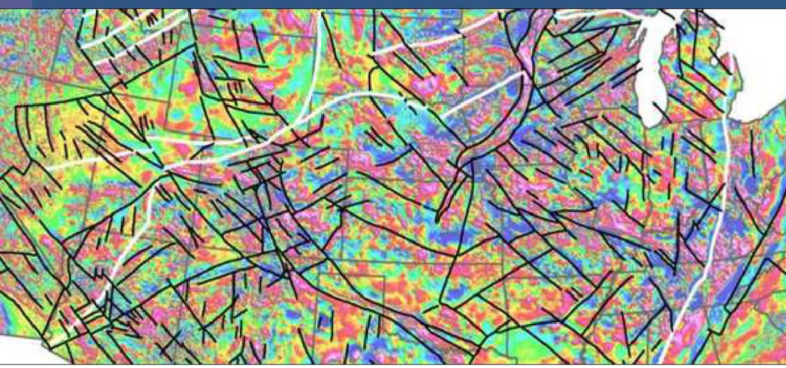
SAND2018-13445PE

Wellbore Stability



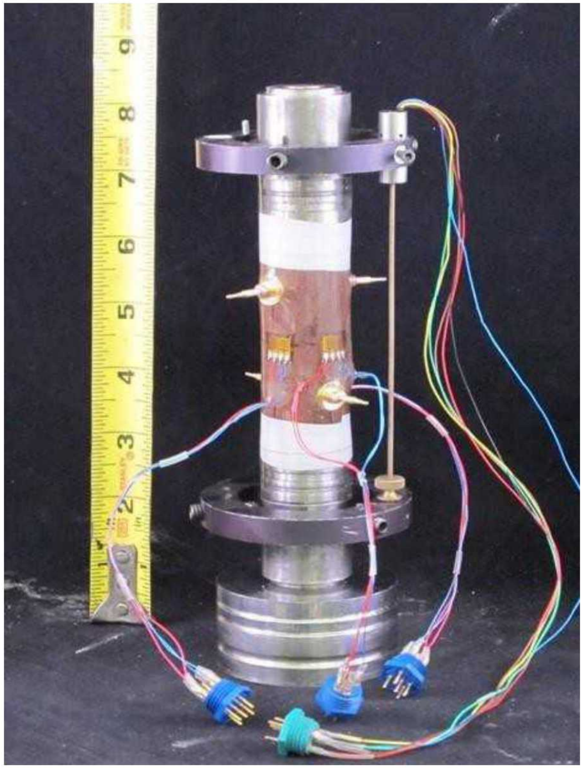
PRESENTED BY

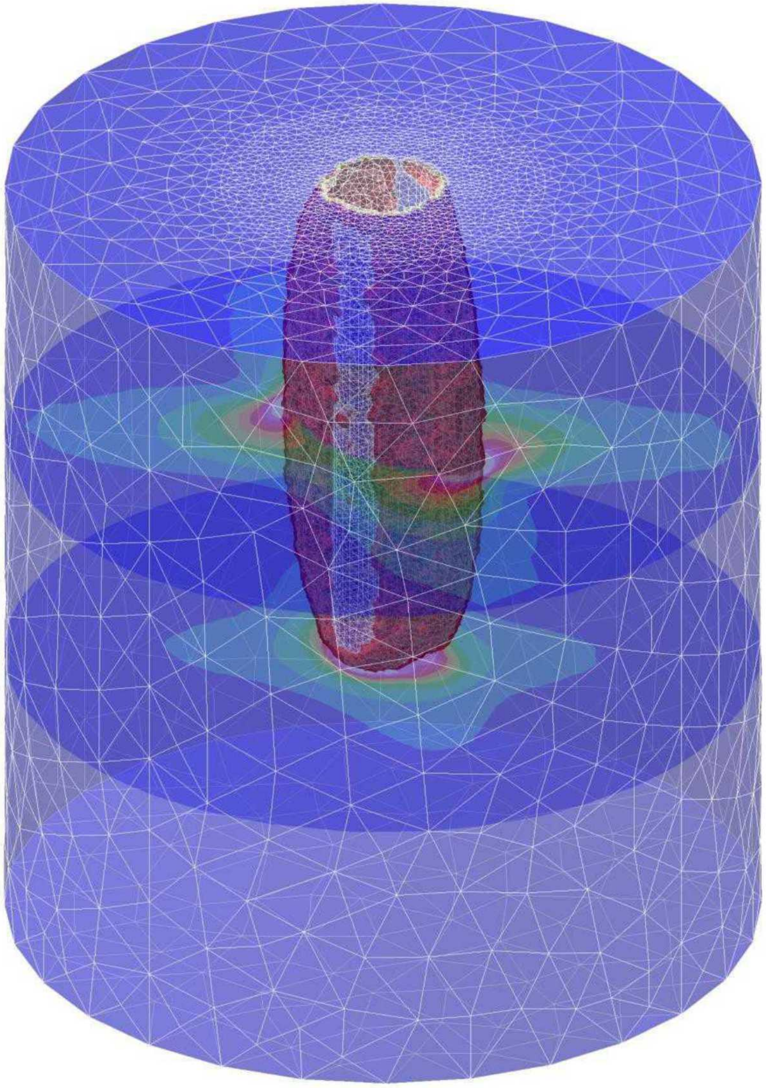
Stephen J. Bauer, SNL; Michael Homel and Antoun Tarabay, LLNL; Harel Levin, Gal Oren, Eyal Shalev,and Vladimir Lyakhovsky, Geological Survey of Israel

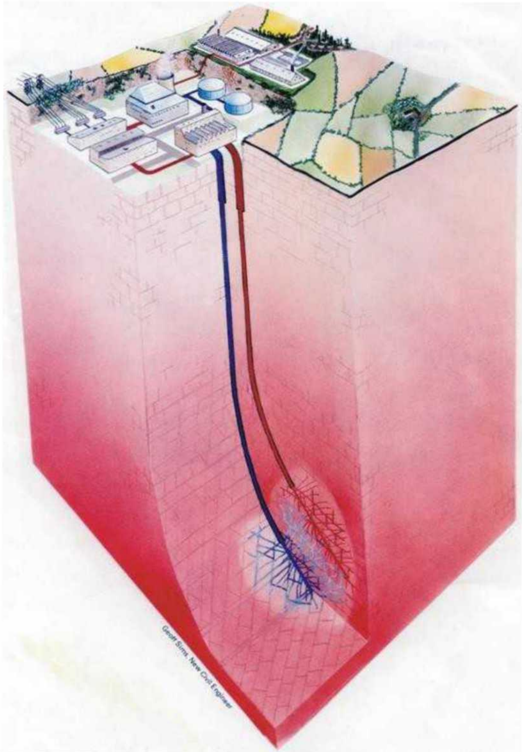
NNSA/IAEC 2018 Workshop
Los Alamos National Laboratory
December 4-5, 2018

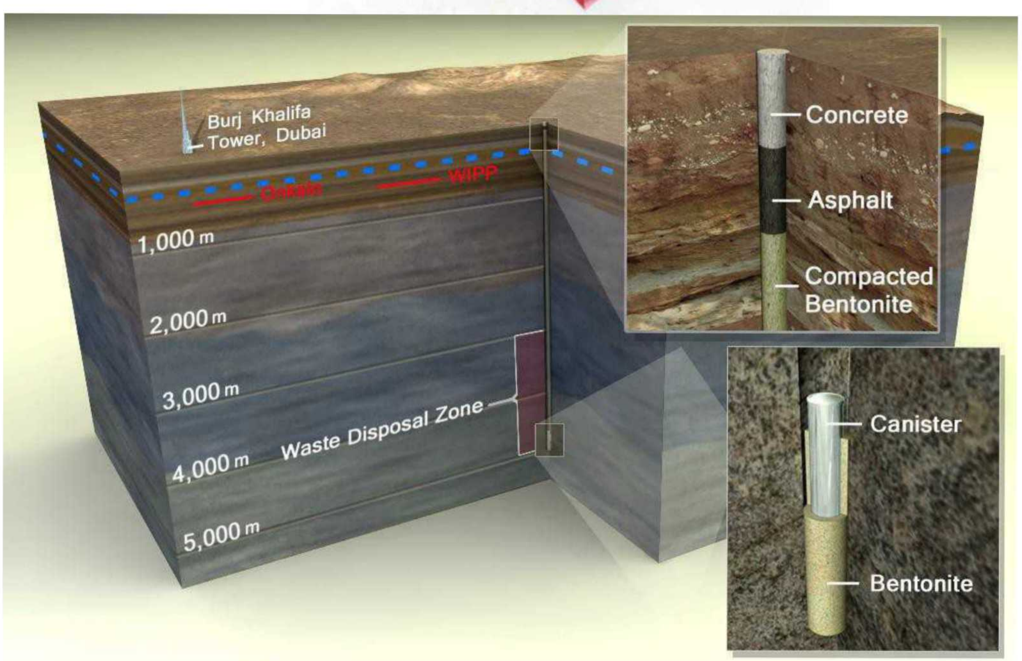
Sandia National Laboratories is a multi-mission laboratory managed and operated by National-Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND2018-XXXXPE.

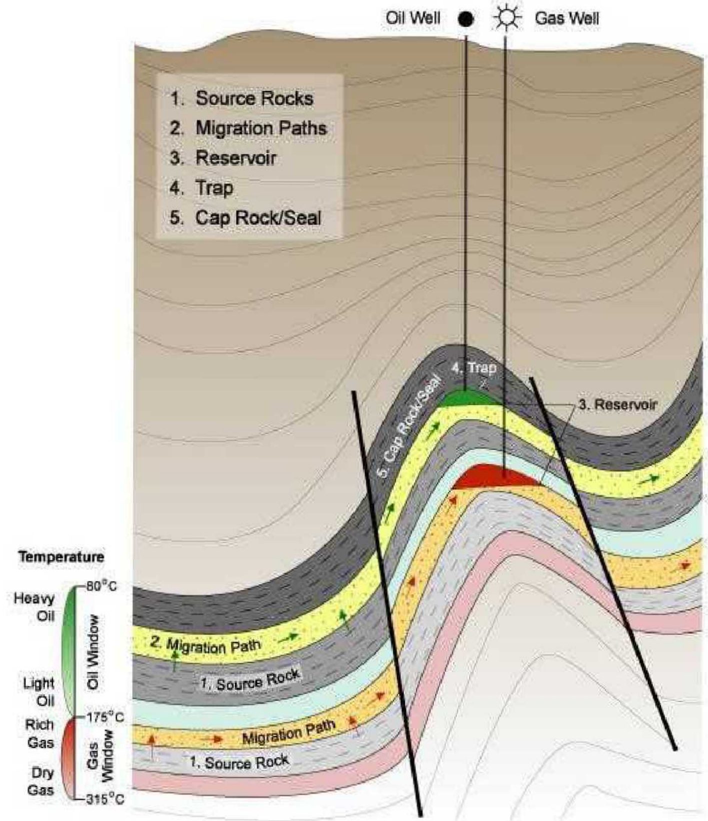
Damage accumulation and wellbore stability

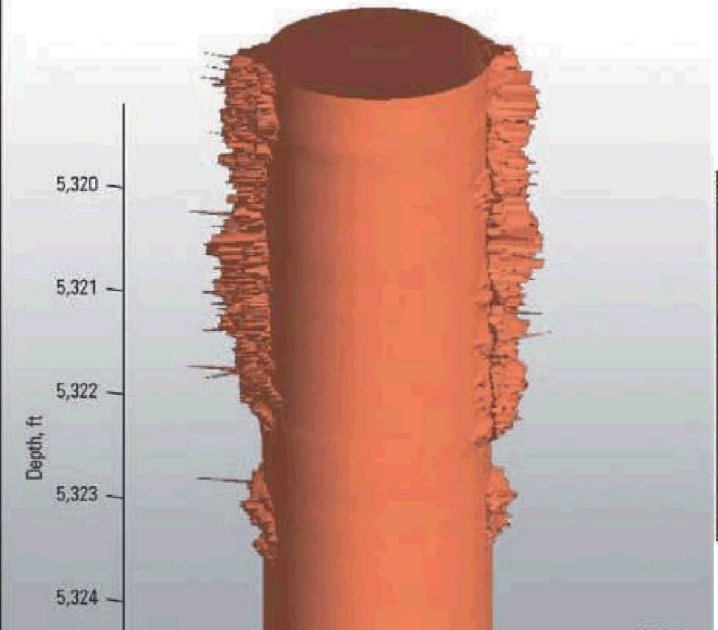


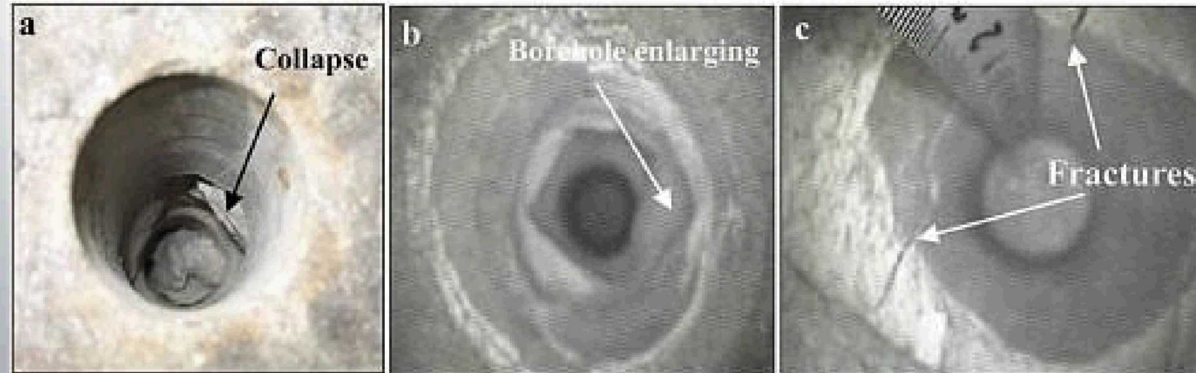




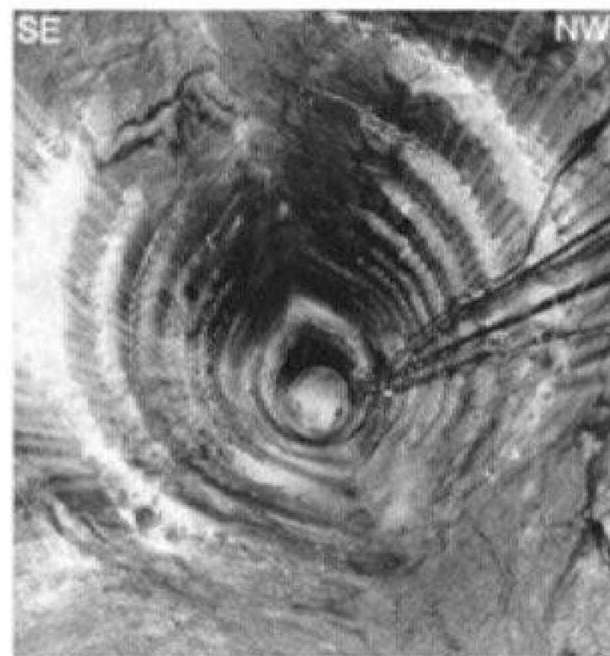

Burj Khalifa Tower, Dubai
Dakota
WIPP
1,000 m
2,000 m
3,000 m
4,000 m
5,000 m
Waste Disposal Zone
Concrete
Asphalt
Compacted Bentonite
Canister
Bentonite

