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

YUCCA MOUNTAIN PROJECT

Drift Stability: Seismic and Thermal

Presented to:
Nuclear Waste Technical Review Board
Joint Meeting of the Natural System and Engineered System Panels

Presented by:
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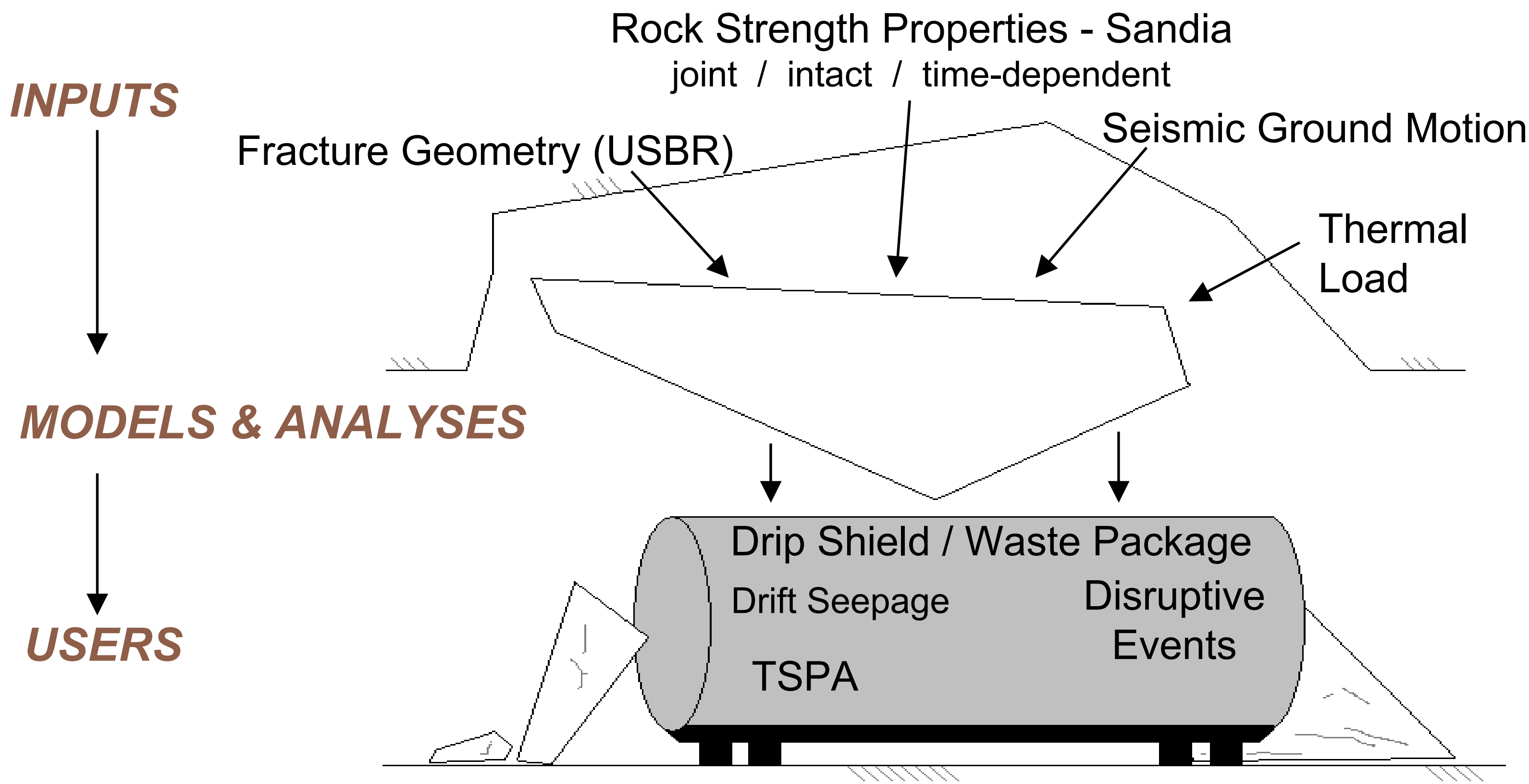
Objectives of Study

- Produce a geologically-based estimate of the distribution of rockfall for lithophysal and non-lithophysal rocks as a function of ground motion
  - Rockfall defined in terms of:
    - Total tons per “unit length” of tunnel
    - Distribution of block sizes/masses
    - History of velocity (energy), position and timing of ejected blocks
- Estimate rockfall as a function of variability of geology, rock properties and ground motion
- Determine impact of thermal load history and time-related degradation

Rockfall Modeling and Analysis



Contributors

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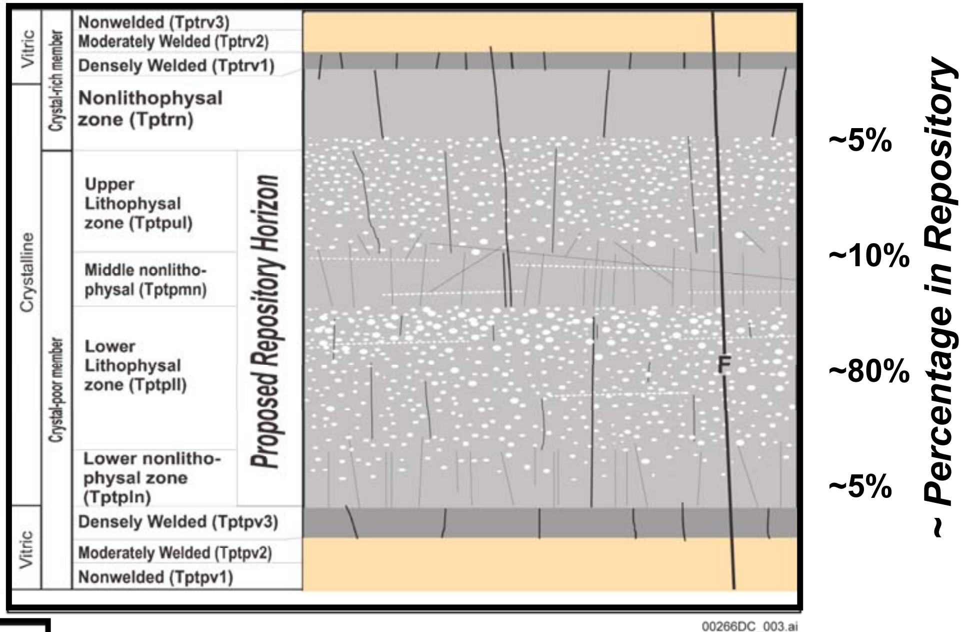
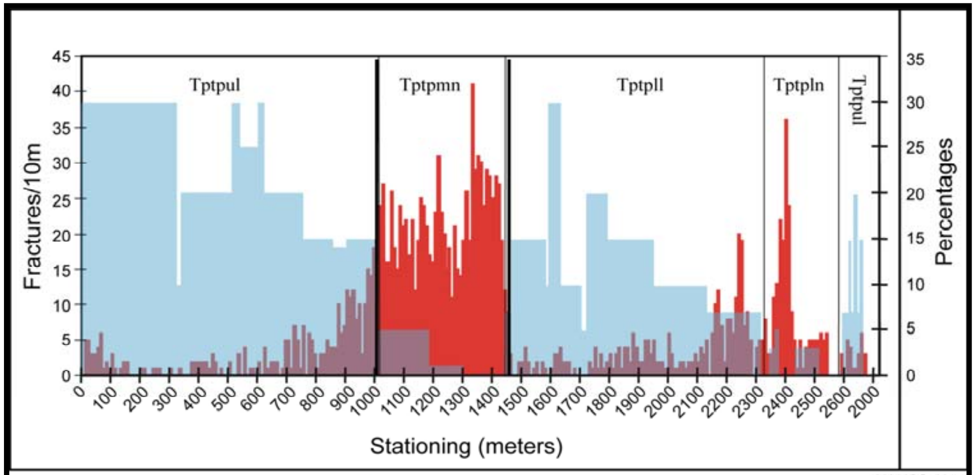
Two Distinct Rock Types in Proposed Repository - Non-Lithophysal and Lithophysal Rock

Non-lithophysal is strong, fractured rock, 150 MPa Unconfined Compressive Strength (UCS) , Modulus (E)~30GPa, GSI ~ 60 - 70

