Failure during CO2 Injection in the Field

Coal-Seq VI
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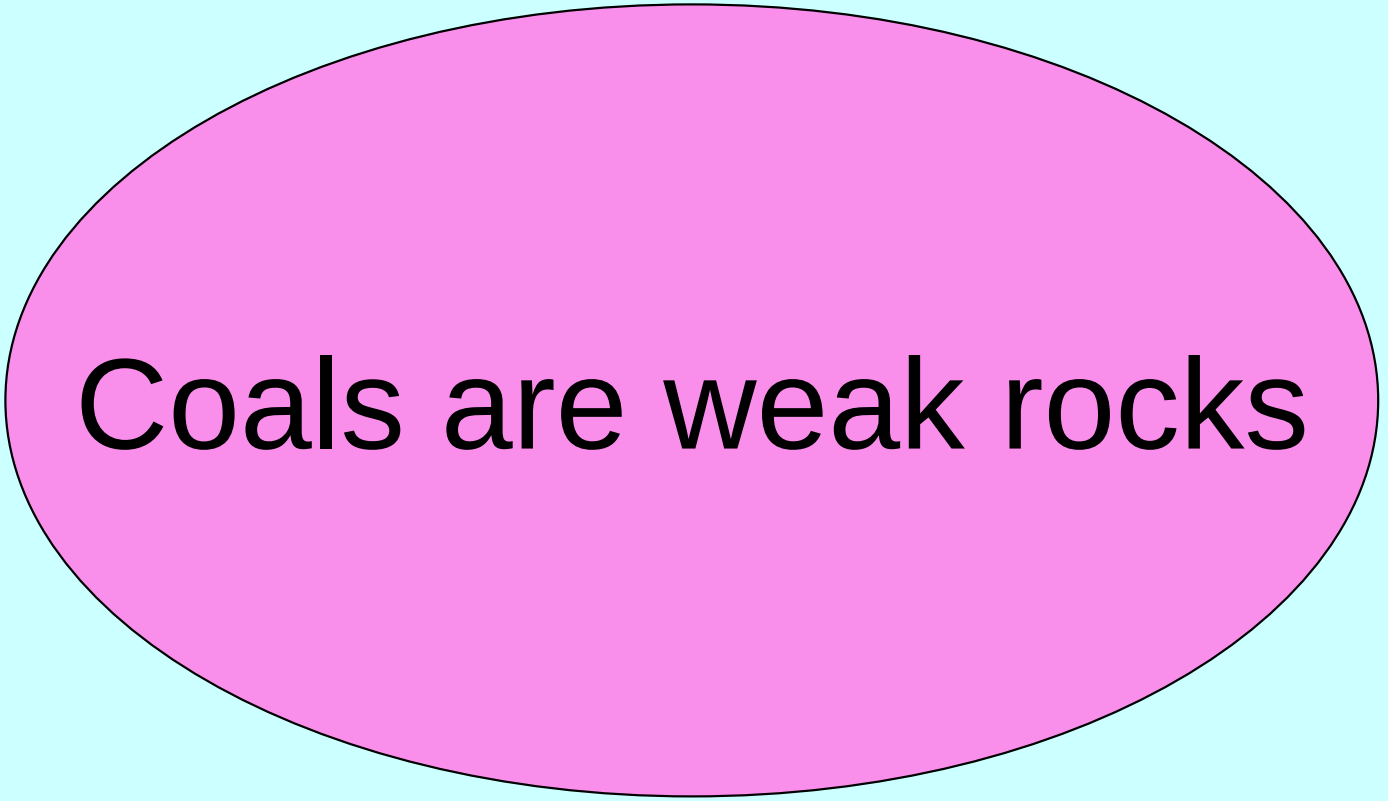
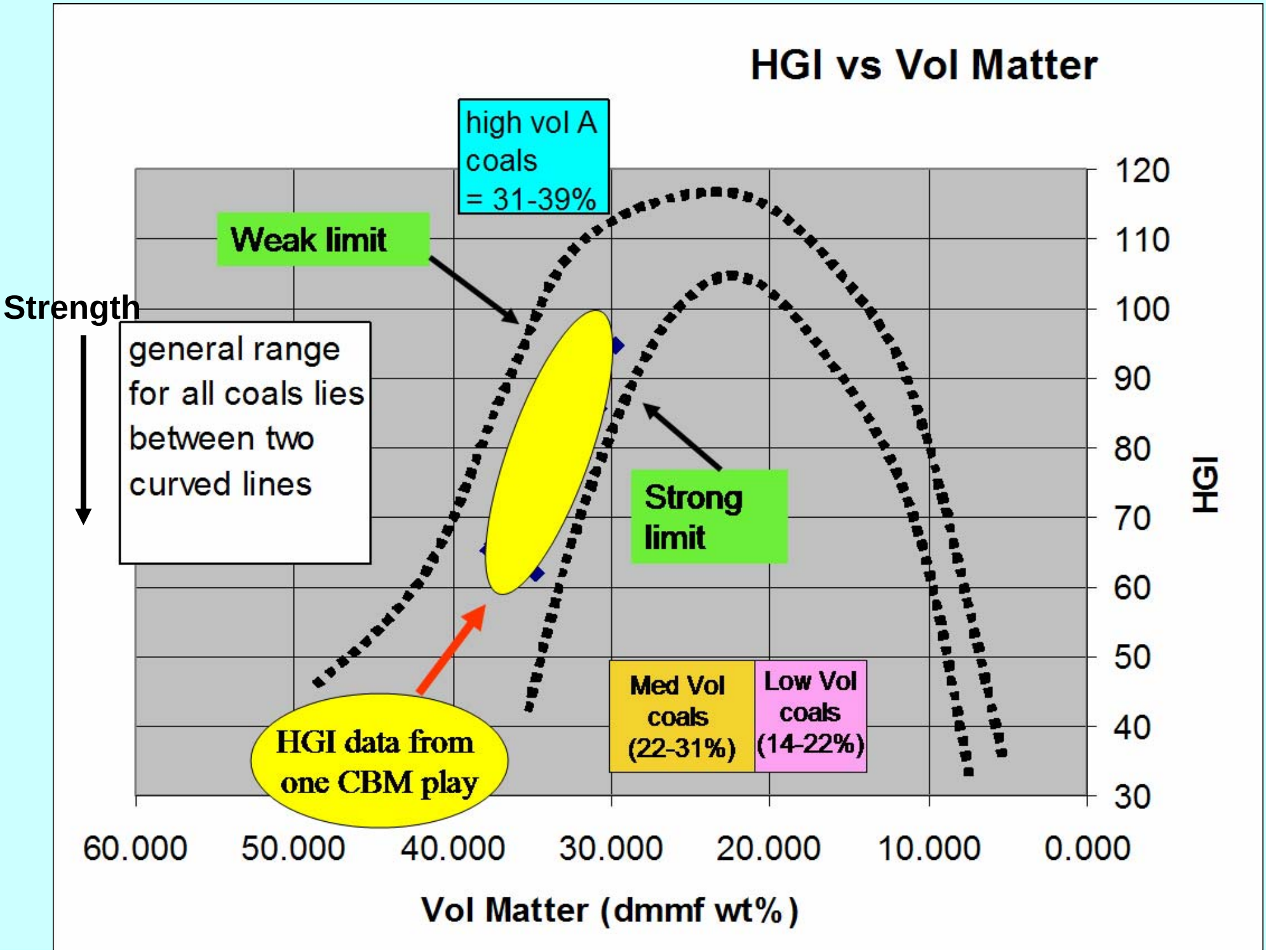
Higgs-Palmer Technologies

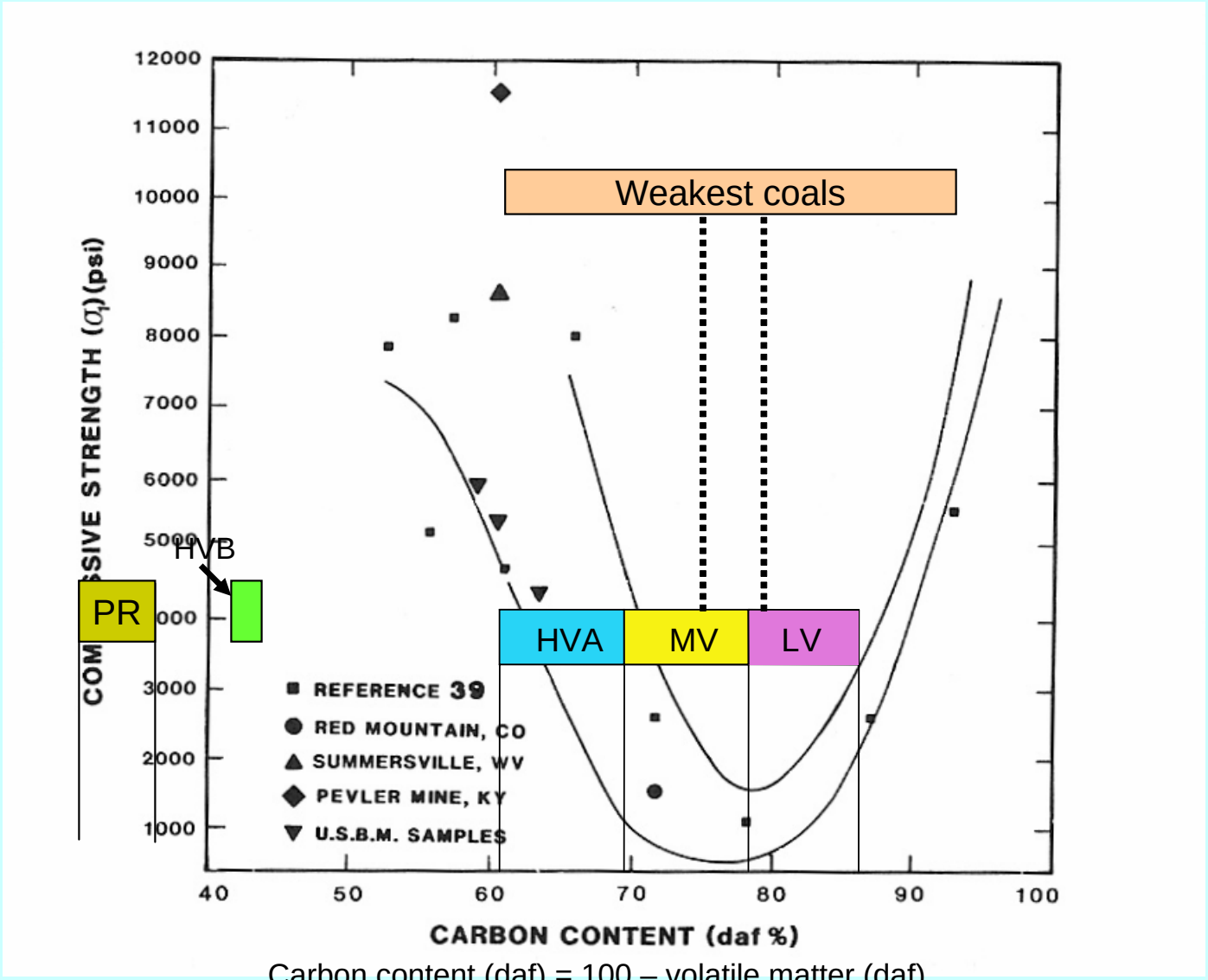
Contents

- Coals are weak rocks
- Injection can induce shear failure
- Lab tests increase perm when coal fails
- This offsets swelling of coal by CO2 adsorption → how affect injectivity
- CO2 adsorption may weaken coal → earlier failure → better injectivity

