Permeability Around the Nojima Fault Detected Using Barometric response of Pore Pressure

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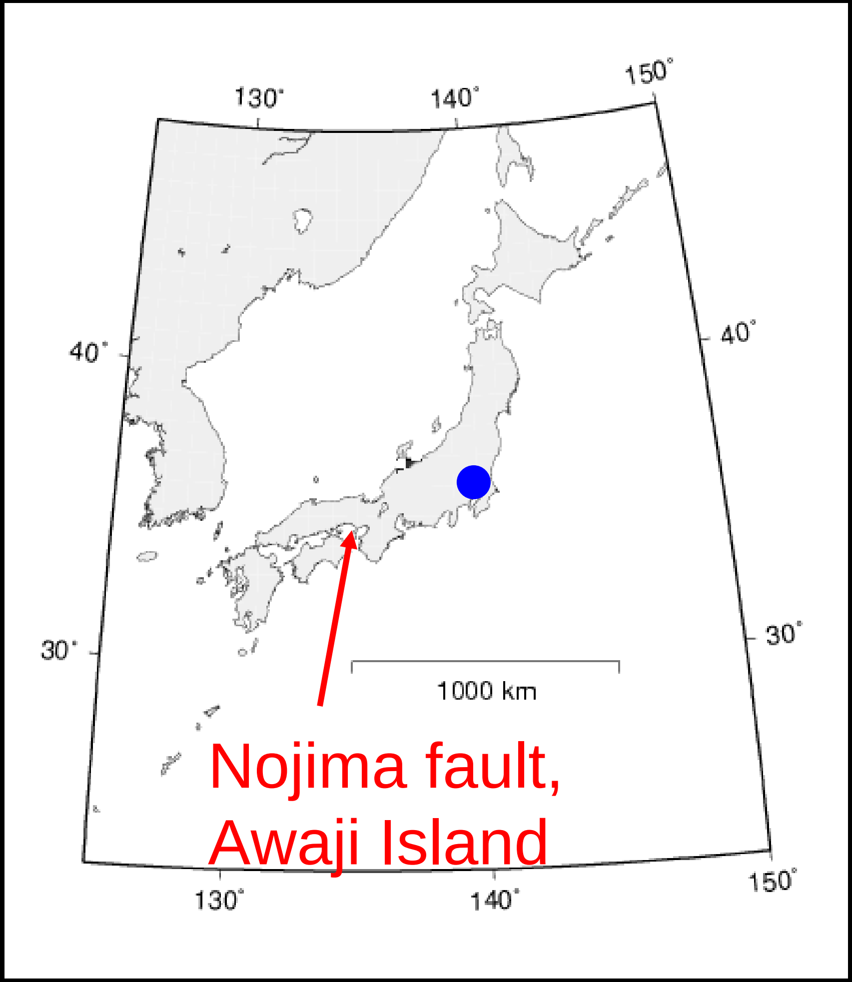
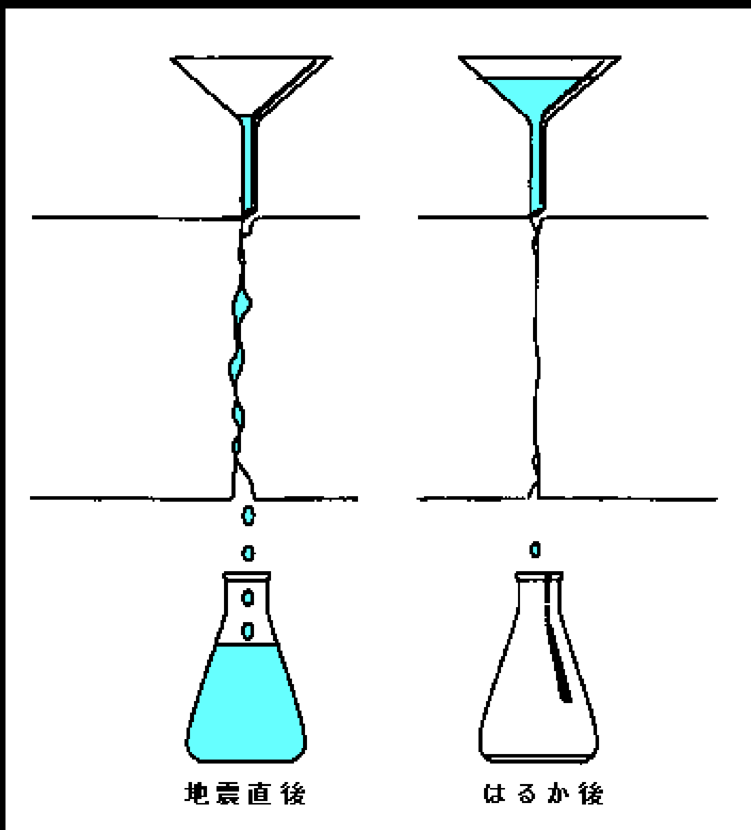
Nojima Experiment

Detect permeability decrease (~ fault recovery process)



Motivation of the Nojima experiment

The recovery process of a fault after an earthquake can be measured using permeability decrease.



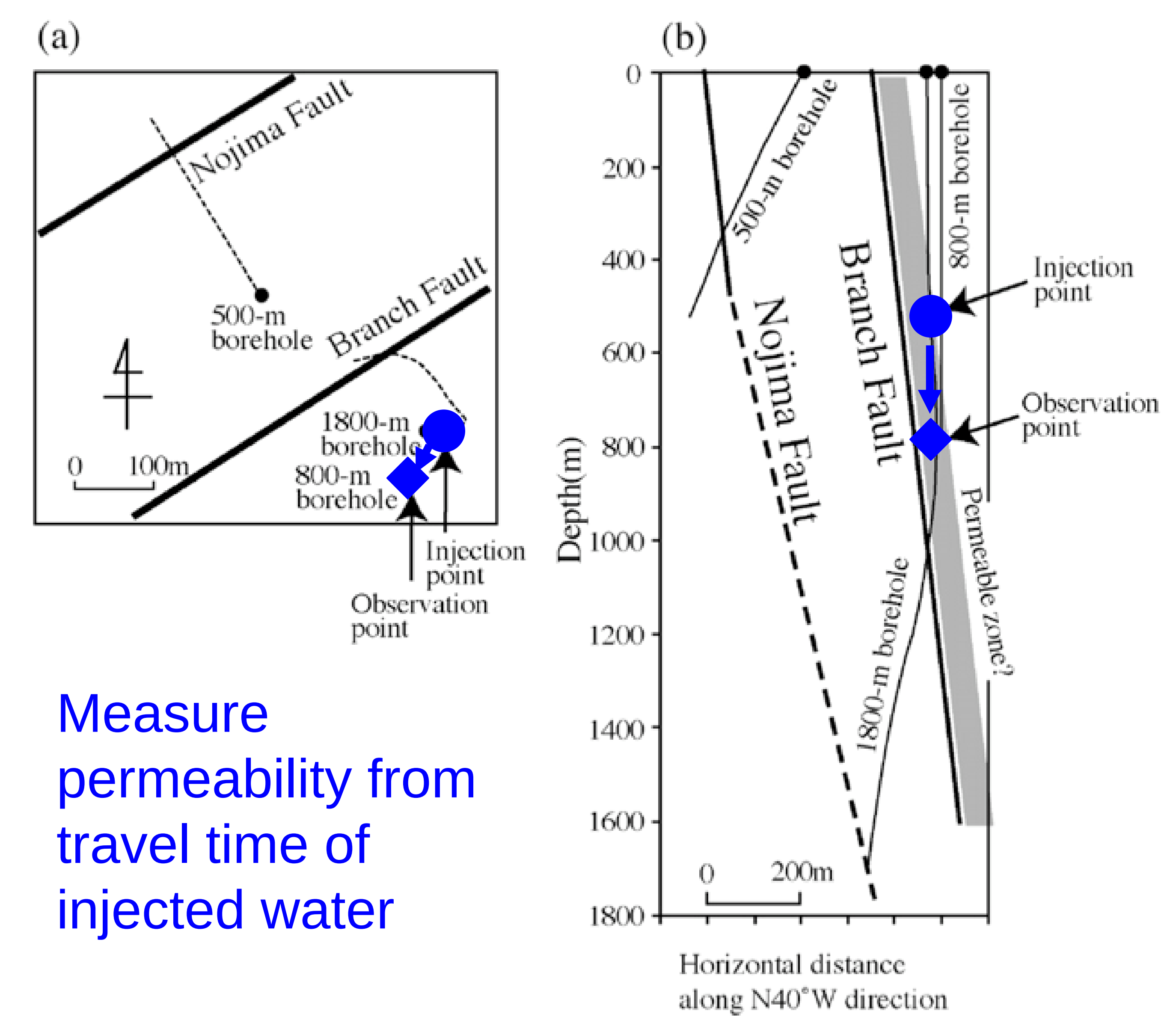
1995 Kobe   t ~ ∞?