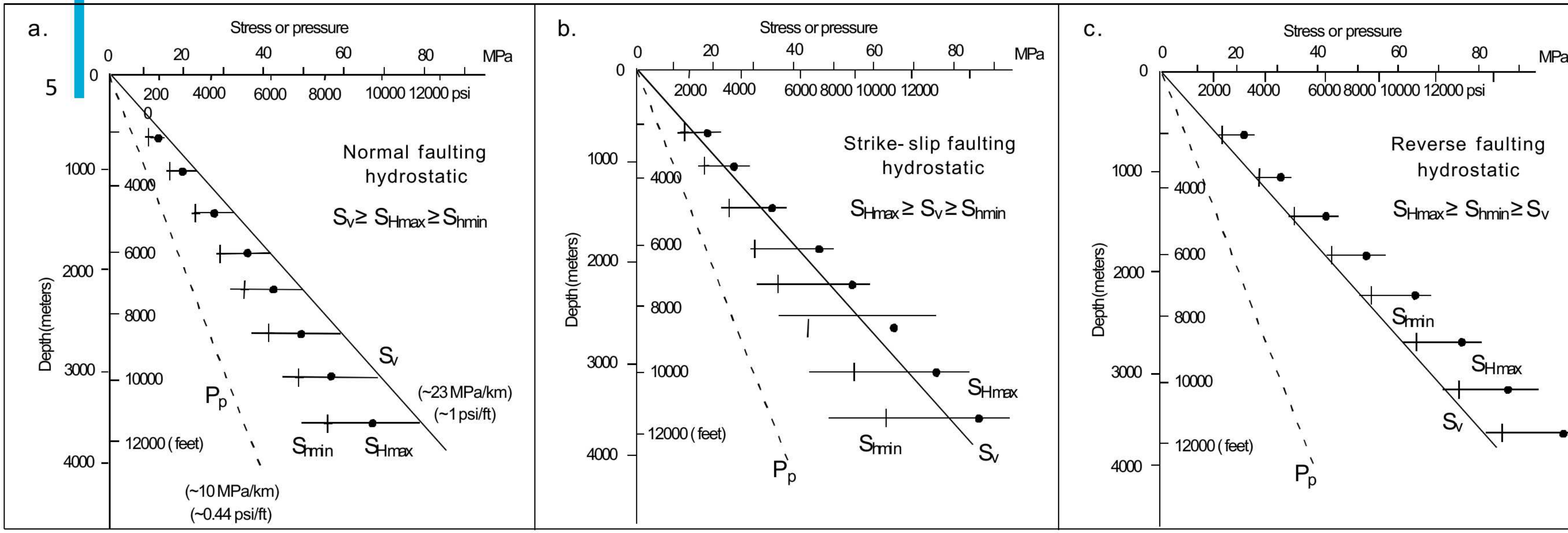

Oil Well
Gas Well
1. Source Rocks
2. Migration Paths
3. Reservoir
4. Trap
5. Cap Rock/Seal
4. Trap
5. Cap Rock/Seal
3. Reservoir
2. Migration Path
1. Source Rock
Migration Path
1. Source Rock
Temperature
Heavy Oil
Light Oil
Rich Gas
Dry Gas
Oil Window
Gas Window
80°C
175°C
315°C

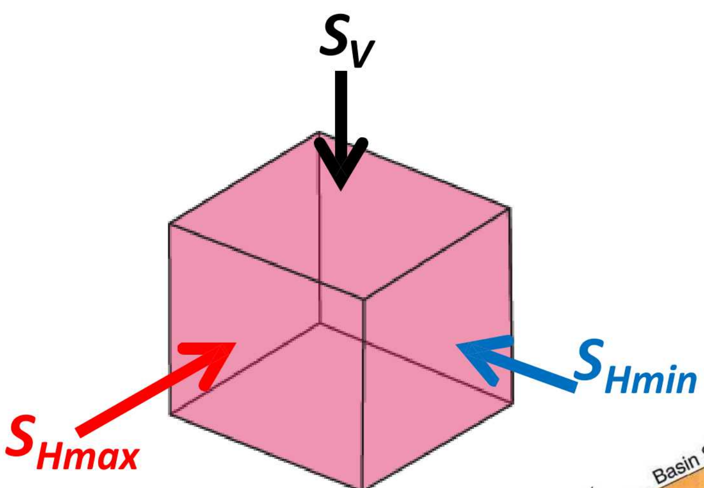

5,320
5,321
5,322
5,323
5,324
Depth, ft

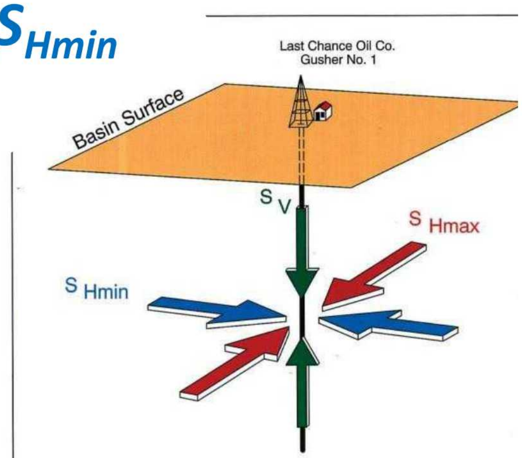

a
Collapse
b
Borehole enlarging
c
Fractures

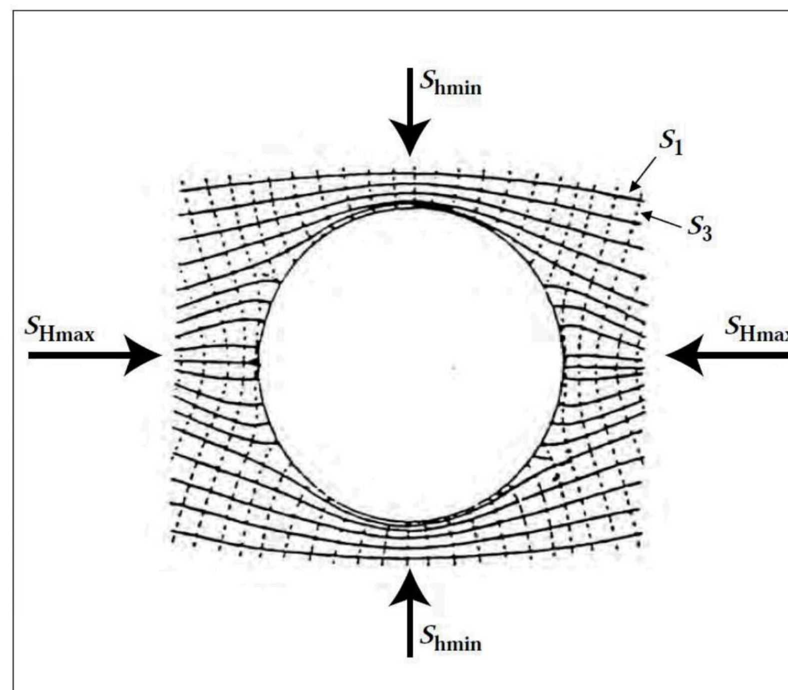

Collapse
0ft


SE
NW


a.
Stress or pressure
0
20
40
60
80
MPa
0
200
4000
6000
8000
10000 12000 psi
1000
4000
2000
6000
8000
3000
10000
12000 (feet)
4000
Depth (meters)
Normal faulting
hydrostatic
$S_v \geq S_{Hmax} \geq S_{hmin}$
S_v
(~23 MPa/km)
(~1 psi/ft)
P_p
S_{hmin}
S_{Hmax}
(~10 MPa/km)
(~0.44 psi/ft)
b.
Stress or pressure
0
20
40
60
80
MPa
2000
4000
6000 8000 10000 12000
1000
4000
6000
2000
8000
3000
10000
12000 (feet)
4000
Depth (meters)
Strike- slip faulting
hydrostatic
$S_{Hmax} \geq S_v \geq S_{hmin}$
S_{Hmax}
S_{hmin}
S_v
P_p
c.
Stress or pressure
0
20
40
60
80
MPa
2000
4000
6000 8000 10000 12000 psi
1000
4000
6000
2000
8000
3000
10000
12000 (feet)
4000
Depth (meters)
Reverse faulting
hydrostatic
$S_{Hmax} \geq S_{hmin} \geq S_v$
S_{hmin}
S_{Hmax}
S_v
P_p


S_V
S_{Hmin}
S_{Hmax}


Last Chance Oil Co.
Gusher No. 1
Basin Surface
S_V
S_{Hmax}
S_{Hmin}

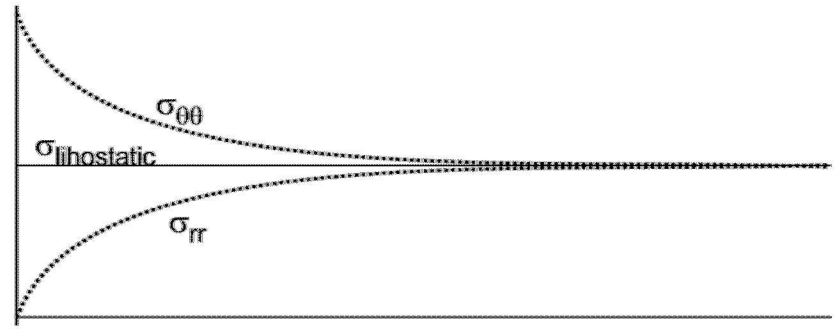

S_{hmin}
S_1
S_3
S_{Hmax}
S_{Hmax}
S_{hmin}

Isotropic/Lithostatic Stress

$$\sigma_{rr} = \frac{1}{2}(S_{Hmax} + S_{Hmin})\left(1 - \frac{R^2}{r^2}\right) + \frac{1}{2}(S_{Hmax} - S_{Hmin})\left(1 - \frac{4R^2}{r^2} + \frac{3R^2}{r^4}\right)cos2\theta$$

$$\sigma_{\theta\theta} = \frac{1}{2}(S_{Hmax} + S_{Hmin})\left(1 + \frac{R^2}{r^2}\right) - \frac{1}{2}(S_{Hmax} - S_{Hmin})\left(1 + \frac{3R^2}{r^4}\right)($$

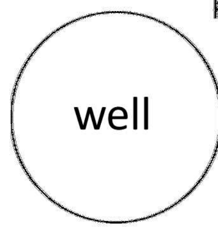
$$\tau_{r\theta} = \frac{1}{2}(S_{Hmax} - S_{Hmin})\left(1 + \frac{2R^2}{r^2} - \frac{3R^2}{r^4}\right)sin2\theta$$



For Lithostatic condition on the well:

$S_{Hmax} + S_{Hmin}$ and $r = R$

$$\sigma_{rr} = 0; \sigma_{\theta\theta} = 2S_{lith}; \tau_{r\theta} = 0$$



Mohr–Coulomb Criterion

$$\frac{\sigma_{\theta\theta}/2}{Cctg\varphi + \sigma_{\theta\theta}/2} = sin\varphi$$

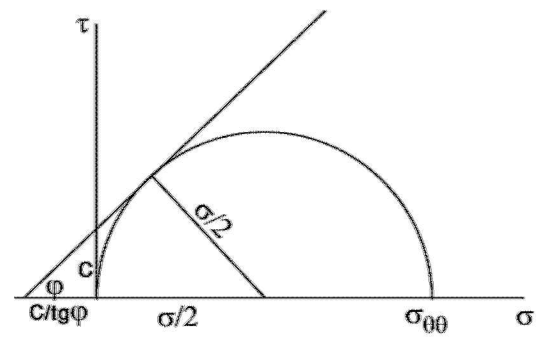
$$\frac{S_{lith}}{Cctg\varphi + S_{lith}} = sin\varphi$$

$$S_{lith}(1 - sin\varphi) = Cctg\varphi sin\varphi$$

$$S_{lith} = \frac{Ccos\varphi}{(1 - sin\varphi)}$$

$$S_{lith} = \frac{Ccos\varphi}{(1 - sin\varphi)}$$

$$\varphi = 38.5^0; C = 10MPa$$



$$S_{lith} = 20.7 \text{ MPa} = \rho g z$$

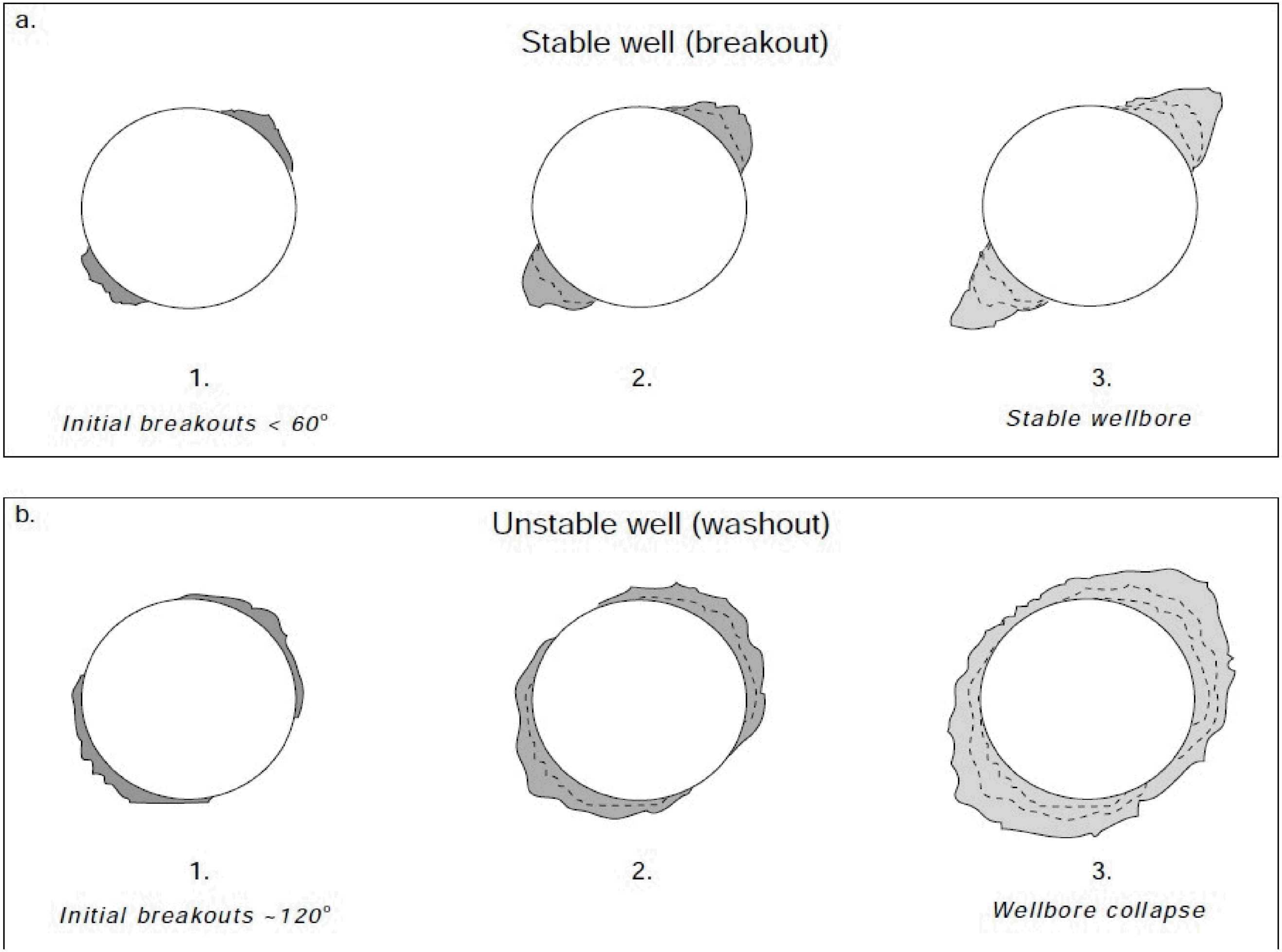
$$\rho = 2800\frac{gr}{cc}; g = 9.81m/s^2$$

