



U.S. Department of Energy  
Office of Civilian Radioactive Waste Management



# Update on Development of Seismic Inputs for Yucca Mountain, Nevada

Presented to:  
**Nuclear Waste Technical Review Board**

Presented by:  
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**DOE/USBR**

**May 18, 2004**  
**Washington, DC**

# Yucca Mountain Ground Motions

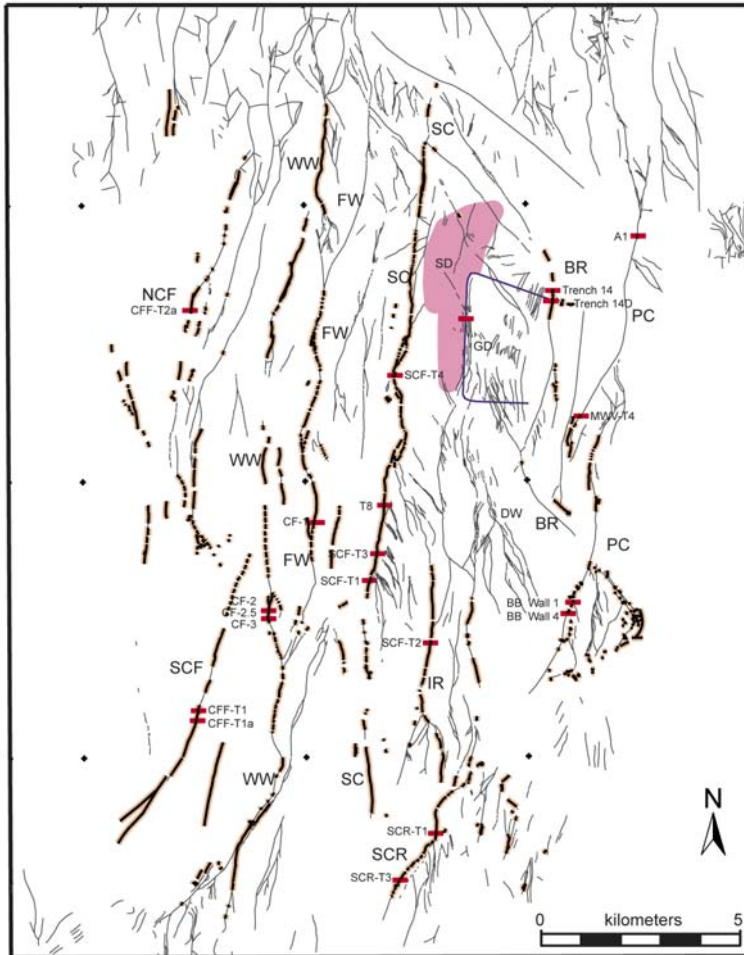
- **Summary of studies to date**
- **Low probability seismic events**
- **Development of realistic low probability ground motions (peak ground velocity)**



# Background

- **Yucca Mountain Probabilistic Seismic Hazard Analysis (PSHA) is based upon good science conducted using state-of-the-art expert elicitation (SSHAC Level 4) methodology**
  - Reviewed by NAS, accepted by NRC for application in nuclear facility licensing, consistent with NRC Branch and Staff technical position
  - Includes epistemic uncertainties and aleatory variability in seismic sources and ground motions
  - Aleatory variability in ground motion attenuation is unbounded lognormal distribution, a highly conservative approach
  - Fundamental basis for preclosure and postclosure ground motion assessment
  - Anticipated focus on annual frequencies greater than  $10^{-5}$  to  $10^{-6}$  based on experience with nuclear power plants
  - Mean seismic hazard used for design and performance confirmation





**Legend**

- Paleoseismic Trench Locations
  - Faults: Quaternary and suspected Quaternary age of last movement
  - Faults: pre-Quaternary or undetermined age of last movement
  - Approximate Repository Area and Exploratory Studies Facility
- |       |                      |
|-------|----------------------|
| BR =  | Bow Ridge            |
| DW =  | Dune Wash            |
| FW =  | Fatigue Wash         |
| GD =  | Ghost Dance          |
| IR =  | Iron Ridge           |
| NCF = | Northern Crater Flat |
| PC =  | Paintbrush Canyon    |
| SD =  | Sundance             |
| SC =  | Solitario Canyon     |
| SCF = | Southern Crater Flat |
| SCR = | Stagecoach Road      |
| WW =  | Windy Wash           |

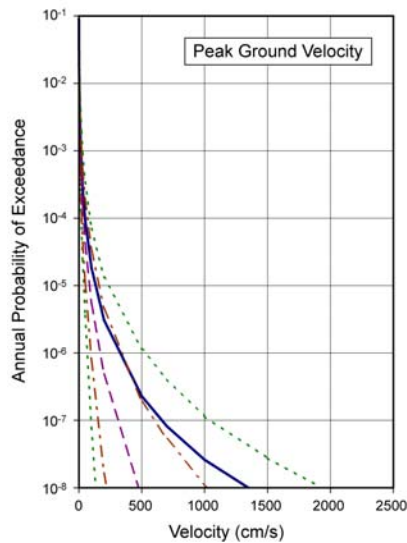
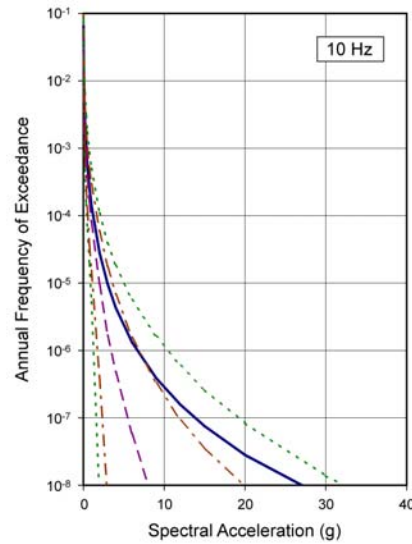
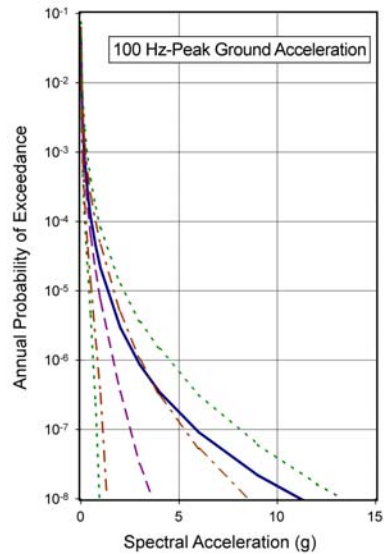
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# PSHA:

- **Source characterization +Ground motion estimation**
- **Evaluation of local fault sources in PSHA, supported by numerous trenches**
- **Empirical and theoretical ground motion estimates**



# PSHA Seismic Hazard Curves



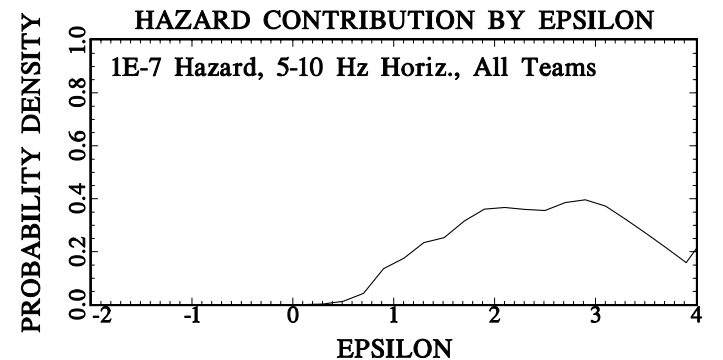
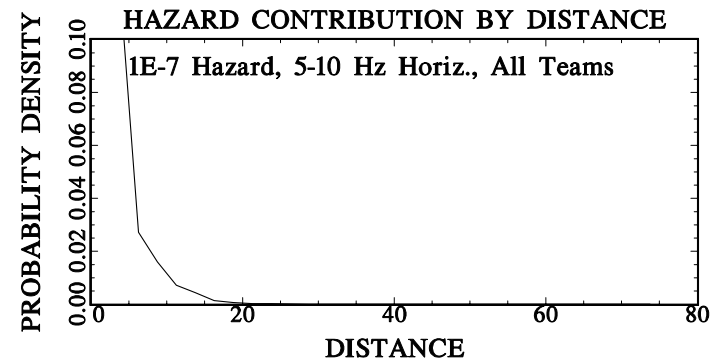
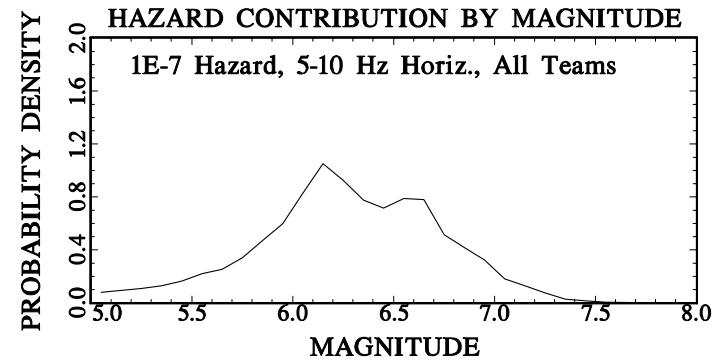
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# Ground Motion Hazard Results:

- Hazard deaggregation based on magnitude, distance, and epsilon
- For low annual probabilities, hazard from moderate magnitude nearby sources, and high epsilon dominates



# Analysis of Results

- **Very large ground motions and highly asymmetric probabilities for low Annual Probability of Exceedance (APE)**
- **Back-calculation of source parameters consistent with low probability ground motions suggests physically unrealistic values**
- **Seismic inputs developed for low APE with site-response model produce very large strains (inconsistent with observed rock strength)**
- **NWTRB has indicated in correspondence to DOE that this highly conservative approach produces unrealistic values**



# Outline

- **A fundamental constraint: Ground motion amplitudes limited by the strength of the materials through which they propagate**
- **Establish shear strain limits that produce failure/fracturing in tuff units**
- **Shear strain-fracturing criteria needs to be consistent with resolution of geologic observations**
- **Calculate ground motions consistent with strain threshold**





# Limits to Ground Motions

- **Cutting edge research topic-Yucca Mountain and PEGASOS (Swiss) projects**
- **Absolute physical limits are difficult to define**
- **Approach as site-specific analysis within a probabilistic framework**

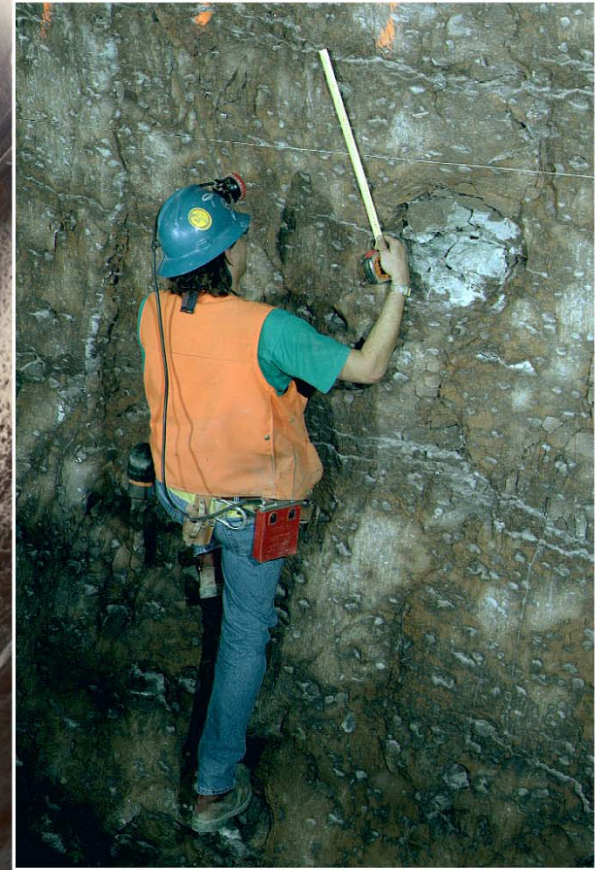
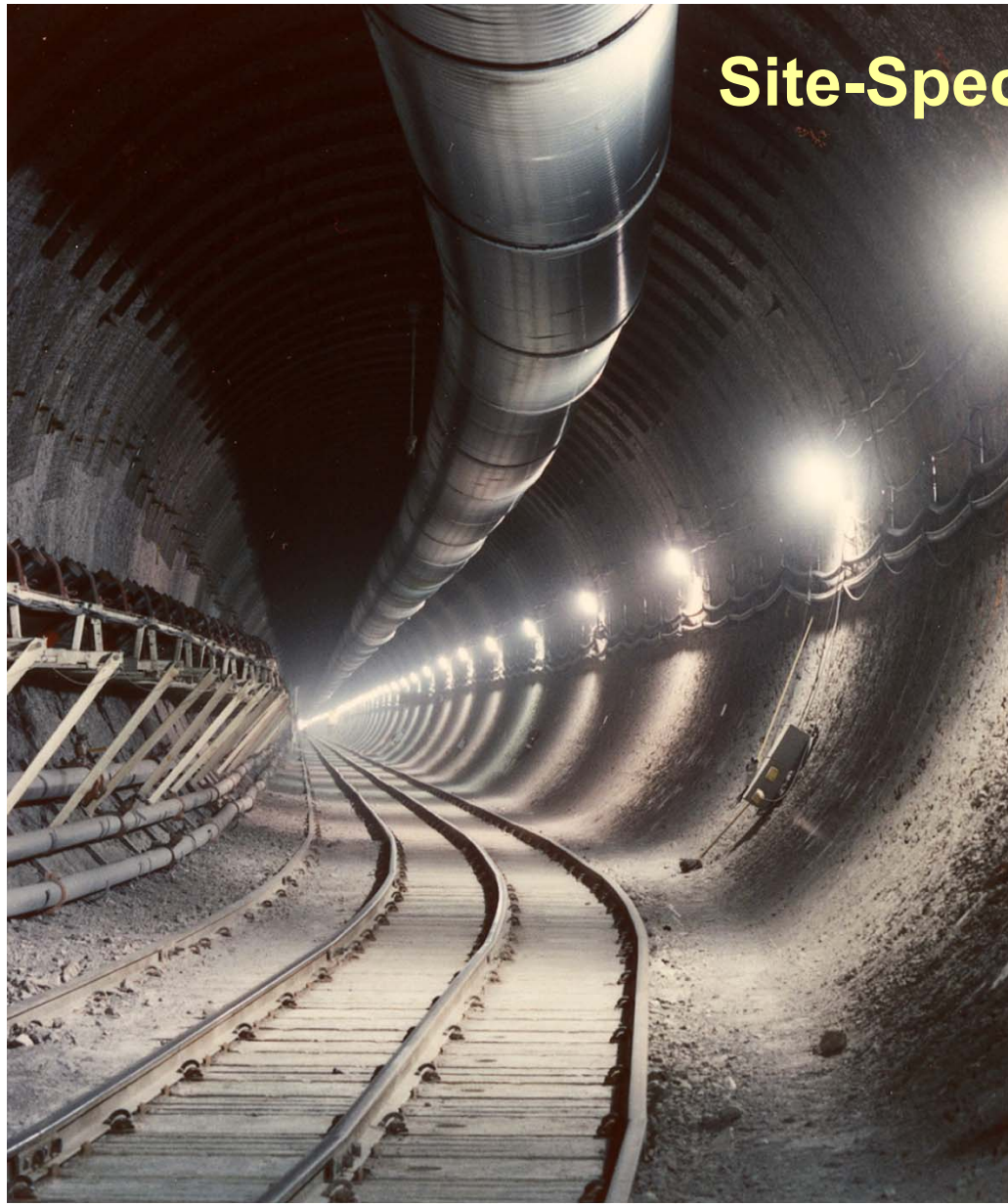


# Background

- **Ground motion amplitudes at very low annual frequencies higher than observed worldwide and may be physically unrealizable**
- **Peak ground velocity (PGV) is ground motion measure of interest; related to EBS damage and rockfall**
- **Intact tuffs and delicate mineral deposits suggests no extreme ground motions have occurred at this site since deposition of repository rocks (~12Mya)**
- **DOE has decided to evaluate bounding ground motions (on PGV) using site-specific physical arguments**



# Site-Specific Investigations



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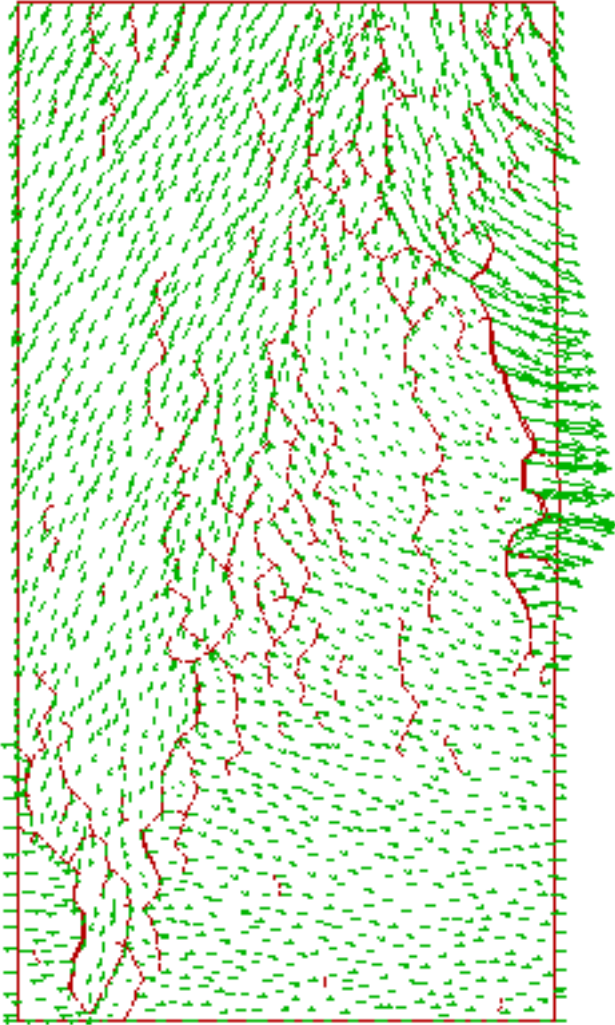
# Geologic Observations of Fractures and Lithophysae