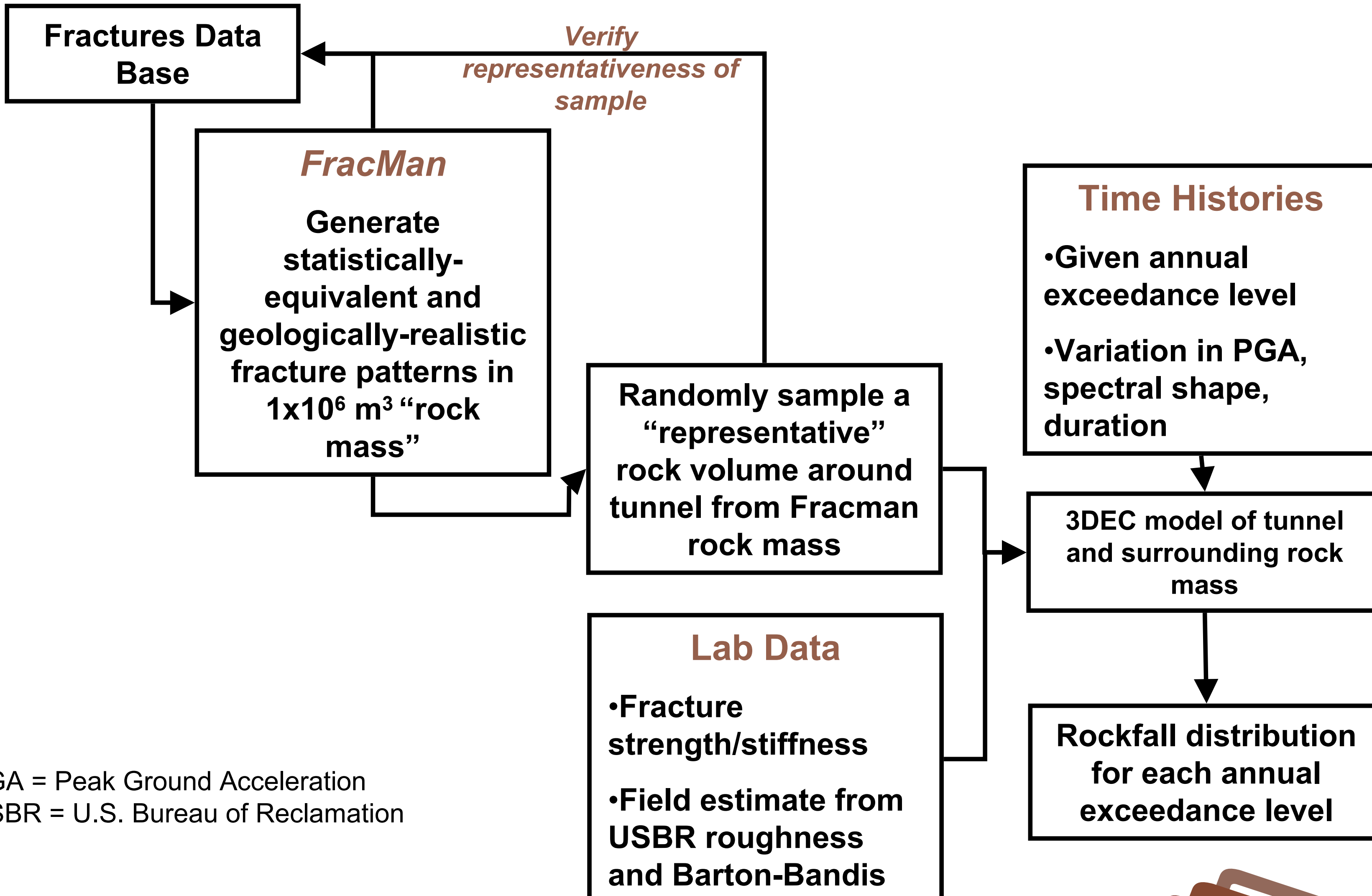




Fracture frequency/ Lithophysal %

Lithophysal rock is high lithophysal porosity (10-30%), ~ 7 to 15 MPa UCS, E~1-5 GPa

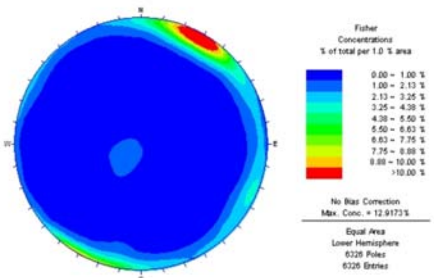
Modeling Approach for Non-Lithophysal Rocks

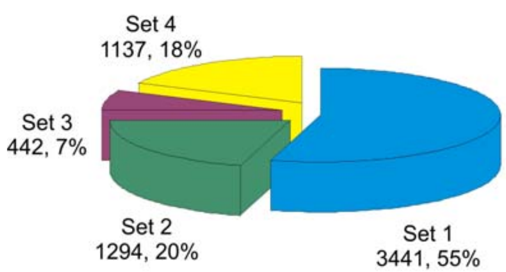


PGA = Peak Ground Acceleration
USBR = U.S. Bureau of Reclamation

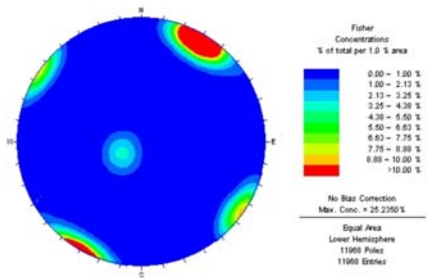
Fracture Modeling using FracMan

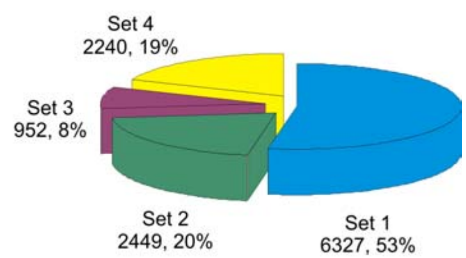
DLS Data

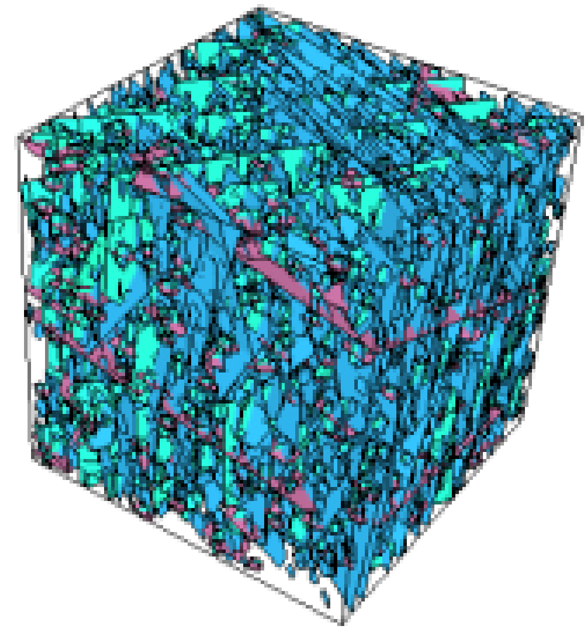




Fracman Data







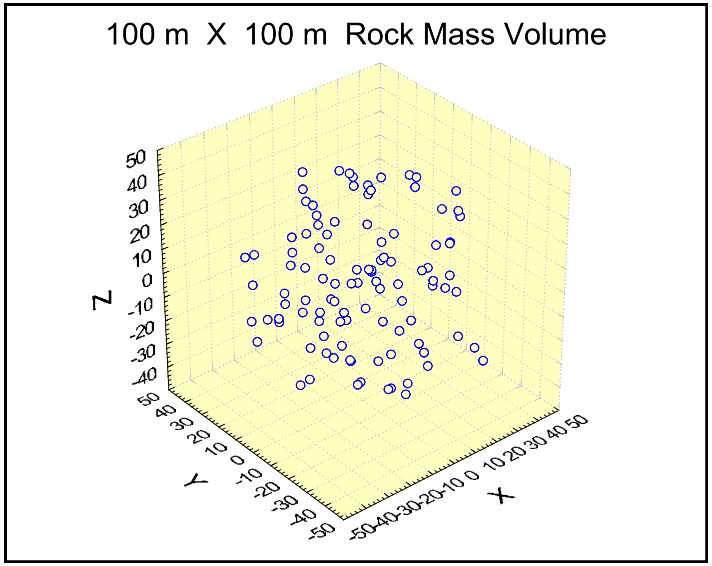
Fracture Data FracMan vs Detailed Line Survey Data					
Orientation of Sets		Trace Length		Spacing	
		FM	DLS	FM	DLS
Set 1	122/84	1.8m	2.3m	0.61m	0.55m
Set 2	195/85	1.5m	1.9m	1.61m	1.48m
Set 3	306/09	2.1m	2.7m	6.8m	4.20m
Set 4	150/90	1.4m	1.7m		