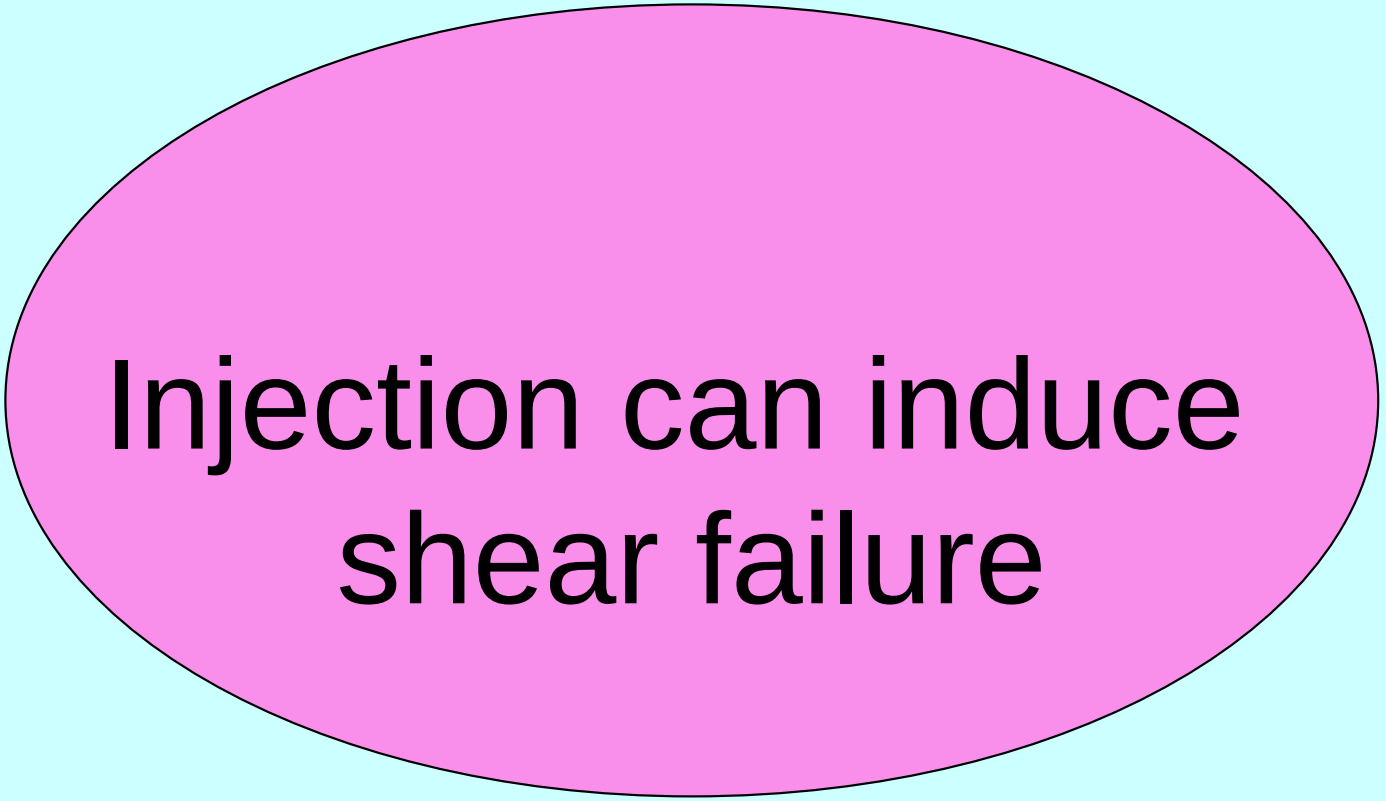

Coals are weak rocks


HGI vs Vol Matter
high vol A coals = 31-39%
Weak limit
Strength
general range for all coals lies between two curved lines
Strong limit
HGI data from one CBM play
Med Vol coals (22-31%)
Low Vol coals (14-22%)
120
110
100
90
80
70
60
50
40
30
HGI
60.000
50.000
40.000
30.000
20.000
10.000
0.000
Vol Matter (dmmf wt%)

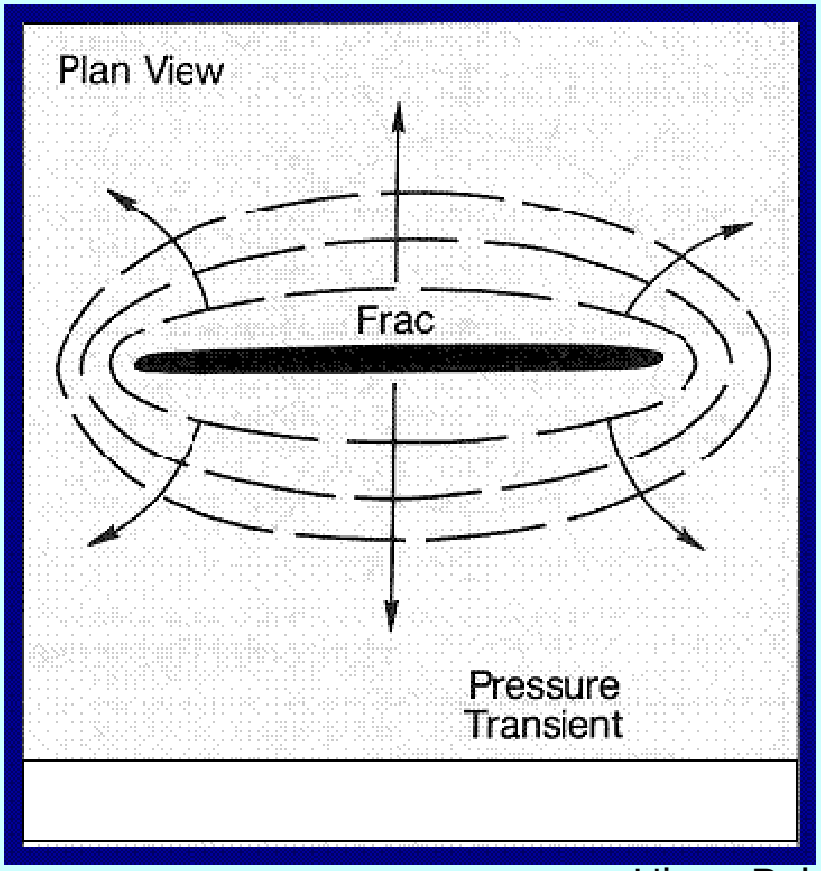
UCS of coals depends on rank and cannot be predicted from logs