- **Core and thin sections**
  - Small-scale (mm to cm)
  - Development and confirmation of petrogenetic relations
- **Detailed line surveys in ESF and ECRB**
  - Small- to large-scale (cm to km)
  - Geometric and petrogenetic relations of discontinuities
- **Photogrametric lithophysae inventory in ECRB**
  - Small- to intermediate-scale (mm to m)
  - Shape of lithophysae as indicators (or lack) of deformation

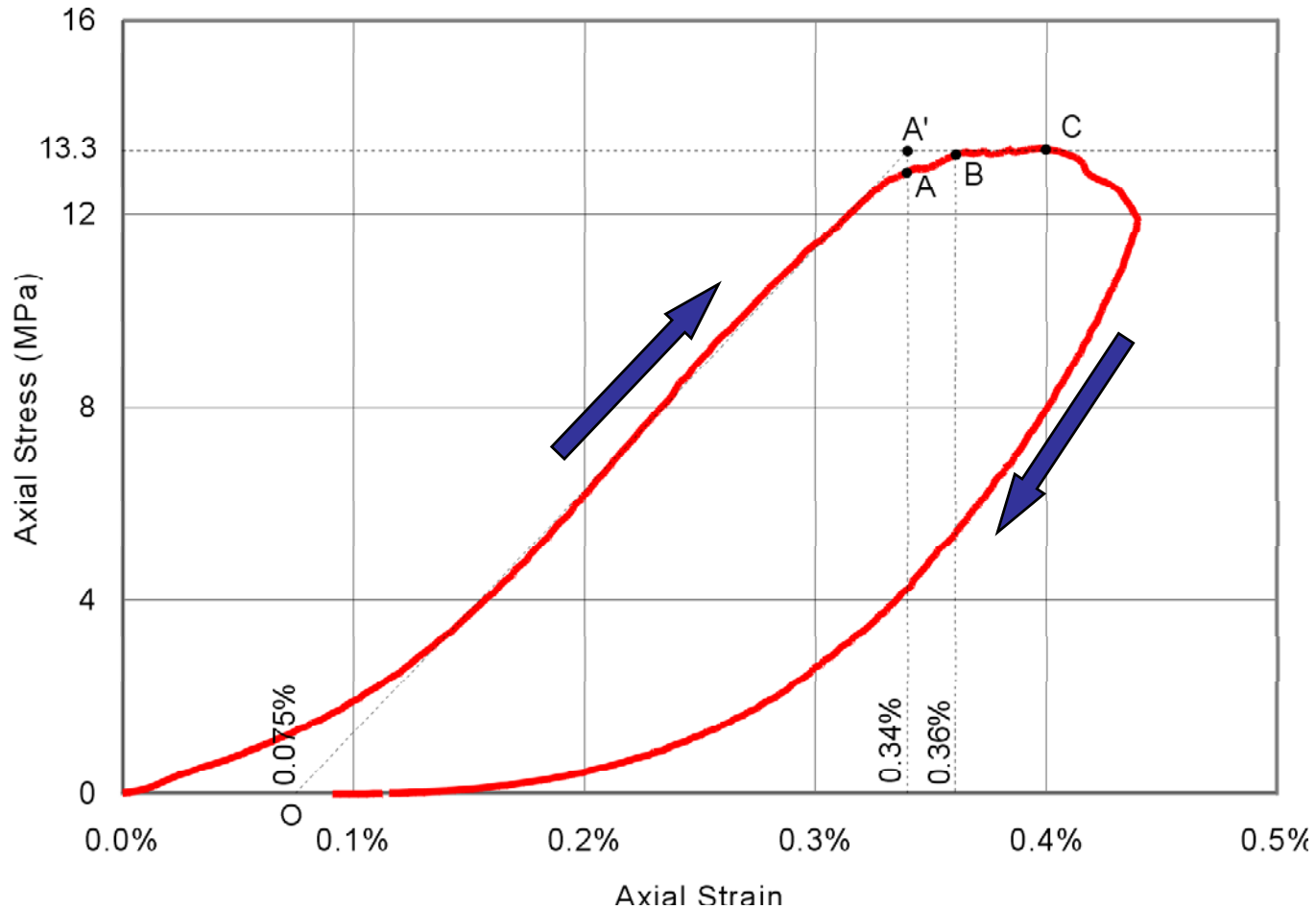




# Comparison of Model Failure Mechanism at Large Core-Scale



# Stress-strain curve for 288-mm Sample of Lower Lithophysal Tuff at Surface Conditions



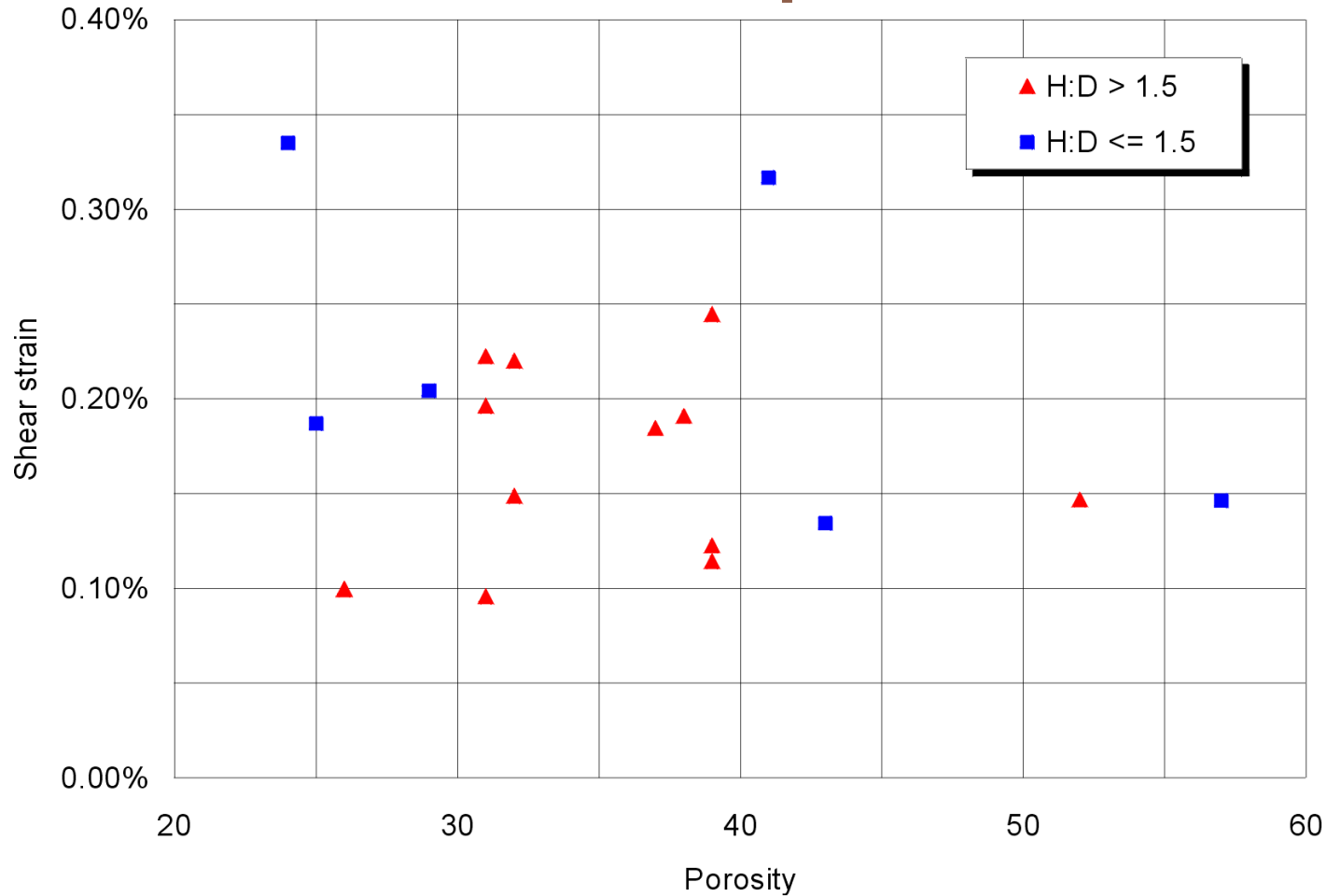
**Strain increment adjusted for 250 m overburden = 0.2%**





