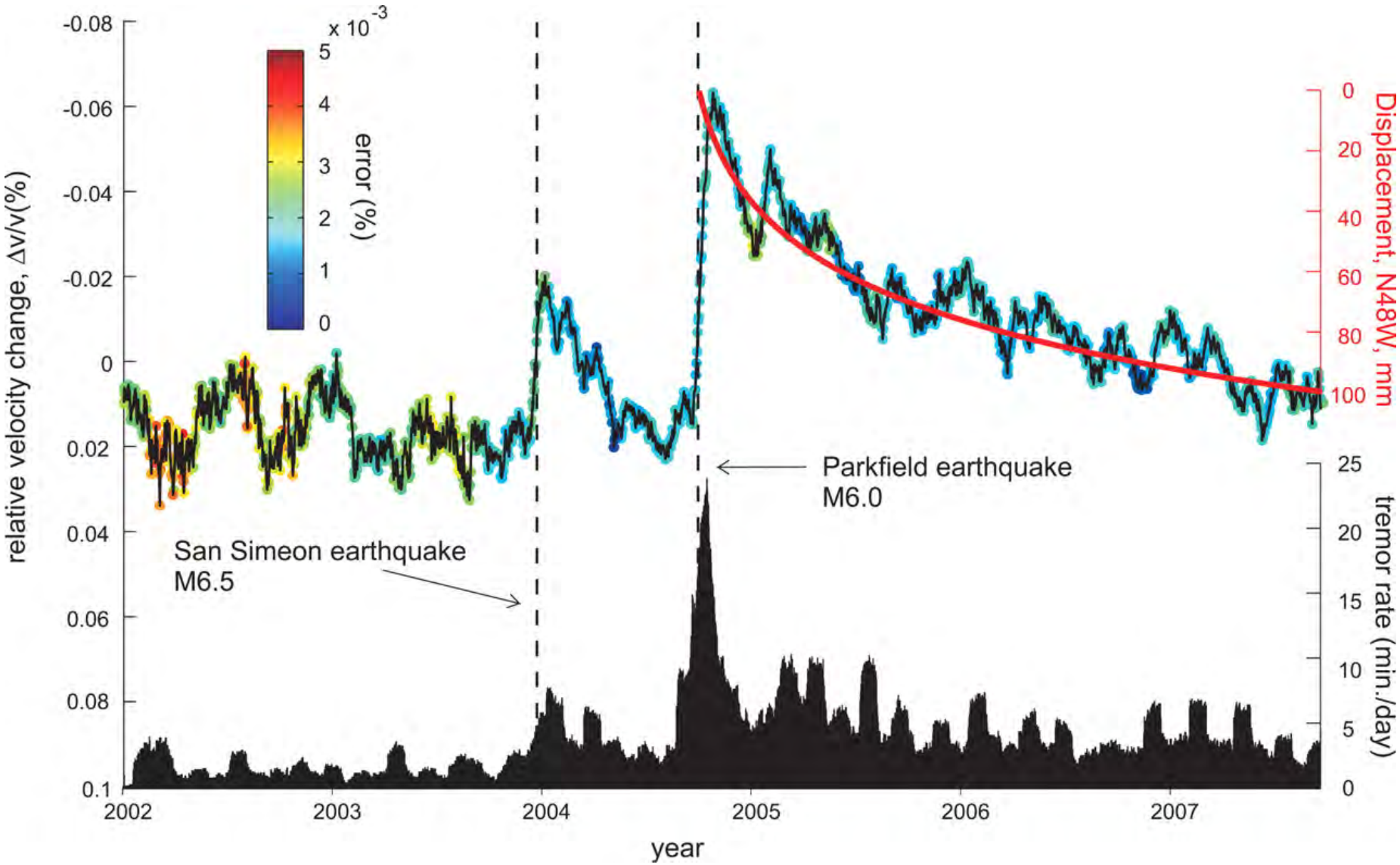
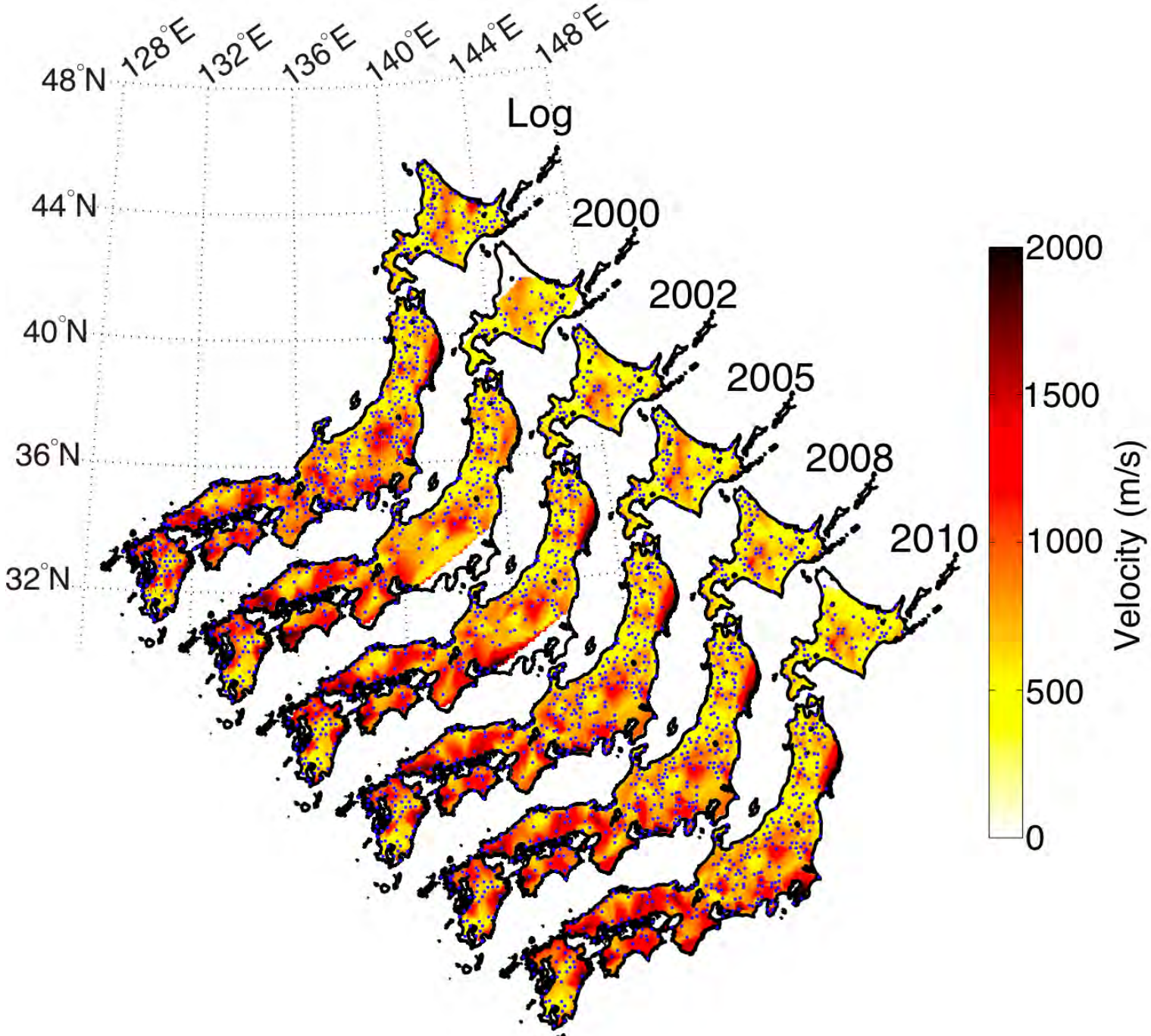