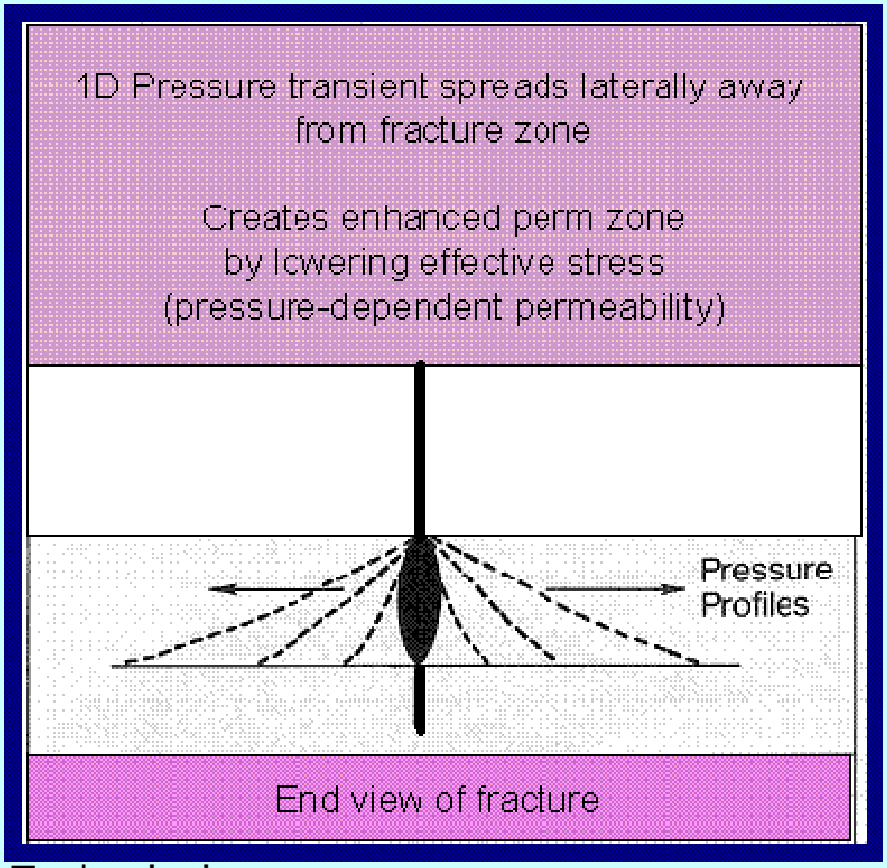


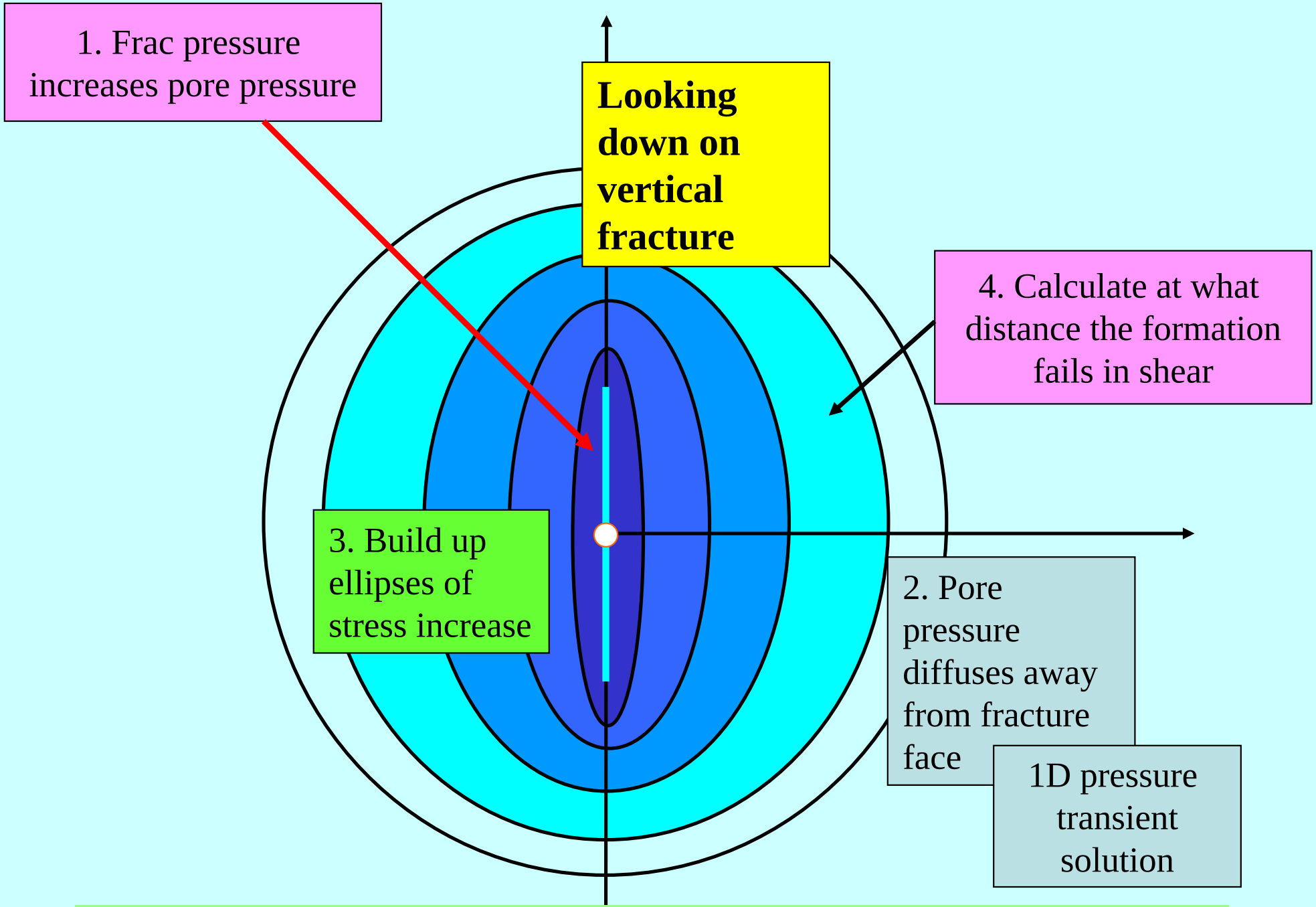
Carbon content (daf) = 100 – volatile matter (daf)


Injection can induce
shear failure

Pressure transient spreads out from central fracture

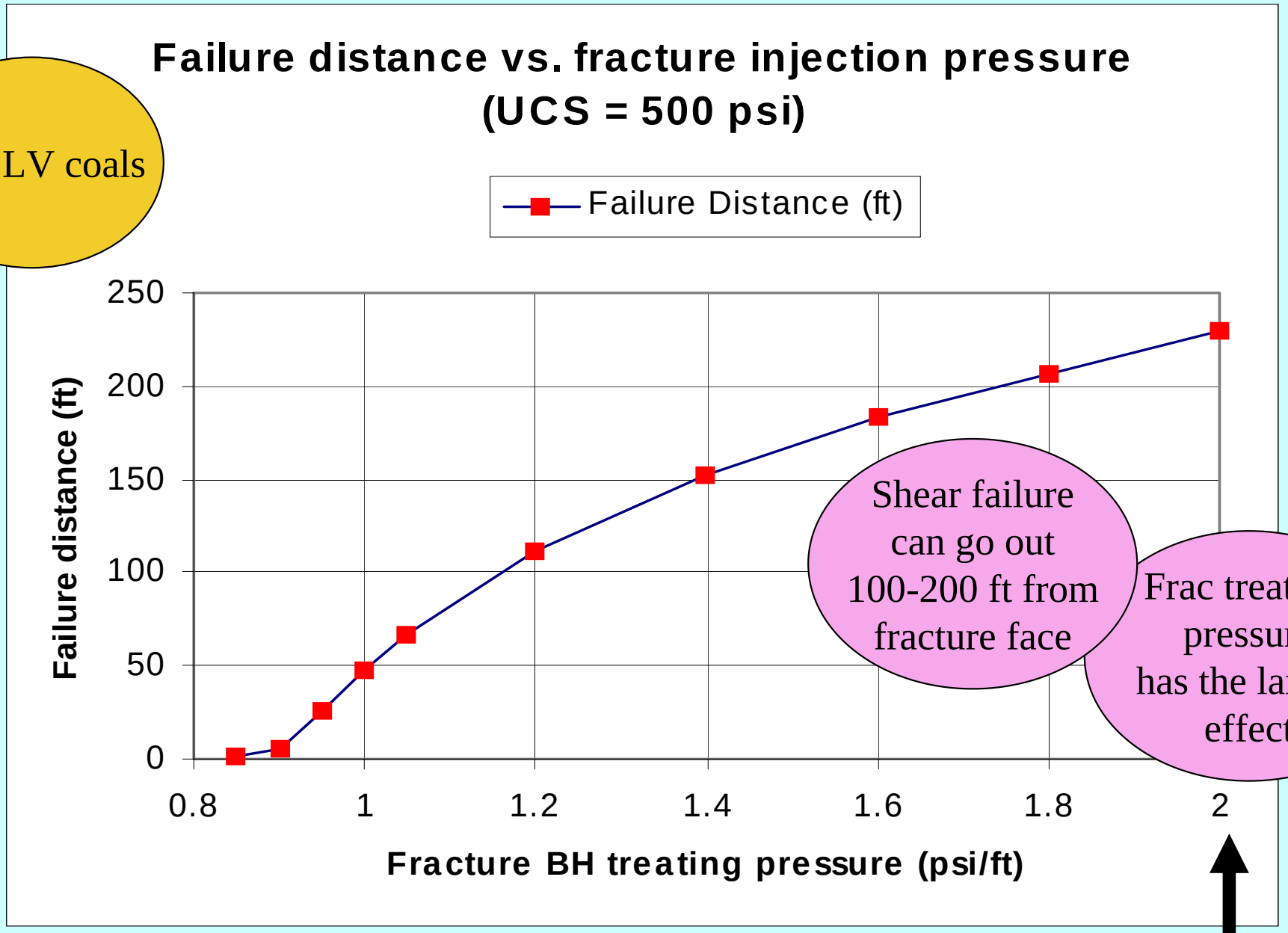






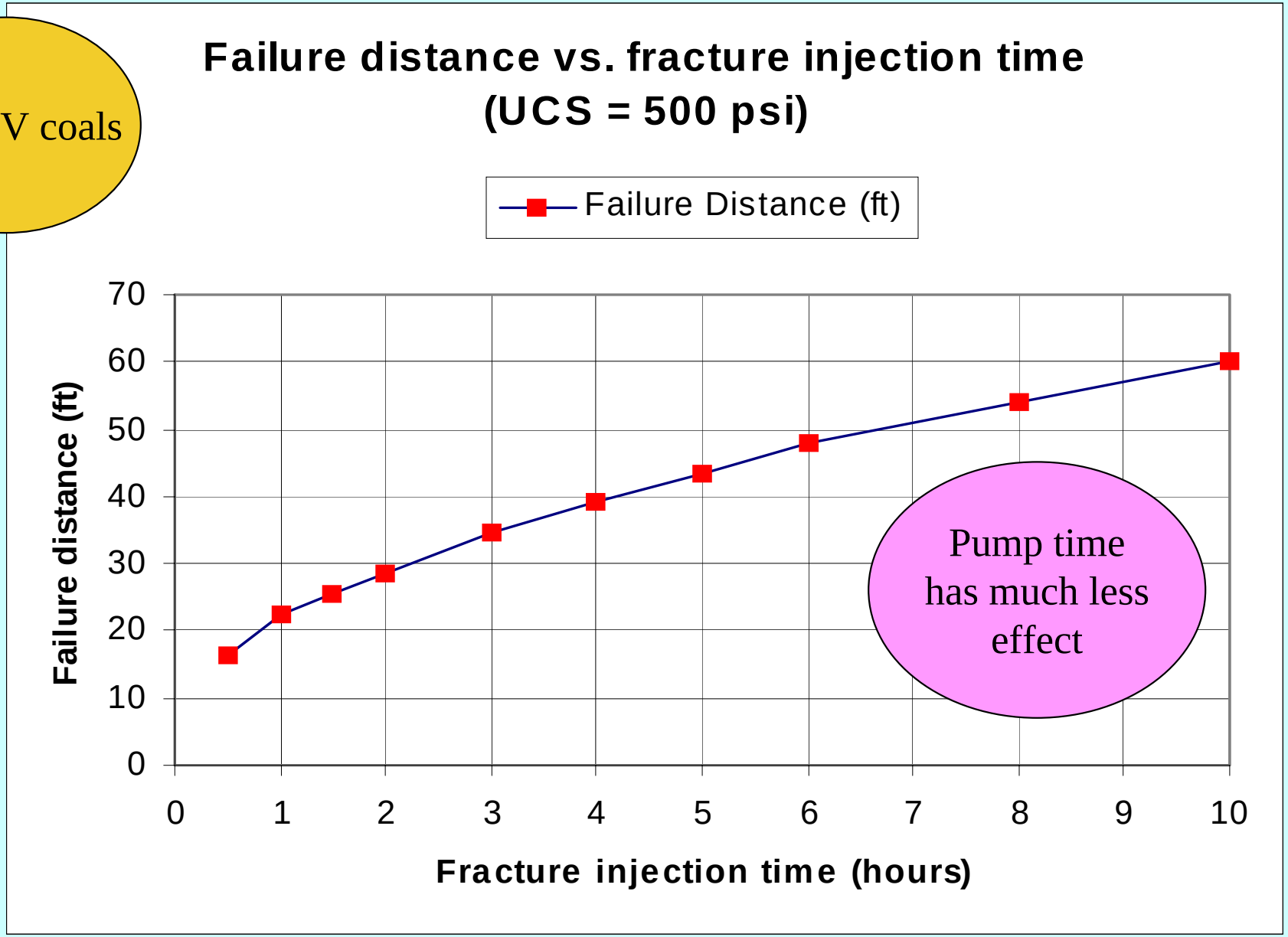
***Palmer, Moschovidis, and Cameron, "Coal Failure and Consequences for Coalbed Methane Wells", SPE 96872, ATCE, Dallas, 9-12 Oct 2005**

