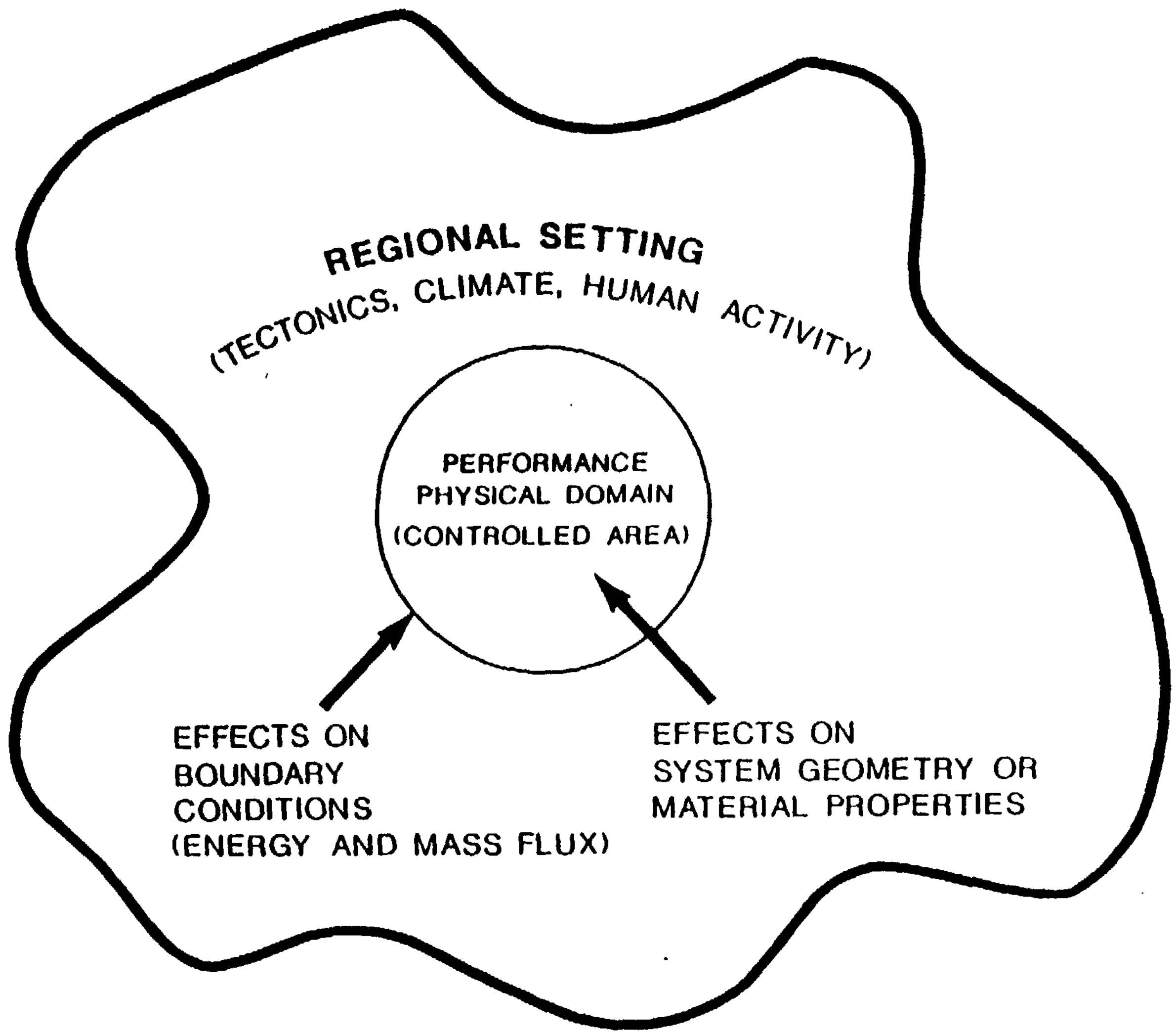
APRIL 11, 1988

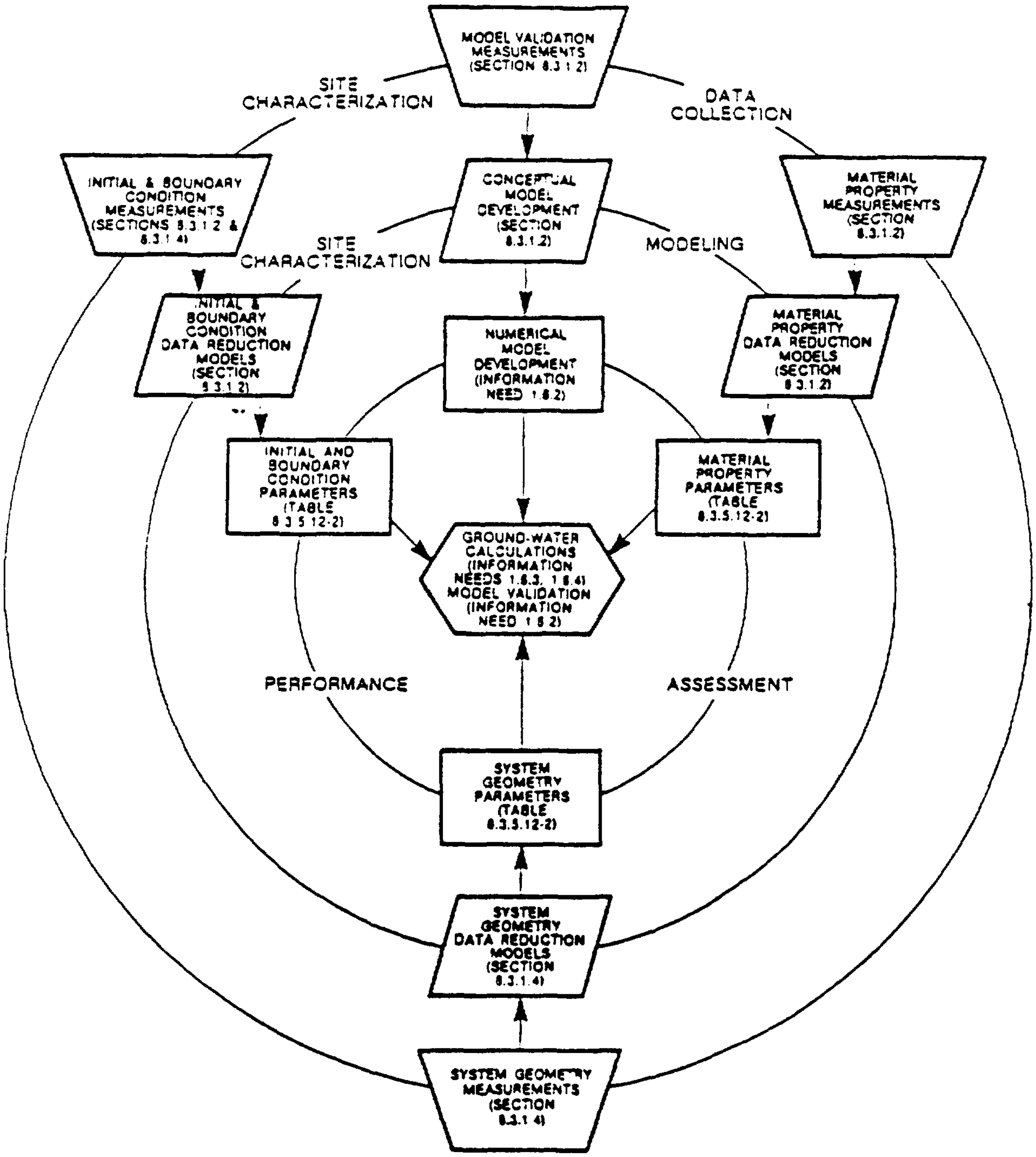
BY

SCOTT SINNOCK

SANDIA NATIONAL LABORATORIES

GEOGRAPHIC ACCOMMODATION OF EVENTS AND PROCESSES





K-5/13/87—FIGURE 8.3.5.12-8

Figure 8.3.5.12-8. Schematic flow of site information on system geometry, material properties, initial and boundary conditions, and model validation through data reduction modeling (Programs 8.3.1.2 and 8.3.1.4) to definition of performance assessment parameters (Table 8.3.5.12-2) for use in ground-water travel time calculations and model validation (Information Needs 1.6.2, 1.6.3, and 1.6.4).

Components of Conceptual Models Requiring Definition

- Physical Processes
- * Physical Domain
  - Geometry of Units (including faults)
  - Property Distributions within Units
- * Initial and Boundary Conditions
- * Calculational (Numerical) Constraints

---

* Ability to Predict Effects of Future Changes will be addressed

CURRENT ASSUMPTIONS
(PHYSICAL PROCESSES)