Wellbore failure at:

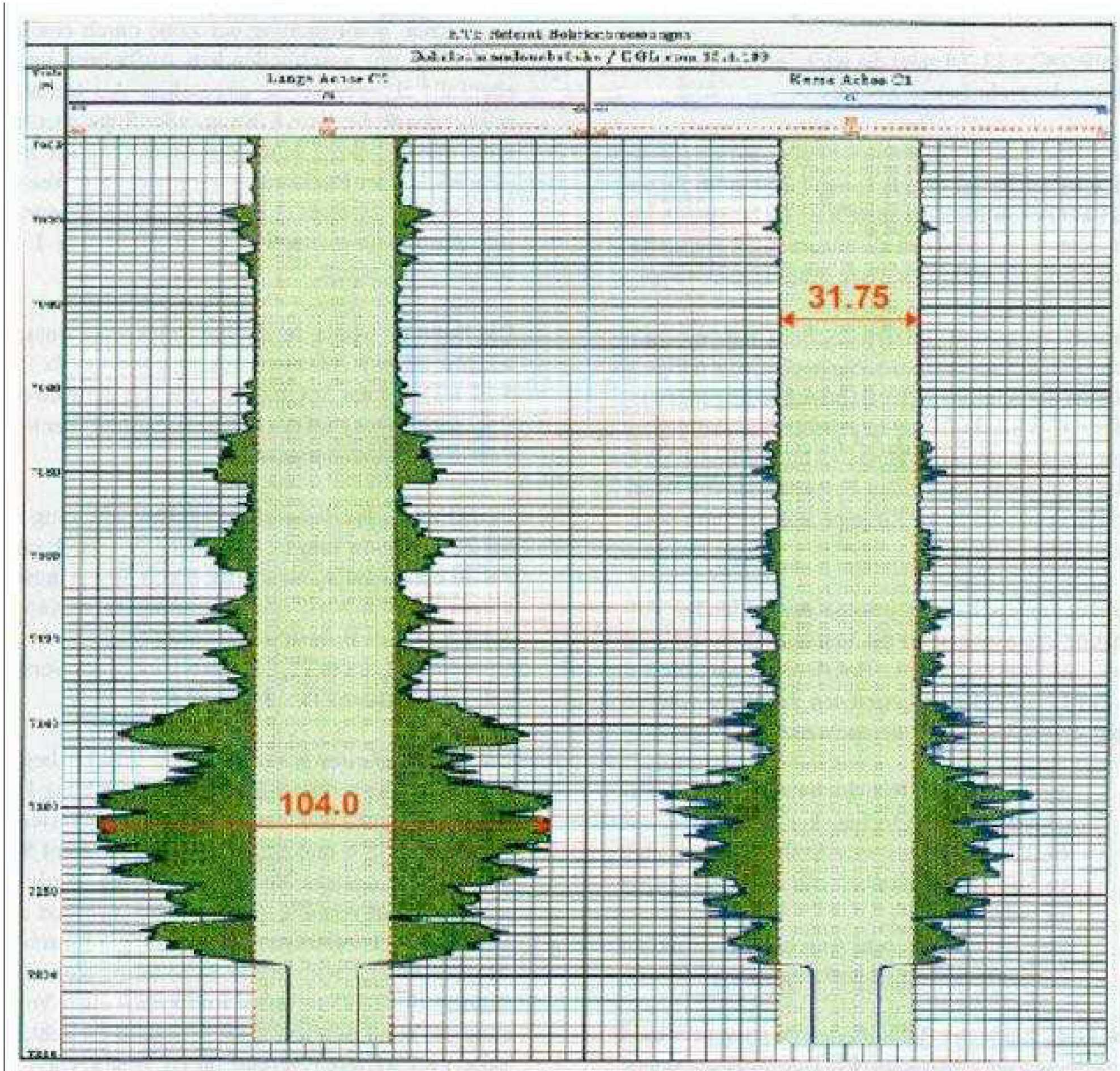
$$\boldsymbol{z = 782\ m}$$

$$\boldsymbol{3D\ criterion}:$$

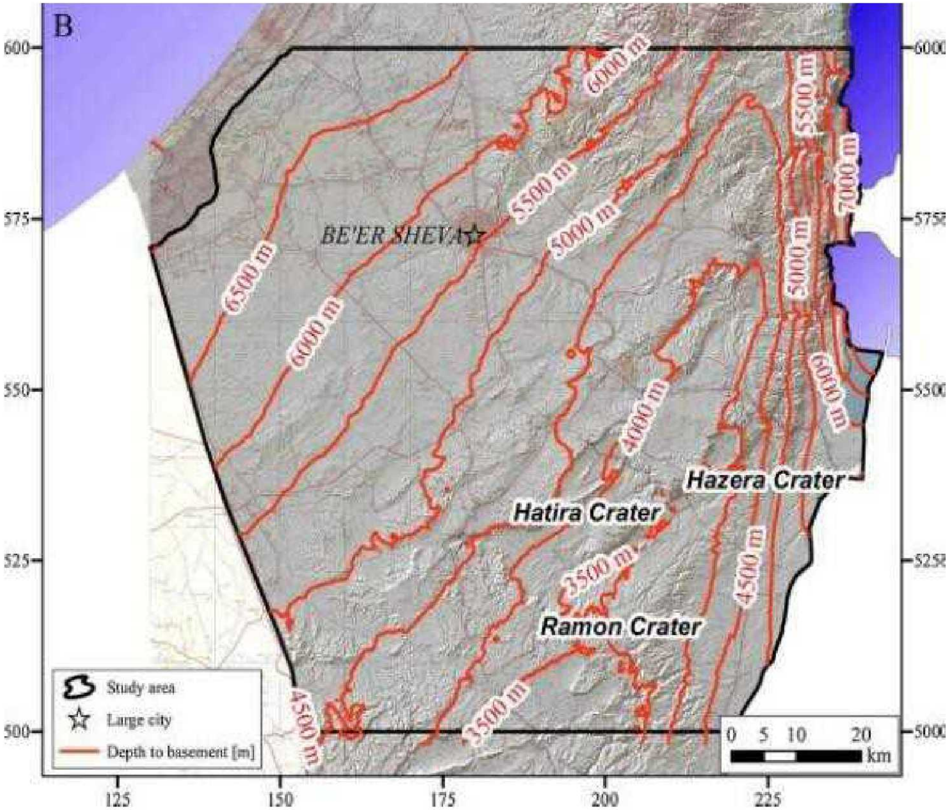
$$\boldsymbol{z = 1,500\ m}$$


a.
Stable well (breakout)
1.
Initial breakouts < 60°
2.
3.
Stable wellbore
b.
Unstable well (washout)
1.
Initial breakouts ~120°
2.
3.
Wellbore collapse

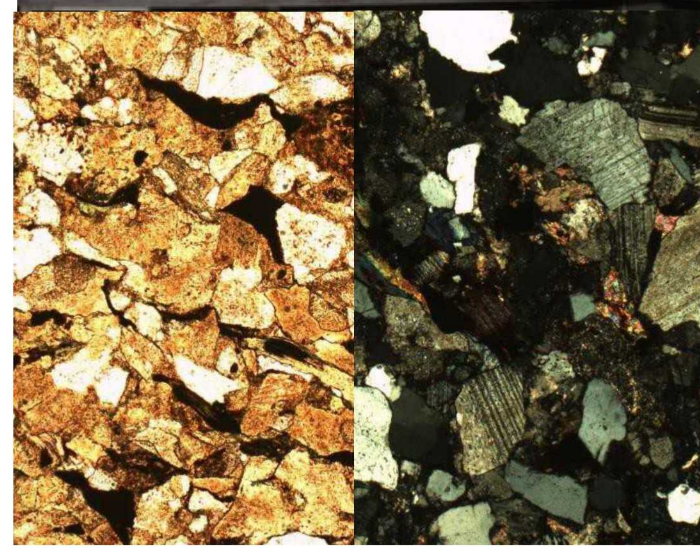
Borehole breakouts of the KTB-HB in the depth interval between 7 and 7.2 km



Target Horizon: Zenifim Formation



Depth of Zenifim formation (Calvo & Gvirtzman, 2013)



Depths of interest: 3-5 km;
70-100MPa confining pressure
Temperatures: ambient to 350C
Dry, water saturated

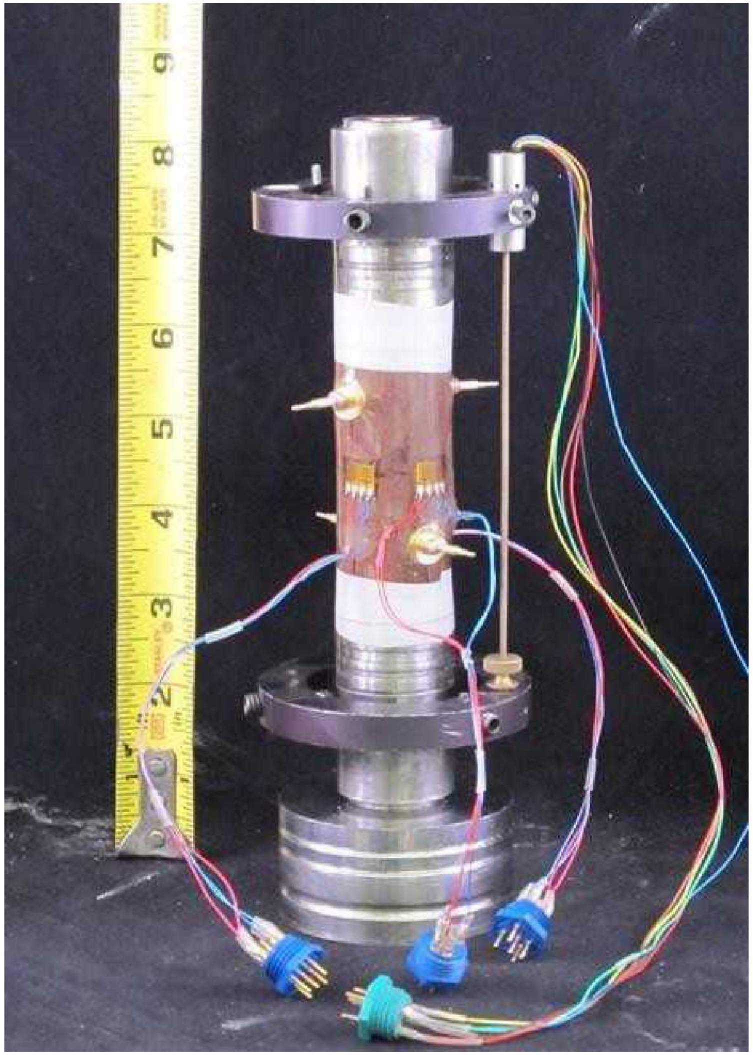
50% feldspar (oligoclase-andesine)
40% quartz, 10% lithics, biotite, chlorite, hornblende (Weissbrod & Sneh 2002)