# Experimental Results

## Large Samples, Corrected for In situ Stresses at Overburden Depth of 250 m



***Calculated shear strain limit for 288-mm diameter samples***



# Testing and Modeling for Shear Strain Threshold

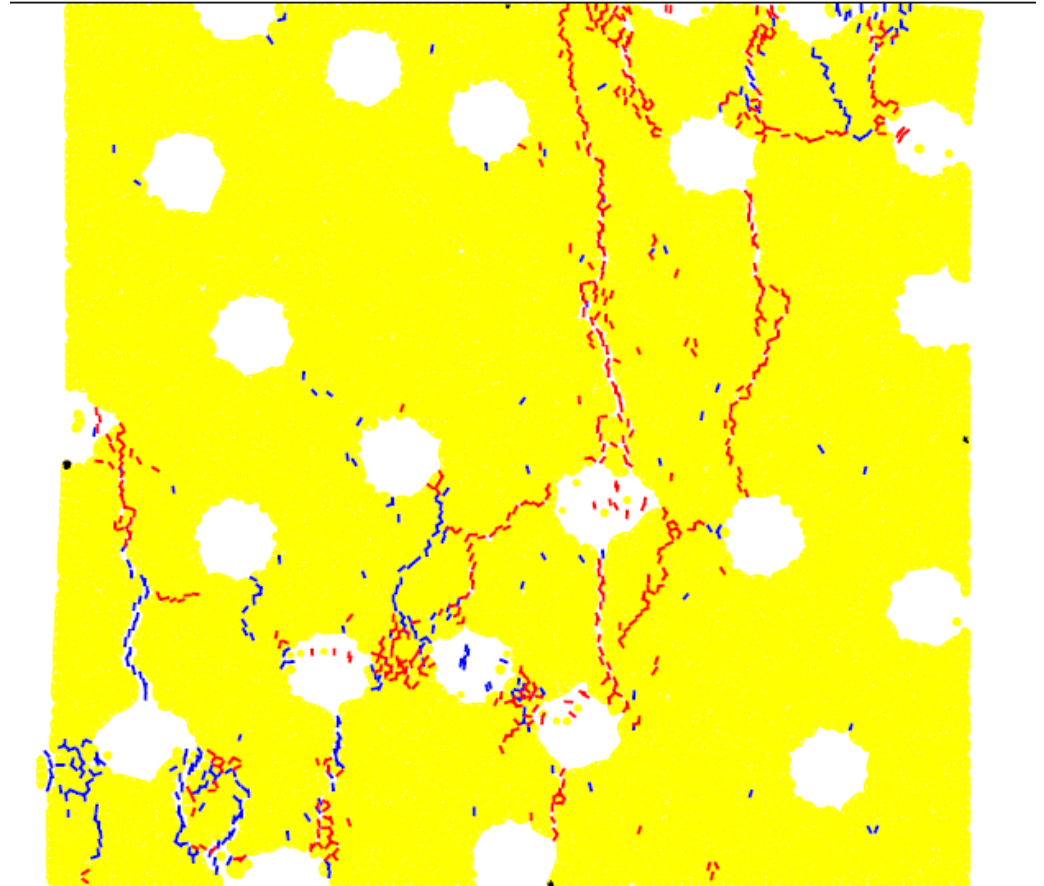
- **Focus on lithophysal units, which would fail at lower strain levels**
- **Uniaxial compression tests, confined and unconfined, large and small samples**
- **Few cyclic tests**
- **Failure criteria: peak stress, volumetric strain reversal**
- **Modeling calibrated to test results**



# Modeled Deformation of Lithophysal Tuff

Fracturing of this magnitude inferred to be within observational limits of geologic mapping

Onset of Systematic Fracturing (OSF)



*Fractures developed in lithophysal sample  
(blue = pre-peak, red = post-peak)*



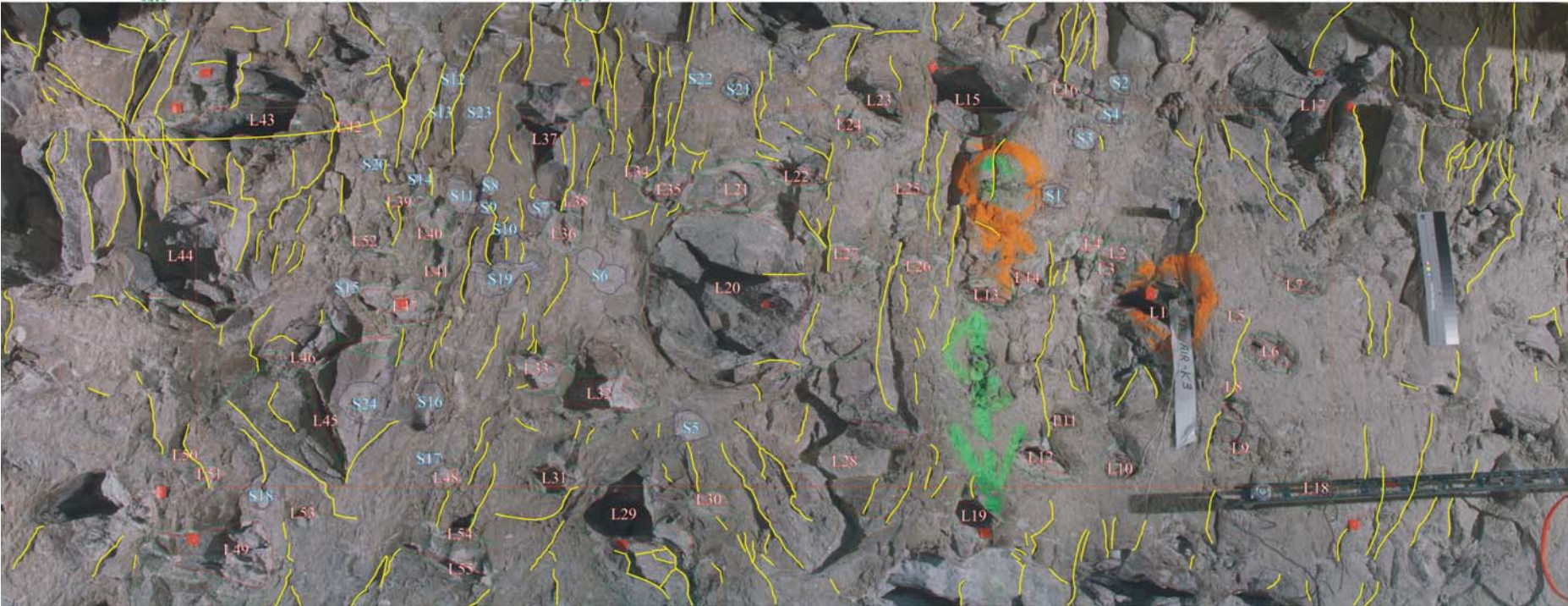
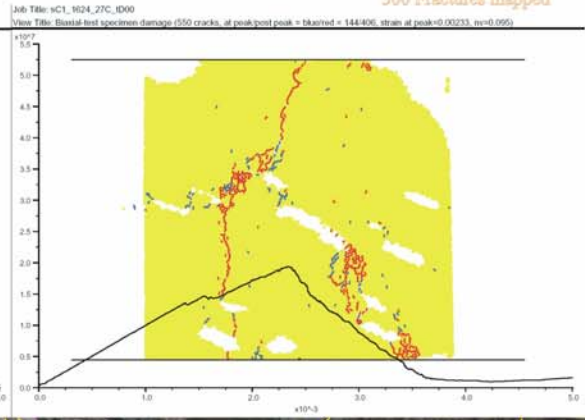
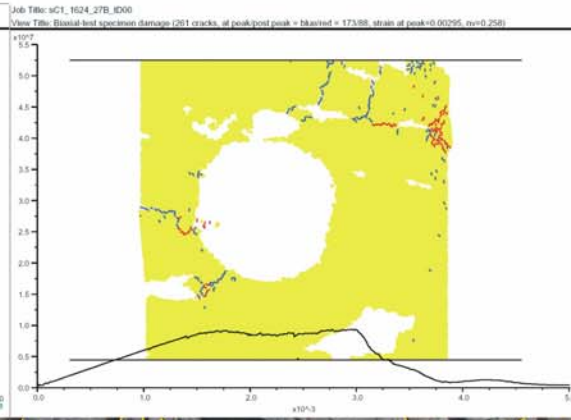
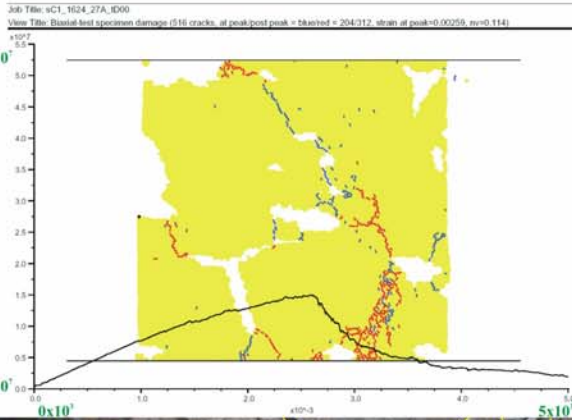