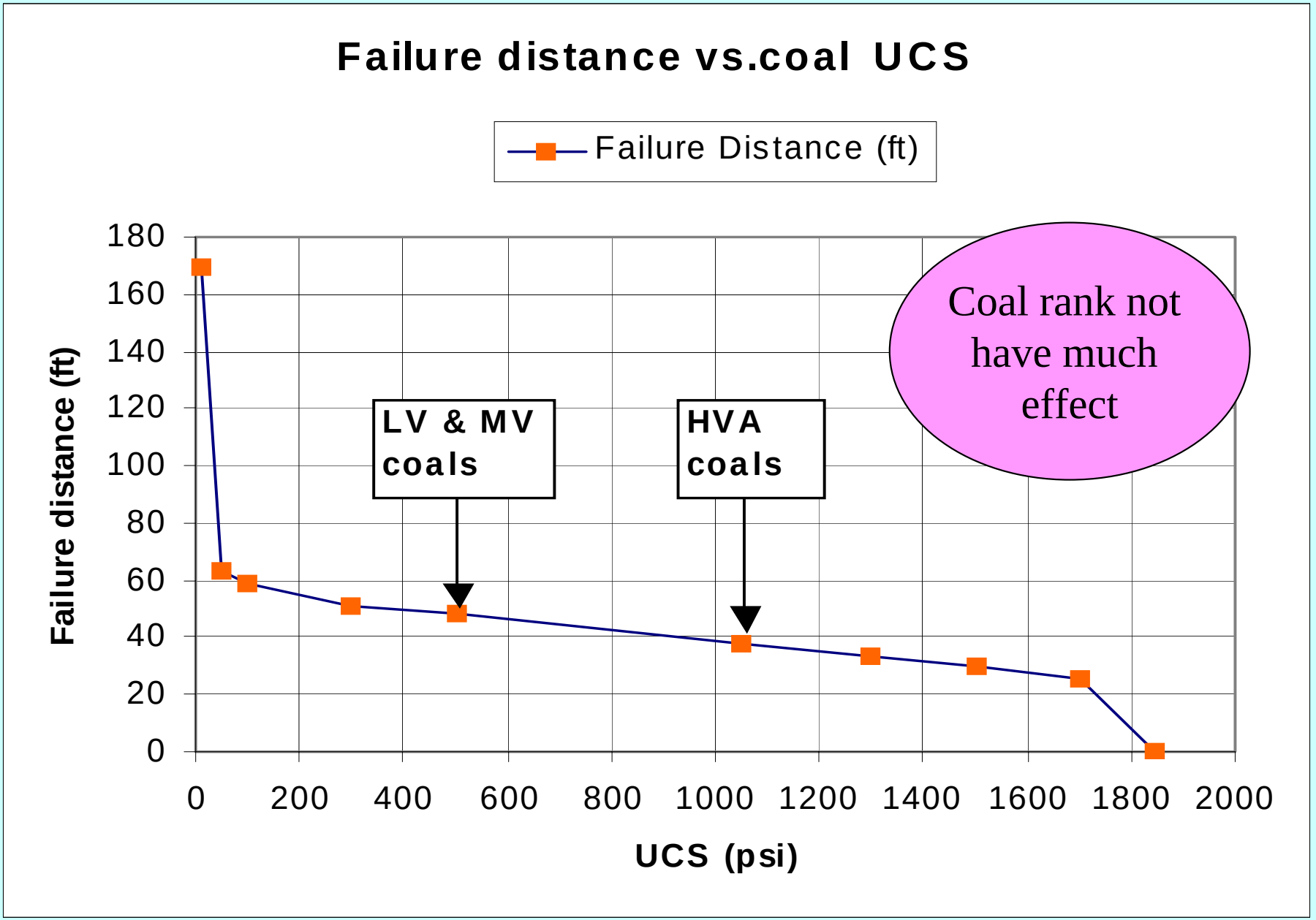
MV, LV coals



Sometimes see frac pressures up to 2.0 psi/ft in coals

MV, LV coals

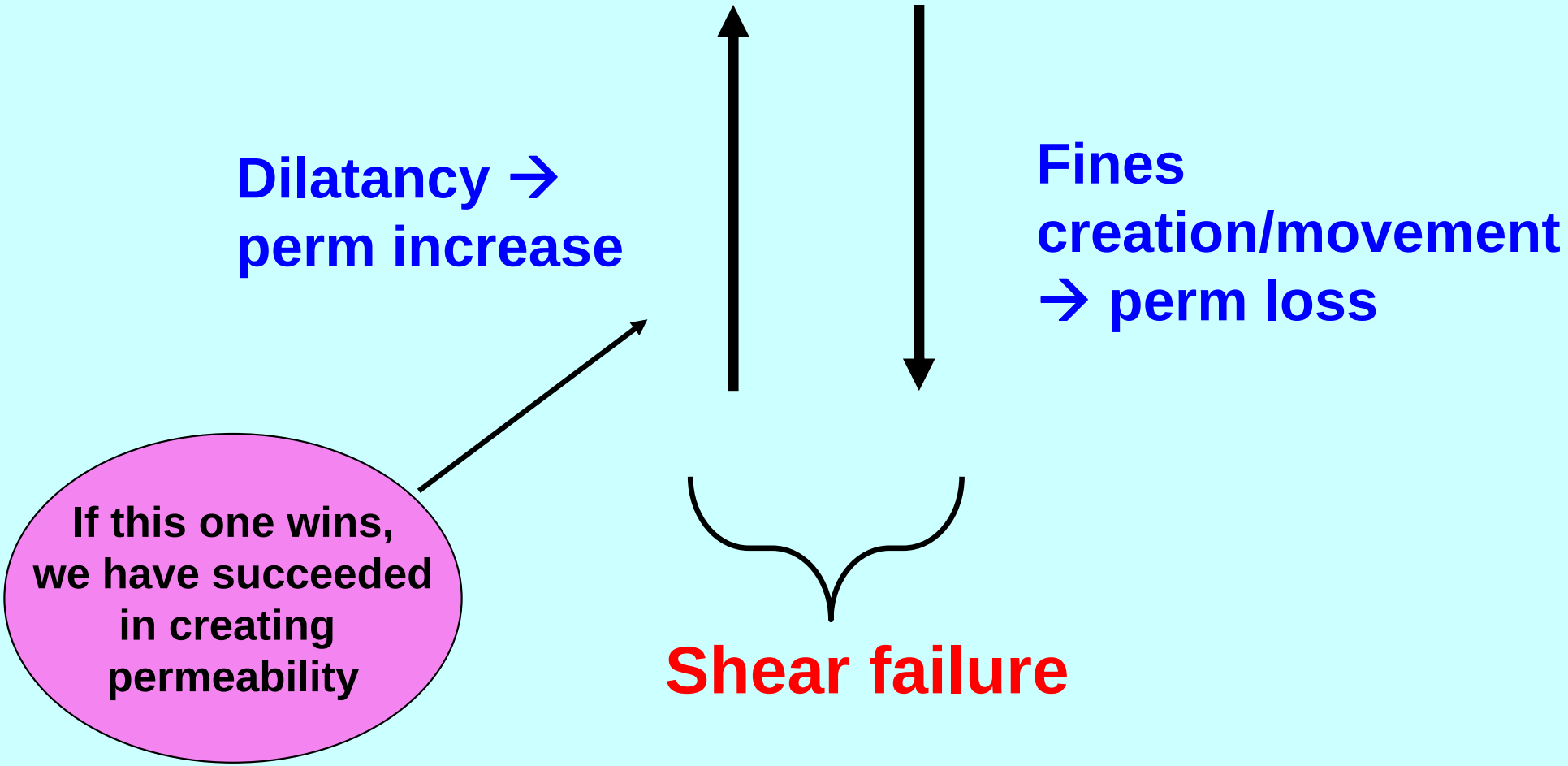

Failure distance vs. fracture injection time
(UCS = 500 psi)
Failure Distance (ft)
Failure distance (ft)
0
10
20
30
40
50
60
70
0
1
2
3
4
5
6
7
8
9
10
Fracture injection time (hours)
Pump time has much less effect


Failure distance vs.coal UCS
Failure Distance (ft)
Failure distance (ft)
180
160
140
120
100
80
60
40
20
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
UCS (psi)
LV & MV coals
HVA coals
Coal rank not have much effect

Summary

- Shear failure occurs away from the face of a hydraulic fracture: the shear zone can extend 50-200 ft away for abnormally high frac treating pressures (1.0-2.0 psi/ft)
- The shear failure may give rise to:
  - Microseismic bursts
  - Fines creation/movement → perm loss
  - Dilatancy → perm increase
- The last two effects can impact gas production from the well: but which one wins?