Orientation = Strike/Dip
FM = Fracture Mapping
DLS = Detailed Line Survey

Sampling Strategy for Rockfall 3DEC Analyses

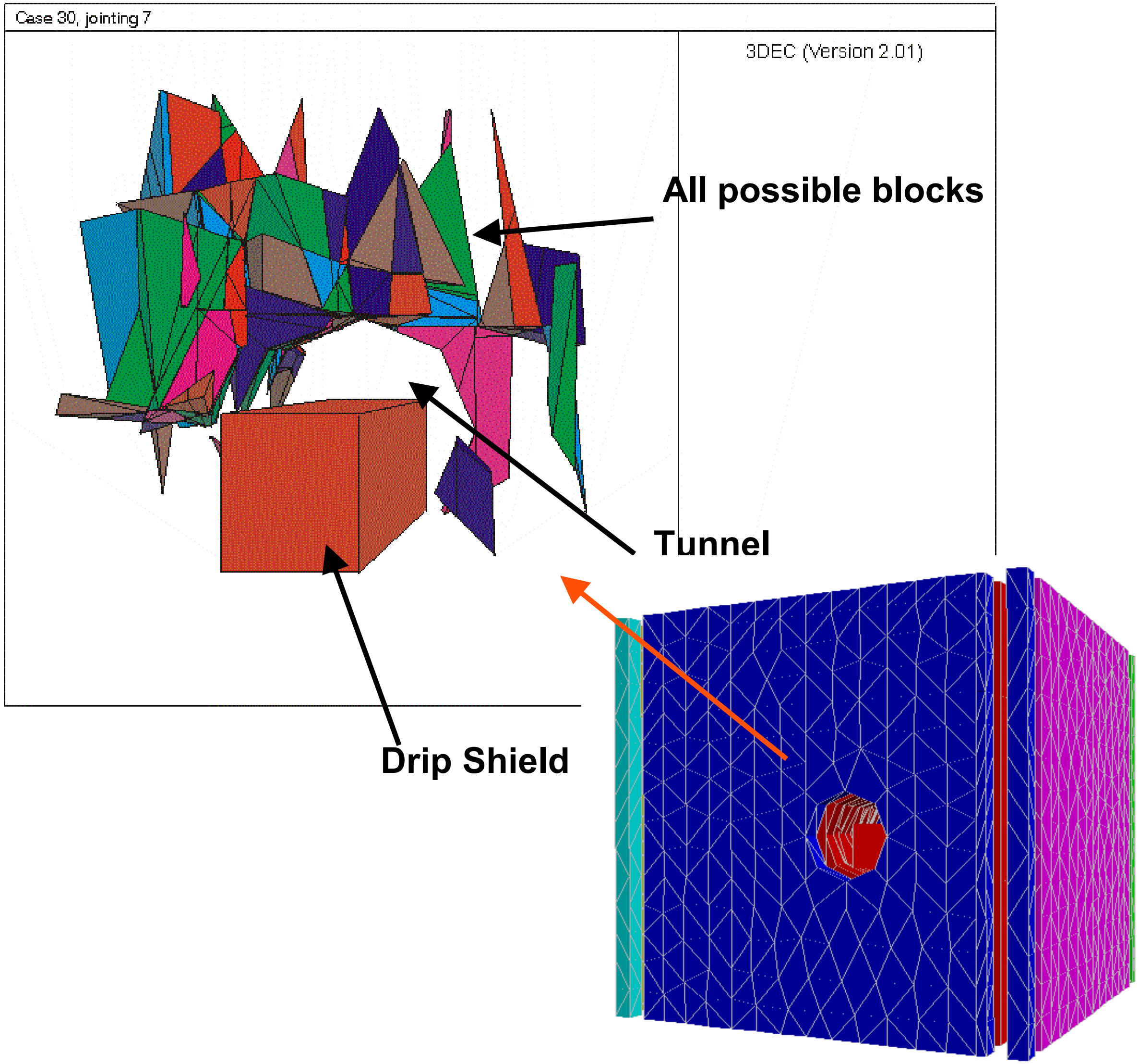
Realization Number	Ground Motion Time History Number	Synthetic Fracture Pattern Number
1	7	22
2	11	21
3	11	30
4	16	27
5	14	26
6	13	10
71	1	100
72	16	13
73	2	73
74	11	43
75	7	72
76	11	105

- **The complete sample space: 105 fracture patterns x 16 ground motions**
- **Apply Latin Hypercube random sampling technique to select 76 representative cases**



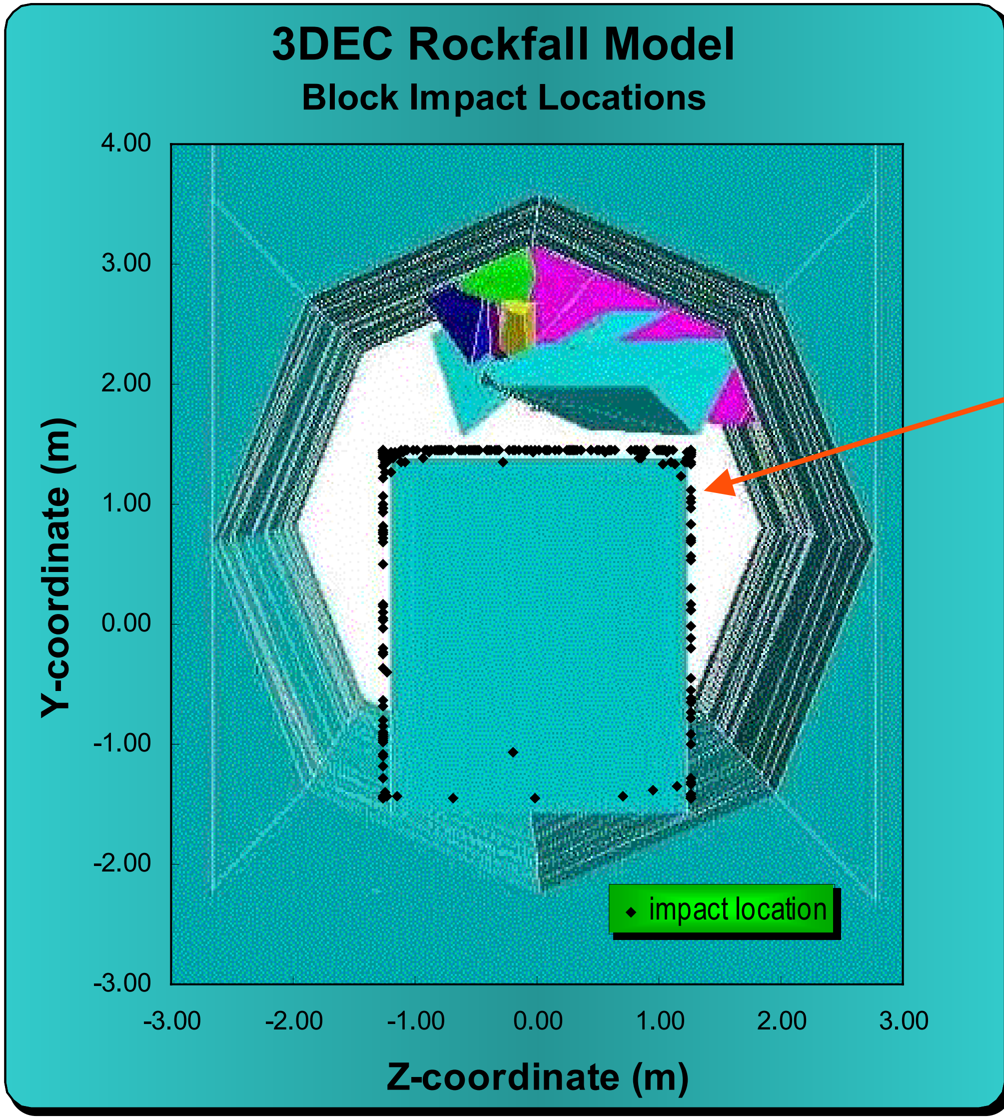
Example 3DEC Model Block Structure

(outside block structure removed)