# PMap 1624L and PFC Models (300 Fractures)

Panel Map at 1624-27R(Ttptll) in the ECRB cross drift and PFC model results (stress -strain & damage)

300 Fractures mapped

100 mm  
10 cm  
200 mm  
20 cm  
500 mm  
50 cm  
1000 mm  
1 m



# Summary of Statistics of Calculated Shear Strain Limits Based on Different Experimental Results

	Number of samples	Mean	Standard deviation
		%	%
<b>288-mm diameter, H/D &gt; 1.5</b>	<b>13</b>	<b>0.16</b>	<b>0.05</b>
<b>288-mm diameter, all</b>	<b>19</b>	<b>0.18</b>	<b>0.07</b>
<b>146-mm diameter</b>	<b>16</b>	<b>0.20</b>	<b>0.04</b>
<b>Busted Butte, 200-mm diameter</b>	<b>5</b>	<b>0.13</b>	<b>0.03</b>

Price, 2004



# Assessment of Bounding PGV

- **Fundamental physical constraint: Absence of geologic indicators of seismically-induced deformation in repository rocks at emplacement level**
  - Geologic observations of fractures and lithophysae
  - Laboratory tests of shear strains causing failure
- **Development of probability distribution on threshold shear strain (OSF)**
  - Ground motions associated with threshold shear strains
- **Multiple lines of supporting evidence**
- **Assessment of bounding PGV expressed as probability distribution to reflect uncertainties; studies are ongoing**





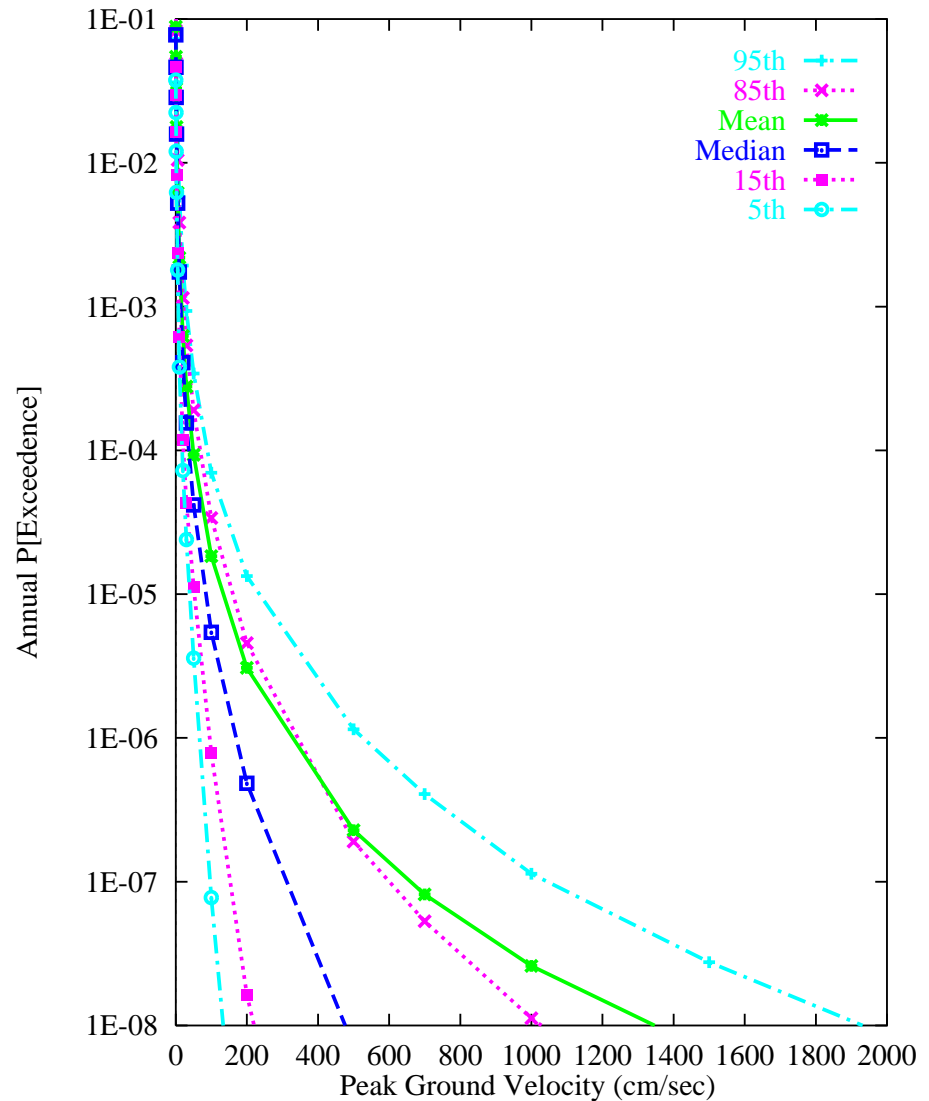
# Distribution for Strain Consistent with OSF

- **Truncated normal distribution**
- **Mean of 0.2%, sigma of 0.1%**
- **Limits at 0.05% and 0.4%**



# Ground Motion Hazard Results

**Application in TSPA:  
Comparison of sampled  
mean PGV from existing  
hazard vs. strength-limited  
value**



# Ground Motion Calculation

- **PGV calculated for given shear strain threshold, and associated uncertainty distribution**
- **Using full site response model to incorporate site specific properties, uncertainties, and variability**
- **Results in probability distribution on mean bounding PGV**



# Supporting Evidence

- **Seismic source constraints and observed ground motions**
- **Consideration of extensional faulting and shattered rocks (large motions will shatter rocks)**
- **Lack of offset of fractures since mineralization**
- **Delicate crystals and coatings showing lack of dynamic deformation**
- **Consideration of strength of geologic units beneath repository limiting motions**
- **Precarious rocks on Yucca Mountain suggest that aleatory variability for given site is too large**



# Shattered Rock, Hanging Wall, Thrust Fault

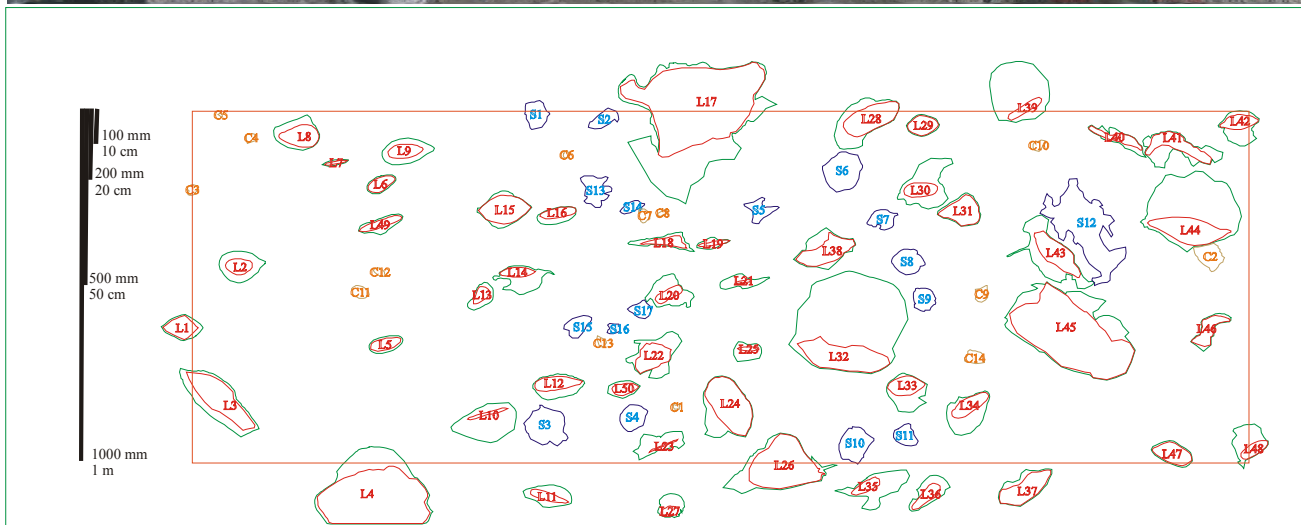
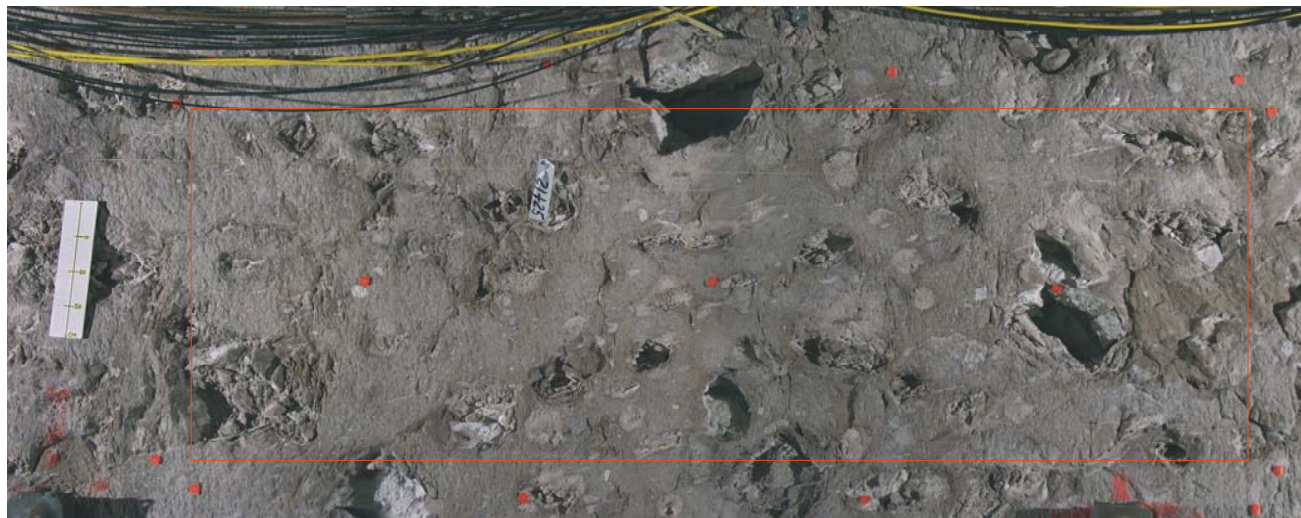


