U.S. Department of Energy

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

Yucca Mountain Site Infrastructure Improvement Plan

Presented to:
169th Advisory Committee on Nuclear Waste

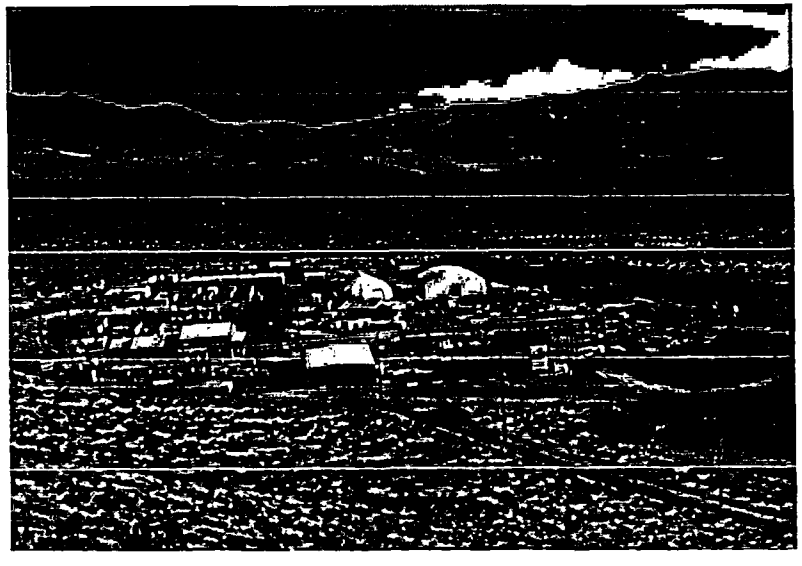
Presented by:
Scott A. Wade
Director, Office of Facility Operations

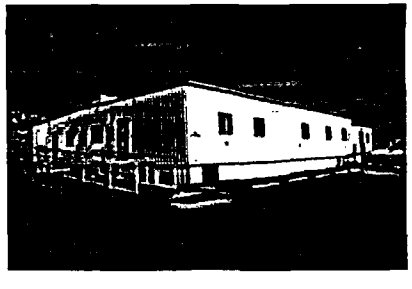
April 19, 2006
Two White Flint North
Rockville, Maryland

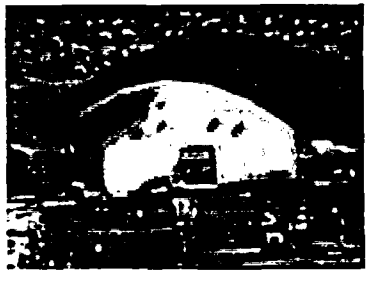
Yucca Mountain Site Facilities

- Include
  - Main and cross tunnels at Exploratory Studies Facility (ESF) (approximately eight miles)
  - Facilities at both North and South Portals
  - Utilities systems (water, power, sewer, ventilation, communication, fire detection and alarm system, underground rail transportation)
  - Network of paved and unpaved roads
  - Parking and presentation areas on the Yucca Mountain crest
  - Boreholes, trenches, test facilities
  - Laydown areas

Current Yucca Mountain Site Facilities







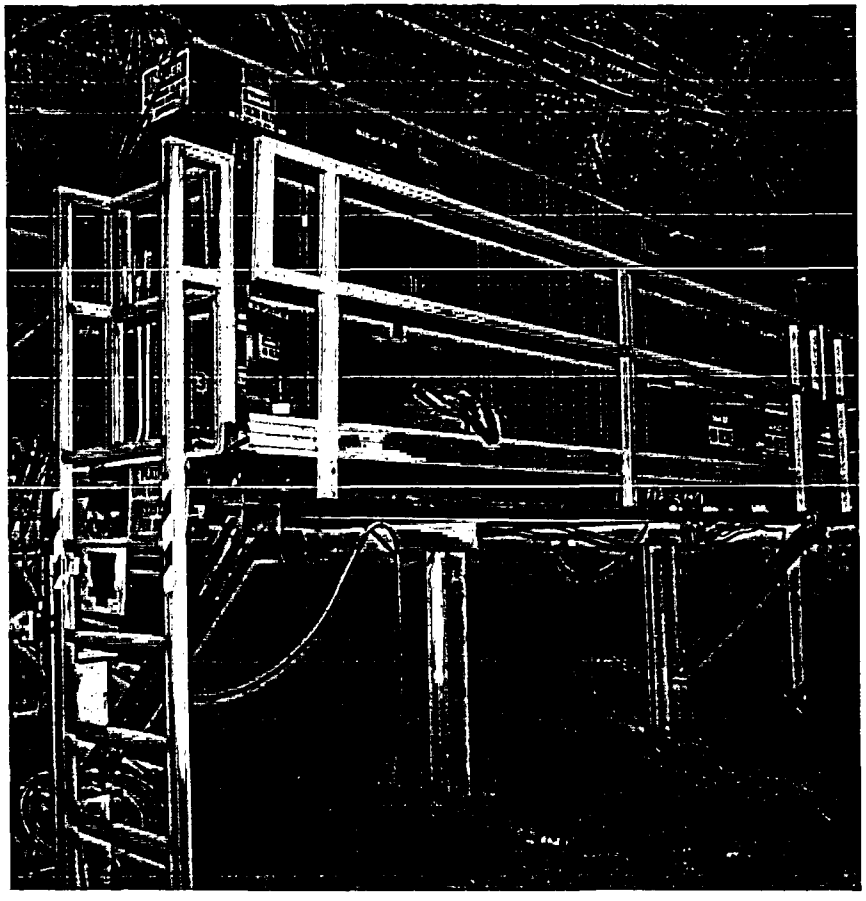
North Portal Facilities

- Two permanent structures
- 121 temporary structures
  - Trailers
  - Cargo containers
  - Tents (fabric covered)
- ~225 full time employees

Subsurface Improvements

- OCRWM has focused funding for 2005 – 2008 towards safety improvements for underground workers through investment in underground systems upgrades

Underground Electrical Maintenance



- Preventative maintenance (PM) of mine power centers recommended by an independent assessment
- PM is necessary to preclude equipment damage and early failure
- Completed in fiscal year (FY) 2005

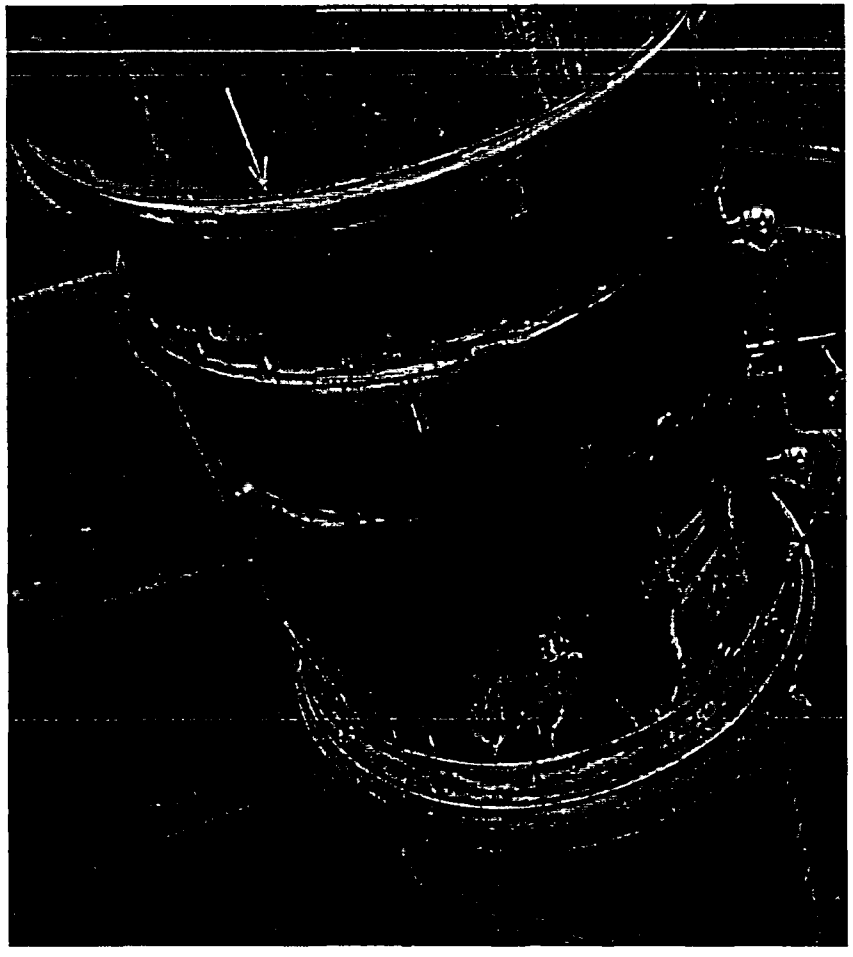
Underground Fire Alarm Detection and Suppression System

- Serves as a means of detecting underground fire, providing notification to personnel, and improving fire-fighting capability
- Need identified in a 2004 Fire Hazards Analysis
- Satisfies the requirements of National Fire Protection Association (NFPA) 72 and 502
- Currently being installed

Underground Lighting Upgrade

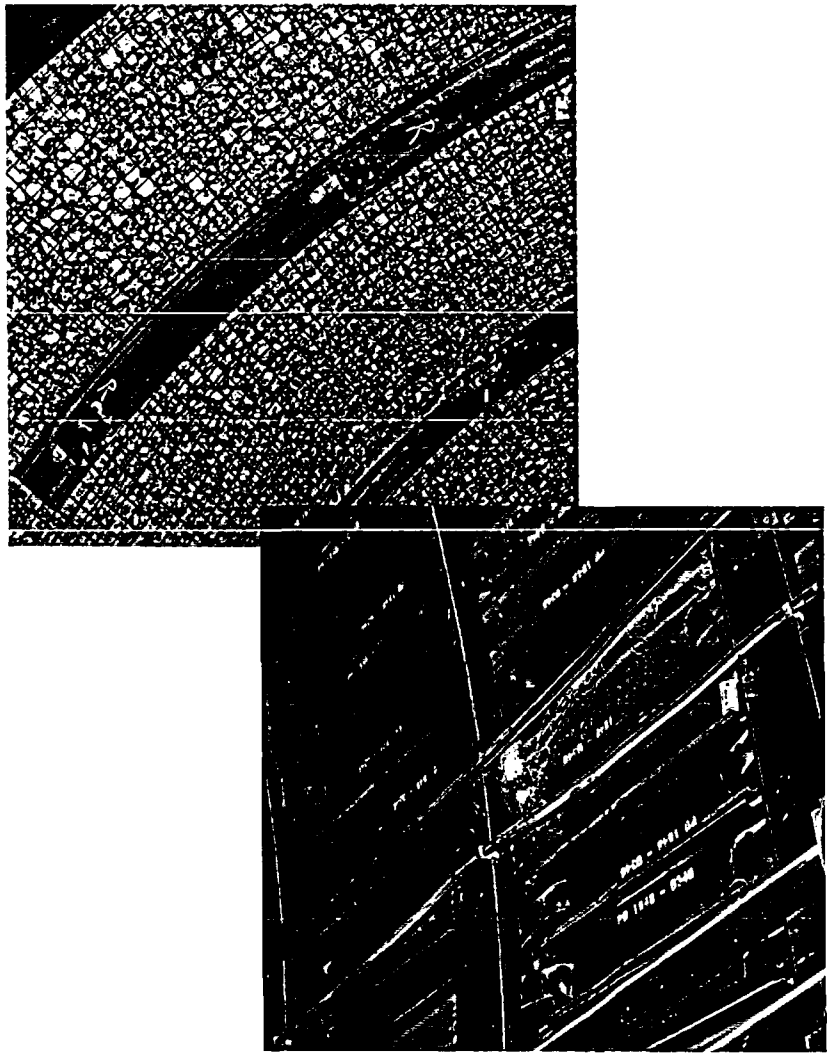
- Based on results of an independent assessment, recommendations made to complete modifications to the lighting system and implement a maintenance/repair program
- Necessary to ensure continued reliability and operability for at least the next 5 years
- In process

Underground Ventilation Improvements



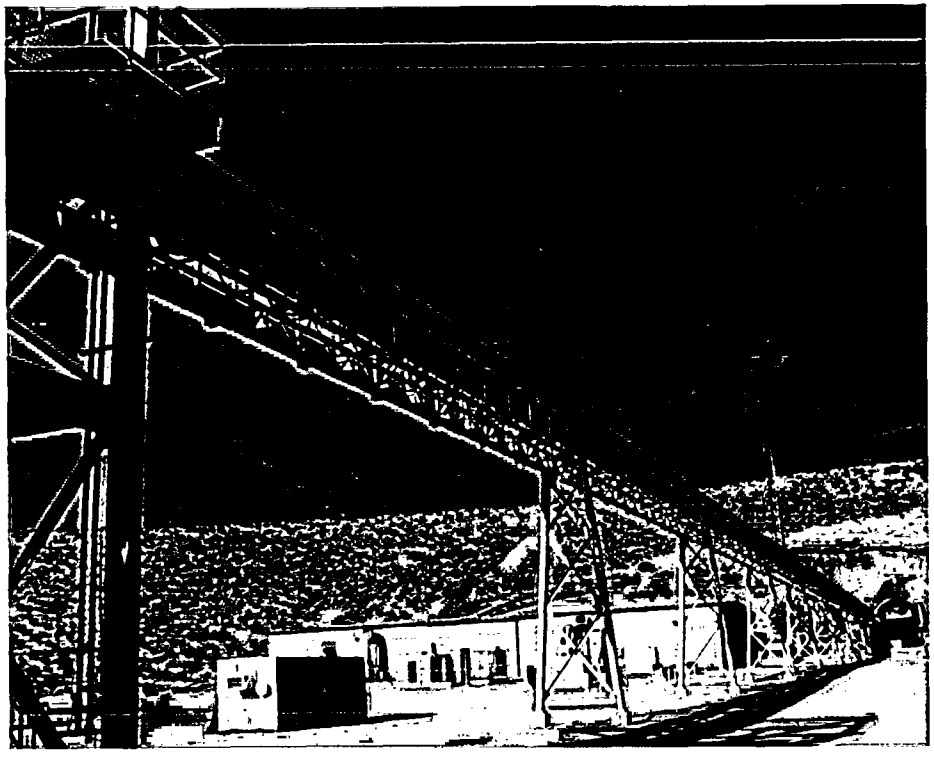
- An independent assessment, recommended modifications to the ventilation system and implement a maintenance/repair program
- Necessary to ensure continued reliability and operability for at least the next 5 years
- In process

Ground Support



- An independent assessment recommended
  - Implement additional ground support controls in certain areas
  - Implement a rockbolt maintenance program
- In process

Conveyor System Removal



- To reduce the fire load underground and improve safety, removal of the tunnel boring machine (TBM) muck conveyor system was recommended in three phases:
  - Belt removal
  - Surface sections removal
  - Subsurface sections removal
- Surface structure and cross drift belt removed; remaining belt removal in process

Future Subsurface Upgrades

- Underground electrical distribution system
  - Upgrade planned for FY 2008
- Underground rail improvements
  - Upgrade planned for FY 2007
- De-mobilization of the Alcove 5 Heater Test
  - Planned for FY 2007
- Remove and dispose 16 foot-diameter tunnel boring machine in the Enhanced Characterization Repository Block drift – Planned for FY 2008

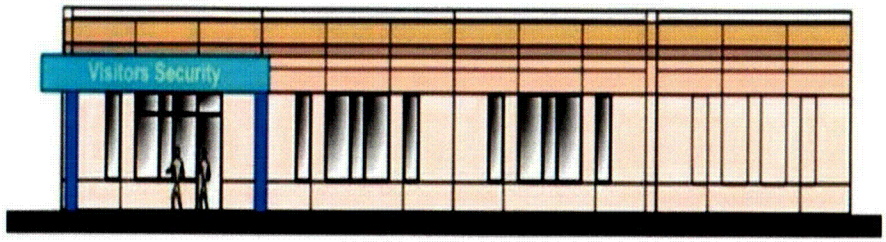
Surface Facilities Improvements

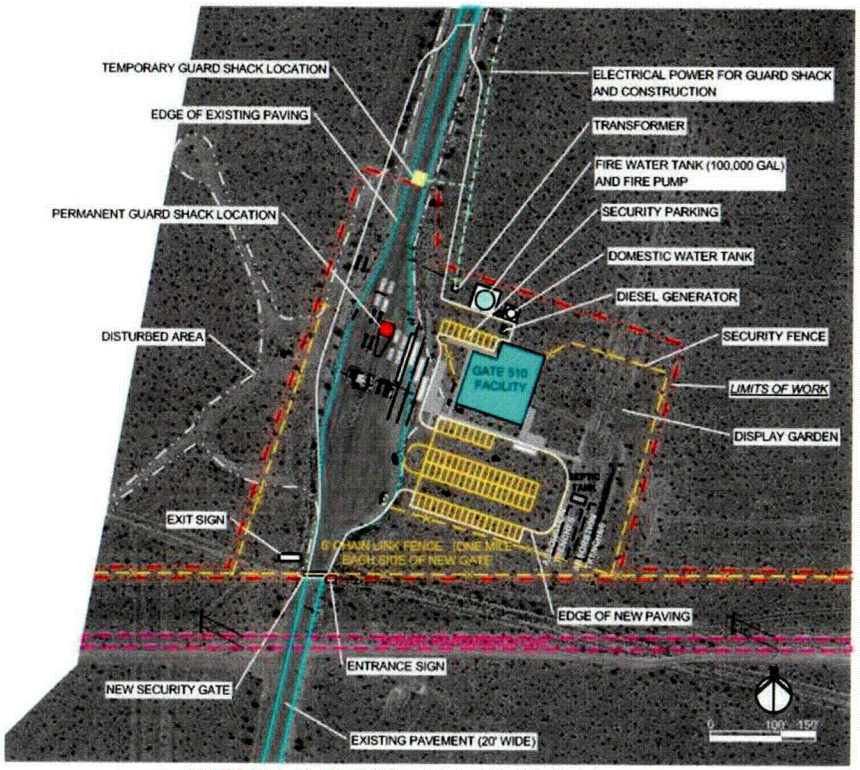
- To address declining condition of temporary structures and utilities at the Yucca Mountain site, OCRWM has focused funding in fiscal years 2006 and 2007 to construct new structures and utilities

Gate 510 – Current Condition

- 100 ft^2 bullet resistant enclosure (BRE)
- No wastewater disposal system
- No potable water source
- No badging capabilities
- No hazardous material tracking capabilities
- No training verification capabilities
- No visitor/vendor waiting areas
- No Ranch Control capabilities

Gate 510 – Proposed Plan

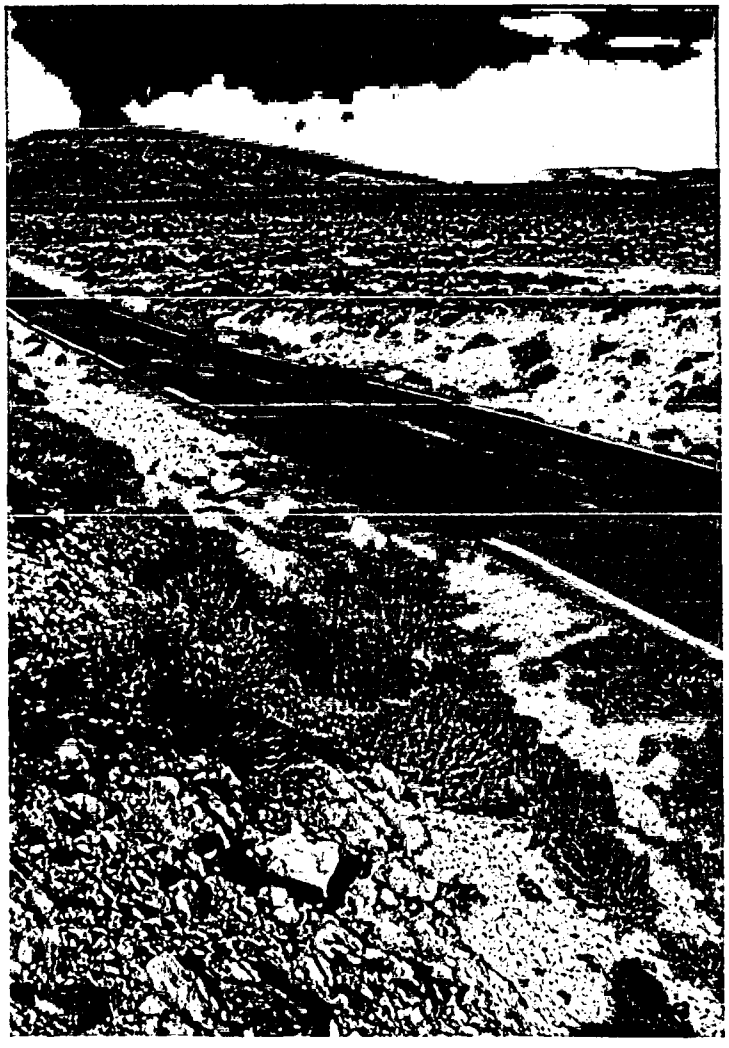




GATE 510 FACILITY - PROPOSED SITE PLAN

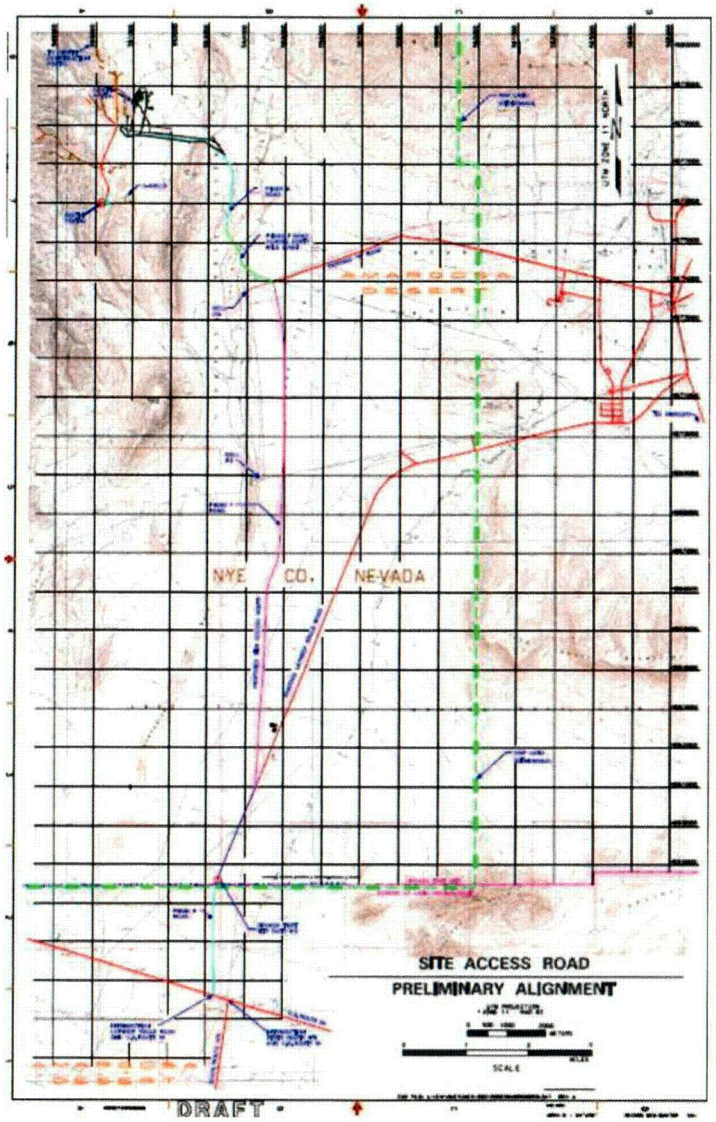
- **9300 ft² facility to be constructed adjacent to existing Gate 510 Guard House**
- **New Gate 510 functions include:**
  - **Enhanced security and access control**
  - **YMP badging**
  - **Ranch control for the site**
  - **Training verification**
  - **Visitors/vendors waiting area**
  - **Hazardous material tracking**
- **Complete by 12/06**

Site Access Road – Current Condition



- Constructed in early 1960s
- Minimal sub-bed
- Deteriorating asphalt surface
- Poor drainage
- Continuing maintenance and repair
- Indirect route to ESF with several 90° turns

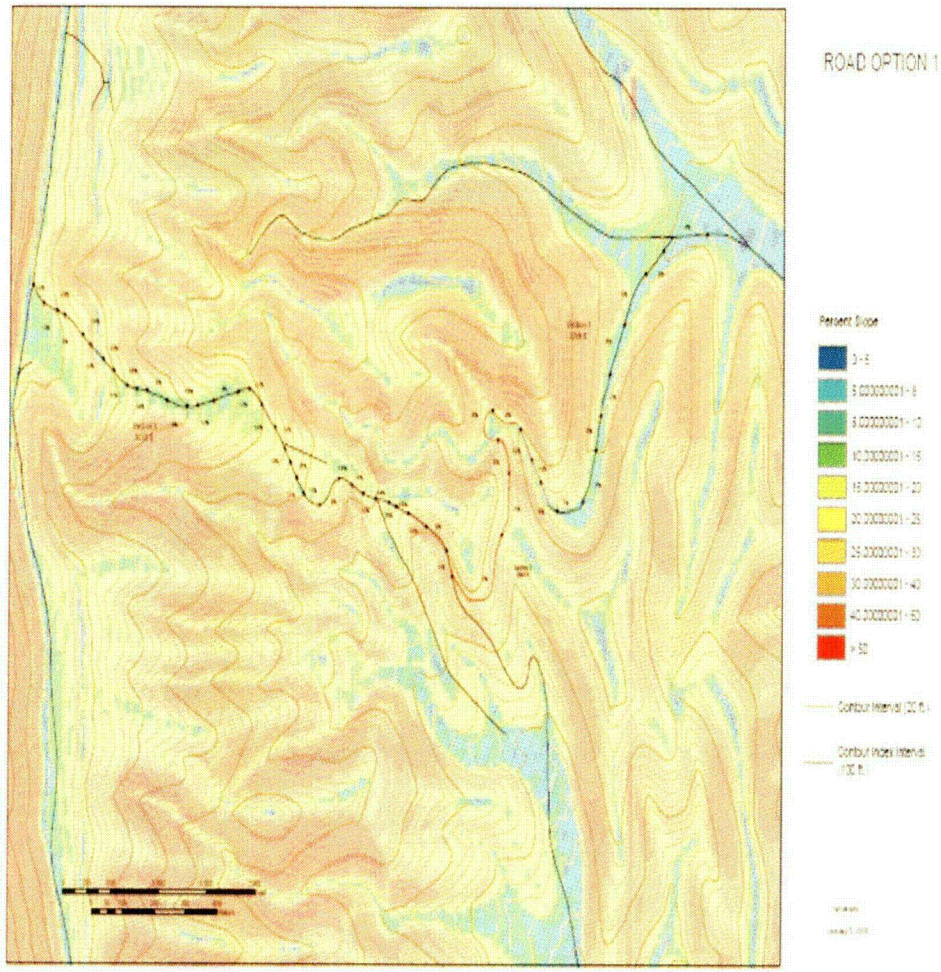
Site Access Road Improvements



- Examining alternatives for a new direct route to ESF
- Eliminates 30% of current distance and majority of 90° turns
- Enhanced safety
- Construction through U.S. Army Corps of Engineers
- Initiate construction following NEPA decision

C02

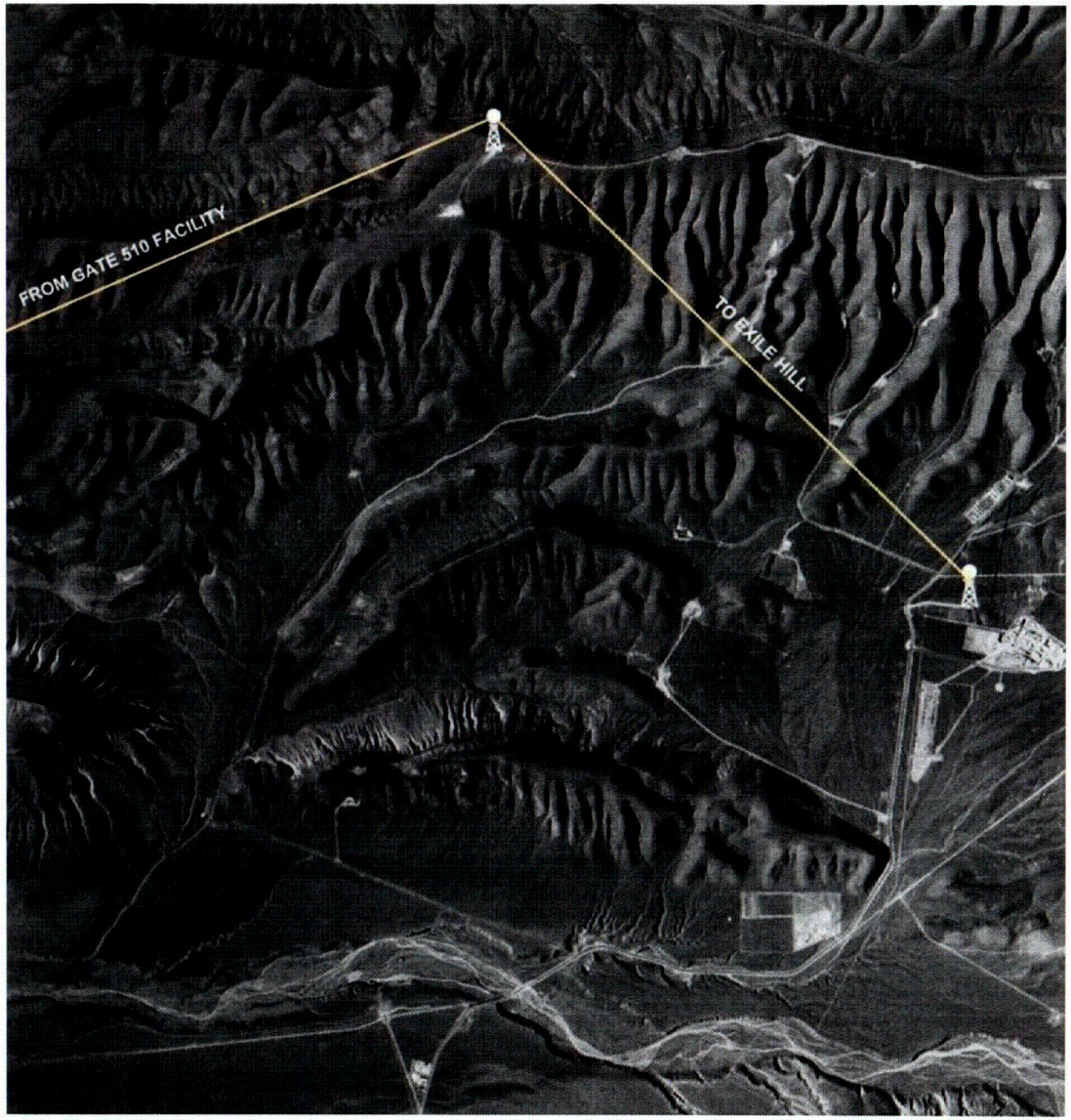
Yucca Mountain Crest Road



- **Current road to Yucca**
  - **Crest has grades up to 25%**
- **Safety risk for existing**
  - **Vehicle transit is addressed with mitigations**
- **Topography does not**
  - **Allow engineered improvements to existing road to meet grade requirements (<8%) for vans and buses**

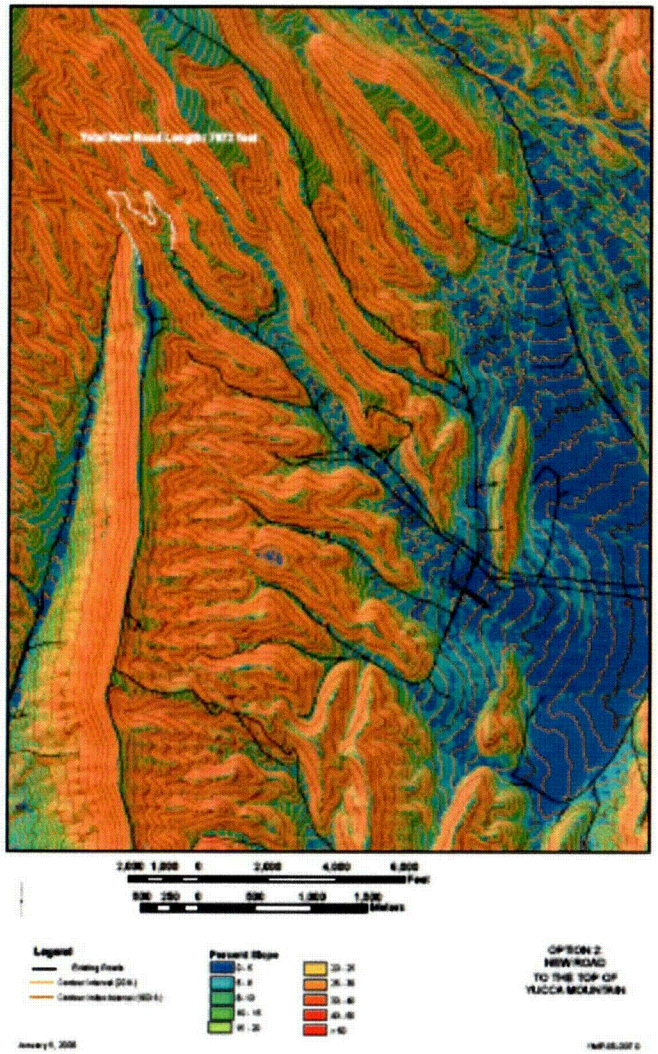
C03

Current Yucca Mountain Crest Road



Cof

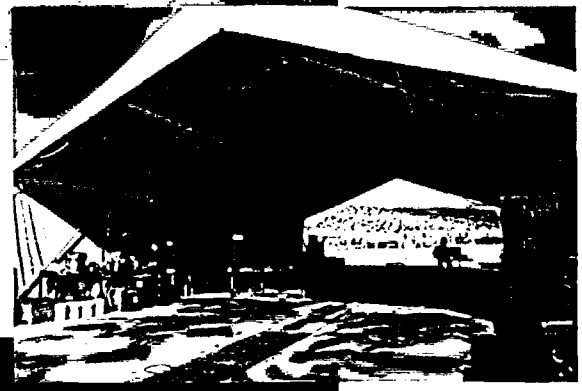
Yucca Mountain Crest Road Improvements



- Examining alternatives to develop a new crest road connection
- Start from vicinity of sub-dock area near North Portal
- Road aligned east of Yucca Mountain
  (approx. 1.3 miles new road)
- Intersect existing road at the crest
- Improve road along Yucca Mountain crest
- Maintain <8% grade

C05

Exploratory Studies Facilities - Current Conditions



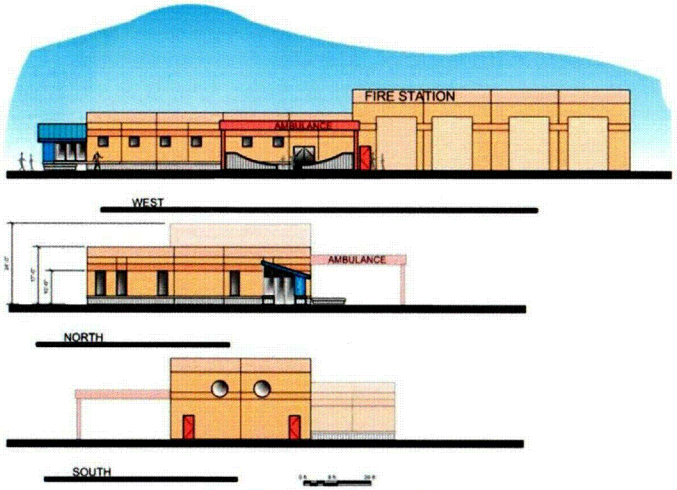
- Warehouse and craft metal fabrication functions located in tent structures on the North Portal pad
- Other craft activities performed under corrugated metal sunshades
- Work environment not climate controlled
- Aged and deteriorating office space for professional contractor staff
- 45 minute minimum response time for fire and rescue services

Lower Muck Yard Complex - Proposed Plan

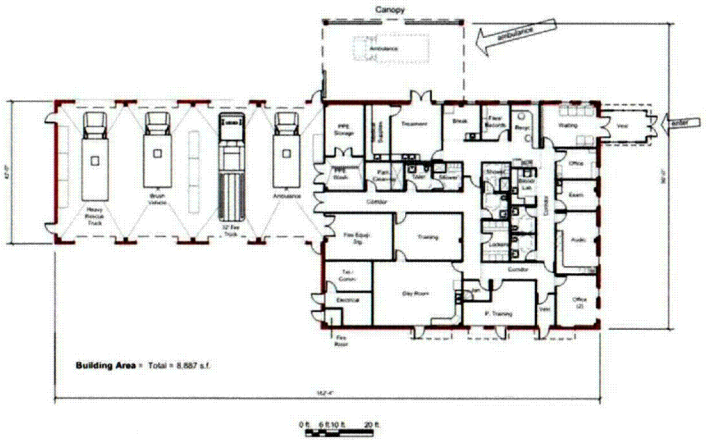
- Examining alternatives to relocate warehouse and craft shops to new facility adjacent to the North Portal Pad on previously disturbed land
- Construct and equip approximately 8000 ft^2 new fire station- completion by 12/06
- Construct new (approximately 30,000 ft^2 each) craft, warehouse, and administrative office buildings
- Craft, warehouse, and administrative facilities complete in FY 2007

COG

Lower Muck Yard Complex - Proposed Fire Station



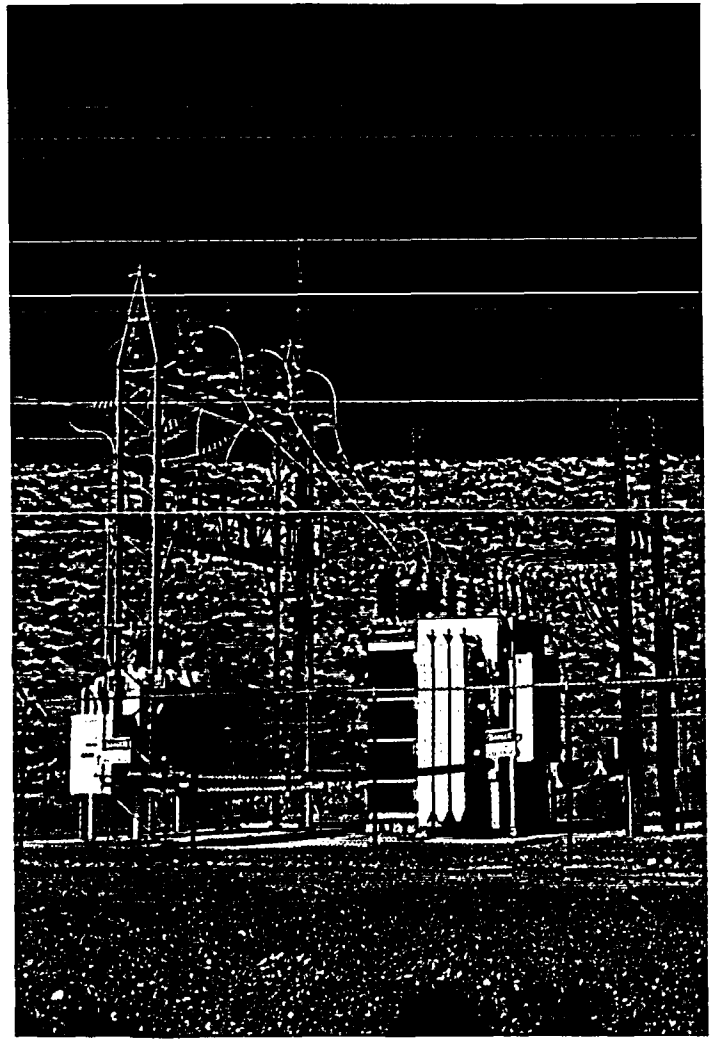
FIRE STATION FACILITY - ELEVATIONS



FIRE STATION FACILITY - PROPOSED FLOOR PLAN

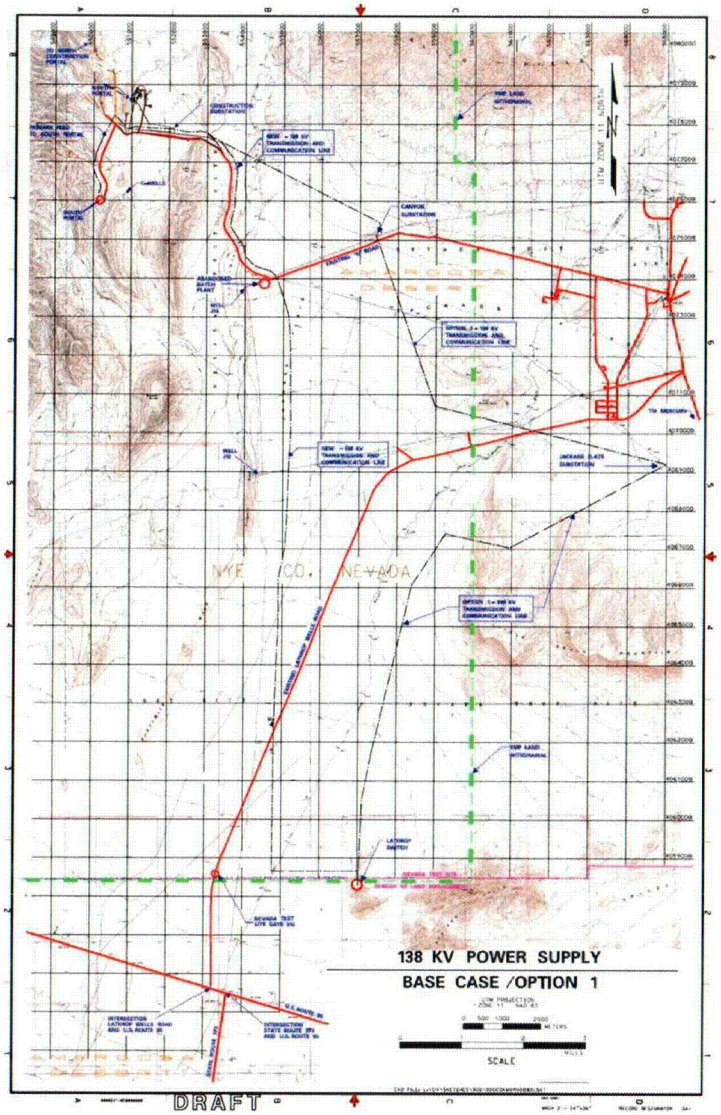
- **Six-person fire and rescue crew**
- **Two medical personnel**
- **Full fire response**
- **Range fire response**
- **Technical rescue**
- **Medical facility**