Nojima experiment:
- Injection test
- seismicity (aftershocks, induced event)
- velocity change (ACROSS)
- core analyses etc.

[Shimazaki et al., 1998]

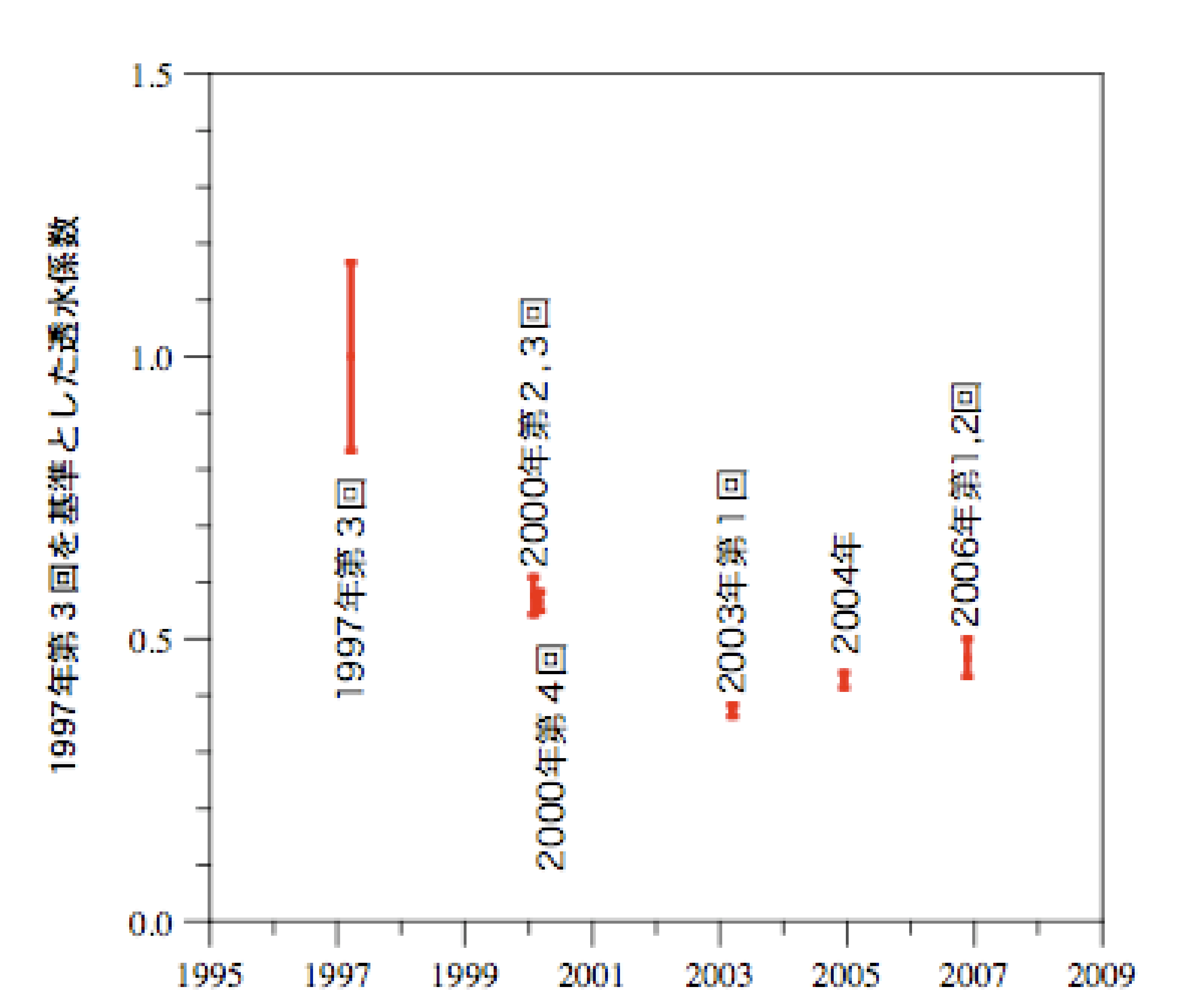
Repeated injection tests

[Kitagawa et al., 2007]



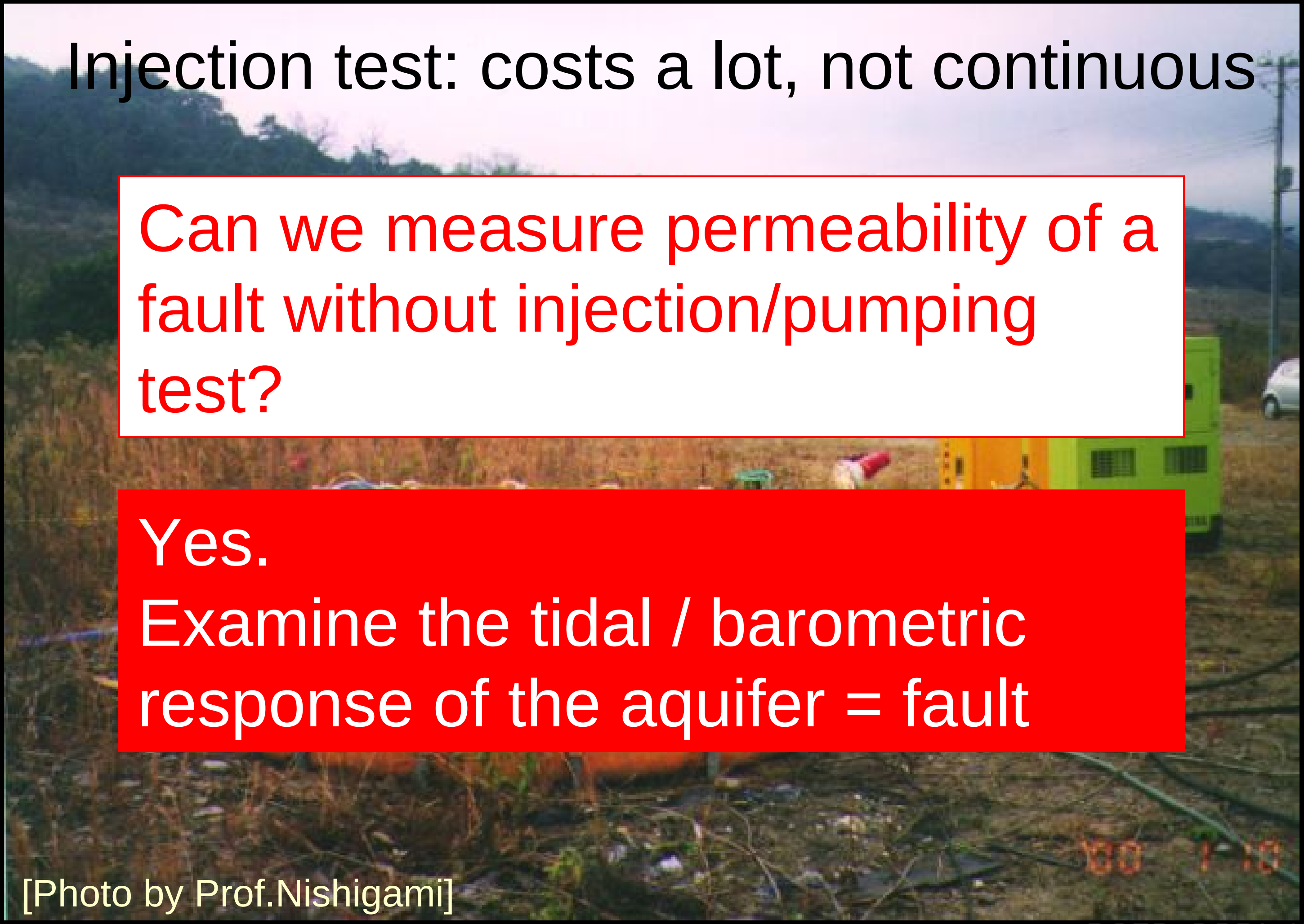
Measure permeability from travel time of injected water

Permeability reduction detected from injection tests



Motivation of this study

Permeability of the fault was measured by the repeated injection tests [e.g. Kitagawa et al., 2007].