**Courtesy of Jim Brune, UNR**





# PMMap 21+25L



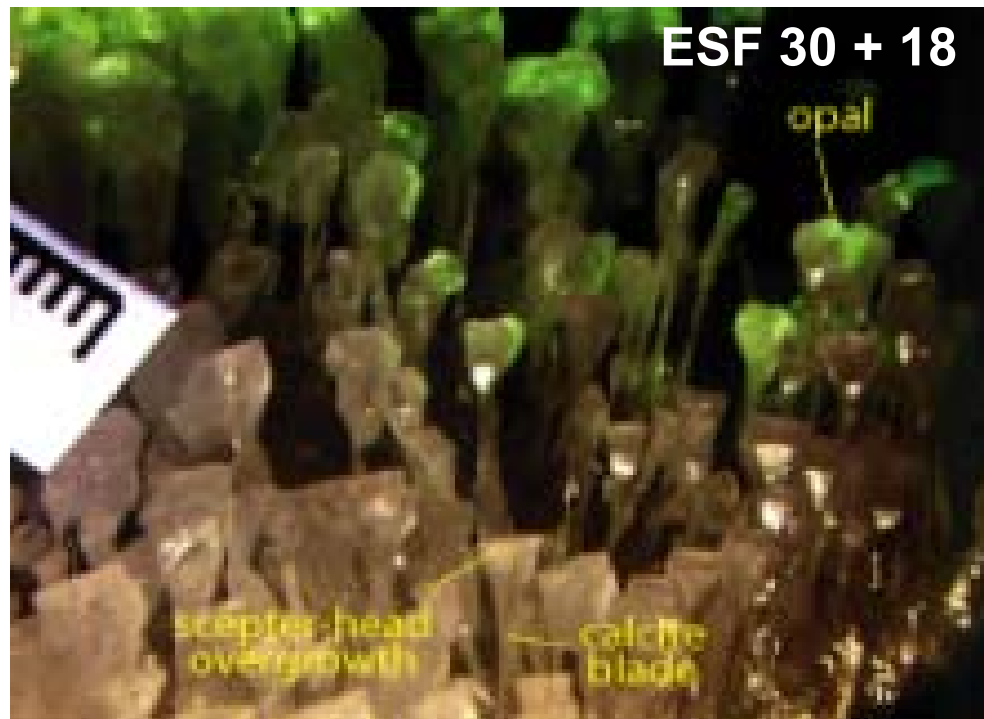
Lithophysae, spots, and clasts of Tptpl in panel map 2125 located on the left rib from station 21+25 to 21+28. Lithophysae have red "L" identifiers with cavities outlined in red and rims in green. Spots have blue "S" identifiers with cyan outlines. Lithic clasts have orange "C" identifiers with gold outlines.





# Preservation of Delicate Textures

- Exceptionally thin blades with top-heavy overgrowths
- Testing could be done to determine the minimum ground motions required to break them
- These late-stage features are relevant to ground motions during the past 2 to 4 million years



# Conclusions

- **PSHA for Yucca Mountain is fundamental basis for preclosure and postclosure ground motion assessment**
- **Strength-limited PGV being developed to ensure ground motions at very low annual frequencies are physically realizable and incorporate uncertainty**
- **Lack of geologic deformation related to seismically-induced strains in rocks at emplacement level**
- **Testing and modeling studies to assess threshold shear strains and associated uncertainties**
- **Documentation being developed for inclusion in License Application**
- **Supporting evidence**



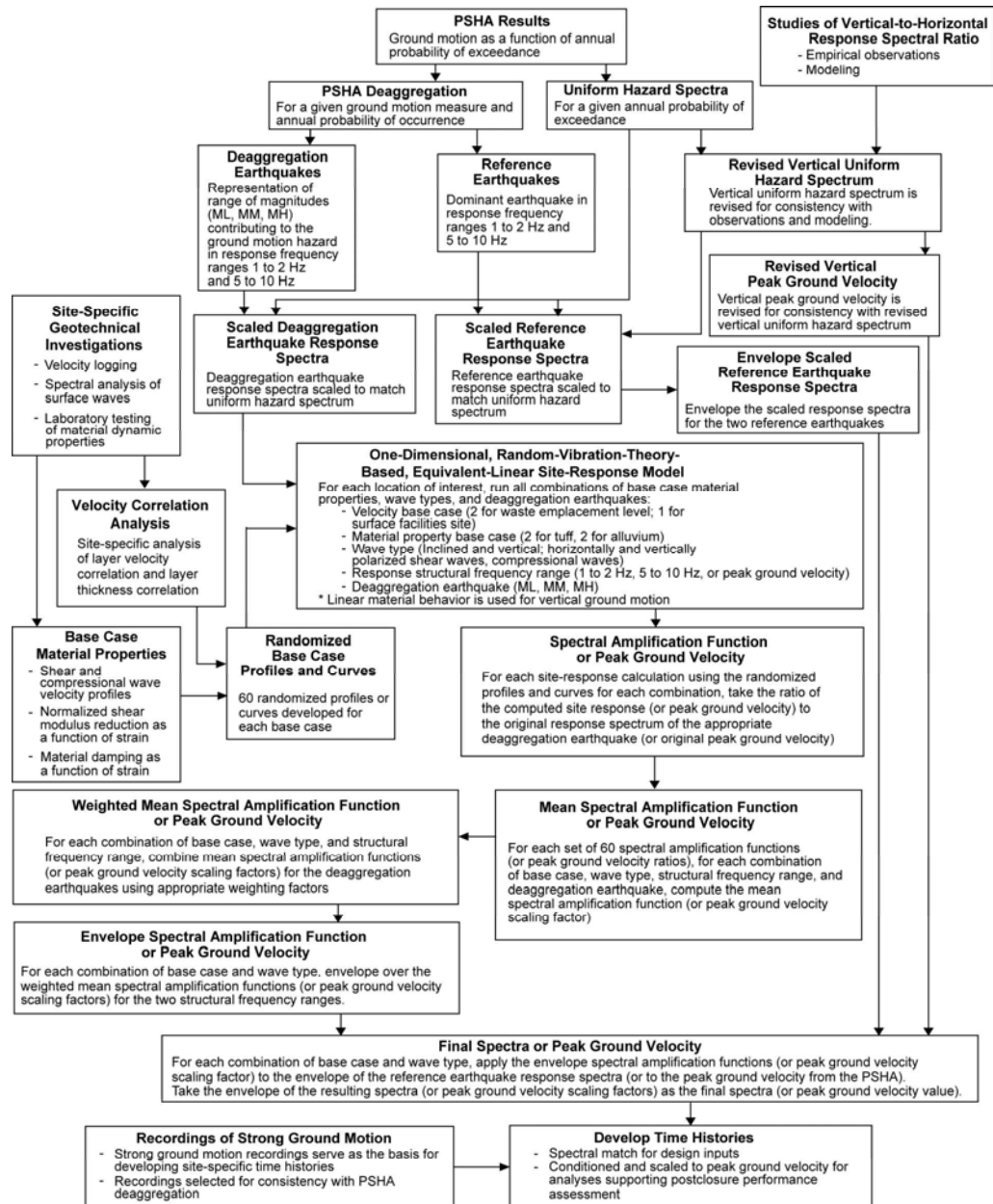
# Follow Up

- **Currently Completing an analysis report that documents the assessment of PGV based on shear strain threshold (OSF)**
- **Additional work will be undertaken that further refines potential limitations to ground motions imposed by the seismic source and non-linear wave propagation**