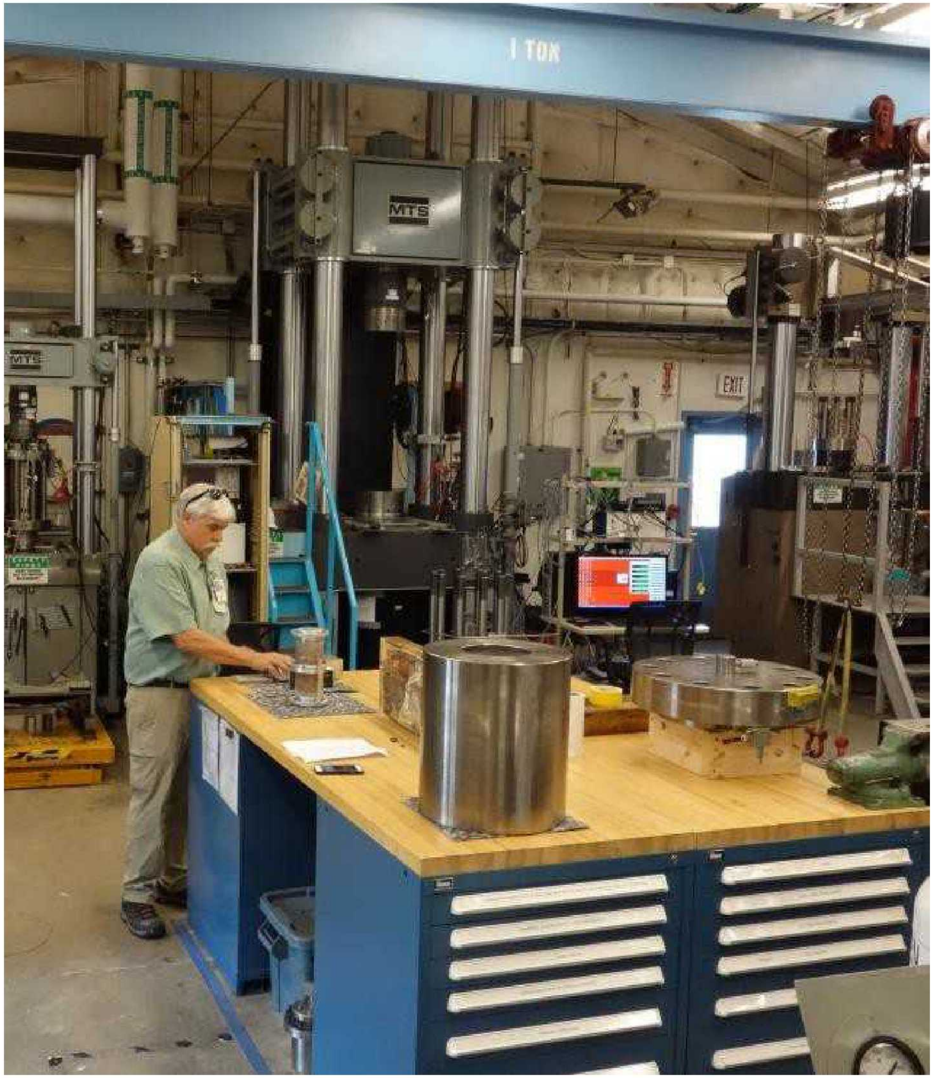
Rock Core transfer to Sandia

Thermal, mechanical, and hydrologic property determinations

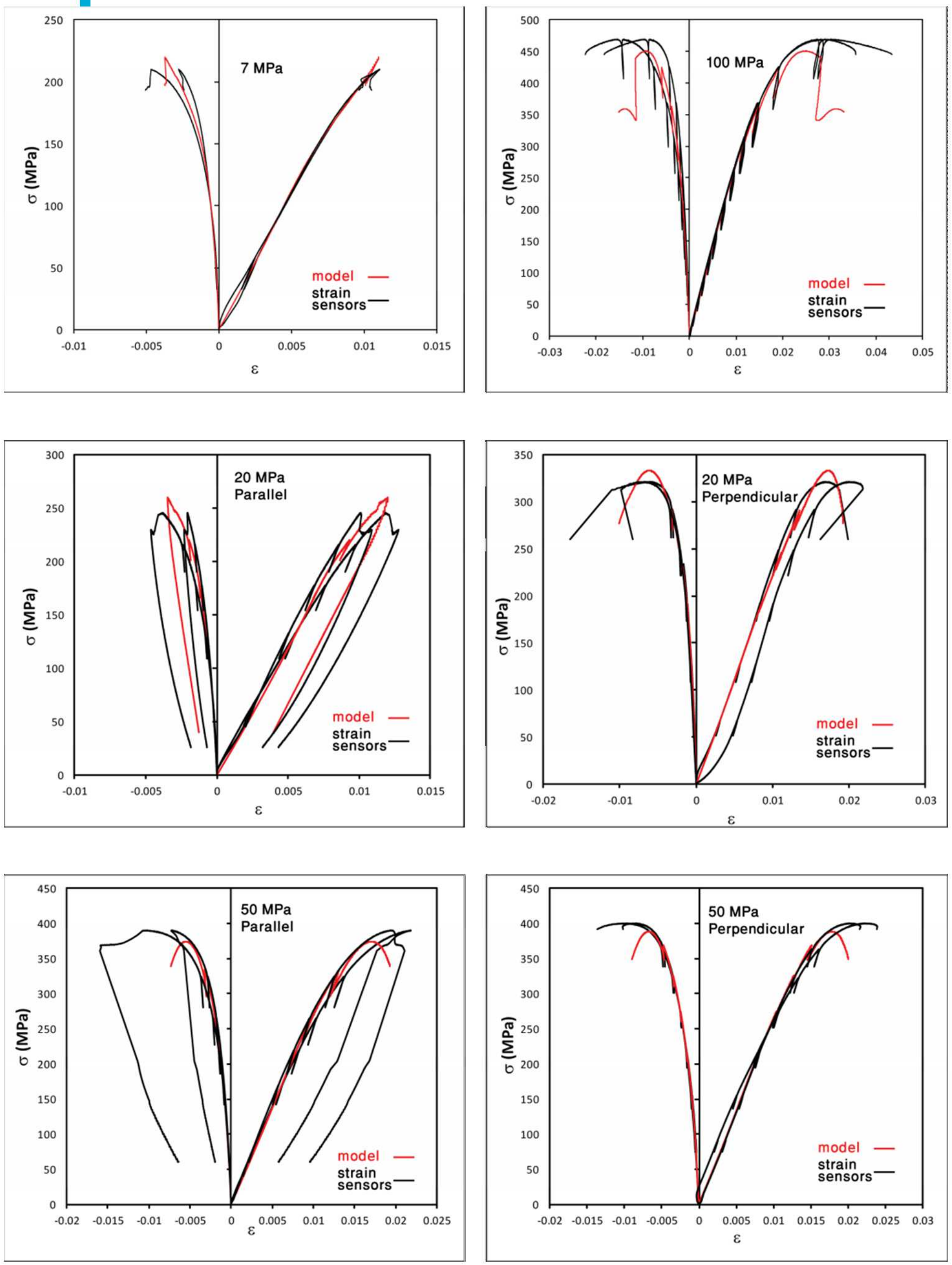
Elastic and Strength Properties

E, μ, β, strength criterion



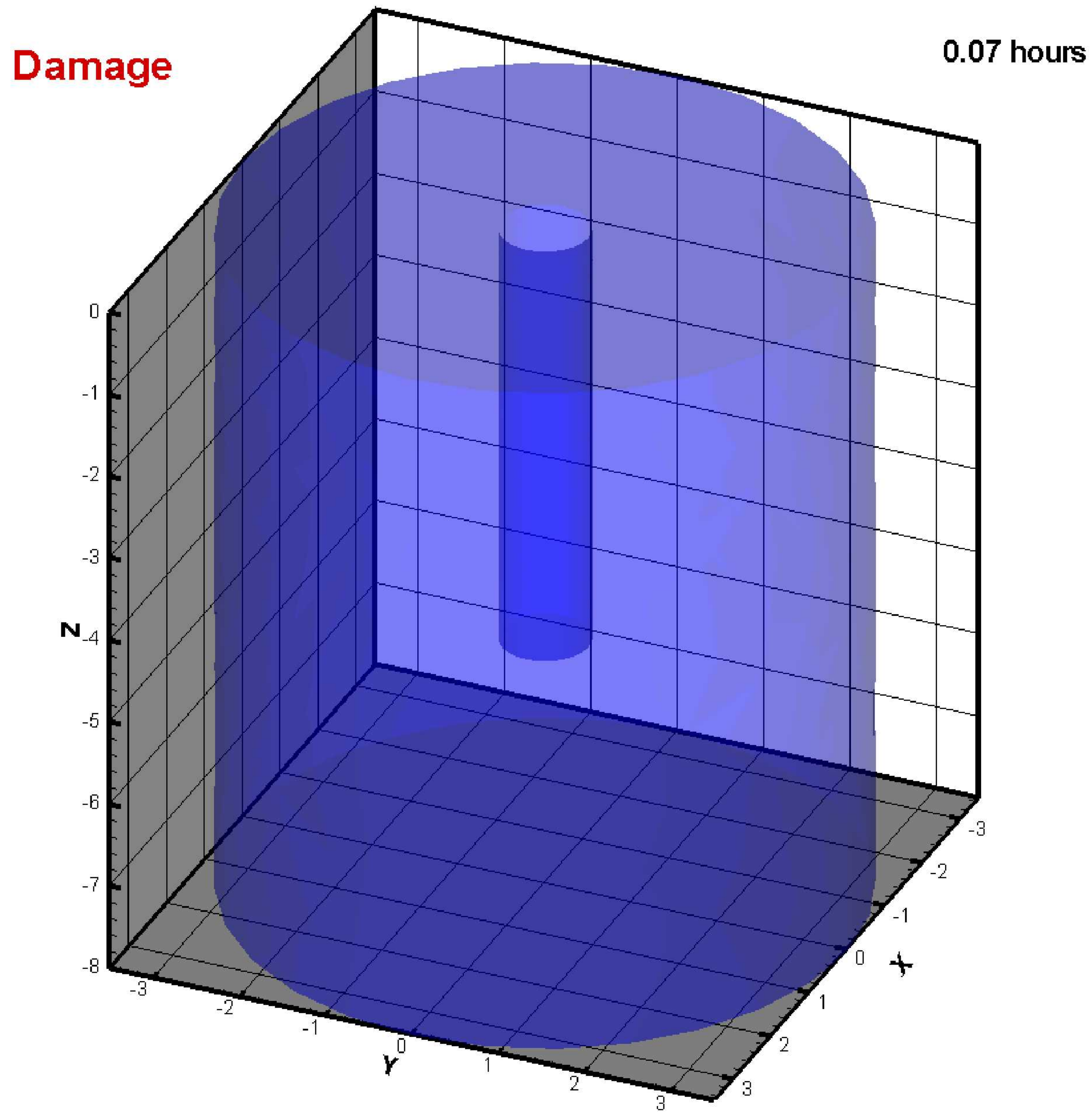


Experimental data and poro-elastic damage model

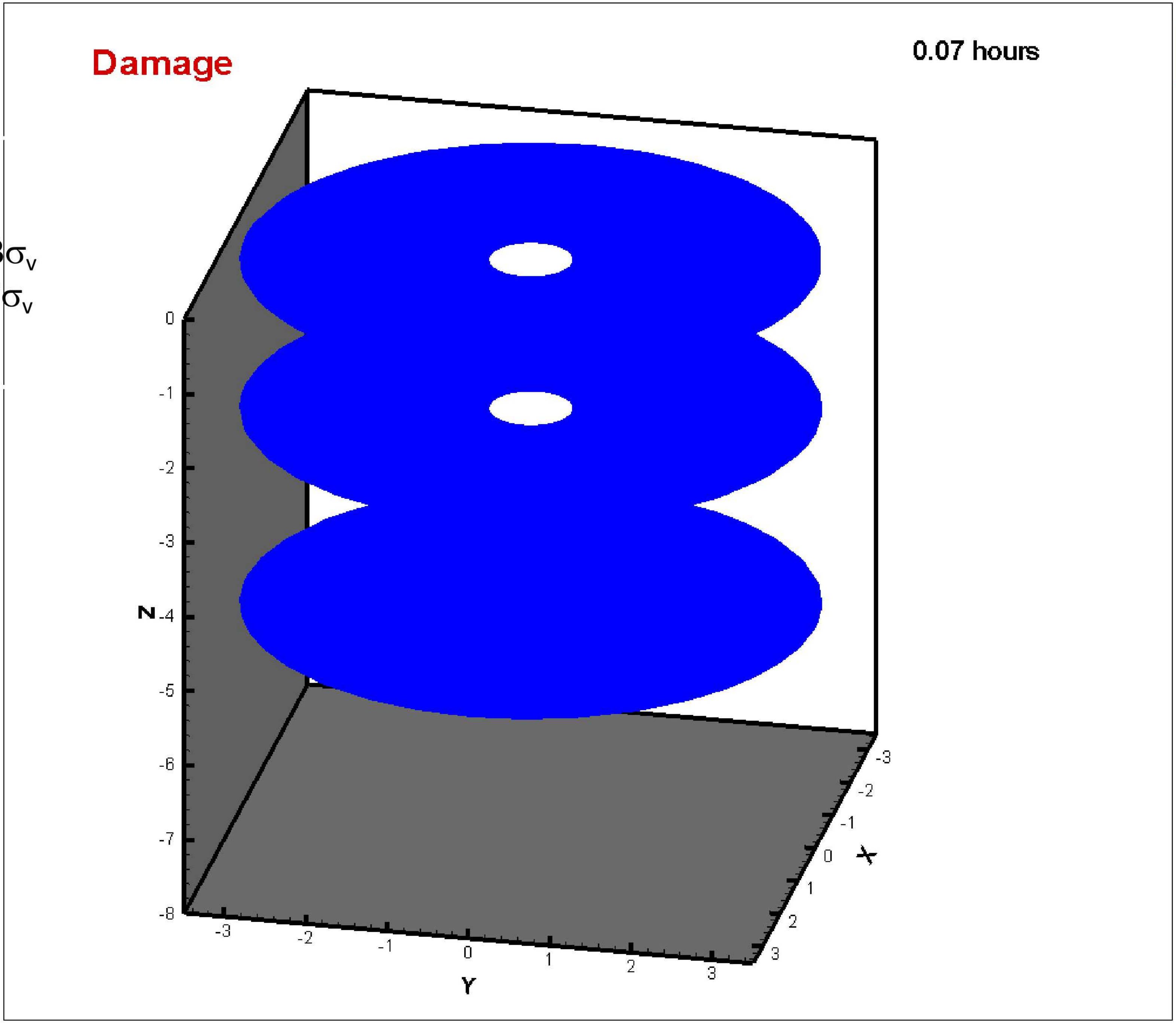


Test	pressure	Orient	Lambda	G	ksi_0	Cd
2933	100	Perp	6000	12000	-0.4	50
8433	20	Paral	6000	10500	-0.4	50
8434	20	Perp	6000	10000	-0.4	30
8435	50	Paral	6000	12000	-0.4	50
8436	50	Perp	6000	11500	-0.4	25
8437	7	Perp	6000	10000	-0.4	12