Offsite Power to Lower Muck Yard – Current Conditions



- Current power provided by 69 kV line from the Nevada Test Site (NTS) grid
- Only remaining 69 kV line on the NTS
- Limited to 10 MW total power
- Cost is 21-25 cents per kilowatt hour (>2M dollars/year)
- Single-point failure

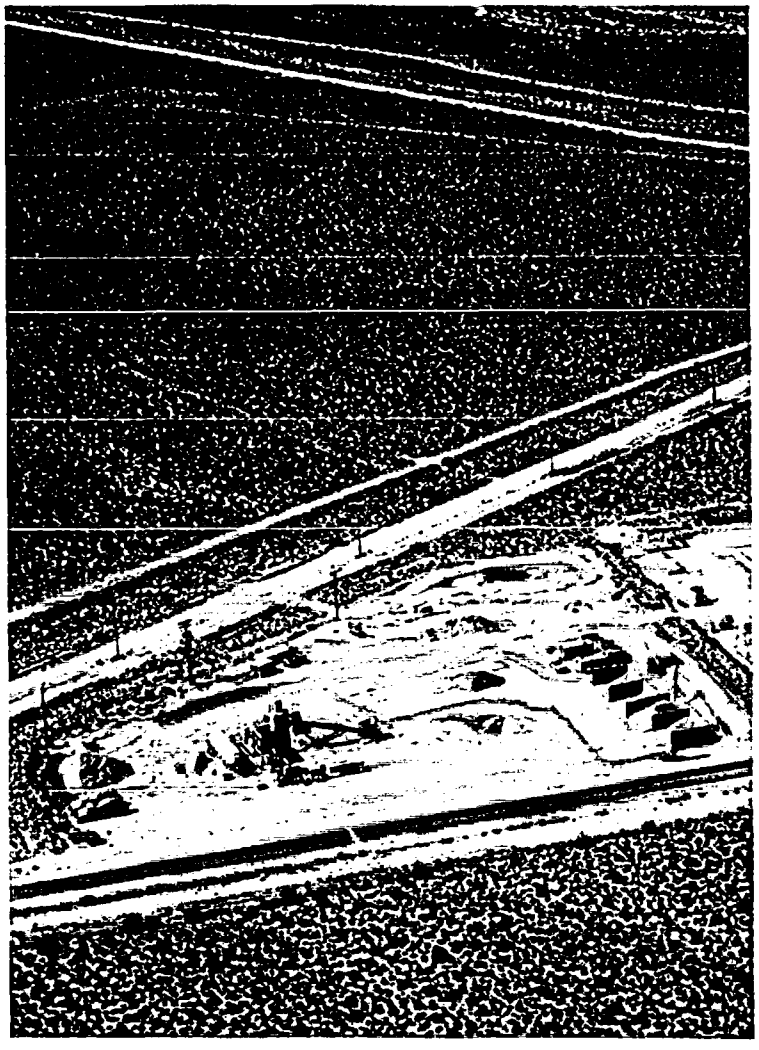
Offsite Power to Lower Muck Yard – Proposed Plan



- Examining alternatives for best method to bring 138 kV line on site from Lathrop Wells switch
- Negotiate preferable utility use rates with utility vendor
- Construct 20-25 MVA (mega volt ampere) substation at Lower Muck Yard
- Provide reliable power to North and South Portals
- Scheduled for completion in FY07

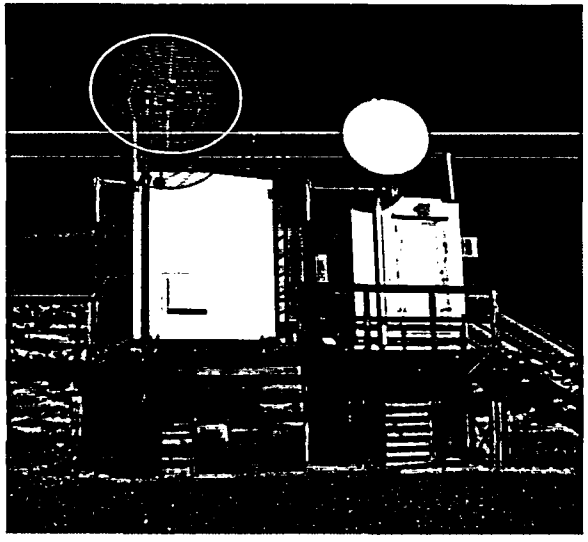
C08

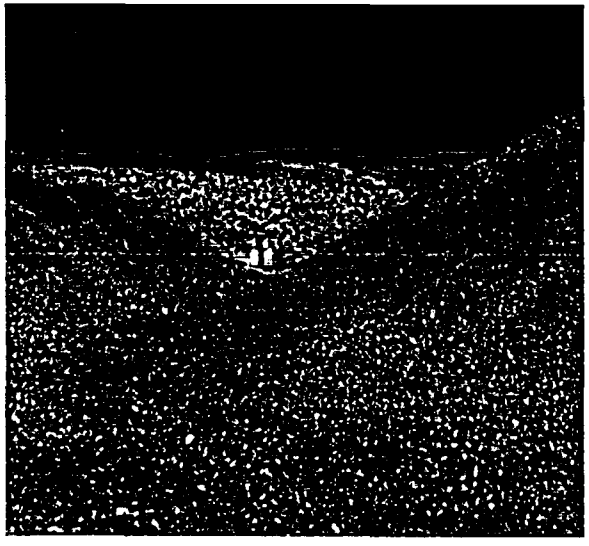
Batch Plant



- The ability to batch cement on site will be critical to future upgrade projects such as
  - Grouting the subsurface rail system
  - Pad and foundation construction for future facilities
  - Completion of subsurface ground support project
- Aggregate crushing and screening capability will be required for use of material from the muck pile or other sources

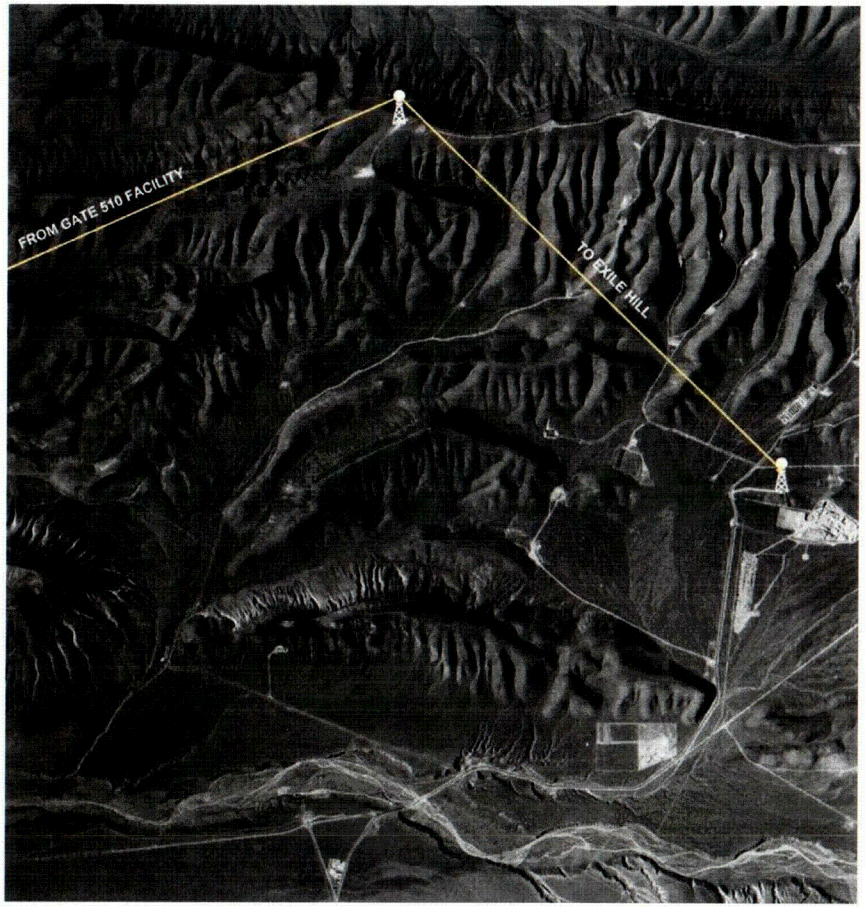
Communications Upgrades – Current Conditions





- Currently provided via analog microwave transmitter at North Portal pad and interfaced with Nevada Test Site microwave system
- Functioning at maximum operating rate of 1 Mb
- Extremely slow
- Single-point failure

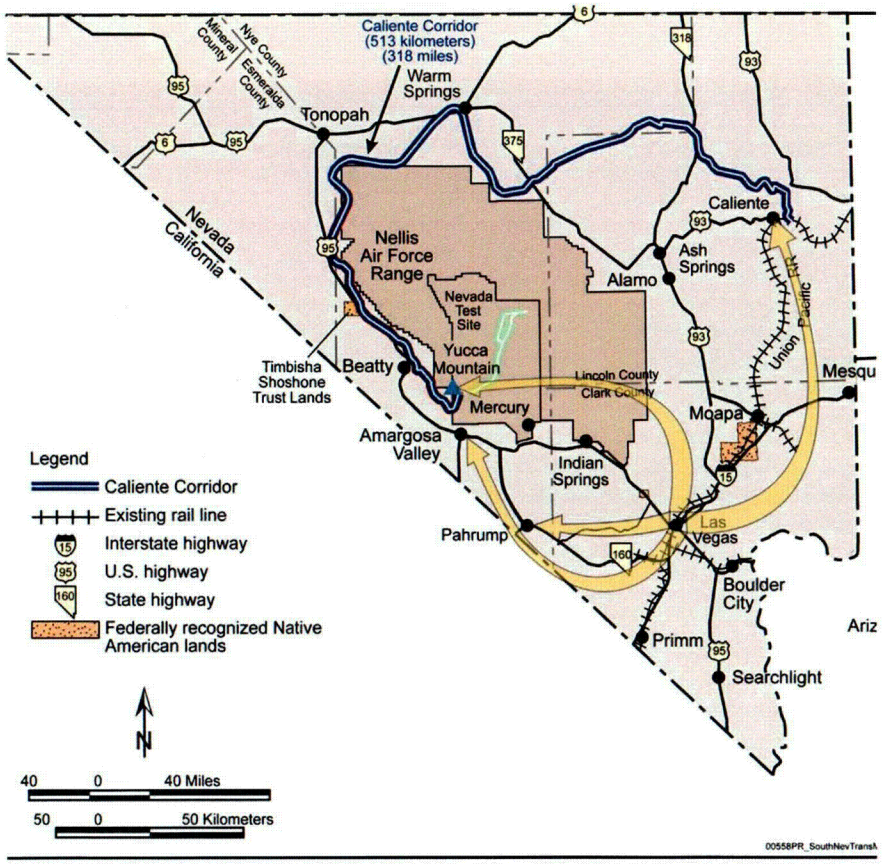
Communications Upgrades – Proposed Plan



- Initial phase – install digital line-of-sight communications infrastructure
- Increased transfer rate to 40 Mb
- Improved radio communications
- Eliminate single-point failure
- Phase 1 complete by 11/06

C09

Proposed Office Locations



- **To ensure mission focus for field assets, OCRWM is transitioning Las Vegas-based leased facilities to rural locations**
  - **Pahrump and Caliente facilities in FY 2006**
  - **Remaining facilities transitioning at the end of lease period (approximately 2010) according to a strategic facility plan**

C10

U.S. Department of Energy

OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT

Cooperative Agreement – Nye County Early Warning Drilling Program

Presented to:

169th Advisory Committee on Nuclear Waste

Presented by:

Drew H. Coleman

Physical Scientist U.S. Department of Energy

April 19, 2006

Two White Flint North

Rockville, Maryland

Cooperative Agreement – Nye County Early Warning Drilling Program

- A Cooperative Agreement is a grant that allows substantial participation by (DOE. 10CFR600.100-200)
- Nuclear Waste Policy Act (NWPA) 1982 The secretary shall make Grants to . . . Affected Units of local government . . . To engage in monitoring, testing or evaluation activities. (Sec 116)
- The fiscal year for the Cooperative Agreement runs from April to April, their FY06 Program has just been reviewed and approved
- The Project provides funding "in kind" services where these make sense, such as curating samples in the Sample Management Facility

Cooperative Agreement – Nye County Early Warning Drilling Program

(Continued)

- Scope of the Cooperative Agreement
  - Work Element 1: Ventilation Related Studies
  - Work Element 2: Alluvial Testing Complex – No activities
  - Work Element 3: Independent Scientific Investigations Program (ISIP) Wells - Finish drilling, sampling, and testing of well NC-EWDP-32P located in the Fortymile Wash braided channel approximately 2 miles south of Highway 95. Complete a Horizontal borehole that spans a major fault system down gradient of the Repository
  - Work Element 4: Geologic Sample Analysis - Determine hydraulic properties of alluvium geologic samples collected from the new boreholes drilled in ISIP fiscal year 2006-07, and a surface outcrop near Site 10 in Fortymile Wash

Cooperative Agreement – Nye County Early Warning Drilling Program

(Continued)

- Work Element 5: Water Chemistry Monitoring - Implement a long-term groundwater sampling and chemical analysis plan for EWDP wells
- Work Element 6: Water Level Monitoring - Conduct groundwater level monitoring in both EWDP wells and selected regional wells in Amargosa, Pahrump, and Stewart Valleys
- Work Element 7: Surface Geophysical Surveys - Conduct a surface resistivity geophysical survey to better characterize the poorly understood Highway 95 fault system on the northern edge of Amargosa Desert

Cooperative Agreement – Nye County Early Warning Drilling Program

(Continued)

- Work Element 9: Nye County Tracer Tests - Conduct natural-gradient cross-hole tracer test at Site 22
- Work Element 10: Regional Geological Characterization - Continue regional geologic mapping activities to identify potential fast groundwater pathways from the Nevada Test Site to Amargosa Valley, with emphasis on the area along Highway 95 between Mercury and Lathrop wells

Nye County Department
of Natural Resources and Federal Facilities

Independent Scientific Investigations Program Review

Prepared by
John D. Campanella

169th ACNW MEETING
APRIL 18-20, 2006

John D. Campanella
Norwest Questa

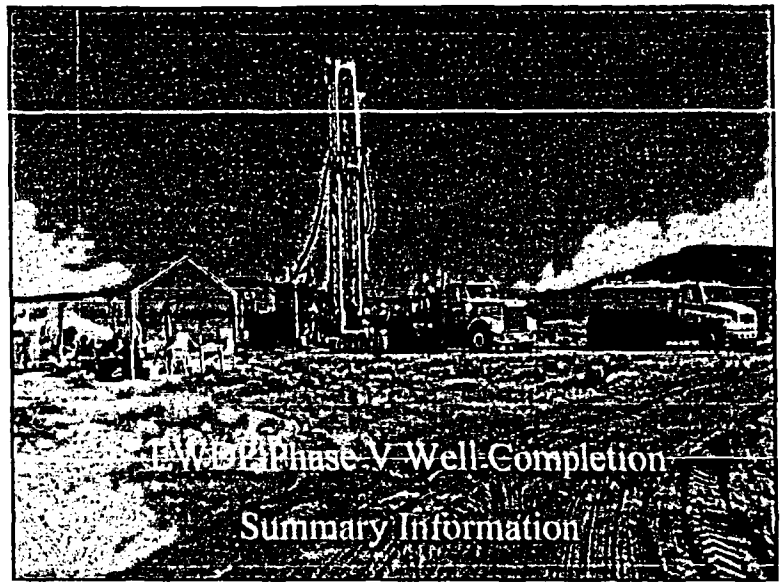
- BS Chemical Engineering
- 25+ years experience in Oil and Gas Industry
- Production work included well design and single- and multi-well testing with pressure measurements and chemical tracers.
- Reservoir engineering experience includes:
  - Developing models for large oil and gas fields (200+ wells).
  - Preparing a detailed fracture flow network model for a giant oilfield (1,500+ wells) which was validated using actual field performance.
  - Simulation studies of dozens of oil and gas fields around the world.

What do I do for Nye County

- Assist Nye County with independently gathering and verifying "Ground Truth" data, such as:
  - EWDP well planning and design
  - Pump test design, data gathering and analysis, using the latest methods developed for oil and gas wells
  - Chemical tracer test design, data gathering and analysis.
- Analyze well tests to improve system models.
- Evaluate technical data and methodologies used by the DOE, YMP, LBNL, USGS and other researchers.

Presentation Overview

- **Update on EWDP Drilling Program**
  - Phase V Wells
  - Location and Completion Information
- **Tracer testing at Site 22s**
  - Tracer Testing Implementation
  - Preliminary Results from numerical modeling
- **Office of Science and Technology & International (OSTI)**
  - Installation of U-tube in NC-EWDP-24PB
- **Proposed Horizontal Well**



Early Warning Drilling Program (EWDP)

- Begun in 1998.
- Major part of Nye County's Independent Scientific Investigation Program (ISIP).
- Funded through cooperative grants from DOE.
- Data collected under formal QA program.
- Data shared with all interested parties through Nye County Technical Reports and web site.

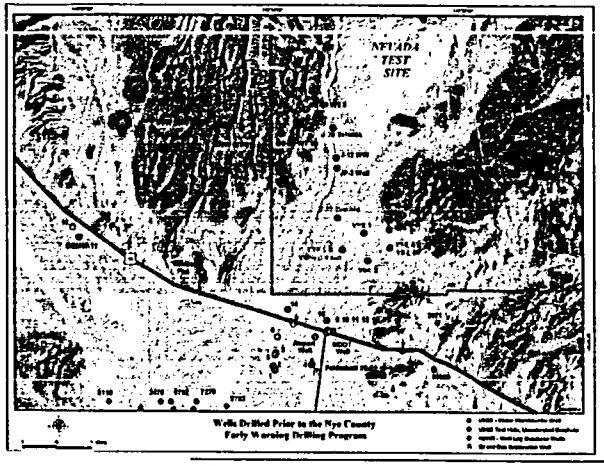
EWDP Goals

- Characterization of potential flow paths between Yucca Mountain and Amargosa Valley.
- Reduction of uncertainty in DOE Yucca Mountain Project (YMP) performance assessment models.
- Support of groundwater monitoring network design.

Major EWDP Activities

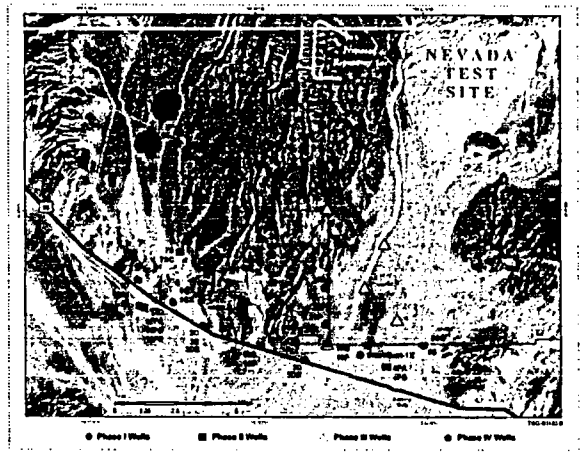
- Drilling, geologic sampling and logging, and well construction.
- Borehole and airborne geophysical logging.
- Aquifer pump testing.
- Groundwater chemistry sampling and analysis.
- Groundwater level monitoring.
- Lab testing (i.e., hydraulic parameters) of geologic samples.

Pre-EWDP Wells



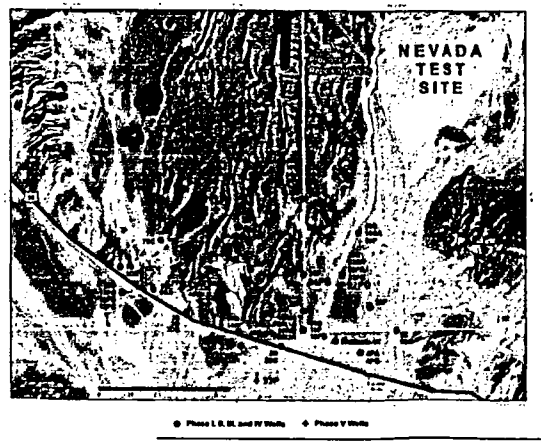
Nye County Department of Natural Resources and Federal Facilities

EWDP - Phase I - IV Wells



Nye County Department of Natural Resources and Federal Facilities

Map of Phase V Wells



Nye County Department of Natural Resources and Federal Facilities

EWDP Phase V Well Completion Summary Information

Well ID	Well Type	Drilling Completion Date	Total Depth	Approximate Open Hole Water Level at End of Drilling	Screened Interval(s)	Sand Pack Interval(s)	Lithology at Sand Pack Intervals
(NC-EWDP-)[a]			(feet, bgs[b])	(feet, bgs)	(feet, bgs)	(feet, bgs)	
22PC	Piezometer	11/11/2004	763.0	472	510.0 - 579.8	505.2 - 585.1	Alluvium
					665.4 - 755.0	659.2 - 763.0	
13P	Piezometer	7/28/2005	1559.0	433	426.0 - 466.0	419.0 - 471.0	Alluvium
24PB	Piezometer	3/26/2006	1394.1	404	729.2 - 769.9	723.1 - 776.9	Tertiary Tuff
33P	Piezometer	3/7/2006	657.0	204	210.8 - 249.9	205.0 - 254.0	Alluvium
					484.5 - 523.6	476.0 - 528.0	Alluvium
					600.9 - 640.0	591.0 - 657.0	Alluvium
32P	Piezometer	In Progress	1000.0	245	TBD[c]	TBD	TBD
					TBD	TBD	TBD
					TBD	TBD	TBD

[a] Official prefix of all new Nye County Wells.

[b] Below ground surface.

[c] To be determined.

Nye County Department of Natural Resources and Federal Facilities

Tracer Testing at Site 22S
Implementation and Preliminary Analysis

Tracer Testing Goals

- Reduce uncertainty in the saturated zone transport parameters.
- Provide estimates of effective flow porosity and longitudinal dispersion.
- Investigate possible existence of stagnant layer.
- Investigate possible hydro-stratigraphic layer communication

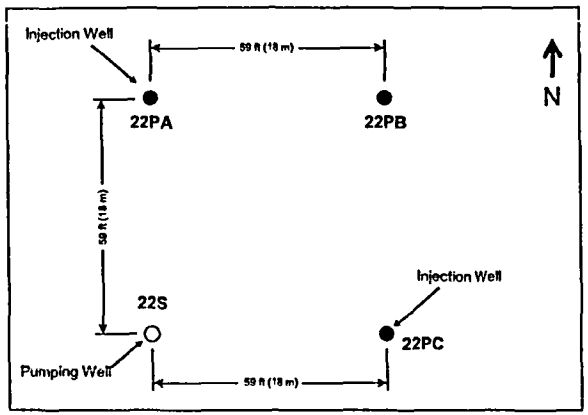
Tracer Testing Methodology

- Utilize and build upon previous NC-EWDP-22S test results.
- Two Single Well Push/Pull Tracer Tests were Performed at NC-EWDP-22S.
- Multi-Well, Cross-hole Tracer Tests were conducted in at Site 22 during January of 2005 with Multiple Tracers

Tracers

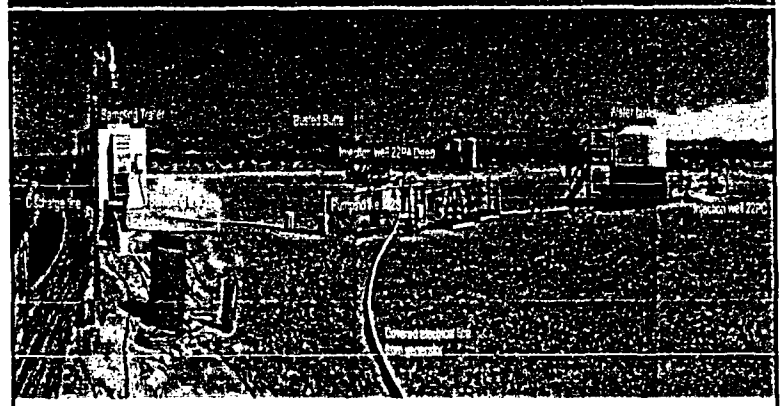
- A total of ten fluorinated benzoates and salts were injected as conservative tracers
- Lithium was used as a cation for one of the halides (LiBr) and additional Li mass was added
- 1.5 kg of 2,5-DFBA was used as qualitative tracer for investigating stratigraphic communication
- 2+ grams of Fluorescent Microspheres were injected

Site 22 Plan View



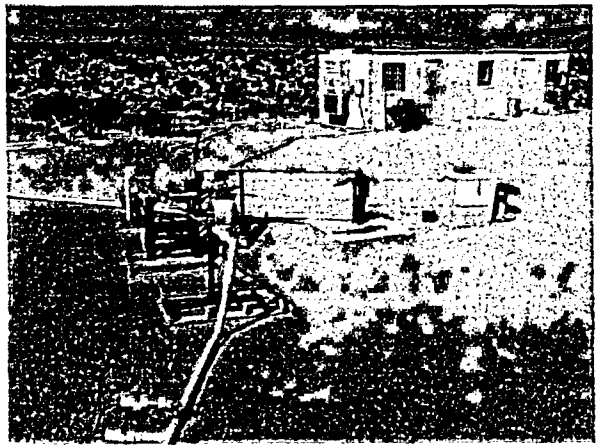
Nye County Department of Natural Resources and Federal Facilities

Tracer Testing at Site 22S



Nye County Department of Natural Resources and Federal Facilities

Tracer Test: Pumping Well and Sampling Trailer

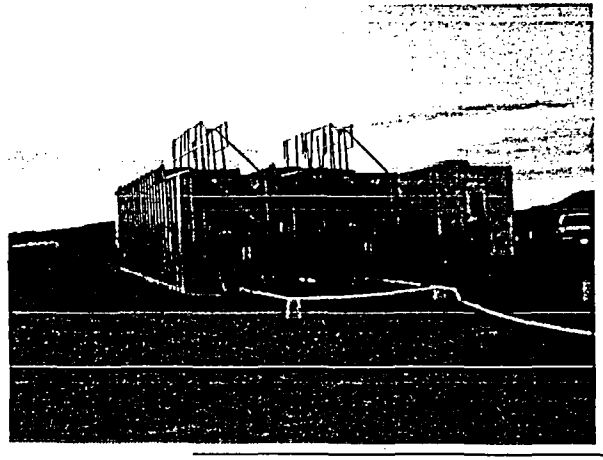


Nye County Department of Natural Resources and Federal Facilities

Tracer Test: Generators

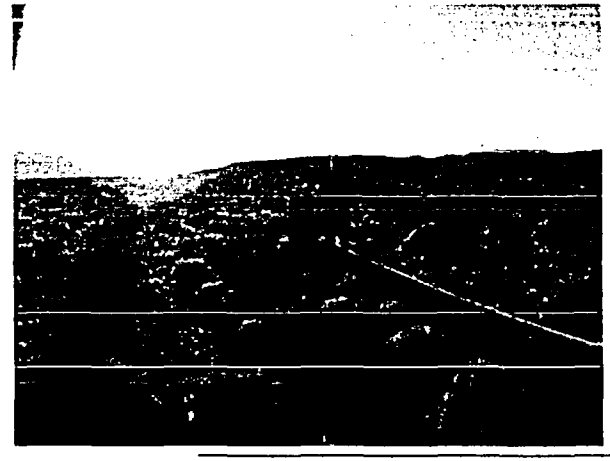
Nye County Department of Natural Resources and Federal Facilities

Tracer Test: Chase-Water Tanks



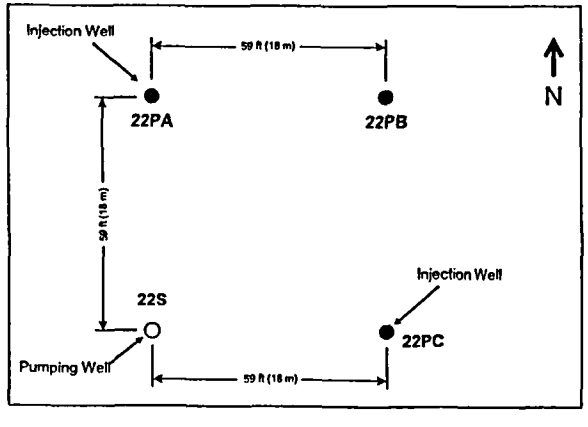
Nye County Department of Natural Resources and Federal Facilities

Tracer Test: Discharge Line



Nye County Department of Natural Resources and Federal Facilities

Site 22 Plan View

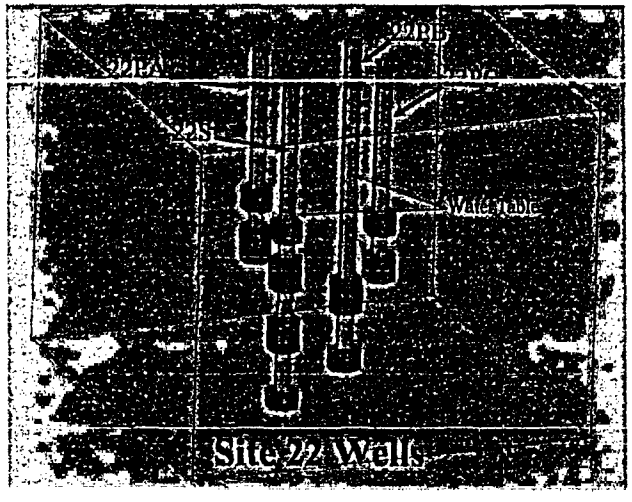


Nye County Department of Natural Resources and Federal Facilities

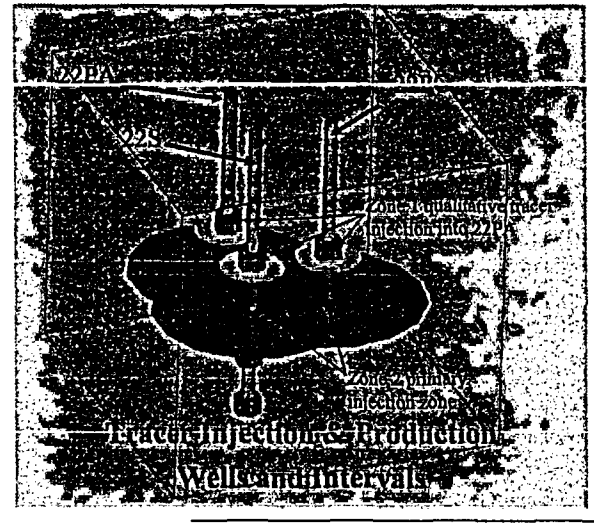
ZONES AND SCREEN DEPTHS SITE 22 WELLS

Well Name	Well Zone	Sand Pack Depth Interval (feet below ground surface) (feet bgs)	Sand Pack Height (feet)	Screen Top to Bottom Measured Depth (feet bgs)	Screen Height (feet)
22S	1	513.4 – 585.3	72.0	521.5 – 591.3	69.8
	2	691.8 – 806.5	114.7	691.2 – 790.0	99.4
	3	875.2 – 990.0	115.0	890.2 – 990.0	99.8
	4	1133.2 – 1196.5	63.3	1140.0 – 1199.0	49.0
22PA	1	590.7 – 667.0	76.3	520.7 – 670.7	90.0
	2	640.7 – 770.8	130.1	691.0 – 790.0	99.0
22PB	3	870.7 – 990.2	119.5	891.3 – 970.7	99.4
	4	1125.2 – 1199.7	74.5	1140.3 – 1170.7	30.4
22PC	1	690.0 – 805.0	95.0	610.0 – 680.0	70.0
	2	690.0 – 790.0	100.0	690.0 – 790.0	90.0

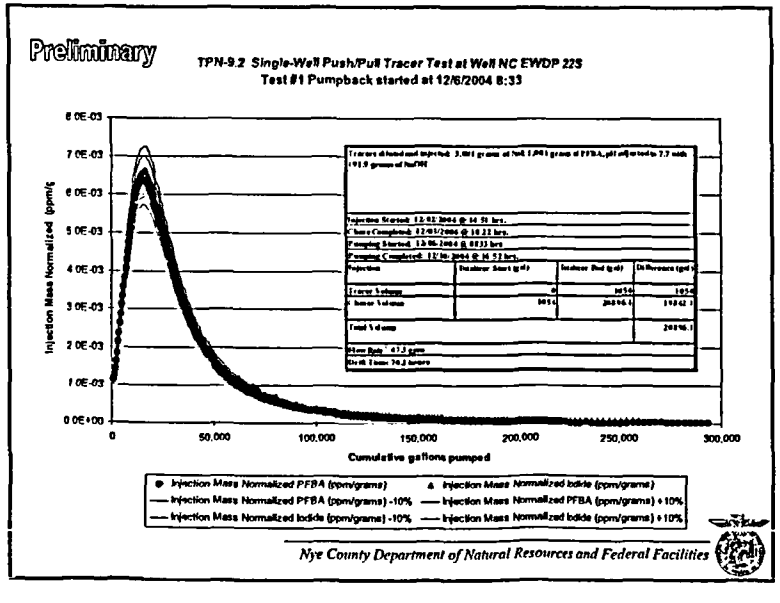
Nye County Department of Natural Resources and Federal Facilities



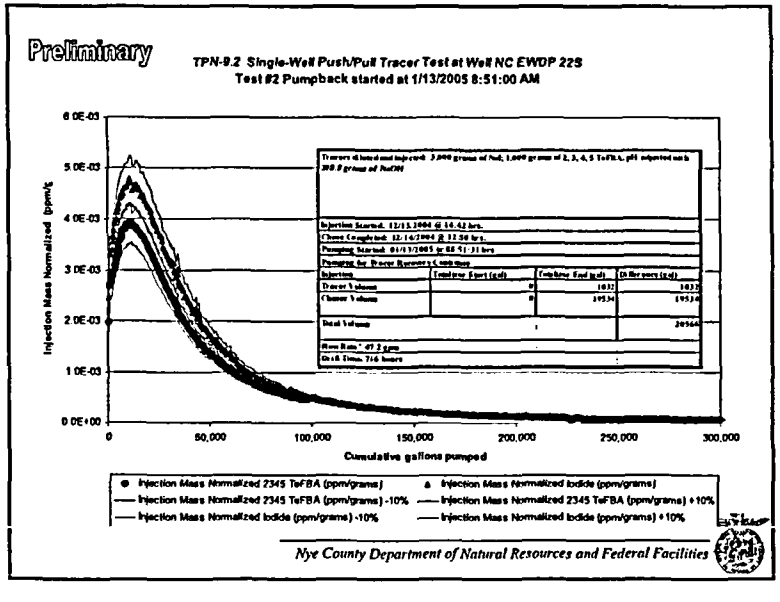
Nye County Department of Natural Resources and Federal Facilities



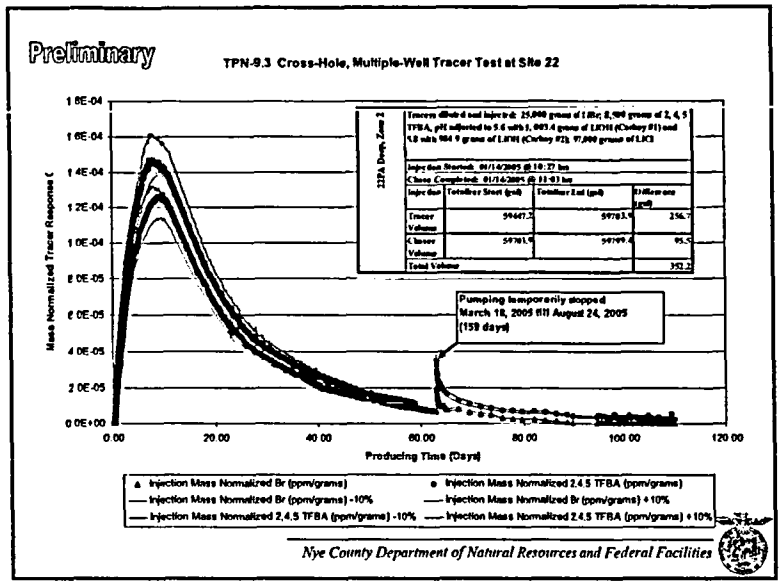
Nye County Department of Natural Resources and Federal Facilities

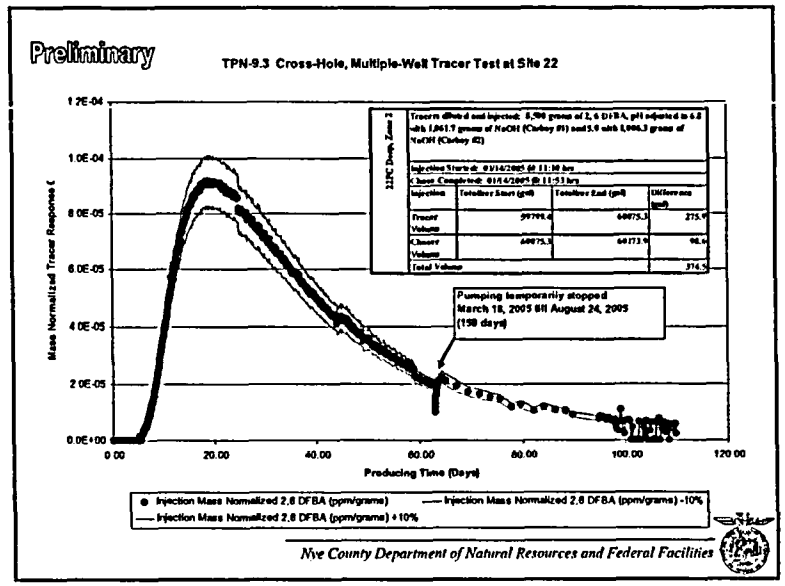


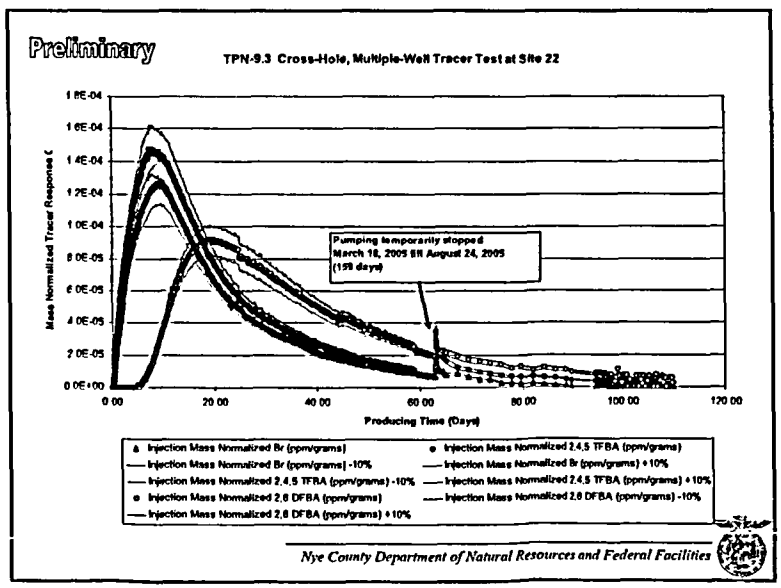
Nye County Department of Natural Resources and Federal Facilities