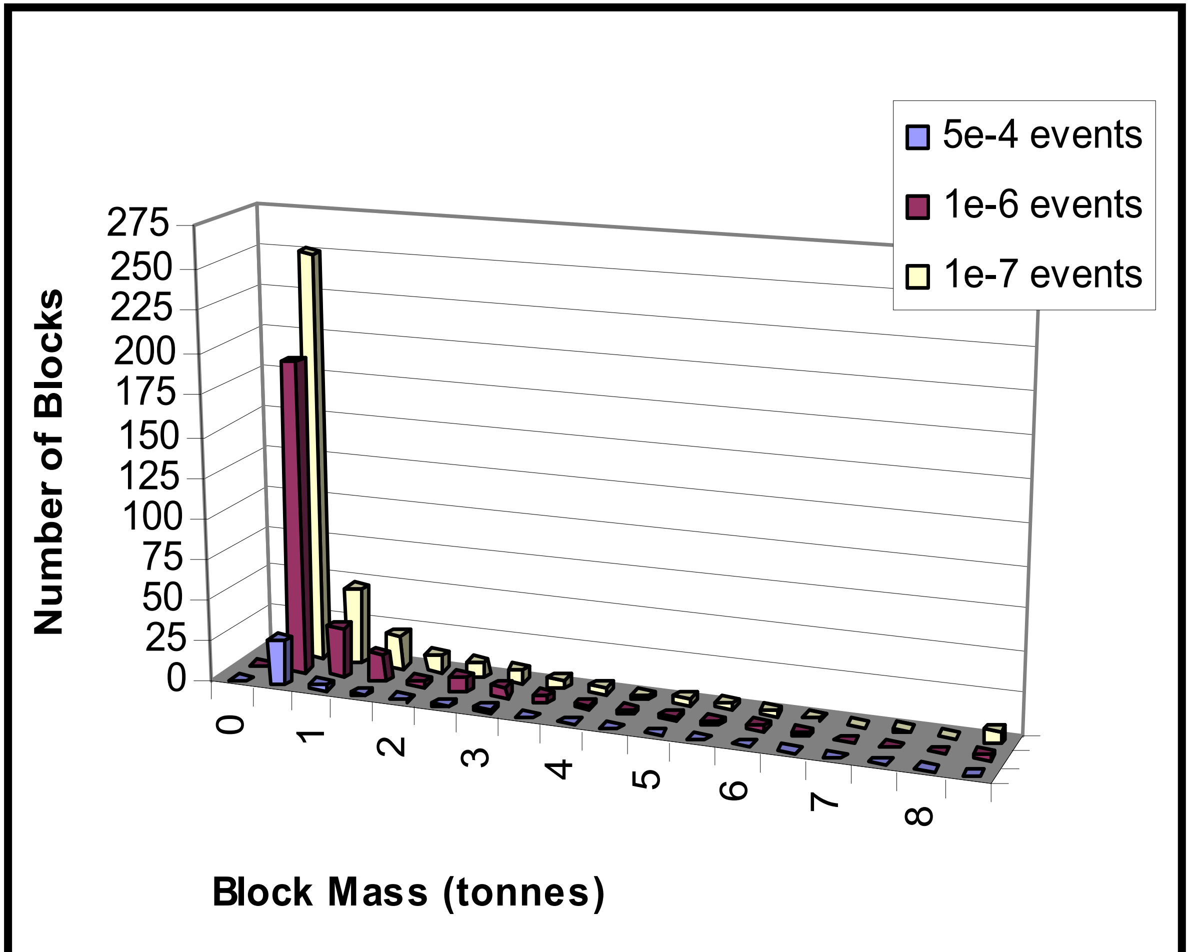
- Currently examining 100 or more analyses per ground motion
- FracMan input of fractures
- Partially-penetrating cracks in larger blocks modeled
- Base case assumes planar, zero dilation joints
- Examine range of joint surface properties
- Examine impact of thermal load history

Determine Block Impact Location, Mass and Velocity



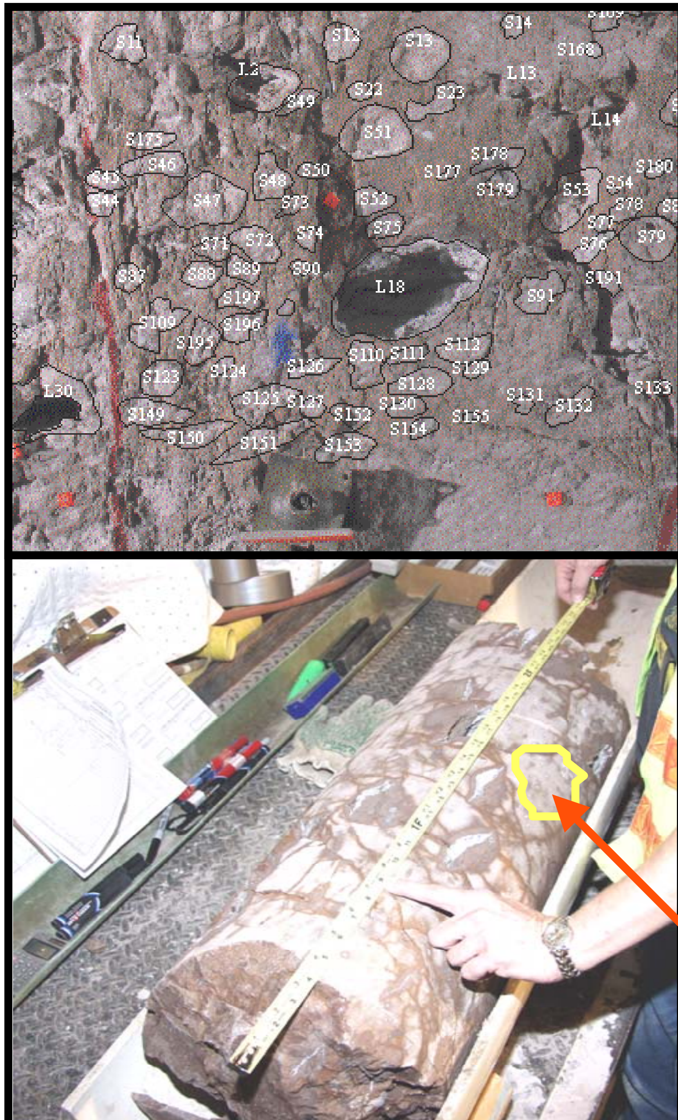
Block impact location to drip shield - record mass, velocity, time

Results - Distribution of Rockfall Block Mass for Non-Lithophysal Rock



- Rockfall largely controlled by block geometry and peak particle velocity (ppv)
- Median block size is approximately 0.25 tonne for all cases
- Fracture dilation angle potentially important, friction angle unimportant
- Thermal load decreases rockfall during heating phase

Lithophysae and Fracturing in the Lower Lithophysal Unit

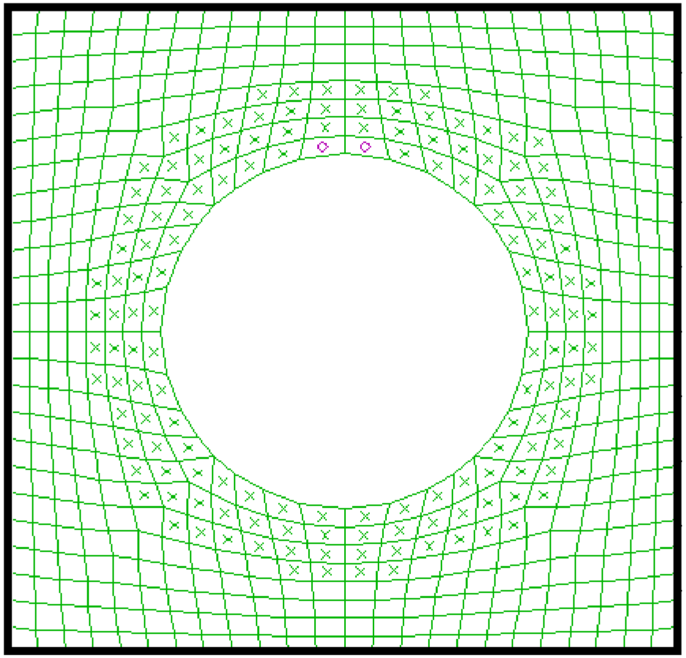


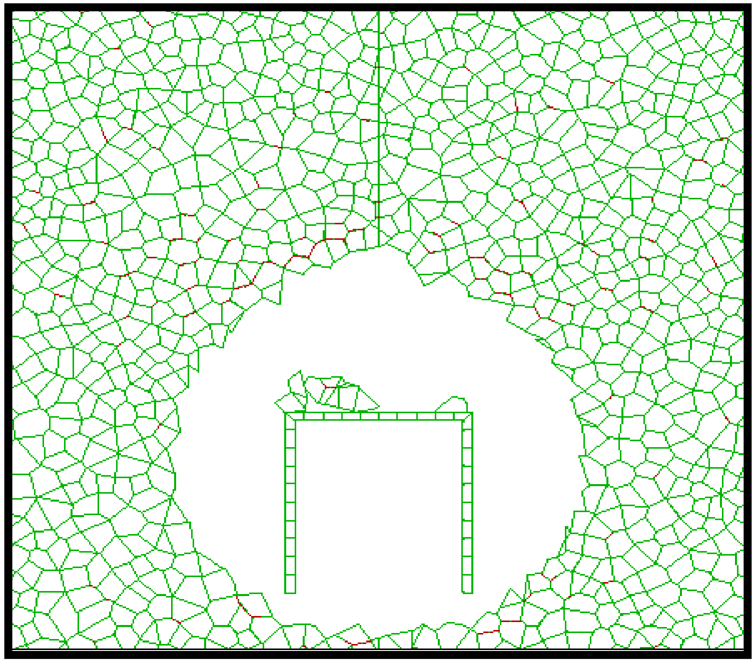
Potential Size of Rock Particles

- Lithophysal porosities of 10% to 30%
- Block size controlled by
  - Lithophysae spacing
  - Extensive cooling fracture network
- Block sizes produced are on order of inches when rock is overstressed