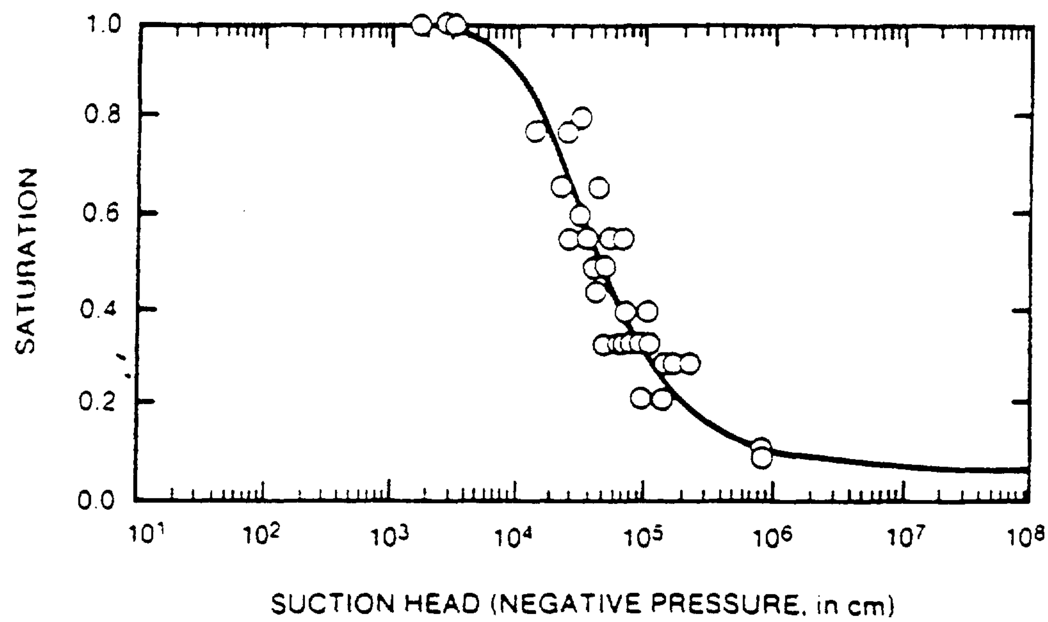
DARCY FLOW

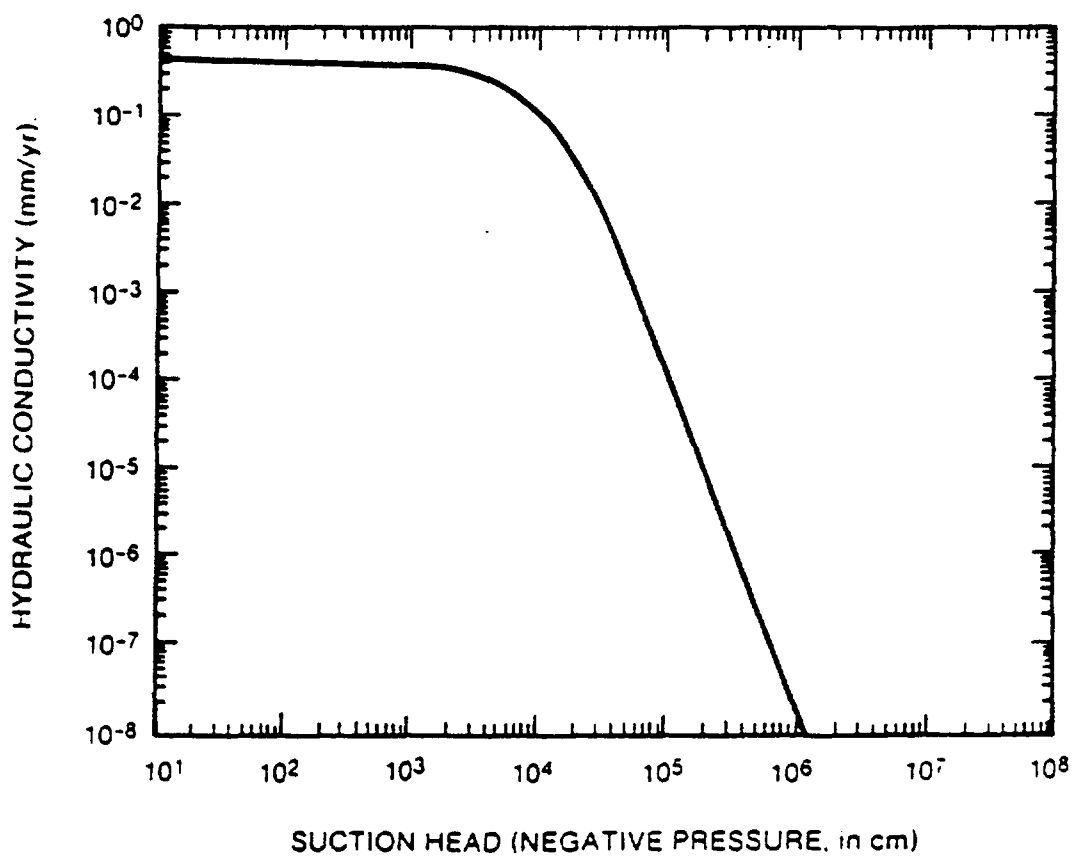
- RICHARD'S EQUATION IN UNSATURATED ZONE
- $K(\psi)$, ψ(PORE SIZE) "CAPILLARY BUNDLE"
- * - PRESSURE EQUILIBRIUM PERPENDICULAR TO FLOW (FRACTURE-MATRIX INTERACTIONS)
- * - "EFFECTIVE POROSITY" = MOISTURE CONTENT
- * - ISOTHERMAL, TRANSIENT OR STEADY STATE, SINGLE PHASE (LIQUID)