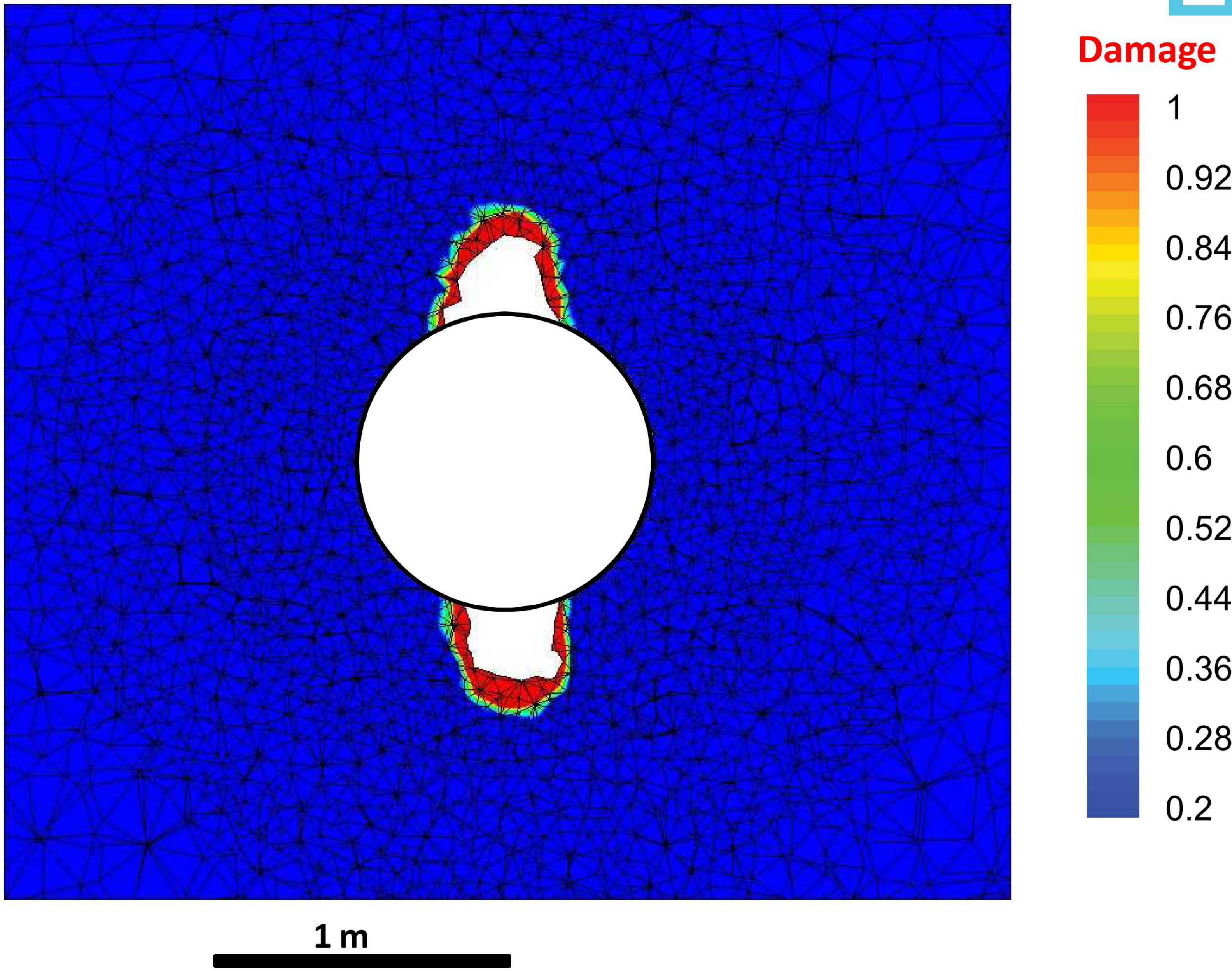
Granite
2 KM
$\sigma_{Hmax}=1.3\sigma_v$
$\sigma_{Hmin}=0.7\sigma_v$



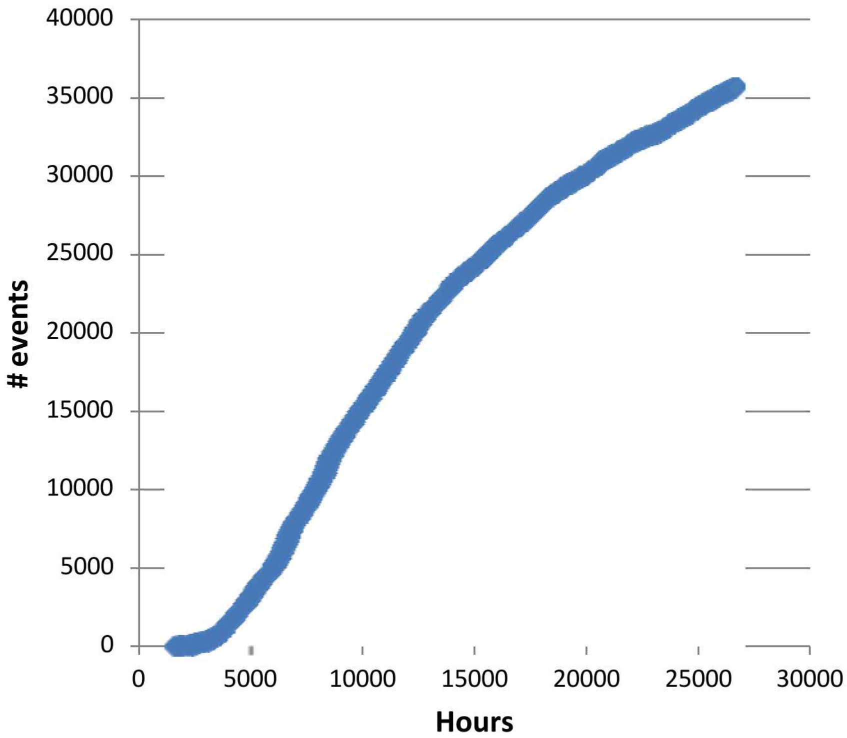
Granite
2 KM
$\sigma_{Hmax}=1.3\sigma_v$
$\sigma_{Hmin}=0.7\sigma_v$

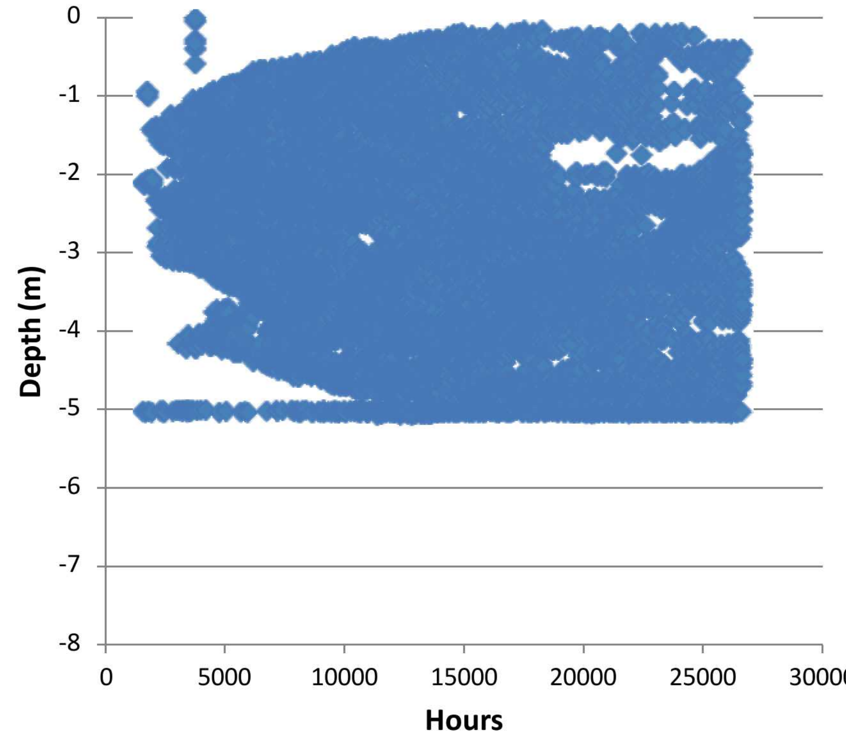


13.47 hours

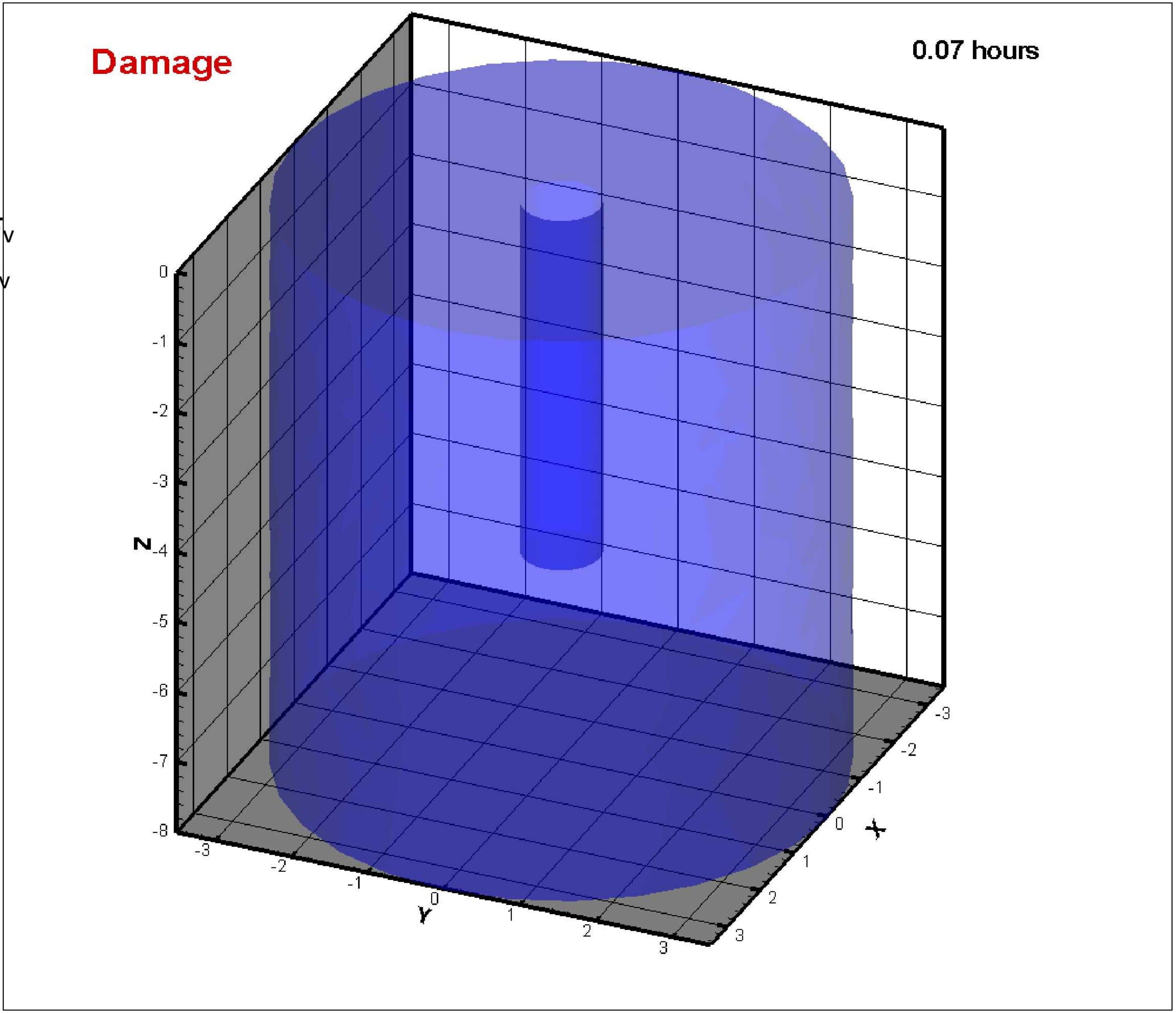


Granite

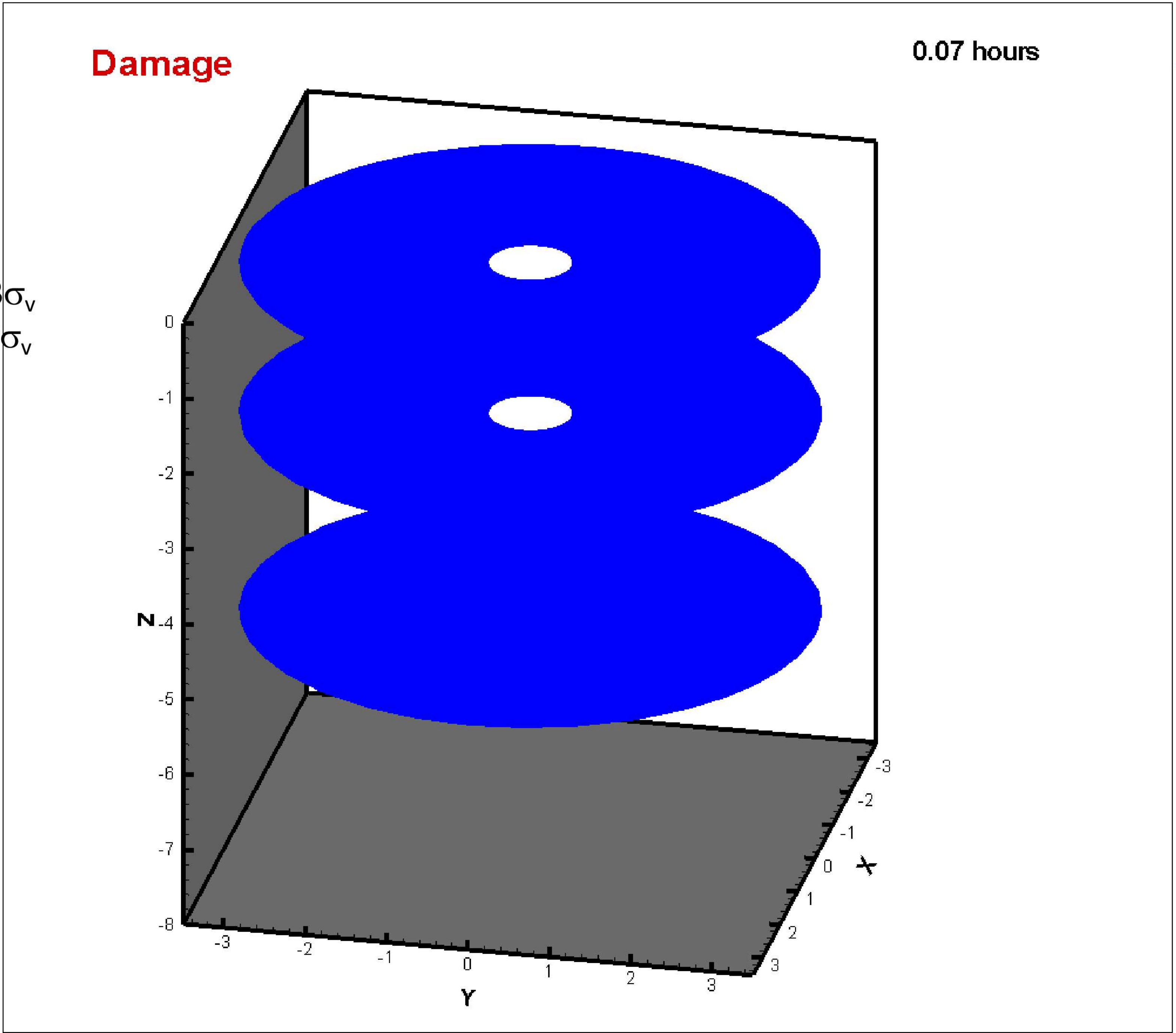

40000
35000
30000
25000
20000
15000
10000
5000
0
events
0
5000
10000
15000
20000
25000
30000
Hours