Modeling Approach

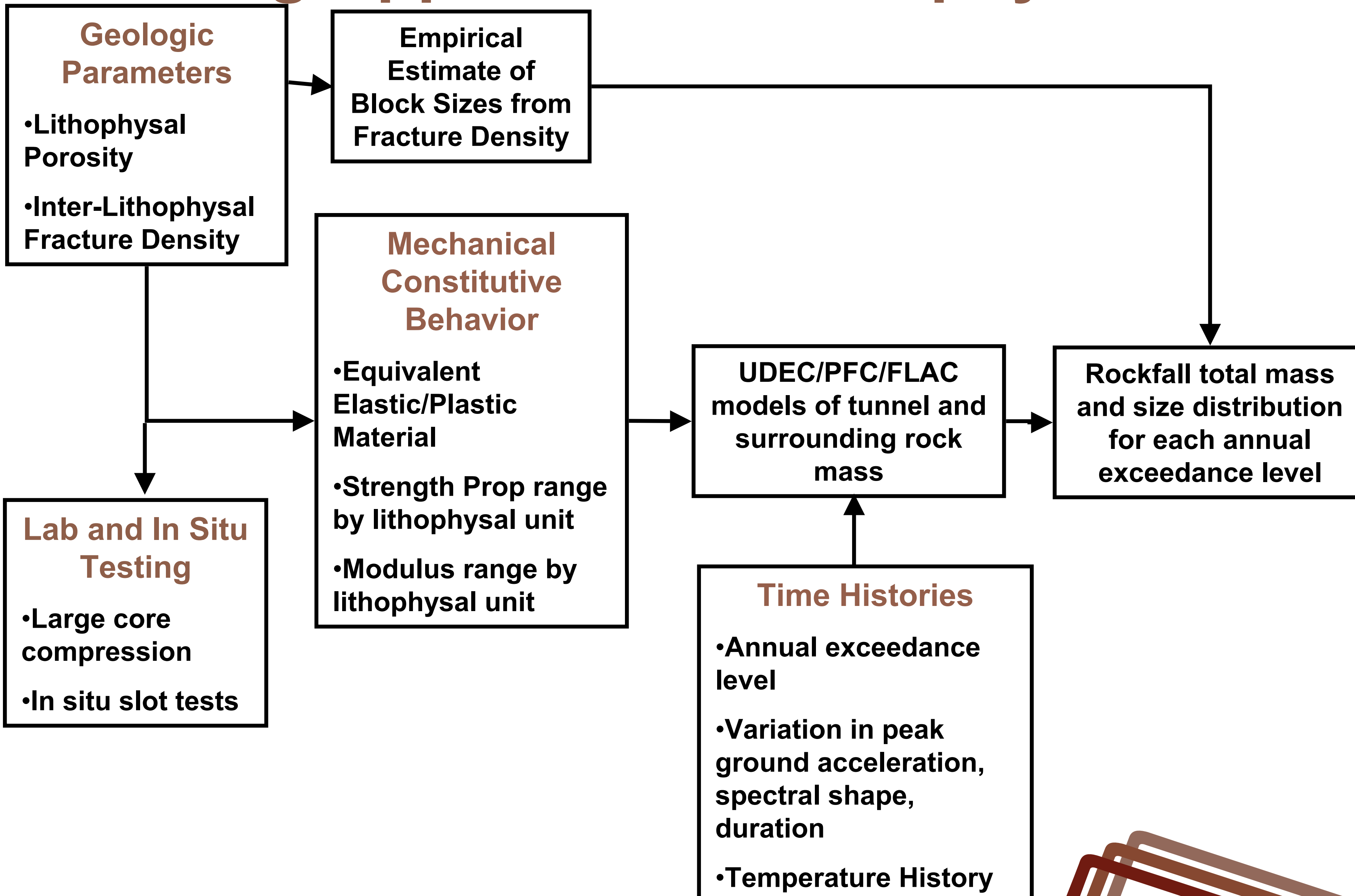
Continuum versus Discontinuum





- **Randomly-shaped "Voronoi" blocks in UDEC model do not represent actual internal structure of the lithophysal rock mass**
- **Blocks are computational tool used to represent damage in the model and formation of loose blocks**
- **Model has to be calibrated to ensure that its "macro" behavior is the same as behavior of the lithophysal rock mass**