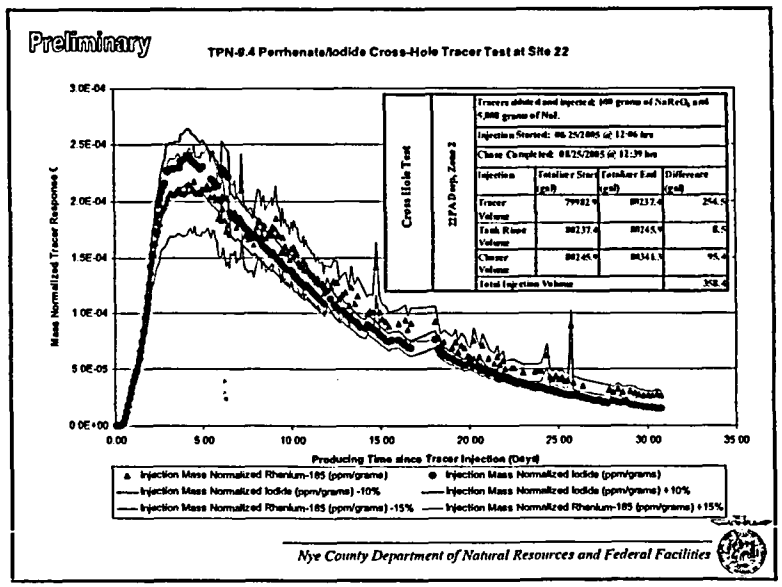


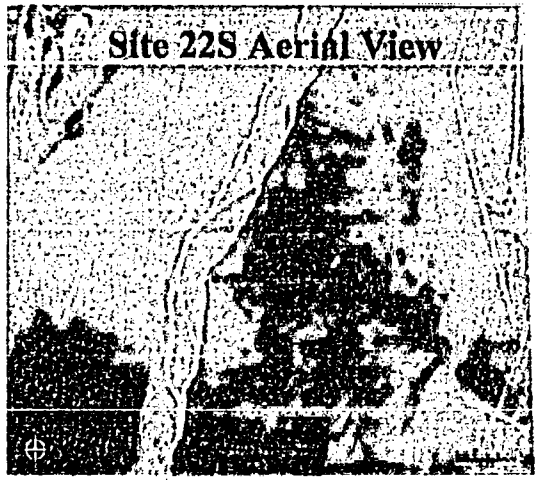
Nye County Department of Natural Resources and Federal Facilities


Preliminary
TPN-9.3 Cross-Hole, Multiple-Well Tracer Test at Site 22
Mass Normalized Tracer Response C
Producing Time (Days)
Pumping temporarily stopped
March 18, 2005 till August 24, 2005
(159 days)
Injection Mass Normalized Br (ppm/grams)
Injection Mass Normalized 2,4,5 TFBA (ppm/grams)
Injection Mass Normalized Br (ppm/grams) -10%
Injection Mass Normalized Br (ppm/grams) +10%
Injection Mass Normalized 2,4,5 TFBA (ppm/grams) -10%
Injection Mass Normalized 2,4,5 TFBA (ppm/grams) +10%
Nye County Department of Natural Resources and Federal Facilities

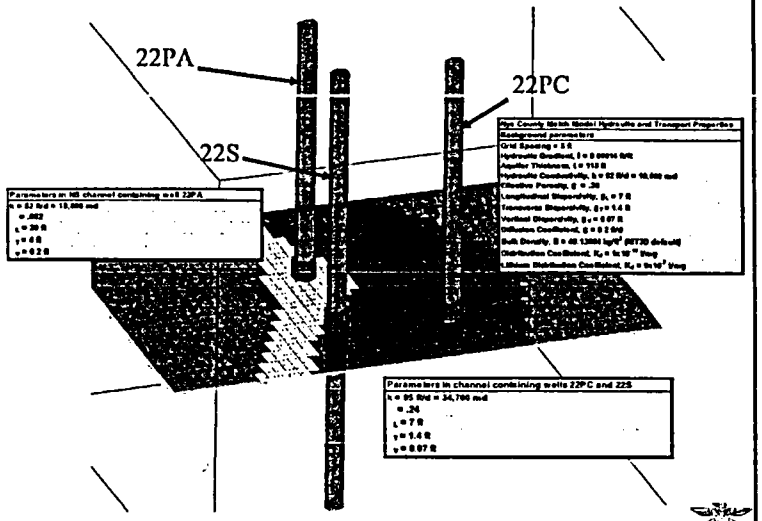

Preliminary
TPN-9.3 Cross-Hole, Multiple-Well Tracer Test at Site 22
Mass Normalized Tracer Response C
Producing Time (Days)
Pumping temporarily stopped
March 18, 2005 till August 24, 2005
(159 days)
Injection Mass Normalized 2,6 DFBA (ppm/grams)
Injection Mass Normalized 2,6 DFBA (ppm/grams) -10%
Injection Mass Normalized 2,6 DFBA (ppm/grams) +10%
Nye County Department of Natural Resources and Federal Facilities


Preliminary
TPN-9.3 Cross-Hole, Multiple-Well Tracer Test at Site 22
Mass Normalized Tracer Response C
Producing Time (Days)
Pumping temporarily stopped
March 18, 2005 till August 24, 2005
(159 days)
Injection Mass Normalized Br (ppm/grams)
Injection Mass Normalized 2,4,5 TFBA (ppm/grams)
Injection Mass Normalized Br (ppm/grams) -10%
Injection Mass Normalized Br (ppm/grams) +10%
Injection Mass Normalized 2,4,5 TFBA (ppm/grams) -10%
Injection Mass Normalized 2,4,5 TFBA (ppm/grams) +10%
Injection Mass Normalized 2,6 DFBA (ppm/grams)
Injection Mass Normalized 2,6 DFBA (ppm/grams) -10%
Injection Mass Normalized 2,6 DFBA (ppm/grams) +10%
Nye County Department of Natural Resources and Federal Facilities

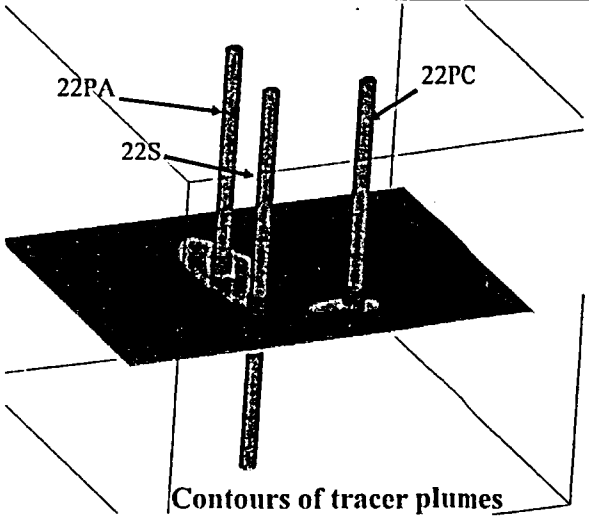

Preliminary
TPN-9.4 Perrhenate/Iodide Cross-Hole Tracer Test at Site 22
Cross Hole Test
Mass Normalized Tracer Response C
Producing Time since Tracer Injection (Days)
Injection Mass Normalized Rhenium-185 (ppm/grams)
Injection Mass Normalized Iodide (ppm/grams)
Injection Mass Normalized Iodide (ppm/grams) -10%
Injection Mass Normalized Iodide (ppm/grams) +10%
Injection Mass Normalized Rhenium-185 (ppm/grams) -15%
Injection Mass Normalized Rhenium-185 (ppm/grams) +15%
Nye County Department of Natural Resources and Federal Facilities



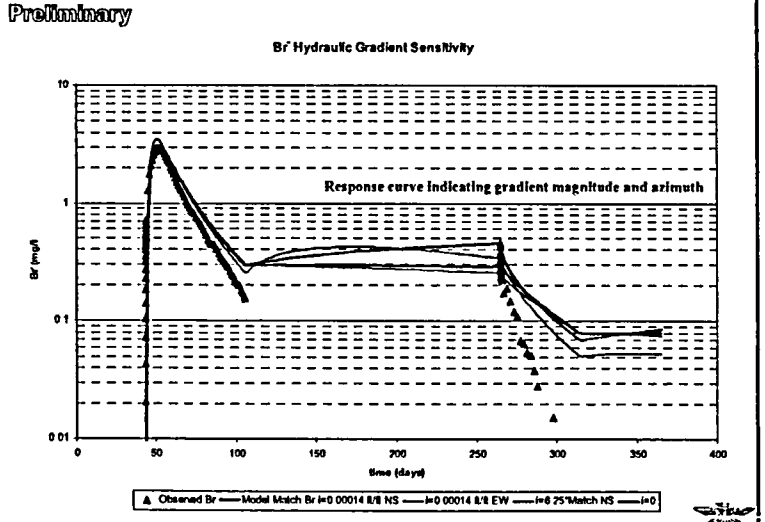
Nye County Department of Natural Resources and Federal Facilities



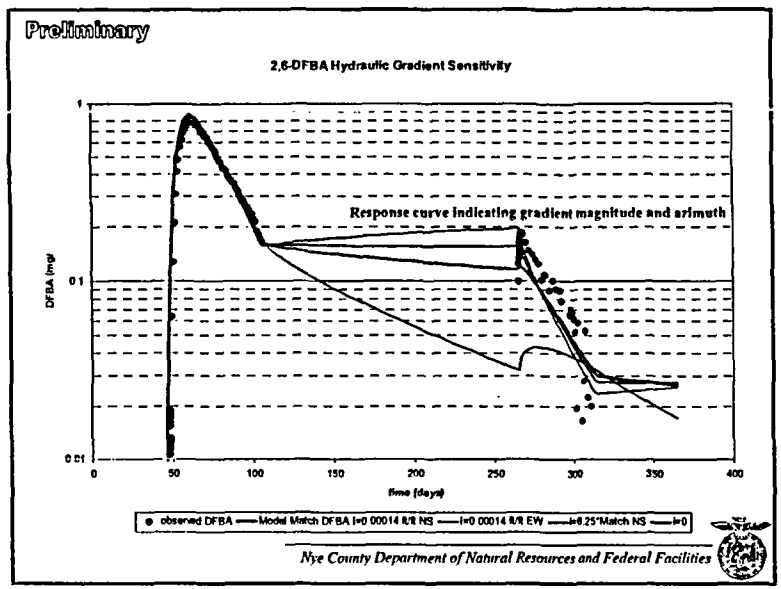
Nye County Department of Natural Resources and Federal Facilities

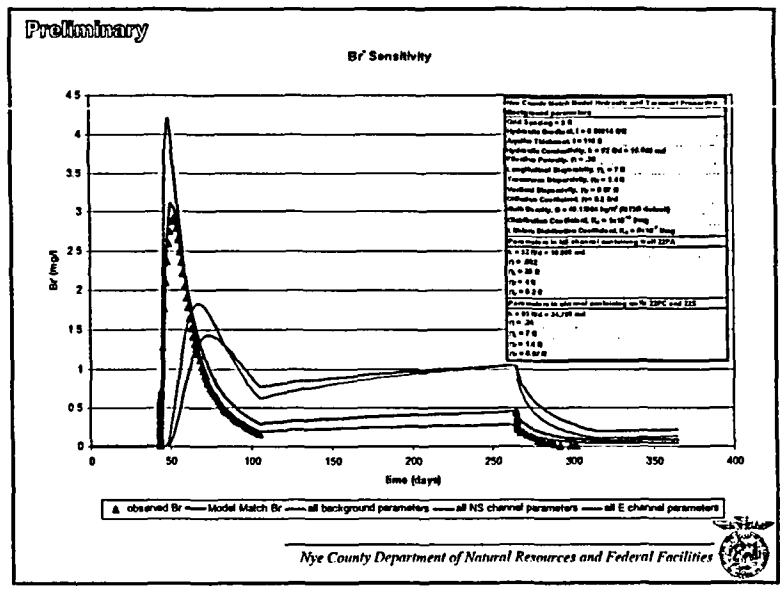


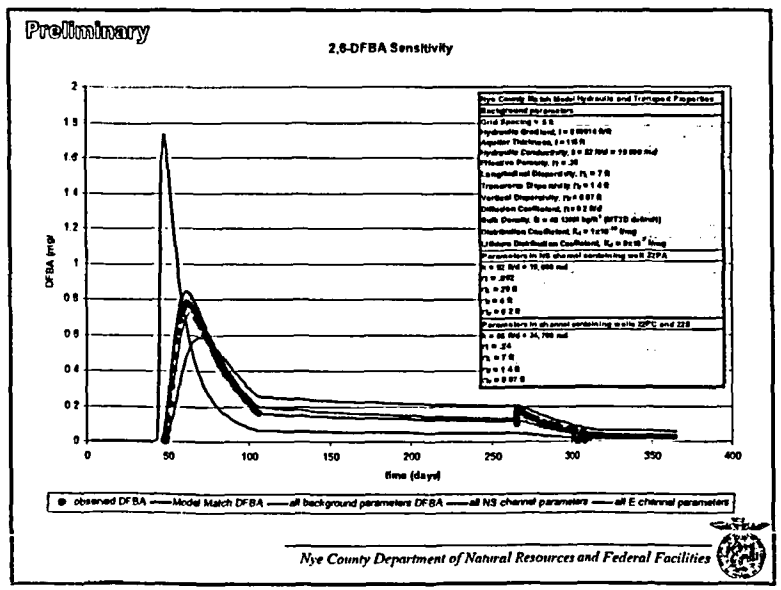
Nye County Department of Natural Resources and Federal Facilities

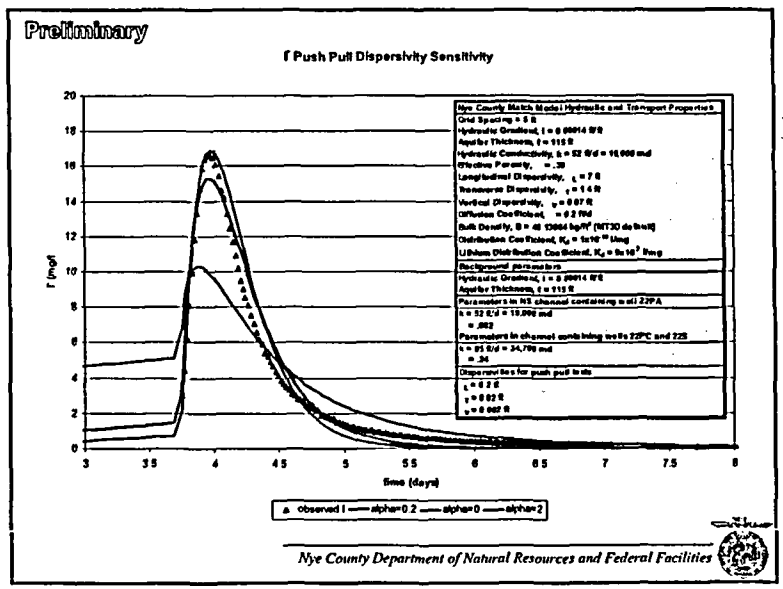


Nye County Department of Natural Resources and Federal Facilities


Preliminary
2,6-DFBA Hydraulic Gradient Sensitivity
Response curve indicating gradient magnitude and azimuth
DFBA (mg/
time (days)
observed DFBA
Model Match DFBA I=0 00014 ft/ft NS
I=0 00014 ft/ft EW
I=0.25*Match NS
I=0
Nye County Department of Natural Resources and Federal Facilities


Preliminary
Br⁻ Sensitivity
Br (mg/l
time (days)
observed Br
Model Match Br
all background parameters
all NS channel parameters
all E channel parameters
Nye County Department of Natural Resources and Federal Facilities


Preliminary
2,6-DFBA Sensitivity
DFBA (mg/
time (days)
observed DFBA
Model Match DFBA
all background parameters DFBA
all NS channel parameters
all E channel parameters
Nye County Department of Natural Resources and Federal Facilities


Preliminary
I⁻ Push Pull Dispersivity Sensitivity
I⁻ (mg/l
time (days)
observed I
alpha=0.2
alpha=0
alpha=2
Nye County Department of Natural Resources and Federal Facilities

Tracer Testing Summary

- Multiple tracer tests have been conducted in the saturated alluvium at Site 22 in lower Fortymile Wash.
- Non-sorbing solute tracers with differing diffusion coefficients were used for two consecutive single-well push-pull tracer tests, beginning in December 2004.
- Single-well tests were followed by two multi-well cross-hole tracer tests using conservative, reactive, and microsphere tracers, beginning in January 2005.
- Preliminary analysis of the tracer tests using both analytical and numerical simulation indicates that diffusion into immobile water was minimal or nonexistent, and that a fast flowpath exists between one of the injection wells (22PA) and the pumping well (22S) in the shallow alluvial aquifer.
- A long pumping interruption between the two cross-hole tests allowed the natural groundwater drift to move the tracer plumes.
- The tracer response curves contain information about the site's natural gradient magnitude and azimuth.

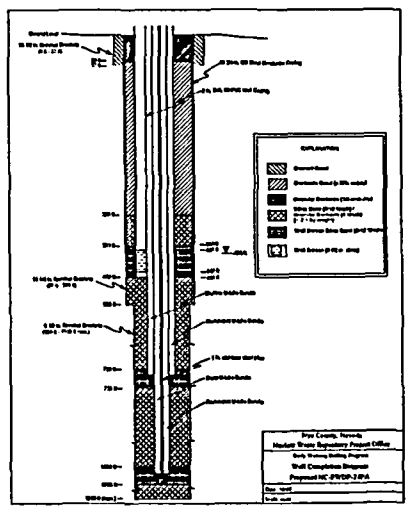
Office of Science and Technology & International

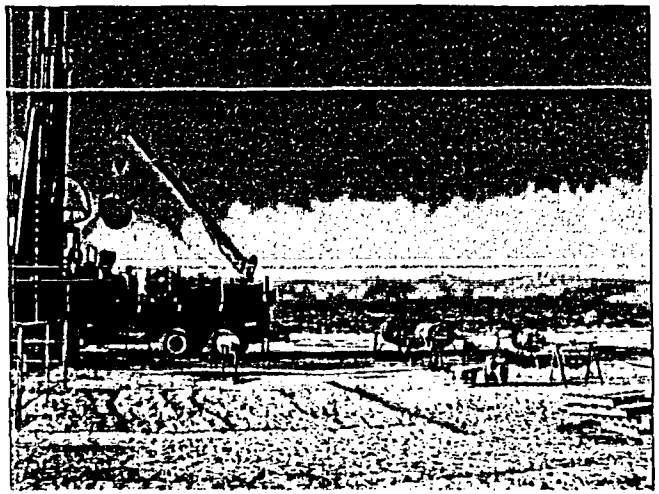
OSTI U-tube Installation in NC-EWDP 24PB

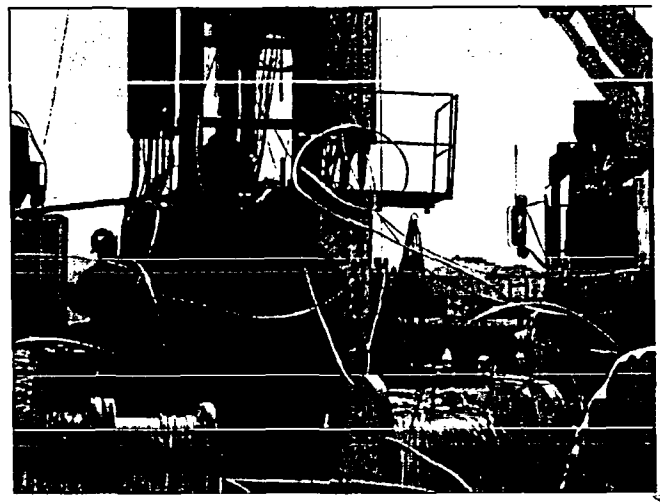
For U-Tube sampling, downhole equipment consists of two stainless steel lines, leading to a downhole check valve, and a filtered inlet mounted below a packer.

The check valve permits native fluid to enter the U-Tube, but prevents its return back into the formation. Using high-pressure ultra-pure nitrogen applied on the drive tube, the check valve closes, and the fluid is forced up to the surface.

An evacuated high-pressure cylinder located at the surface termination of the sample tube collects fluid samples at *in situ* pressures without exposure to external contaminants, such as oxygen.







Proposed Horizontal Well

Goals and Background Information

How Have We Investigated Large Scale Flow Features?

- Drifts
- Vertical wellbores
- Large scale geophysical measurements
- Geochemical analysis
- Tracer testing
- Lab testing of rock and fluid interactions
- Data integration and modeling

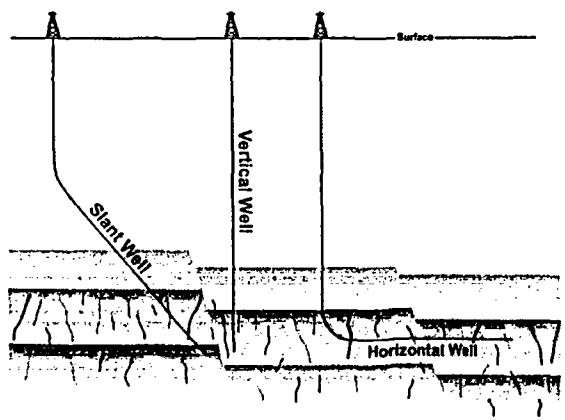
Several Key Hydrogeologic Features Are Still Not Well Understood:

- Hydraulic properties of major block bounding faults
- Impact of fracture frequency, fracture mineralization, and matrix fracture interaction
- Connection between the tuffs, alluvial and carbonate systems
- These features can impact radionuclide transport time by thousands of years

How Do We Cost Effectively Reduce The Uncertainty?

- We need to:
  - Intersect faults in saturated zone
  - Quantify fault and fractures
  - Obtain geophysical measurements
  - Obtain hydrogeologic properties
  - Allow for future access and long term monitoring
- Horizontal wells fulfill these requirements

Different Well Types



Why Go Horizontal?

- Improved well productivity
- Better connection to fractures and vertical features
- Obtain detailed information over larger scales through vertical fractures or faults that are poorly identified in vertical wells

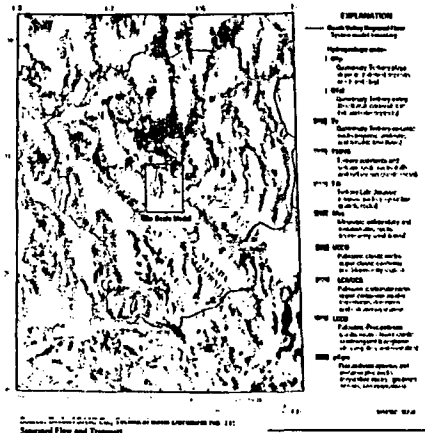
Are Horizontal Wells "Experimental"?

- Over the last 15 years, horizontal drilling for oil and gas has exploded
- In 1987, 51 horizontals were drilled; by 1997, the number was 4,000!
- Major horizontal well areas include Alberta Canada, Texas, and N Dakota
- Through 2000, there were 23,385 horizontal wells in the US, 9,655 in Canada

Introduction

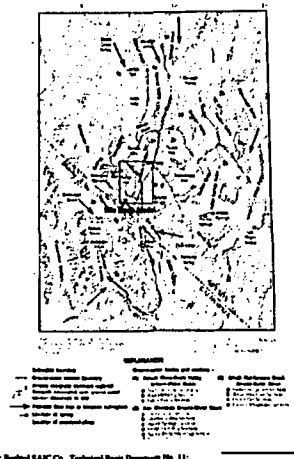
- Regional Hydrogeologic Setting
  - Death Valley Regional Flow System (DVRFS).
  - Yucca Mountain Site Scale Model.
- Local Hydrogeologic Setting
- Early Warning Drilling Program (EWDP).
  - Overview of the program and some geologic results and insights from EWDP.
- Goals of Proposed Horizontal Drilling
  - What questions are we expecting to answer with the proposed wells?
- Cross Sections with Proposed Horizontal Wells.

Regional Hydrogeologic Setting



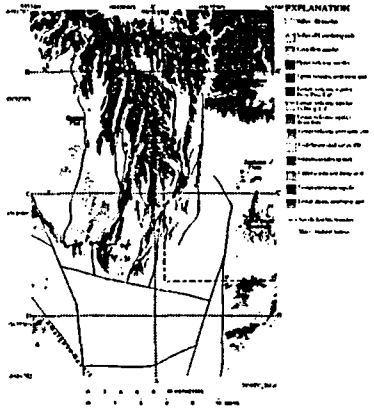
- Southwest corner of Paleozoic Carbonate Province.
- Structurally within the Walker Lane Belt at the and SE margin of the Basin and Range Province
- Within The DVRFS
- YMP Site-Scale Model is in the south-central of the DVRFS

Regional Groundwater Flow



- Most of the groundwater flow is fed from the North and Northeast.
- Discharge areas to south and southwest.

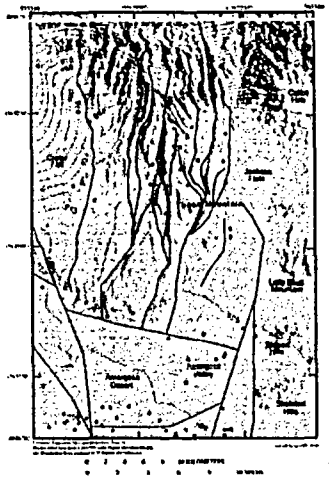
Local Hydrogeologic Setting



- At Yucca Mountain:
  - Saturated zone in lower section of UVA (Topopah Spring Tuff).
  - Flow occurs predominantly in UVA and LVA discharging into the VFA (alluvium) toward the south and southeast.
- Underflow may occur at depth.
- Nye County is concerned primarily with shallow accessible aquifers.

Nye County Department of Natural Resources and Federal Facilities

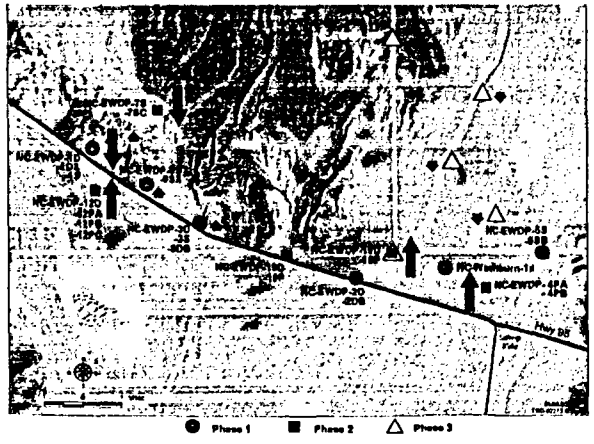
Local Hydrogeologic Setting



- Groundwater flow driven from steeper gradients to the north and northwest.
- Much flatter apparent gradient in Yucca Mountain/Fortymile Wash area.
- Southeasterly apparent flow direction may be intercepted by north-south steep faults.

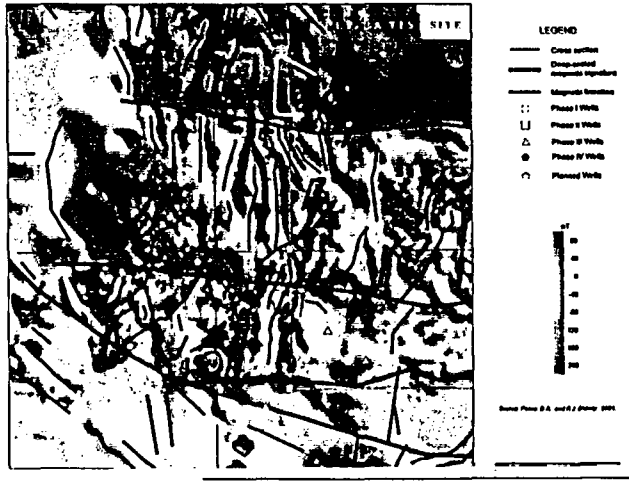
Department of Natural Resources and Federal Facilities

Vertical Gradients In EWDP Wells



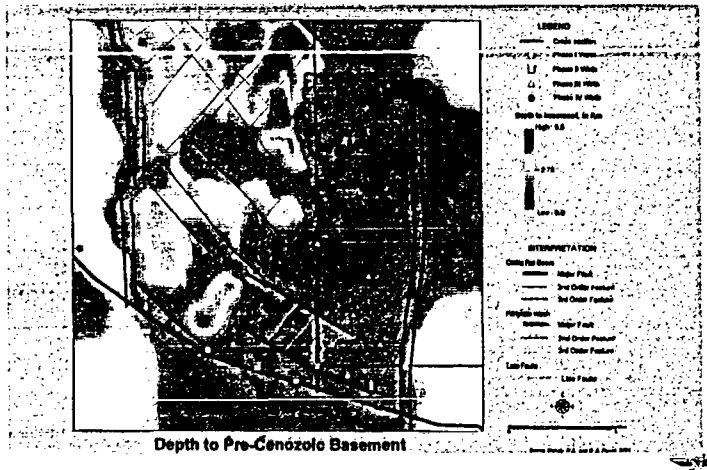
Nye County Department of Natural Resources and Federal Facilities

Aeromagnetics



Nye County Department of Natural Resources and Federal Facilities

Gravity/Depth to Pre-Cenozoic



Some Major EWDP Findings

- Permeability of alluvium and underlying volcanic aquifers can be very high.
- Upward hydraulic gradients generally observed from deeper to shallower aquifers. Local large downward gradients at paleospring well sites.
- Focus of flow likely occurs in Fortymile Wash alluvium due to permeability contrasts.
- Particle size distributions of alluvial samples is significantly different in saturated alluvium drill cuttings and core samples. Sonic coring is the best (only?) method to sample saturated alluvium.

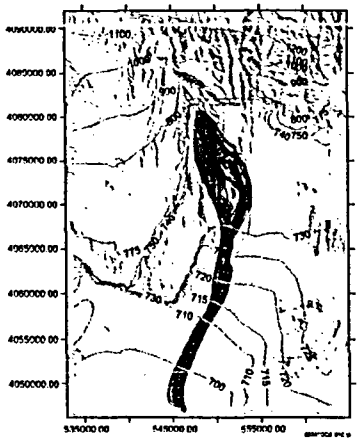
Some Major EWDP Findings (cont'd)

- Layer cake hydrostratigraphy at Yucca Mountain does not exist at Highway 95. Continuity of volcanic aquifer units complicated by:
  - Buried older faults in volcanic units at Highway 95 and several miles north of Highway 95 likely complicate flow paths (longer and more convoluted).
  - Older growth faults likely either terminate major ashflow sheets or create abrupt textural/facies boundaries.
  - Structures also provide "plumbing" for large upward hydraulic gradients.
  - Vertical gradients can be orders of magnitude larger than horizontal gradients.

The Bottom Line

- Flow in the volcanic aquifers likely occurs in structurally controlled compartments.
- Flow in alluvial aquifers is controlled by textural units (channels) and likely affected by local vertical gradients near underlying faults.

Proposed Horizontal Wells



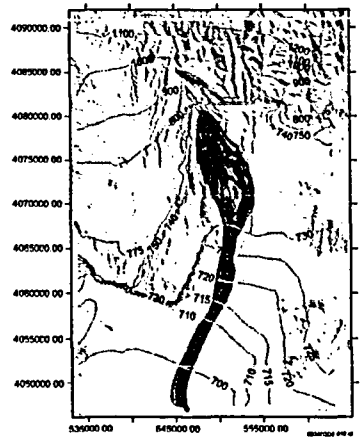
Justification

- Modeled flow paths dependant on poorly constrained hydraulic gradient.
- Flow occurs in areas of variable upward vertical gradients.
- Modeled flow is apparently unaffected by large vertical structural features.

Source: Bechtel SAIC Co., Technical Basis Document No. 11: Saturated Flow and Transport

Nye County Department of Natural Resources and Federal Facilities

Proposed Horizontal Wells



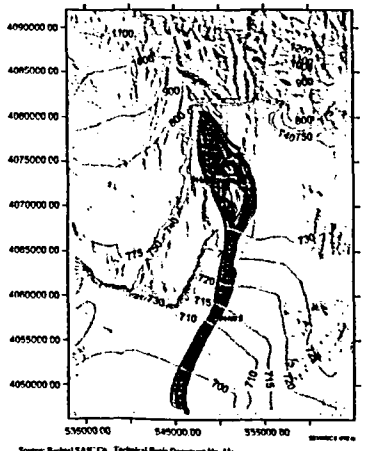
Goals

- Cost-effectively test large faults within the projected flow paths from Yucca Mountain.
- Determine hydraulic properties of structures for future updates of models.
- Better align monitor wells with flow path.

Source: Bechtel SAIC Co., Technical Basis Document No. 11: Saturated Flow and Transport

Nye County Department of Natural Resources and Federal Facilities

Proposed Horizontal Wells



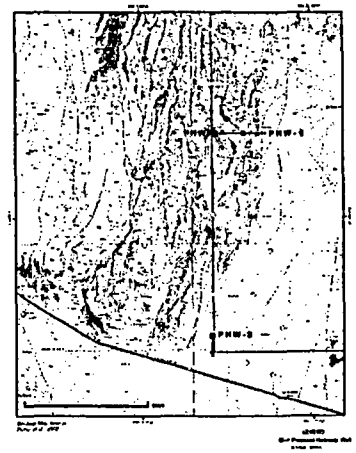
Method

- Drill, complete and test two horizontal wells approximately 6 km southeast of the repository that intersect three major faults systems: Dune Wash, Bow Ridge and Paintbrush Canyon Faults.
- Drill, complete and test a third horizontal well across the Highway 95 fault system.

Source: Bechtel SAIC Co., Technical Basis Document No. 11: Saturated Flow and Transport

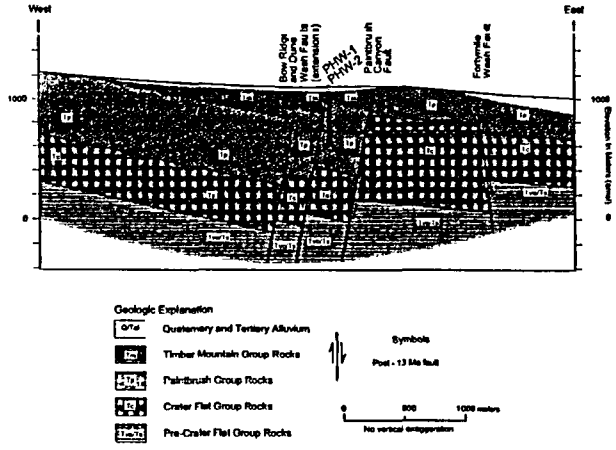
Nye County Department of Natural Resources and Federal Facilities

Geology - PHW-1, -2 and -3



Nye County Department of Natural Resources and Federal Facilities

PHW-1 and PHW-2



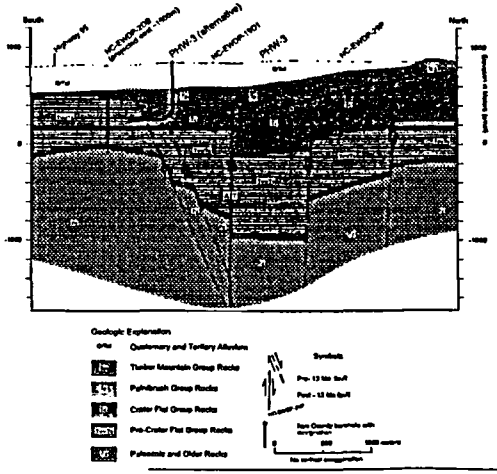
Nye County Department of Natural Resources and Federal Facilities

PHW-1 and PHW-2

- Both drilled vertically to 100 ft below water table (~1200').
- PHW-1 drilled east through the Paintbrush Canyon Fault. Fault recognized lithologically as a gouged and brecciated contact between Topopah Spring Tuff and Bullfrog Tuff.
- PHW-2 drilled west through the extensions of the Bow Ridge and Dune Wash Faults. Faults recognized lithologically as gouged and brecciated contacts between successively stratigraphically higher subzones within the Topopah Spring Tuff.
- Faults will also be located and characterized by geophysical methods including high-resolution resistivity imaging and sonic imaging.

Nye County Department of Natural Resources and Federal Facilities

PHW-3



Nye County Department of Natural Resources and Federal Facilities

PHW-3

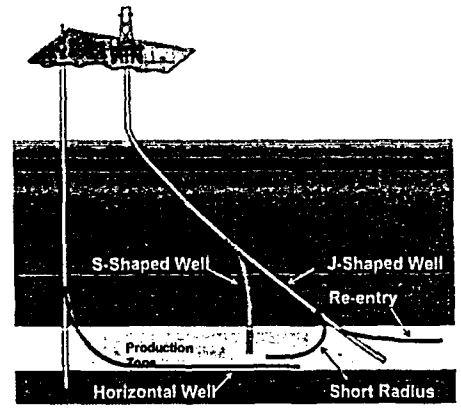
- Drilled vertically 100 ft below water table (~425 ft), then drilled south through the Highway 95 Fault. Fault recognized lithologically as a gouged and brecciated contact between Site 19D "Topopah Spring Tuff" and ???????.
- PHW-3 (alternative) drilled vertically to approx. 1500 ft into the Crater Flat Group then south through the geophysically imaged Fortymile Wash Basin Fault/Highway 95 structural high. Faults recognized lithologically as deformed and likely altered contacts between Crater Group units and successively older rocks.

Nye County Department of Natural Resources and Federal Facilities

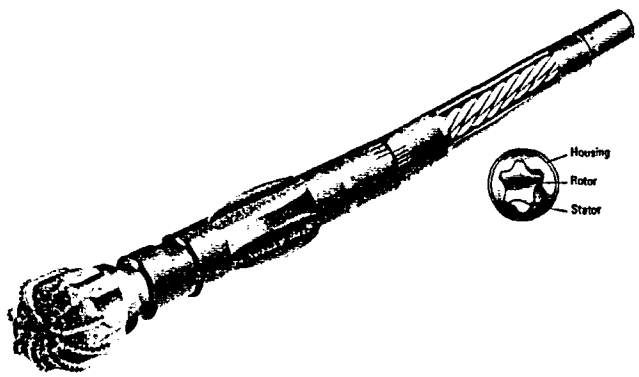
Conclusions

- Proposed wells and testing program will cost-effectively test the effects of large faults in the flow path from Yucca Mountain to Amargosa Valley.
- Program can be completed in a timely manner using "off-the-shelf" technology.
- Program can be implemented in a cooperative manner with all interested parties.