Damaging and healing of earth materials as a multi-scale phenomenon

Roel Snieder

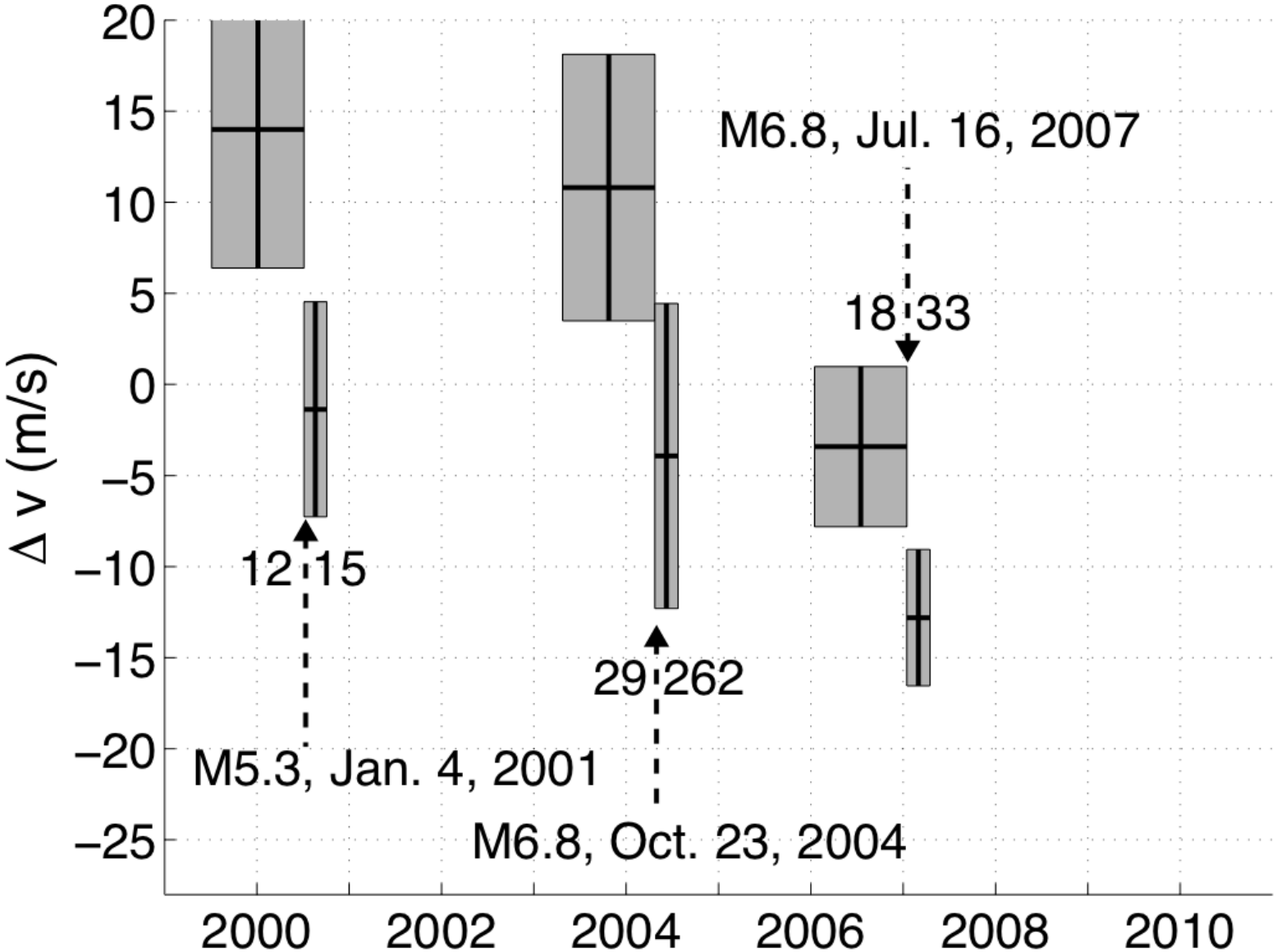


(Brenguier et al., Science, 321,1478-1481, 2008)