# Additional Slides

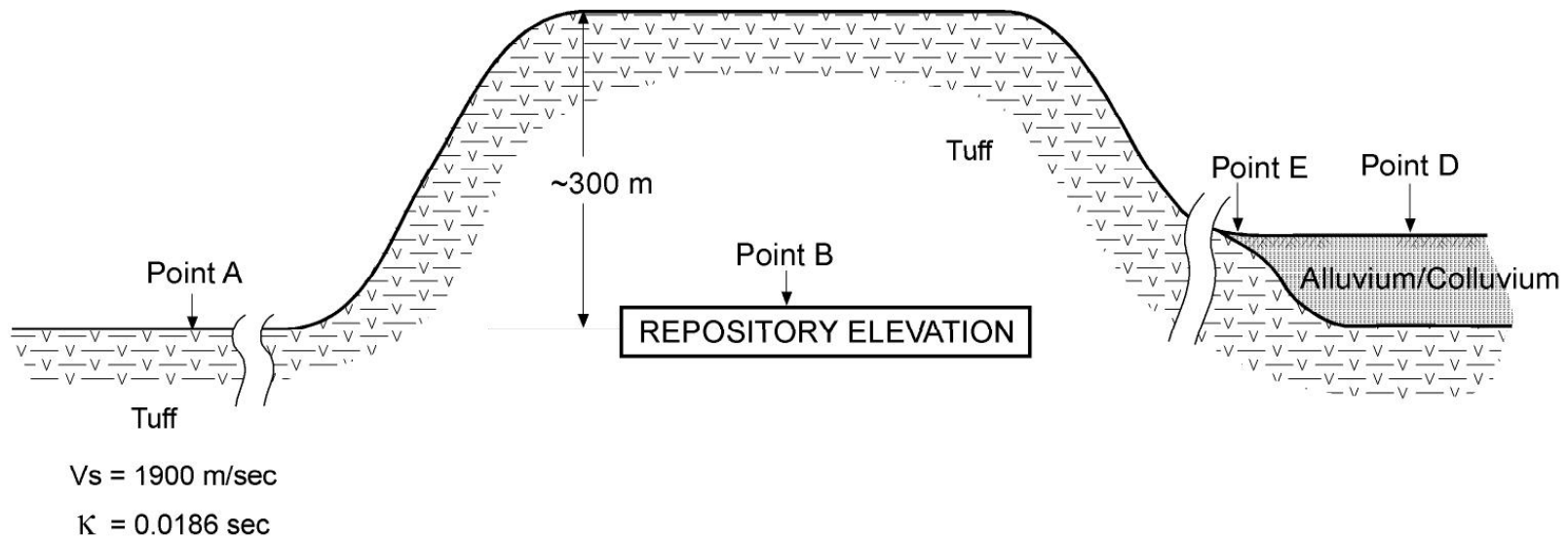




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# Ground Motion Hazard Results

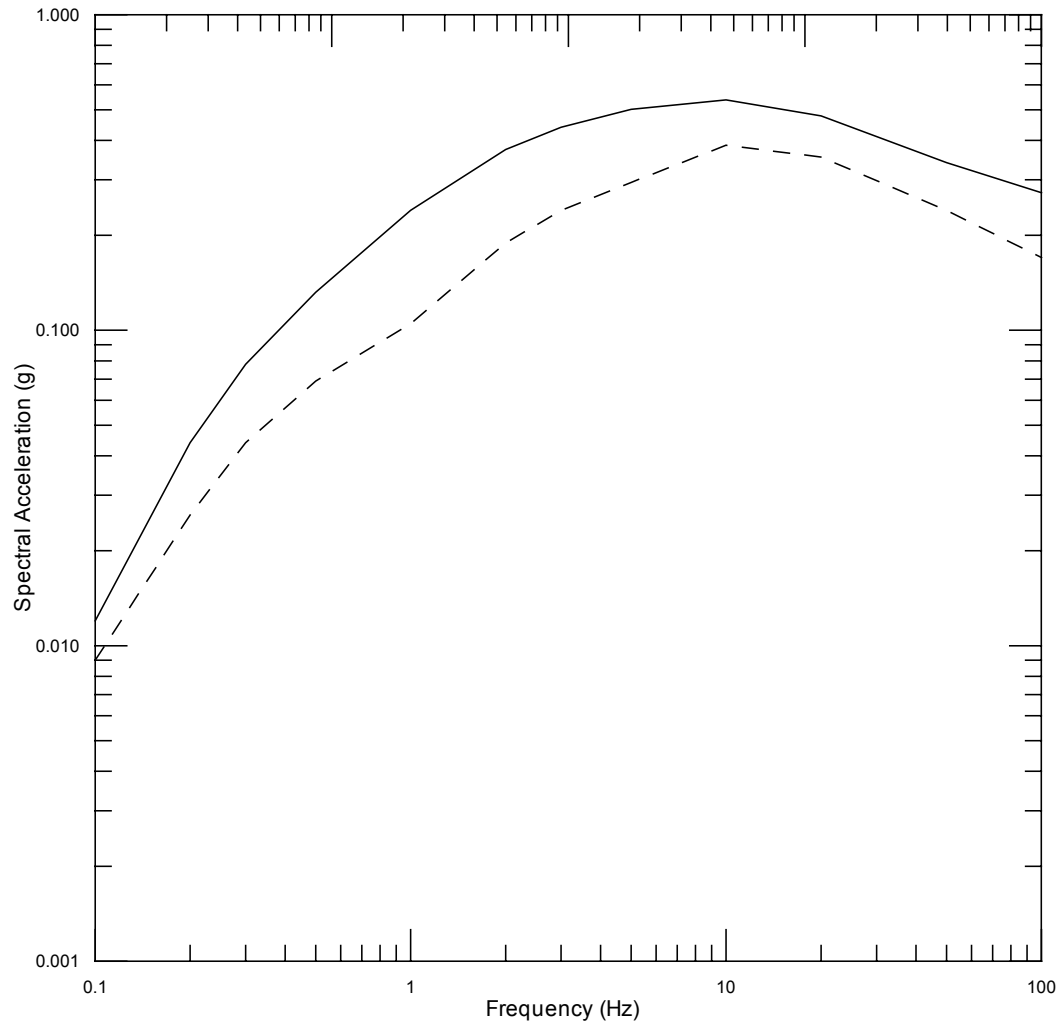


- **Ground motion hazard computed at control location (hypothetical point A), rock properties at control location are the same as those at repository elevation**
- **Aleatory variability of ground motion about the median motion for M and D not truncated**