---

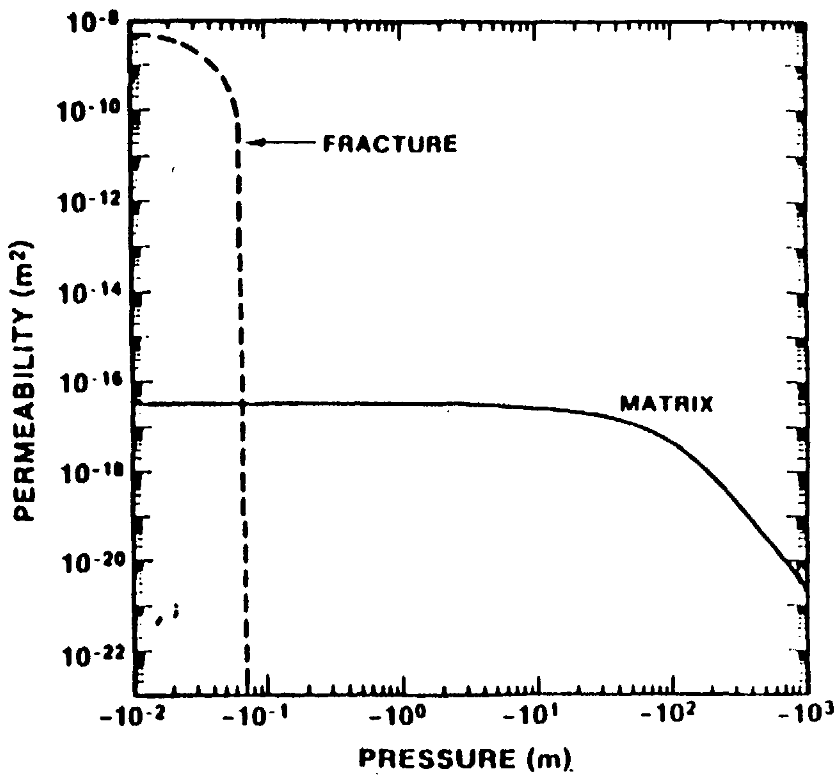
* POTENTIALLY OVERCONSTRAINING

CHARACTERISTIC CURVES
TOPOPAH SPRING MEMBER

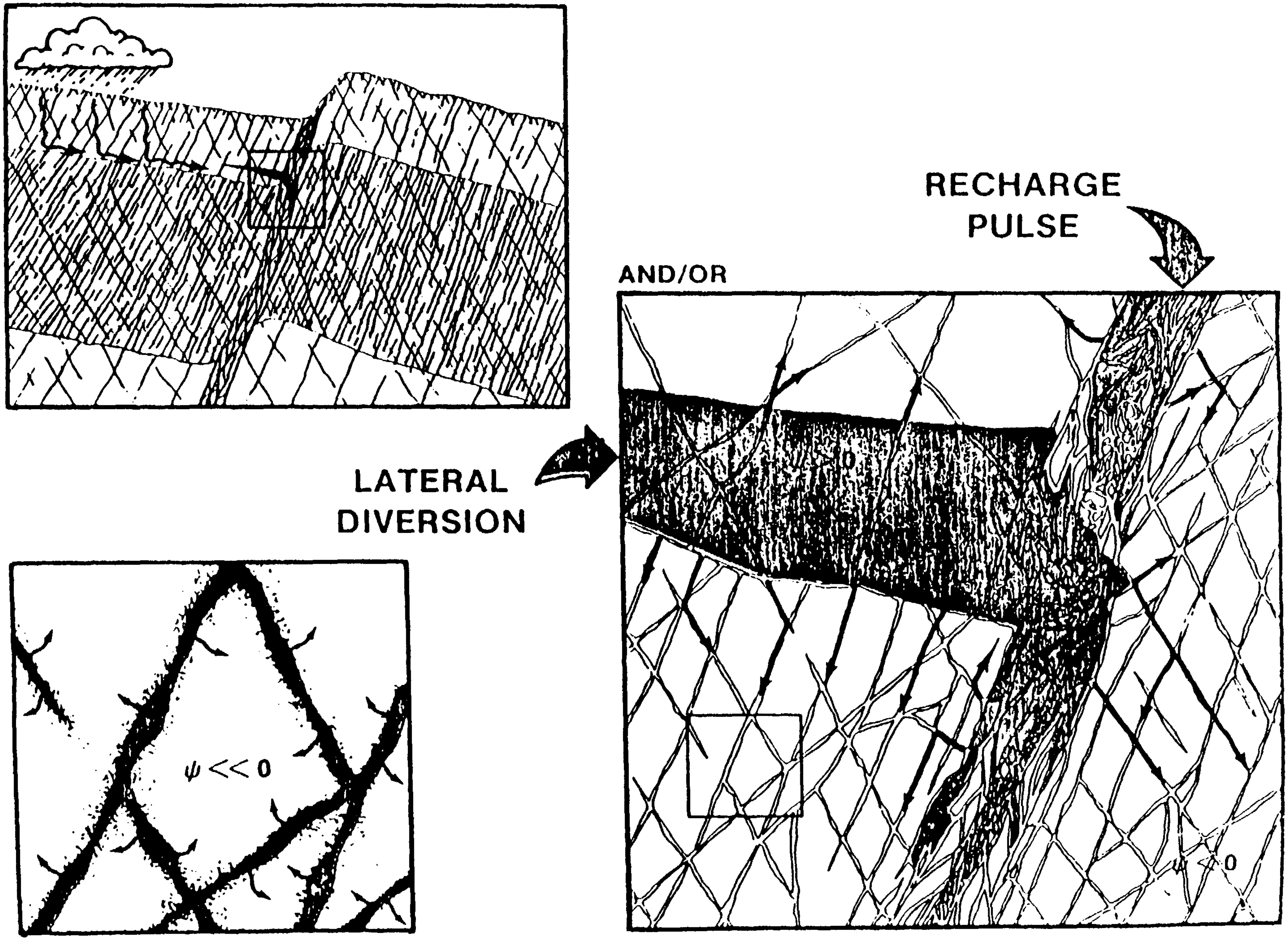




PERMEABILITIES OF PARTIALLY SATURATED DISCRETE FRACTURES FROM TOPOPAH SPRING

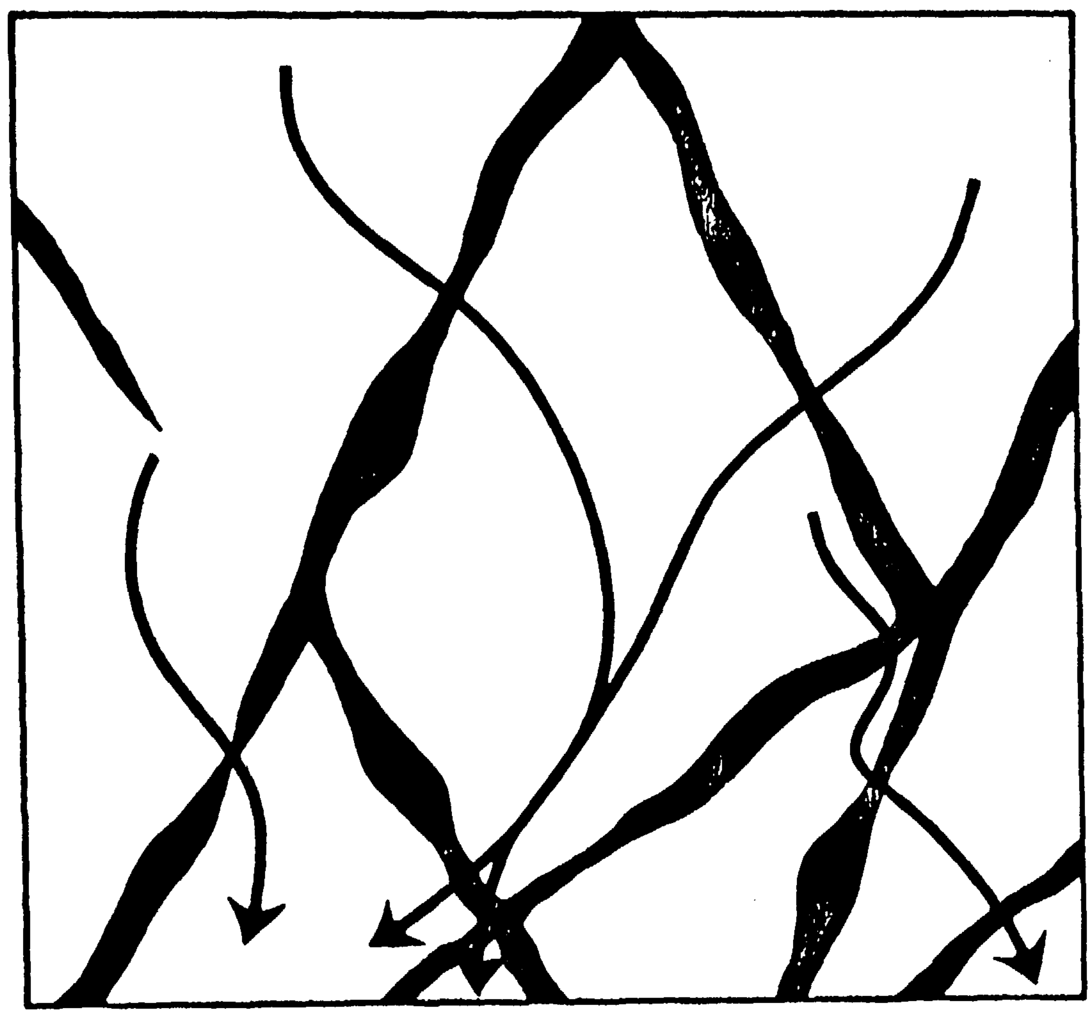


(From Wang and Narasimhan, 1984)



RECHARGE
PULSE
AND/OR
LATERAL
DIVERSION
ψ << 0

CONCEPTUAL FRACTURE - MATRIX INTERACTIONS



Components of Conceptual Models Requiring Definition

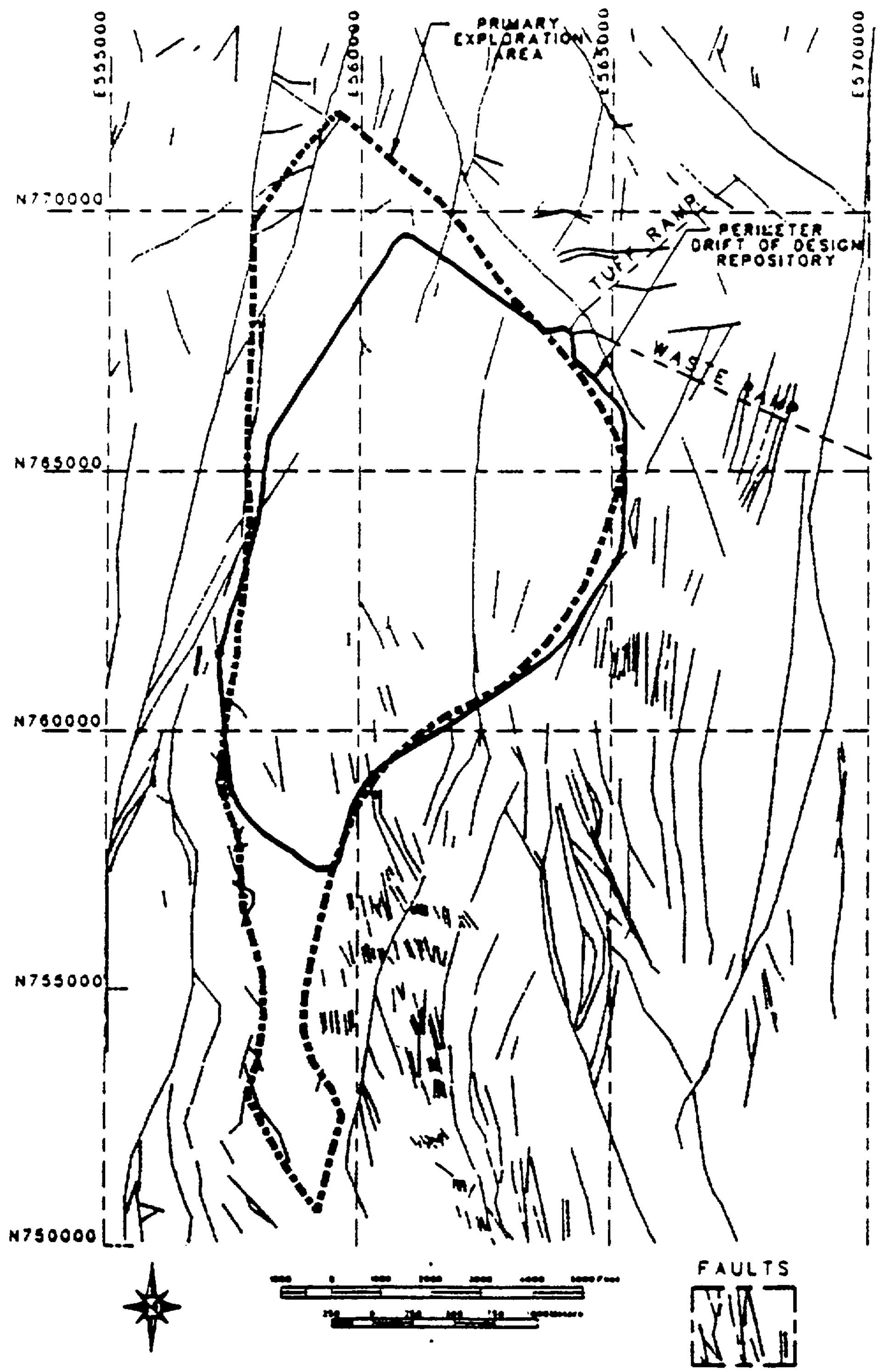
- Physical Processes
- * Physical Domain
  - Geometry of Units (including faults)
  - Property Distributions within Units
- * Initial and Boundary Conditions
- * Calculational (Numerical) Constraints

---

* Ability to Predict Effects of Future Changes will be addressed

CURRENT ASSUMPTIONS
(PHYSICAL DOMAIN)

- GEOMETRY OF HYDROLOGIC SYSTEM (IGIS COMPUTER GRAPHICS MODEL)
  - HYDROSTRATIGRAPHY
  - STRUCTURE
  - WATER TABLE
  - BOUNDARY DEFINITION
- DISTRIBUTION OF PHYSICAL PROPERTIES
  - PROPERTY-BASED PATTERN RECOGNITION DEFINES UNITS
  - NON-UNIFORM, HETEROGENEOUS WITHIN UNITS
  - GEOSTATISTICS (SPATIAL VARIANCE, COVARIANCE, KRIGING)
  - SIMULATION OF INTERPOLATED PROPERTIES
  - SCALING EFFECTS
- EXAMPLES OF CURRENT "NOMINAL CASE" FOLLOW