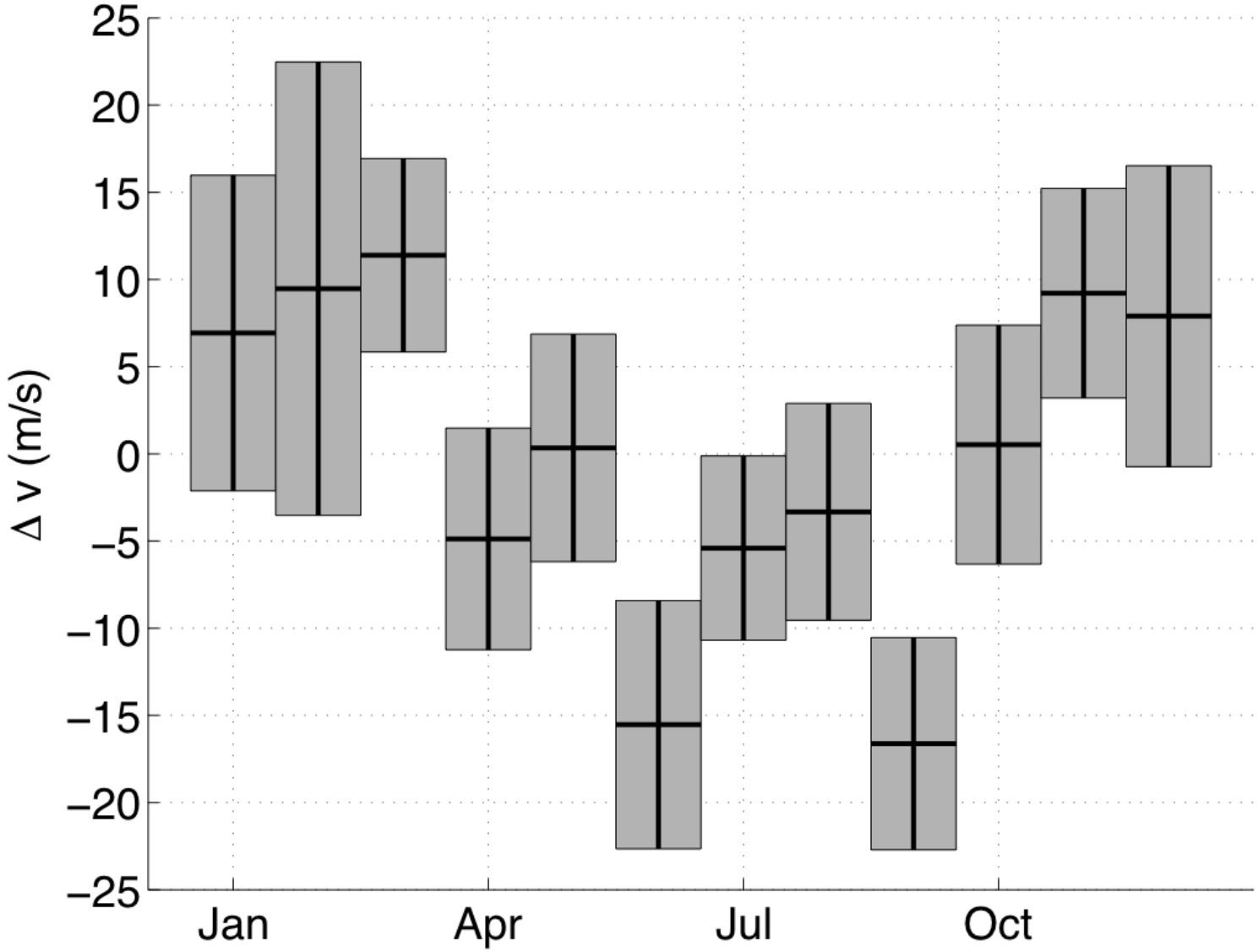


(Nakata and Snieder, JGR, 117, B01308, 2012)