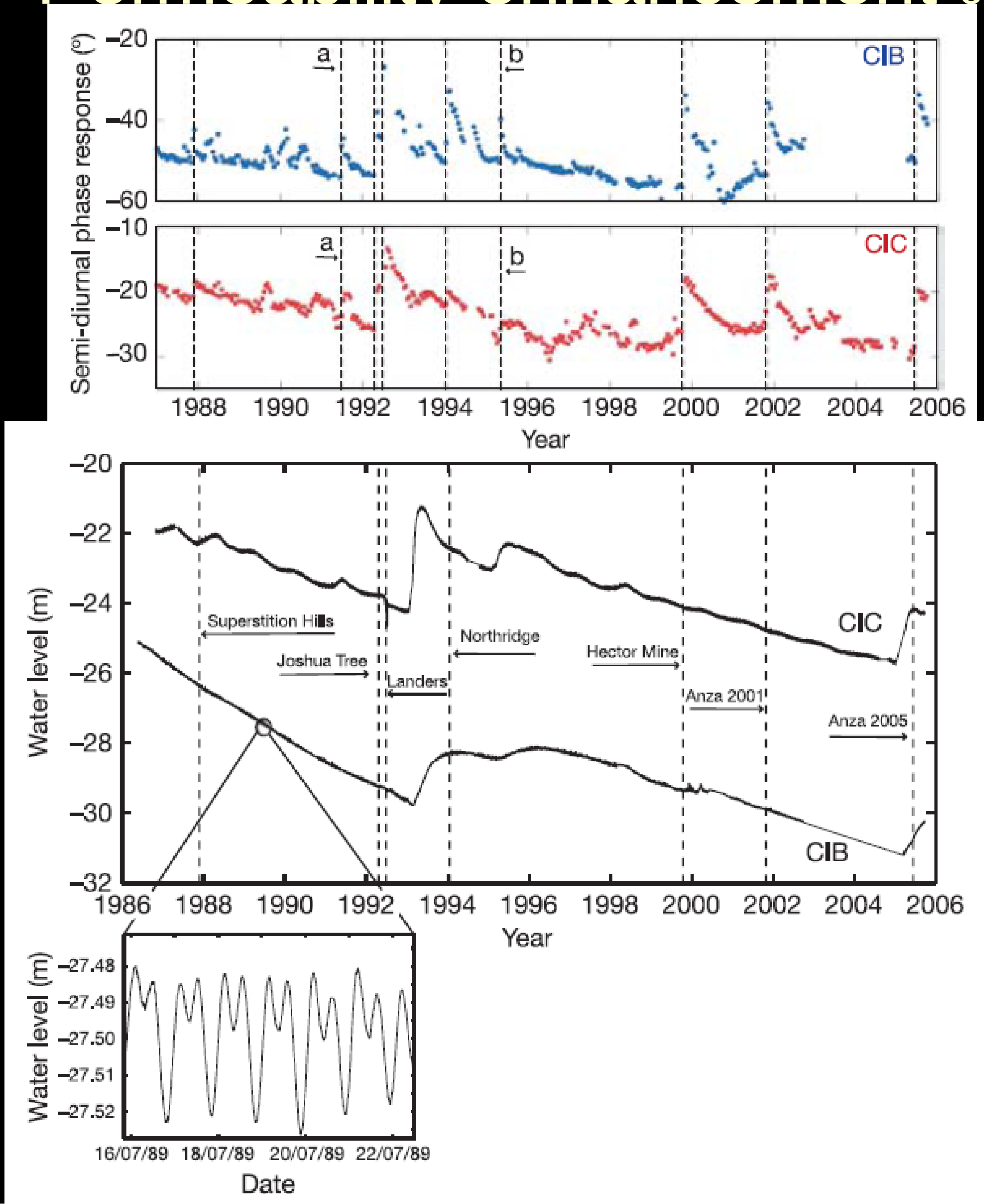
Injection test: costs a lot, not continuous

Can we measure permeability of a fault without injection/pumping test?

Yes.
Examine the tidal / barometric response of the aquifer = fault

[Photo by Prof.Nishigami]

Permeability enhancement caused by earthquake shaking



[Elkhoury *et al.*, 2006, Nature]

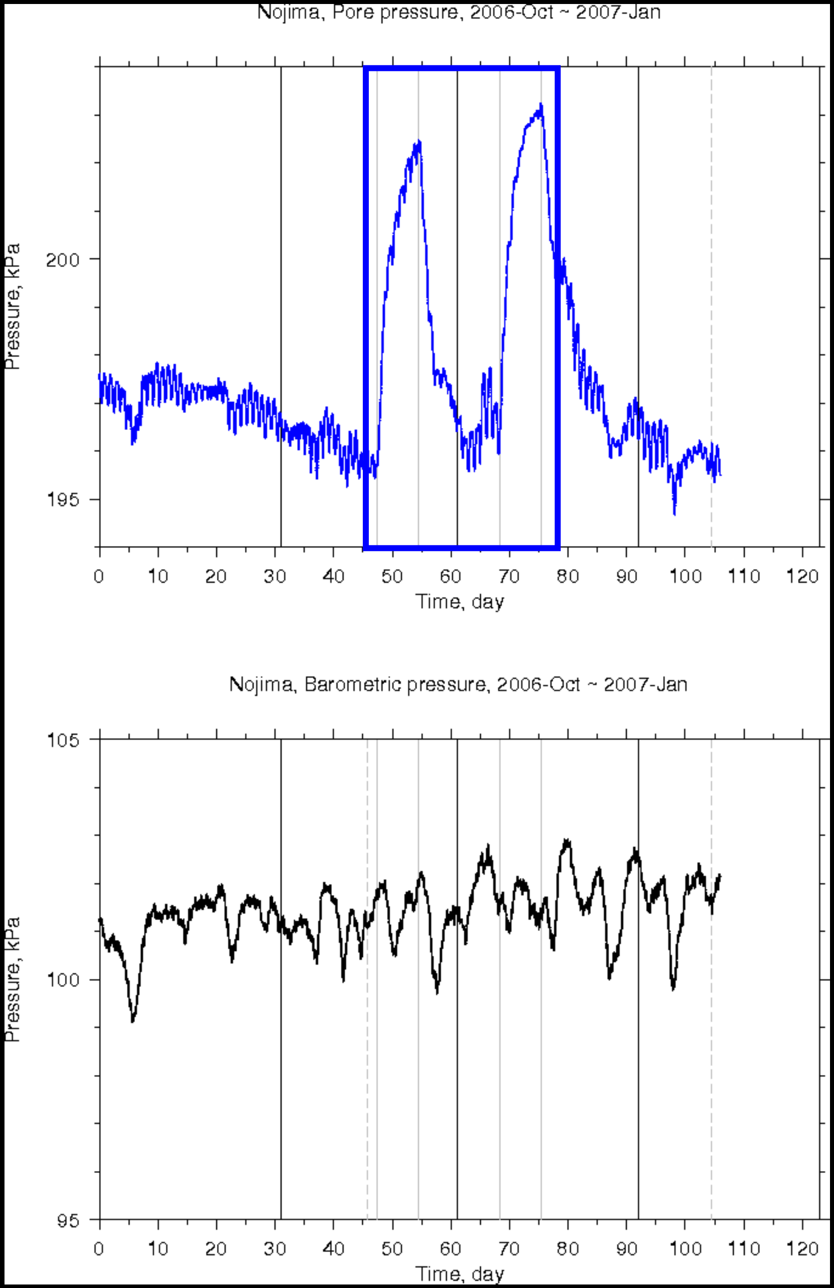
Tidal response of wells(PFO)