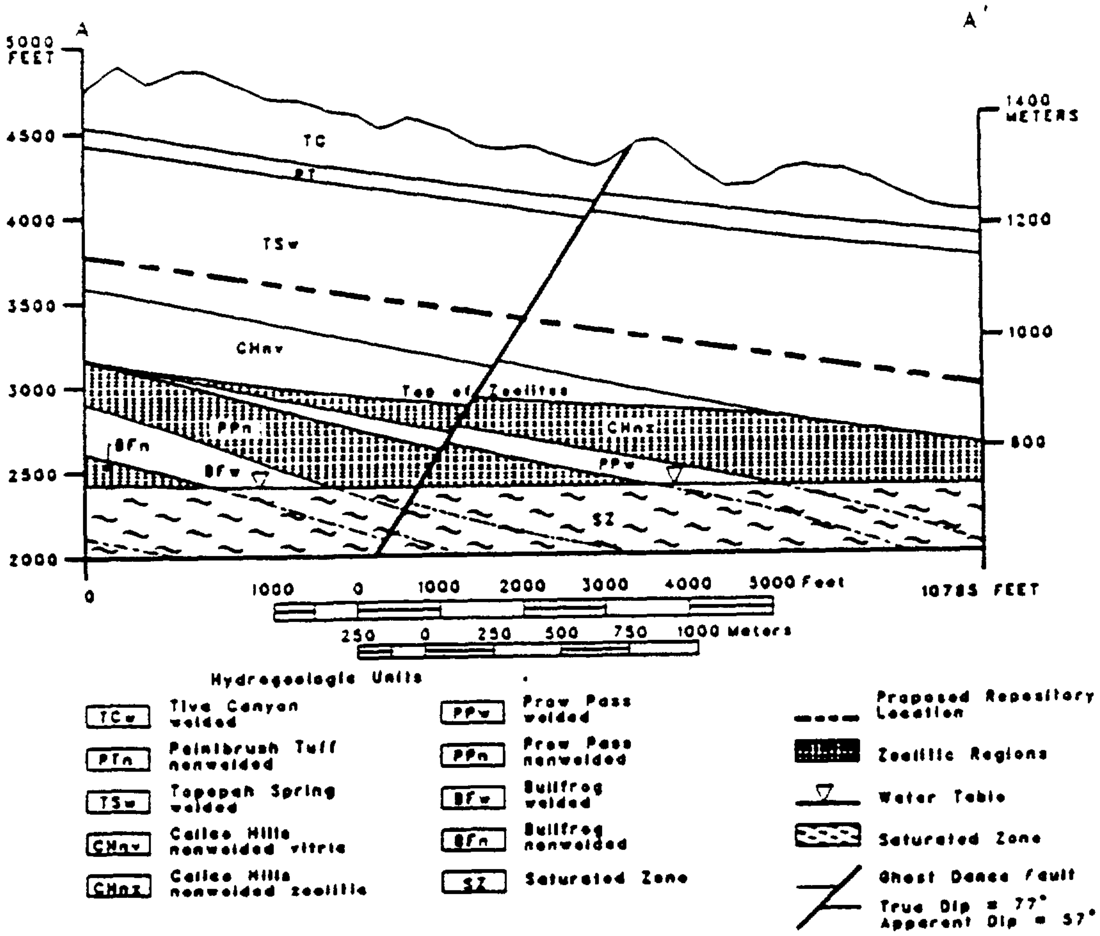


NNWSI

TITLE

FAULTS LOCATIONS IN AREA FROM SCOTT AND BONK 1984

CLASSIFICATION	SIZE	CODE IDENT NO.	PRODUCT NUMBER
UNCLASSIFIED	A	14213	CAL0126
			SHEET 1 OF 1



NNWSI	TITLE	Example of Hydrostratigraphic Unit from Computer Graphics System
CLASSIFICATION UNCLASSIFIED	SIZE A	CODE IDENT NO. 14213
PRODUCT NUMBER CAL0199	SHEET 1 OF	

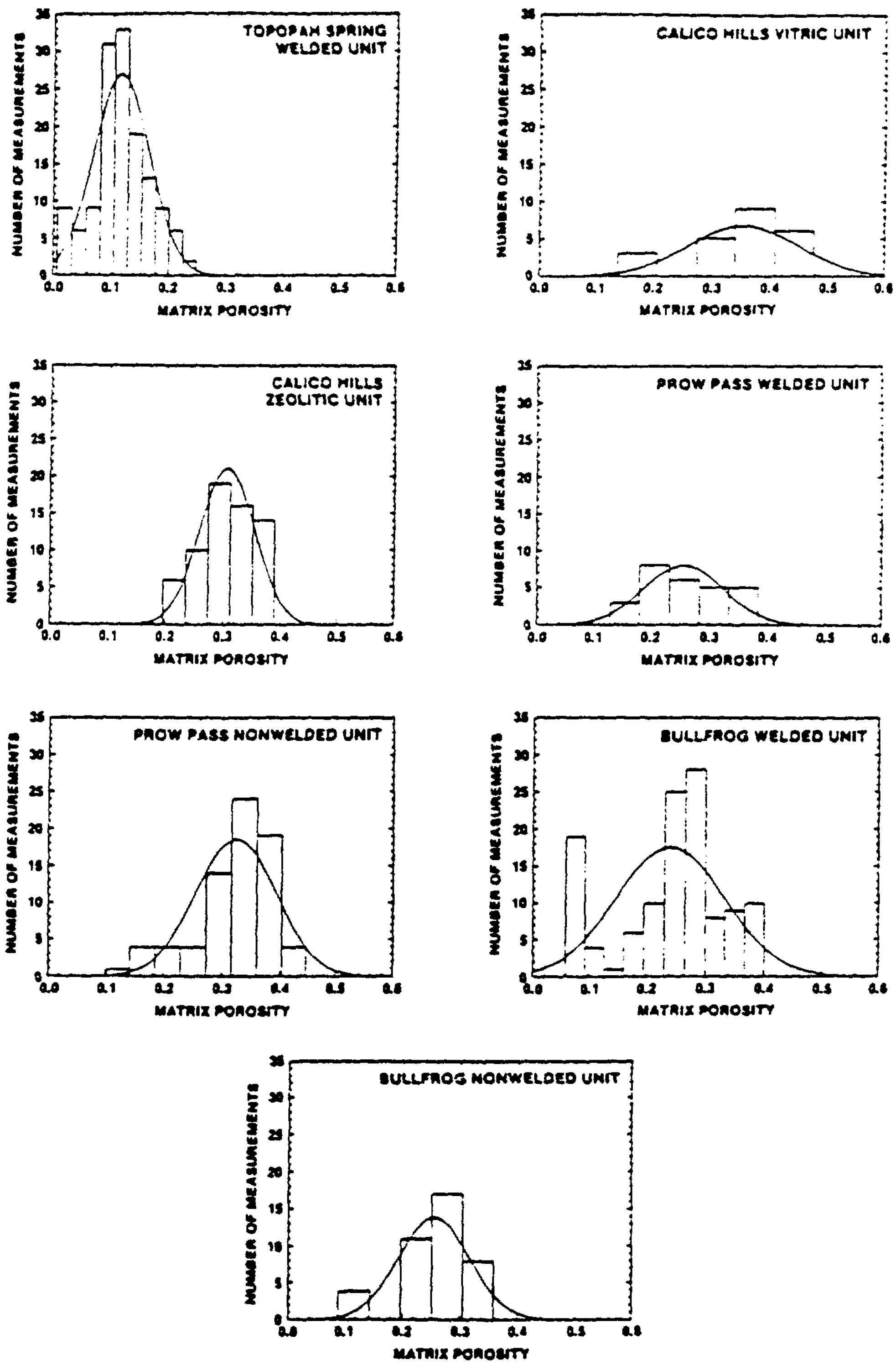


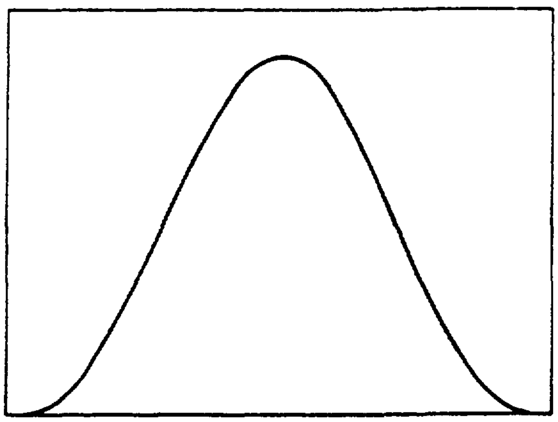
Figure 5. Histograms of bulk matrix porosity for each hydrogeologic unit and their normal distribution curves. These were derived from the calculated means and standard deviations of the sample population represented by the histograms.

EXAMPLE OF NEED FOR CONCEPTUAL ASSUMPTIONS AT PARAMETER LEVEL OF CONCERN

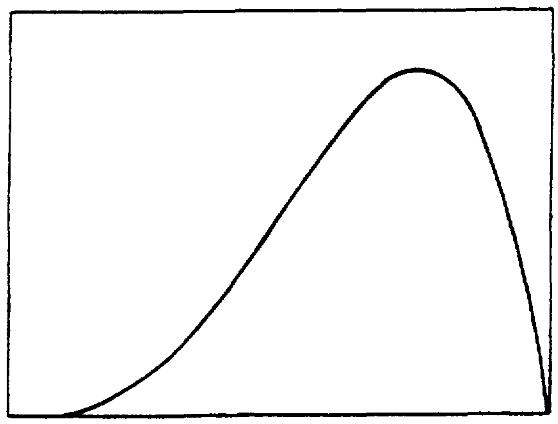
BETA DISTRIBUTION OF ANY SHAPE CAN BE DEFINED BY FOUR VALUES

- MEAN ($\bar{x}$)
- STANDARD DEVIATION (σ)
- MINIMUM VALUE
- MAXIMUM VALUE

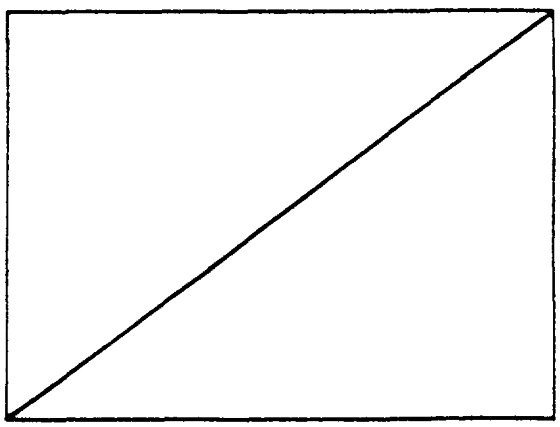
WHERE COEFFICIENT OF VARIATION = $\frac{\sigma}{\bar{x}}$