0
-1
-2
-3
-4
-5
-6
-7
-8
Depth (m)
0
5000
10000
15000
20000
25000
30000
Hours

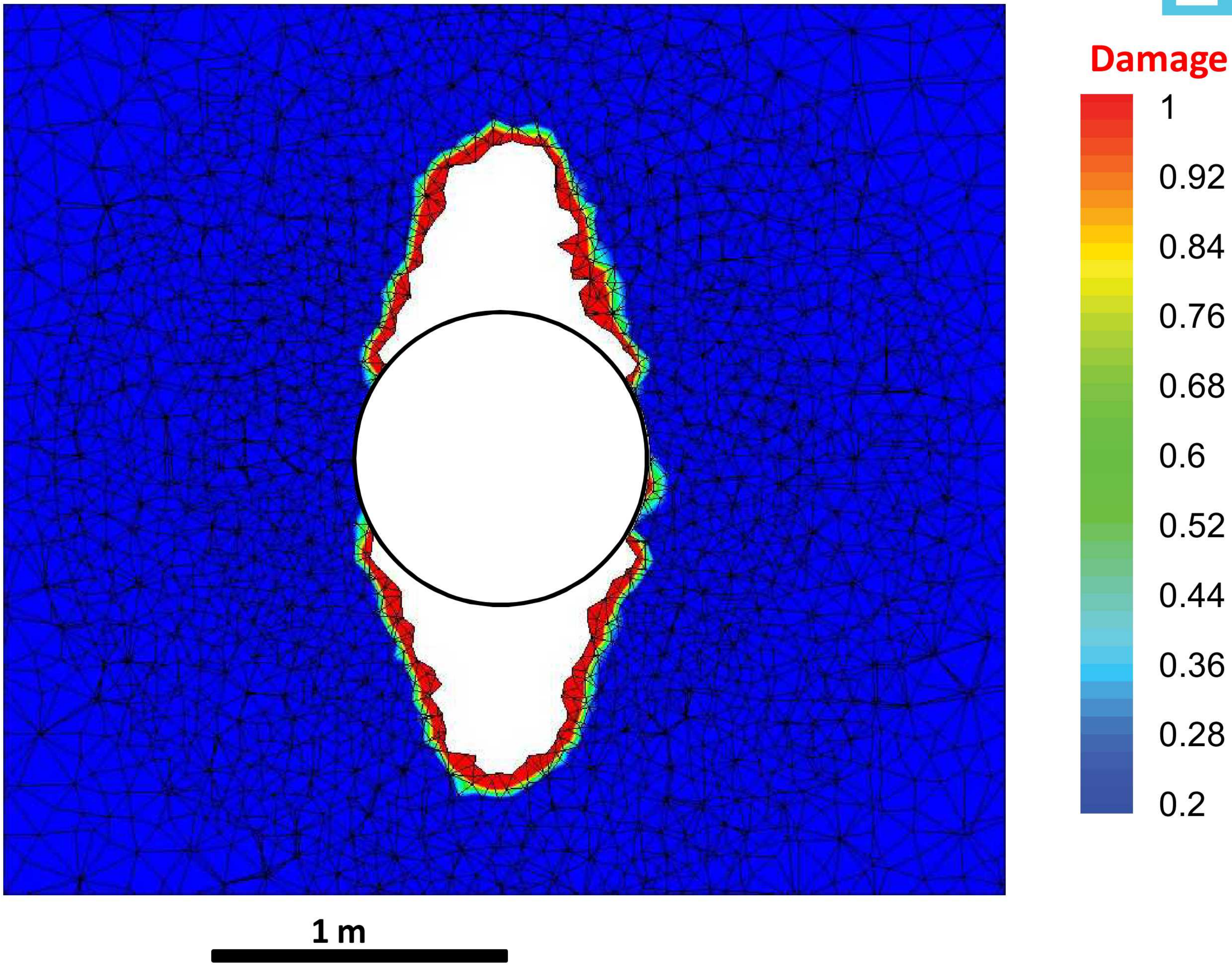
Granite
5 KM
$\sigma_{Hmax}=1.3\sigma_v$
$\sigma_{Hmin}=0.7\sigma_v$



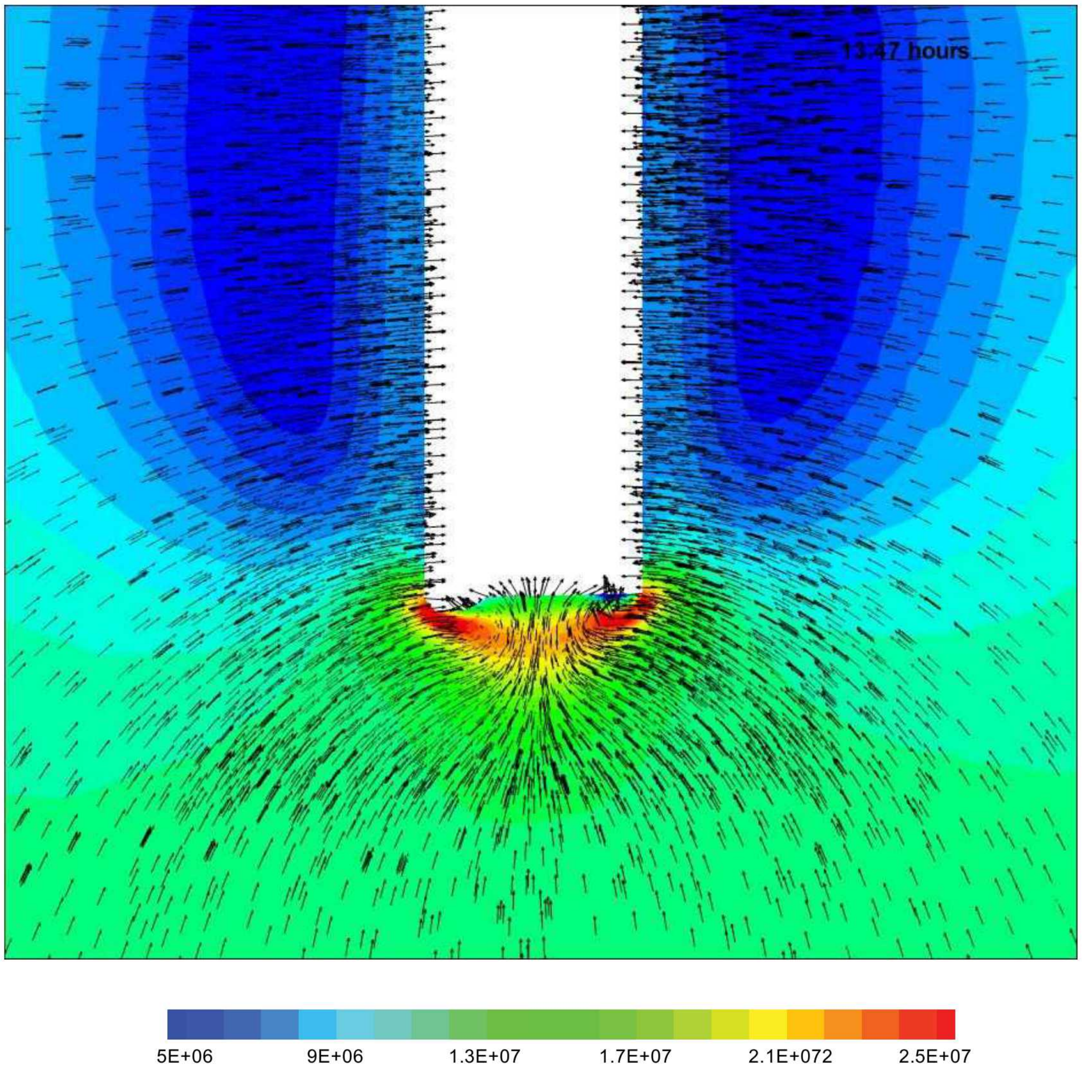
Granite
5 KM
$\sigma_{Hmax}=1.3\sigma_v$
$\sigma_{Hmin}=0.7\sigma_v$