Creating Permeability: Fines Movement may Destroy it



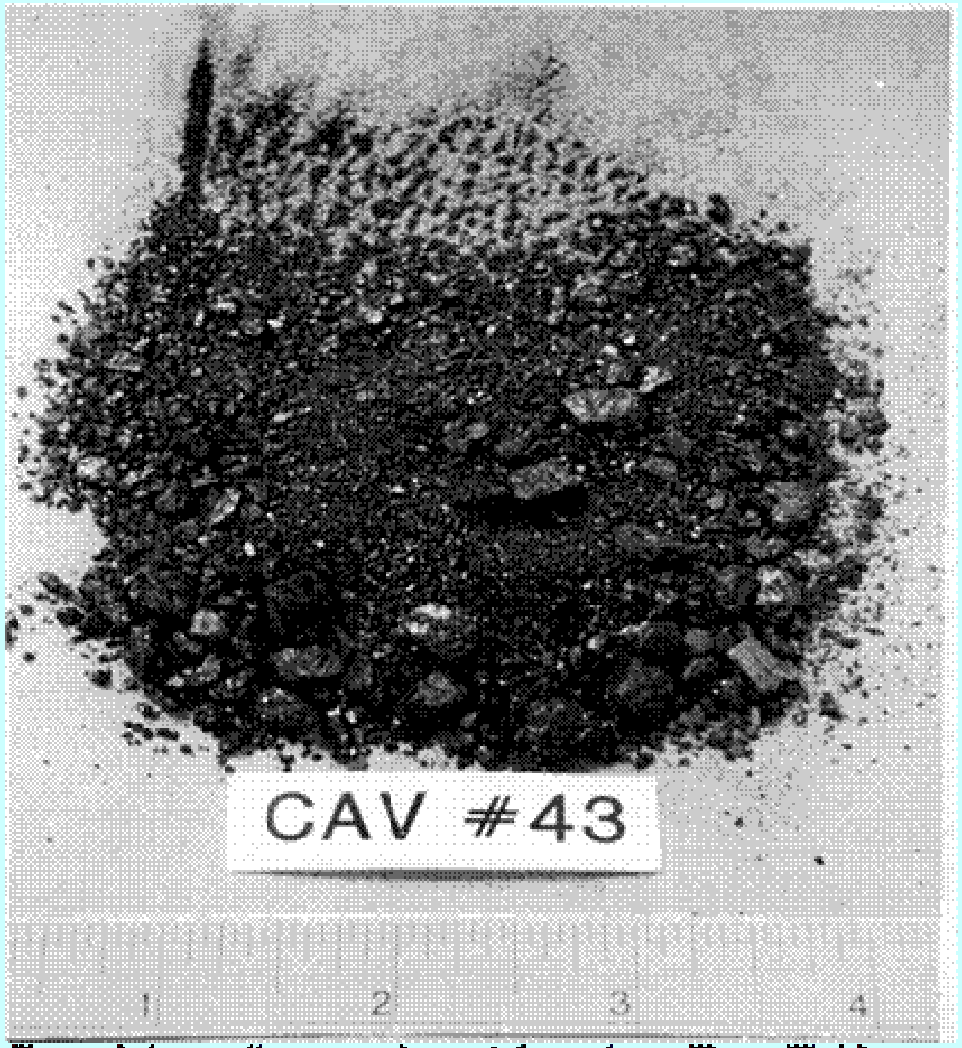
Prediction of coal fines during production

Coal fines are the result of coal failure …

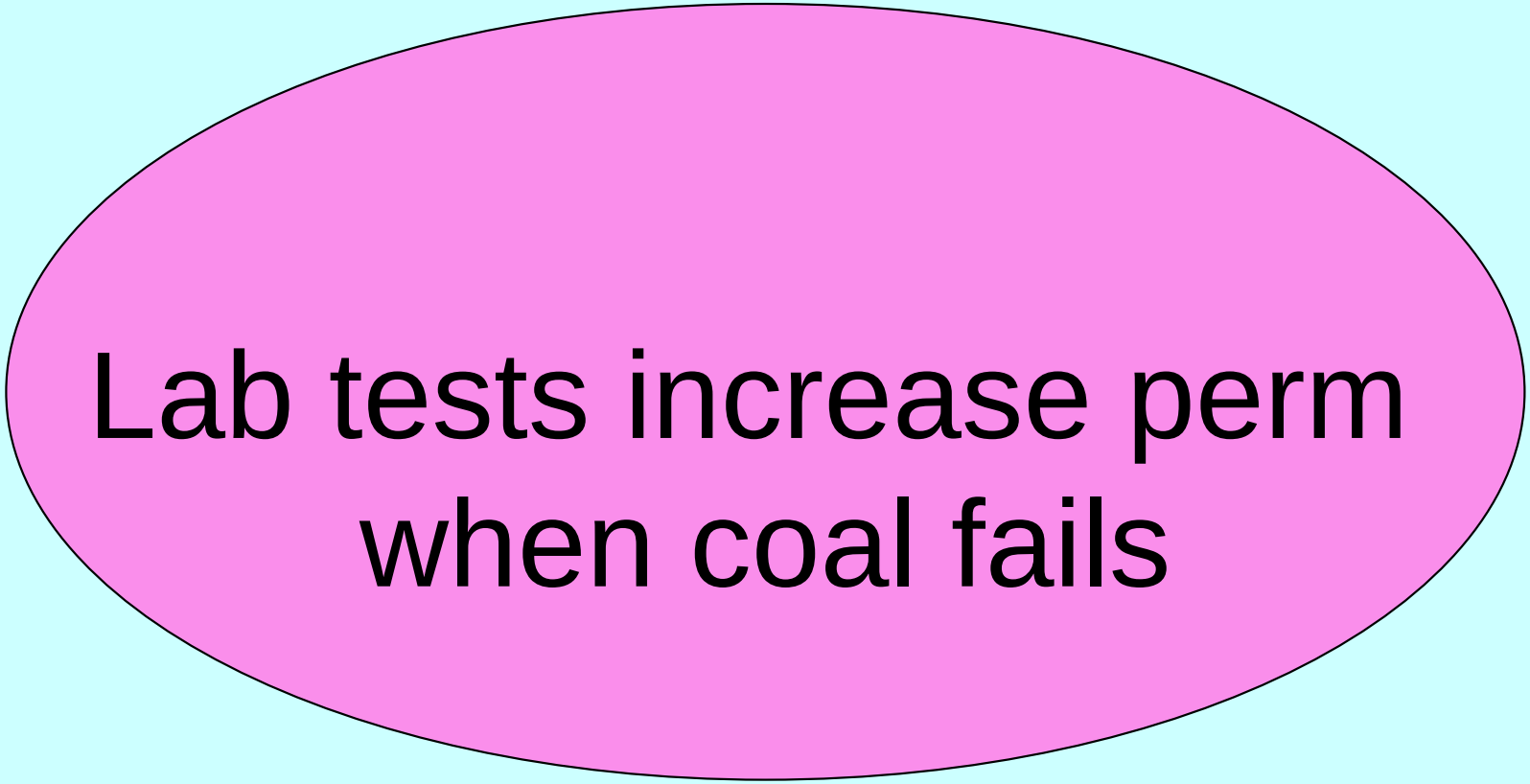
- **Plug and reduce formation permeability**
- **Plug and reduce fracture conductivity**
- **Plug down-hole pumps**
- **Erode surface lines**
- **Accumulate in separators**
- **Must be disposed**

Problem for MV, LV coals, which are very weak: minimum likely UCS ~500 psi

- In **Powder River** sub-bituminous coals: fines are endemic
- Fines are a common problem in **San Juan, Uinta, and Raton Basins**



From lab cavity experiment (courtesy TerraTek)


Lab tests increase perm
when coal fails

Shear Dilation Concept

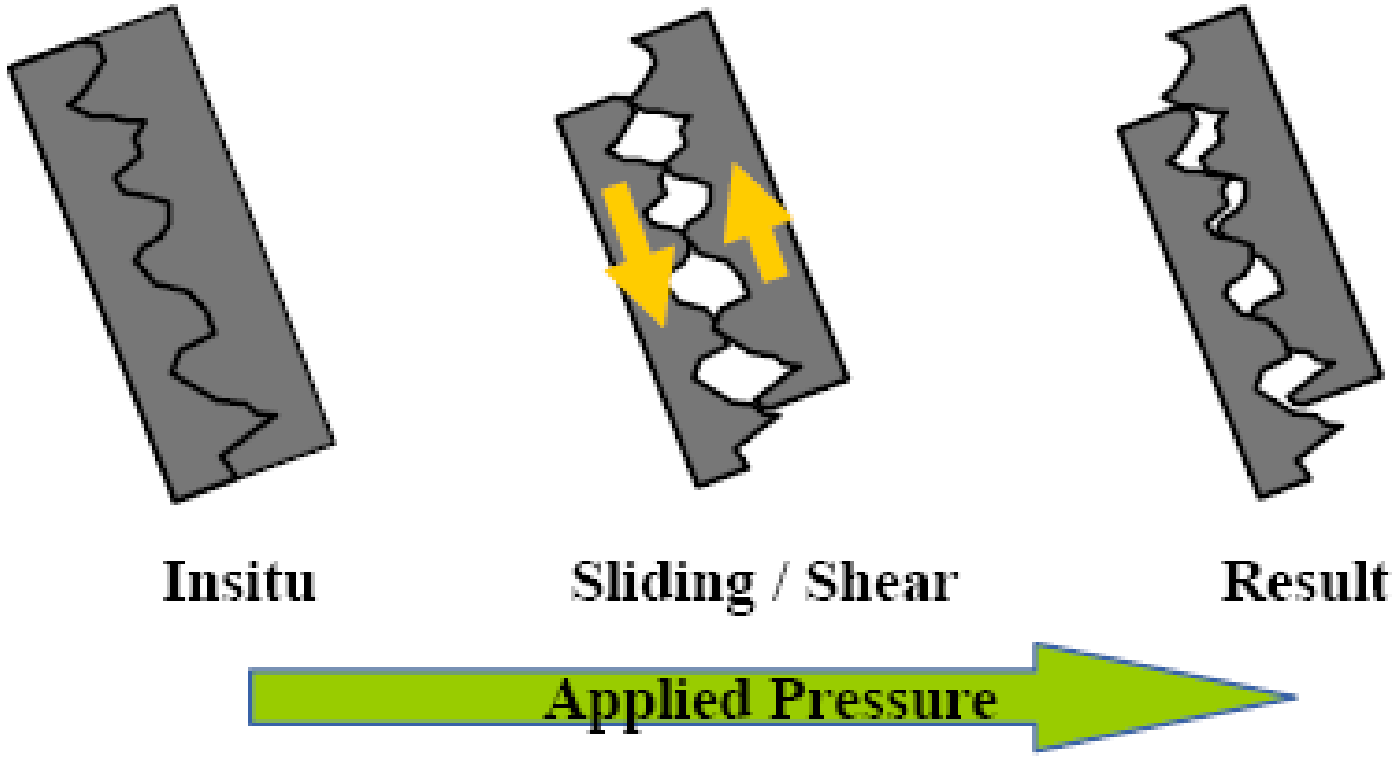
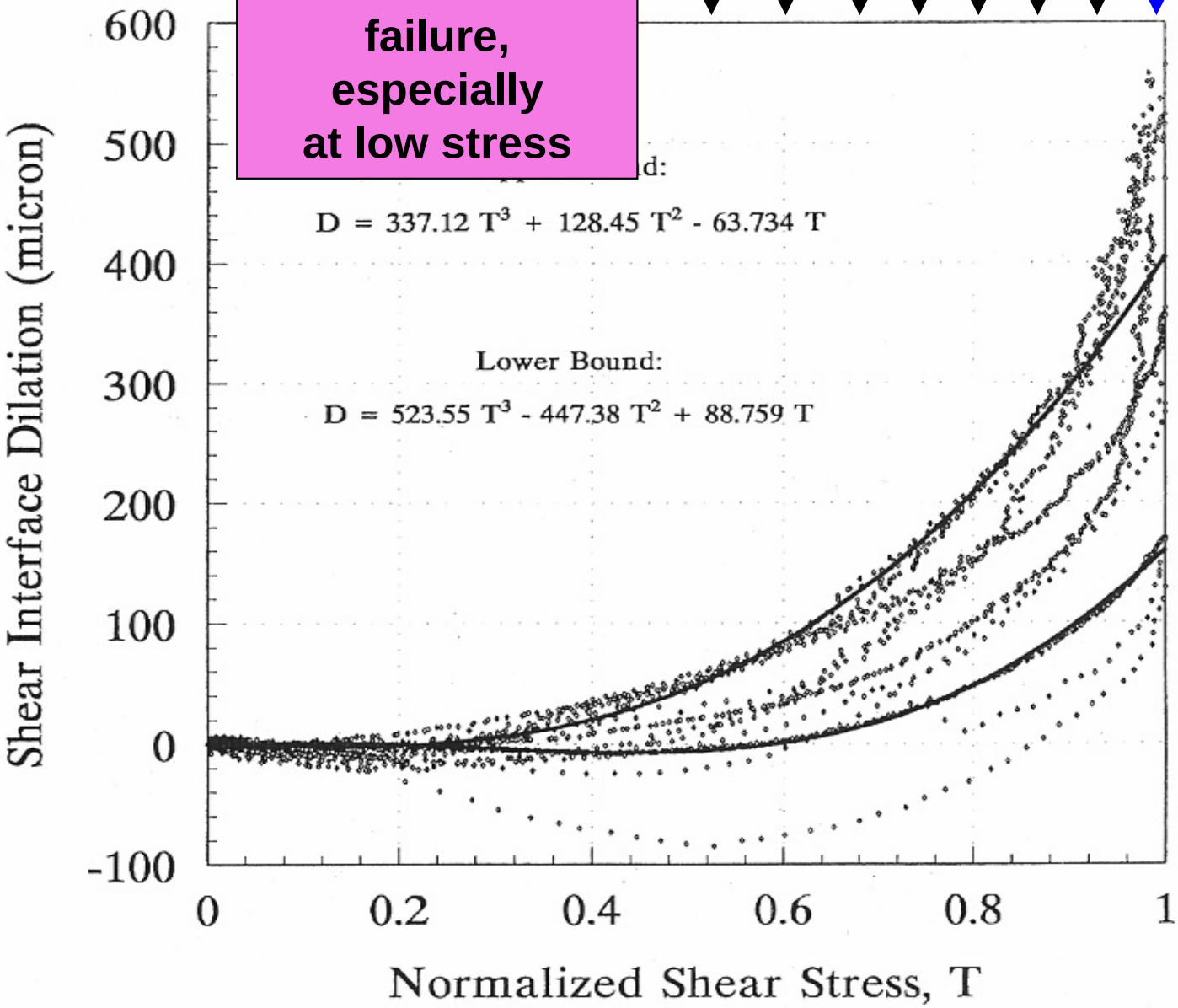