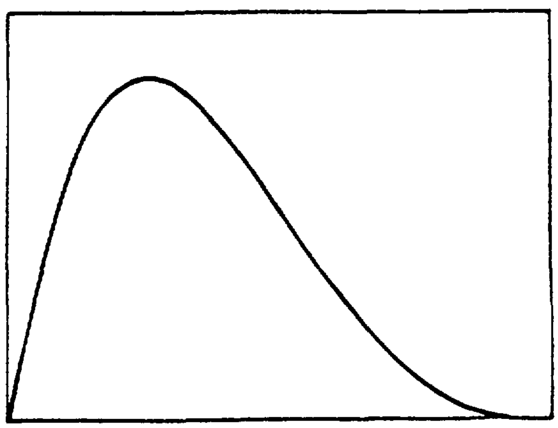
SYMMETRICAL DISTRIBUTION



SKEWED DISTRIBUTION

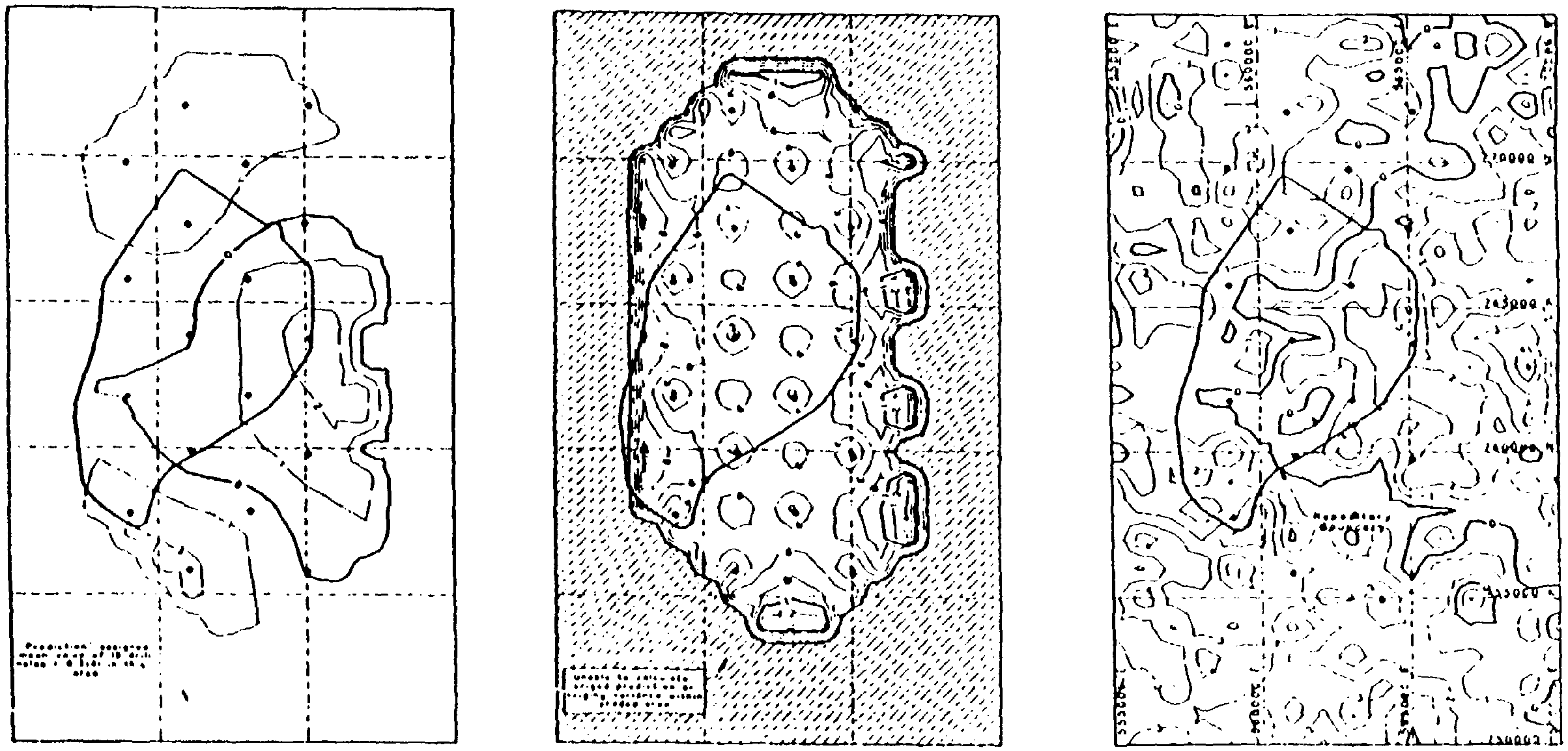


TRIANGULAR DISTRIBUTION



SKEWED DISTRIBUTION

EXAMPLE OF EXISTING DATA REDUCTION AND INTERPOLATION
USING GEOSTATISTICAL ASSUMPTION



KRIGED ESTIMATE

KRIGING VARIANCE

GEOSTATISTICAL SIMULATION

NUMERICAL ACCOMMODATION OF DISRUPTIVE SCENARIOS BY MODIFYING PHYSICAL DOMAIN PARAMETERS

METHOD (NUMERICAL EXPERIMENTS)

- SELECTIVELY ALTER UNIT GEOMETRY TO ACCOUNT FOR TECTONICS, HUMAN INTRUSION (?) SCENARIOS (E.G. ADD OFFSET TO GHOST DANCE OR BOW RIDGE FAULT)

- MODIFY PHYSICAL PROPERTY DISTRIBUTIONS TO ACCOUNT FOR FAULTING, VOLCANIC, CLIMATIC, HUMAN INTRUSION SCENARIOS (E.G. FAULT PERMEABILITY, RETARDATION COEFFICIENTS, ROCK MATRIX PERMEABILITY

DATA NEEDS

- MAGNITUDE, FREQUENCY, AND DURATION OF CHANGES PROVIDED BY TECTONIC, CLIMATIC, GEOCHEMICAL, IN CONJUNCTION WITH HYDROLOGY ETC. PROGRAMS (SITE CHARACTERIZATION MODELS)

REQUESTED PARAMETER	SPACIAL LOCATION	ISSUE
PARAMETER CATEGORY: PROPERTY CHANGES OVER 10,000 YR		
Chemical Reactivity, i-th Sp, Change Due to Irrigation	Repository Area	01.01.01
Chemical Reactivity, i-th Sp, Change Due to Surface-Water Impoundment	Repository Area	01.01.01
Chemical Reactivity, i-th Sp, Change Due to Surface or Subsurface Mining	Repository Area	01.01.01
Permeability, Change Due to Igneous Intrusion (Local)	Repository Area	01.01.01
Permeability, Change Due to Tectonism	Controlled Area	01.01.01
Permeability, Change due to Faulting (Local)	Repository Area	01.01.01
Porosity, Effective, Change Due to Construction	Repository Area	01.06.05
Porosity, Effective, Change Due to Faulting (Local)	Repository Area	01.01.01
Porosity, Effective, Change Due to Igneous Intrusion (Local)	Repository Area	01.01.01
Porosity, Effective, Change Due to Tectonism	Controlled Area	01.01.01
Porosity, Effective, Change Due to Waste Heat	Repository Area	01.06.05
Radionuclide Travel Pathway, Change Due to Faulting	Controlled Area	01.01.01
Solubility Limits, i-th Sp, Change Due to Irrigation	Controlled Area	01.01.01
Sorption Ratio, i-th Sp, Change Due to Faulting	Controlled Area	01.01.01
Sorption Ratio, i-th Sp, Change Due to Igneous Intrusion	Repository Area	01.01.01
Sorption Ratio, i-th Sp, Change Due to Irrigation	Controlled Area	01.01.01
Sorption Ratio, i-th Sp, Change Due to Irrigation	Controlled Area	01.01.01
Sorption Ratio, i-th Sp, Change Due to Radionuclide Inventory	Repository Area	01.11.01
Sorption Ratio, i-th Sp, Change Due to Surface Water Impoundment	Controlled Area	01.01.01
Sorption Ratio, i-th Sp, Change Due to Surface Water Impoundment	Repository Area	01.01.01
Sorption Ratio, i-th Sp, Change Due to Surface or Subsurface Mining	Controlled Area	01.01.01
Sorption Ratio, i-th Sp, Change Due to Surface or Subsurface Mining	Repository Area	01.01.01
Sorption Ratio, i-th Sp, Change Due to Tectonic Induced Water Movement	Controlled Area	01.01.01
Topography, Change Due to Igneous Extrusion	Controlled Area	01.01.01
Topography, Pr(Cum) of Change in Elevation >30 m	Controlled Area	01.01.01

COMPONENTS OF CONCEPTUAL MODELS REQUIRING DEFINITION

- PHYSICAL PROCESSES
- * PHYSICAL DOMAIN
  - GEOMETRY OF UNITS (INCLUDING FAULTS)
  - PROPERTY DISTRIBUTIONS WITHIN UNITS
- * INITIAL AND BOUNDARY CONDITIONS
- * CALCULATIONAL (NUMERICAL) CONSTRAINTS

---

* ABILITY TO PREDICT EFFECTS OF FUTURE CHANGES WILL BE ADDRESSED

Current Assumptions for Baseline Case (Boundary and Initial Conditions)

Unsaturated Zone

- Upper Boundary Flux (Variable)
- Lower Boundary (ψ= 0)
- Side Boundaries (No Flow or Fixed ψ)
- Gas Phase Not Yet Included

Saturated Zone

- Upper Boundary (ψ = 0) (Variable Water Table)
- Lower Boundary (No flow or Transient specified "Leakage" flux)
- Side Boundary (ψ from regional modeling, kriging?)

Initial Conditions

- Calibration Standards
- Numerical Convenience

NUMERICAL ACCOMMODATION OF DISRUPTIVE SCENARIOS BY MODIFYING BOUNDARY CONDITIONS

METHOD (NUMERICAL EXPERIMENTS)