shaking ->

permeability（c）increase ->

recovery of phase shift

Nojima 800-m borehole

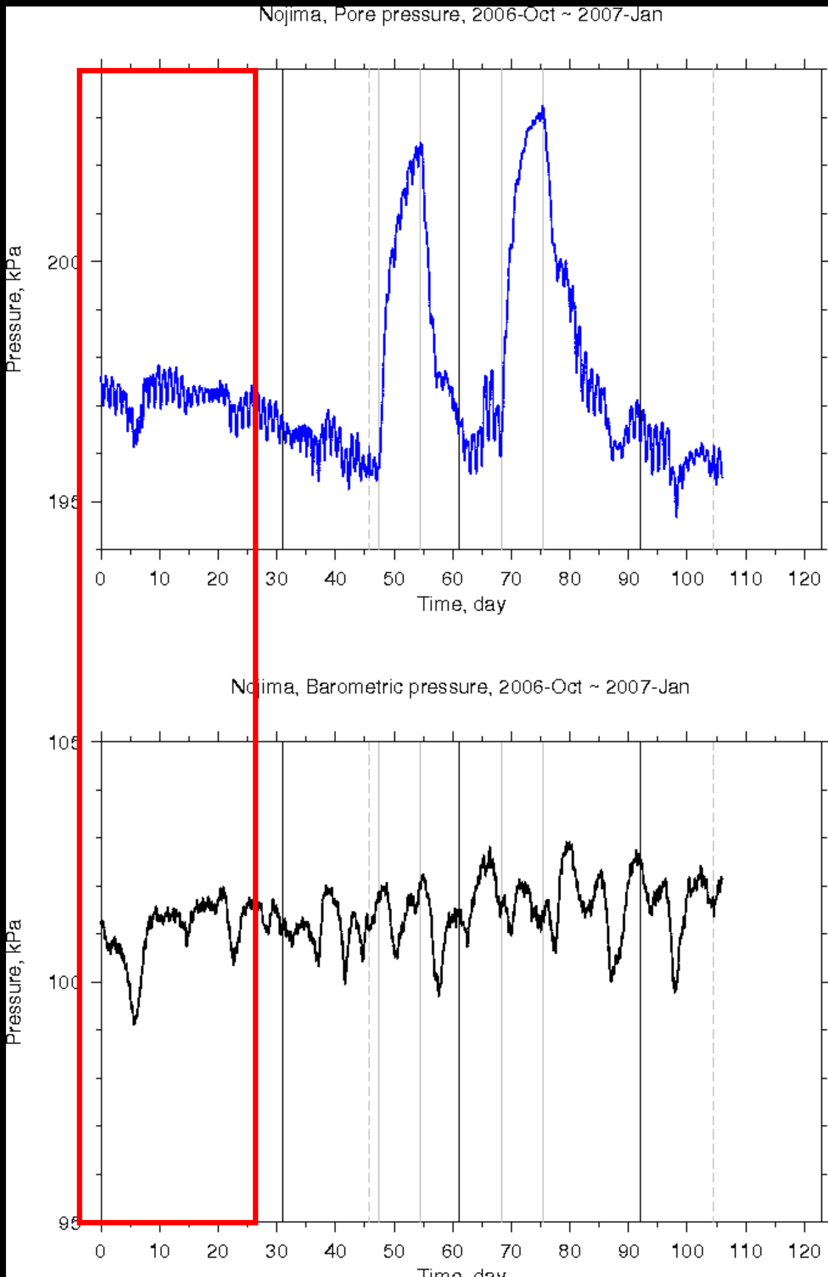


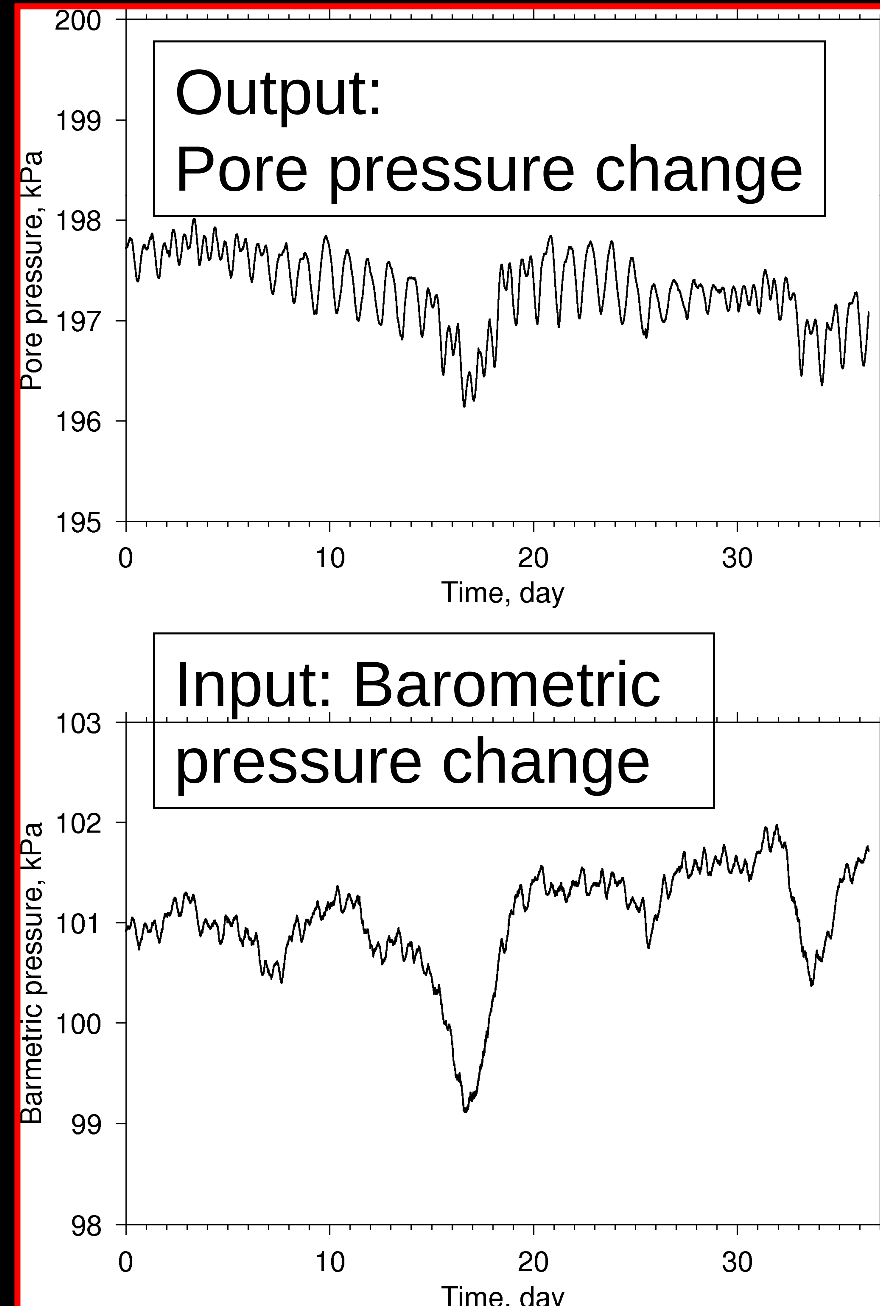
Injection test:

Input: Injected water

Output: pressure change in obs. well

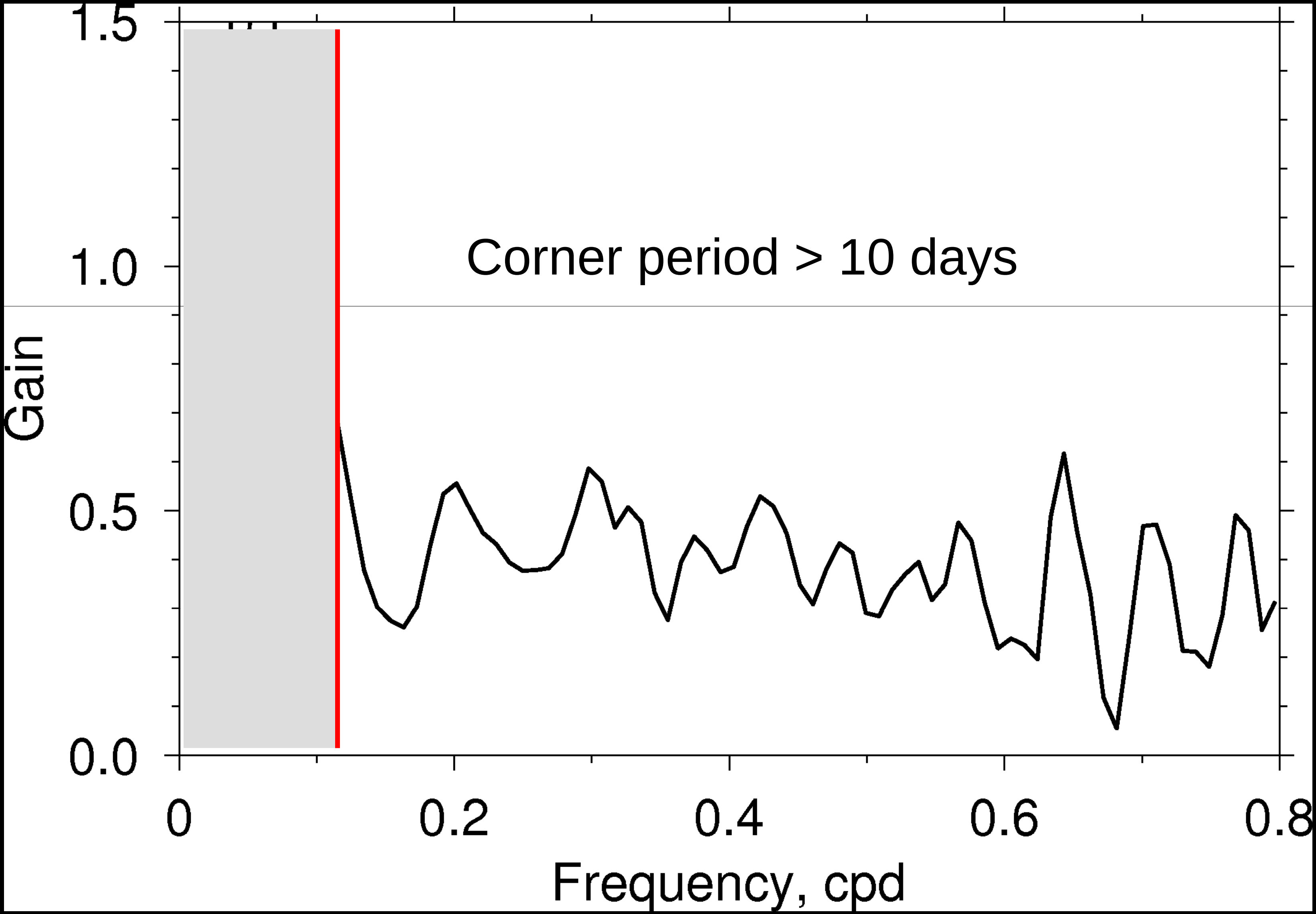
(Time domain)


