Finite Element Solution of Nonlinear Transient Rock Damage with Application in Geomechanics of Oil and Gas Reservoirs

Saeid Enayatpour and Tad Patzek

The University of Texas at Austin

Department of Petroleum and Geosystems Engineering

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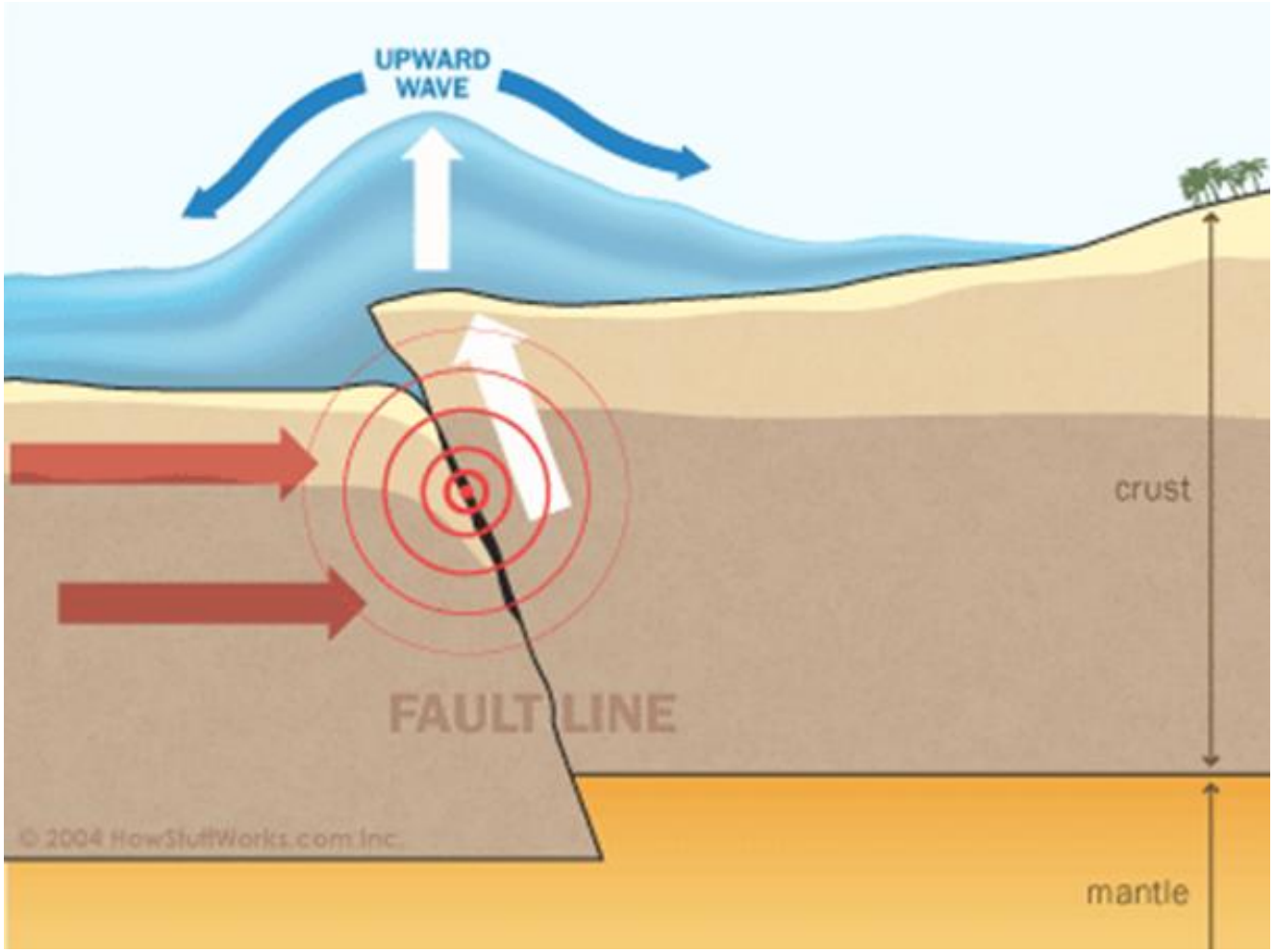
COMSOL CONFERENCE BOSTON 2012