Fig. 1: Shear Dilation Mechanism

From Chipperfield et al "Shear dilation diagnostics: a new approach for evaluating tight gas stimulation treatments", SPE 106289

Perm increase begins long before actual failure, especially at low stress

Actual failure

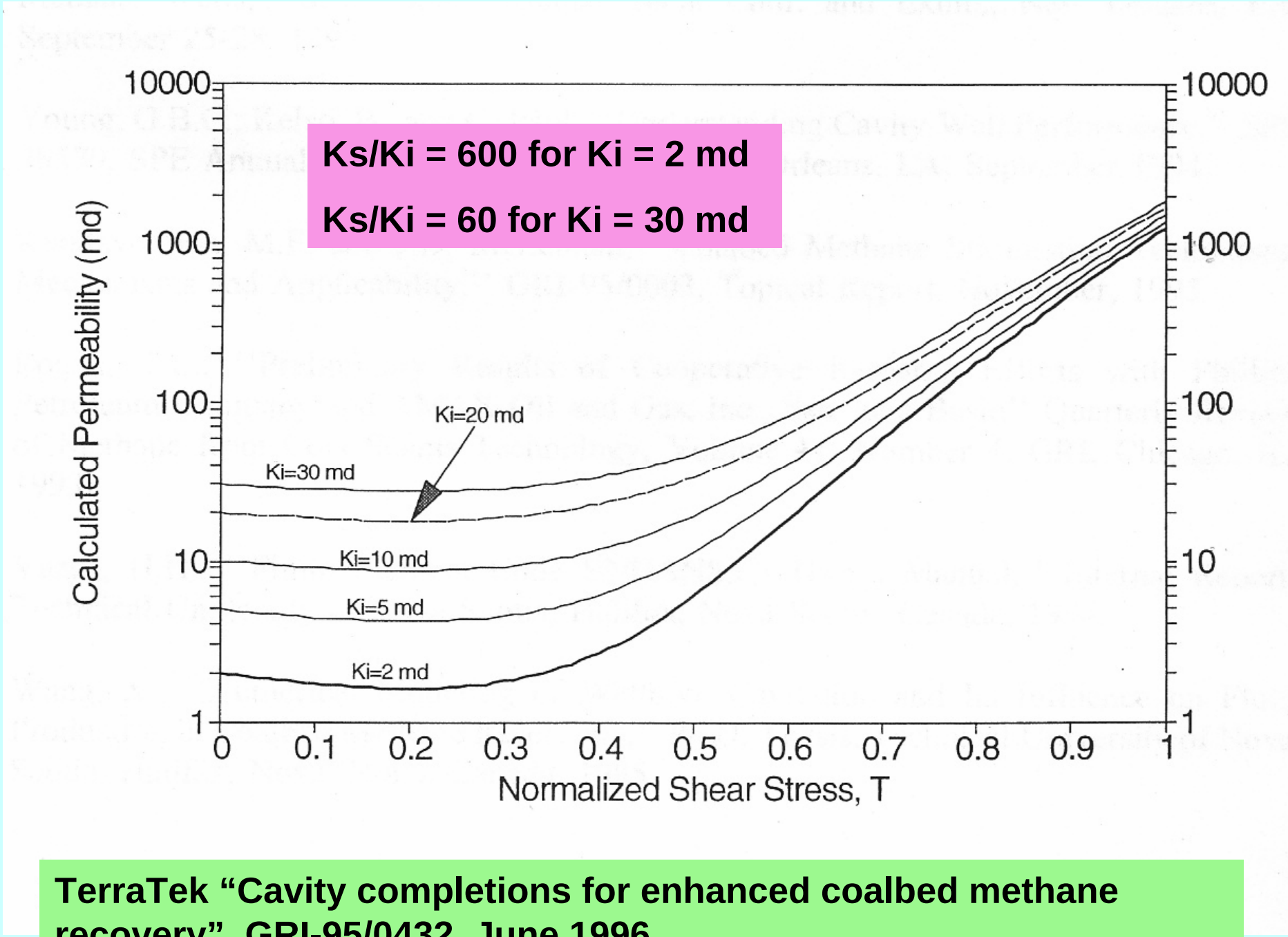


Perm increasing

This is total dilation of 5 cleats in lab test

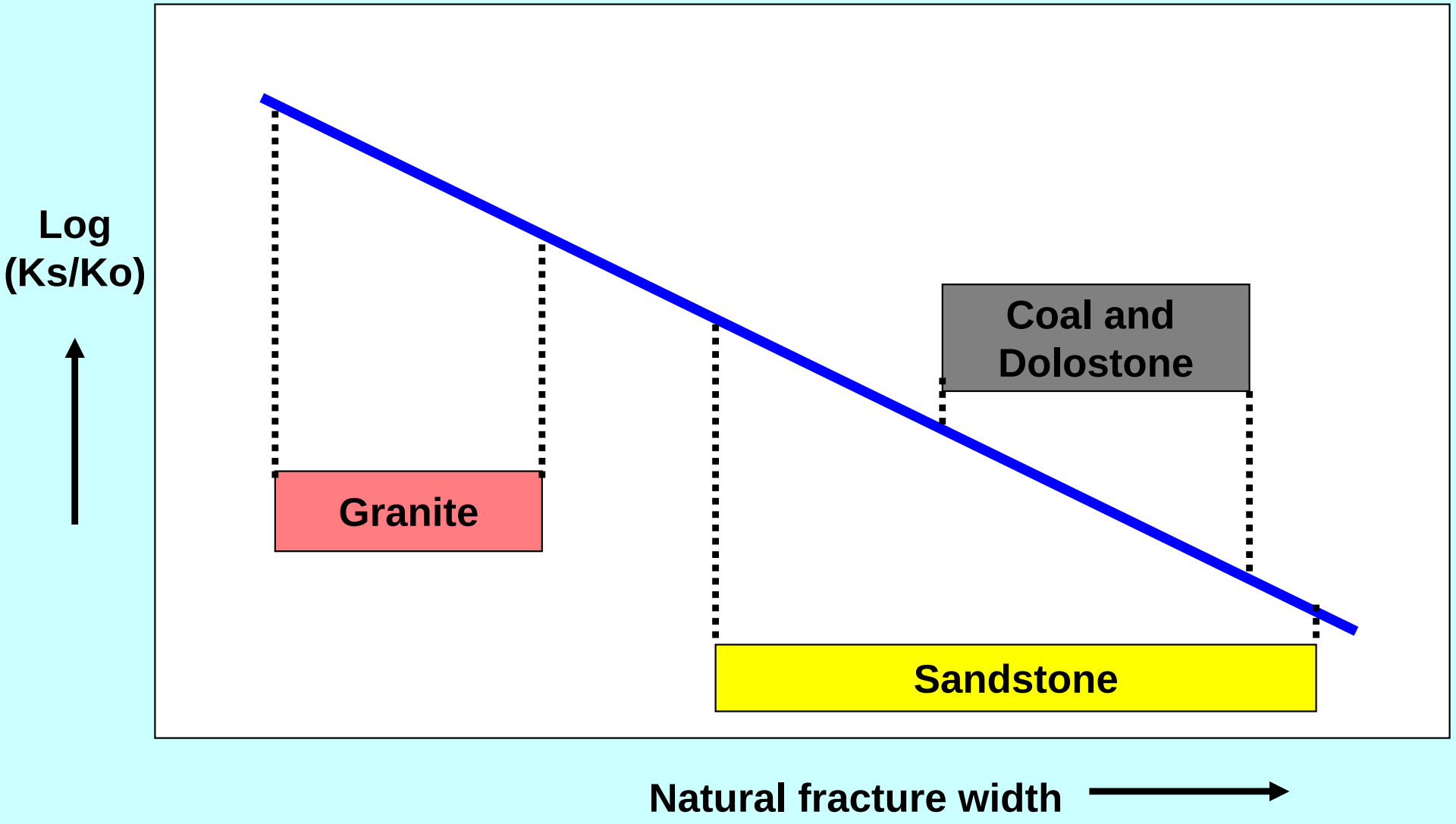
TerraTek "Cavity completions for enhanced coalbed methane recovery", GRI-95/0432, June 1996.