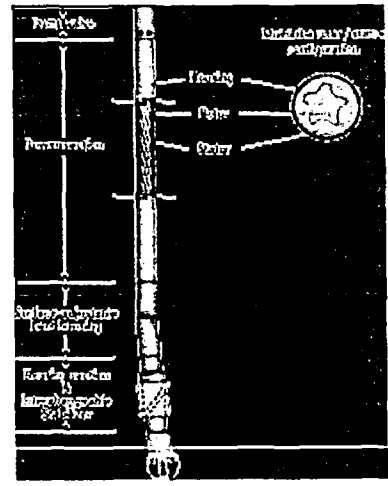
Directional Possibilities



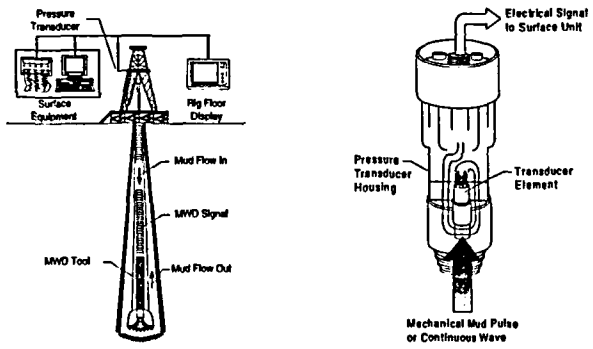
PowerPak Steerable Motor



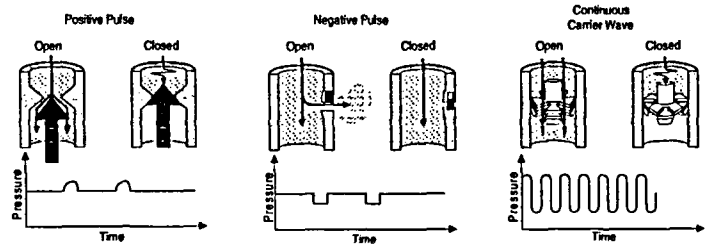
PowerPak Steerable Motor



MWD System



MWD Telemetry



MWD Measurements

Inclination
- aka: drift, slant, angle

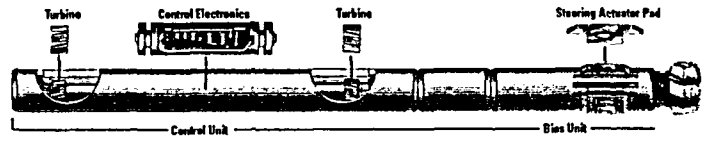
Azimuth
- aka: direction, compass heading

Tool Face
- magnetic, gravity

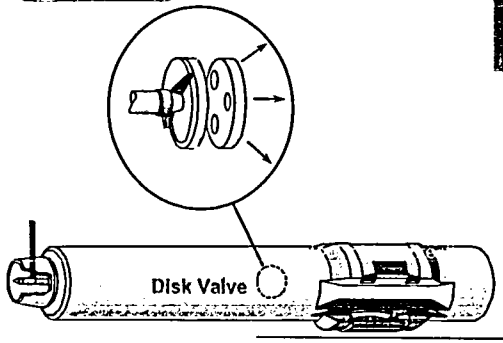
Gamma Ray

Formation Evaluation Measurements
- e.g. resistivity, density, neutron, sonic, pressure

PowerDrive* Rotary Steerable System



PowerDrive Operation

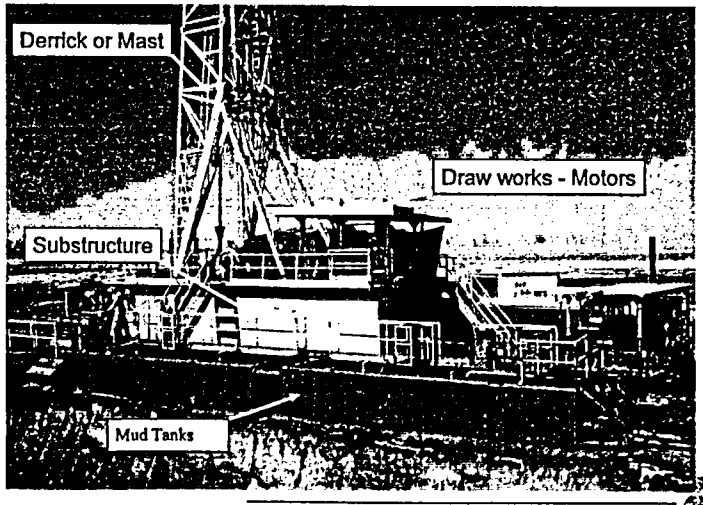


Nye County's Horizontal Drilling Plans

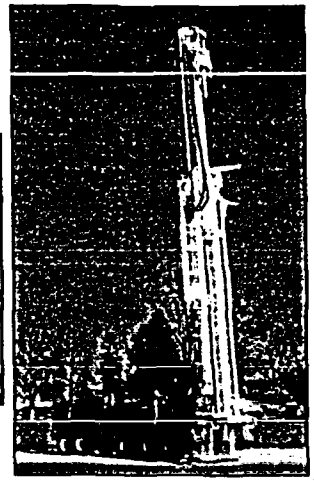
- Nye County is proposing three horizontal wells
- The three wells are planned to intersect the
  - Paint Brush Canyon fault (PHW-1)
  - Midway Valley, Bow Ridge and Dune Wash faults (PHW-2)
  - Highway 95 fault (PHW-3)

Drilling and Completion

- Move in a top-drive, "single" drilling rig
- Drill 12 1/4" hole to 100 ft below water level
  - Obtain Nye County standard geophysical logging suite
- Set 9-5/8" casing 100 ft below water table at approximately 1,200 feet

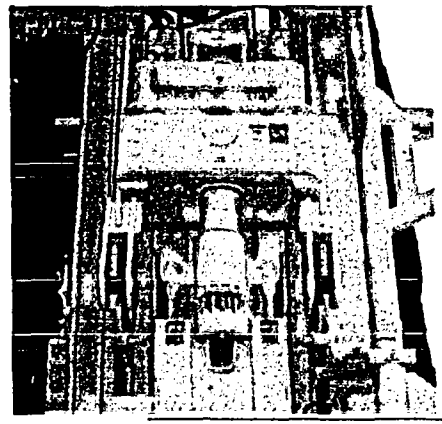


Top-Drive, "Single" Drilling Rig

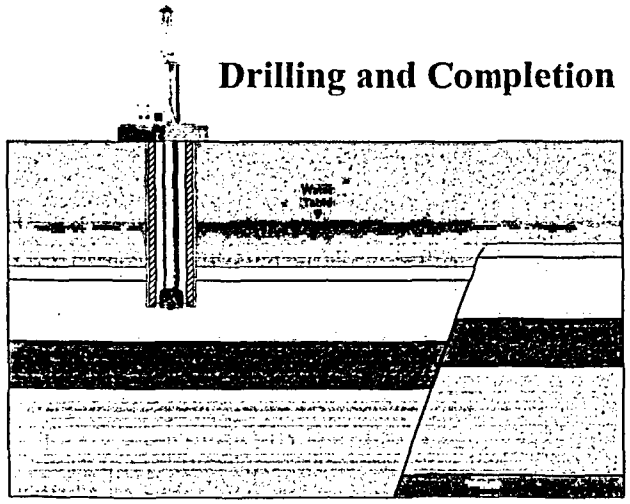


Rotation Head

(0-146 rpm @ 106,600 in-lb)



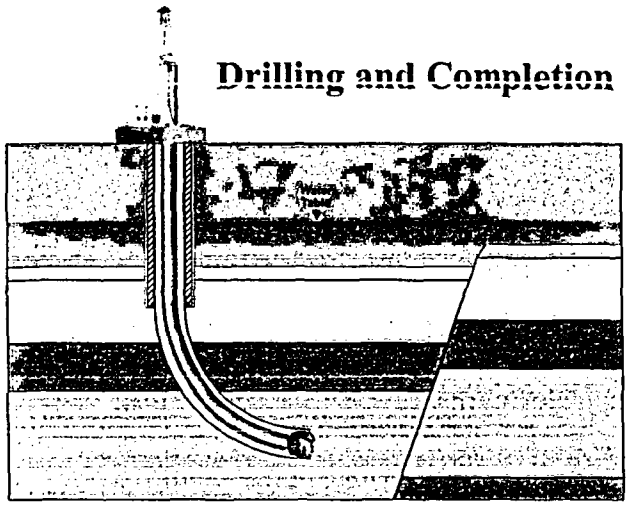
Drilling and Completion



Drilling and Completion

- Drill out with 7-7/8" bit with underbalanced mud system
- Build medium radius horizontal at 10° /100 ft
  - Curve will be 900 ft
- Drill 500-1,500 ft horizontal lateral
  - Final lateral length will depend upon drilling conditions

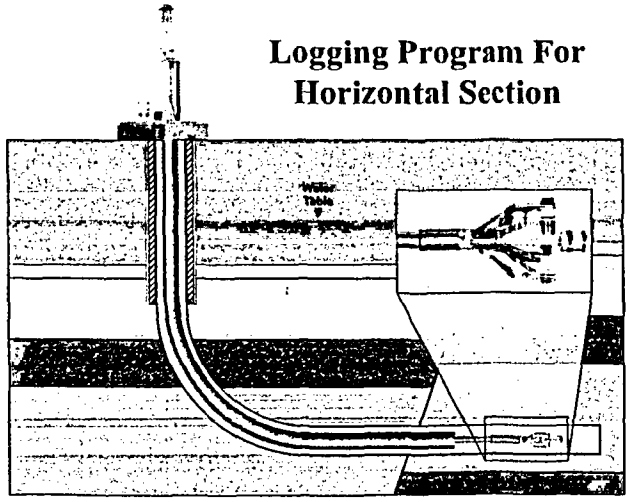
Drilling and Completion



Logging Program For Horizontal Section

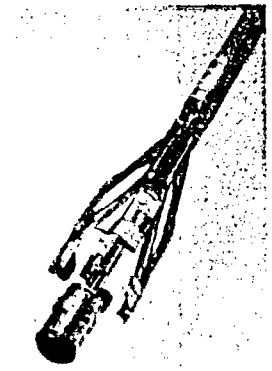
- Log well with wireline tools on drill pipe
- Run Formation Micro Image (FMI)
- Schlumberger PEX Platform Express
- DSI Dipole Shear Imager
- ECS Elemental Capture Spectroscopy
- NGS Natural Gamma Spectroscopy

Logging Program For Horizontal Section

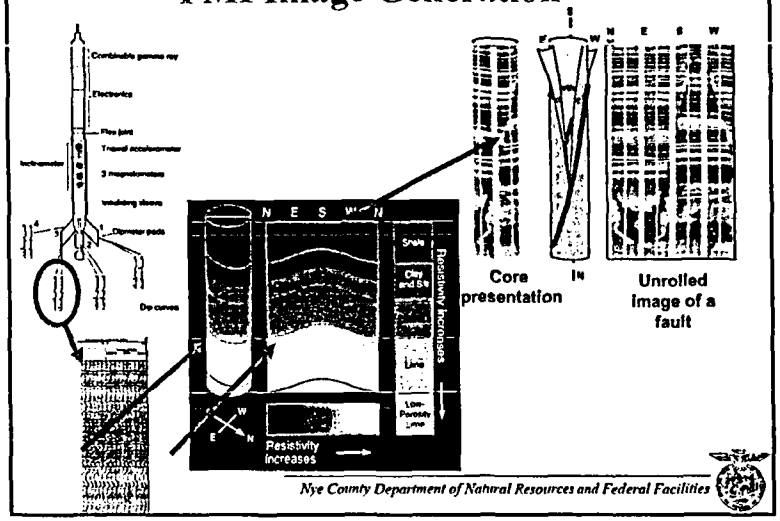


Fullbore Formation Micro-Imager

- High resolution oriented electrical resistivity image of just beyond borehole wall
- Used to measure stratigraphic and structural features
  - Accounts for borehole deviation
  - Map discrete planar features in 3d space
  - Bedding, faults, fractures
- Estimate discrete fracture aperture
  - Requires independent shallow resistivity measurement
- Derive fracture density, trace length, and porosity
- Very limited depth of investigation, cannot estimate fracture transmissibility
- Operable in fluid-filled open hole

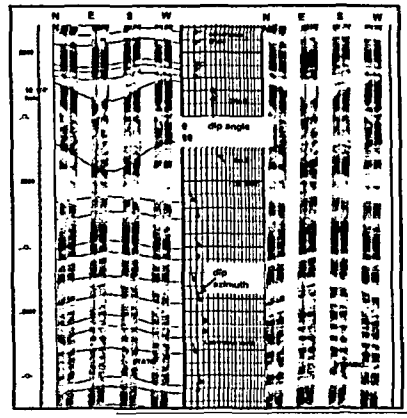


FMI Image Generation



Nye County Department of Natural Resources and Federal Facilities

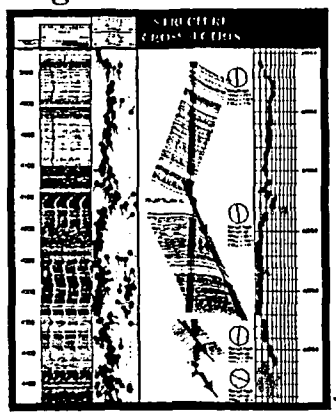
FMI Strike and Dip Calculation from Fully Oriented Image



Nye County Department of Natural Resources and Federal Facilities

Develop Structural Model From Oriented Bedding and Faults

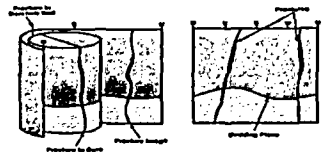
- Images correspond to virtual outcrops on which hundreds of sedimentary and tectonic structures are observable
- They are oriented, allowing to measure a multitude of dips and fractures accurately (~2 deg)
- They are made of high resolution (0.2 in.) measurements of resistivity which allows "quantification" of textures and facies over long intervals



Nye County Department of Natural Resources and Federal Facilities

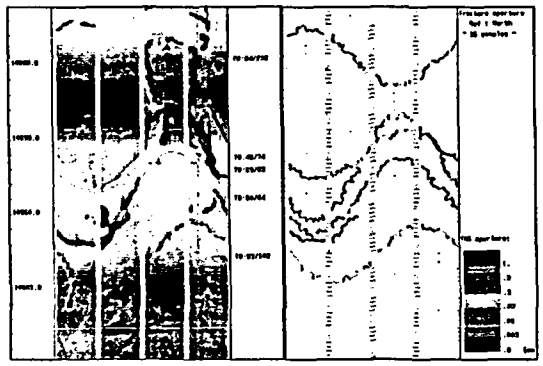
Characterization of Fractures From Electrical Images

- Classification of fractures (open, healed/mineralized, vuggy; natural or drilling induced)
- Fracture trace
- Fracture strike/dip orientation
- Fracture aperture estimate
- Effective properties (fracture density, porosity)



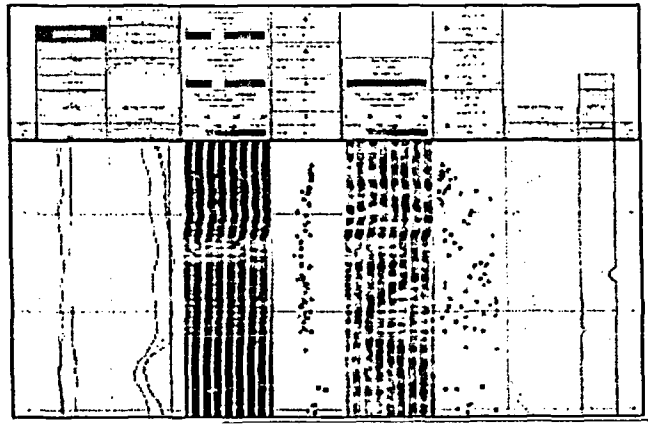
Nye County Department of Natural Resources and Federal Facilities

Aperture Computed Along Each Fracture Trace



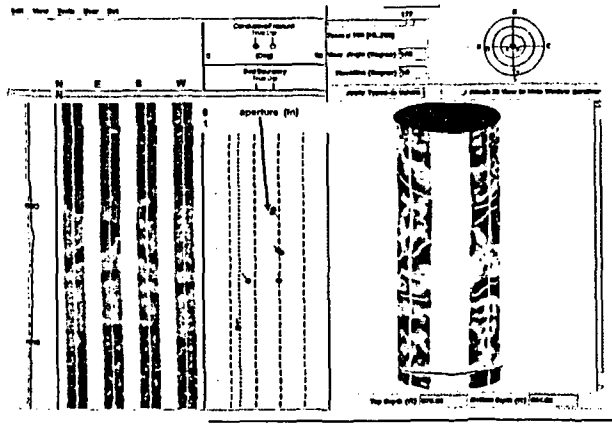
Nye County Department of Natural Resources and Federal Facilities

Electrical Image Fracture Composite Log Columbia River Basalts



Nye County Department of Natural Resources and Federal Facilities

FMI Electrical Image Example Fractured Tuff (Los Alamos, NM)

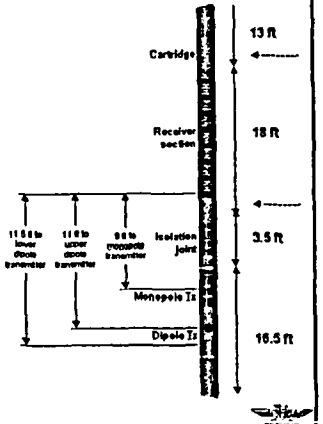


Nye County Department of Natural Resources and Federal Facilities

Dipole Shear Imager

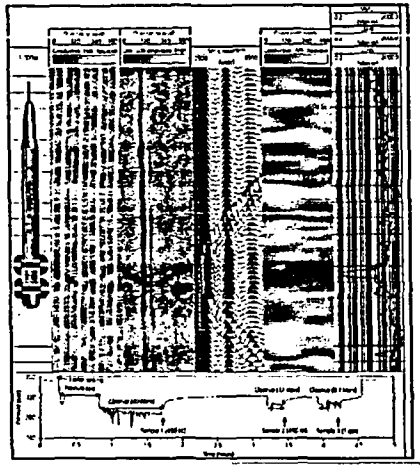
In-Situ Formation Geomechanical Evaluation

- Transmits and records high frequency, multi-component acoustic/sonic waves
  - Compressional, shear, and Stoneley waves
- Used to derive:
  - Formation velocities, porosity
  - Major fracture location, relative aperture, and magnitude/extent of open fractures (Stoneley)
  - Discrete formation permeability (Stoneley)
  - Dynamic elastic geomechanical properties (e.g. Poisson's ratio, Young's and bulk modulus)
  - Stress orientation
- Used to tie seismic to depth
- Open or cemented cased hole
- Borehole must contain water



Nye County Department of Natural Resources and Federal Facilities

Fracture Analysis FMI & DSI combination



DSI + FMI fracture answer product

- Identification of the location and the orientation of the fractures that most contribute to the reservoir permeability
- Selection of the intervals to test

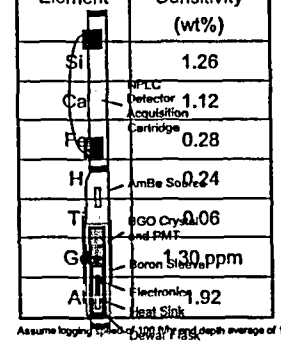
DSI Chevron pattern indicate energy losses of Stoneley waves in front of large open fracture

Nye County Department of Natural Resources and Federal Facilities

Elemental Capture Spectrometer

In-Situ Formation Geochemistry

- Emits neutrons and records induced gamma ray spectroscopy signature
- Measured total gamma ray spectrum decomposed to determine concentration of many primary rock-forming elements
  - Si, Fe, Ca, S, Ti, Gd, H, Al
  - High precision
- Robust estimation of mineralogy / lithology
- 20" vertical resolution and 7" median depth of investigation
- Operable in any borehole environment

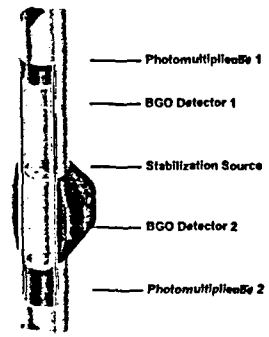


Nye County Department of Natural Resources and Federal Facilities

Natural Gamma Spectroscopy

In-Situ Formation Geochemistry

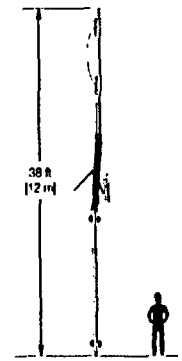
- Passively measures full natural gamma radiation energy spectrum
- Total gamma ray spectrum decomposed to determine concentration of natural gamma-emitting elements
  - Potassium, Thorium, Uranium
  - Also highly Gross Gamma Ray, non-uranium GR
- High precision
  - *Th – 1.5 ppm; U – 0.9 ppm; K – 0.25% (1 std)*
- Applications
  - Lithology identification, clay typing
  - Geochemical stratigraphy
  - Identification of organic material
  - Qualitative REDOX indicator by measuring where uranium has sorbed
- 20" vertical resolution, 9.5" median depth of inv.
- Operable in any borehole environment



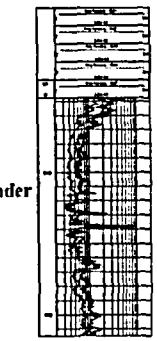
Nye County Department of Natural Resources and Federal Facilities

PLATFORM EXPRESS

Advanced Nuclear-Resistivity Logging String



- **Optimized tool string combination of primary formation evaluation services**
  - Gamma ray
  - Spontaneous potential
  - Compensated neutron porosity
  - LithoDensity (bulk density and Pe)
  - Focused micro-resistivity
  - Borehole fluid resistivity
  - Resistivity (induction or laterolog) – multiple radial depths of investigation, highly focused
- **Integrated sensors - measure similar volumes under similar environmental conditions**
  - Improved data quality
  - Easier measurement integration and interpretation
- **Combinable with other tools**
- **Efficient operation**



Nye County Department of Natural Resources and Federal Facilities

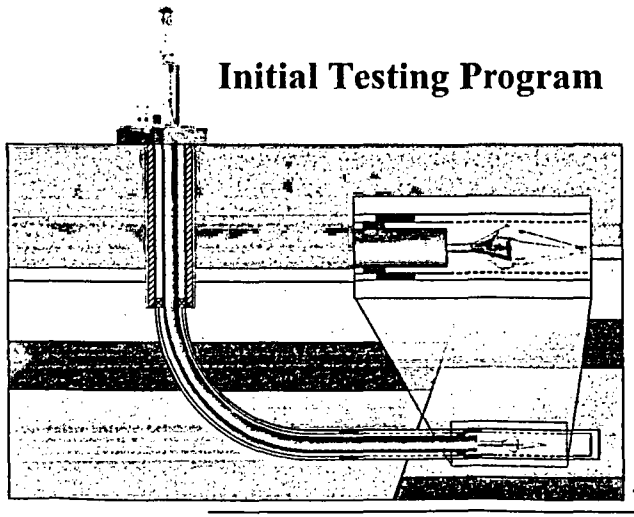
Completion Program

- Determine screen and packer configuration
  - Drilling and logging data will determine configuration
- Install 6 inch screens, blanks and external packers
- Drilling rig changes to completion fee schedule

Initial Testing Program

- Individual screen completions are tested for productivity
- Retrievable packers and plugs are used to isolate screens
- Well is produced with air lift
- Each screen is logged with a spinner tool

Initial Testing Program



Potential Future Testing Programs

- Long term pump testing and observation
- Tracer testing
- Detailed production logging with water flow log
- Detailed pressure transient analysis with multiple pressure transducers and retrievable packer/plug combinations
- Multiply the impact of lower cost vertical wells

Estimated Costs

- Costs presented are for drilling, completing, and initial testing program of PHW-1
- Drilling and Logging
  - $ 831,000
- Completion
  - $ 137,000
- Testing
  - $132,000

Estimated Costs

- Total estimated costs for PHW-1
  - $ 1.1 Million
- Total estimated cost for 3 well program
  - $ 3.3 Million
- Drilling and testing all three wells sequentially saves $ 105,000

Horizontal Wells Can:

- Intersect faults in saturated zone
- Increase productivity in fracture dominated flow
- Quantify fault and fractures
- Obtain geophysical measurements
- Obtain hydrogeologic properties
- Allow for future access and long term monitoring

Modelling the Dynamics of Simultaneous Flank and Summit Eruptions of Basaltic Magma

Advisory Committee on Nuclear Waste

Presented by

Dr. A. Woods

+44 01223 337183 (andy@bpi.cam.ac.uk)

BP Institute, Cambridge, United Kingdom

NRC Program Manager

J. Trapp

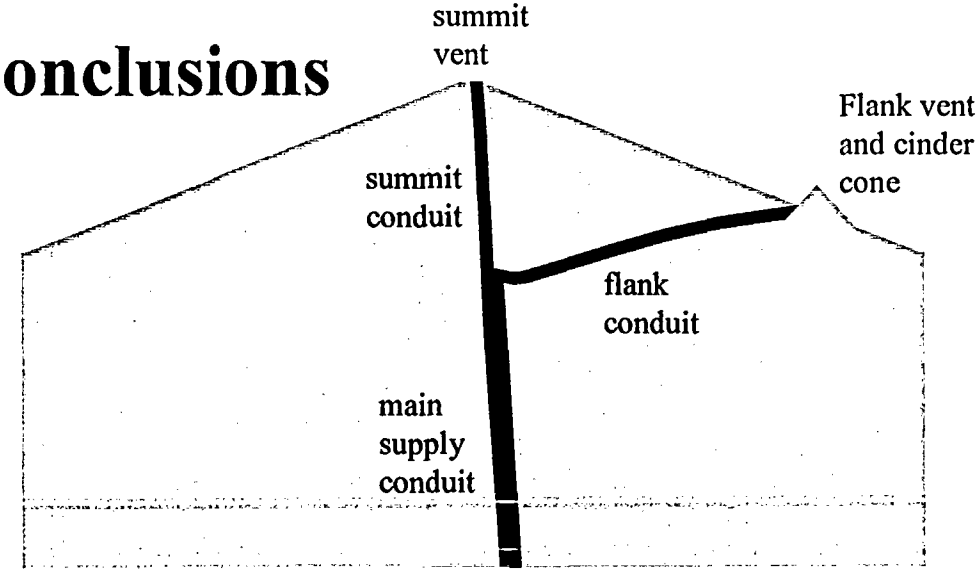
Contributors

C. Gladstone, B. Hill

April 18-20, 2006

Outline

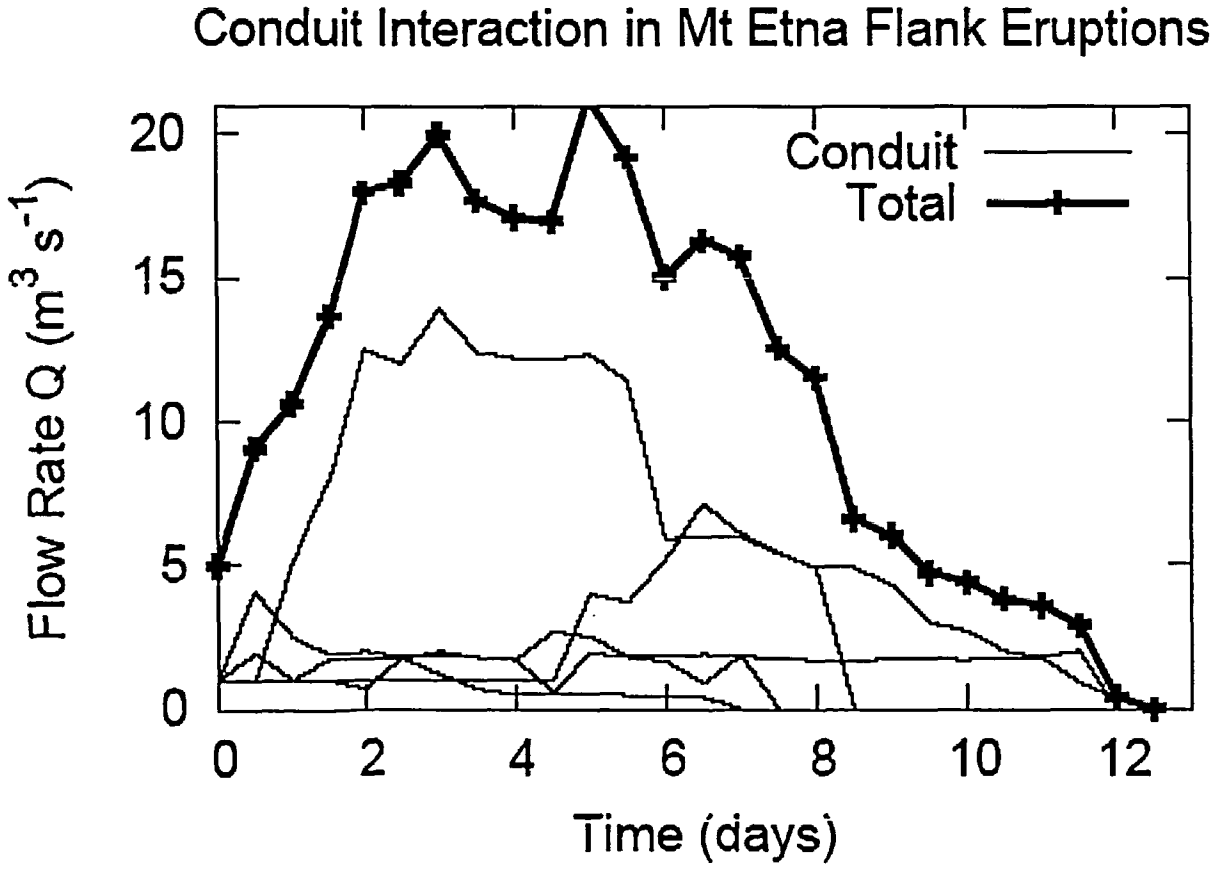
- Introduce Problem – Geological Data
- Develop Model Framework – Explore Some of the Controls on System
- Describe Experimental Modelling – Illustrate the Control of Gas-Liquid Separation
- Draw Conclusions



Geological Data

- **Paricutin, 1947 (Krauskopf, 1948)**
  - –Summit and flank eruptions simultaneously subsurface plumbing system coupled
- **Mt. Cameroon, 1999–2000 (Suh, et al., 2003)**
  - –20–30 day eruption – high level vents (2650m) and low level vents (1500m)
  - –High level vents – cyclic explosive activity
  - –Low level vents – lava flow behaviour
- **Mt. Etna, 2001**
  - –complex eruptive activity with summit and flank eruptions occurring concurrently

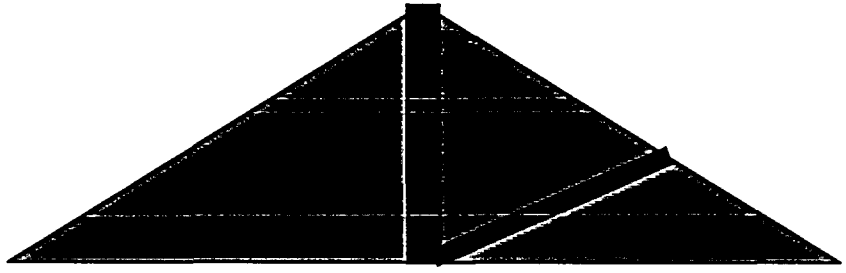
Mt. Etna–Etna, Italy–2001 Eruption (Data after Behncke and Neri, 2003)



Dynamics of Flank–Summit Eruptions of Hydrous Basalt: Study Objectives

- **Controls on Eruption Rates at Summit and Flank**
  - impact of volatile-magma separation
  - effusive flank
  - explosive summit
  - distance of flank vent from the summit
- **Stability of Eruption Regime – Experimental Analogue**

Model Assumptions



- Conduit geometry fixed
- Deep supply of magma – constant pressure source
- Steady state flow (assume evolution of source is slower than the time needed to establish the flow)
- Flow exits the vent either with atmospheric pressure or with the speed of sound of the two-phase mixture
- Homogeneous flow of magma-gas simplification to illustrate some aspects of two-conduit flow
- Assume magma is in thermodynamic equilibrium with the gas

Numerical Model Formulation: Coupled Flow of Gas-Liquid Mixture

- **Homogeneous Mixture (small bubbles)**
  nt Qt = ns Qs + nf Qf (flux partitions to summit and flank)
- **Flow Driven by Buoyancy of Bubbly-Mixture and Overpressure of Chamber**
- **Turbulent Drag in Each Conduit Reduces Pressure with Height**

$$\rho u \frac{du}{dz} = -\rho g_e + \frac{dp}{dz} - \left(\frac{12\mu}{w^2} + \frac{2C\rho u}{w} \right) u$$

- **Mass Conservation in Each Conduit**

$$\rho u w = Q$$

Numerical Model Formulation: Coupled Flow of Gas-Liquid Mixture (cont'd)

- Henry's Law for exsolution of gas (assumed to be water vapor)

  $n = n_o - s\, p^{1/2}$

- Condition at vent

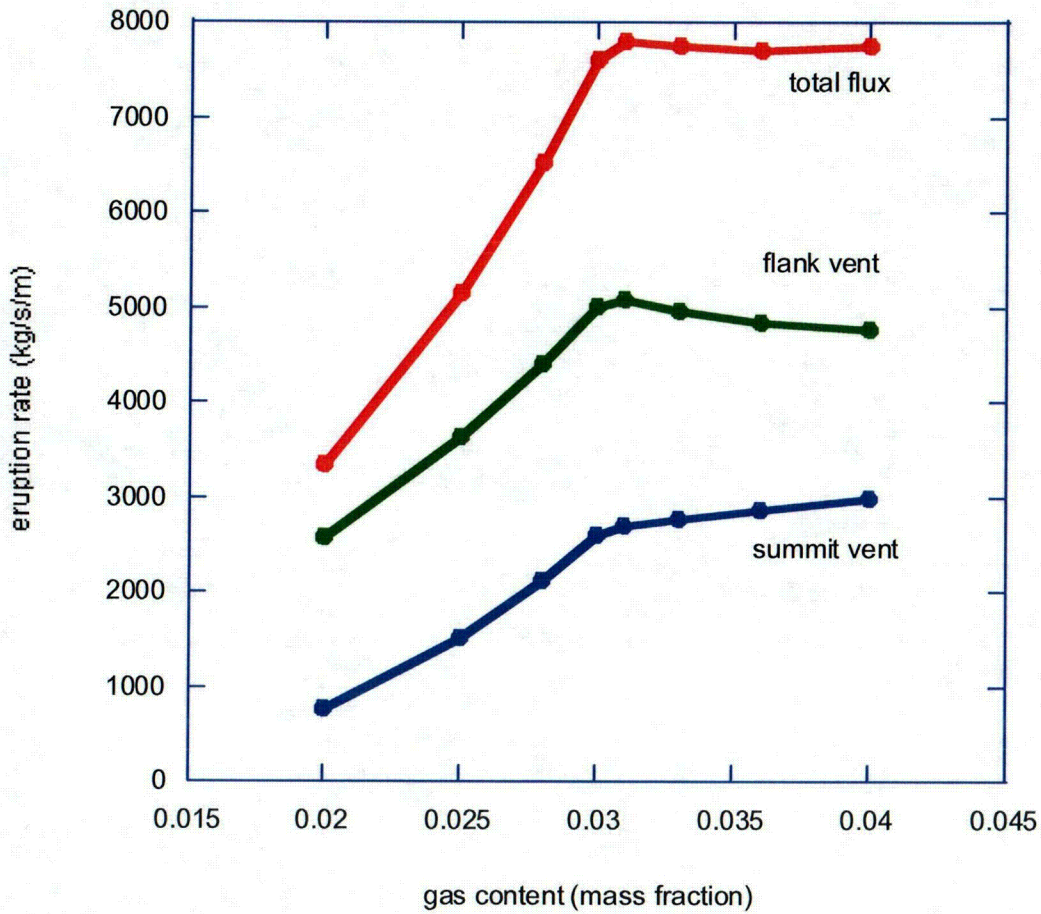
Either

(I) Flow issues at atmospheric pressure (low gas content)

(II) Flow is choked at vent (high gas content)

- With separated flow, the choked flow speed of sound may differ at the summit and flank vents
- Simple model assumes no gas-liquid separation
- Solve governing coupled equations by numerical integration with 'shooting' to ensure boundary conditions apply at both vents

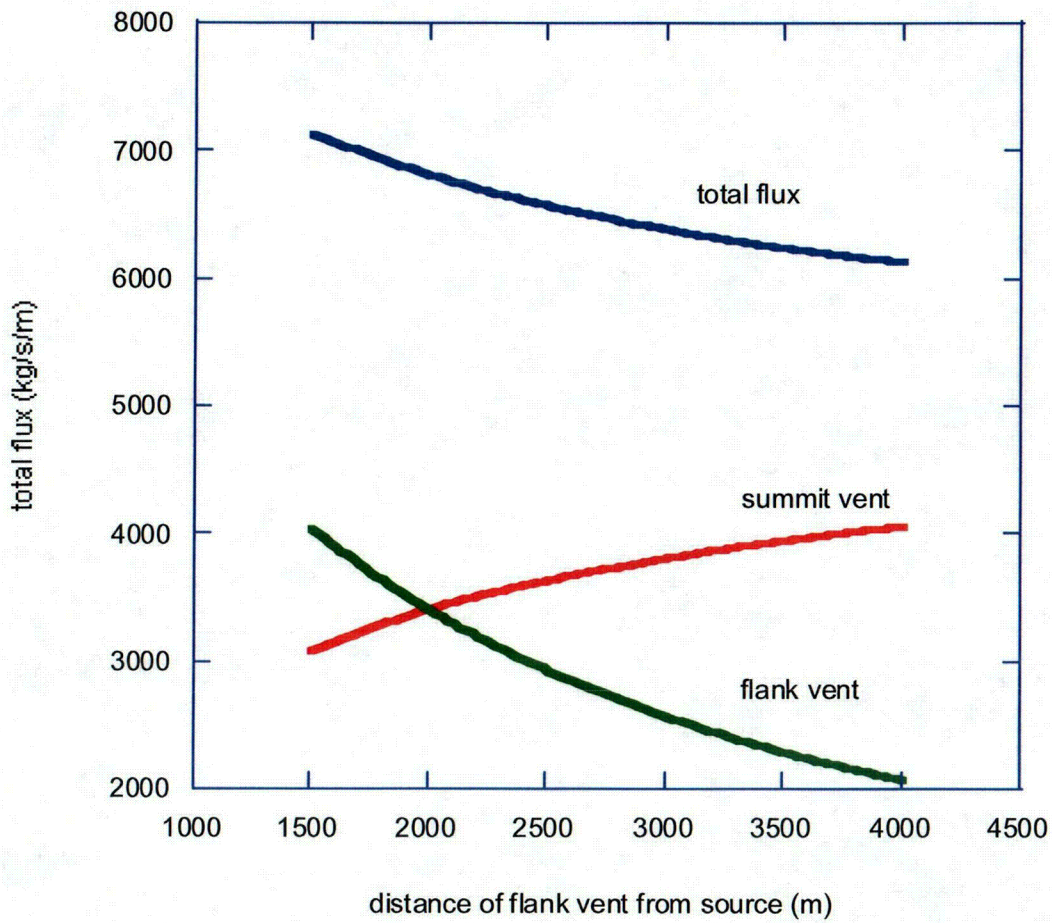
Model Results: Gas Content Versus Eruption Rate



- As gas content increases the flow becomes choked at the summit and the flank vents.
- For low gas content, the lower flank vent is preferred route to surface.
- As the gas content and pressure increase, the shorter flow path to the summit vent provides the easier route to surface.

C10A

Model Results: Gas Content Versus Eruption Rate (cont'd)

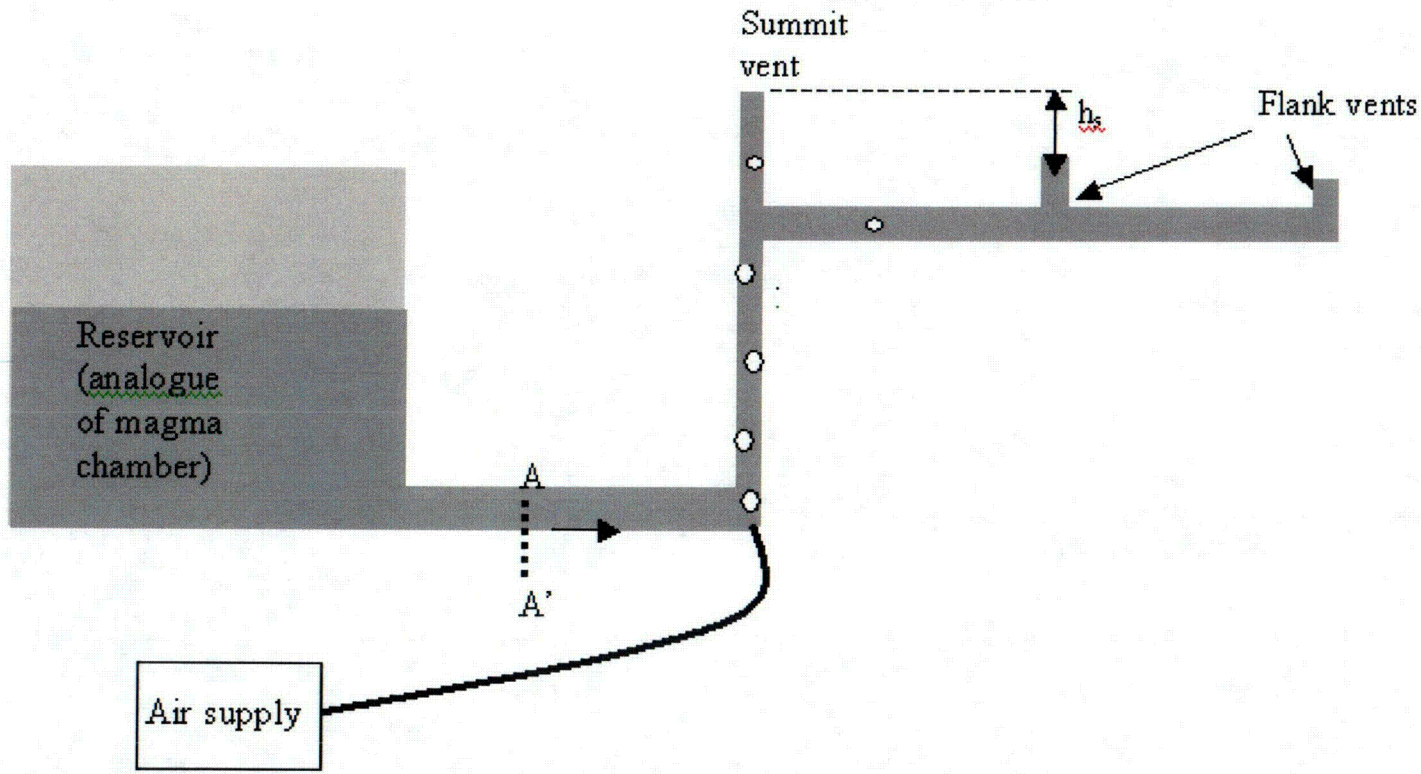


- As lateral distance of flank vent from summit increases, there is a re-partitioning of flux to the summit vent.
- Relative fluxes depend on gas content and conduit lengths.
- Conduit width has similar control.