Fractures everywhere

Faults, **Km** scale



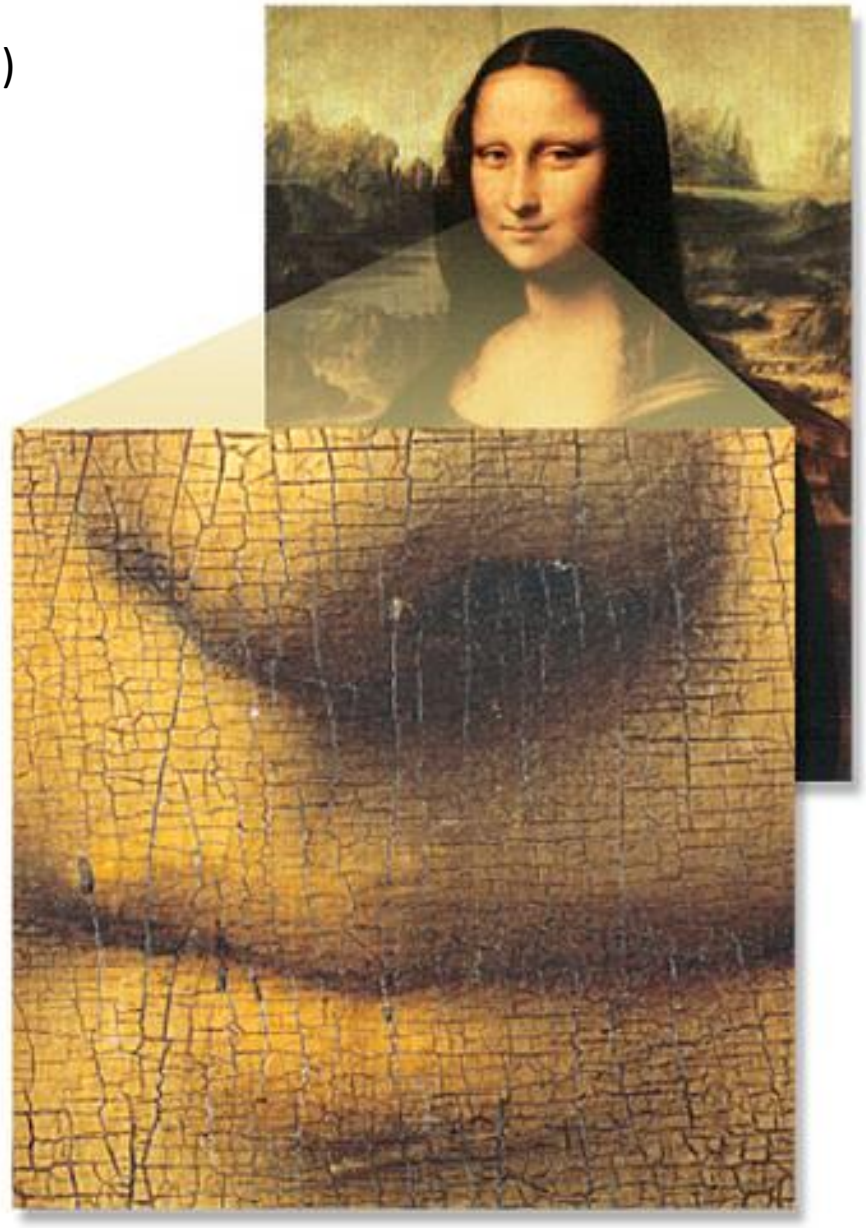
http://science.howstuffworks.com/nature/natural-disasters/tsunami2.htm

Fractures everywhere

Aircraft Accident Report, NTSB/AAR-04/04
(http://www.ntsb.gov/doclib/reports/2004/AAR0404.pdf)

Fractures everywhere

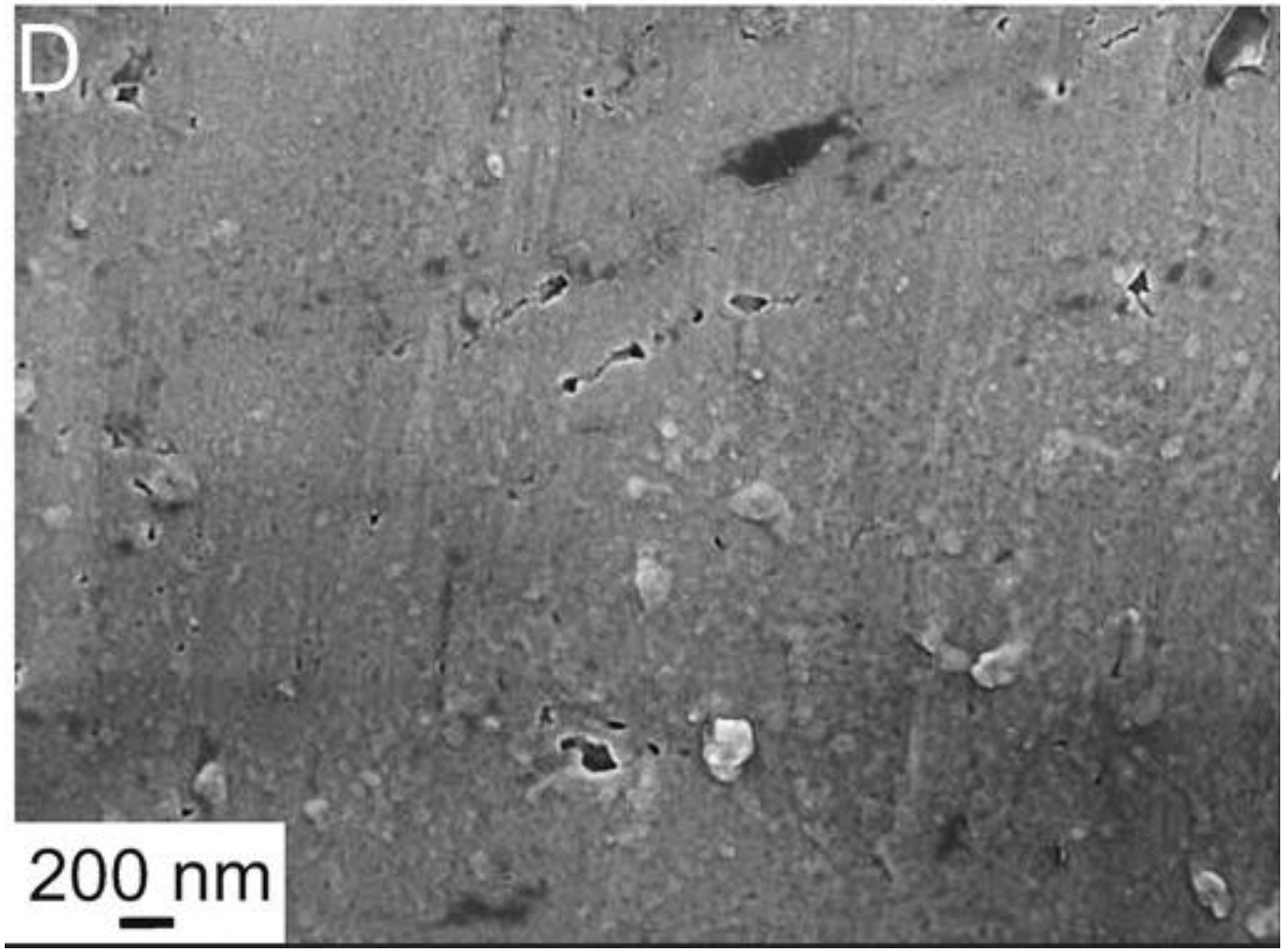
Age crackling in the Mona Lisa (Scale:**mm-cm**)



http://www.chromaonline.com

Fractures everywhere

Fractures in rock (Scale:**nm-μm**)