Perm Increases from Shearbox Tests in Coal



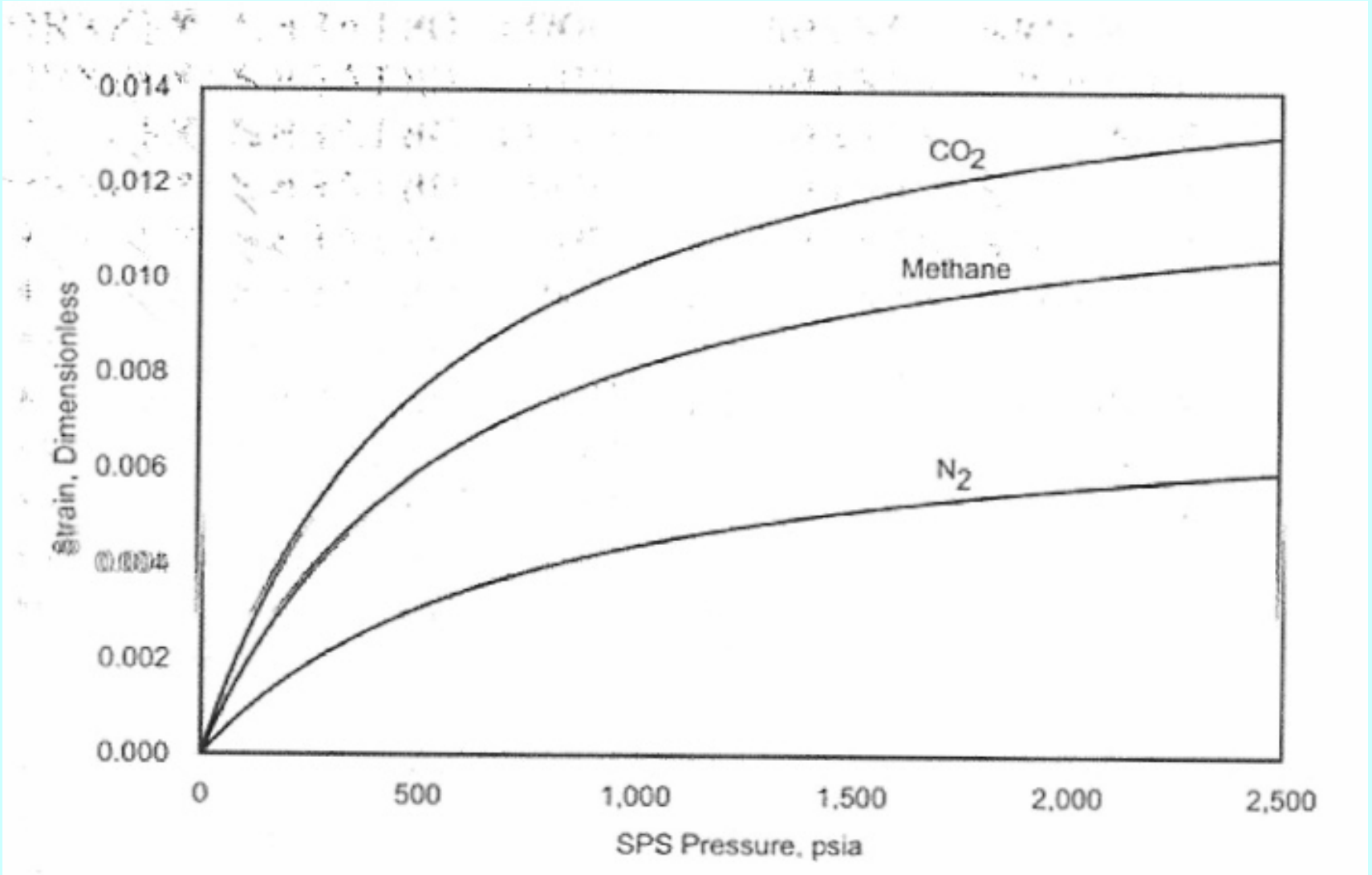
TerraTek "Cavity completions for enhanced coalbed methane recovery", GRI-95/0432, June 1996.

Perm Enhancement Trend



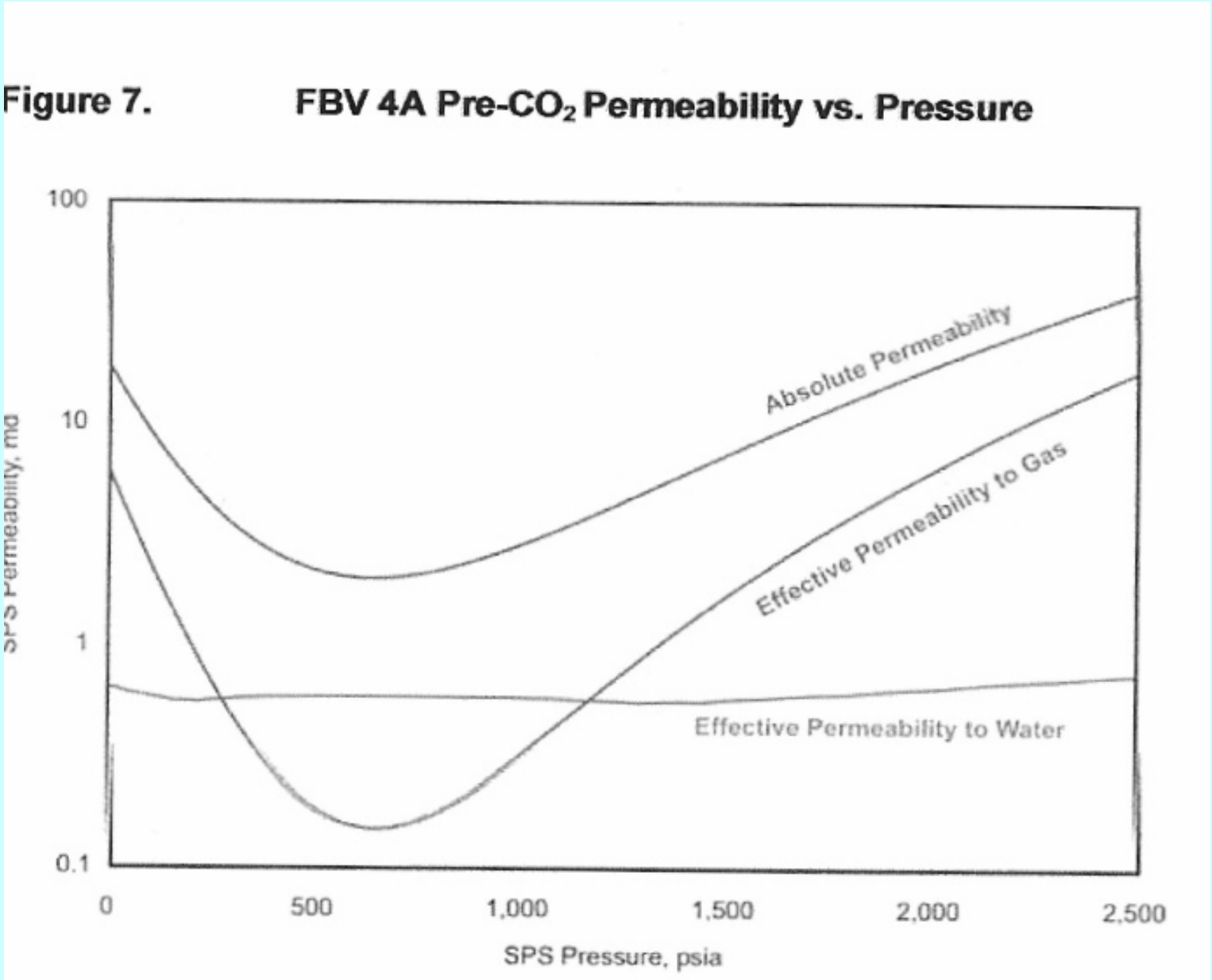
This offsets swelling of coal by CO_2 adsorption