C11

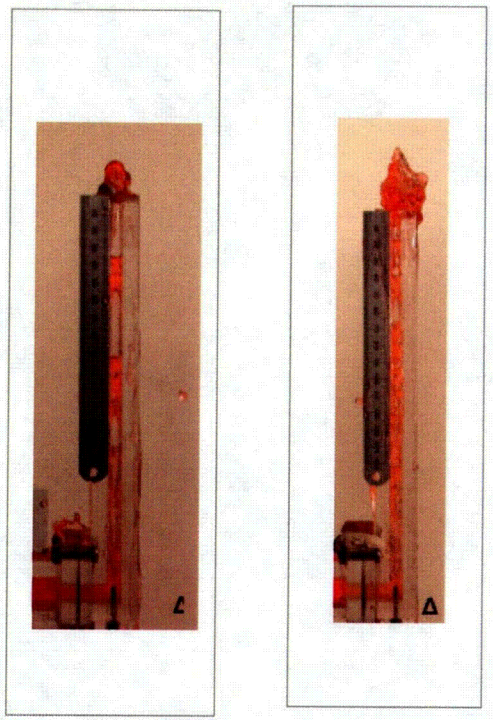
Analogue Model Experimental Apparatus: Vary Height and Lateral Offset of Flank Vent

Analogue experiments to explore dynamics of bubble separation in simple model → insight into controls on gas-liquid partitioning in the flank and summit vents



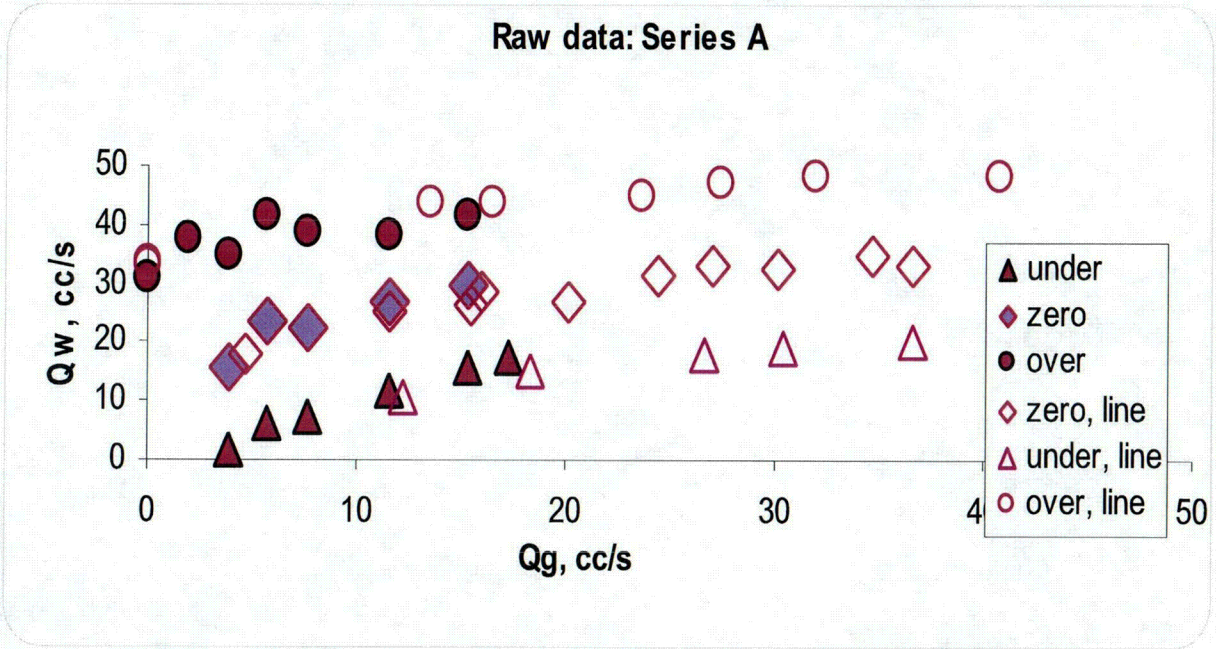
C12

Analogue Model Results

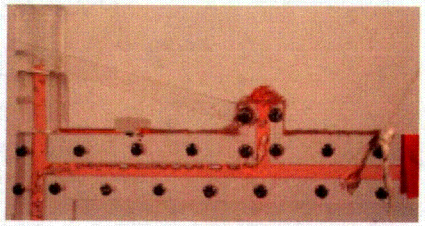


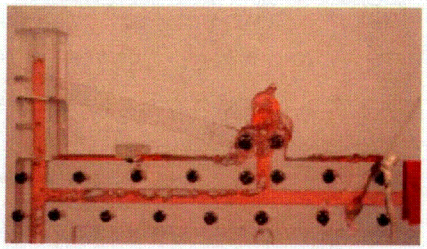
A B

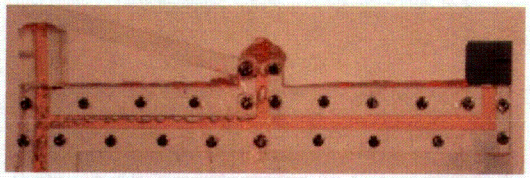
- Experimental data for a single conduit
- Flow increases with gas flux and reservoir pressure

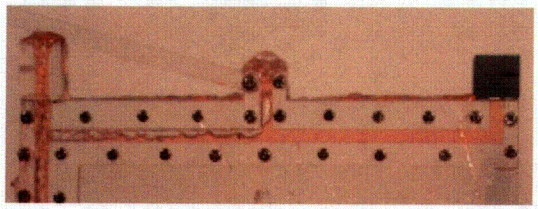


Analogue Model Results (cont'd)





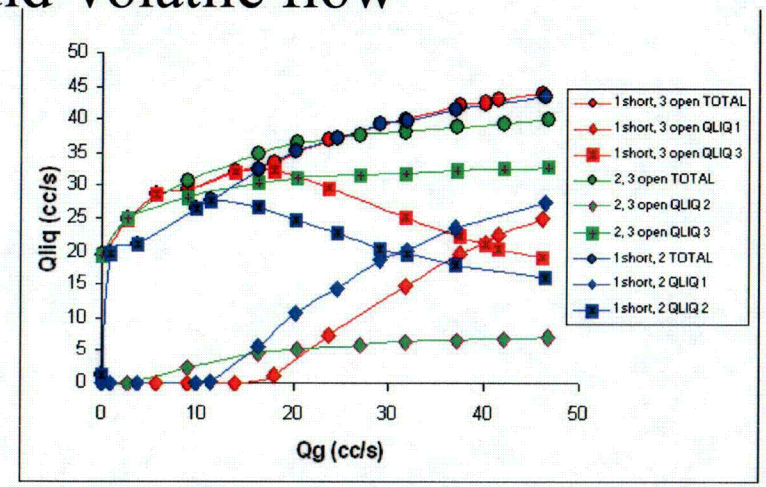




- **Double vent flow: as gas flux increases**

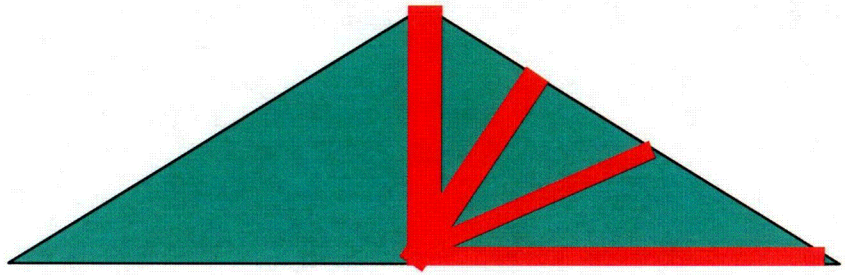
(i) Flank eruption becomes less vigorous evolving from effusive style (low gas) to bubble bursting type events with less liquid flow

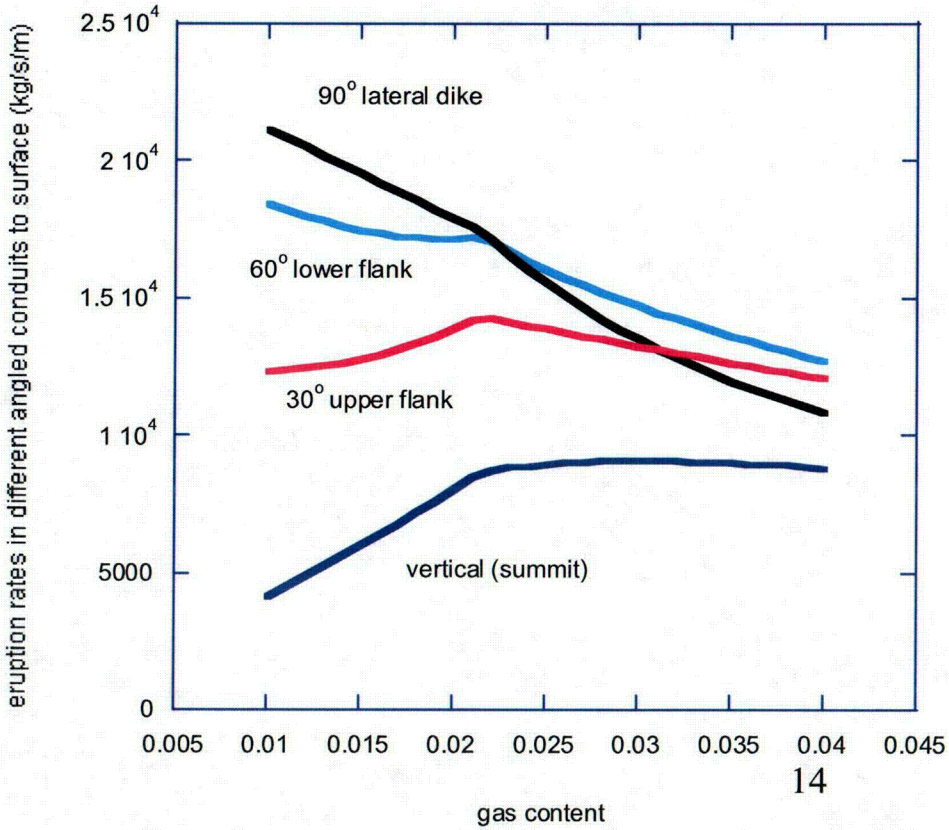
(ii) Summit vent evolves from simple degassing (no liquid flow) to more vigorous liquid-volatile flow



Analogue Model Results (cont'd)

- Angle of lateral dike to the vertical affects eruption rate.
- Reduction in head with horizontal dike increases the flow rate for low gas content.
- Effects of choked flow at high gas content dominate, increasing flow in shorter conduits.





C15

Conclusions

- **Fluxes Are Partitioned Between Summit and Flank Vents**

- **Key Controls Were Deduced From Numerical / Experimental Modelling**

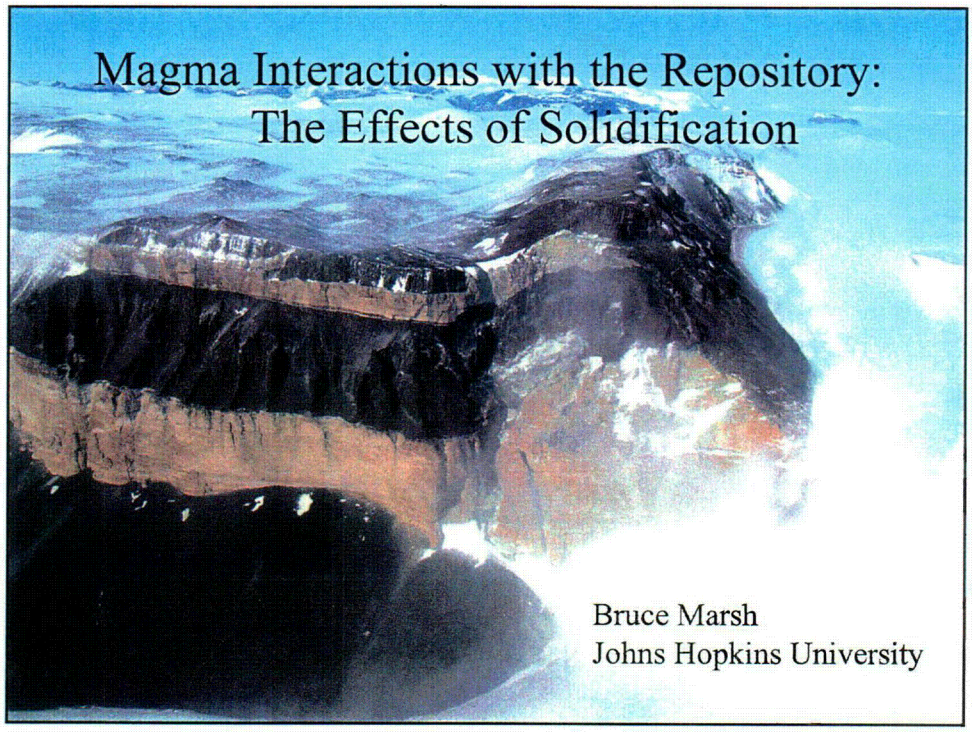
- **Gas Content of Magma (choked / non-choked flow)**
  - large gas content – greater flow from summit (explosive)
  - larger bubbles – more separation from flank (effusive)
  - small gas content – effusive eruption from flank dominates

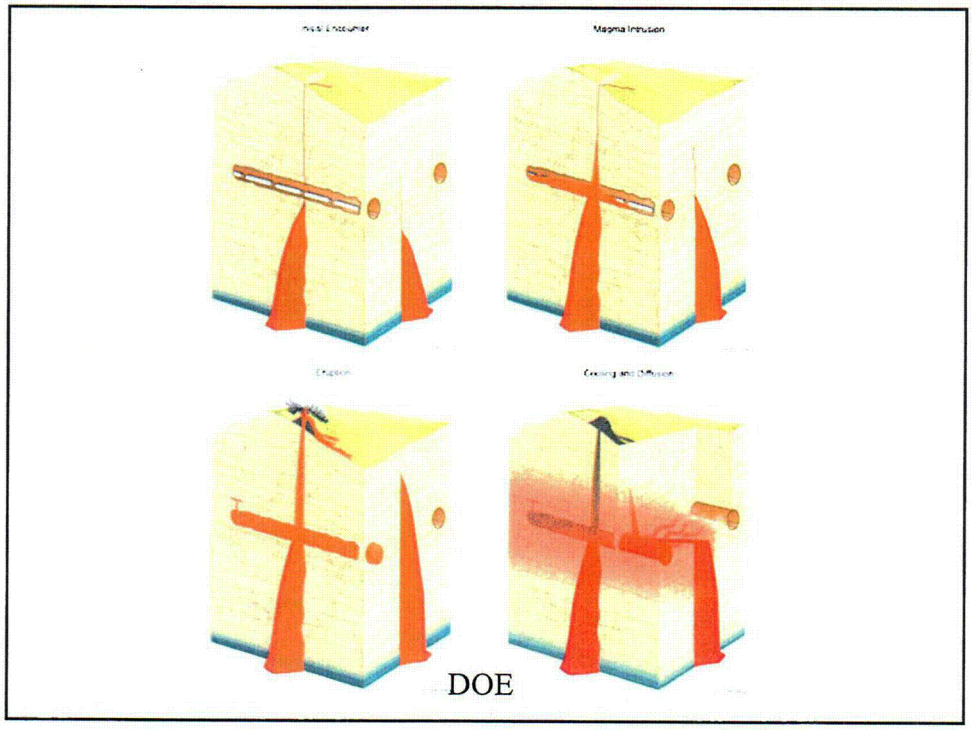
Conclusions (cont'd)

- **Distance to Flank Vent / Relative Sizes of Conduits**
  - Laterally distant flank vent – weak secondary flow
  - Flank vent on edifice – strong secondary or even dominant flow, especially with low volatile content magma
- **Gas-Liquid Separation**
  - Leads to explosive/strombolian behaviour at summit and effusion at the flank vent

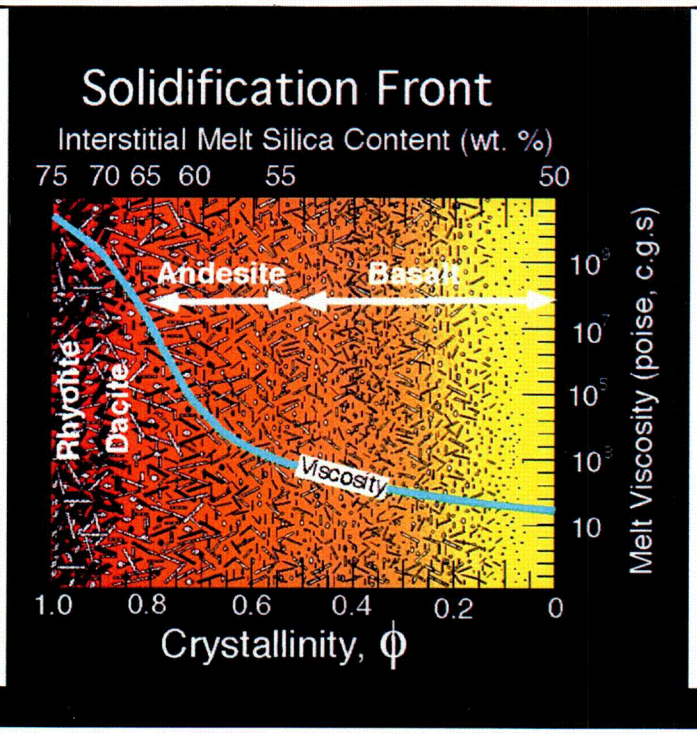
Acknowledgment

"This presentation was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) and its contractors for the Nuclear Regulatory Commission (NRC) under Contract No. NRC–02–02–012. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards, Division of High-Level Waste Repository Safety. This presentation is an independent product of the CNWRA and does not necessarily reflect the view or regulatory position of the NRC."


Magma Interactions with the Repository:
The Effects of Solidification
Bruce Marsh
Johns Hopkins University

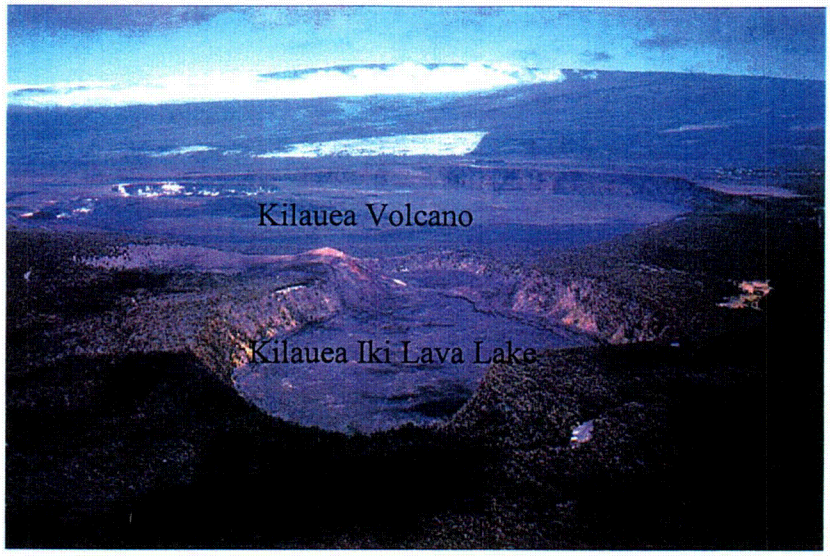

Magma Intrusion
DOE

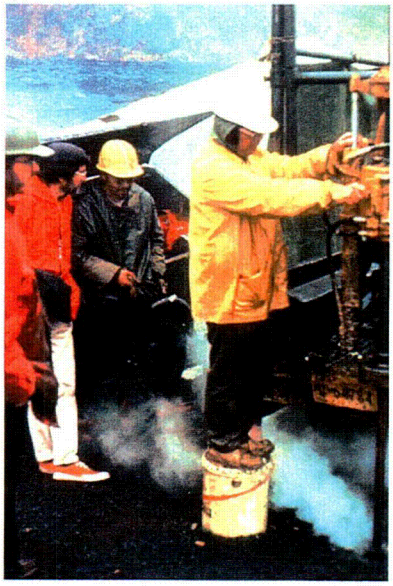
C16


Solidification Front
Interstitial Melt Silica Content (wt. %)
75 70 65 60 55 50
Andesite
Basalt
Rhyolite
Dacite
Viscosity
10
Melt Viscosity (poise, c.g.s)
1.0 0.8 0.6 0.4 0.2 0
Crystallinity, ϕ

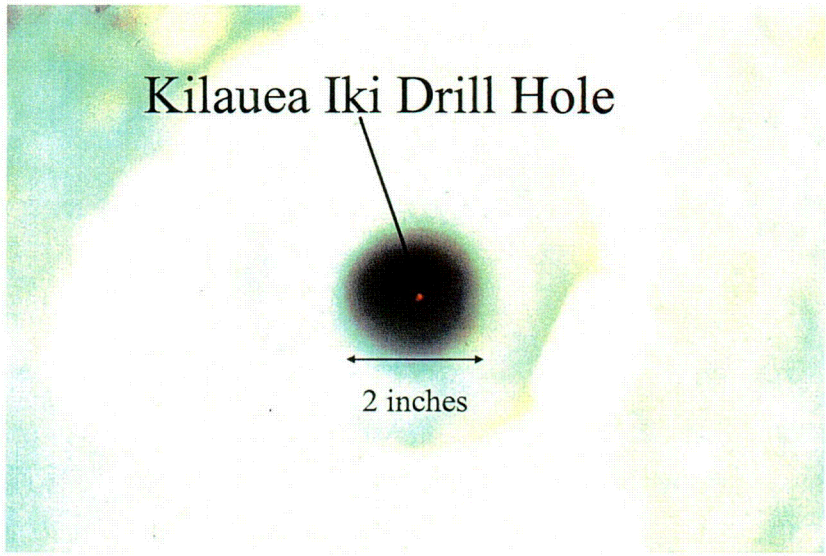
8. HAWAII: THE VIEW FROM SPACE.
0 10 20 30 KILOMETERS

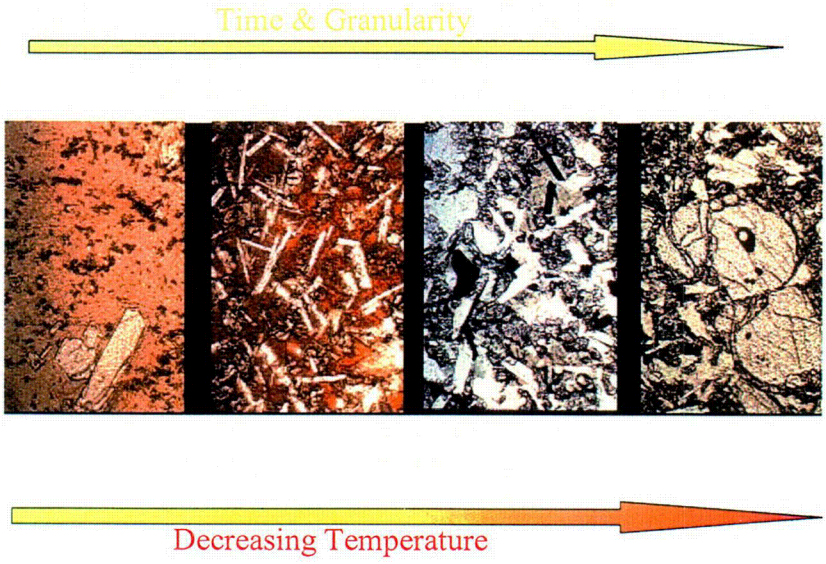
C17





C18A


Kilauea Iki Drill Hole
2 inches

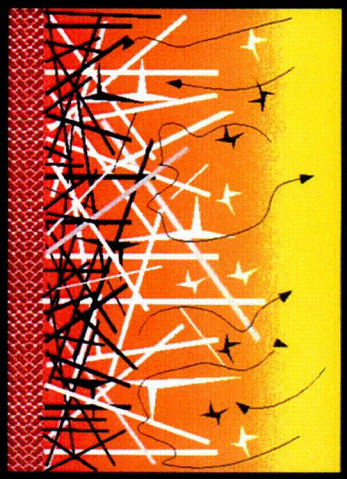

Time & Granularity
Decreasing Temperature

C18E

Long Range Chemical Exchange

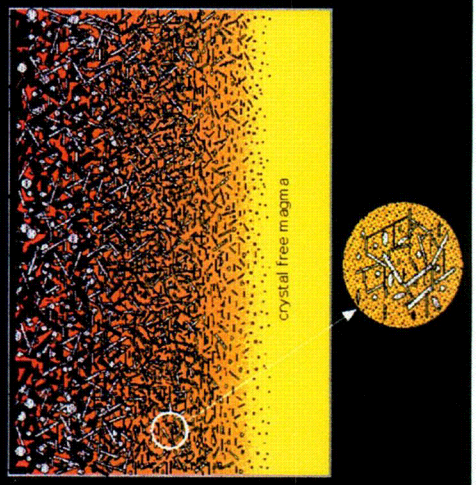
Alloys & Aqueous Solutions

Long Range Chemical Exchange



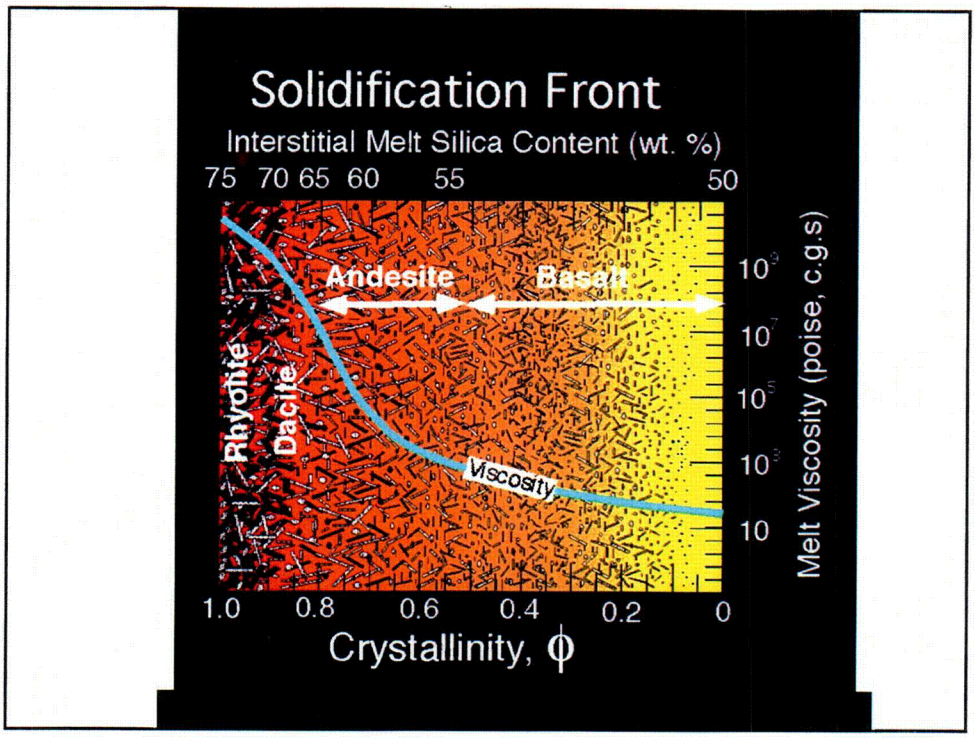
Alloys & Aqueous Solutions

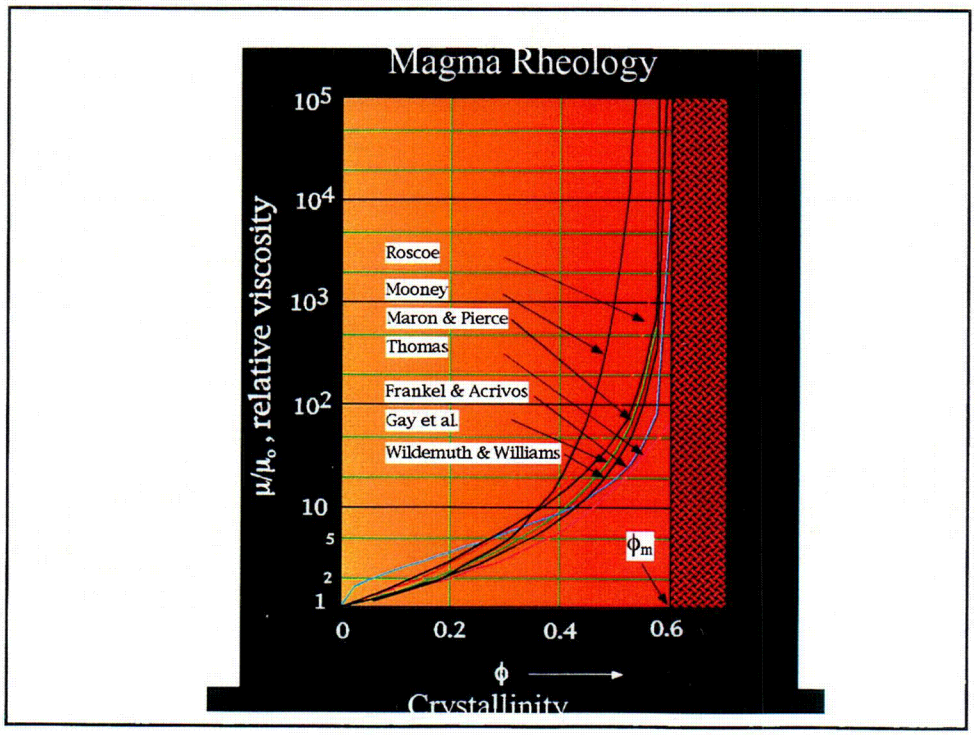
Local, Short Range Chemical Exchange



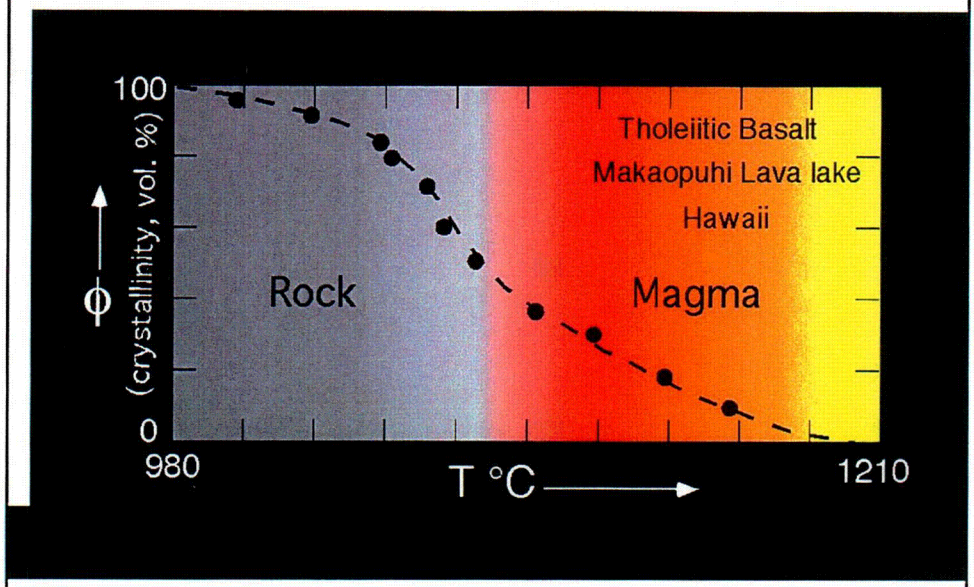
Silicate Magmas

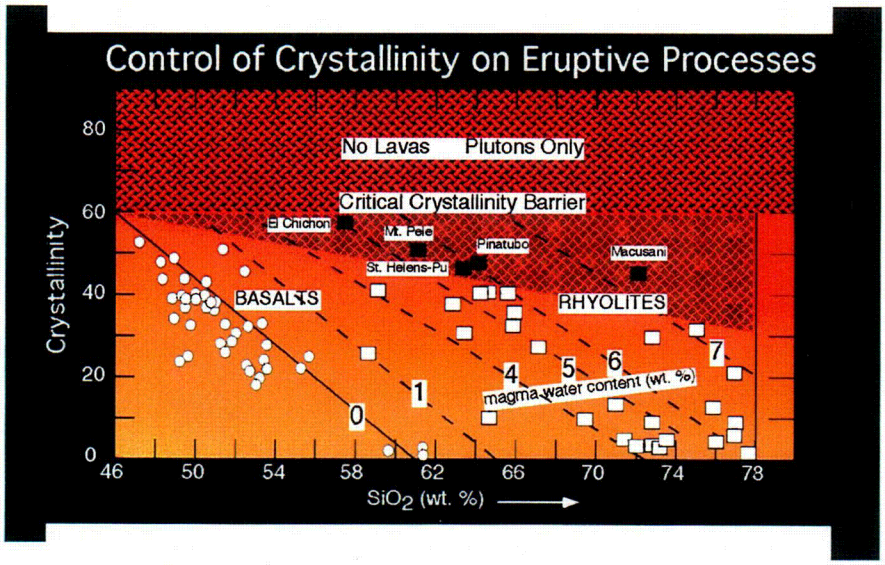
C19


Solidification Front
Interstitial Melt Silica Content (wt. %)
75 70 65 60 55 50
Andesite
Basalt
Rhyolite
Dacite
Viscosity
Melt Viscosity (poise, c.g.s)
10
1.0 0.8 0.6 0.4 0.2 0
Crystallinity, ϕ

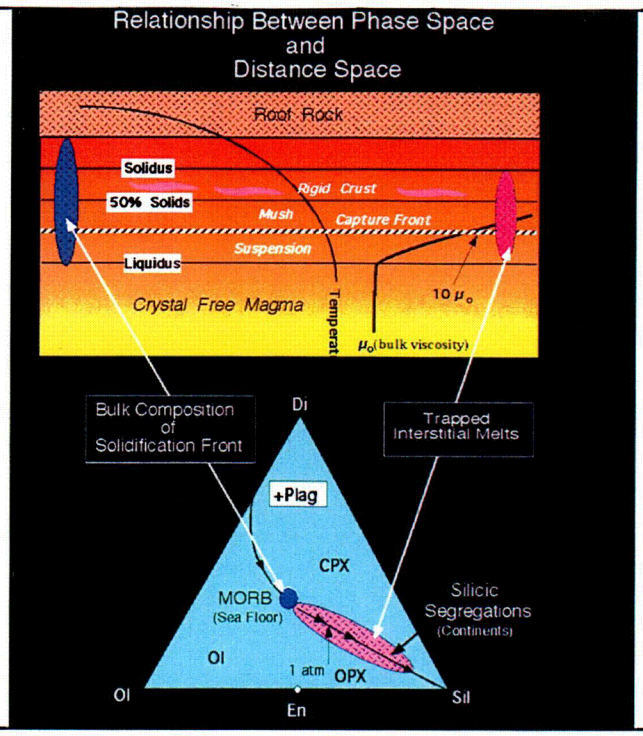

Magma Rheology
10^5
10^4
10^3
10^2
10
5
2
1
μ/μ_o, relative viscosity
Roscoe
Mooney
Maron & Pierce
Thomas
Frankel & Acrivos
Gay et al.
Wildemuth & Williams
ϕ_m
0 0.2 0.4 0.6
ϕ
Crystallinity

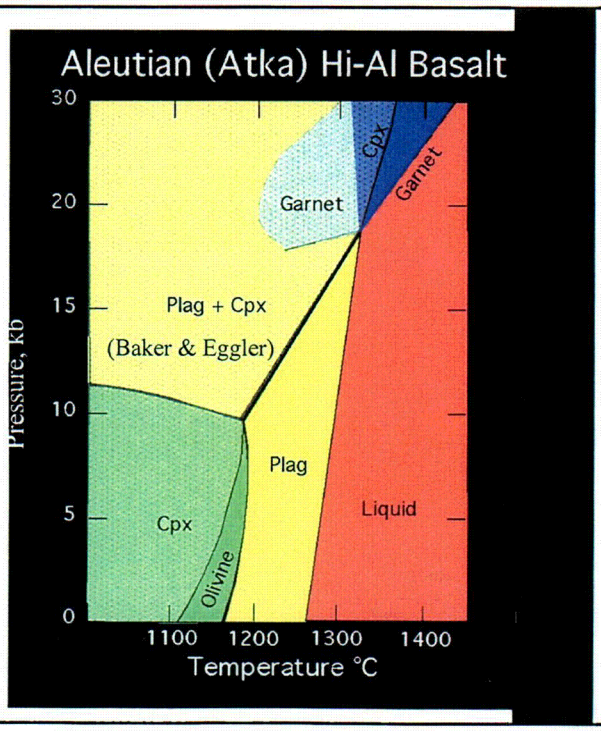
C20


100
0
980
1210
T °C
ϕ (crystallinity, vol. %)
Rock
Magma
Tholeiitic Basalt
Makaopuhi Lava lake
Hawaii

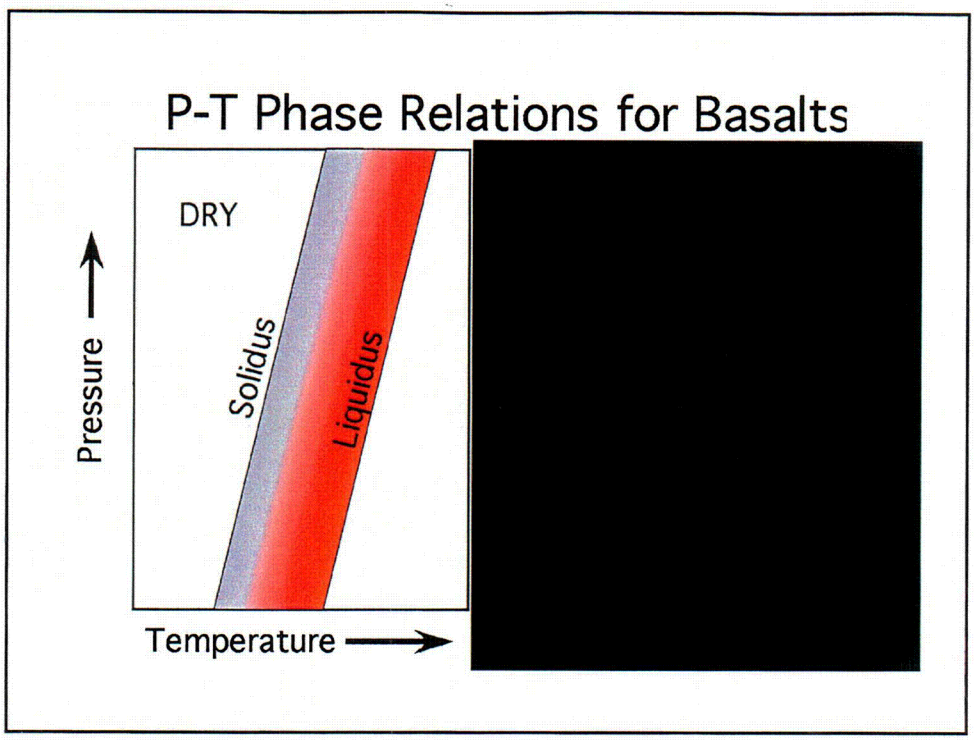

Control of Crystallinity on Eruptive Processes
No Lavas
Plutons Only
Critical Crystallinity Barrier
El Chichon
Mt. Pele
Pinatubo
Macusani
St. Helens-Pu
BASALTS
RHYOLITES
magma water content (wt. %)
0
1
4
5
6
7
Crystallinity
80
60
40
20
0
46
50
54
58
62
66
70
74
78
SiO2 (wt. %)