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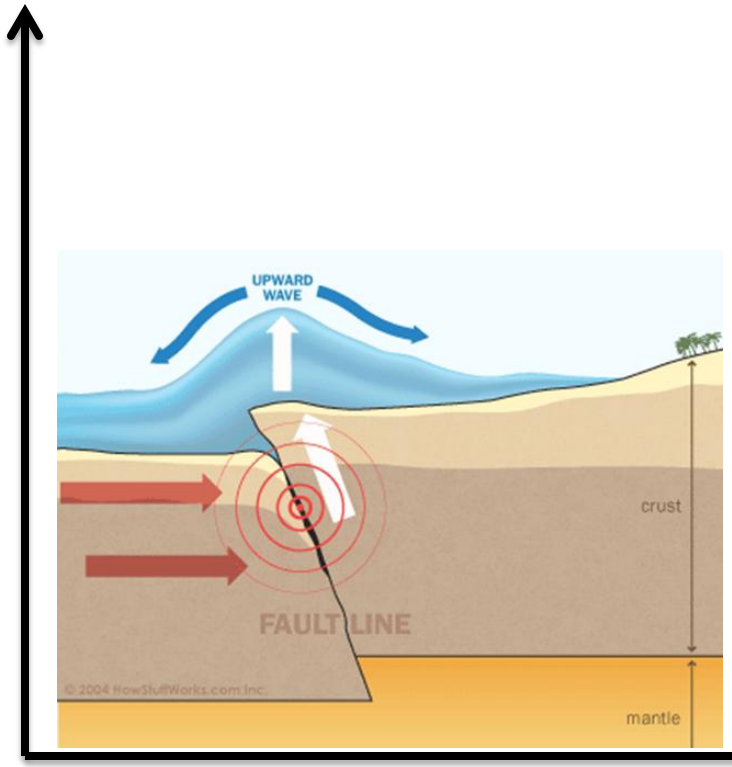
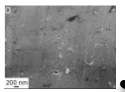
Fracture: A multiscale problem



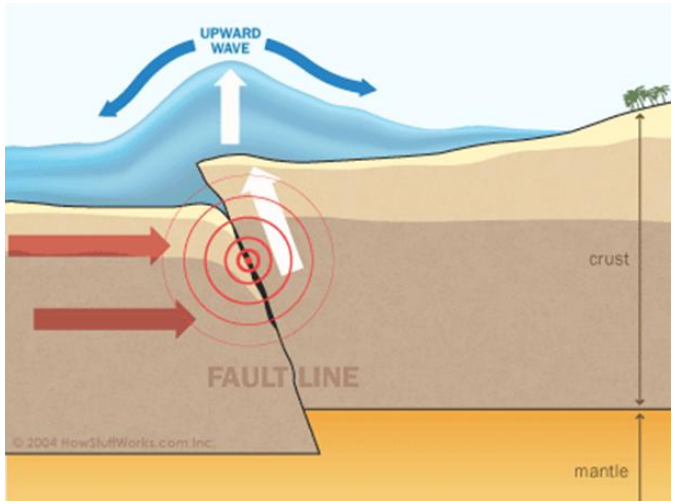


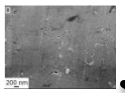
Scale

Km m cm nm

Fracture: A multiscale problem

Question: Which **scale** should we use when solving the fracture problems in rocks?