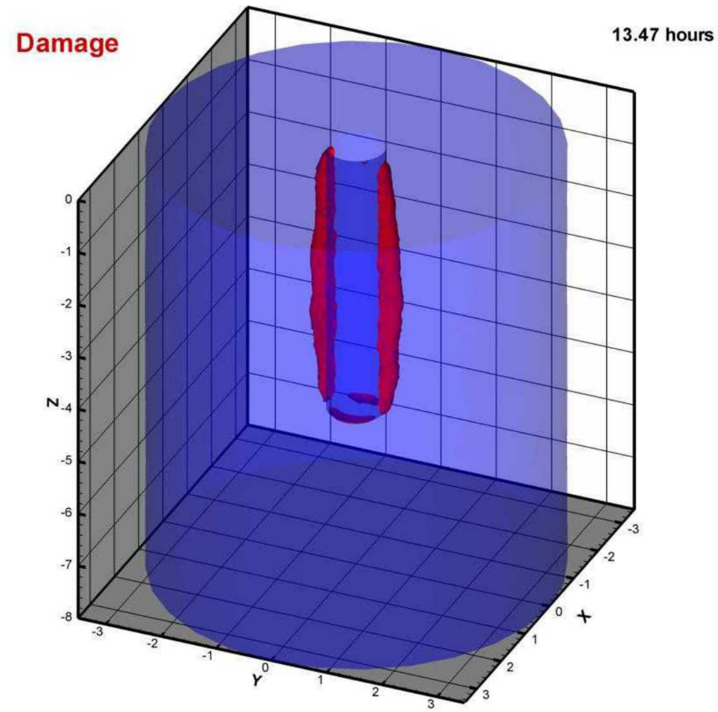


3 hours

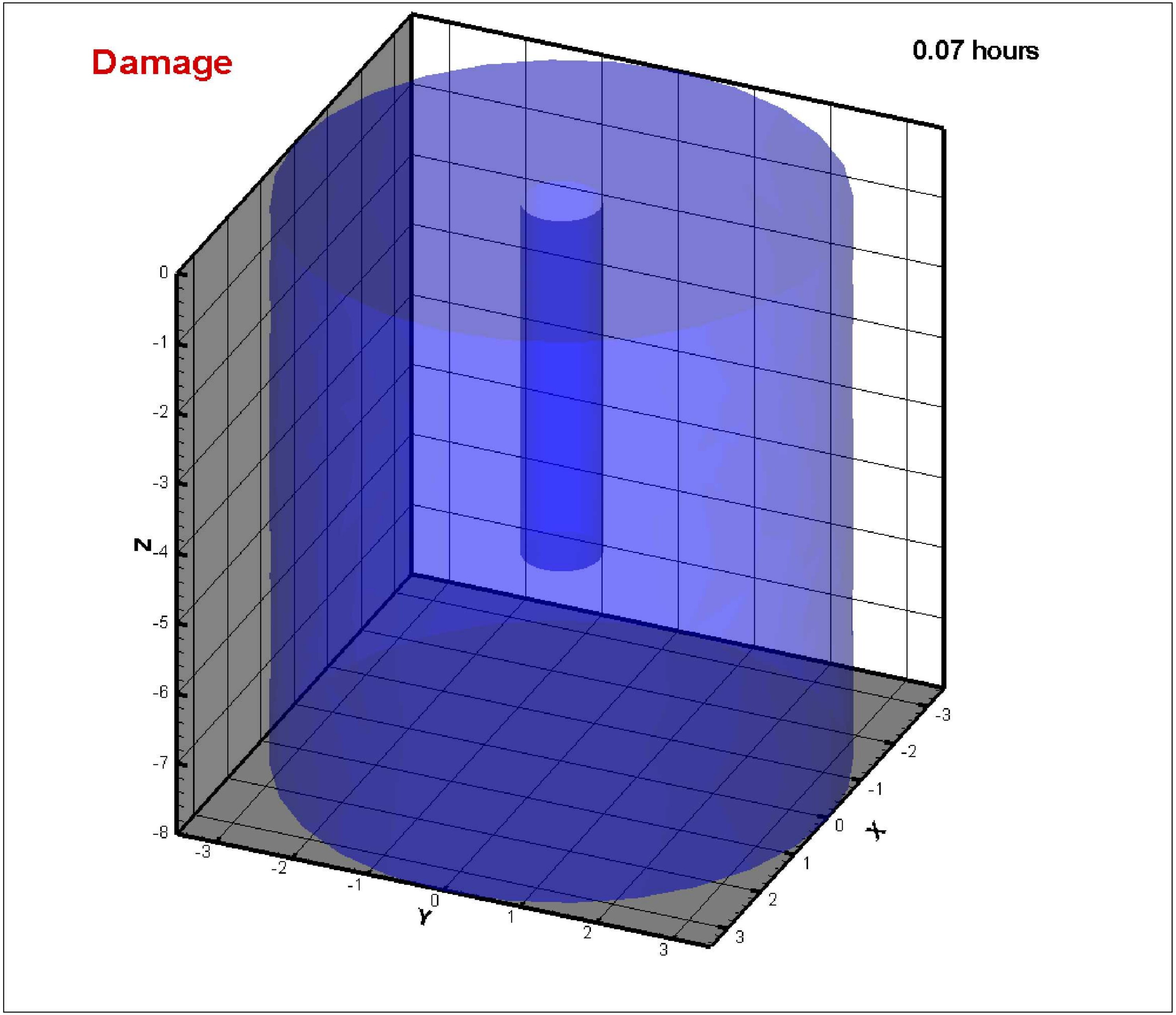


Granite

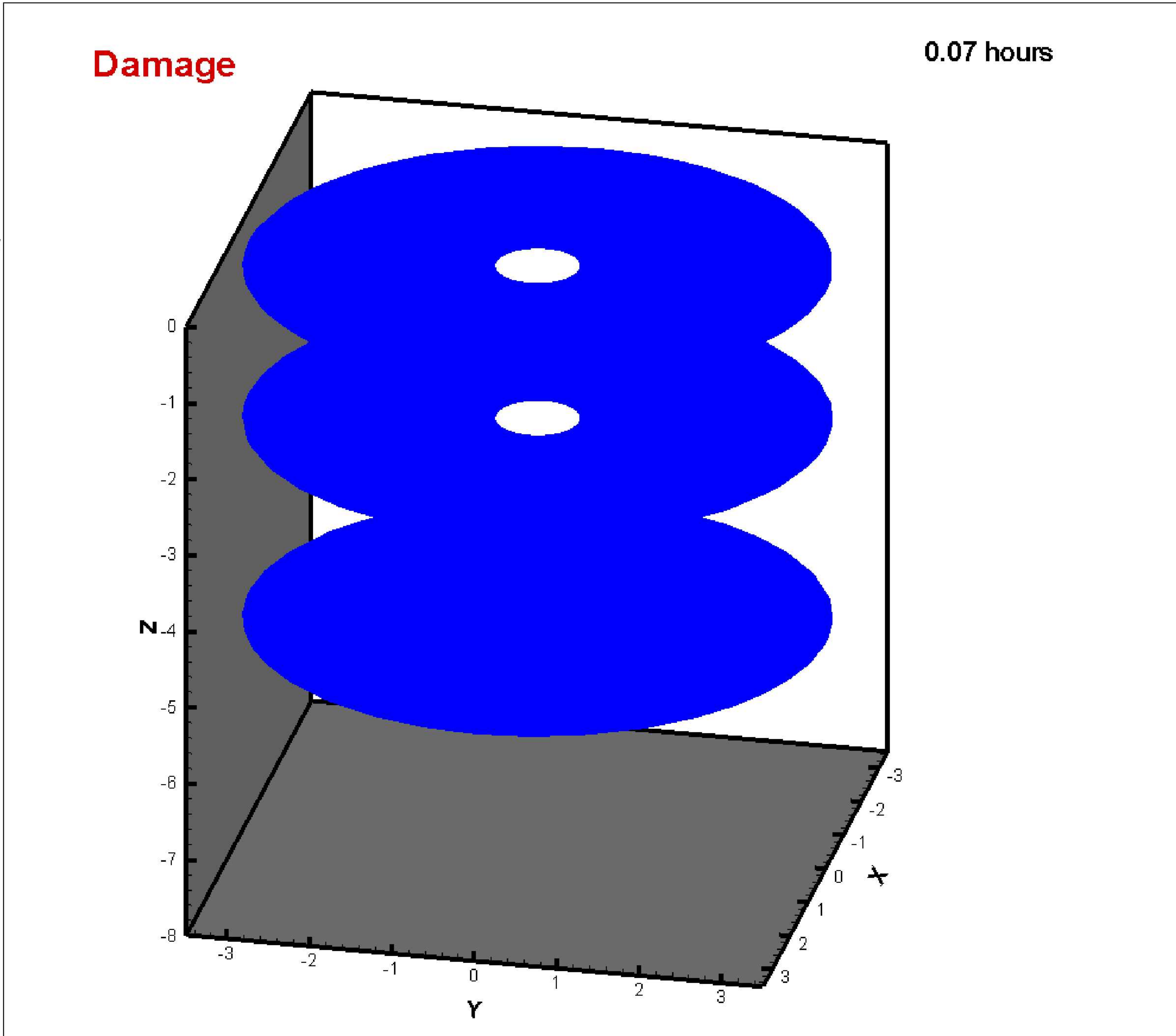

13.47 hours
5E+06
9E+06
1.3E+07
1.7E+07
2.1E+072
2.5E+07


Damage
13.47 hours
Z
X
Y

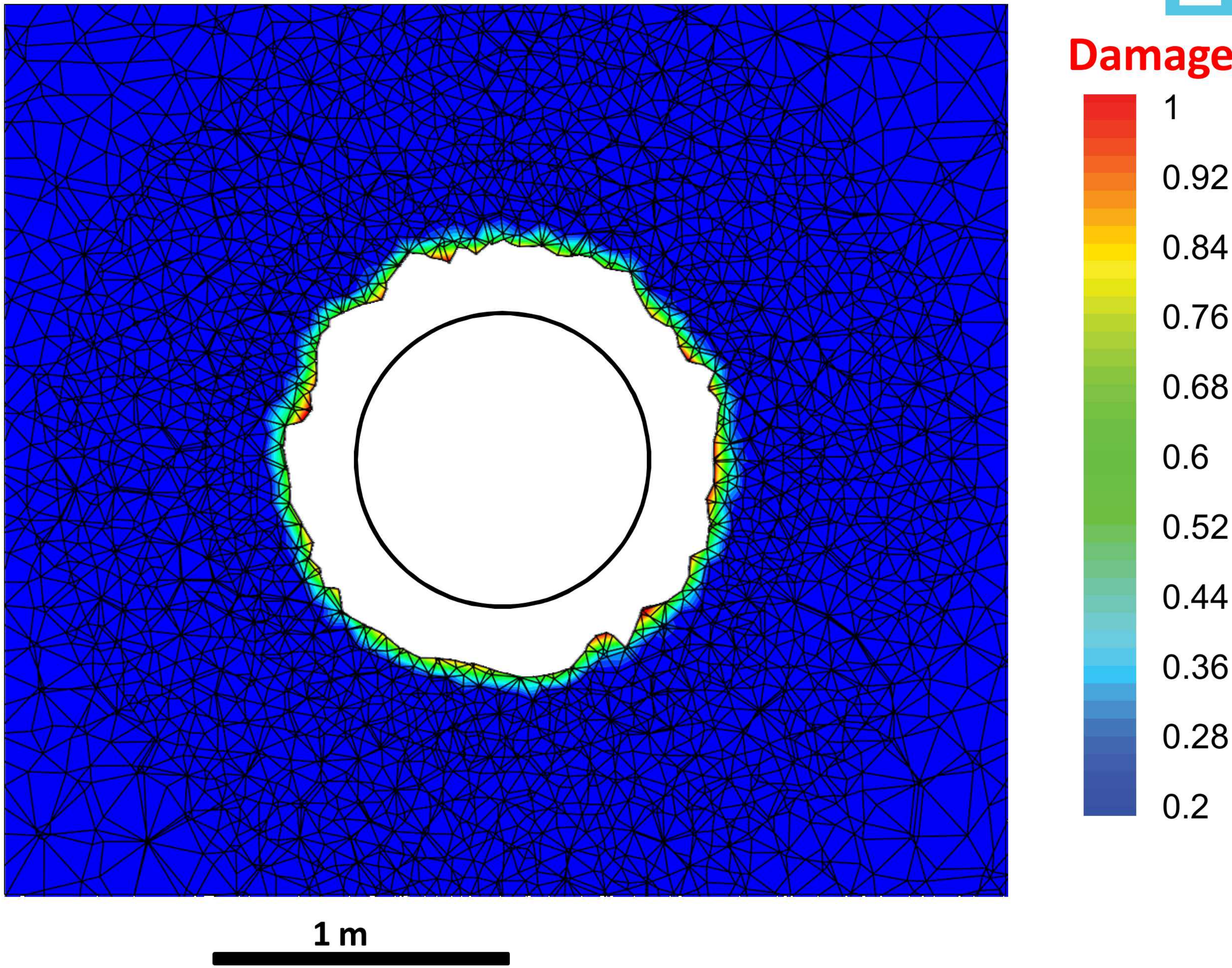
Granite
5 KM
$\sigma_{Hmax}=\sigma_v$
$\sigma_{Hmin}=\sigma_v$



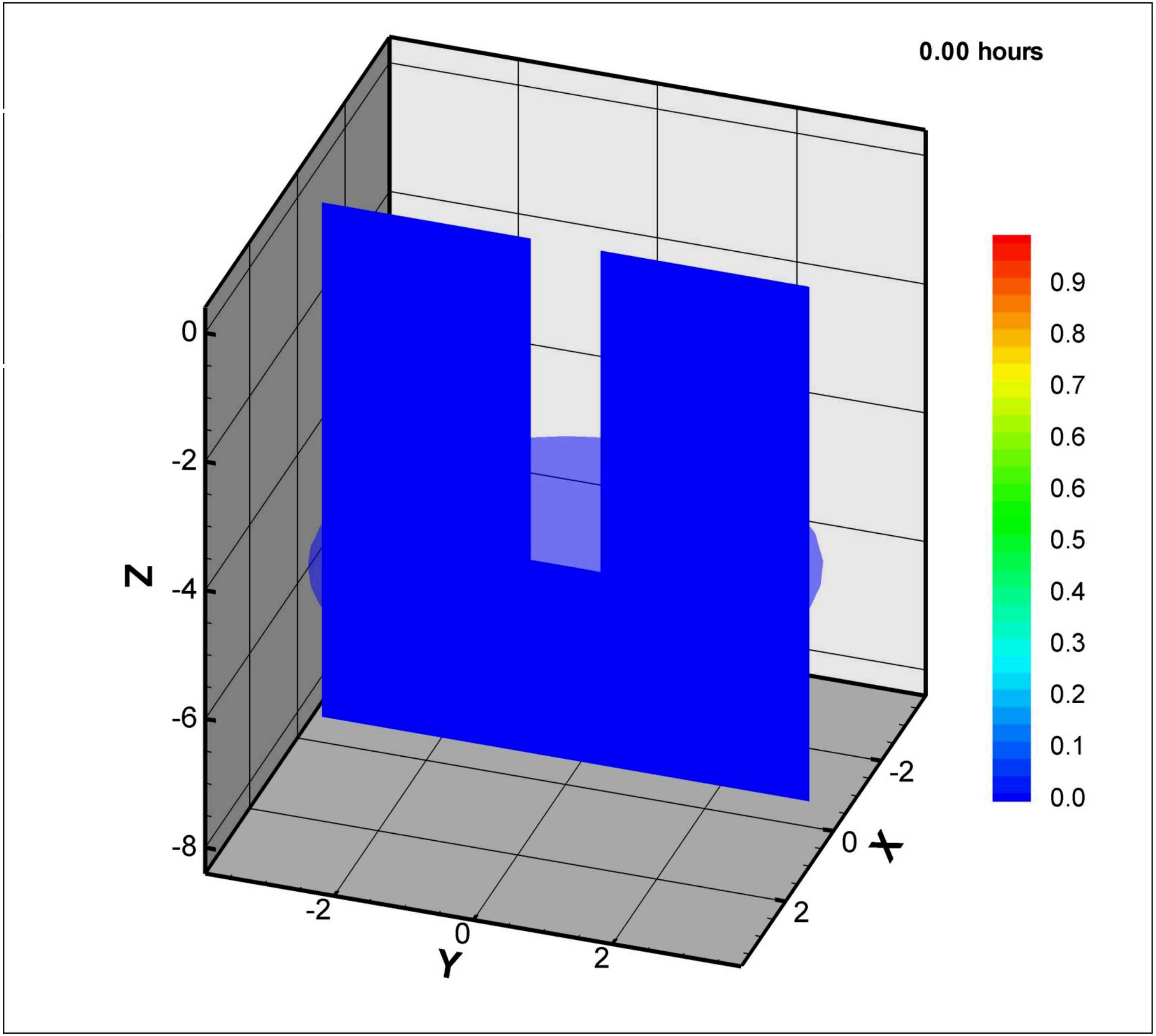
Granite
5 KM
$\sigma_{Hmax}=\sigma_v$
$\sigma_{Hmin}=\sigma_v$



0.47 hours



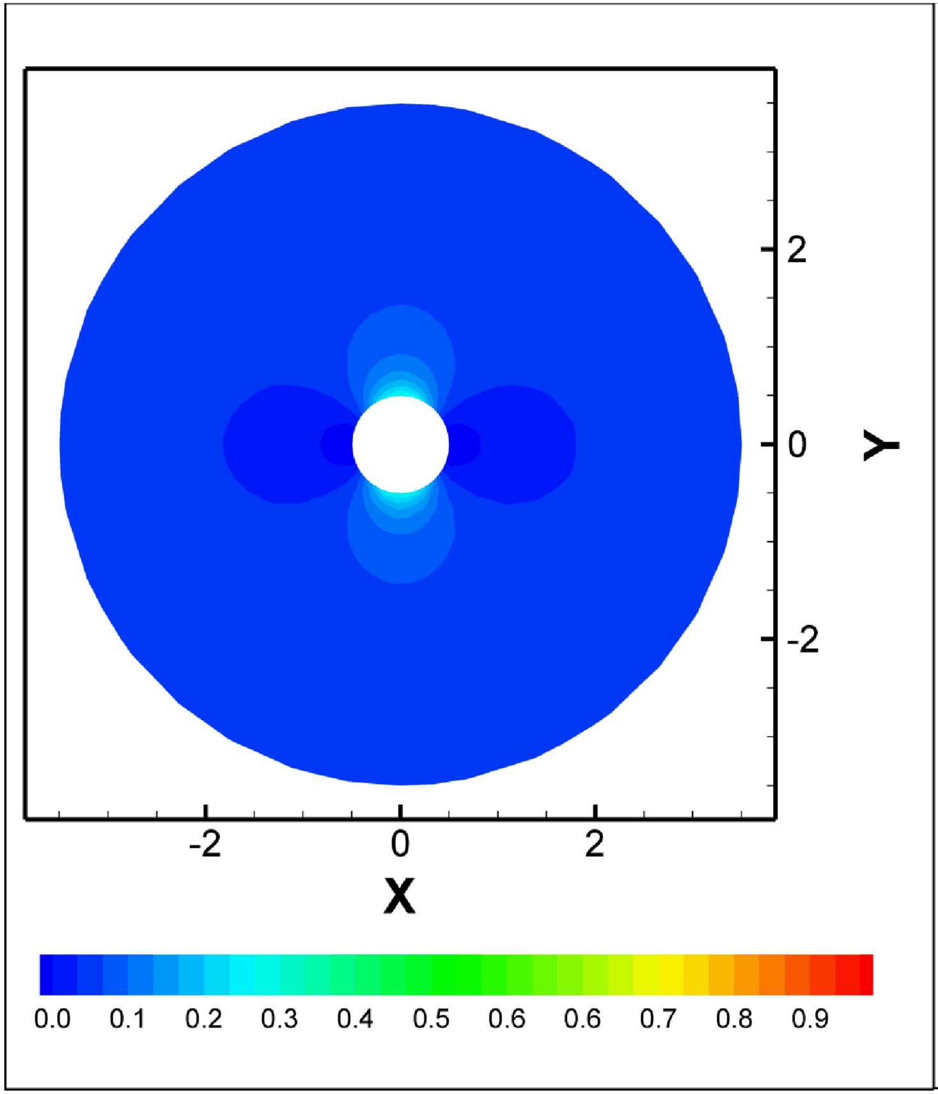
Zenifim
5 KM
$\sigma_{Hmax}=1.3\sigma_v$
$\sigma_{Hmin}=0.7\sigma_v$