Modeling Approach for Lithophysal Rocks



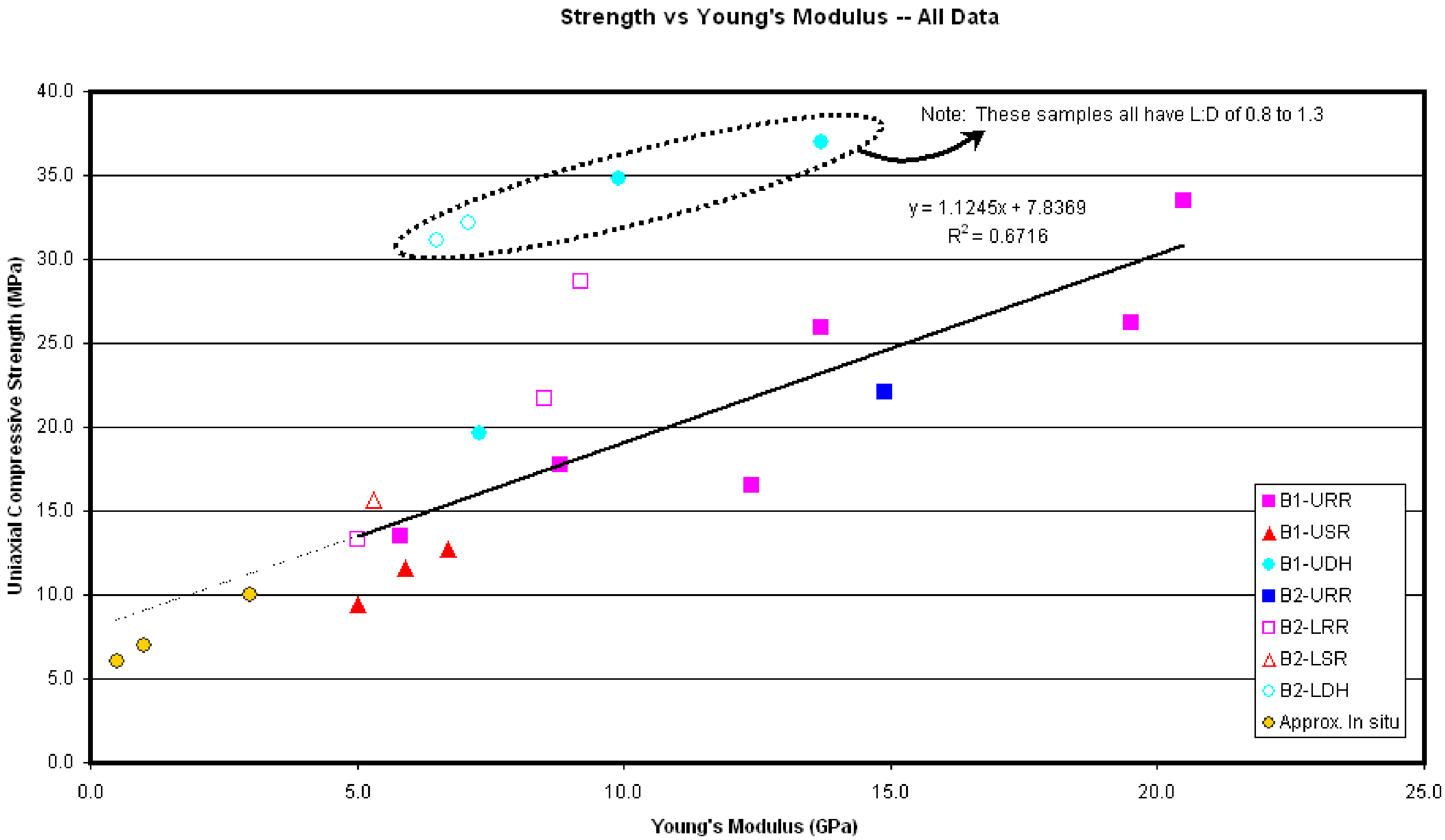
Testing

Mechanical and Physical Properties

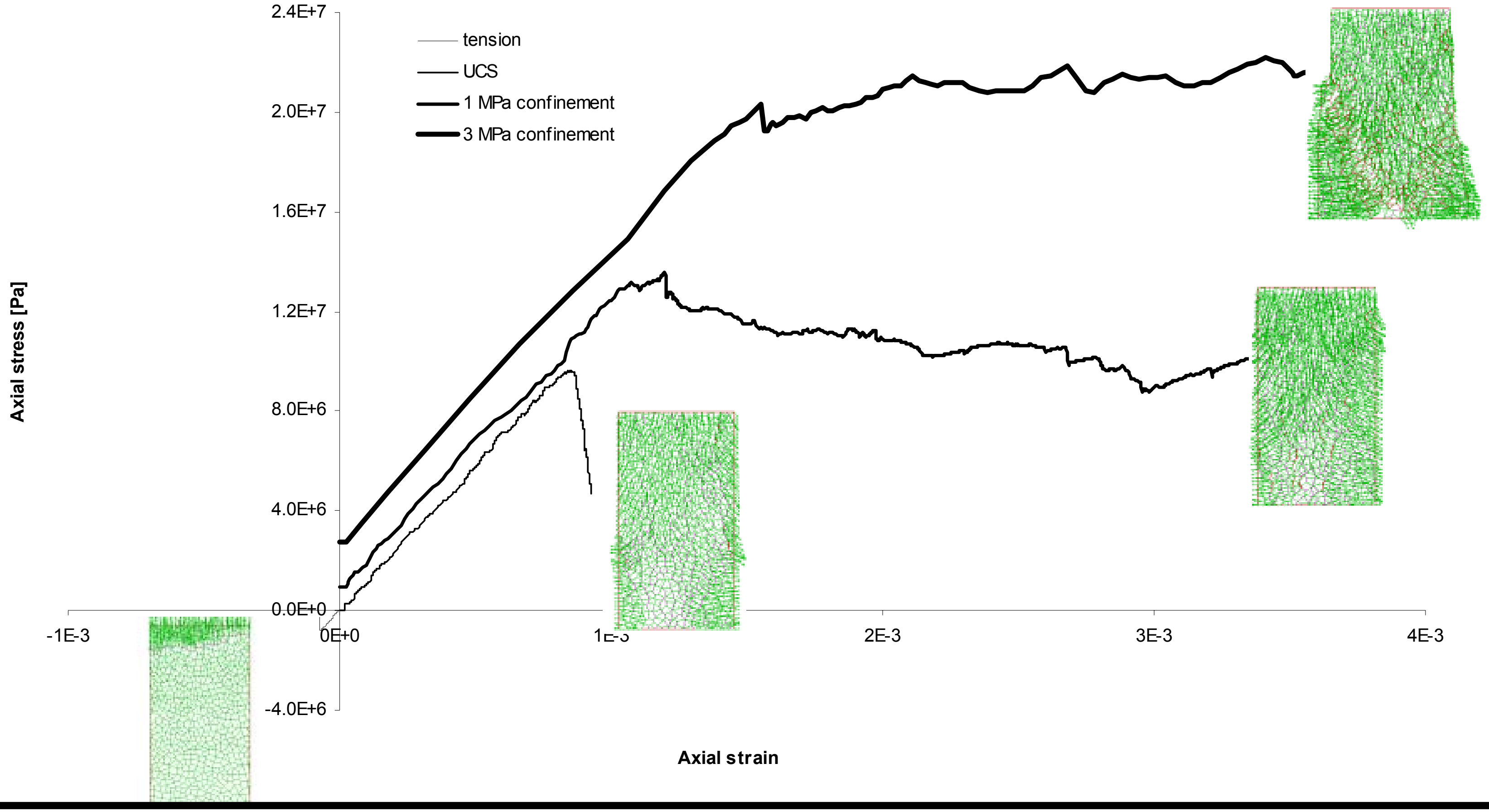
In Situ Slot Compression Testing

Laboratory Testing of 12-inch Cores

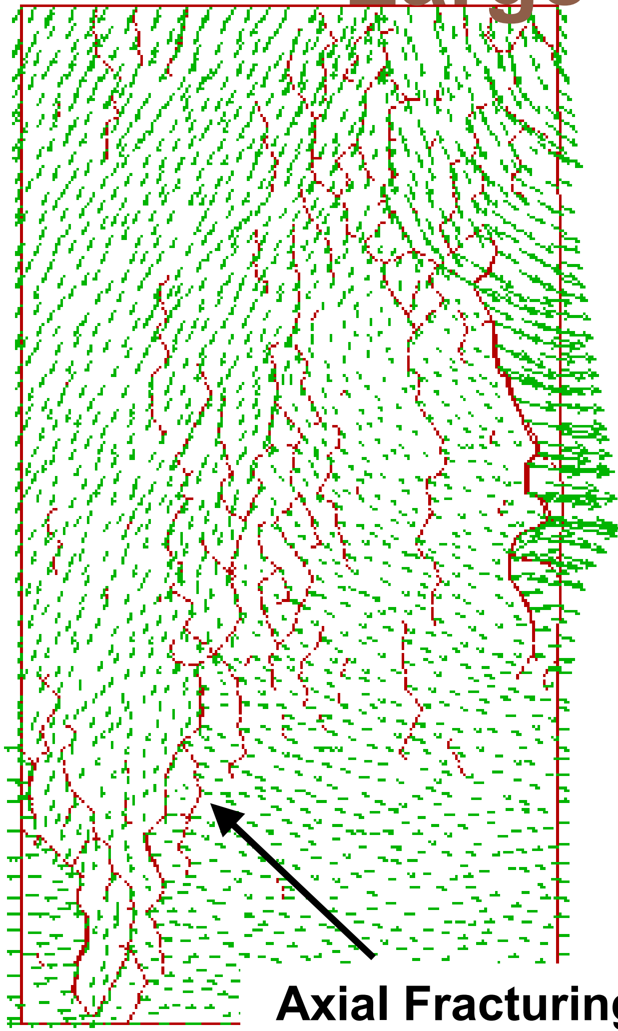
Summary of Compression Data on Large Lithophysal Core Samples and In Situ Tests