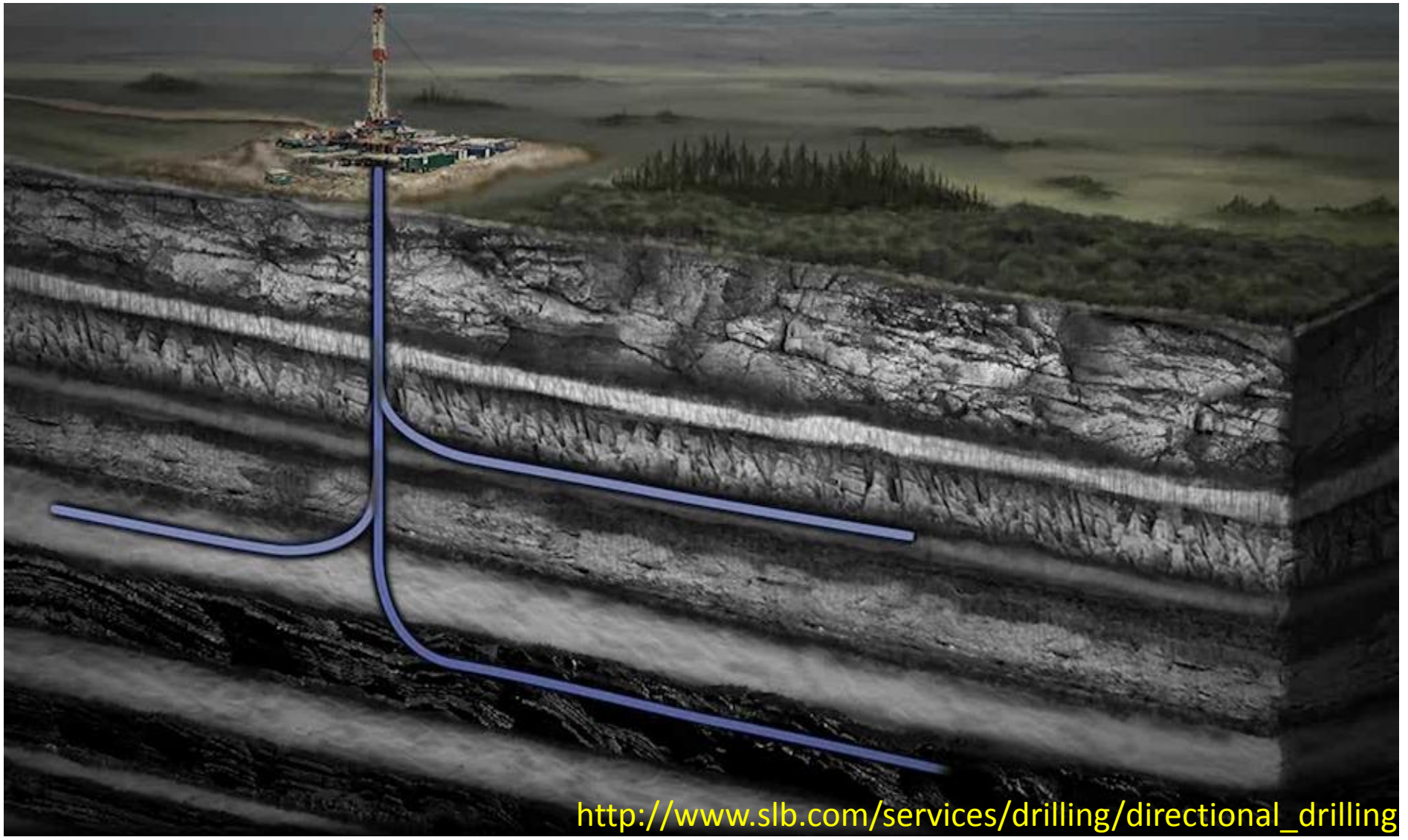




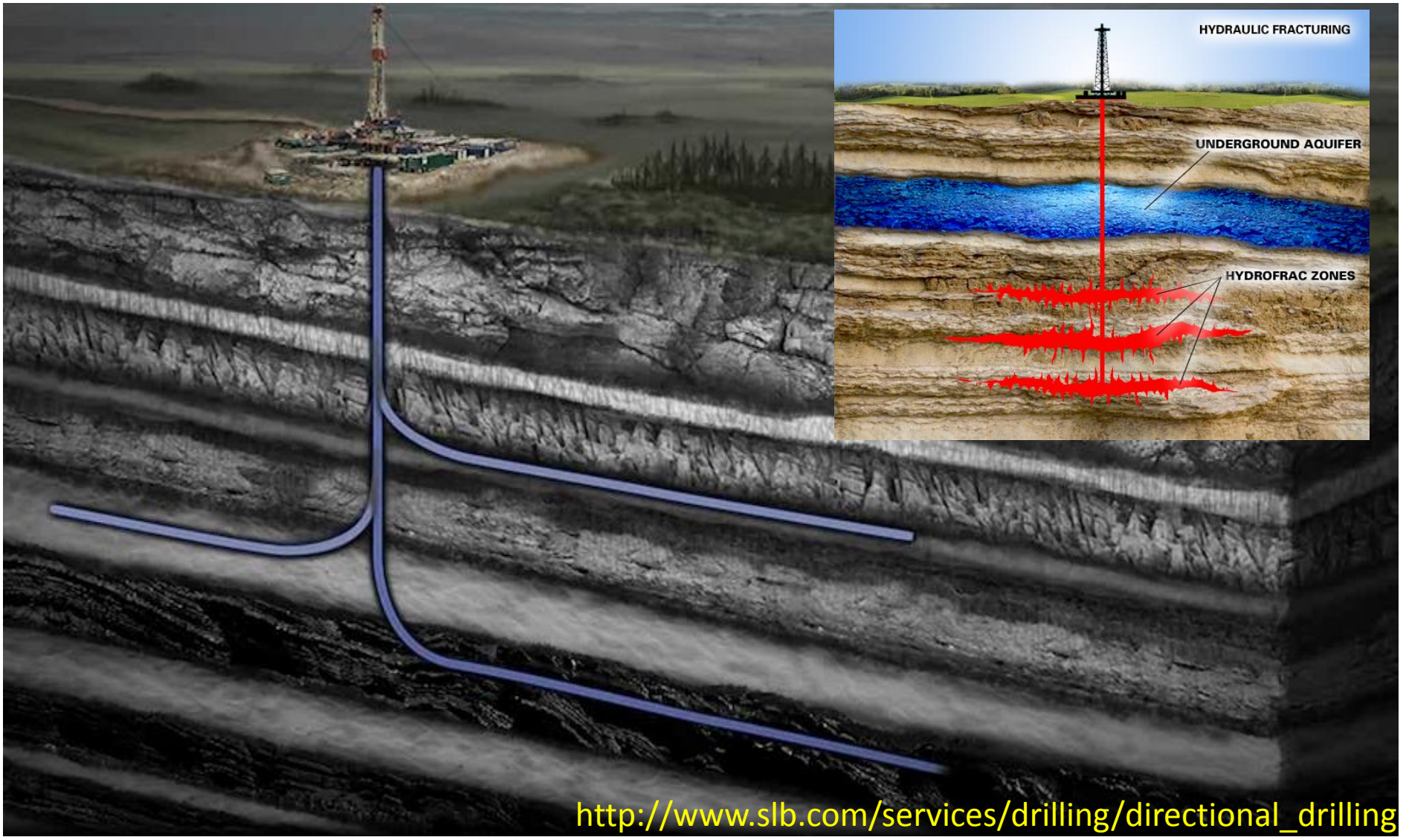
Scale

Km m cm nm

Application: Rock (Hydraulic) Fracturing



Application: Rock (Hydraulic) Fracturing

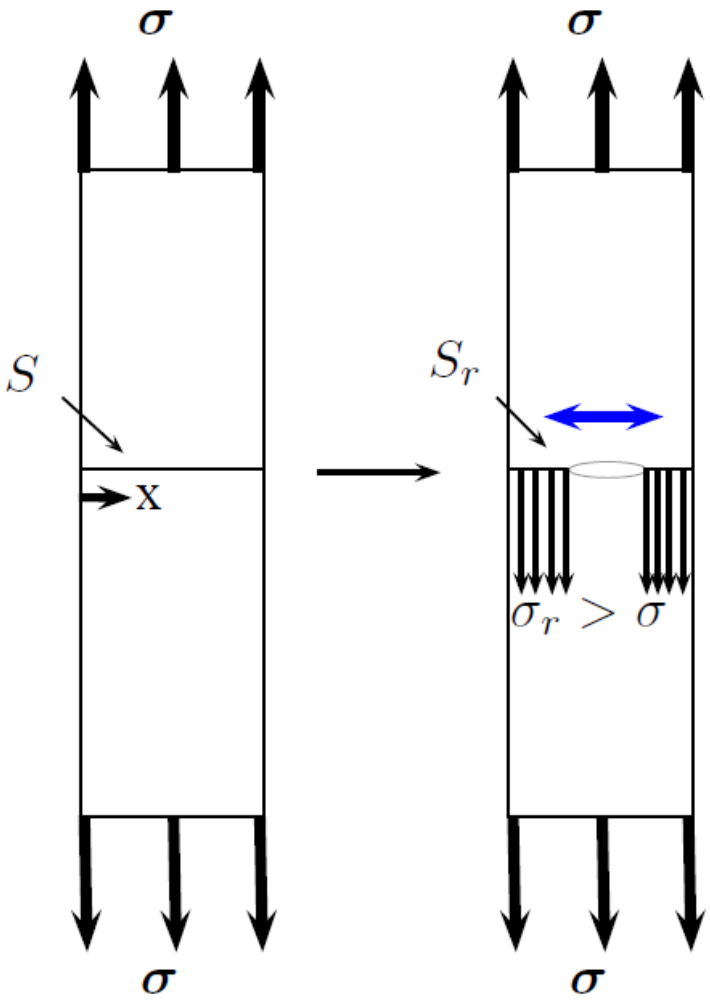


http://www.slb.com/services/drilling/directional_drilling

Description of Problem

- How does fracture propagate in rock?
- What is the governing equation of **rock damage**?