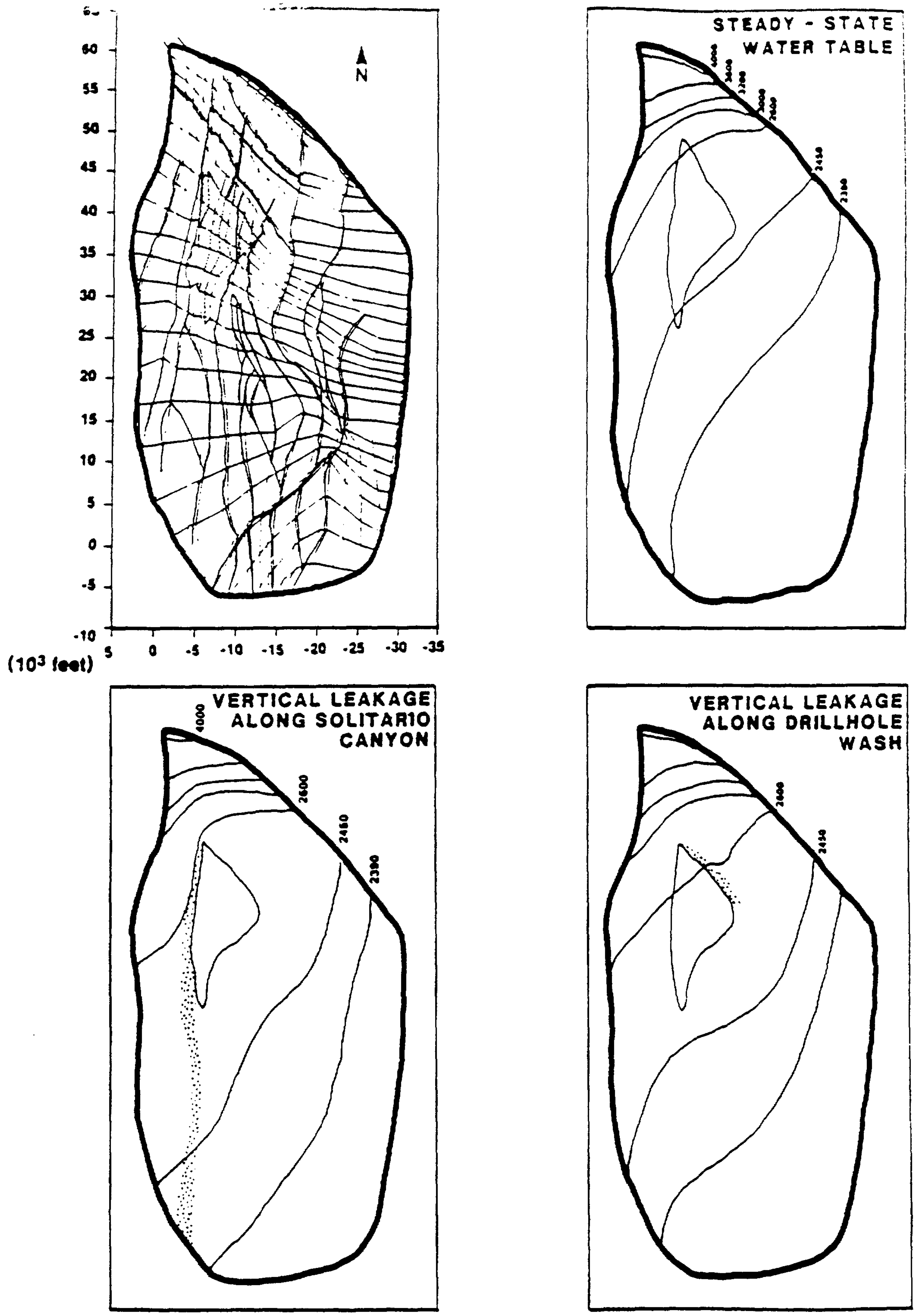
- MODIFY WATER TABLE ELEVATION/LOWER SZ HEAD BOUNDARY (TECTONIC SCENARIOS, E.G. "SEISMIC PUMPING", VOLCANISM)
- MODIFY SURFACE INFILTRATION FLUX (CLIMATIC, FLOODING, FAULTING, HUMAN ACTIVITIY SCENARIOS)
- MODIFY SIDE SZ HEAD BOUNDARY (CLIMATIC, HUMAN ACTIVITY, TECTONIC SCENARIOS)

DATA NEEDS

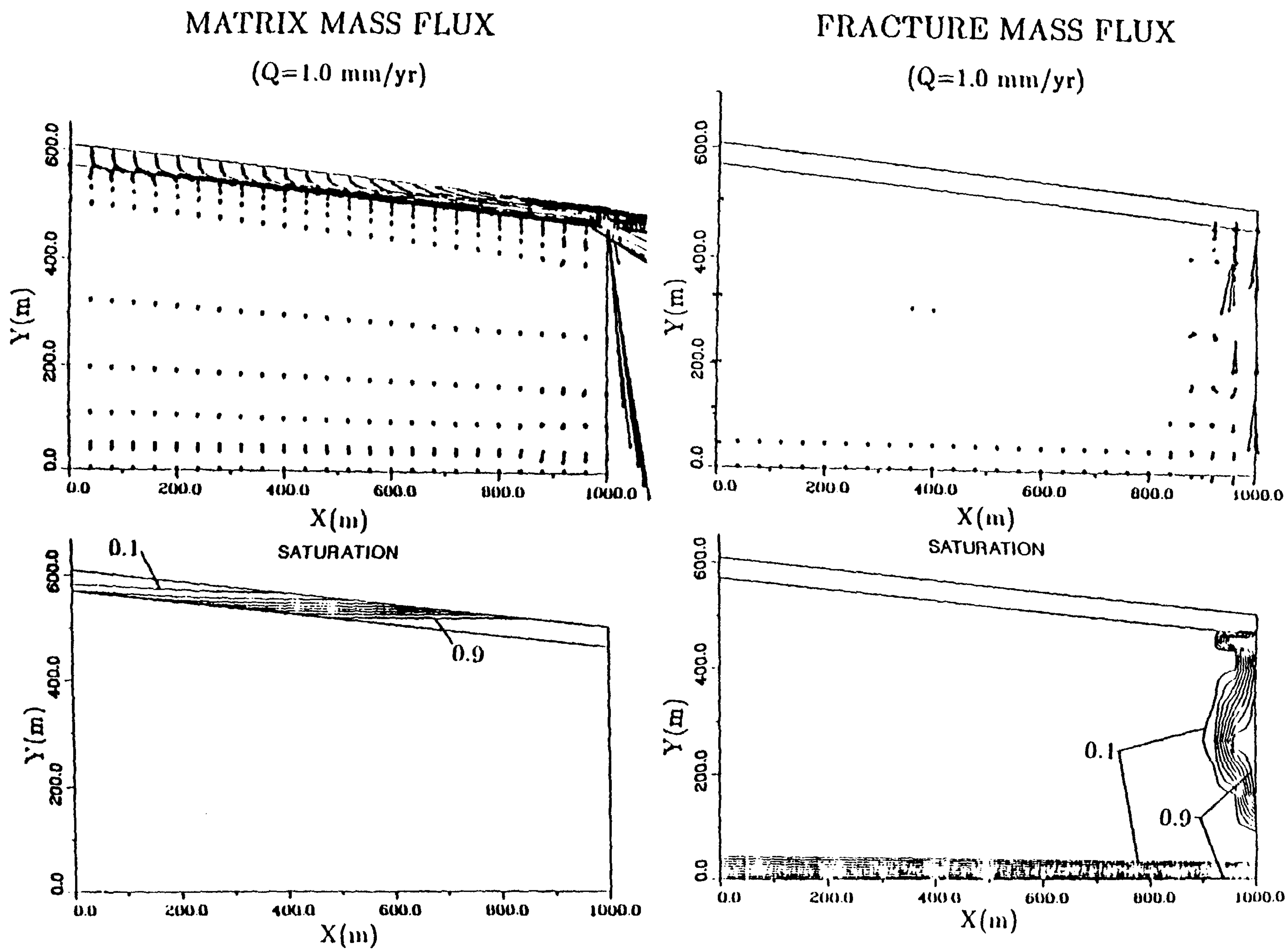
- MAGNITUDE, FREQUENCY, AND DURATION OF CHANGES PROVIDED BY TECTONIC, CLIMATIC, PROGRAMS IN CONJUNCTION WITH HYDROLOGY, (SITE CHARACTERIZATION MODELS)

PARAMETER CATEGORY: BOUNDARY CONDITION CHANGES OVER 10,000 YR

REQUESTED PARAMETER	SPACIAL LOCATION	ISSUE
Water Table, Change in Altitude Due to Climate	Controlled Area	01.01.01
Water Table, Change in Altitude Due to Climate	Controlled Area	01.09.00
Water Table, Change in Altitude Due to Fault Displacement	Controlled Area	01.01.01
Water Table, Change in Altitude Due to Faulting	Controlled Area	01.01.01
Water Table, Change in Altitude Due to Faulting	Controlled Area	01.01.01
Water Table, Change in Altitude Due to Groundwater Withdrawal	Controlled Area	01.01.01
Water Table, Change in Altitude Due to Igneous Intrusion Barrier	Controlled Area	01.01.01
Water Table, Change in Altitude Due to Igneous Intrusion Barrier	Controlled Area	01.01.01
Water Table, Change in Altitude Due to Igneous Intrusion Thermal Effects	Controlled Area	01.01.01
Water Table, Change in Altitude Due to Igneous Intrusion Thermal Effects	Controlled Area	01.01.01
Water Table, Change in Altitude Due to Irrigation	Controlled Area	01.01.01
Water Table, Change in Altitude Due to Mine Usage or Dewatering	Controlled Area	01.01.01
Water Table, Change in Altitude Due to Surface-Water Impoundment	Controlled Area	01.01.01
Water Table, Change in Gradient Due to Climate	Controlled Area	01.01.01
Water Table, Change in Gradient Due to Climate	Controlled Area	01.09.00
Water Table, Change in Gradient Due to Faulting	Controlled Area	01.01.01
Water Table, Change in Gradient Due to Ground-Water Withdrawal	Controlled Area	01.01.01
Water Table, Change in Gradient Due to Igneous Intrusion Thermal Effects	Controlled Area	01.01.01
Water Table, Change in Gradient Due to Irrigation	Controlled Area	01.01.01
Water Table, Change in Gradient Due to Surface-Water Impoundment	Controlled Area	01.01.01
Water Table, Change in Gradient Due to Surface or Subsurface Mining	Controlled Area	01.01.01
Water Table, Expected Location of Surficial-Discharge Points	Controlled Area	01.01.01
Water Table, Igneous Intrusion Barrier Effects	Controlled Area	01.01.01
Water Table, Pr(Ann) of Potentiometric Rise to >850 m Due to Tectonism	Controlled Area	01.01.01
Water Table, Pr(Ann) of Potentiometric Rise to >850 m Due to Tectonism	Controlled Area	01.01.01
Water Table, Surficial-Discharge Points, Magnitude per Point Over 100000 yr	Controlled Area	01.09.00
Water Table, Surficial Discharge Points, Locations Over 100000 yr	Controlled Area	01.09.00
Flux, Change Due to Climate	Controlled Area	01.01.01
Flux, Change Due to Climate	Controlled Area	01.09.00
Flux, Change Due to Climate, Conf Bounds	Controlled Area	01.01.01
Flux, Change Due to Flooding Through Access Shafts	Repository Area	01.01.01
Flux, Change Due to Flooding Through Access Shafts, Conf Bounds	Repository Area	01.01.01
Flux, Change Due to Igneous Extrusion Topographic Changes	Controlled Area	01.01.01
Flux, Change Due to Igneous Intrusion	Repository Area	01.01.01
Flux, Change Due to Irrigation	Controlled Area	01.01.01
Flux, Change Due to Surface-Water Impoundment	Controlled Area	01.01.01