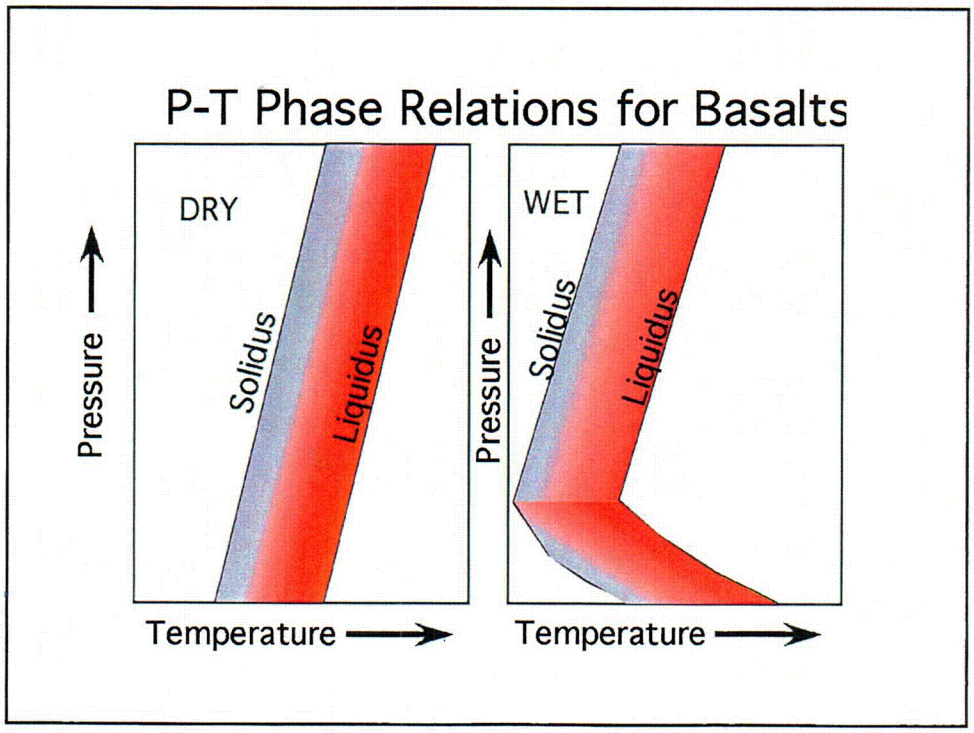
C21
7

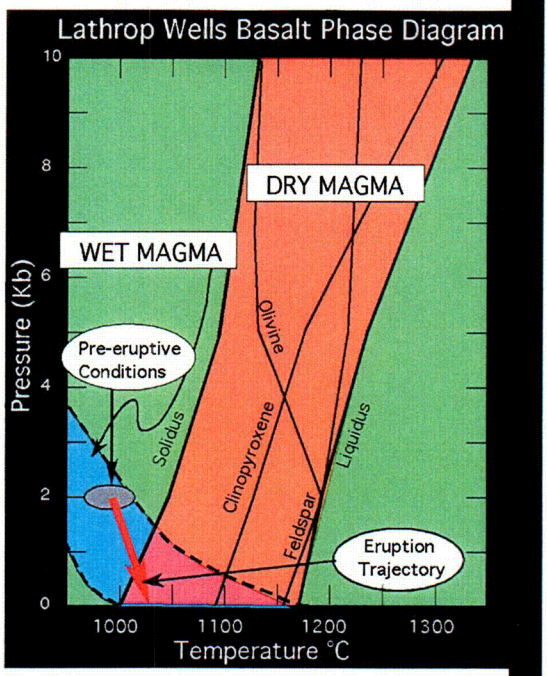

Relationship Between Phase Space
and
Distance Space
Roof Rock
Solidus
50% Solids
Rigid Crust
Mush
Capture Front
Suspension
Liquidus
Crystal Free Magma
Temperat
10 μ_o
μ_o(bulk viscosity)
Bulk Composition
of
Solidification Front
Trapped
Interstitial Melts
Di
+Plag
CPX
MORB
(Sea Floor)
Silicic
Segregations
(Continents)
Ol
1 atm
OPX
Ol
En
Sil

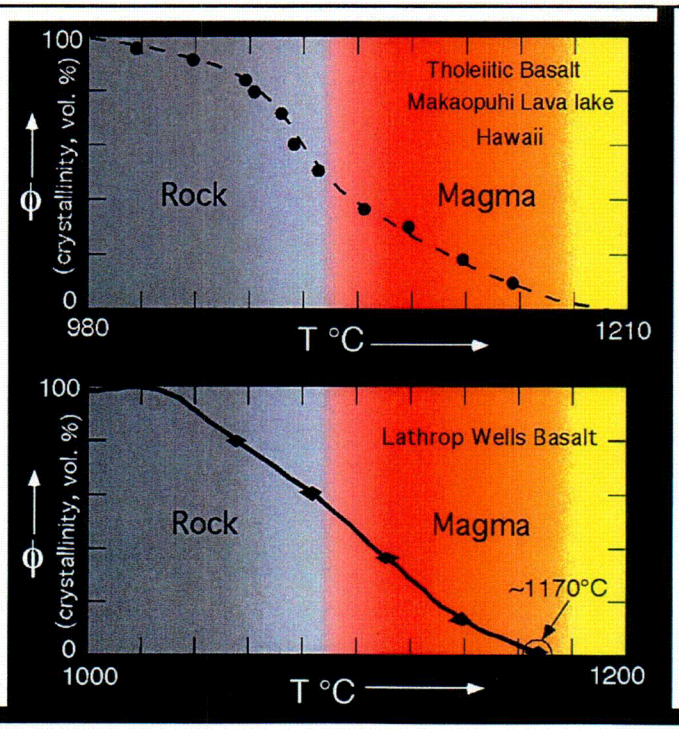

Aleutian (Atka) Hi-Al Basalt
Pressure, kb
30
20
15
10
5
0
Cpx
Garnet
Garnet
Plag + Cpx
(Baker & Eggler)
Plag
Liquid
Cpx
Olivine
1100
1200
1300
1400
Temperature °C

C22

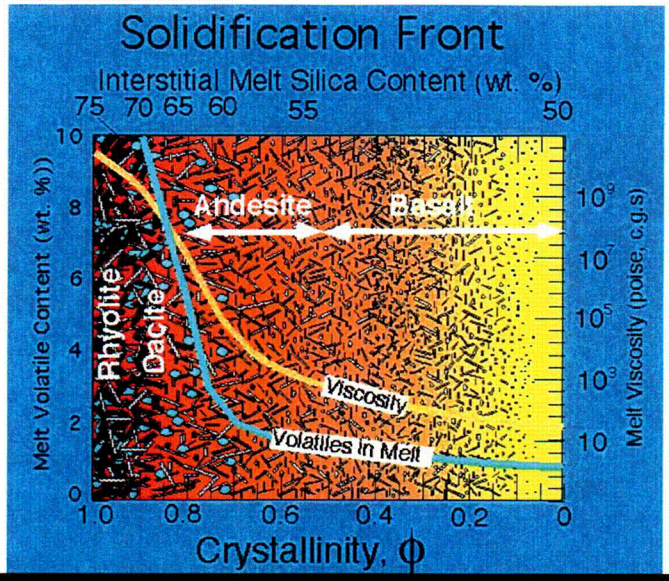

P-T Phase Relations for Basalts
DRY
Solidus
Liquidus
Pressure
Temperature

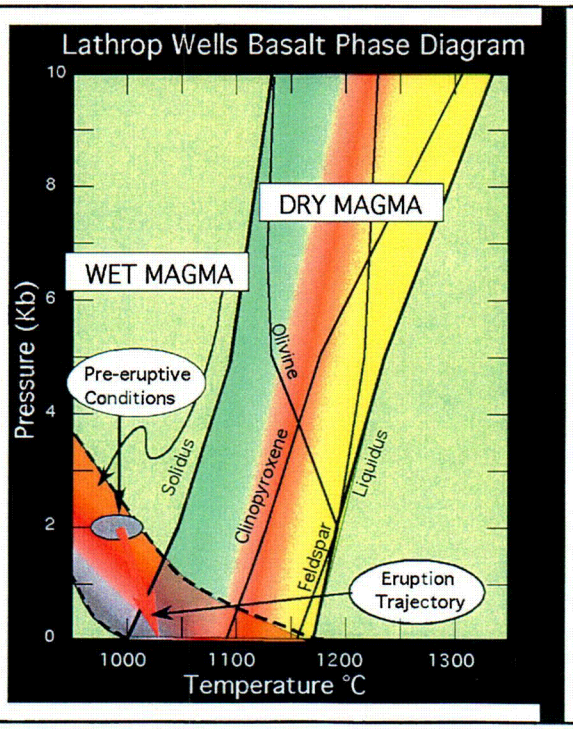

P-T Phase Relations for Basalts
DRY
Solidus
Liquidus
Pressure
Temperature
WET
Solidus
Liquidus
Pressure
Temperature


Lathrop Wells Basalt Phase Diagram
DRY MAGMA
WET MAGMA
Pre-eruptive Conditions
Eruption Trajectory
Olivine
Clinopyroxene
Feldspar
Solidus
Liquidus
Pressure (Kb)
Temperature °C
0
2
4
6
8
10
1000
1100
1200
1300

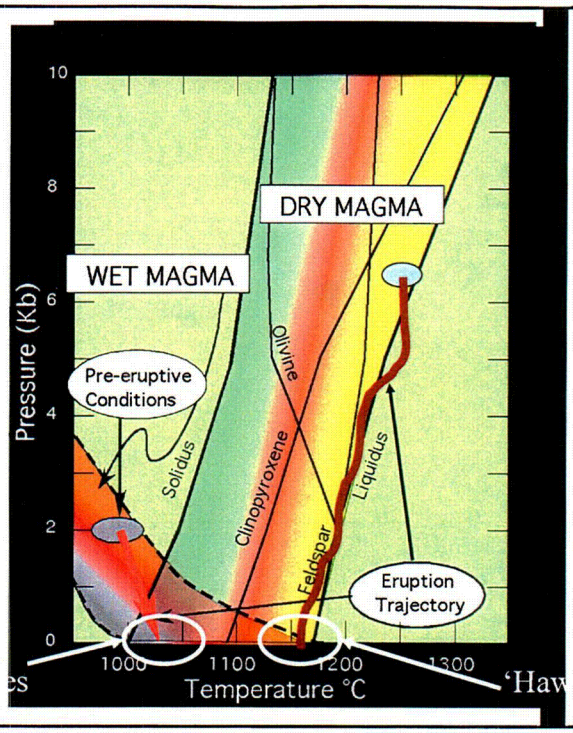

Tholeiitic Basalt
Makaopuhi Lava lake
Hawaii
Rock
Magma
ϕ (crystallinity, vol. %)
T °C
100
0
980
1210
Lathrop Wells Basalt
Rock
Magma
~1170°C
ϕ (crystallinity, vol. %)
T °C
100
0
1000
1200

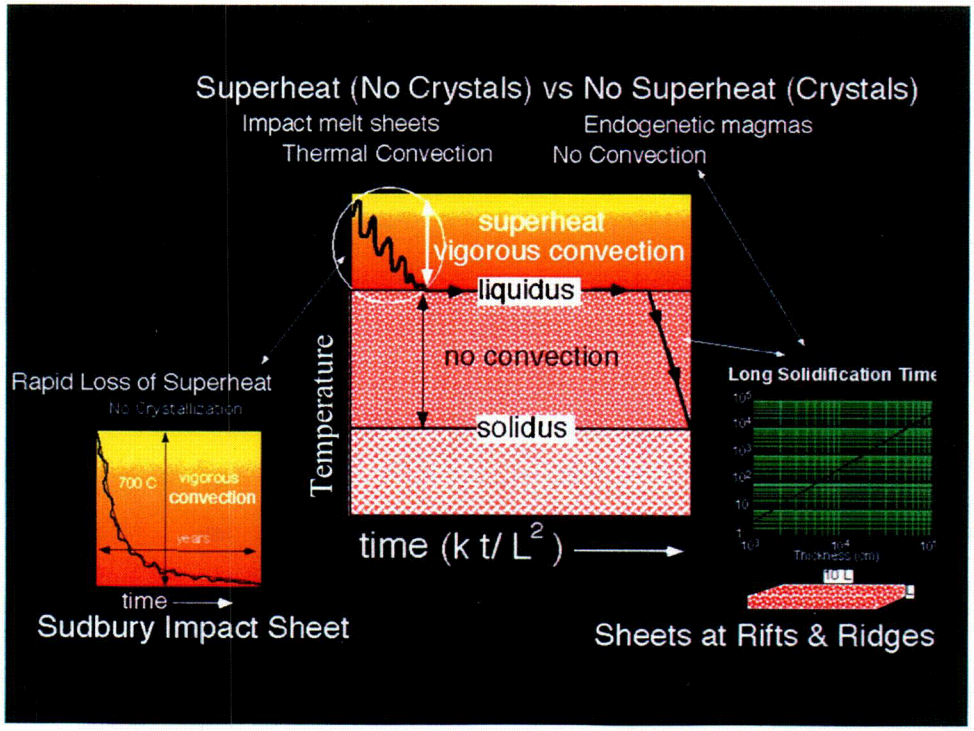
C24


Solidification Front
Interstitial Melt Silica Content (wt. %)
75 70 65 60 55 50
Melt Volatile Content (wt. %))
Rhyolite
Dacite
Andesite
Basalt
Viscosity
Volatiles in Melt
Melt Viscosity (poise, c.g.s)
Crystallinity, Φ


Lathrop Wells Basalt Phase Diagram
DRY MAGMA
WET MAGMA
Pressure (Kb)
Pre-eruptive Conditions
Solidus
Olivine
Clinopyroxene
Feldspar
Liquidus
Eruption Trajectory
Temperature °C

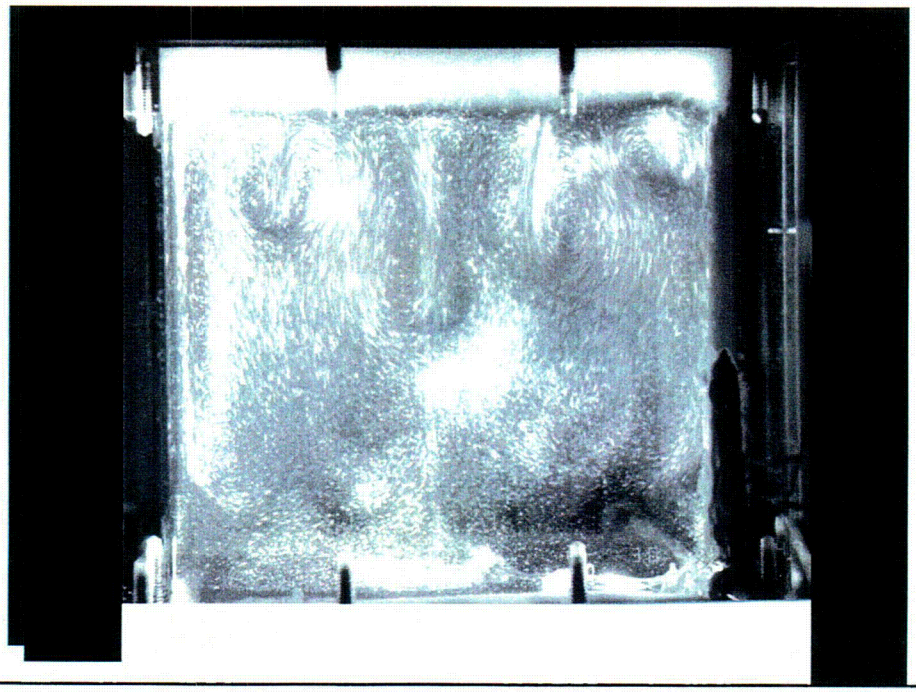
C25


DRY MAGMA
WET MAGMA
Pre-eruptive Conditions
Eruption Trajectory
Solidus
Olivine
Clinopyroxene
Feldspar
Liquidus
Pressure (Kb)
Temperature °C
10
8
6
4
2
0
1000
1100
1200
1300

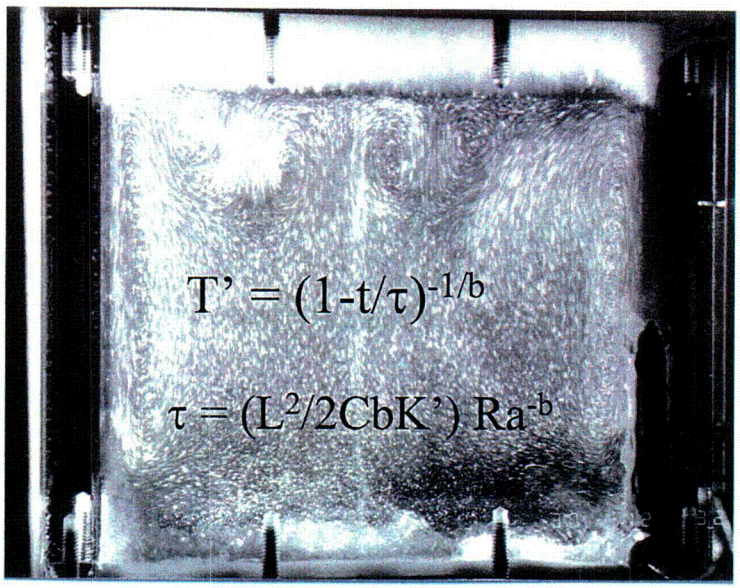

Superheat (No Crystals) vs No Superheat (Crystals)
Impact melt sheets
Thermal Convection
Endogenetic magmas
No Convection
superheat
vigorous convection
liquidus
no convection
solidus
Temperature
time (k t/ L²)
Rapid Loss of Superheat
No Crystallization
700 C
vigorous convection
years
time
Sudbury Impact Sheet
Long Solidification Time
Sheets at Rifts & Ridges

C26

Solidification Front
t = (150/(Ra-Ra$_c$))(L^2/K)
Paraffin Solid-Solution

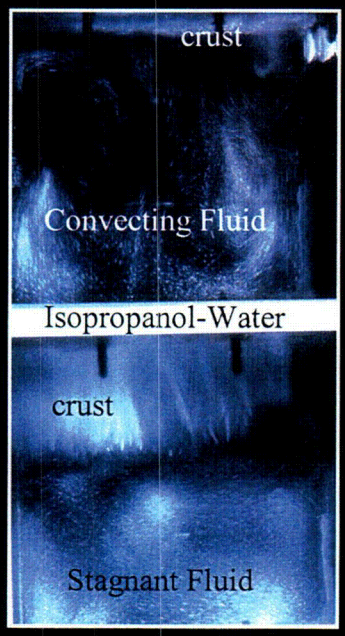


C27



$$T' = (1 - t/\tau)^{-1/b}$$

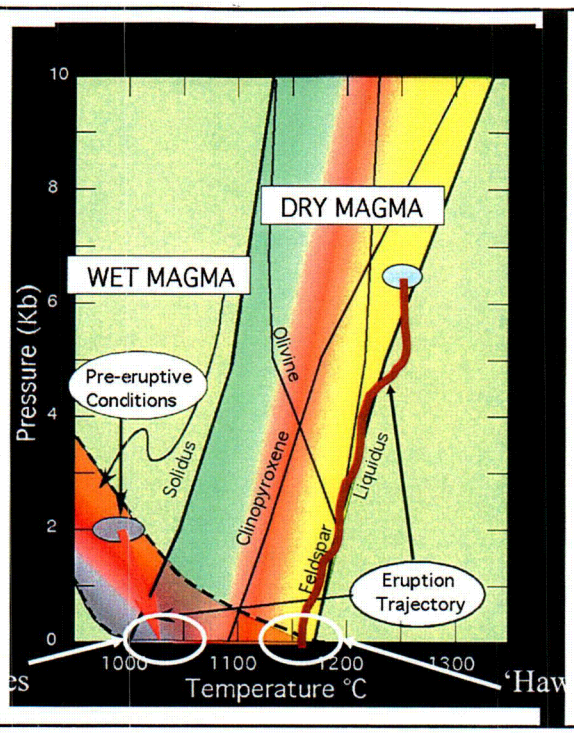
$$\tau = (L^2/2CbK')\,Ra^{-b}$$

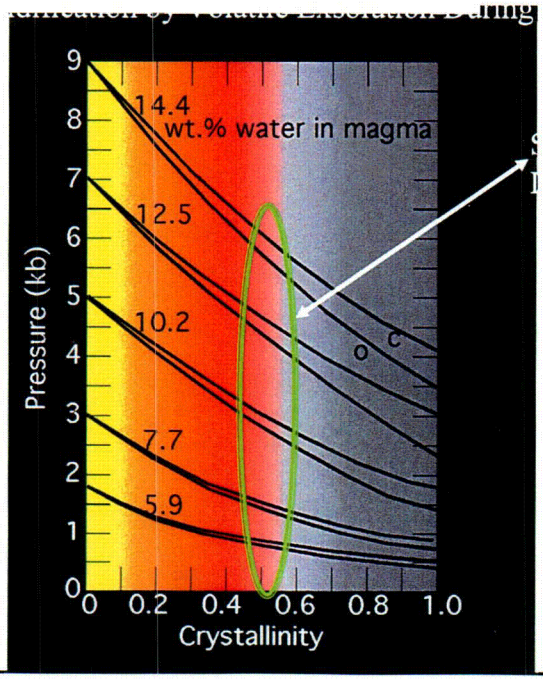


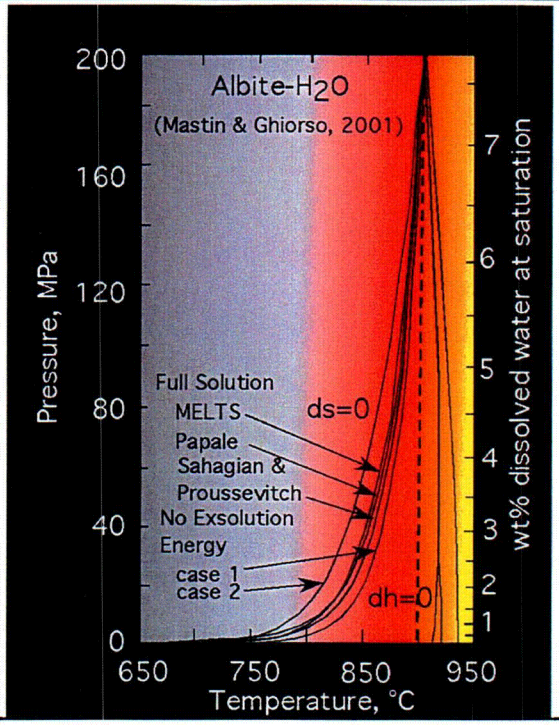
Early
Conve
in sup

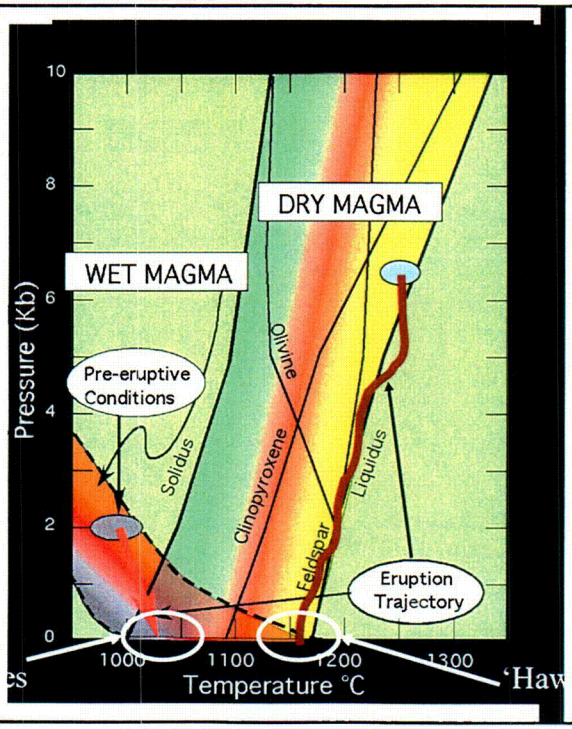
Later
no su
no co

Hort, M


DRY MAGMA
WET MAGMA
Pre-eruptive Conditions
Eruption Trajectory
Solidus
Olivine
Clinopyroxene
Feldspar
Liquidus
Pressure (Kb)
Temperature °C
0
2
4
6
8
10
1000
1100
1200
1300

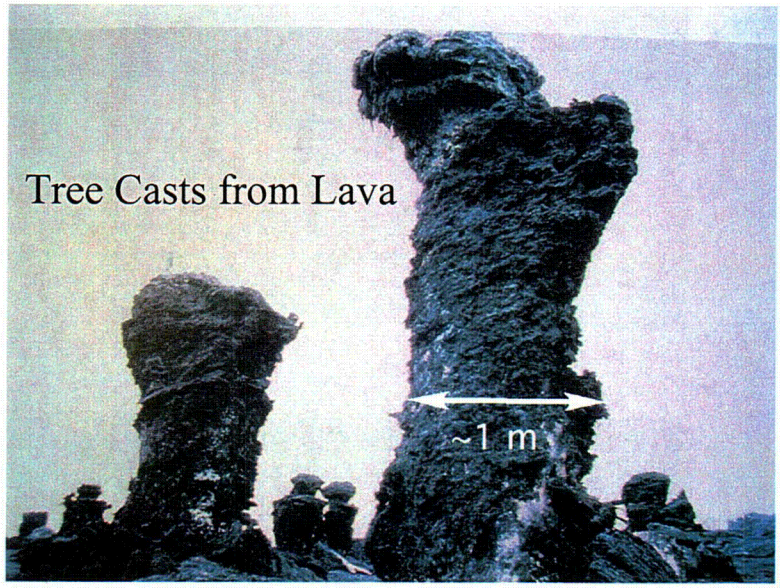

14.4
wt.% water in magma
12.5
10.2
7.7
5.9
Pressure (kb)
Crystallinity
0
1
2
3
4
5
6
7
8
9
0.2
0.4
0.6
0.8
1.0


Albite-H2O
(Mastin & Ghiorso, 2001)
Pressure, MPa
200
160
120
80
40
0
Full Solution
MELTS
Papale
Sahagian &
Proussevitch
No Exsolution
Energy
case 1
case 2
ds=0
dh=0
650
750
850
950
Temperature, °C
wt% dissolved water at saturation
7
6
5
4
3
2
1

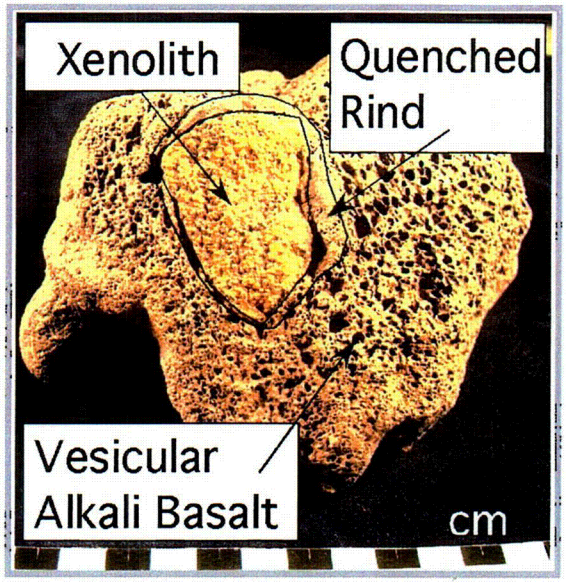

DRY MAGMA
WET MAGMA
Pressure (Kb)
10
8
6
4
2
0
Pre-eruptive
Conditions
Solidus
Olivine
Clinopyroxene
Feldspar
Liquidus
Eruption
Trajectory
1000
1100
1200
1300
Temperature °C

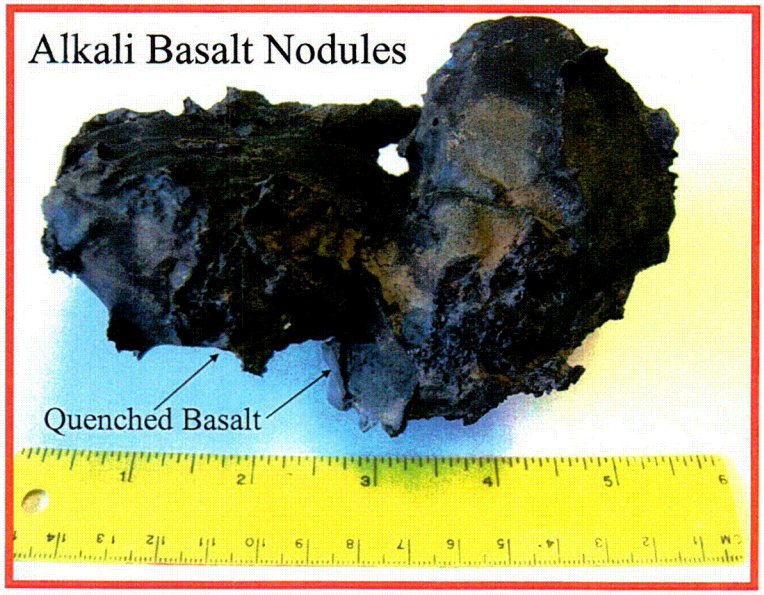
C30

C31



C32


Xenolith
Quenched Rind
Vesicular Alkali Basalt
cm


Alkali Basalt Nodules
Quenched Basalt

C33

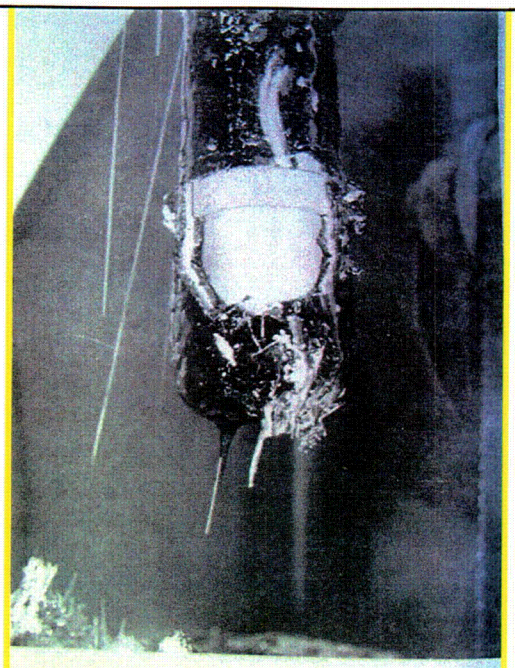
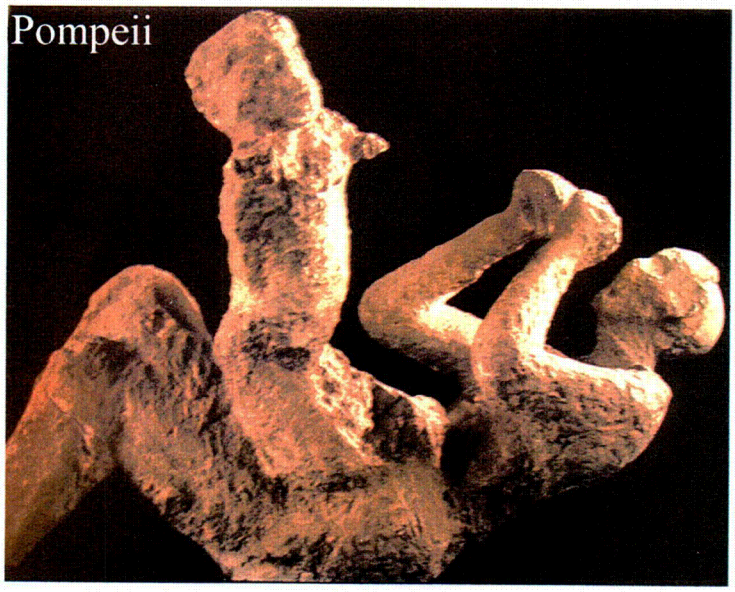


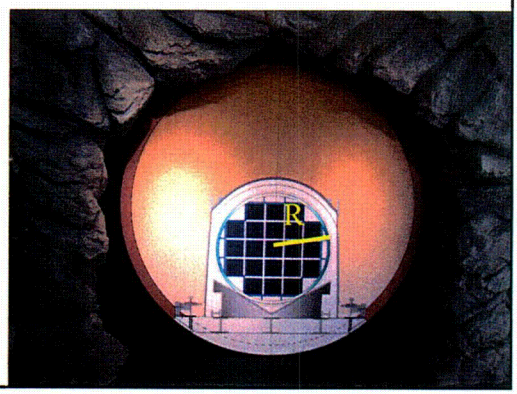
Figure 4. Heat exchanger probe with lava crust (portion of crust removed showing steel probe underneath)



C34

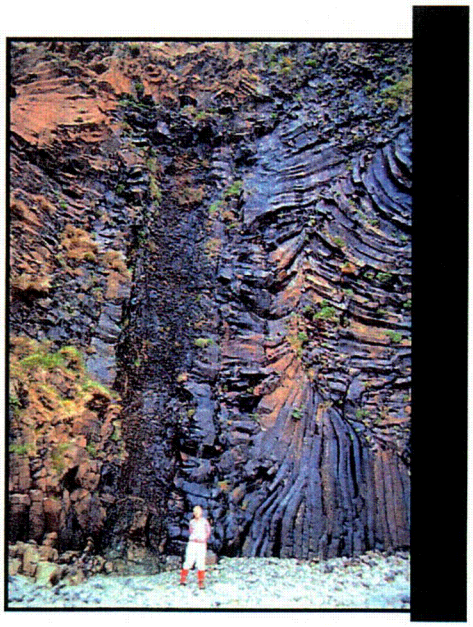
Conservation of Energy:

Contact Temperature:

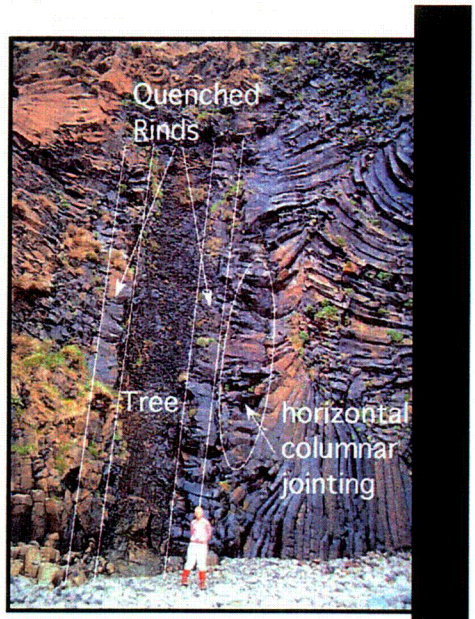


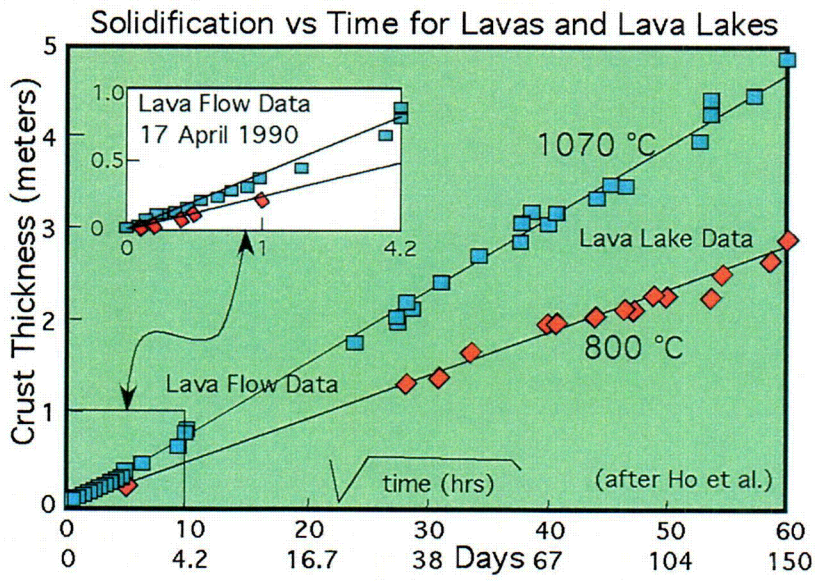
Case 1: d = 0.42 R

Case 1: d = R

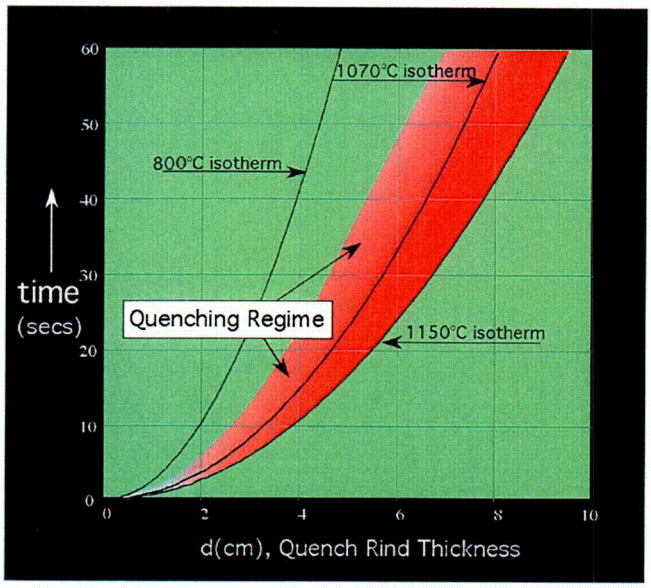


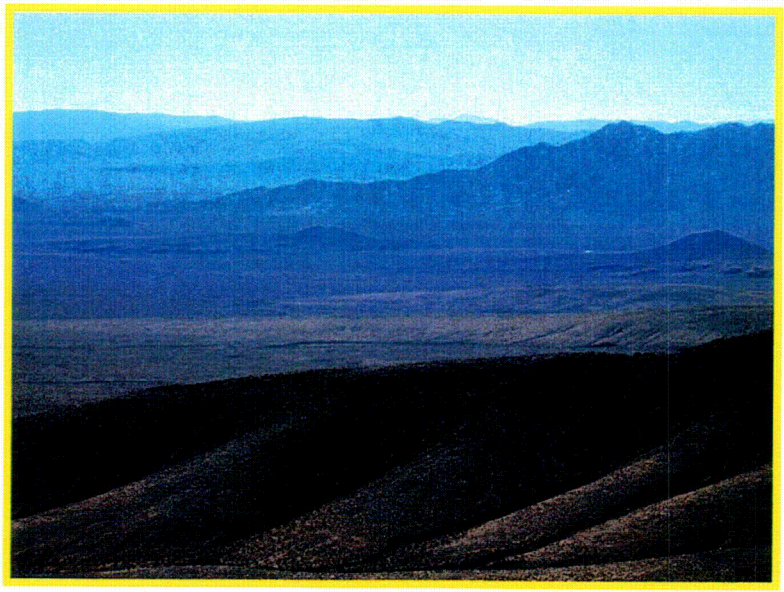
C35


Quenched
Rinds
Tree
horizontal
columnar
jointing


Solidification vs Time for Lavas and Lava Lakes
Crust Thickness (meters)
Lava Flow Data
17 April 1990
1070 °C
Lava Lake Data
800 °C
Lava Flow Data
time (hrs)
(after Ho et al.)
Days
0
10
20
30
40
50
60
0
4.2
16.7
38
67
104
150

C36


1070°C isotherm
800°C isotherm
time
(secs)
Quenching Regime
1150°C isotherm
d(cm), Quench Rind Thickness
0
10
20
30
40
50
60
0
2
4
6
8
10



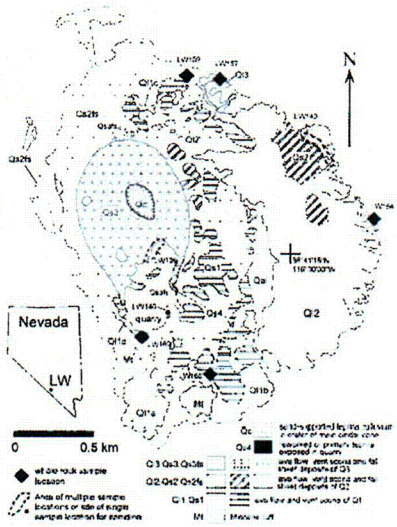


Figure 1. Geological map of the Lathrop Well volcanic center near Yucca Mountain, Nevada. "Qf" refers to Quaternary lava, "Qc" refers to Quaternary scoria, and "Qtb" refers to Quaternary scoria ash fall tuff.

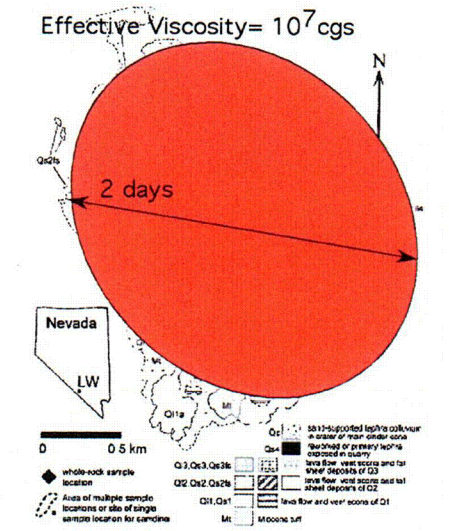


Figure 1. Geological map of the Lathrop Well volcanic center near Yucca Mountain, Nevada. "Ql" refers to Quaternary lava, "Qs" refers to Quaternary scoria, and "Qsfs" refers to Quaternary scoria/ash fall sheet.