- How can we solve the equation using COMSOL?

Description of Problem: **rock damage**

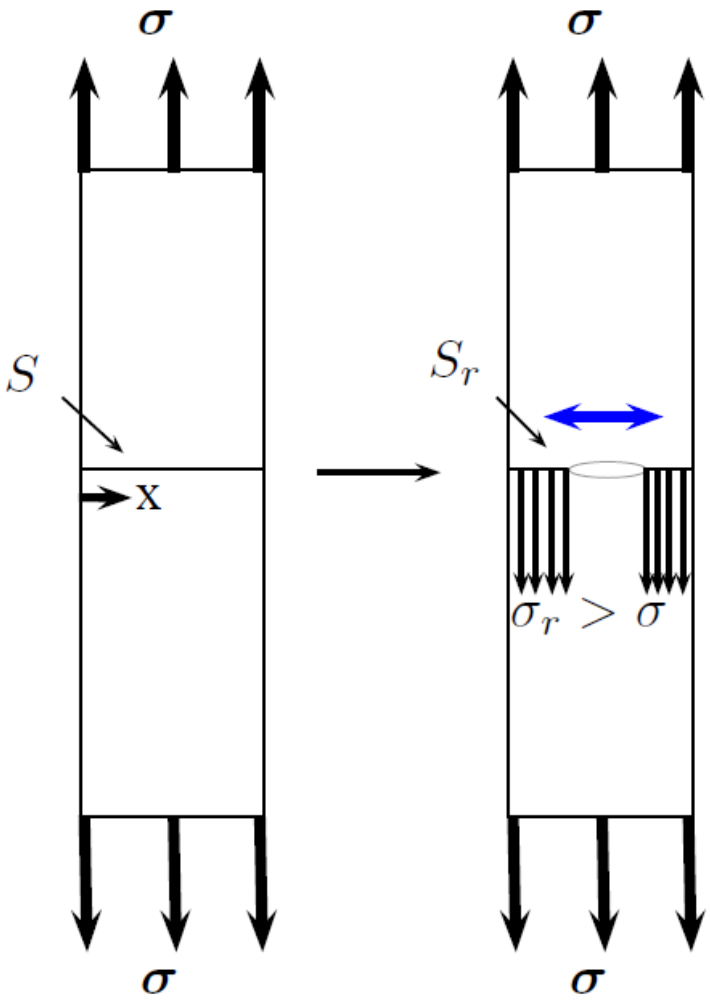


$$\omega = \frac{S - S_r}{S}$$

Damage parameter ω varies between 0 and 1.

0: intact rock
1:fully pulverized rock

Description of Problem: **rock damage**



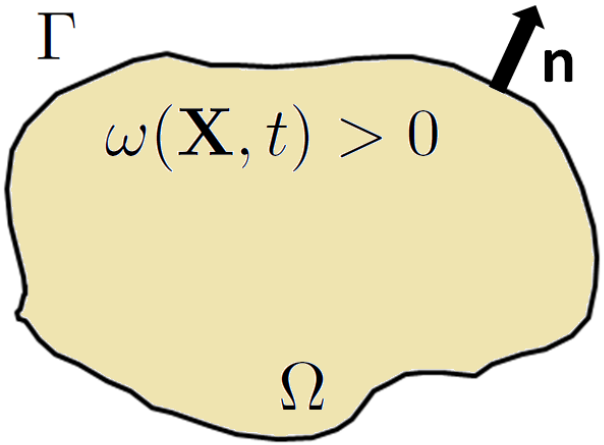
Total **Remaining**

$$\omega = \frac{S - S_r}{S}$$

Damage parameter ω varies between 0 and 1.