# Uniform Hazard Spectra and Representative Events Used to Develop Time Histories

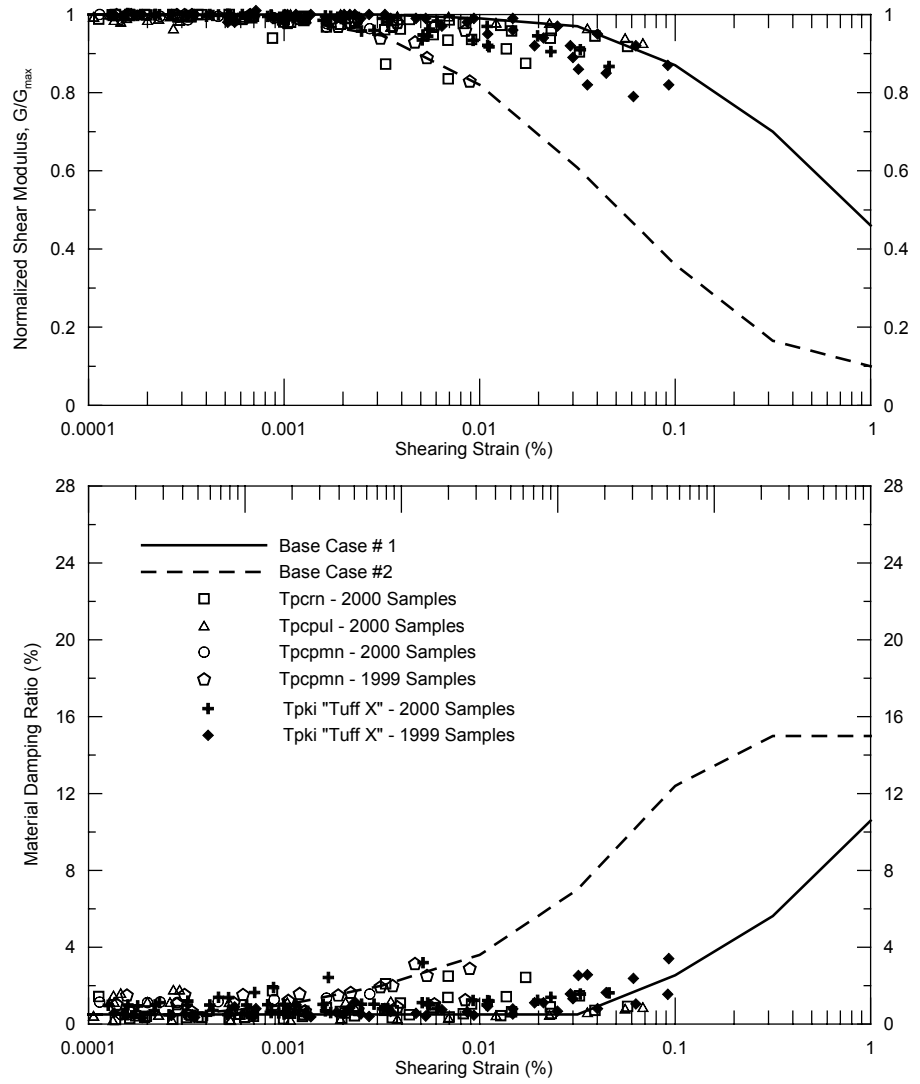


**$5 \times 10^{-4}$  AEP**

**LEGEND**  
— HORIZONTAL, PEAK GROUND ACCELERATION (PGA) = 0.273 g (Acceleration due to gravity)  
- - - VERTICAL, PGA = 0.170 g



# Variation in Normalized Shear Modulus and Damping Ratio with Shearing Strain (Tuff)



# Secondary Mineral Evidence of Past Seismicity

- **Drift Degradation AMR predicted future seismicity could produce extensive damage to emplacement drift walls**
- **Observational evidence from the secondary calcite and silica deposits in fractures and cavities shows some tuff fragmentation but it is restricted to the early history of the tuffs**



# Secondary Mineral Evidence of Past Seismicity

(Continued)

- **Three types of textural evidence of past seismicity:**
  - **Tuff fragments incorporated into secondary mineral coatings**
    - ◆ **Possible analog to degradation of drift walls**
  - **Preservation of delicate bladed textures**
  - **Undisturbed weakly attached fracture coatings**
- **The last two could provide paleo-seismoscopes**



# Incorporation of Tuff Fragments

**Mineral coatings have incorporated tuff fragments**

- **Common in the early stage (>6 to 8 Ma)**
- **Less common in the intermediate stage**
- **Rare in the late stage (last 2 to 4 million years)**

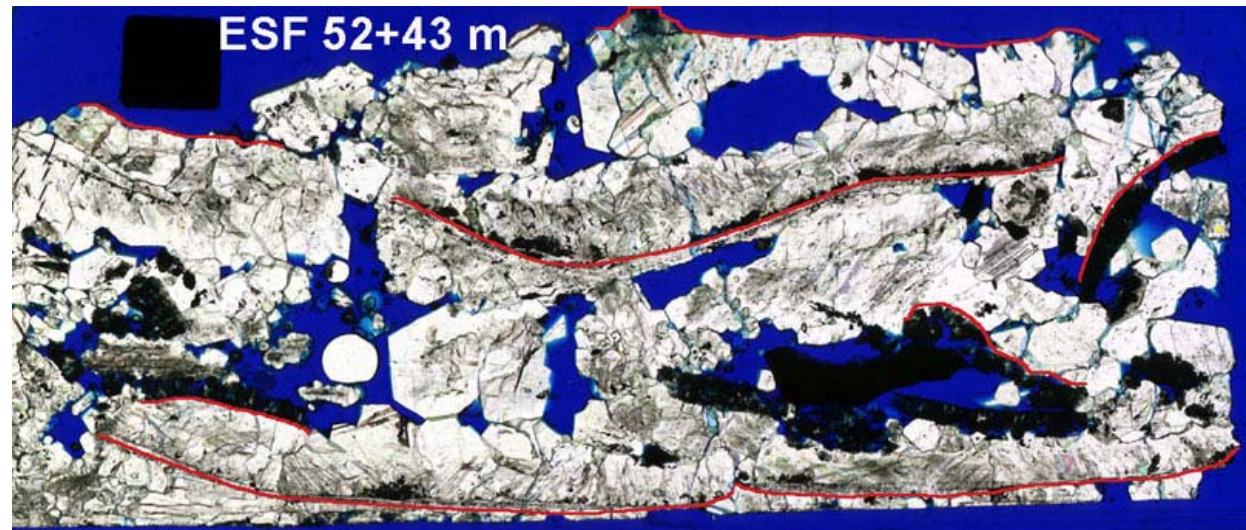


**Implies processes resulting in tuff fragmentation have become less common with time**

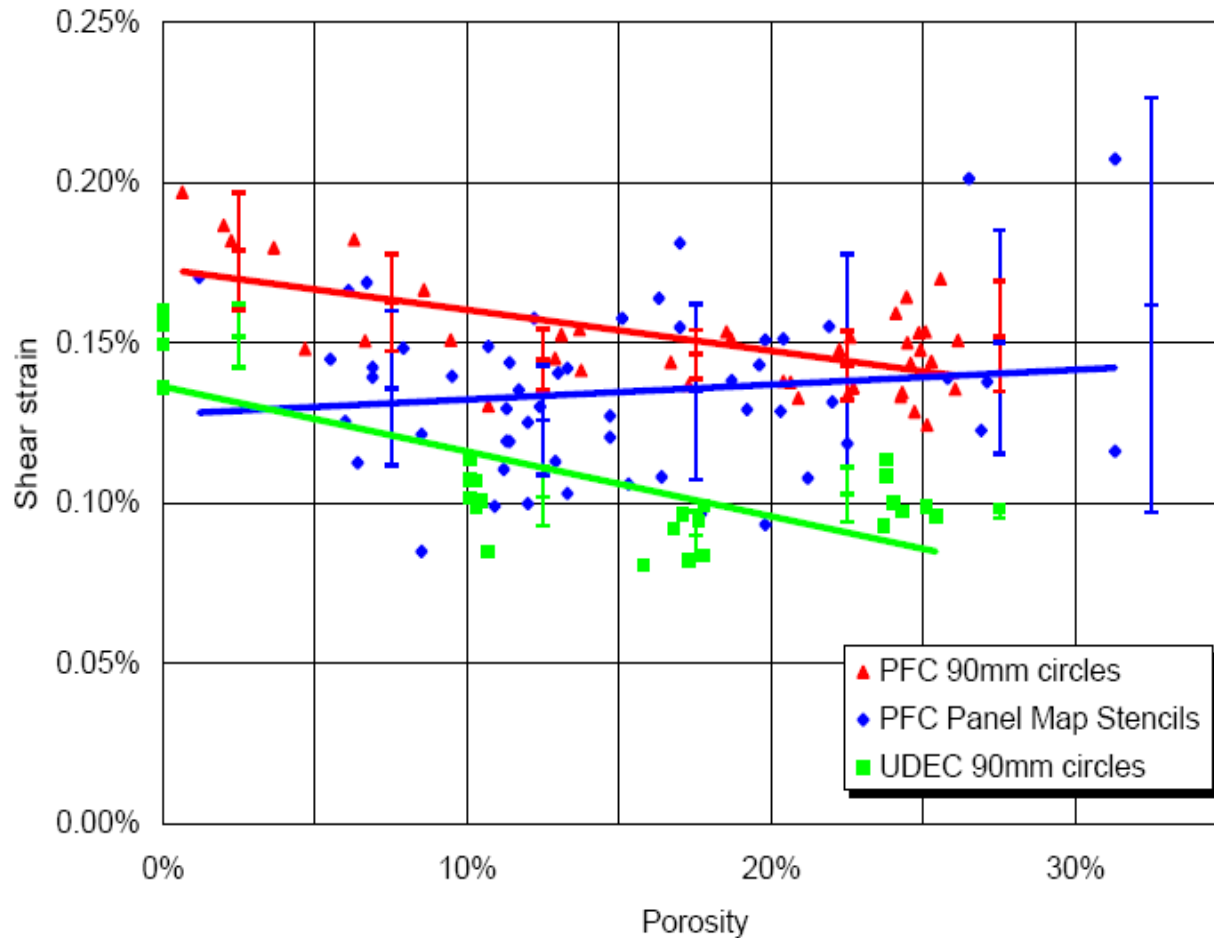


# Preservation of Weakly Attached Fracture Coatings

- Some fracture coatings are so weakly attached that they can be removed by hand or with a pocket knife
- Some, as shown in this thin section photograph, have been disturbed and are now re-cemented masses of coating fragments
- Such features may be useful in estimating peak ground motions



# Modeling Results



***Shear strain vs. porosity for peak-stress criterion;  
overburden = 250 m***