Nojima, Pore pressure, 2006-Oct ~ 2007-Jan
Pressure, kPa
200
195
0 10 20 30 40 50 60 70 80 90 100 110 120
Time, day
Nojima, Barometric pressure, 2006-Oct ~ 2007-Jan
Pressure, kPa
105
100
95
0 10 20 30 40 50 60 70 80 90 100 110 120
Time, day


Output:
Pore pressure change
Pore pressure, kPa
200
199
198
197
196
195
0 10 20 30
Time, day
Input: Barometric
pressure change
Barmetric pressure, kPa
103
102
101
100
99
98
0 10 20 30
Time, day

Spectral ratio Pp/Pb : passive test

Tidal response ->



Hydraulic diffusivity

Corner period is larger than 10 days

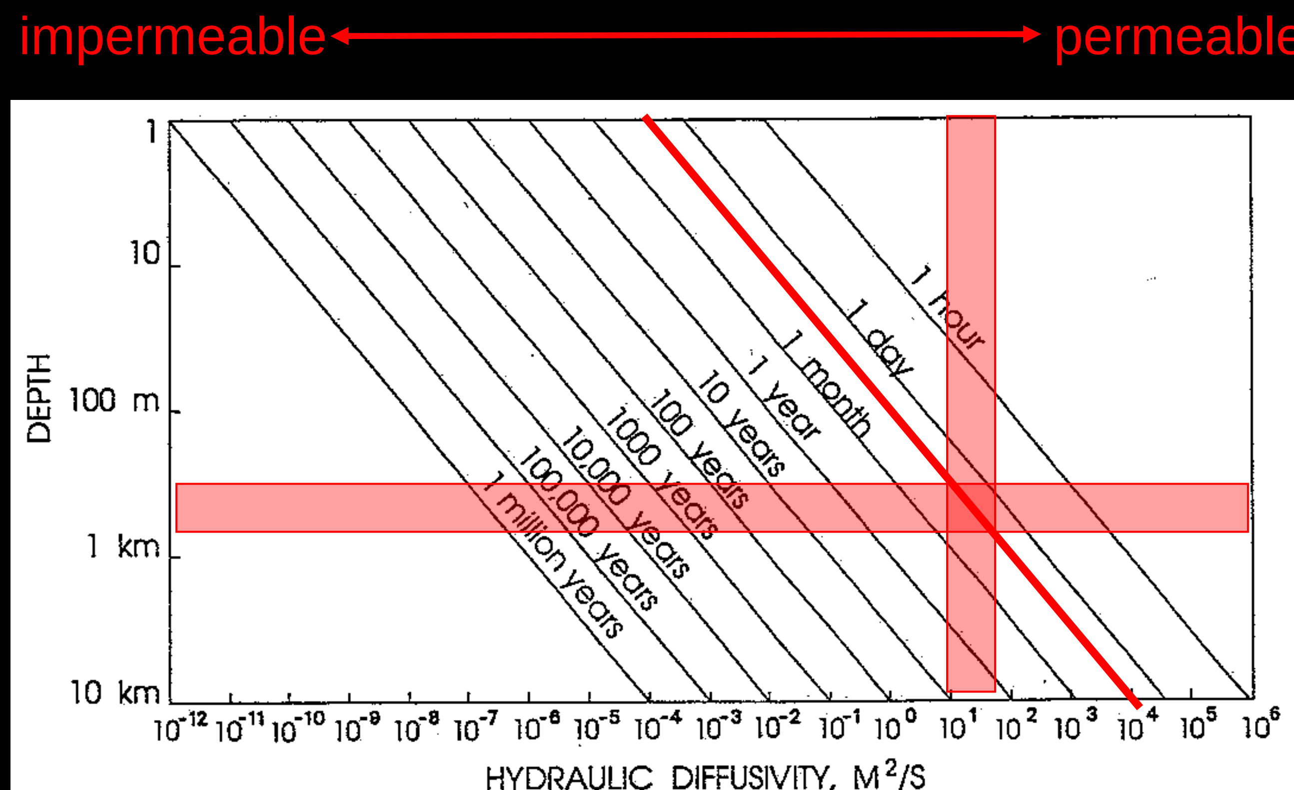
Assuming one-dimensional flow to water-table,