60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
5
0
-5
-10
-15
-20
-25
-30
-35
(10³ feet)
N
STEADY - STATE
WATER TABLE
2450
2390
VERTICAL LEAKAGE
ALONG SOLITARIO
CANYON
4000
2600
2390
VERTICAL LEAKAGE
ALONG DRILLHOLE
WASH
2600
2450



MATRIX MASS FLUX
(Q=1.0 mm/yr)
FRACTURE MASS FLUX
(Q=1.0 mm/yr)
Y(m)
X(m)
0.0
200.0
400.0
600.0
800.0
1000.0
SATURATION
0.1
0.9

Components of Conceptual Models Requiring Definition

- Physical Processes
- * Physical Domain
  - Geometry of Units (including faults)
  - Property Distributions within Units
- * Initial and Boundary Conditions
- * Calculational (Numerical) Constraints

---

* Ability to Predict Effects of Future Changes will be addressed

Current Numerical Approach
Types of Analyses That Can Be Performed

- Solution of 2nd order PDE's for ψ Distribution (Richard's Equation) $K(\psi)$

  (1) Discrete Fractures (Wang & Narasimhan)
  (2) Composite Continuum (Peters & Klavetter)

  - Pressure Equilibrium

  (3) Single Porosity Continuum (low flux - Matrix Porosity in Unsaturated Zone, Fracture Porosity in Saturated Zone)

- Solution of Algebraic Equations ($K = Q$, $\psi = F(SAT) = F(Q,N)$)

  (1) Composite Fracture - Porous "Elements"
  (2) Particle-in-Cell (?)

TRADEOFFS BETWEEN FULL SOLUTIONS AND SIMPLIFIED APPROXIMATIONS

- CODE DIMENSIONALITY (1D, 2D, 3D)
- STEADY STATE VS. TRANSIENT
- MESH SIZE-TIME STEP CONVERGENCE CRITERIA
- TREATMENT OF SPATIAL PROPERTY VARIABILITY AND UNCERTAINTY
- CONSERVATISM VS. REALISM

FULL SOLUTIONS REALISTICALLY TREAT PROCESS (PRESSURE CONTINUITY) BUT MAY NOT PRACTICALLY ACCOUNT TRANSIENT RESPONSES AND PROPERTY VARIABILITY AND UNCERTAINTY THROUGHOUT THE DOMAIN

ALGEBRAIC SOLUTIONS CAPABLE OF REALISTIC TREATMENT OF PROPERTY VARIABILITY AND UNCERTAINTY (WITHIN LIMITS) BUT MAY VIOLATE PRESSURE CONTINUITY

FULL SOLUTIONS OF "REPRESENTATIVE" SUB DOMAINS USED TO CONSTRAIN INITIAL AND BOUNDARY CONDITIONS FOR SIMPLIFIED APPROXIMATIONS OF FLOW THROUGHOUT FULL PHYSICAL DOMAIN

PARAMETER NEEDS FROM SITE CHARACTERIZATION TO SUPPORT PERFORMANCE MODELING

- Nominal Case
  - Based on Measurements and Interpretations of Current Site Conditions
- Disruptive Scenarios
  - Based on Modeling and Inference of Potential Changes in Parameters Defining Nominal Case
  - Modeling Performed by Site Characterization Programs
  - Inferences Drawn in Consultation with Peer Reviewers, Performance Analysts
  - Scenarios Iteratively Selected for Consideration and/or Analysis of Consequences
- Validation of Models
  - Based on Measurements and Interpretations of Site Conditions, Laboratory Experiments, Natural Analogues
  - Process Open to Periodic Peer Review, Publication of Technical Reports

MATHEMATICAL BASIS FOR SELECTED PARAMETER NEEDS

(NOMINAL CASE)

MATHEMATICAL BASIS FOR MODELING	PARAMETER NEEDS
GWTT = d/v	d = STRATIGRAPHIC GEOMETRY(1) (HYDROGEOLOGIC UNITS)
WHERE	q = WATER FLUX(1), (2)
$v = \frac{q}{n_e} = \frac{K \times \delta h/\delta l}{n_e}$	K = PERMEABILITY(1), (2)
	$\delta h/\delta l$ = PRESSURE FIELD(1), (2)
IN UNSATURATED ZONE	n_e = POROSITY(1), (2)
$K = f(\psi_c)$	ψ_c = CAPILLARY MATRIC POTENTIAL(2)
$\psi_c = f(\theta, S)$	θ = MOISTURE CONTENT(2)
	S = SATURATION(2)

FOOTNOTES:

(1) UNSATURATED AND SATURATED ZONES

(2) FRACTURES AND MATRIX

Model Component: Initial and Boundary Conditions

Flux, Percolation Rate	Fault Zones Repository Area	UZ, TSw2, Repository Level	Mean
Flux, Percolation Rate	Fault Zones Repository Area	UZ, TSw2, Repository Level	SCor
Flux, Percolation Rate	Fault Zones Repository Area	UZ, TSw2, Repository Level	SDev
Flux, Percolation Rate	Fractures Repository Area	UZ, TSw2, Repository Level	Mean
Flux, Percolation Rate	Fractures Repository Area	UZ, TSw2, Repository Level	SCor
Flux, Percolation Rate	Fractures Repository Area	UZ, TSw2, Repository Level	SDev
Flux, Percolation Rate	Rock Matrix Repository Area	UZ, TSw2, Repository Level	Mean
Flux, Percolation Rate	Rock Matrix Repository Area	UZ, TSw2, Repository Level	SCor
Flux, Percolation Rate	Rock Matrix Repository Area	UZ, TSw2, Repository Level	SDev
Moisture Content (Volumetric)	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Moisture Content (Volumetric)	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Moisture Content (Volumetric)	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Moisture Content (Volumetric)	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	Mean

Model Component: Material Property

Density, Bulk	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Density, Bulk	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Density, Bulk	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Density, Bulk	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Density, Bulk	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Moisture Ret Curve	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Moisture Ret Curve	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Moisture Ret Curve	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Moisture Ret Curve	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Moisture Ret Curve	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Moisture Ret Curve	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Moisture Ret Curve	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Moisture Ret Curve	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Moisture Ret Curve	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Moisture Ret Curve	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Moisture Ret Curve	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Permeability, Rel	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Permeability, Rel	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Permeability, Rel	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Permeability, Rel	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Permeability, Rel	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Permeability, Rel	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Permeability, Rel	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Permeability, Rel	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Permeability, Rel	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Permeability, Rel	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Permeability, Rel	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Permeability, Rel, Pneumatic	Fault Zones Repository Area	UZ, Each Hydro Unit	Mean
Permeability, Rel, Pneumatic	Fractures Repository Area	UZ, Each Hydro Unit	Mean
Permeability, Rel, Pneumatic	Fractures Repository Area	UZ, Each Hydro Unit	SDev
Permeability, Rel, Pneumatic	Rock Matrix Repository Area	UZ, Each Hydro Unit	Mean
Permeability, Rel, Pneumatic	Rock Matrix Repository Area	UZ, Each Hydro Unit	SDev
Permeability, Saturated	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Permeability, Saturated	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Permeability, Saturated	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Permeability, Saturated	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Permeability, Saturated	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Permeability, Saturated	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Permeability, Saturated	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Permeability, Saturated	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Permeability, Saturated	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Permeability, Saturated	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Permeability, Saturated	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Porosity, Eff	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Porosity, Eff	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Porosity, Eff	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Porosity, Eff	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Porosity, Eff	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Porosity, Eff	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Porosity, Eff	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Porosity, Eff	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Porosity, Eff	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Porosity, Eff	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Porosity, Eff	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	SDev

Model Component: System Geometry

Contact Altitude, Hydrologic Units	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Contact Altitude, Hydrologic Units	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Contact Altitude, Hydrologic Units	Rock Mass Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Fault Displacement	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Fault Displacement	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Fault Displacement	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Fault Locations	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Fault Locations	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SCor
Fault Locations	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SDev

Model Component: Validation of Model Concepts

Isotopic Ratios, Ground-Water Residence	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Isotopic Ratios, Ground-Water Residence	Fault Zones Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Isotopic Ratios, Ground-Water Residence	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Isotopic Ratios, Ground-Water Residence	Fractures Repository Area	UZ, Each Hydro Unit Below Repo	SDev
Isotopic Ratios, Ground-Water Residence	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	Mean
Isotopic Ratios, Ground-Water Residence	Rock Matrix Repository Area	UZ, Each Hydro Unit Below Repo	SDev

TREATMENT OF PARAMETER UNCERTAINTY

Sensitivity Analysis

- Identify most influential variables

Uncertainty Analysis

- Treat sensitive input variables as random distributions
- Probabalistic Prediction of GWTT
  - Monte Carlo
  - Direct Stochastic Simulation

TREATMENT OF CONCEPTUAL UNCERTAINTY

- Less Amenable to Quantification
- Addressed by Consideration of Alternative Concepts
  - Weighting by Professional Judgment, DELPHI, or Bounding Calculations
  - Extensive Dialogue with State, NRC, Expert Consultants
- Validation of Modeling Approaches
  - Calibration with respect to field observations (ψ, S, $\delta h/\delta \ell$)
  - Comparison to controlled field experiments
  - Comparison to controlled laboratory experiments
  - Periodic Formal Peer Review

CONCEPTUAL CONCERNS FOR GROUNDWATER FLOW

(NOMINAL CASE)

- **Unsaturated Zone Fracture Flow: Existence, Quantity, Locations**
  - — Fracture-matrix pressure-conductivity relations (e.g., "skin" effects)
  - — Existence and effects of potential lateral flow (diversion to fault conduits)
  - — Capillary "channeling" of flow (matrix and fracture)
  - — Etc.
- **Unsaturated and Saturated Zone "Matrix Diffusion"**
  - — Channeling
  - — Skin effects
  - — Sorption effects
  - — Etc.
- **Scalar Relationships**
  - — Measurement scale vs. modeling scale
  - — Influence of heterogeneity on dispersion
  - — Sample averaging effects on geostatistical predictions
  - — Etc.
- **Vapor Flux in Unsaturated Zone**
  - — Ambient and repository thermal effects
  - — Depth and magnitude of seasonal variations
  - — Drying potential and transport of gaseous radionuclides
  - — Etc.