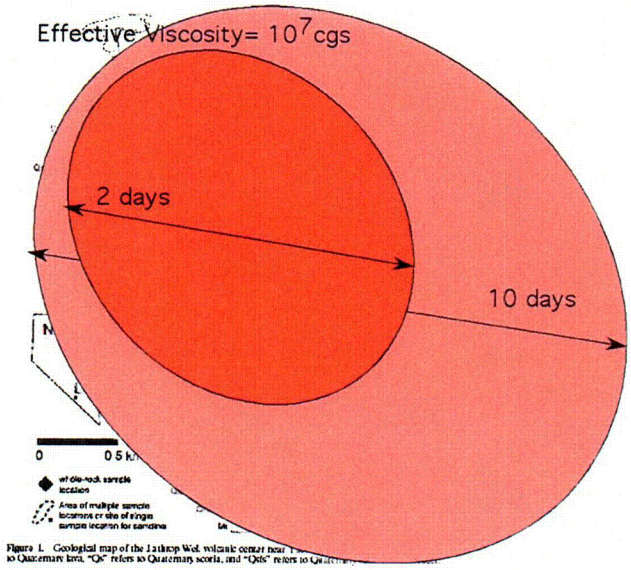


Figure 1. Geological map of the Lathrop Well volcanic center near
to Quaternary lava, "Qs" refers to Quaternary scoria, and "Qsfs" refers to

C39

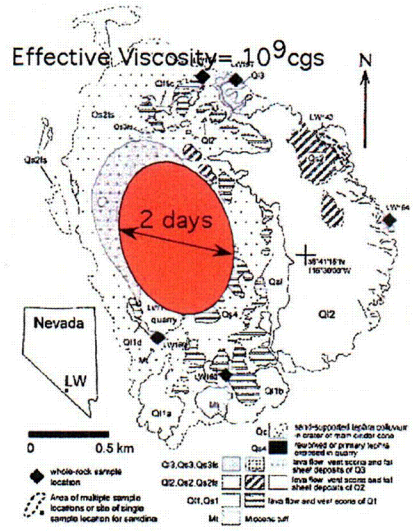


Figure 1. Geological map of the Lathrop Wells volcanic center near Yucca Mountain, Nevada. "Ql" refers to Quaternary lava, "Qs" refers to Quaternary scoria, and "Qsb" refers to Quaternary scoria/ash fall sheet.

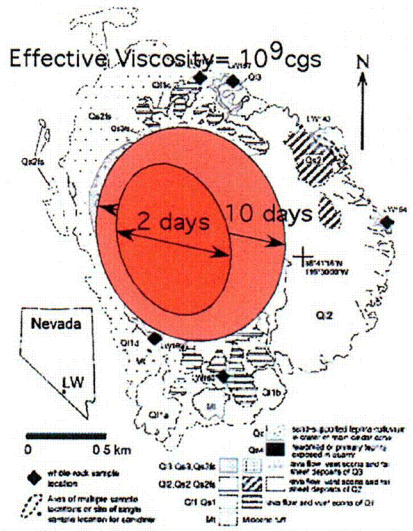


Figure 1. Geological map of the Lathrop Wells volcanic center near Yucca Mountain, Nevada. "Ql" refers to Quaternary lava, "Qs" refers to Quaternary scoria, and "Qsb" refers to Quaternary scoria/ash fall sheet.

CYO

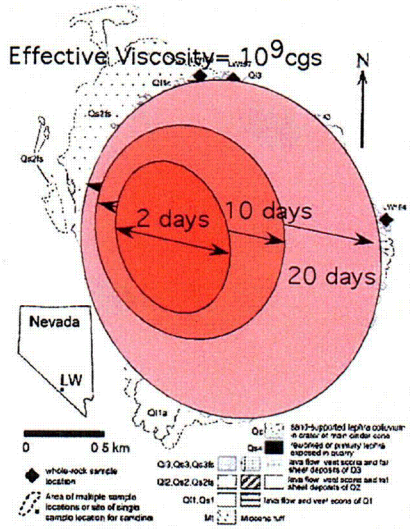
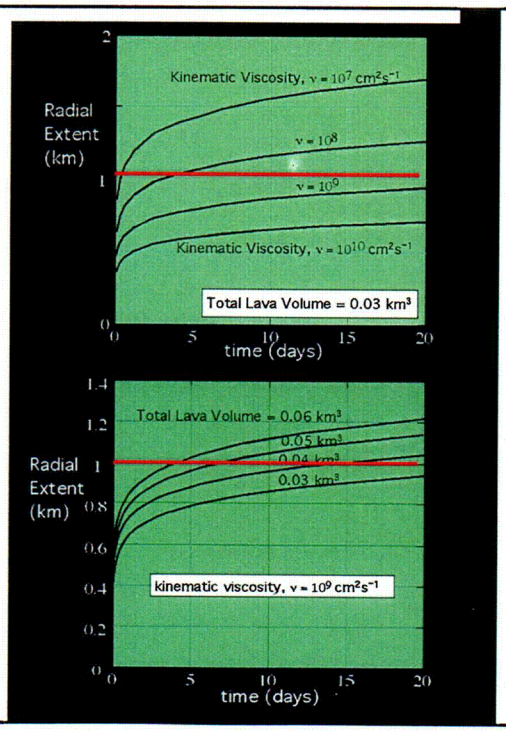
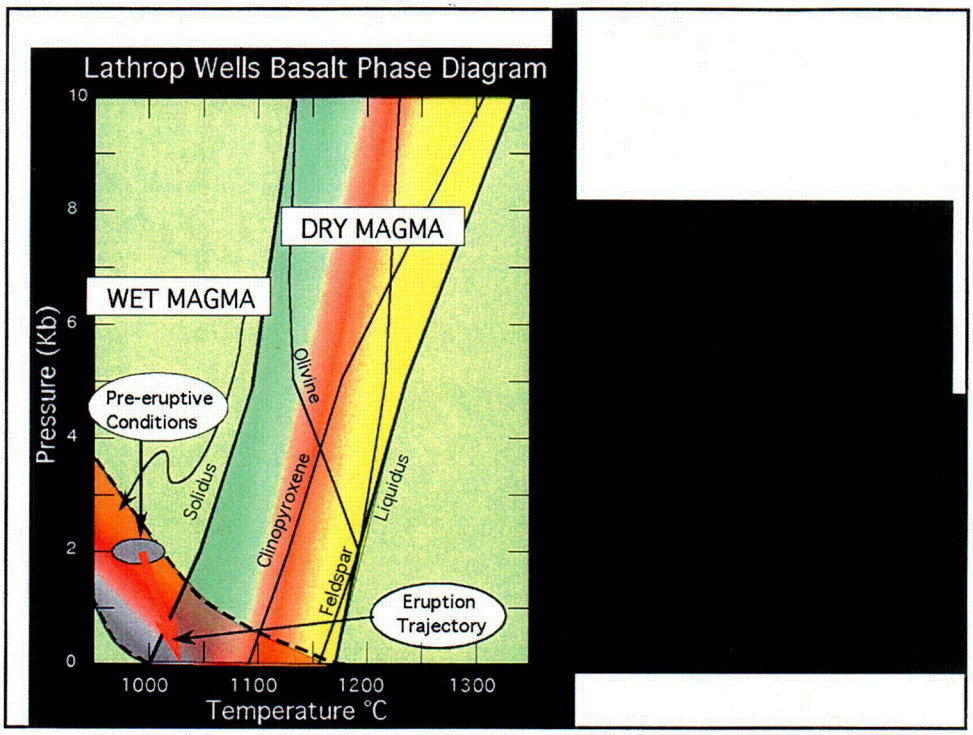
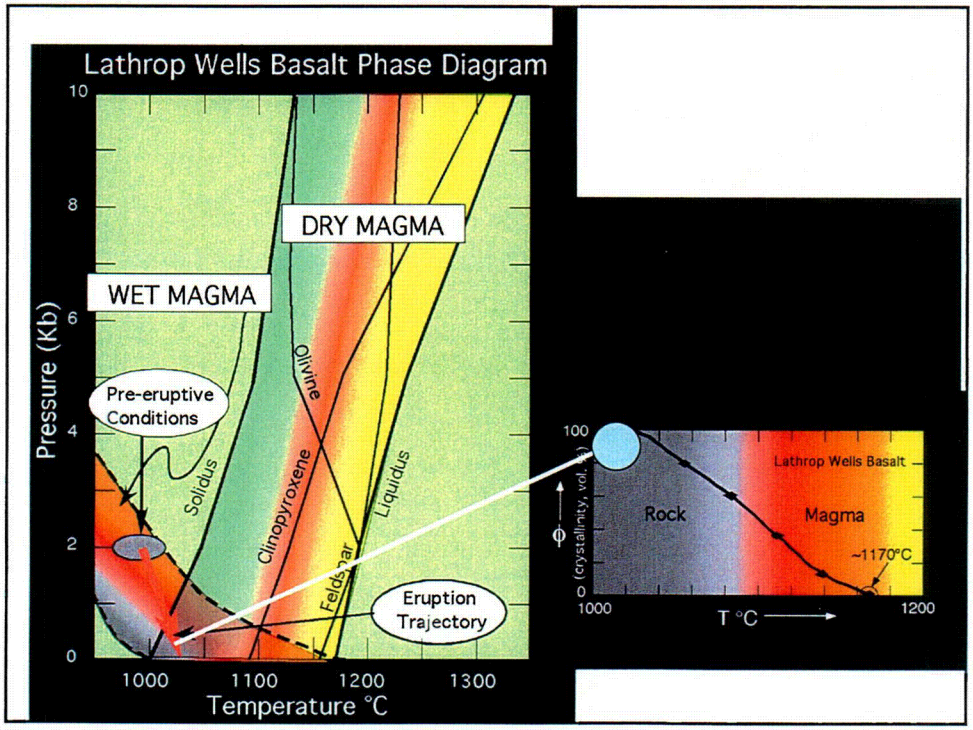


Figure 1. Geological map of the Lathrop Well volcanic center near Yucca Mountain, Nevada. "Ql" refers to Quaternary lava, "Qs" refers to Quaternary scoria, and "Qsfs" refers to Quaternary scoria/ash fall sheet.

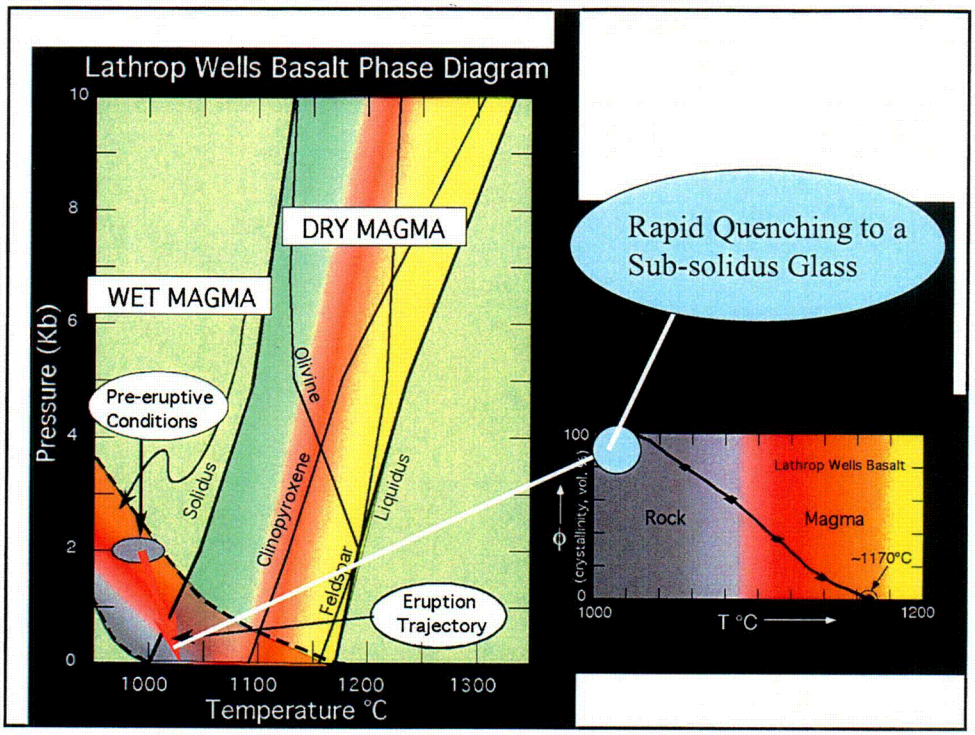


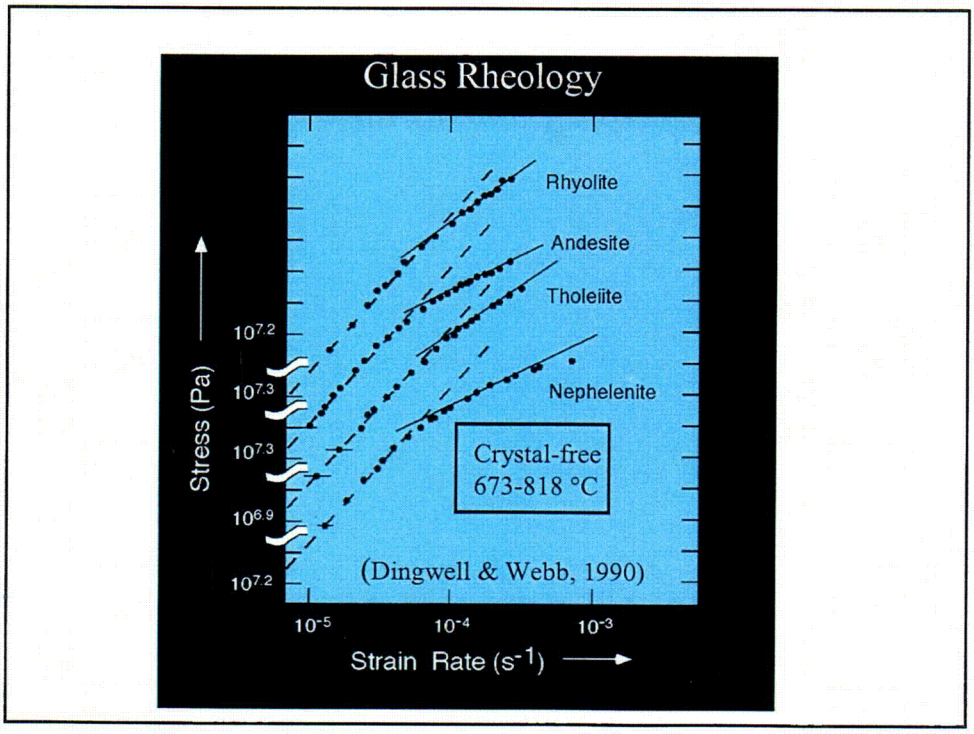
C41


Lathrop Wells Basalt Phase Diagram
DRY MAGMA
WET MAGMA
Pre-eruptive Conditions
Eruption Trajectory
Solidus
Olivine
Clinopyroxene
Feldspar
Liquidus
Pressure (Kb)
Temperature °C
0
2
4
6
8
10
1000
1100
1200
1300

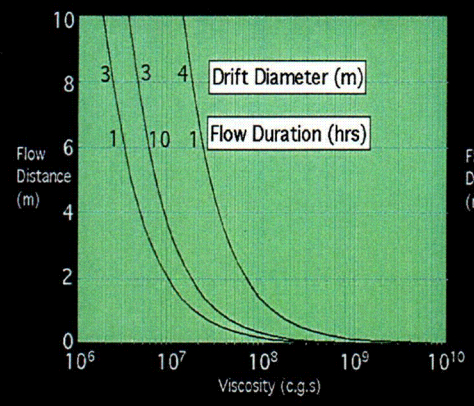

Lathrop Wells Basalt Phase Diagram
DRY MAGMA
WET MAGMA
Pre-eruptive Conditions
Eruption Trajectory
Solidus
Olivine
Clinopyroxene
Feldspar
Liquidus
Pressure (Kb)
Temperature °C
0
2
4
6
8
10
1000
1100
1200
1300
Lathrop Wells Basalt
Rock
Magma
~1170°C
ϕ (crystallinity, vol.%)
T °C
100
0
1000
1200

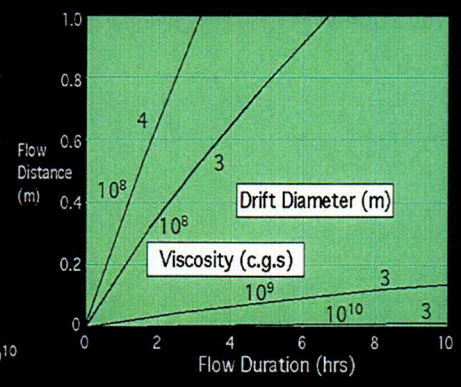
CY2


Lathrop Wells Basalt Phase Diagram
Pressure (Kb)
Temperature °C
DRY MAGMA
WET MAGMA
Pre-eruptive Conditions
Solidus
Olivine
Clinopyroxene
Feldspar
Liquidus
Eruption Trajectory
Rapid Quenching to a Sub-solidus Glass
Lathrop Wells Basalt
Rock
Magma
~1170°C
T °C


Glass Rheology
Rhyolite
Andesite
Tholeiite
Nephelenite
Crystal-free
673-818 °C
(Dingwell & Webb, 1990)
Stress (Pa)
Strain Rate (s-1)

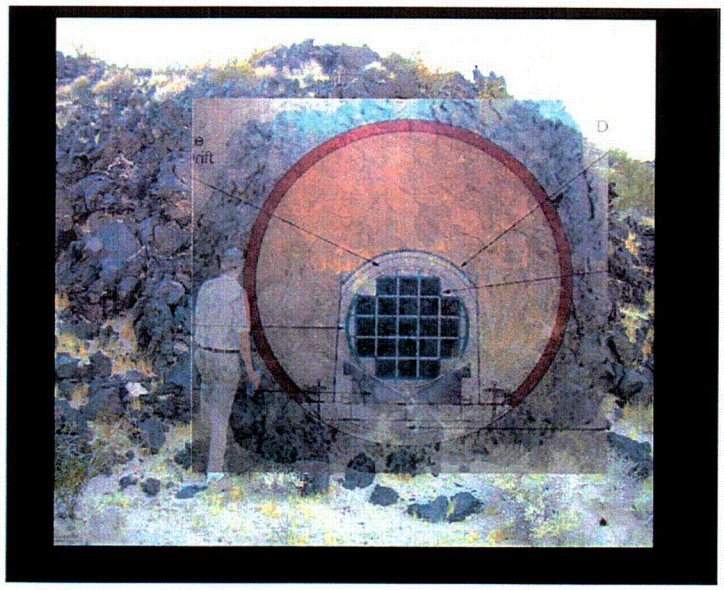
Drift Flow Distance for a Lathrop Wells Alkali Basalt

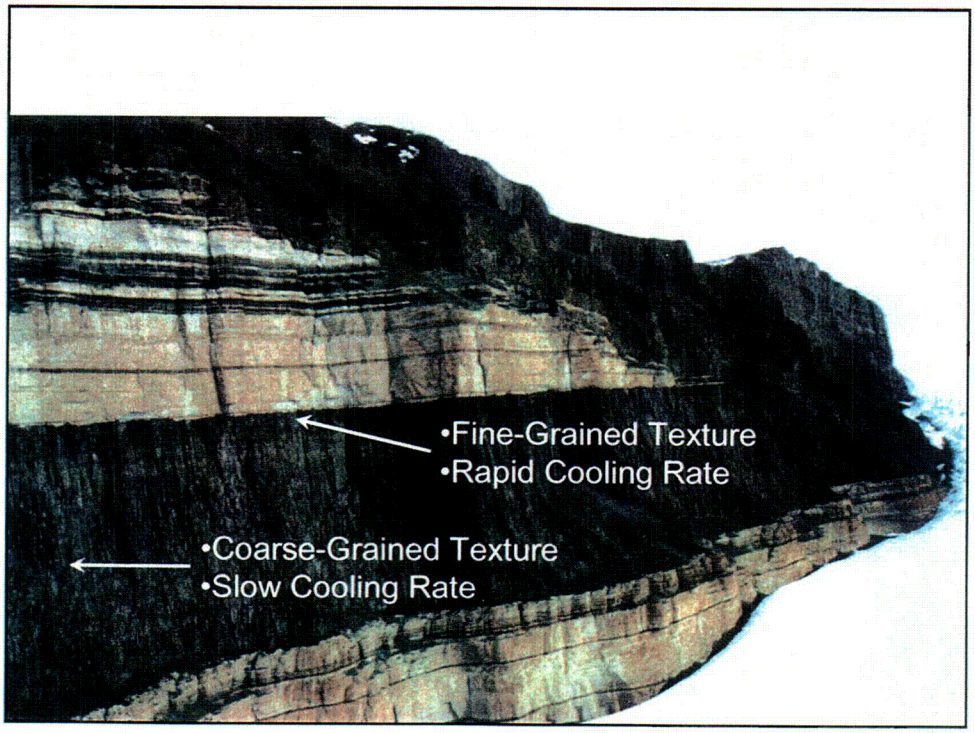




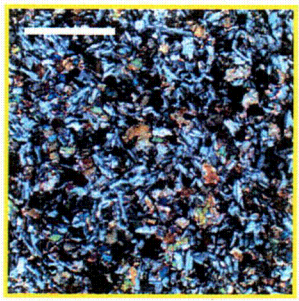
Total Flux(t,T)) = Local Flux(t,T)/ Drift Volume-meter

C44




•Fine-Grained Texture
•Rapid Cooling Rate
•Coarse-Grained Texture
•Slow Cooling Rate

C45



CSD Measurements

$$\ln[n(L)] = \ln(n^\circ) - SL$$

$$n(L) = n^\circ \exp(-SL)$$

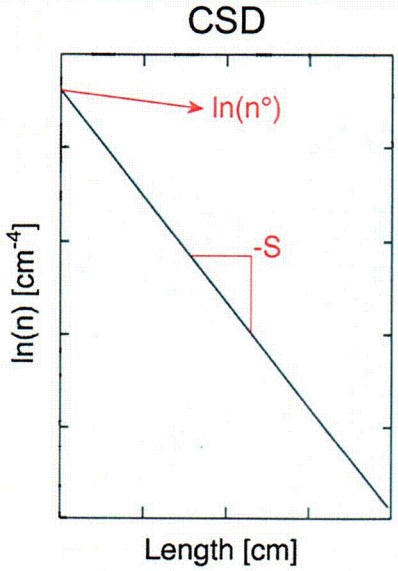
Total Number of Crystals:

$$N_T = \int_0^\infty n(L)\, dL = \frac{n^\circ}{S}$$

$$L_T = \int_0^\infty L\, n(L)\, dL = \frac{n^\circ}{S^2}$$

Mean Size of Crystals:

$$L_{mean} = \frac{L_T}{N_T} = \frac{1}{S}$$



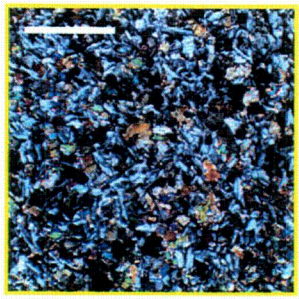
Scaling Analysis - Texture and Kinetics

$$L_0 = C_L \left(\frac{G_0}{J_0}\right)^{\frac{1}{4}}$$ •Characteristic length

$$N_0 = C_N \left(\frac{J_0}{G_0}\right)^{\frac{3}{4}}$$ •Characteristic number

$$(C^* \cdot N_0)^{-1/3} = L_0$$ •J_0 and G_0 eliminated

$$N_T^{-\frac{1}{3}} \propto L_{mean}$$ •Result - to be evaluated



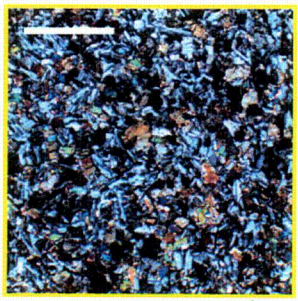
Fine Texture

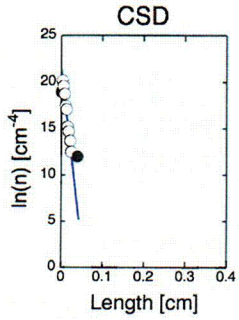
- $N_T = 5.9\times10^6\ cm^{-3}$
- $L_{mean} = 0.0028\ cm$

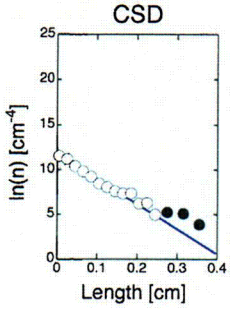
Coarse Texture

- $N_T = 4.4\times10^3\ cm^{-3}$
- $L_{mean} = 0.036\ cm$

C47





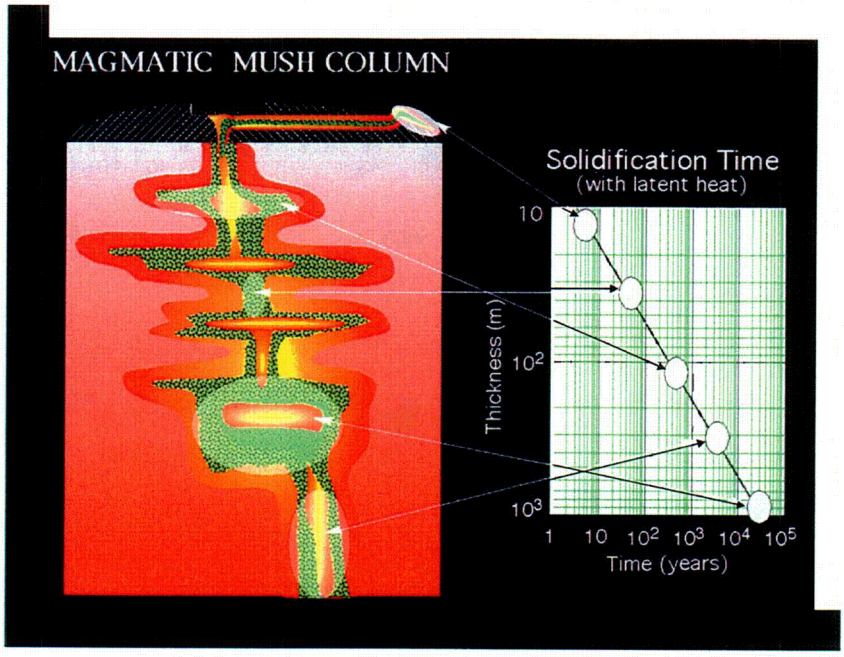


Fine Texture

- CSD Intercept High
- CSD Slope Steep

Coarse Texture

- CSD Intercept Low
- CSD Slope Shallow


MAGMATIC MUSH COLUMN
Solidification Time
(with latent heat)
10
10^2
10^3
Thickness (m)
1
10
10^2
10^3
10^4
10^5
Time (years)

PERFORMANCE CONFIRMATION

NRC STAFF ACTIVITY UPDATE

Presented by:
Jeffrey Pohle and Randall Fedors
NMSS/DHLWRS/RSS

169th ACNW Meeting
April 18-20, 2006

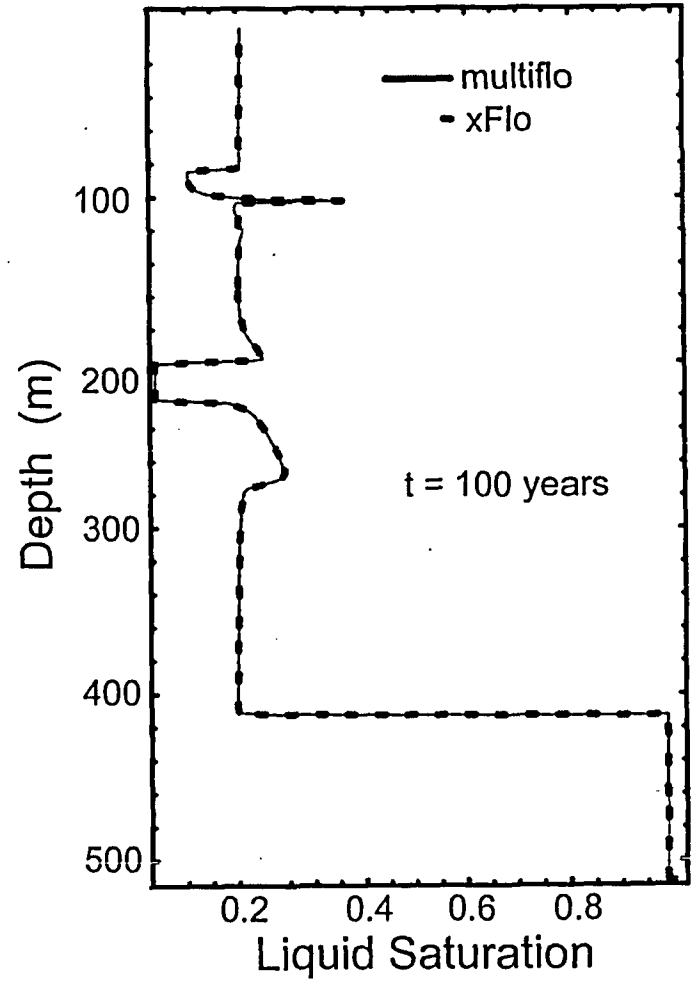
Fiscal Year 2005 Accomplishments

Three Activity Areas

- Continued development of xFlo computer code
- Initiated review of monitoring technologies for potential application to performance confirmation of hydrologic and geotechnical Parameters
- To prepare for future licensing review, initiated a preliminary review of DOE Performance Confirmation Plan (Revision 5)

xFlo Code Development

- Next Generation Computer Code
  - Modern, flexible software design
  - Easy to incorporate new process-level thermal-hydrologic-chemical models
- Successfully Compared *xFlo* and MULTIFLO™ Simulations of Strongly Heated Repository
- Implemented and Began Testing Dual-Permeability Capability



Monitoring Technologies

Two CNWRA Reports will provide the results of the literature review of monitoring technologies for potential application to performance confirmation of hydrologic and geotechnical parameters

- Review of Vadose Zone Measurement and Monitoring Tools
- Review of Tools and Technologies to Monitor Repository Excavations

DOE Performance Confirmation Plan

- DOE to Conduct Performance Confirmation Activities to Meet 10 CFR Part 63, Subpart F Requirements

- Performance Confirmation Activities:
  - Monitoring
  - Field Investigations
  - Laboratory testing

- Use of Data:
  - Confirm assumptions
  - Refine process models

Guidance for Review of DOE Performance Confirmation Plan

- 10 CFR Part 63, Subpart F
- Yucca Mountain Review Plan
- NRC Risk Insights Baseline Report
  - Key attributes and their significance to waste isolation
  - Important assumptions and uncertainties in models and parameters
- Our current understanding of DOE's safety strategy in terms of key attributes of engineered and natural barriers

Types of Comments on DOE Performance Confirmation Plan

- Uncertainties in barrier attributes not addressed
- Activities not practicable with current technologies
- Activities that may not provide useful data
- Activities that may conflict with other activities

Review Comment: Uncertainties in Barrier Attributes Not Addressed

- Properties and extent of non-welded vitric units of the Calico Hills Formation below potential repository horizon are known only to a limited extent

- DOE assumes
  - No fracture flow
  - Near-surface distal deposits at Busted Butte provide a good analog

- Comment

  Because retardation in the Calico Hills non-welded unit is of some significance to transport in the unsaturated zone, it is not clear why confirmatory activities related to this unit are not included in DOE's plan.

Review Comment: Activities Not Practicable with Current Technologies

- DOE plans extensive in-drift and near-drift measurements to monitor seepage and hydrological properties of fracture networks

- Comments
  - Collecting in-drift water near or above boiling will likely rely on future development of techniques
  - Techniques for use in ambient and accelerated thermal drifts will likely have to be developed to distinguish:
    - seepage
    - diversion
    - along-wall flow
    - evaporation and in-drift redistribution

Review Comment: Activities That May Not Provide Useful Data

- DOE is considering the option of either a one-drift or two-drift thermally accelerated drift test
- Comment
  - The objectives of the thermally accelerated drift test, as stated in the performance confirmation plan, may not be met by the one-drift option

Review Comment: Activities That May Not Provide Useful Data

- DOE's plan for corrosion testing requires placing test samples in repository relevant conditions

- Comment
  - There is no clear method presented in the plan for correlating test results with estimates of expected corrosion modes in actual emplacement drifts

Review Comment: Activities That May Conflict With Other Activities

- DOE plans to clean tunnel walls with water to photograph fractures
- Comment
  - This activity could impact other planned activities requiring hydrologic or geochemical sampling or testing

Summary

- Reviewed DOE's Performance Confirmation Program Plan, Revision 5
- Initiated literature review of monitoring technologies for potential application to performance confirmation of hydrologic and geotechnical parameters
- Continued development of xFlo computer code

10CFR Part 63, Subpart F

BACKUP SLIDES

REGULATORY REQUIREMENTS
RELEVANT TO
PERFORMANCE CONFIRMATION

General Requirements Objective

§ 63.131(a)

Provide data, where practicable, to:

- Indicate whether actual subsurface conditions are within limits assumed in licensing review, and
- Indicate whether natural and engineered barriers are functioning as intended and anticipated

General Requirements
Program Duration

§ 63.131(b)

Program must have been started during site characterization, and it will continue until permanent closure.

General Requirements
Testing

§ 63.131(c)

Program must include in situ monitoring, laboratory and field testing, and in situ experiments, as may be appropriate to provide the data required.

General Requirements Implementation

§ 63.131(d)

- Does not adversely affect the ability of the geologic and engineered elements of the repository to meet performance objectives
- Provides baseline information on those parameters and processes pertaining to geologic setting that may be changed by characterization, construction and operation
- Monitors changes from baseline of parameters that could affect repository performance

Confirmation of Geotechnical and Design Parameters

§ 63.132(a), (b), and (c)

- During construction and operation, continuing program of activities to confirm geotechnical and design parameters and ensure Commission informed if design changes needed to accommodate conditions found.
- Monitor subsurface conditions against design assumptions
- DOE identifies specific parameters and interactions between natural and engineered systems and components in Performance Confirmation Plan

Confirmation of Geotechnical and Design Parameters

§ 63.132(d) & (e)

- Data compared with design bases and assumptions. If significant differences, DOE determines need to modify design or construction methods and reports any changes to NRC
- In situ monitoring of thermomechanical response conducted until permanent closure

Design Testing

§ 63.133(a), (b), (c), and (d)

- Tests of engineered systems and components, as well as the thermal interaction effects of the engineered systems and components, rock, and water, must be conducted.
- Testing initiated as early as practicable
- If backfill included, must test to evaluate effectiveness of placement and compaction procedures before permanent placement begun
- Must test to evaluate effectiveness of seals before full-scale sealing operation begins.

Monitoring and Testing Waste Packages

§ 63.134(a), (b), (c), and (d)

- A program must be established at the GROA for monitoring the condition of the waste packages. Waste packages representative of those to be emplaced.
- Consistent with safe operations, testing environment representative of emplacement environment.
- Program must include laboratory experiments that focus on internal condition of waste packages. To extent practical, duplicate emplacement environment in lab.
- Monitoring must continue as long as practical up to the time of permanent closure.

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Preliminary Analysis of the Maximum Disposal Capacity for CSNF in a Yucca Mountain Repository

John Kessler

Manager, HLW and Spent Fuel Management Program

+1-704-595-2249; jkessler@epri.com

Presented to the Advisory Committee on Nuclear Waste, 19 April 2006

Acknowledgements

EPRI draft report of preliminary work in preparation

- Publicly available end of May 2006

Draft report authors

- Mick Apted, Monitor Scientific LLC (lead)
- John Kemeny, University of Arizona
- Fraser King, Integrity Corrosion Consulting, Ltd.
- Alan Ross, Alan M. Ross & Associates
- Ben Ross, Disposal Safety, Inc.
- Frank Schwartz, The Ohio State University
- Wei Zhou, Monitor Scientific LLC

© 2006 Electric Power Research Institute, Inc. All rights reserved.

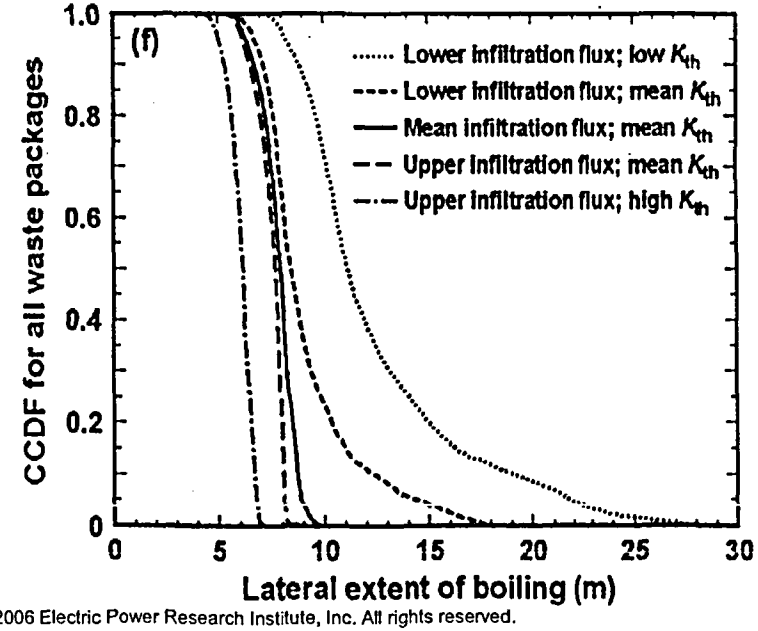
Purpose & Approach

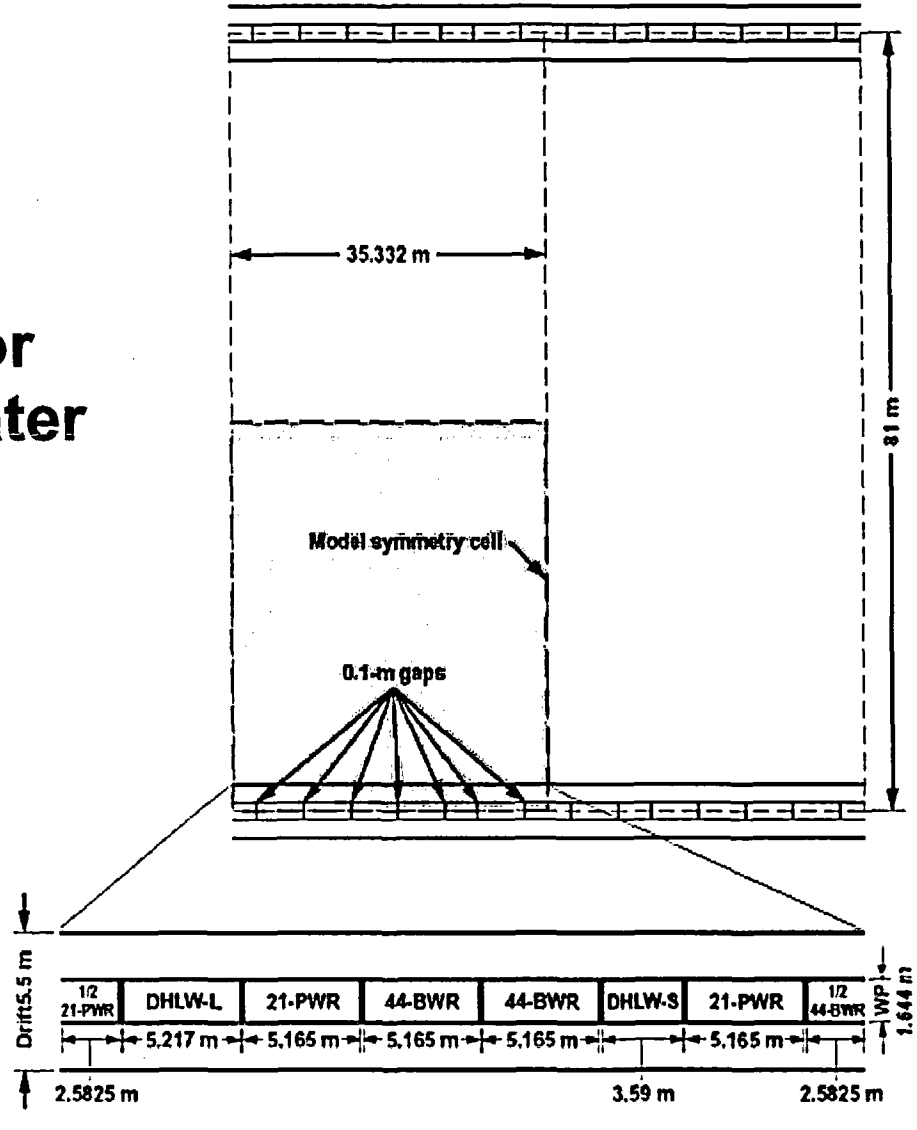
- *Preliminary* analysis of the maximum physical capacity of a geological repository at Yucca Mountain for the disposal of commercial spent nuclear fuel (CSNF)
  - NWPA: 70,000 MTHM (63,000 MTHM CSNF)
- Assure minimal impacts on cost or schedule of DOE's current 70,000 MTHM design:
  - Consider only Yucca Mountain area currently characterized by DOE
  - Start with DOE's current 'line-load', high-temperature operating mode (HTOM) repository design
  - Apply thermal constraints on natural and engineered barriers
- Use conservative, convection-only, thermal modelling
- Identify alternatives that may further optimize CSNF disposal capacity

© 2006 Electric Power Research Institute, Inc. All rights reserved.