Upper bound

c : 10~100 m^2/s

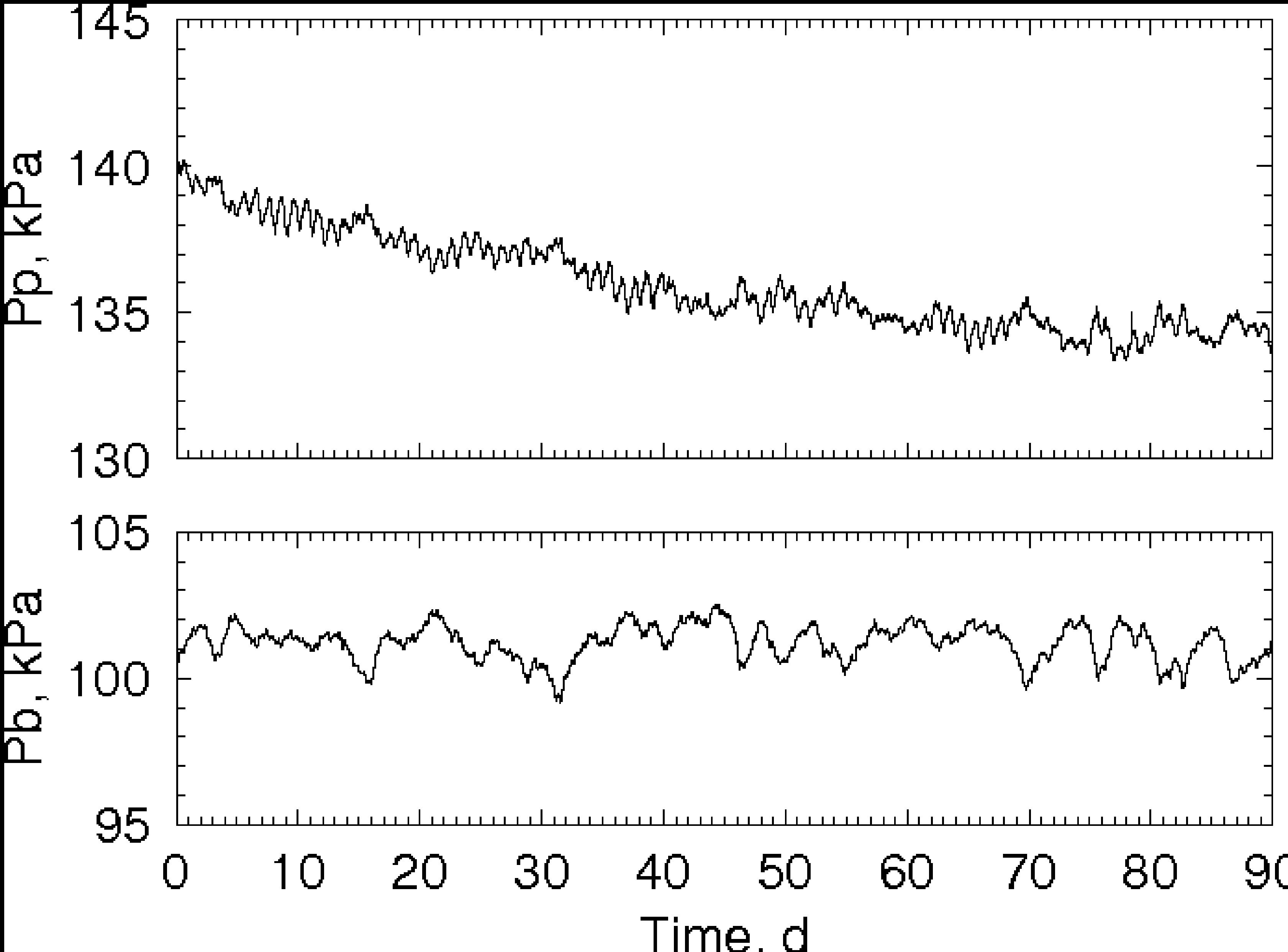
K : 10^{-3} ~10^{-2} m/s

k : 10^{-10} ~10^{-9} m^2



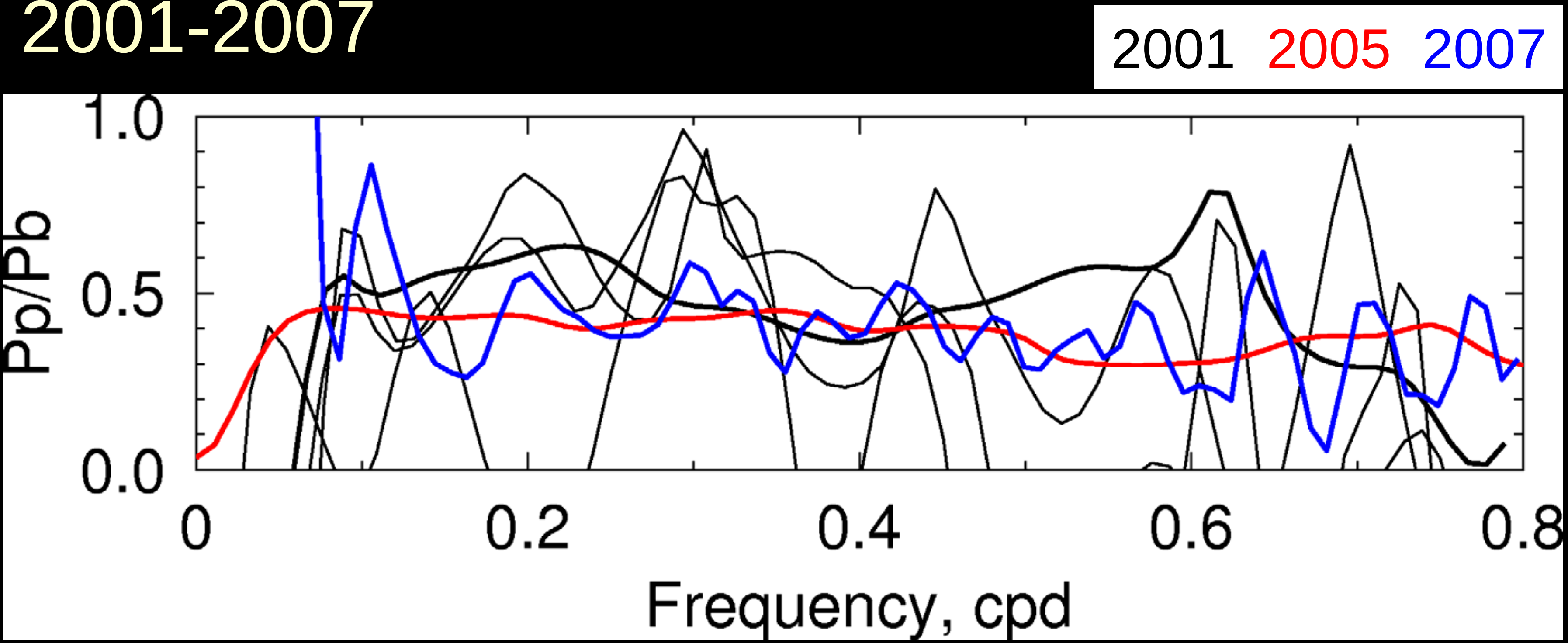
[Roeloffs, 1996]

2005

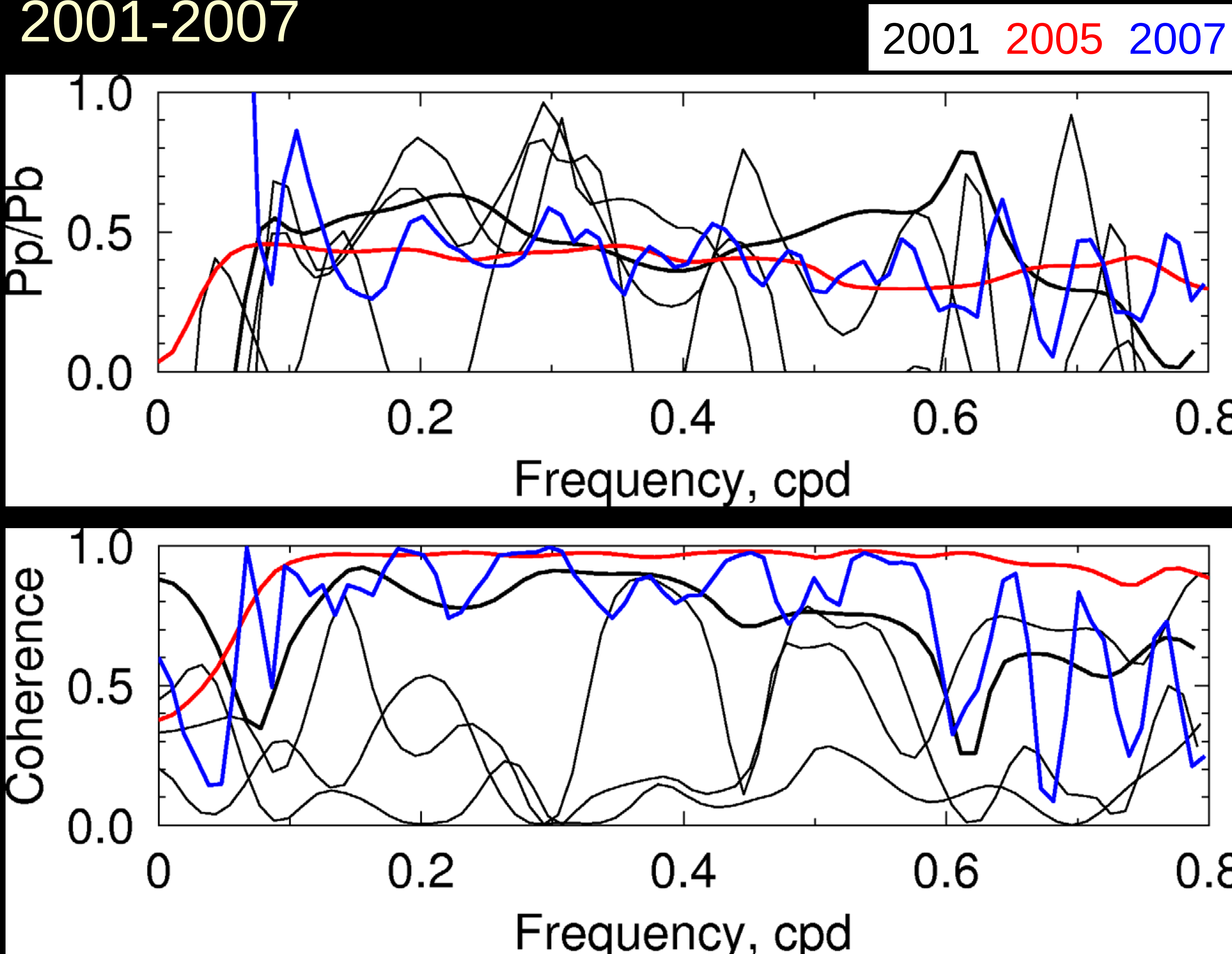


145
140
135
130
Pp, kPa
105
100
95
Pb, kPa
0
10
20
30
40
50
60
70
80
90
Time, d

2001-2007



2001-2007


2001 2005 2007
1.0
0.5
0.0
Pp/Pb
0
0.2
0.4
0.6
0.8
Frequency, cpd
1.0
0.5
0.0
Coherence
0
0.2
0.4
0.6
0.8
Frequency, cpd