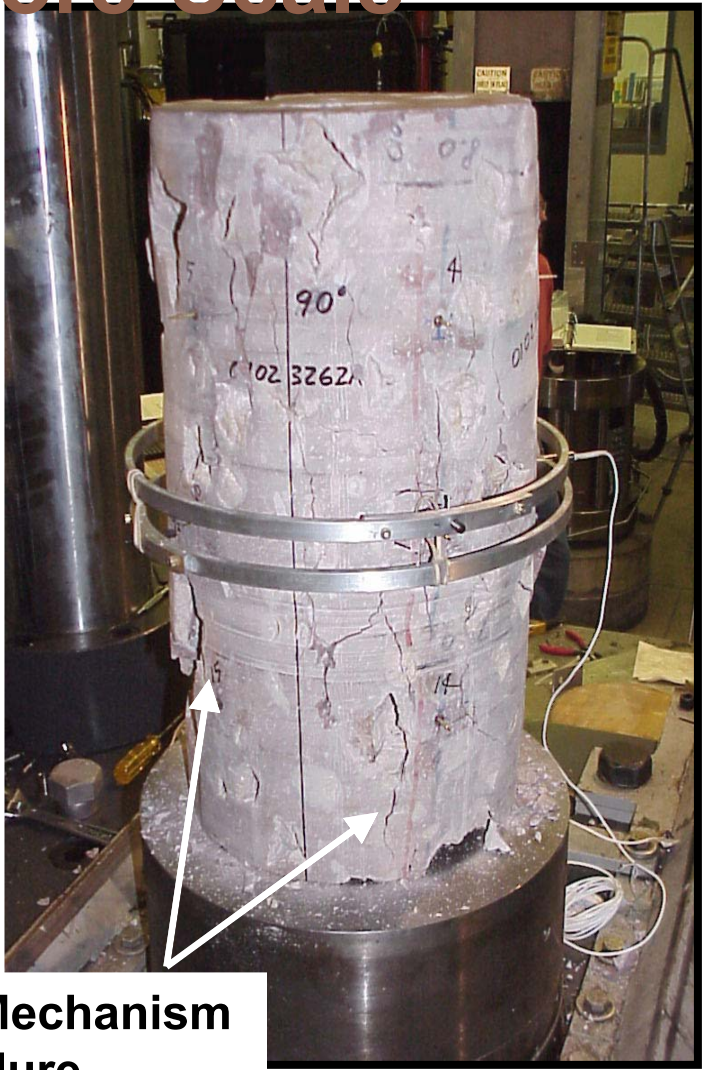


Example of UDEC Model Calibration



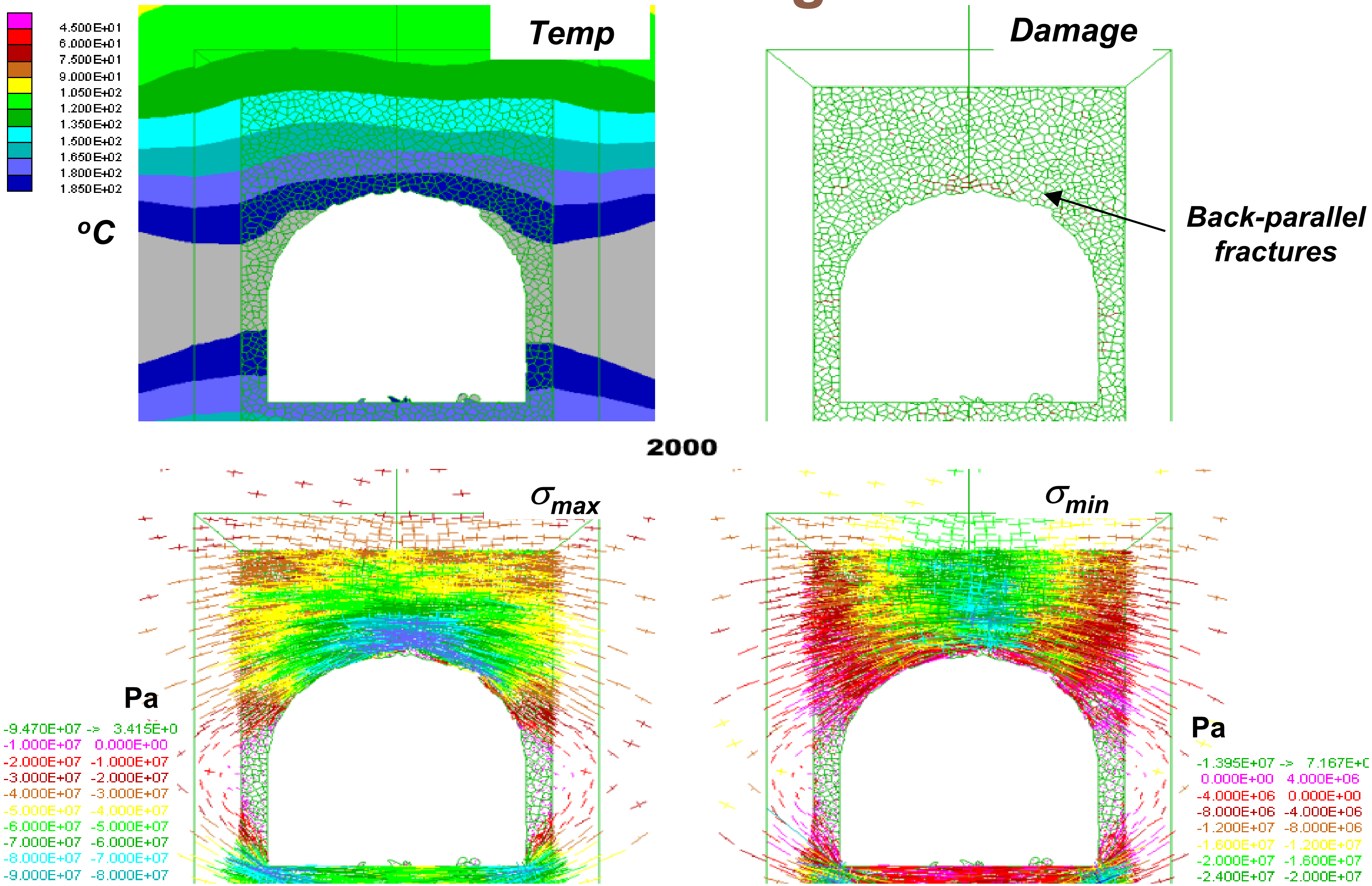
Comparison of Model Failure Mechanism at Large Core-Scale





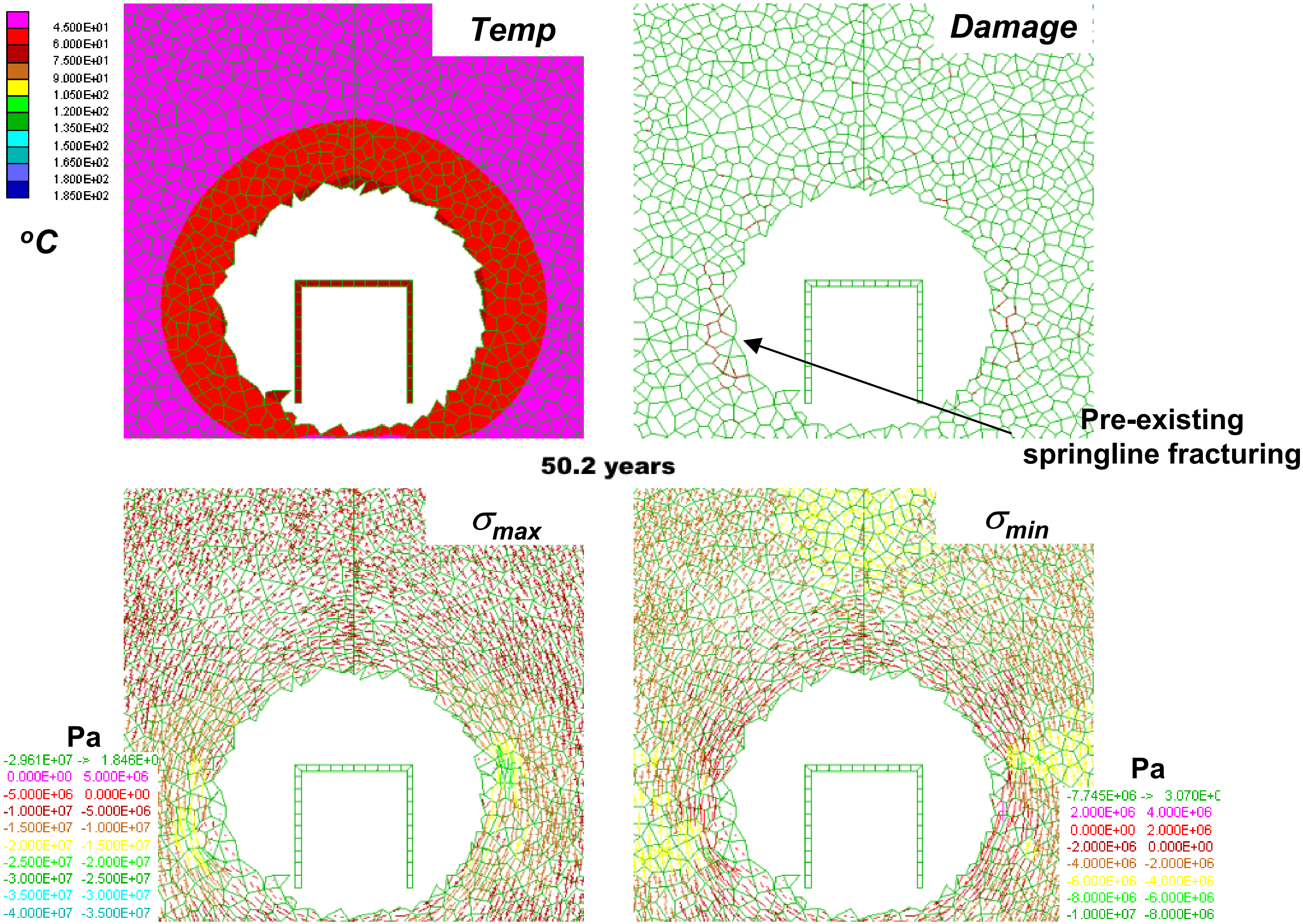
Axial Fracturing Mechanism of Core Failure

Verification of Model Prediction of Thermal Stress-Induced Roof Slabbing to Drift Scale Test