DOE's Line-loaded, High-Temperature Operating Mode (HTOM) Repository Design

- Maximum waste package temperature 160-180°C
- Conservative 81-m pitch between drifts to maintain sub-boiling 'pillar' of tuff for drainage of condensate water





© 2006 Electric Power Research Institute, Inc. All rights reserved.

Temperature Limits Assumed in Preliminary EPRI Analysis

- Cladding: 350°C (optional?)
  - E.g. NRC's TPA does not take credit for cladding
- Waste package surface: up to 309°C analyzed (could easily go higher)
- Rock wall: 200°C (somewhat higher possible and still avoid SiO_2 phase change)
- Relax goal of maintaining pillars below boiling for all time after repository closure

© 2006 Electric Power Research Institute, Inc. All rights reserved.

Options the EPRI Team Analyzed

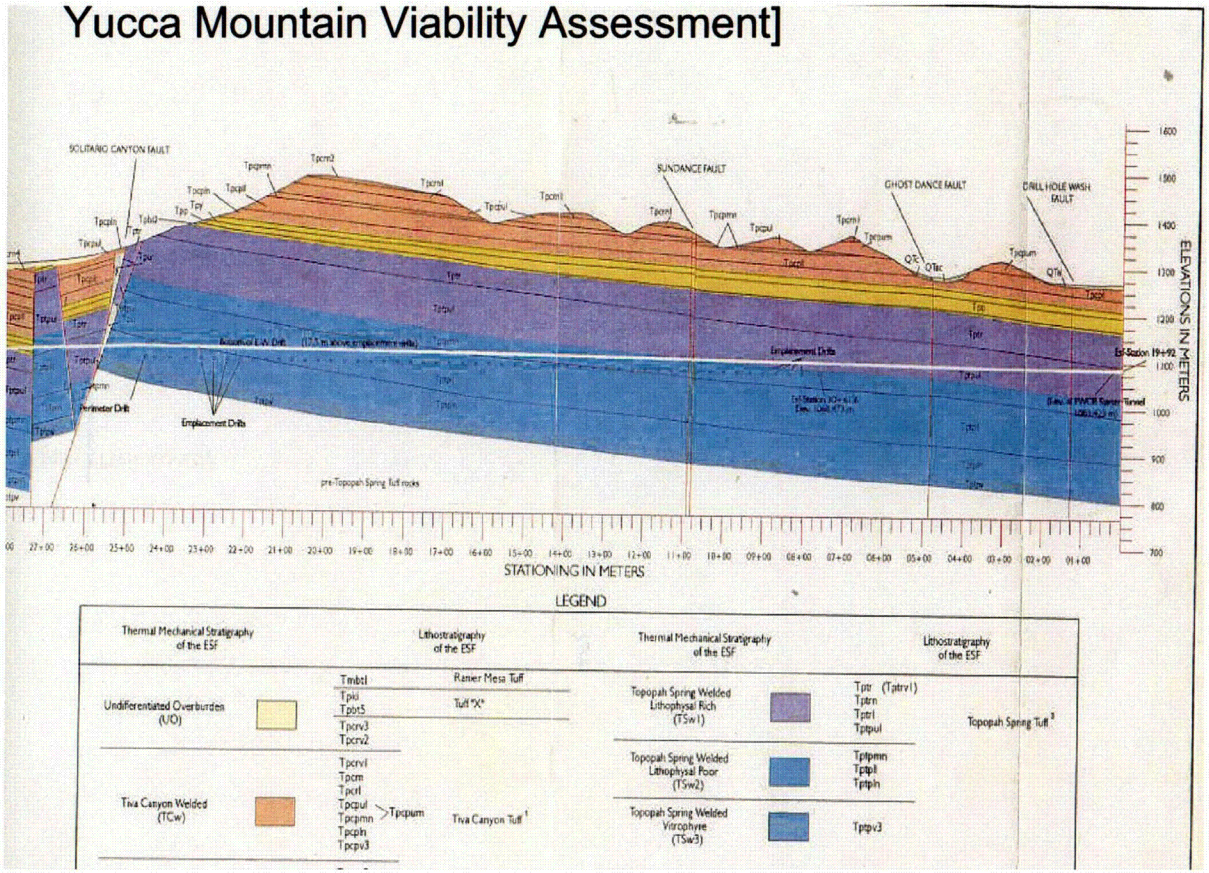
- Option 1: Expanded repository 'footprint'
- Option2: Multi-level repository
- Option 3: Grouped, single-level emplacement drifts
- Determine the range in 'expansion factor' attributable to each option
- Combinations of Options

© 2006 Electric Power Research Institute, Inc. All rights reserved.

Option 1: Current One-level HTOM Design but Extended Over a Larger Explored Area

- **Proposed repository is located in the lower Topopah Spring Tuff (~170-m thick)**
- **Major NW-trending faults define suitable rock blocks (although 'respect distance' from faults required)**
- **Maintain ~200 to 400-m of rock cover**
- **Maintain ~200 to 400-m to water table below**

[**Approximate Location of Emplacement Drifts, DOE Line-loaded HTOM Design,** taken from Yucca Mountain Viability Assessment]



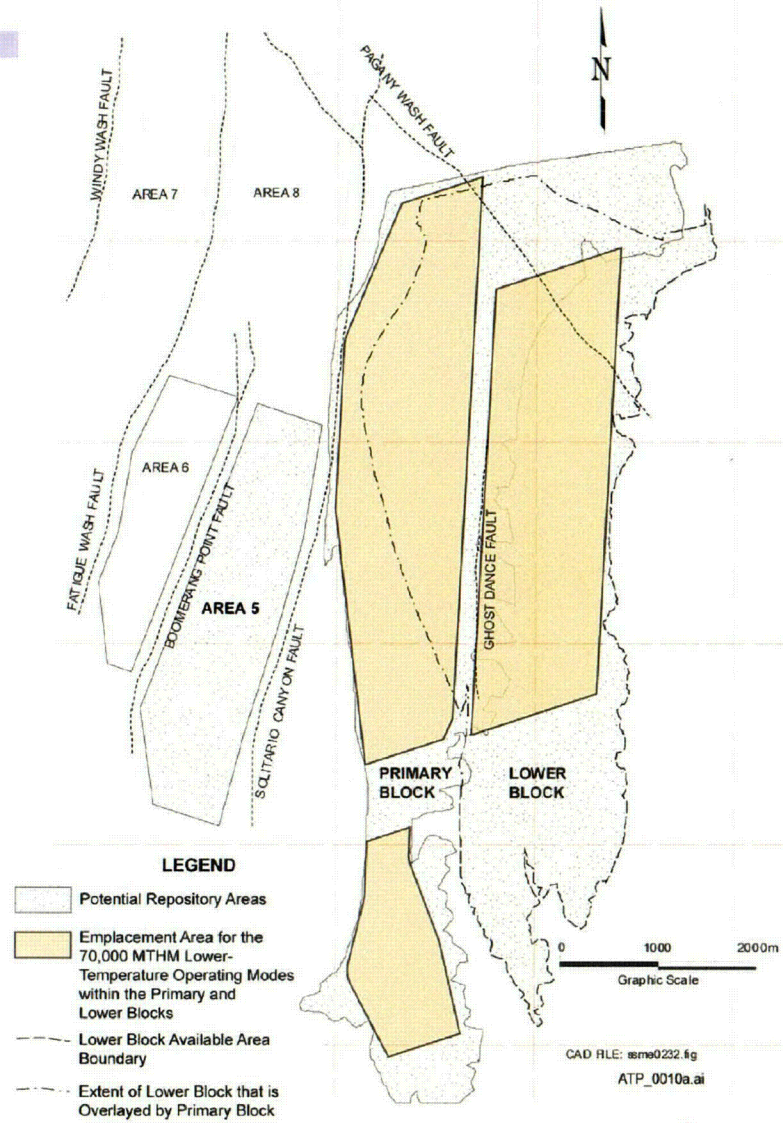
© 2006 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

C50

Option 1: Extended 'Footprint' (2)

- FEIS (DOE, 2002) identified additional rock blocks suitable for expansion of YM repository, based on various designs and thermal-loading strategies.



© 2006 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

C51

Option 1: Extended 'Footprint' (3)

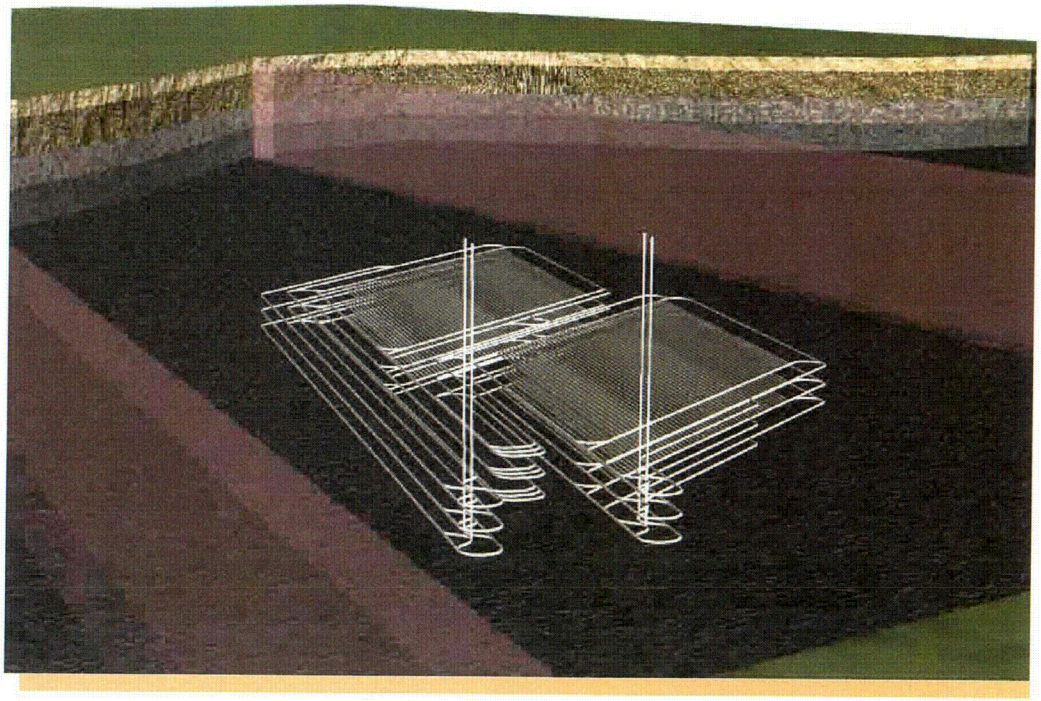
Source	Extended Area (km^2)	Expansion Factor
Mansure and Ortiz (1984)	37.03	5.7
CRWMS M&O (1994)	10.90	1.7
Yucca Mountain Science and Engineering Report (USDOE, 2002b)	23	3.5
FEIS (2002a and earlier drafts, Section 2.1.2.2)	10	1.5
Peterson (2006)	17	2.6
This Study		
Confident	13	2.0
Possible	17-23	2.6-3.5

Expansion Factor = Maximum MTHM of CSNF/ 70,000 MTHM

© 2006 Electric Power Research Institute, Inc. All rights reserved.

Option 2: Multi-level Repository

- Three-level repository design
- Additional drifts 30 to 50 meters above and below current HTOM design
- Same and lower line loads considered (1.45 and 1.0 kW per meter)



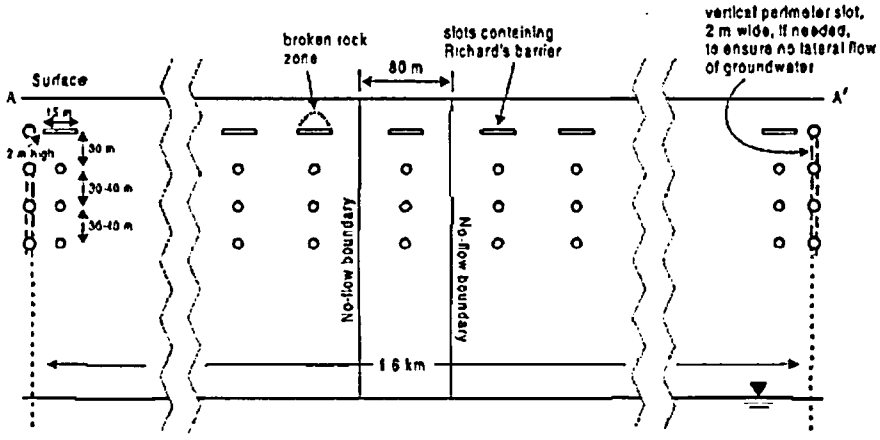
© 2006 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

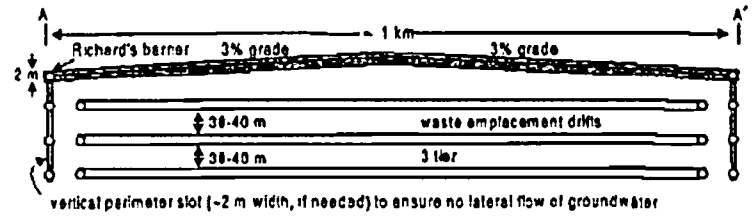
C52

Multi-level Repository Designs are not New

- Previously considered by DOE for Yucca Mountain
- Europeans and Japanese considering it
- Charles Fairhurst 1999 report to ACNW (right)
  - Figure 2b and 2c from "Engineered Barriers at Yucca Mountain: Some Impressions and Suggestions"



b) Cross section normal to long axes of drifts
(20x 3 tier columns)



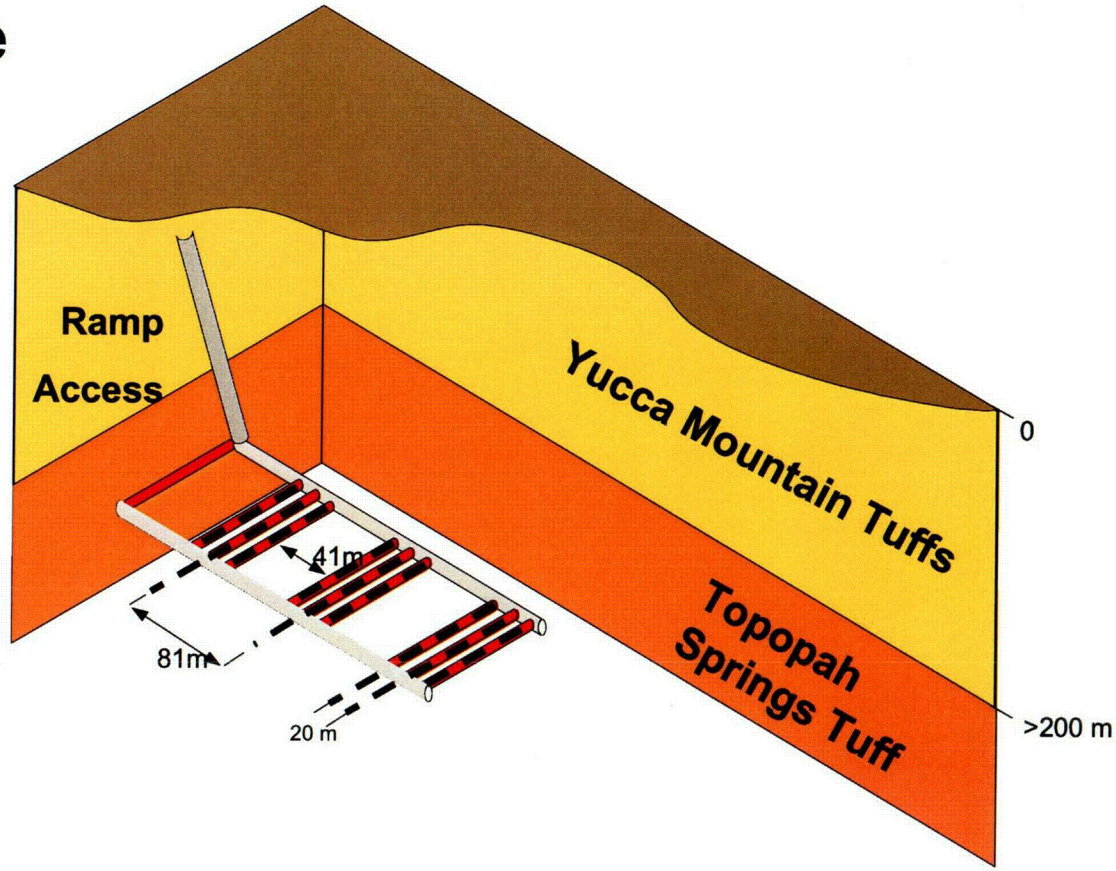
c) Section perpendicular to AA'
Note: The 60 km of drifts in the EDA II design could be accommodated as 3 layers of 20 drifts per layer, each drift 1 km long

© 2006 Electric Power Research Institute, Inc. All rights reserved.

ELECTRIC POWER RESEARCH INSTITUTE

Option 3: "Grouped" Disposal Drifts

- Groups of three at the same elevation
- 20-meter spacing within the group
- Leaves 41 meters between groups ("pillar")
- Same and lower line loads considered (1.45 and 1.0 kW per meter)



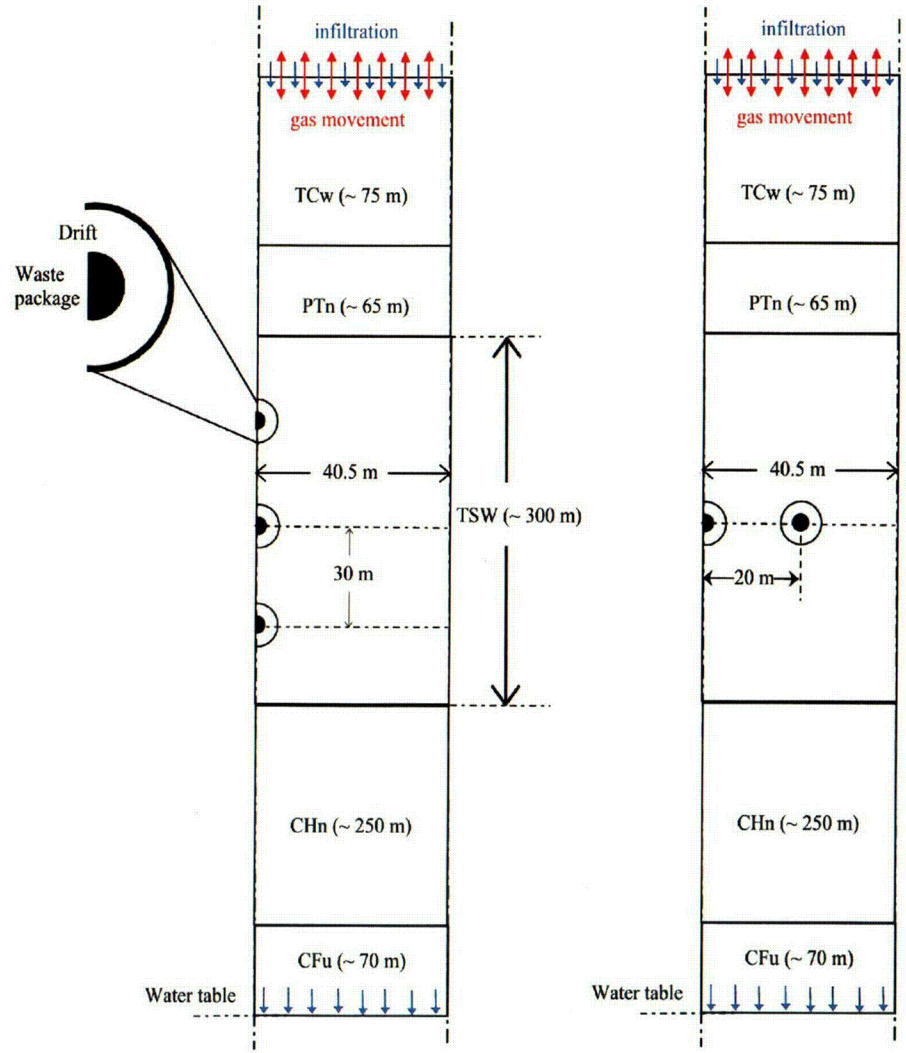
© 2006 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

C53

Thermal Analysis of Options 2 and 3

- Used TOUGH2 Code (same as used by DOE/YMP)
  - 2-D model initially
- Used DOE/YMP published, reference tuff properties
- Successful calibration benchmark to DOE/YMP results for reference repository design
- Option 2: 3-level repository (left)
- Option 3: 3-grouped drifts (right)



© 2006 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

C54

Option 2: Multi-level Repository Permutations Considered

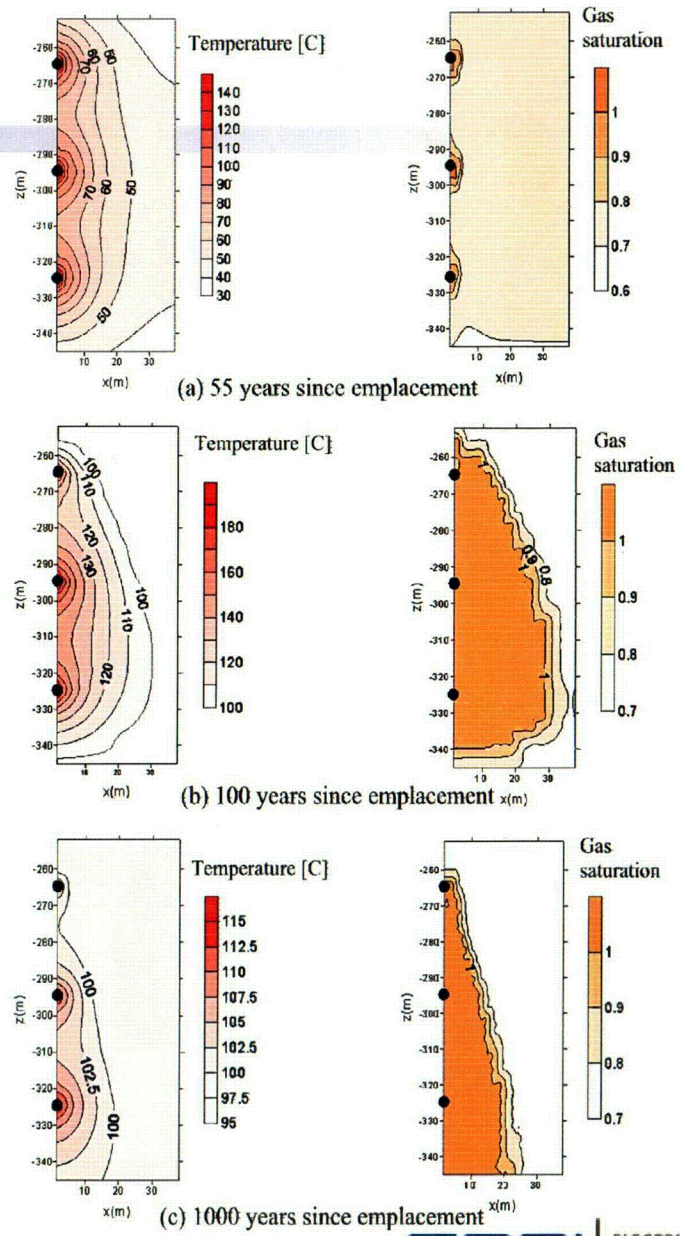
Case	Repository Concept	Initial Loading	Expansion Factor	Ventilation Duration/Effic.
1	Three-level, 30-m vertical drift spacing	1450 W/m for all waste packages	3 times	0 – 50 yrs: 86.3%
2	Three-level, 30-m vertical drift spacing	1000 W/m for all waste packages	2 times	0 – 50 yrs: 86.3%
3	Three-level, 50-m vertical spacing	1000 W/m for all waste packages	2 times	0 – 50 yrs: 86.3%
4	Three-level, 50-m vertical spacing	1450 W/m for all waste packages	3 times	0 – 50 yrs: 86.3%
5	Three-level, 30-m vertical spacing	1450 W/m for all waste packages	3 times	0 – 50 yrs: 87.3%; 50 – 300 yrs: 93%
6	Three-level, 30-m vertical spacing	1000 W/m for all waste packages	2 times	0 – 50 yrs: 87.3%; 50 – 300 yrs: 93%

Expansion Factor = Maximum MTHM of CSNF/ 70,000 MTHM

© 2006 Electric Power Research Institute, Inc. All rights reserved.

Option 2: Multi-level Repository Example Output (Case 1)

- Upper level performs the same as the DOE 1-level HTOM design.
- Above-boiling period in lower drifts lasts several thousands of years after repository closure.
- In some cases, the 'pillar' between the lower two levels is predicted to dry out for 200-300 years before returning to sub-boiling drainage conditions.
- *Conservative analysis*: Including convection and 3-D edge-cooling/ condensation effects would lead to drainage of condensate water as well as lower, less extensive and shorter temperature excursions, (i.e., no blockage of 'pillars').



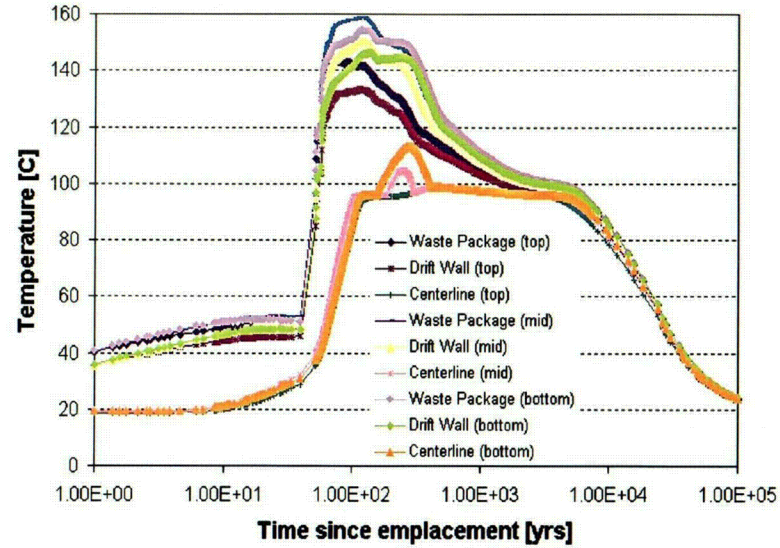
© 2006 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

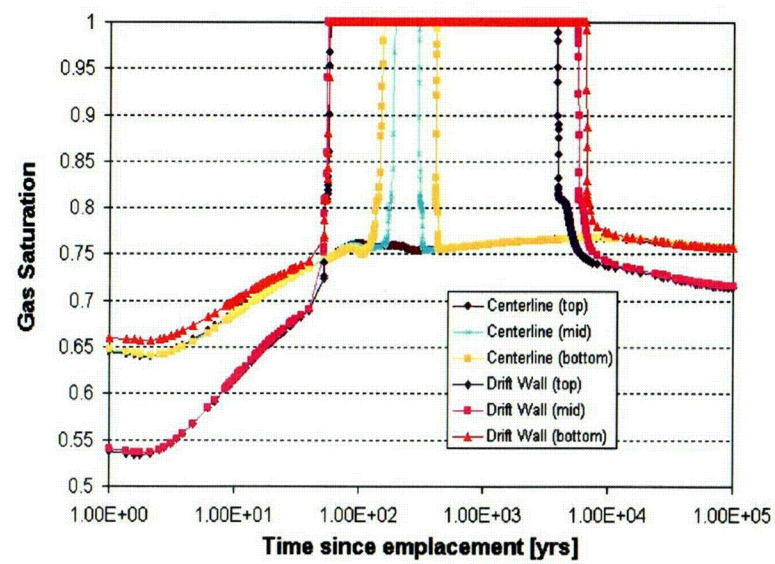
C55

Option 2: Multi-level Repository Example Output (Case 1) (cont'd.)

- Peak temperatures do not exceed limits for waste package, cladding, or tuff
- Duration of 'pillar' blockage is short relative to 'thermal barrier' period around drifts
- Blocked condensate water unlikely to be transported via 'heat pipes' through 'thermal barrier' to emplacement drifts



(a) Temperature vs. time



(b) Gas saturation vs. time

© 2006 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

C56

Option 3: Grouped-drift Repository Permutations Considered

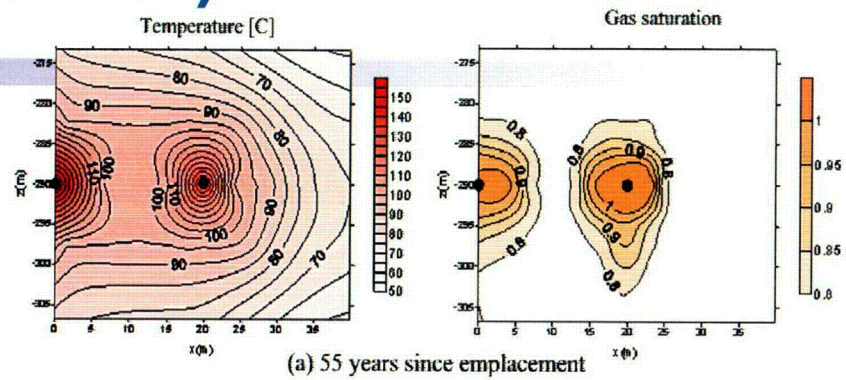
Case	Repository Concept	Initial Loading	Expansion Factor	Ventilation Duration/Effic.
7	Single-level, 3-drifts 20-m apart	1450 W/m for all waste packages	3 times	0 – 50 yrs: 87.3%; 50 – 300 yrs: 93%
8	Single-level, 3-drifts 20-m apart	1450 W/m for center waste package, 725 W/m for side drifts	2 times	0 – 50 yrs: 87.3%; 50 – 300 yrs: 93%
9	Single-level, 3-drifts 20-m apart	1450 W/m for center waste package, 725 W/m for side drifts	2 times	0 – 50 yrs: 86.3%.
10	Single-level, 3-drifts 20-m apart	1450 W/m for all waste packages	3 times	0 – 50 yrs: 86.3%.
11	Single-level, 3-drifts 20-m apart	1450 W/m for all waste packages	3 times	0 – 50 yrs: 91%; 50 – 300 yrs: 96%
12	Single-level, 3-drifts 20-m apart	1450 W/m for center waste package, 725 W/m for side drifts	2 times	0 – 50 yrs: 91%; 50 – 300 yrs: 96%

Expansion Factor = Maximum MTHM of CSNF/ 70,000 MTHM

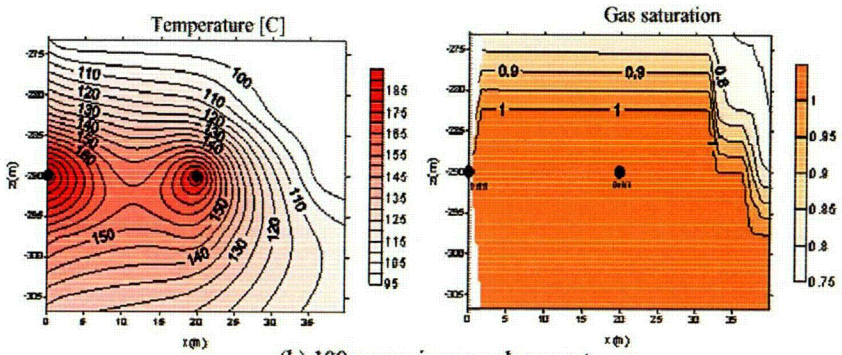
© 2006 Electric Power Research Institute, Inc. All rights reserved.

Option 3: Grouped-drift Repository Example Output (Case 10)

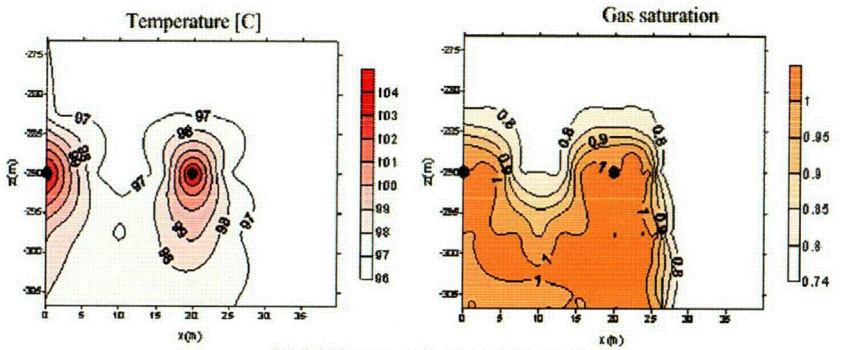
- Center drift attains and sustains highest temperature
- Temporary blockage of 'pillars' for several hundred years
- Sub-boiling 'pillar' eventually opens between all emplacement drifts



(a) 55 years since emplacement



(b) 100 years since emplacement



(c) 1000 years since emplacement

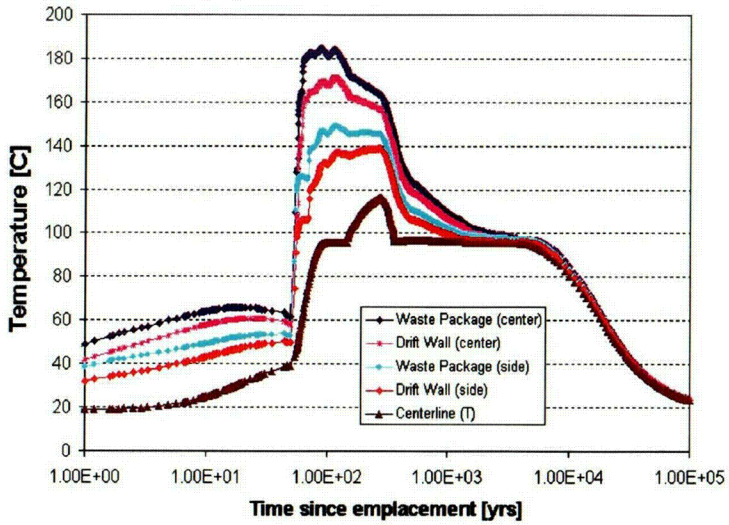
© 2006 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

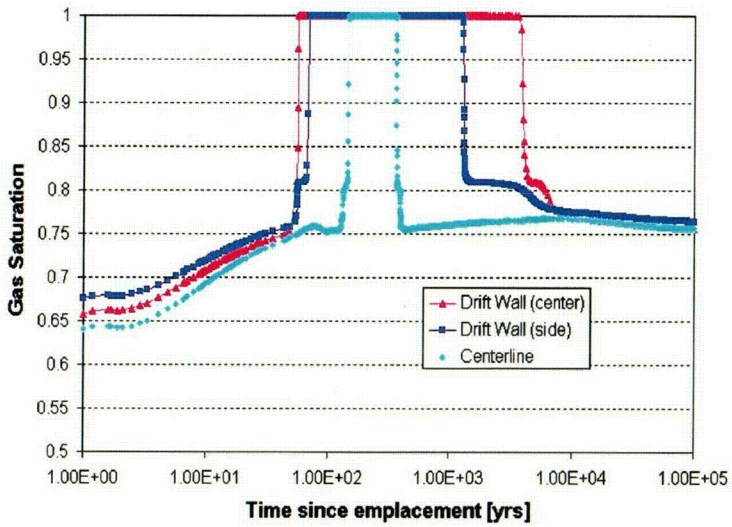
C57

Option 3: Grouped-drift Repository Example Output (Case 10) (continued)

- Peak temperatures do not exceed limits for waste package, cladding, or tuff
- Duration of blockage (i.e., above-boiling condition) of 'pillar' much shorter than 'thermal barrier' period of drifts



(a) Temperature vs. time



(b) Gas saturation vs. time

© 2006 Electric Power Research Institute, Inc. All rights reserved.

EPRI ELECTRIC POWER RESEARCH INSTITUTE

C58

Derived Expansion Factors

Option 1: Extended 'Footprint":
2 to 3.5 times the current legislative limit of 70,000 MTHM

Option 2: Multi-level Repository:
2 to 3 times the current CSNF limit of 63,000 MTHM

Option 3: Grouped-drift Repository:
2 to 3 times the current CSNF limit of 63,000 MTHM

© 2006 Electric Power Research Institute, Inc. All rights reserved.

Combining Option 1 with Option 2 or 3

- At least four times the existing CSNF limit can be emplaced at Yucca Mountain with current or limited additional information (~260,000 MTHM)

- With additional site characterization and/or design optimization, possibly upwards of nine times the existing CSNF limit could be emplaced (~570,000 MTHM)

© 2006 Electric Power Research Institute, Inc. All rights reserved.

Summary

- *Preliminary* EPRI analysis of the Yucca Mountain maximum physical capacity for CSNF
  - Additional work in 2006 will explore these options in more detail
- Four to nine times the existing limit for CSNF possible
- Options EPRI considered have minimal impacts on cost or schedule of DOE's current 70,000 MTHM design:
  - Start with DOE's High-Temperature Operating Mode (HTOM), line-loaded repository design
  - Use current site characterization information
  - Additional information required to expand repository can be collected in parallel

© 2006 Electric Power Research Institute, Inc. All rights reserved.

BACKUP SLIDES

© 2006 Electric Power Research Institute, Inc. All rights reserved.

Results Summary

Cases	Maximum WP Temperature	Maximum Drift Wall Temperature	Above-Boiling Time Duration at WP and near Drift [yrs][1]	Maximum Temperature at Centerlines of Pillars between Drifts	Location and Duration of Dry-out at Centerline of Pillars between Drifts[2]
1	214 °C at 90 yrs	197 °C at 94 yrs	53 – 12,700	142 °C at 300 yrs	Lower two drifts; 112 – 414 yrs
2	158 °C at 113 yrs	150 °C at 122 yrs	57 – 6,550	113 °C	Lower two drifts; 155 – 406 yrs
3	138 °C at 182 yrs	132 °C at 186 yrs	65 – 6,200	100 °C	Bottom drift; 245 - 344 yrs
4	184 °C at 118 yrs	172 °C at 121 yrs	54 – 12,100	129 °C	Lower two drifts; 142 – 396 yrs
5	128 °C at 576 yrs	124 °C at 608 yrs	400 – 12,100	96 °C	No
6	111 °C at 844 yrs	109 °C at 844 yrs	500 – 6,500	96 °C	No
7	147 °C at 519 yrs	139 °C at 519 yrs	340 – 3,840	111 °C	433 – 593 yrs
8	115 °C at 744 yrs	112 °C at 746 yrs	490 – 3,600	96 °C	No
9	184 °C at 88 yrs	171 °C at 115 yrs	60 – 3,600	116 °C	148 – 362 yrs
10	229 °C at 67 yrs	198 °C at 227 yrs	56 – 3,870	154 °C	107 – 382 yrs
11	146 °C at 523 yrs	138 °C at 525 yrs	330 – 3,660	110 °C	441 – 603 yrs
12	115 °C at 718 yrs	111 °C at 805 yrs	520 – 3,500	96 °C	No

[1]: The listed above-boiling time period is the longest among all the drifts.

[2]: In cases where more than one pillars experience dry-out, the listed is the longest among all the pillars

© 2006 Electric Power Research Institute, Inc. All rights reserved.

Potential Additional 2006 EPRI Work on Yucca Mountain Technical Capacity

- More detailed hydrothermal modeling
  - 3-D to include edge effects
- Construction issues
  - No significant issues expected
  - May have to construct 2nd/3rd drifts after first is loaded
- Need for additional ventilation
- Surface aging to achieve even higher mass loadings
- Different loadings within drift "triplets"
- Description of additional site investigation and R&D needs and general schedule for completion
- Effects of higher pillar temperatures on fracture opening or closing
- Report to be completed by end of 2006

© 2006 Electric Power Research Institute, Inc. All rights reserved.