Discussion

<u>Hydraulic diffusivity from passive test (2001-2007)</u>

< 100 m^2/s to water-table

Setting of drainage

Corner period 100 m & 1 month => 0.1 m^2/s

<u>Hydraulic diffusivity from injection tests</u>

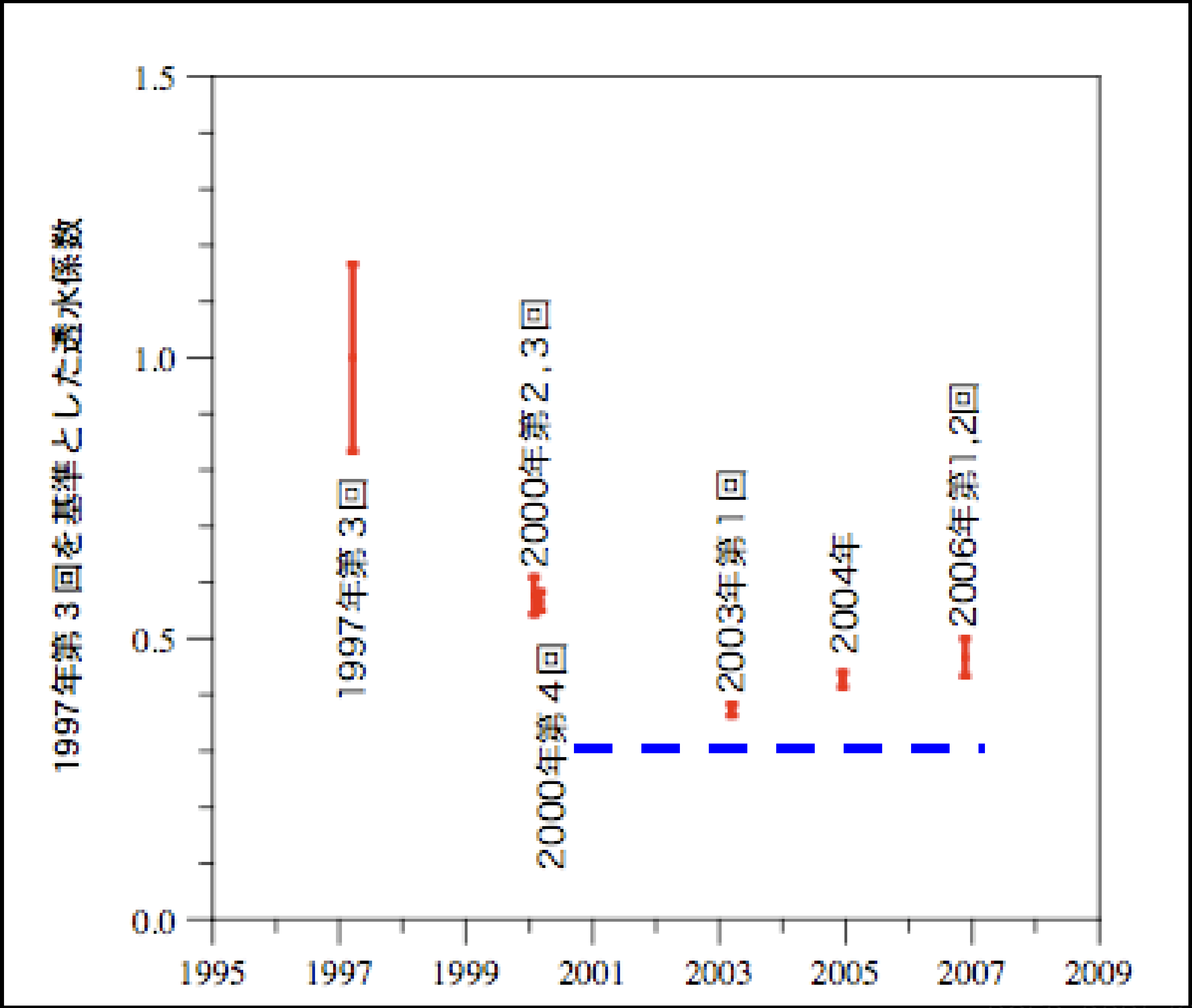
- Kitagawa et al., 2006, Tectonophys.

1.5 m^2/s (1997) --> 0.4 m^2/s (2003) between wells

- Mukai et al., 2006, Tectonophys.

0.9 m^2/s (1997) --> 0.4 m^2/s (2003) between wells

Permeability variation



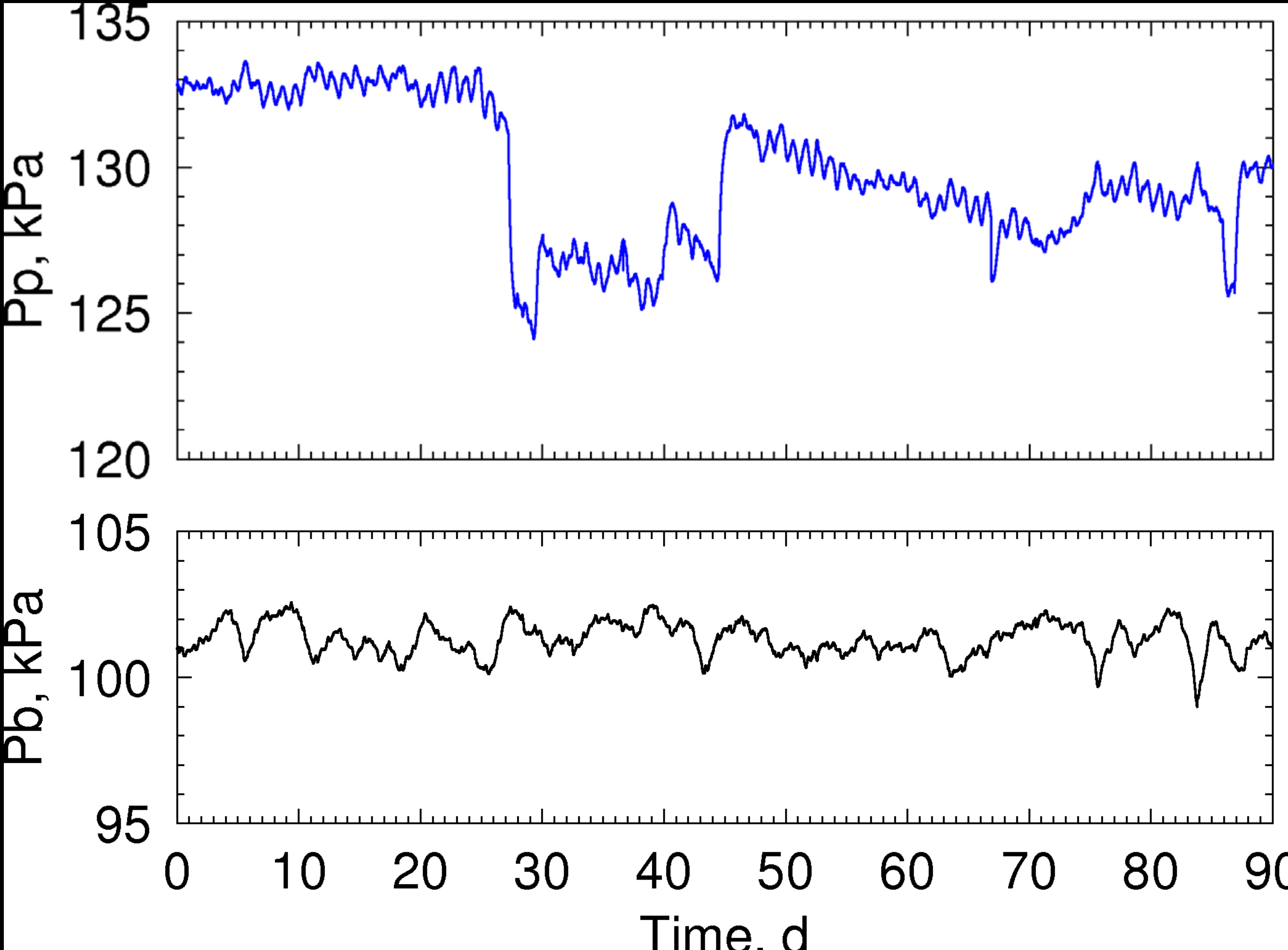
Summary

Hydraulic diffusivity around 800-m borehole is estimated to be < 100 m^2/s from 2001 to 2007.