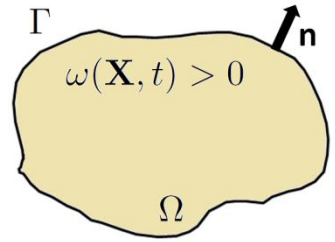
0: intact rock
1:fully pulverized rock

Description of Problem: **rock damage**



$$\begin{cases} \omega : \Omega \to R \\ \omega = 0, \; D\dfrac{\partial \omega}{\partial n} = 0 \quad \text{on} \quad \Gamma \end{cases}$$

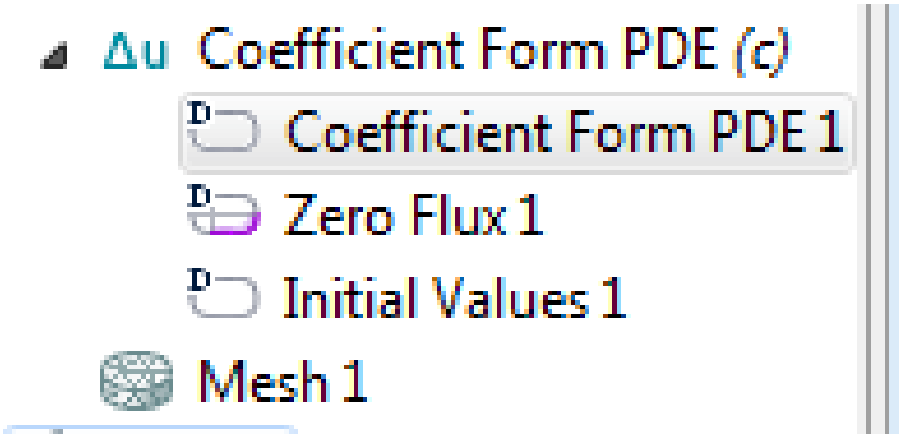
Description of Problem: **rock damage**

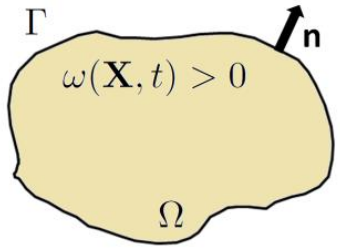


$$\begin{cases} \omega : \Omega \to R \\ \omega = 0,\ D\dfrac{\partial \omega}{\partial n} = 0 \quad \text{on} \quad \Gamma \end{cases}$$

$$\frac{\partial \omega(X,t)}{\partial t} = [\nabla \cdot [\kappa \nabla (f(\omega))] + f(\omega)]_+$$

Coefficient form of PDE in COMSOL





$$\begin{cases} \omega : \Omega \to R \\ \omega = 0,\ D\dfrac{\partial \omega}{\partial n} = 0 \quad \text{on} \quad \Gamma \end{cases}$$

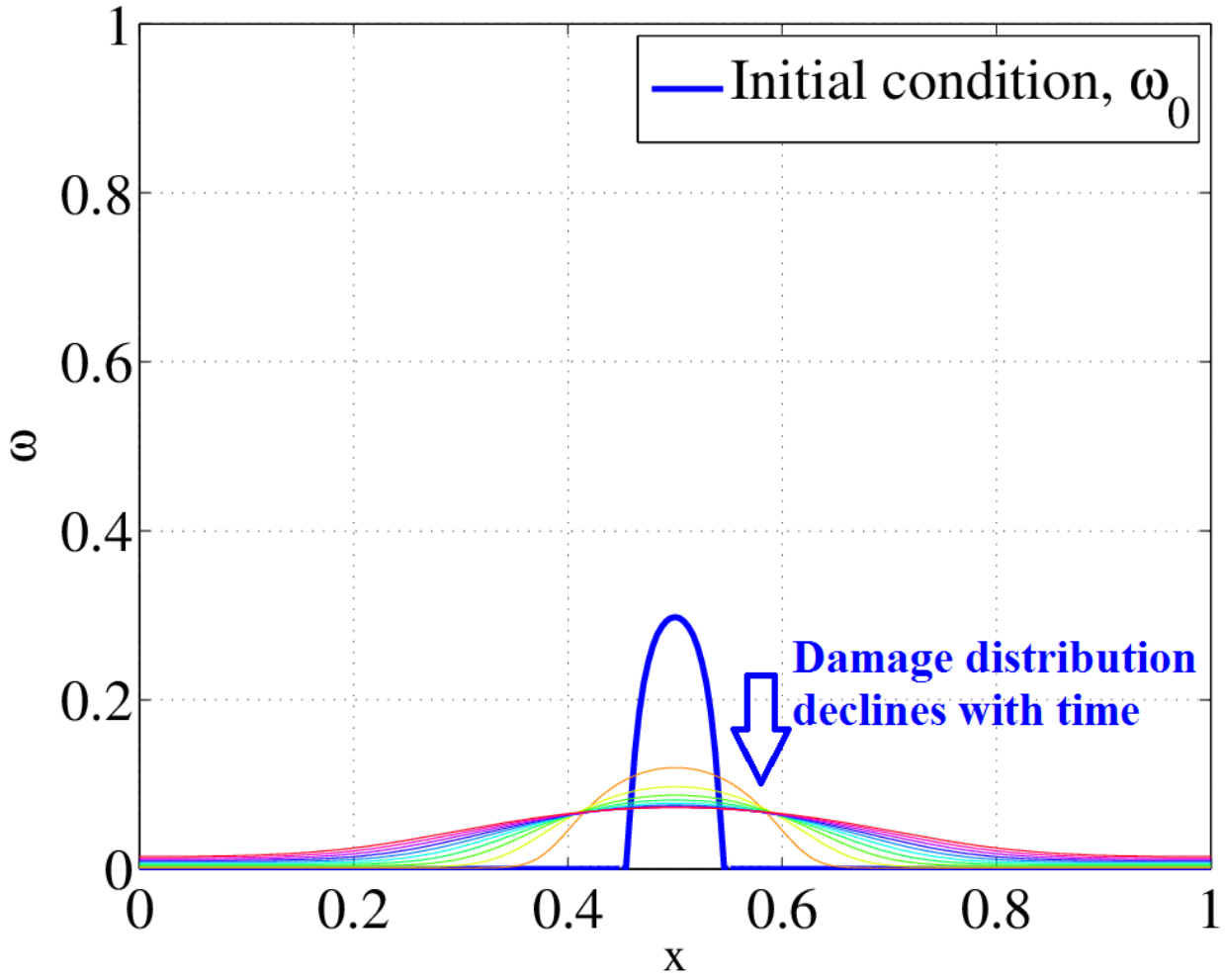
$$e_a\frac{\partial^2 u}{\partial t^2} + d_a\frac{\partial u}{\partial t} + \nabla \cdot (-c\nabla u - \alpha u + \gamma) + \beta \cdot \nabla u + au = f$$