SUMMARY

- TOTAL CONCEPTUAL MODEL HAS DISTINCT COMPONENTS - EACH WITH ITS OWN CONCEPTUAL BASIS

- TRANSLATING DESCRIPTIVE ASPECTS TO NUMERICAL REPRESENTATIONS REQUIRES EXPLICIT DEFINITIONS OF ASSUMPTIONS IN TERMS OF DEFINING PARAMETERS FOR:

  - PHYSICAL PROCESSES
  - PHYSICAL GEOMETRY
  - MATERIAL PROPERTIES
  - BOUNDARY CONDITIONS

SUMMARY
(CONTINUED)

- RELATION OF NUMERICAL MODELING TO DATA GATHERING INVOLVES ITERATIVE APROACH:
  - CONSIDER, EVALUATE, AND EVENTUALLY SELECT ALTERNATIVE PROCESSES FOR ANALYSIS
  - CHARACTERIZE DEFINING MATERIAL PROPERTIES AND BOUNDARIES FOR A NOMINAL CASE
  - CHARACTERIZE POTENTIAL FOR TECTONIC CLIMATIC, HUMAN, AND REPOSITORY INDUCED CHANGES TO DEFINING PARAMETERS AND PROCESSES
  - ASSESS POTENTIAL EFFECTS OF THESE CHANGES TO NOMINAL CASE BY NUMERICAL EXPERIMENTS

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Hydrogeology • Mineral Resources Waste Management • Geological Engineering • Mine Hydrology

May 6, 1988
Contract No. NRC-02-85-008
Fin No. D-1020
Communication No. 181

Mr. Jeff Pohle
Division of Waste Management
Mail Stop 4-H-3
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Jeff:

We have been evaluating the basic assumptions inherent in the description of the groundwater flow system presented in the Consultation Draft SCP (CDSCP). Some of the assumptions that we have considered are not stated explicitly in the CDSCP; nevertheless, we believe the assumptions noted below are inherent in the description of the groundwater flow system and in the testing plans presented in the CDSCP. Please view this letter as a first draft that outlines some major assumptions that we believe are inherent in the CDSCP. We foresee expanding this analysis to incorporate additional assumptions as we continue to develop our thoughts on the description of groundwater flow presented in the CDSCP. We have broken down our discussion of the assumptions into two general categories. The first category lists assumptions that are relevant to the mechanics of flow and the hydraulic properties which govern that flow. The second category lists those assumptions that are implicit in the discussion in the CDSCP that describes proposed testing to characterize the hydrogeology of the site.

Category 1: Assumptions About Mechanics of Flow and Related Hydraulic Properties

One of the primary assumptions inherent in the entire discussion of flow at the Yucca Mountain site is that Darcian flow is applicable ubiquitously. We have little doubt that Darcian flow is applicable at the regional scale. Questions may arise about the applicability of Darcian flow on smaller scales such as the scale of tens of feet in the vicinity of a pumping well during a pumping test. It is possible that non-Darcian flow may dominate in such a small-scale regime under stress conditions imposed by pumping. The validity of Darcian flow should be verified for tests conducted at this scale at the site.

NH14
D1020
WM-11

The CDSCP assumes that no recharge occurs to the groundwater system through Yucca Mountain. The CDSCP assumes further that recharge is so low that lateral flow predominates in the saturated zone just below the water table beneath the site. These two assumptions are important to the consideration of transport of radionuclides from the site to the accessible environment. The implication that there is no recharge to the groundwater system implies that lateral flow will dominate within the upper few tens to hundreds of meters of the saturated zone. This assumption may not be valid if recharge is greater. Recharge will create a downward component of flow in recharge areas from the water table to deeper, possibly more transmissive hydrostratigraphic units. It is possible that a downward component of flow could intercept a highly transmissive unit which would provide a means of rapidly transporting potential radionuclides away from the site.

The question of whether or not a significant amount of recharge to the saturated zone occurs should be investigated further. Several different approaches could be used to answer this question regarding the amount of recharge. Continuous water level measurements should be made on a routine basis with wells open just below the water table, along with isolated, discrete intervals below the water table. The vertical distribution of head in the saturated zone will determine whether or not a significant downward component of flow occurs in the saturated zone in the area. Variable fluid density effects may be significant; this consideration is discussed below. Monitoring of the unsaturated zone above the water table also may indicate whether or not there is a significant amount of recharge to the groundwater system. However, the vertical gradient in the saturated zone is more definitive and easier to measure.

It is assumed in the CDSCP that flux through the unsaturated zone is essentially steady state at the depths below land surface encountered at Yucca Mountain. This assumption requires the predominance of matrix properties over fracture properties for the movement of water toward the water table. Periodic measurements of the elevation of the water table near the interface with the unsaturated zone should indicate whether or not pulses of recharge occur to the saturated zone. Such monitoring may provide more reliable and immediate evidence of recharge pulses than the evidence that can be detected using unsaturated zone monitoring techniques at the depths encountered in the vicinity of Yucca Mountain.

The CDSCP assumes that any potential upward flux from the regional ground water flow system to the shallow groundwater system is minor in the vicinity of Yucca Mountain. At this time detailed measurements of water levels at discrete depths over a significant areal extent have not been made. Such data are needed to verify whether or not this assumption is valid. Quantification of the hydrogeologic properties of the saturated tuffs will enable investigators to determine whether upward flux is significant. Two components, which are required for this estimation, are the distribution of head along a vertical line and the distribution of vertical hydraulic conductivity along that vertical line. Variable fluid density effects also may prove to be significant in this estimation. Variable fluid density effects are discussed subsequently herein.

The CDSCP assumes that composite heads can provide a reasonable portrayal of the configuration of the water table. This assumption may be valid but it is important that composite water levels not be used to evaluate it. In addition, wells that are open to multiple zones should be redesigned so that only isolated intervals are open within the wells or piezometers. Such isolation will prevent the alteration of the natural hydraulic gradients in a lateral and vertical sense in the vicinity of those wells. Wells should be completed at specific isolated intervals along a vertical line in order to determine the vertical distribution of potential. These wells can be used in conjunction with additional data to portray the water table configuration in the vicinity of the site. Only then can the direction of groundwater flow be determined with any degree of certainty. Variable fluid density effects may have to be considered in evaluating data from such wells.

The CDSCP assumes continuity of flow paths along predicted flow directions that are based on what is believed to be the configuration of the water table. It is not clear that boundary conditions have been incorporated into the prediction of such flow paths. It may become evident that boundary conditions are more important to the distribution of groundwater flow than is believed to exist currently. The paucity of data points (wells) allows considerable latitude in the process of contouring water levels. It is probable that boundary conditions may alter the configuration of the water table significantly. The alteration of the configuration would then change the directions of groundwater flow in the vicinity of the site. The detection of hydrogeologic barriers is important to developing an accurate water table configuration map. In addition, additional data points are required to describe the water table configuration accurately. As discussed above, additional data are required to describe the distribution of potential along a vertical line. The potential existence of upwelling or downwelling is essential to identifying the fastest flow path.

The CDSCP assumes the variable fluid density effects will not have a significant effect on groundwater levels measured in monitoring wells. This assumption should be investigated further to insure that the effects indeed are insignificant. The variable fluid density effects could be created either by differences in total dissolved solids or temperature or both. Fluid densities are important for defining the distribution of potential along a vertical line. It is important that the water levels that have been measured at specific depth intervals be representative of those depth intervals. They should not be a composite of water levels in several zones. Also, variable fluid density effects may be significant with respect to interpreting groundwater potentials along a horizontal plane.

The CDSCP assumes that the current definition and sequence of "hydrogeologic units" is adequate for portraying groundwater flow in the region and in the vicinity of Yucca Mountain. This assumption was mandatory for the analyses contained in the CDSCP. We are confident that DOE is aware that further testing may necessitate additional subdivisions of the current hydrogeologic units. An obvious implication of this assumption is that a high hydraulic conductivity unit may exist at the site that has not been defined at this time. Such a high hydraulic conductivity unit could act as a primary flow path to the accessible environment. Such a unit would exhibit shorter travel times than may be encompassed by the current methods of prediction. Resolution of this assumption requires that further testing be conducted at the site. The spatial correlation of values for hydraulic conductivity and related properties must be determined. This requires that adequate testing be conducted along the most probable pathway to the accessible environment.

Category 2: Assumptions Pertinent to Proposed Hydrogeologic Testing to Characterize Site Hydrogeology

The CDSCP assumes implicitly that conventional hydrogeologic testing techniques will be applicable at the Nevada Test Site. The testing conducted to date in the saturated zone does not indicate whether or not conventional testing techniques will be appropriate. The testing techniques could prove adequate but the analytical techniques for analyzing the data may prove inadequate for evaluating data derived from this testing; nonunique analyses may result. Conventional testing techniques must be applied with discretion and cognizance of the fact that the testing techniques may be inappropriate. Testing techniques must be evaluated before, during and after their use at a test site.

The CDSCP assumes implicity that one or possibly two test sites in the saturated zone will be adequate for characterizing the groundwater flow properties along the most probable fastest pathway to the accessible environment. This assumption is not warranted. Additional test sites will be required unless the two test sites happen to characterize the groundwater flow properties along two separate groundwater flow paths. In addition, these sites must be capable of characterizing the hydrogeologic properties between the repository block and the accessible environment which is 5 kilometers wide. It is highly unlikely that this assumption is valid. Additional testing of the site will be required to define the hydrogeologic properties adequately within the saturated zone. In addition, an adequate distribution of values for individual hydrogeologic units will not be possible with two test sites. Additional test sites will be required to provide reasonable assurance that the appropriate range of values has been quantified for the hydrogeologic properties.

Conclusions

We believe that assumptions are inherent in the CDSCP that are not stated or explained explicitly. We have outlined the major assumptions in this category that are apparent at this time. We will continue our review of the assumptions that are implicit in the CDSCP. We believe that these assumptions should be reviewed and evaluated in order to determine whether or not the appropriate action has been outlined in the CDSCP to verify the validity of these assumptions. We will continue to update this analysis as our thoughts develop on this subject.

Please call us if you have any questions regarding this letter.

Sincerely,

Roy Williams /sl

Roy E. Williams

REW:sl

cc: D.L. Chery, Jr.