Swelling due to CO2 Injection



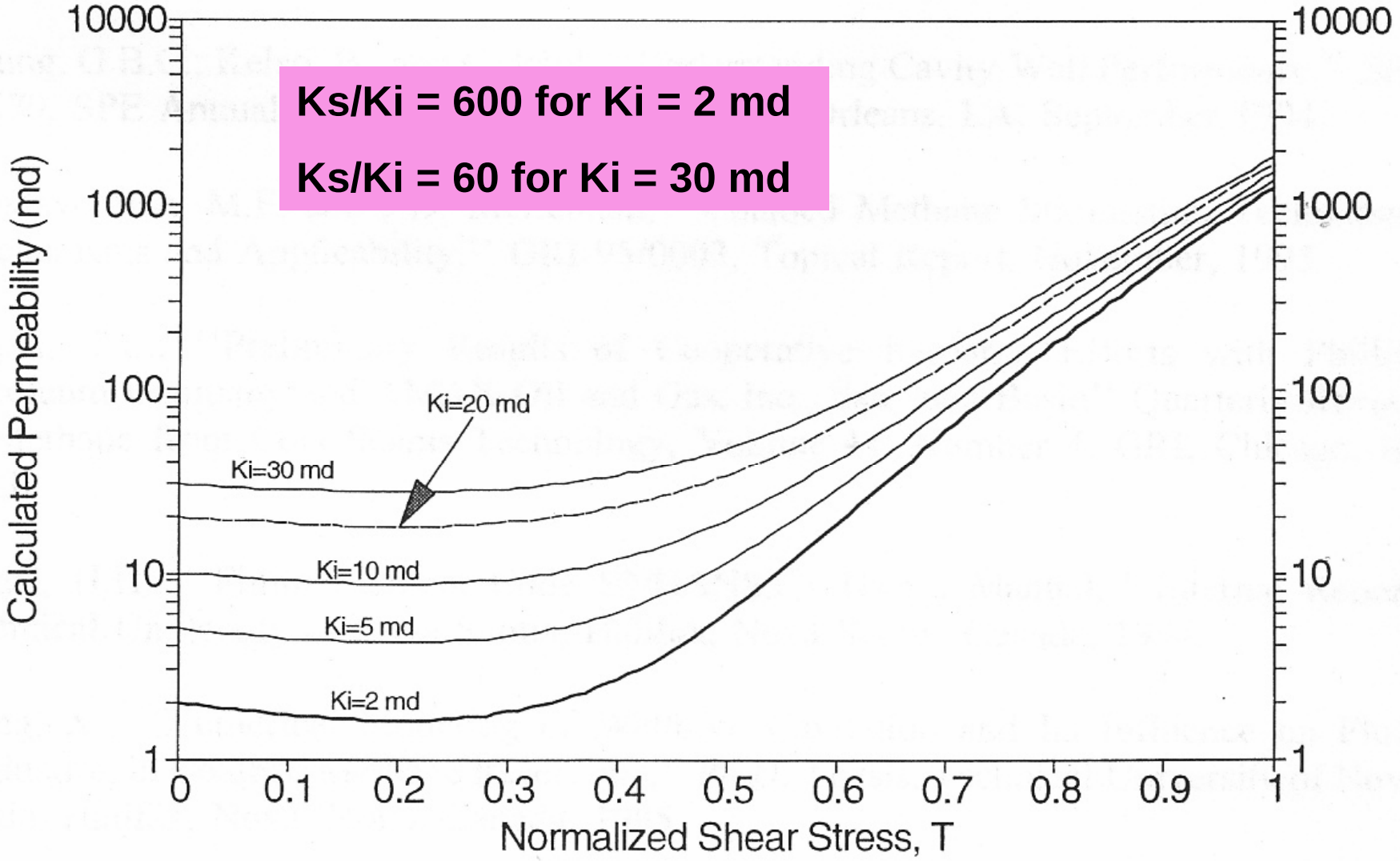
* Mavor et al SPE 90255, 2004

Perm Decrease due to Swelling



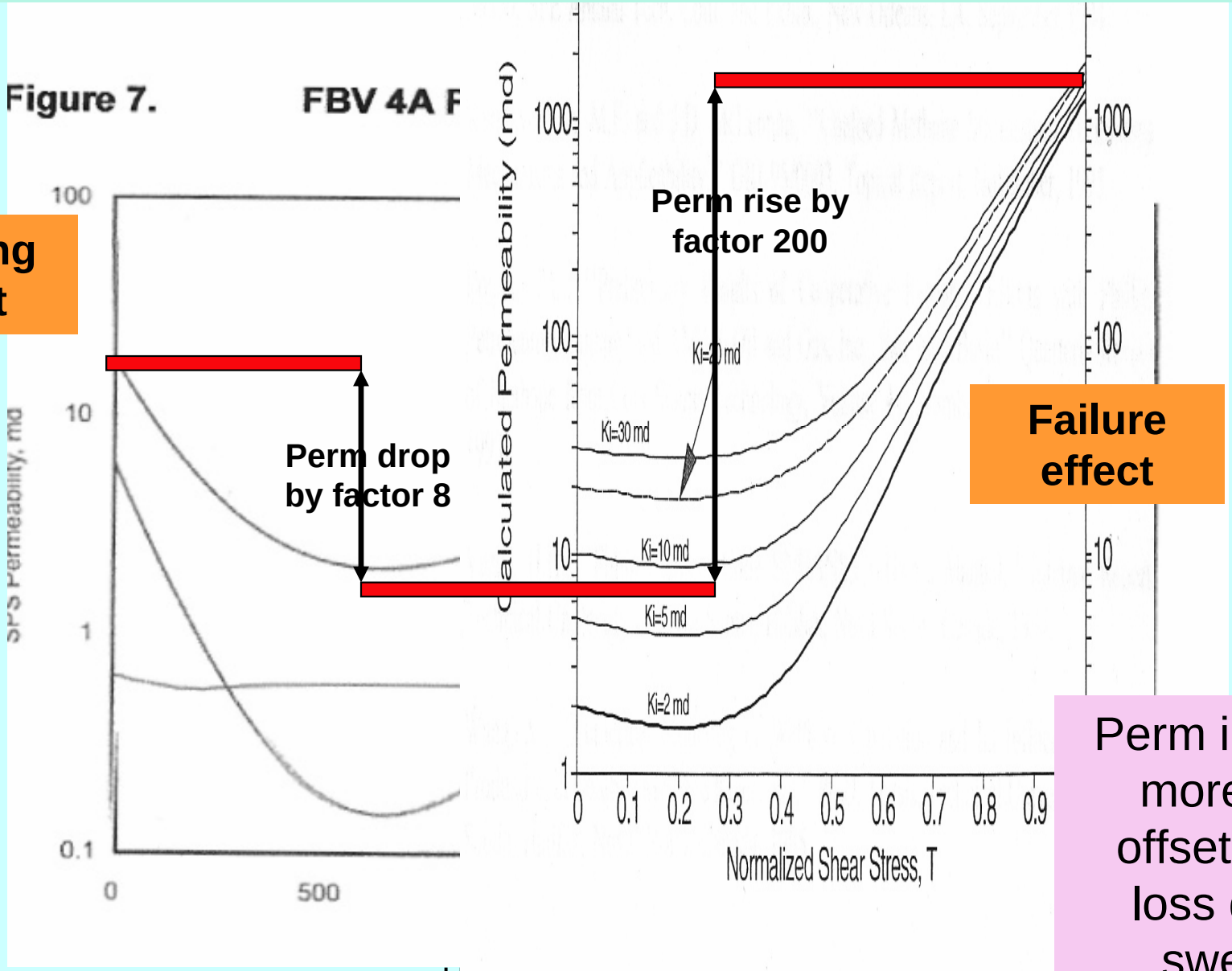
* Mavor et al SPE 90255, 2004

Perm Increases by Failure from Shearbox Tests in Coal



TerraTek "Cavity completions for enhanced coalbed methane recovery", GRI-95/0432, June 1996.

Combine the Two Effects



Swelling effect

Failure effect

Perm increase more than offsets perm loss due to swelling

Figure 6-8. Predicted permeability, on a logarithmic scale; a = 1 cm, n = 5.

Implications for CO2 Injectivity

- In last slide perm increase due to failure exceeds perm loss due to swelling
- CO2 injectivity will increase
- But the result depends on several factors:
  - Whether the coal reaches shear failure (ie, coal strength, in-situ stress, etc)
  - The magnitude of the perm increase (ie, initial coal perm, in-situ stress, etc)
- More geomechanics modeling work needs to be done to achieve predictability

CO2 adsorption
may weaken coal
→ better injectivity

Evidence for CO2 Weakening Coal

- Studies have been made of coal samples subject to CO2 sorption, and examined under X-ray CT. Cracks developed between coal and non-coal units, and hairline cracks appear in the coal units after CO2 cycles. A hairline crack is all that is needed at a localized failure site, before many such sites are linked up by stress increase needed to maintain a uniaxial strain condition.

* Karacan, O. “Heterogeneous sorption and swelling in a confined and stressed coal during CO2 injection”, Energy and Fuels, 17, 1595-1608, 2003.
Karacan, O. “Swelling-induced volumetric strains internal to a stressed coal associated with CO2 sorption”, Intl J. Coal Geology, in press, 2007.

….more

- Two Australian papers give interesting results on CO2-induced failure and permeability changes. The papers conclude that weakening by CO2, failure by in-situ stresses, and permeability increases will not be an issue for sufficiently deep coal seams. However, this is based on lab tests of very weak lignite, and its risky to apply the same conclusion to much stronger bituminous coals, such as HVB, HVA, or MV. Further study of how CO2 weakening depends on coal rank and in-situ stress will be important.

Viete, D.R. and Ranjith, P.G. “The effect of CO2 on the geomechanical and permeability behavior of brown coal: implications for coal seam CO2 sequestration”, Int J. of Coal Geology, 66, 204-216, 2006.

Viete, D.R. and Ranjith, P.G. “The mechanical behavior of coal with respect to CO2 sequestration in deep coal seams”, Fuel, in press, 2007.

….more

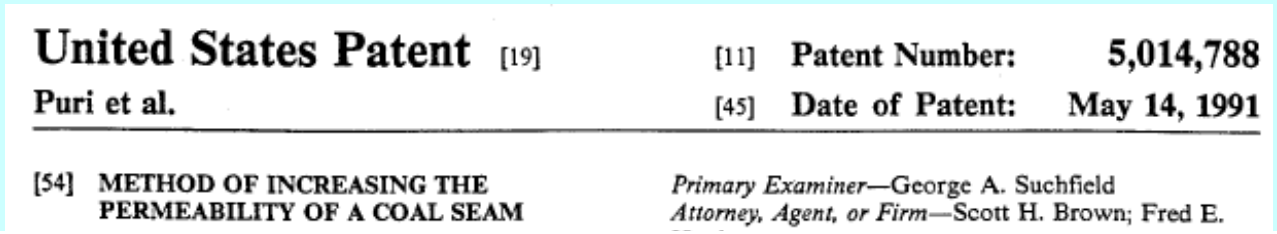
- Cracking by thermal cycling in granite, and weakening of this very strong rock, appears to be an analog to the situation of CO2 adsorption/cycling in coal and the weakening of coal*

* Higgs, N., private communication, 2007.

….more

- It has been reported* that huff-and-puff cycles of CO2 injection caused coal cores to fail in the lab, and that more cycles gave more breakage (each cycle was a few days). Some experiments were done to explore if CO2 huff-n-puff could be used to enhance near-wellbore permeability, by inducing coal to fracture. Some coals are fragile enough that the swelling and shrinking of coal by CO2 adsorption and desorption can induce sufficient stress to cause the coal to fall apart. Each cycle was a few days: injection followed by time to reach equilibrium. The failure seemed to be progressive, and became more apparent after several cycles. None of this was published, but the idea was transmuted into a patent, by Raj Puri (see below).

* Unpublished Amoco work
Puri, R., private communication, 2007.



United States Patent [19]
Puri et al.

[11] **Patent Number: 5,014,788**
[45] **Date of Patent: May 14, 1991**

[54] **METHOD OF INCREASING THE PERMEABILITY OF A COAL SEAM**

Primary Examiner—George A. Suchfield
Attorney, Agent, or Firm—Scott H. Brown; Fred E.

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- In a micropilot in China, a well produced better after a huff-and-puff treatment with CO2, and this may indicate failure of coal*
- In a CO2 sequestration project in Japan, there is evidence for an injectivity increase over time**

*Gunter et al, Report on CO2 micropilot in China, 2004 or 2005?

**Fujioka, M. “Yubari project”, Coal-Seq V, Houston, November 2006.

The Promise of Injectivity

- Loss of injectivity may hurt commercial schemes of CO2 sequestration
- Earlier coal failure should increase CO2 injectivity
- CO2 injections should be designed to maximize coal failure:
  - Huff-and-puff cycles of CO2 injection may cause more failure
  - Injecting liquid CO2 may cause more failure by thermal cooling (opposite of matrix swelling)
- Future work should include geomechanics modeling of shear failure and permeability increase, as an input to reservoir modeling of CO2 injectivity


The End