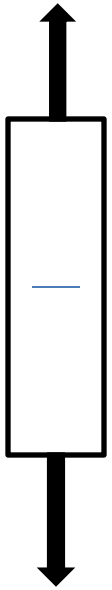
$$f = (1- u)\exp(\frac{\mu_0}{1- u})$$

$$c = \kappa(\frac{\mu_0 + u - 1}{1- u})\exp(\frac{\mu_0}{1- u})$$

Use zero for e_a, α, γ, β

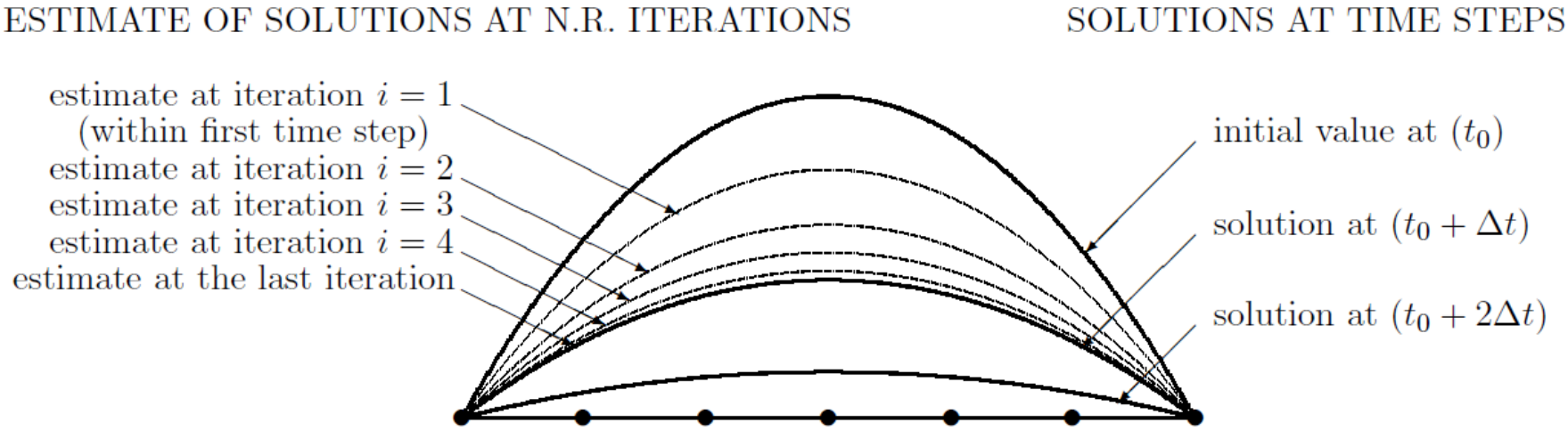
Results





Distribution of damage in a bar under tension

Use MATLAB to fix the problem



Use MATLAB to fix the problem

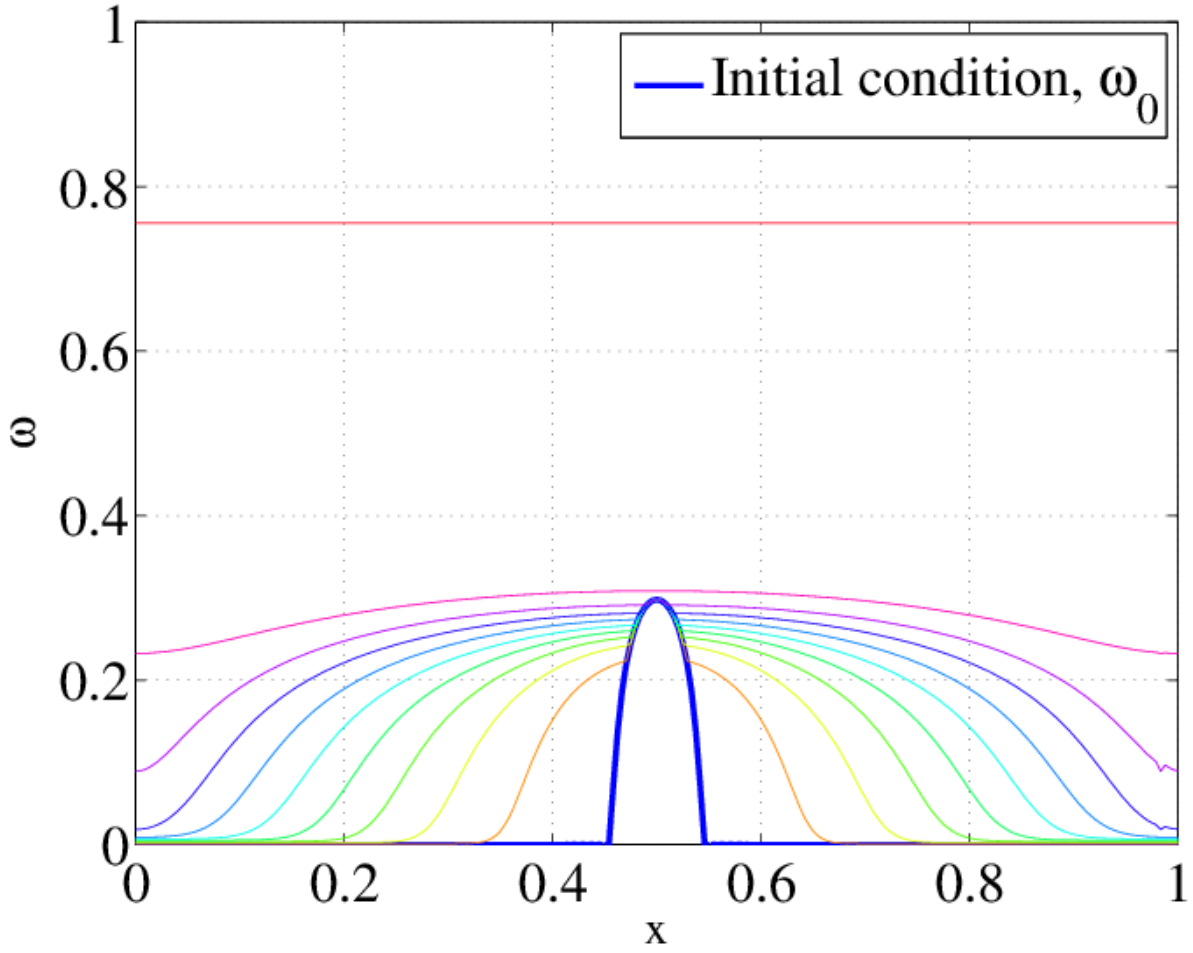
STEP 1: Obtain solution data

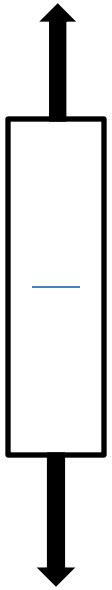
```
nodes = xmeshinfo(fem,'out','nodes');
dofs=nodes.dofs;      %Obtain degrees of freedom
coords=nodes.coords; %Obtain coordinates for the DOFs
X=fem.sol.u;          %Store solution vector
```

STEP 2: Remove negative results

```
X=fem.sol.u; %Assigns the entire solution vector to X
 for i1=1:length(dofs)
     if (X(i1,2))<(X(i1,1))
         X(i1,2)=X(i1,1);