Passive measurement of permeability using pore pressure monitoring is effective.

Make continuous measurement without cost

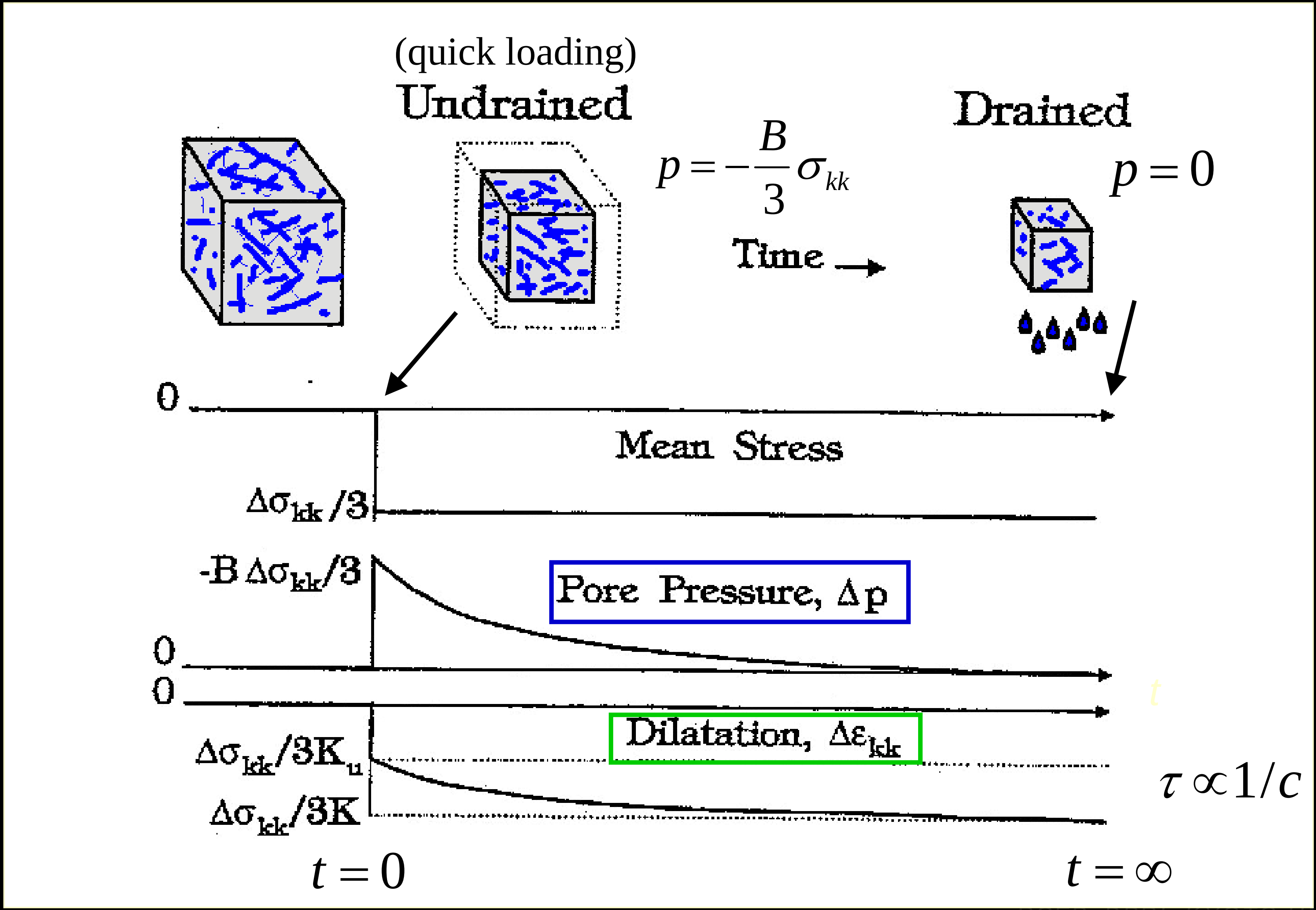
2004



135
130
125
120
Pp, kPa
105
100
95
Pb, kPa
0
10
20
30
40
50
60
70
80
90
Time, d

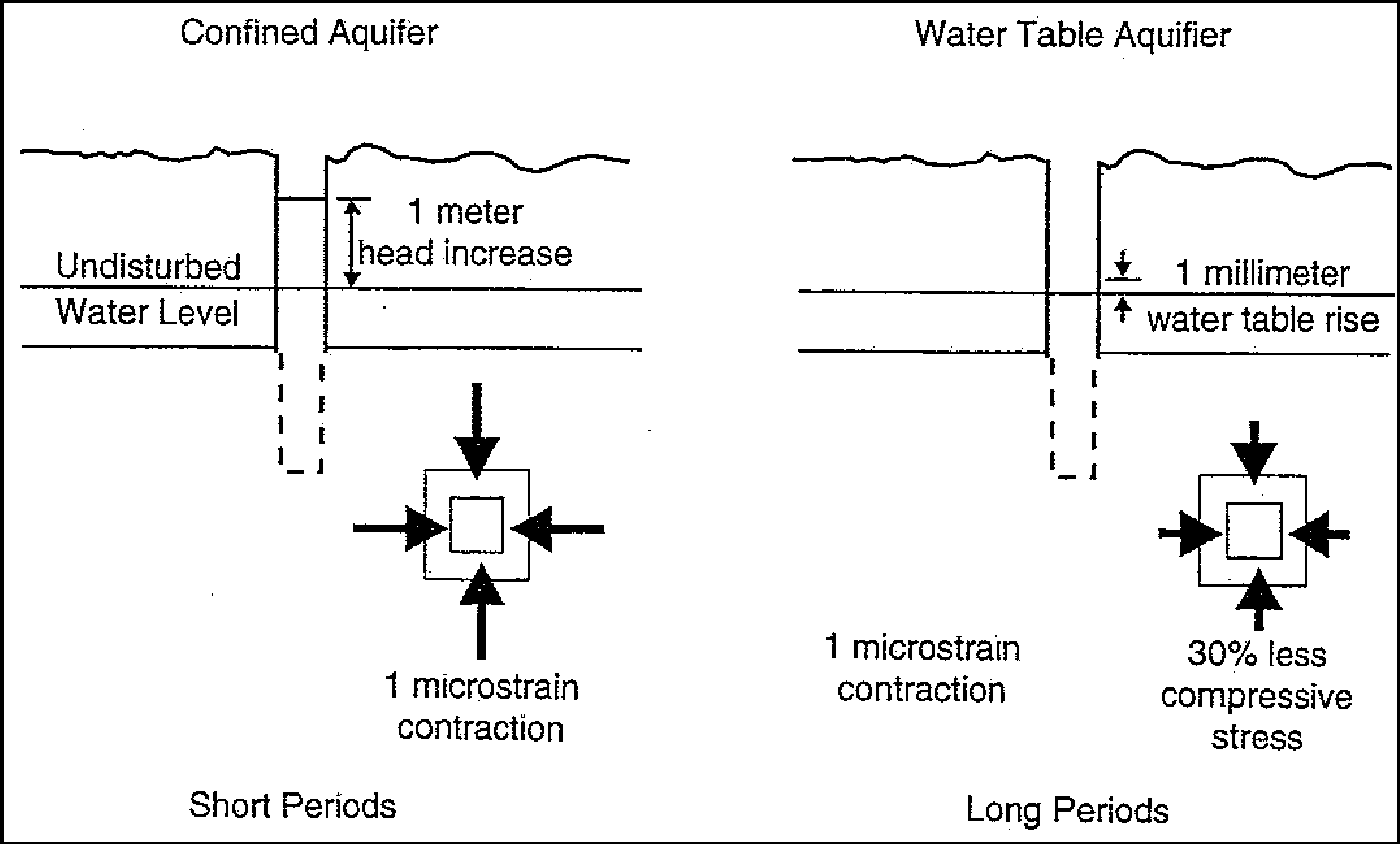
Time-dependent response of poroelastic material

(Roeloffs, 1996)



Confined and water-table aquifer

Cutoff at low frequency



[Roeloffs, 1996]