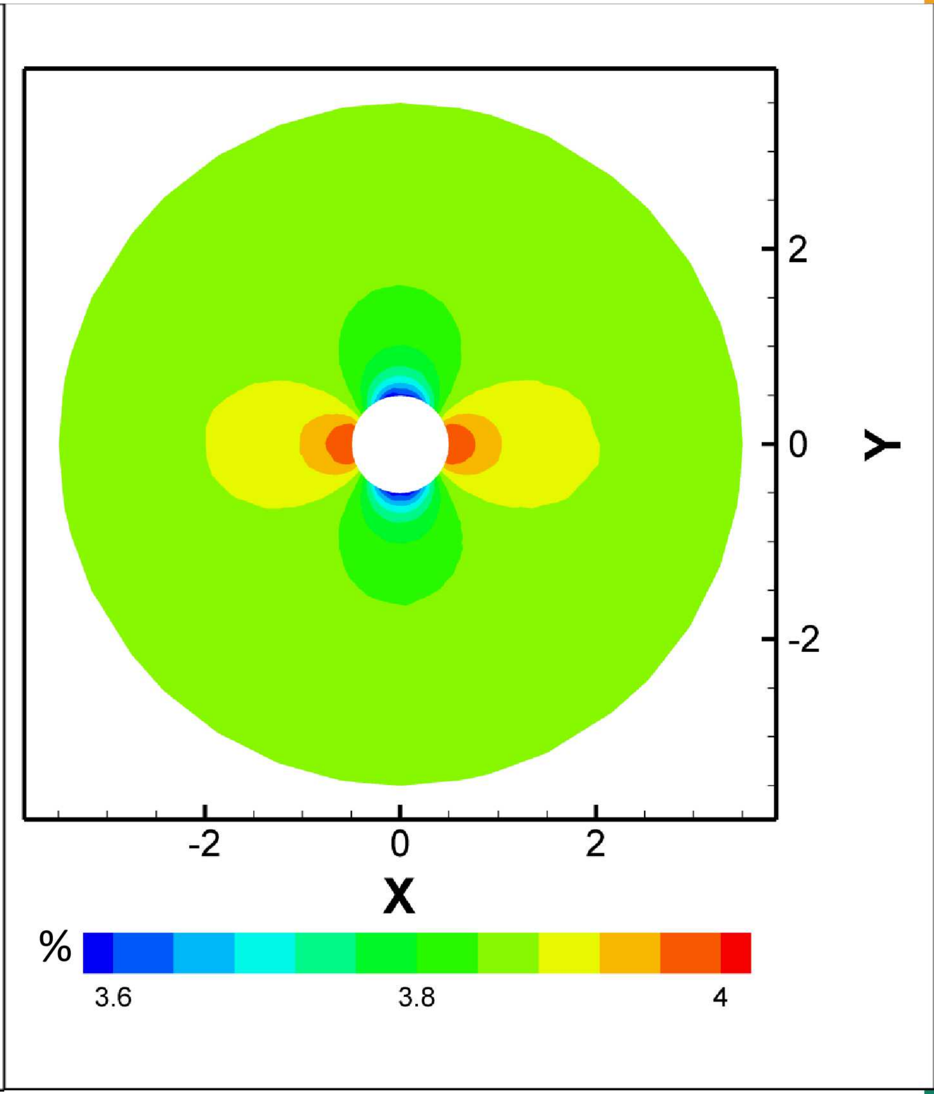
Zenifim
5 KM

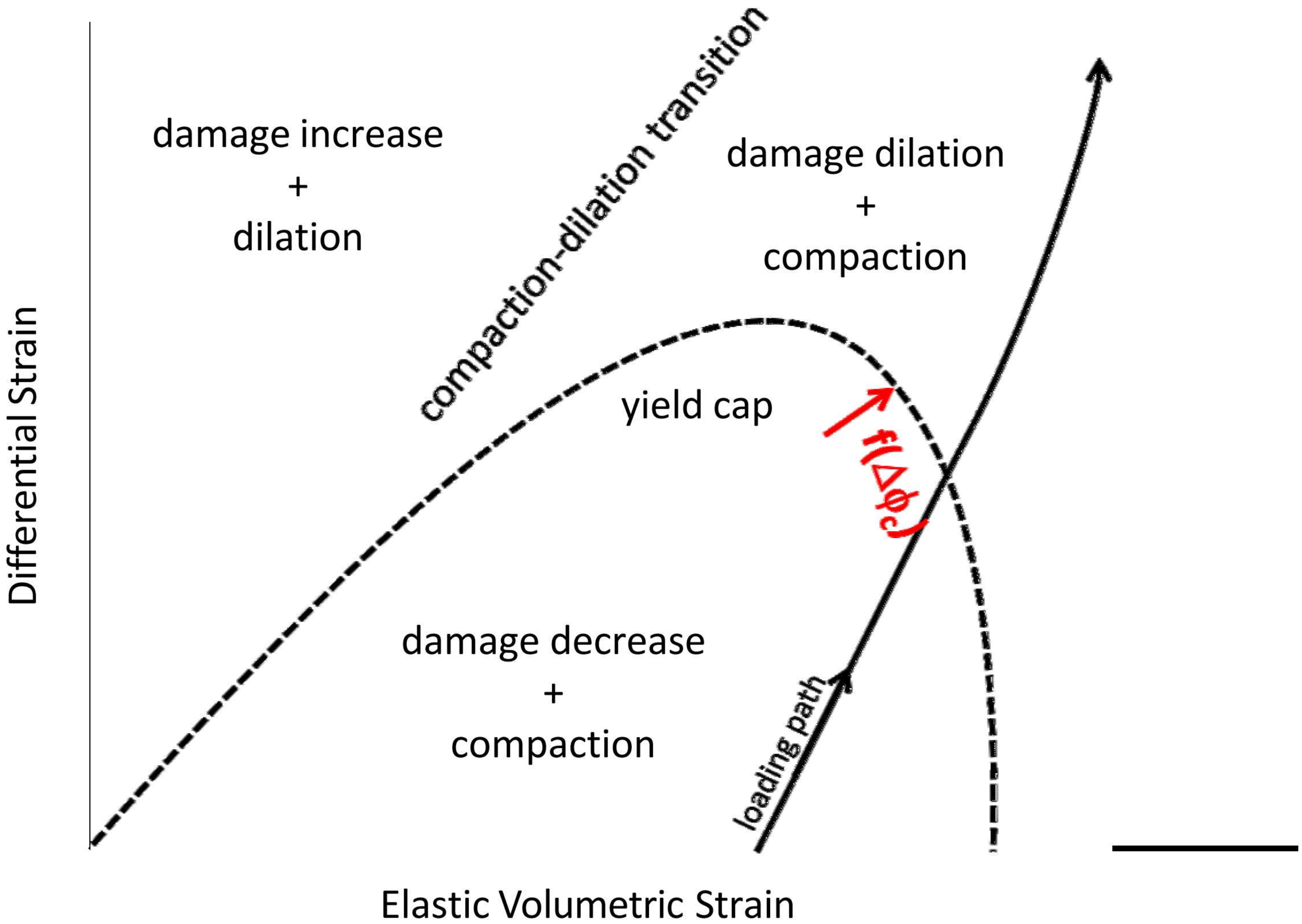
$\sigma_{Hmax}=1.3\sigma_v$
$\sigma_{Hmin}=0.7\sigma_v$

Damage

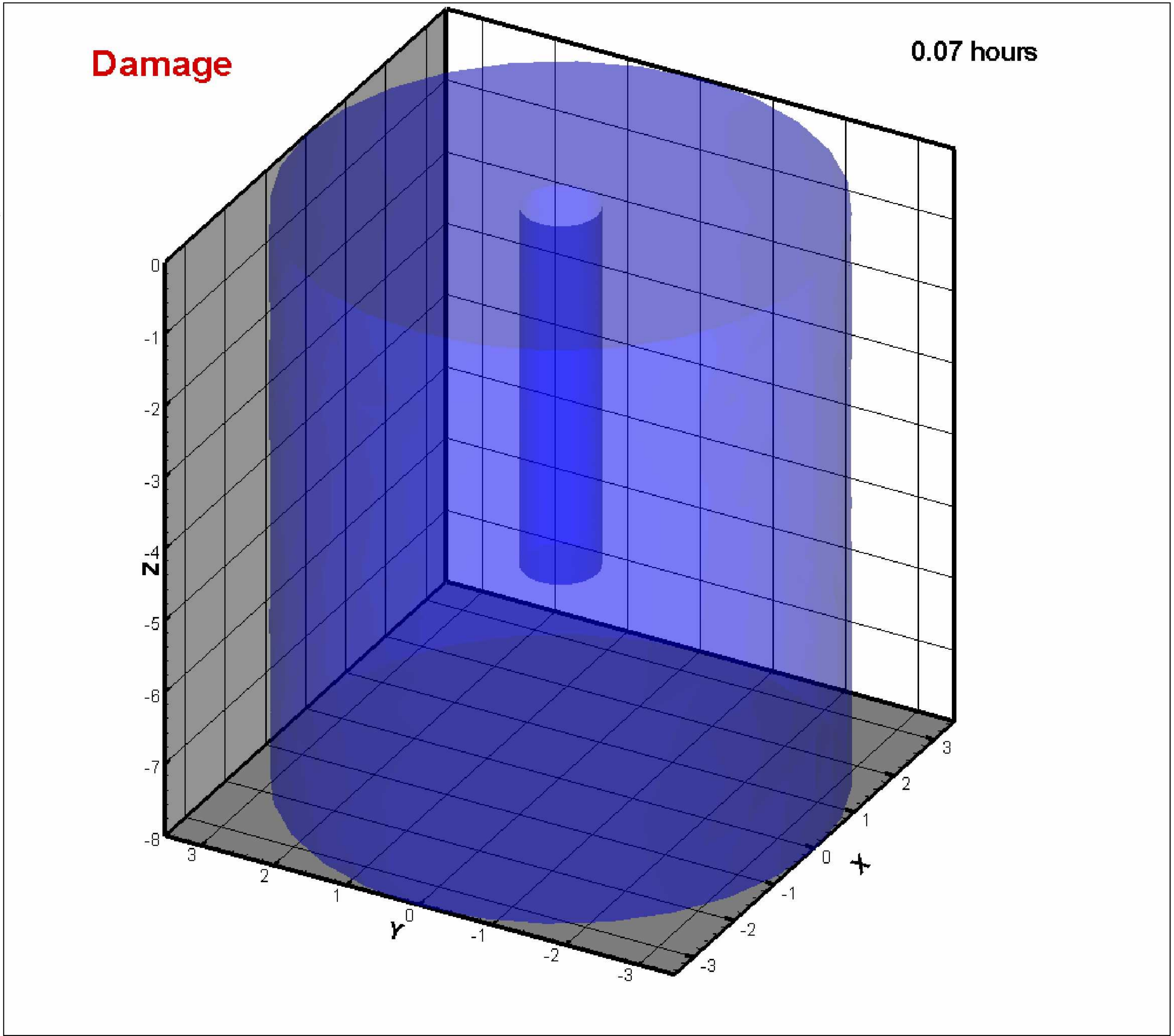


Porosity



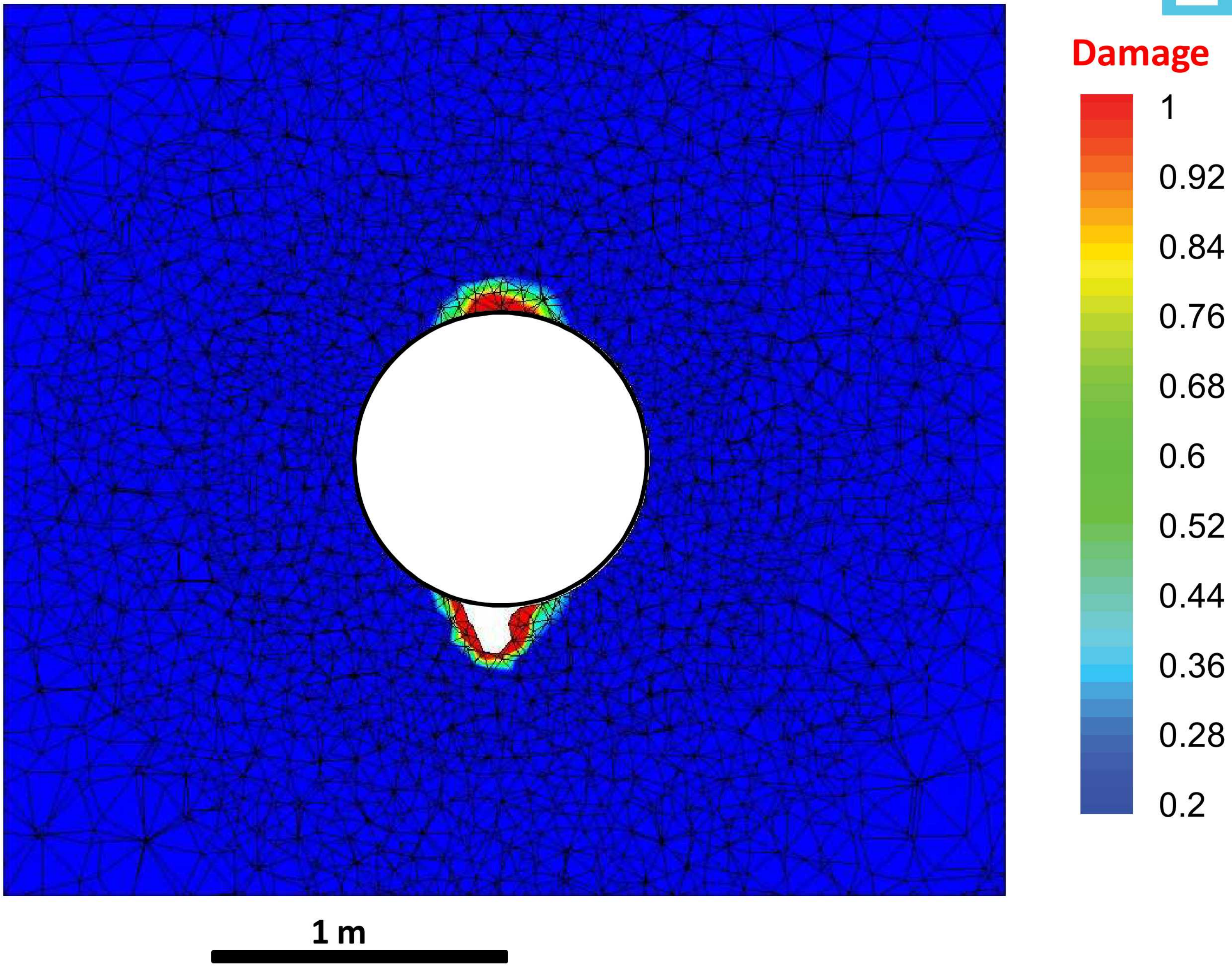

damage increase
+
dilation
compaction-dilation transition
damage dilation
+
compaction
yield cap
$f(\Delta\phi_c)$
damage decrease
+
compaction
loading path
Differential Strain
Elastic Volumetric Strain

Zenifim
5 KM
$\sigma_{Hmax}=1.4\sigma_v$
$\sigma_{Hmin}=0.6\sigma_v$



0.47 hours

Zenifim
5 KM
$\sigma_{Hmax}=1.4\sigma_v$
$\sigma_{Hmin}=0.6\sigma_v$



Conclusions

- Modeling rock deformation using continuum damage mechanics successively reproduces three dimensional breakouts.
- In crystalline rocks (Granite), deeper than 2km, conditions are unstable even in lithostatic stress.
- In porous rocks (Zenifim), the occurrence of breakouts stabilizes the wellbore and inhibits further failure. Only at high stress anisotropy conditions are unstable