     end
 end
```

Results





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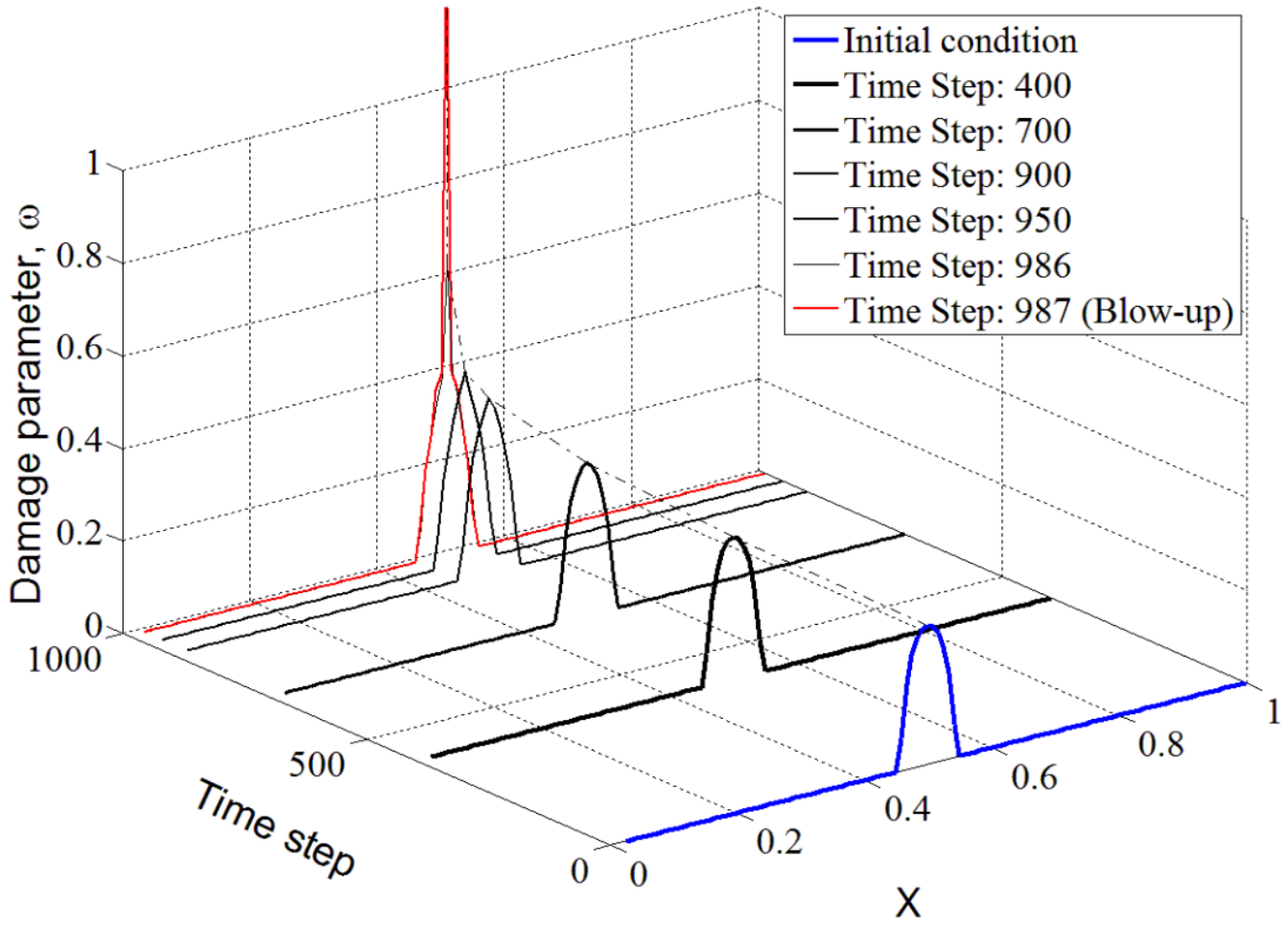

Distribution of damage : Blow-up of solution (**Fracture initiation**)

Conclusions

- In this paper we have used COMSOL Multiphysics and COMSOL Script to solve the transient rock damage problem. **We have analyzed the non-healing process and incorporated the positive rate of damage** in the finite element solution we obtained from COMSOL.

- Due to the nonlinearity of damage problem, to obtain an accurate converged solution, time steps have to be very small. Our numerical results indicate that for the number of **time steps beyond 10,000**, the solution converges.

- Inducing rock damage, enhances the permeability of rock and **increases productivity of oil and gas wells**.

Thank You