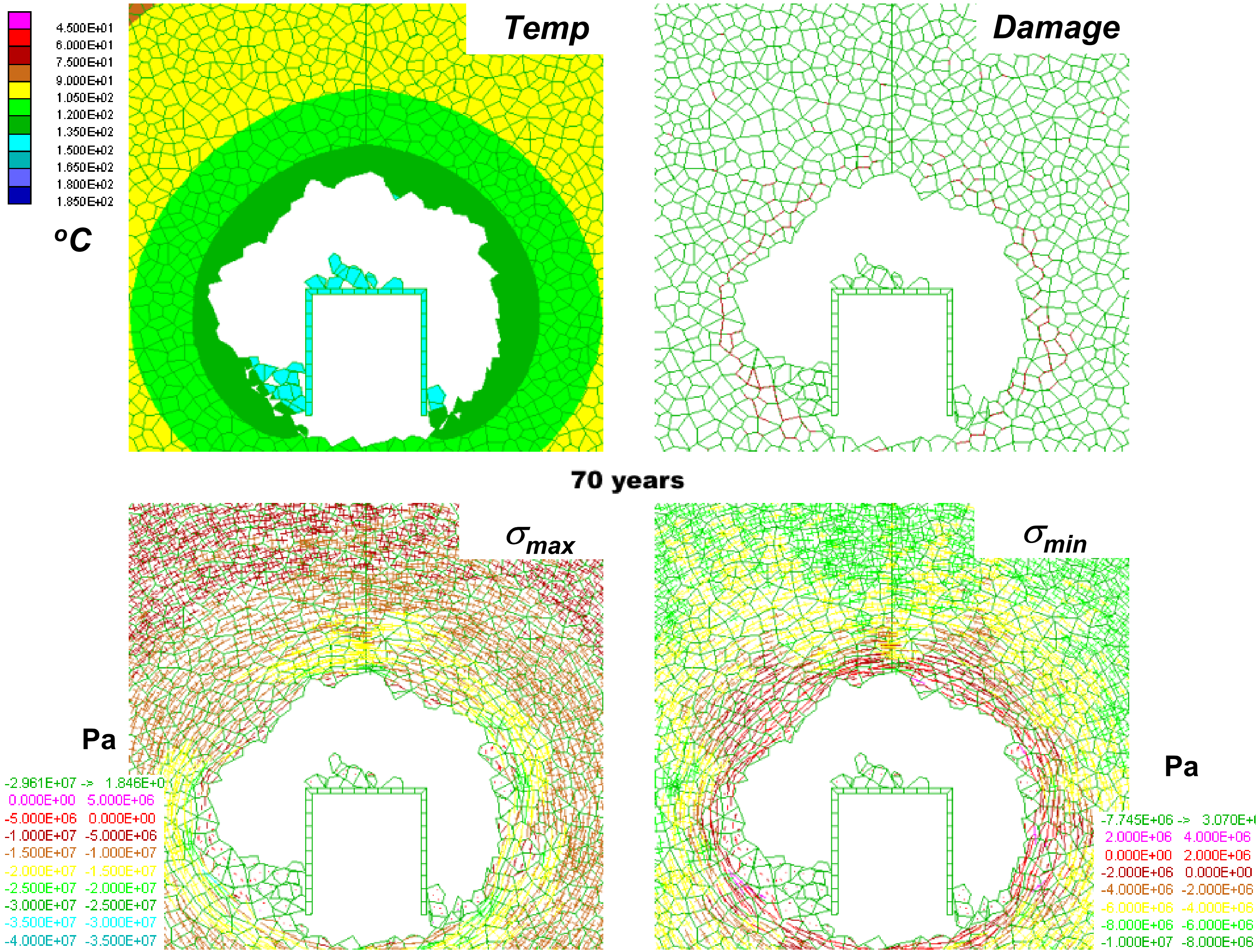


Thermal Drift Degradation Analysis in Lithophysal Rock

- **50 year ventilation**
- **Temperatures imported from NUFT - 1.45 kW/m scenario, peak temperature at drift wall of approx. 135°C reached 20 years (year 70) after closure**
- **Temperatures applied to UDEC lithophysal model in small increments**
- **Allow thermal stressing and fracturing to form naturally with potential gravitationally-induced rockfall**



Immediately at end of ventilation

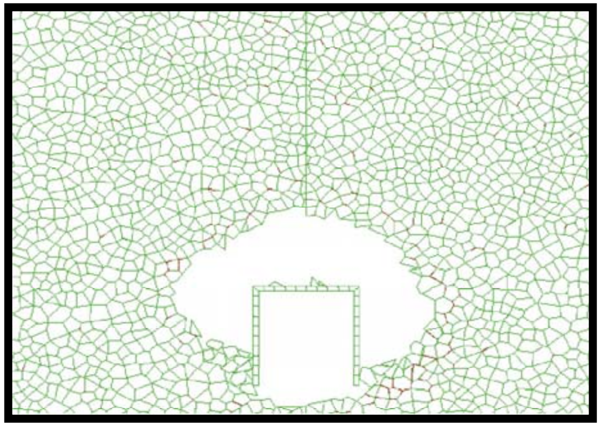


20 years after end of ventilation - peak stress change/damage

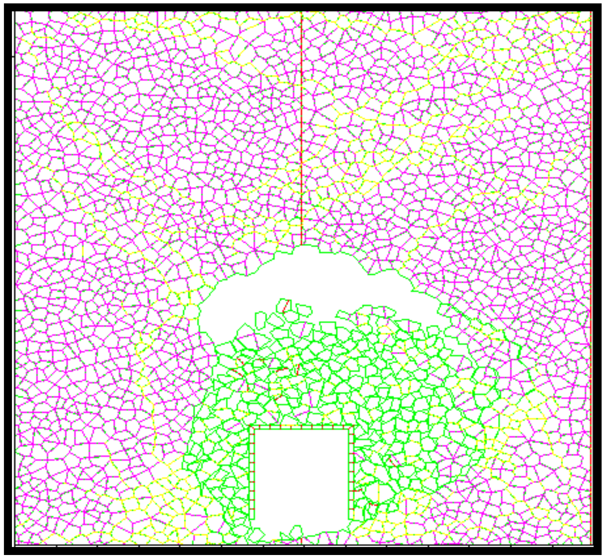
Preliminary Draft Materials

Seismic Drift Stability - Lower Lithophysal Unit

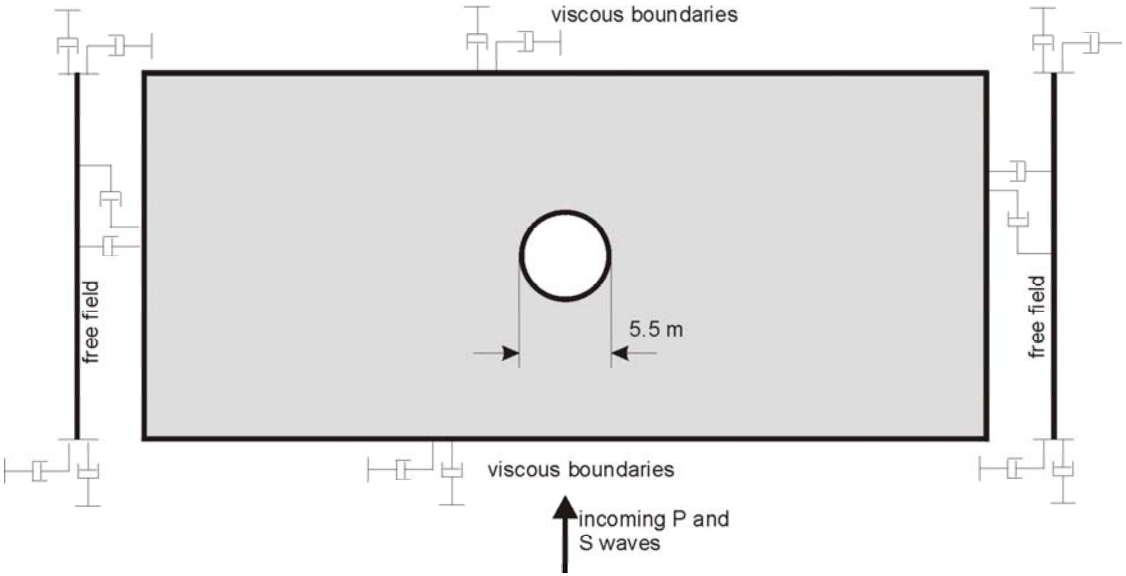
Example Results



$5x10^{-4}$, unsupported



$1x10^{-6}$, unsupported



- **Results**
  - $5x10^{-4}$ - sidewall spalling only
  - $1x10^{-6}$ and $1x10^{-7}$ - similar damage - rock failure over drip shield - primary impact is dead weight load on drip shield
- **Damage levels for low prob. events not consistent with observations of no damage in lithophysae in Exploratory Study Facility**

Preliminary Draft Materials

Summary of Drift Degradation Studies

- **Preliminary Conclusions Based on Estimated Ground Motions:**
  - **Non-Lithophysal rock**
    - **Median rock size approx. 0.25 tonne**
    - **Relatively small rockfall volume**
  - **Lithophysal rock**
    - **Thermal stressing in post-closure results in small displaced volume of rock from springline areas**
    - **Pre-closure motion results in loosening of springline for unsupported conditions**
    - **Significant damage for 10^{-6} and 10^{-7} motions**
    - **Estimated ground motions at 10^{-6} and 10^{-7} not consistent with geological observations of undamaged lithophysae in ESF and Enhanced Characterization of the Repository Block Drift**
    - **Time-dependency work currently underway**