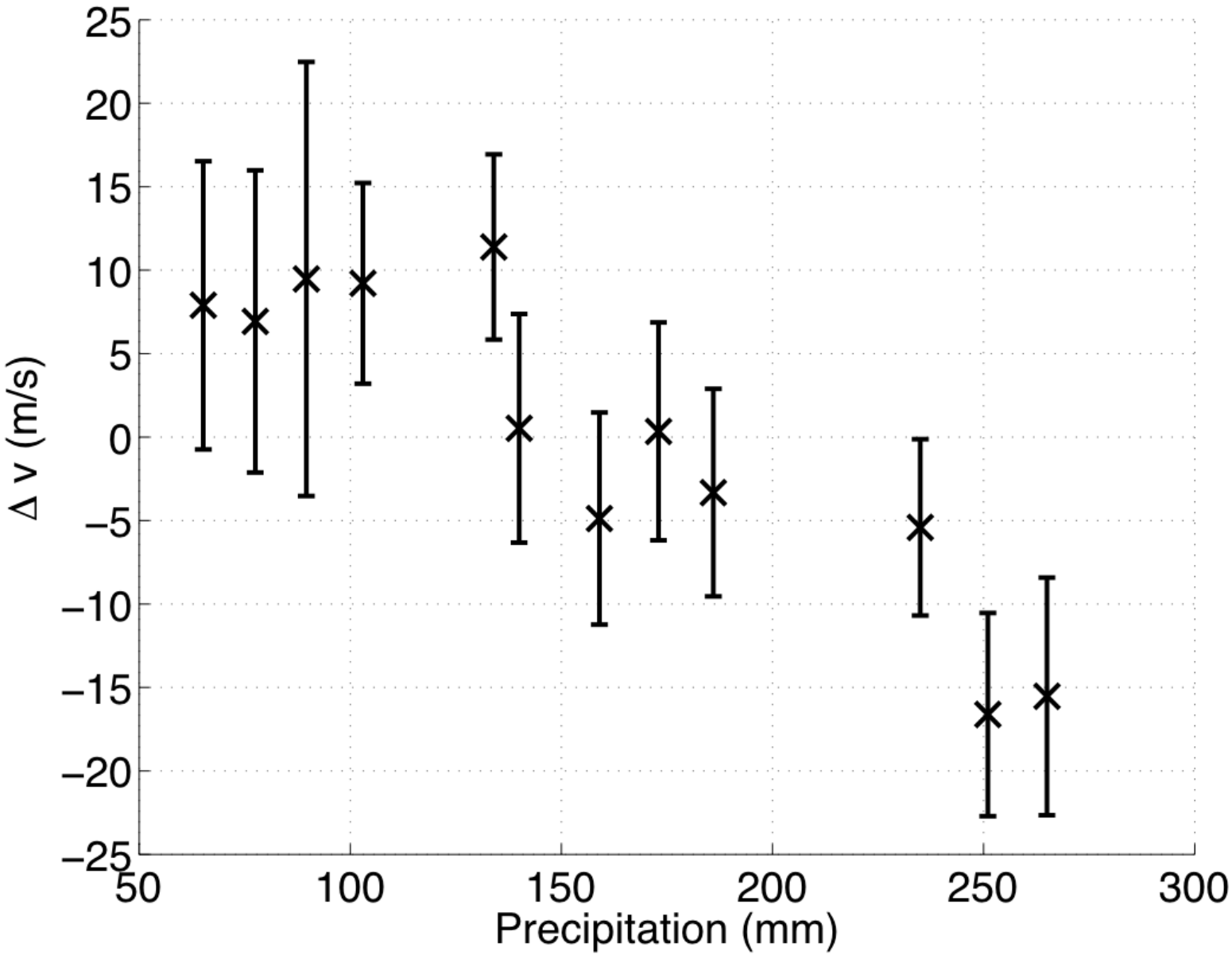
S-waves in Niigata and earthquakes



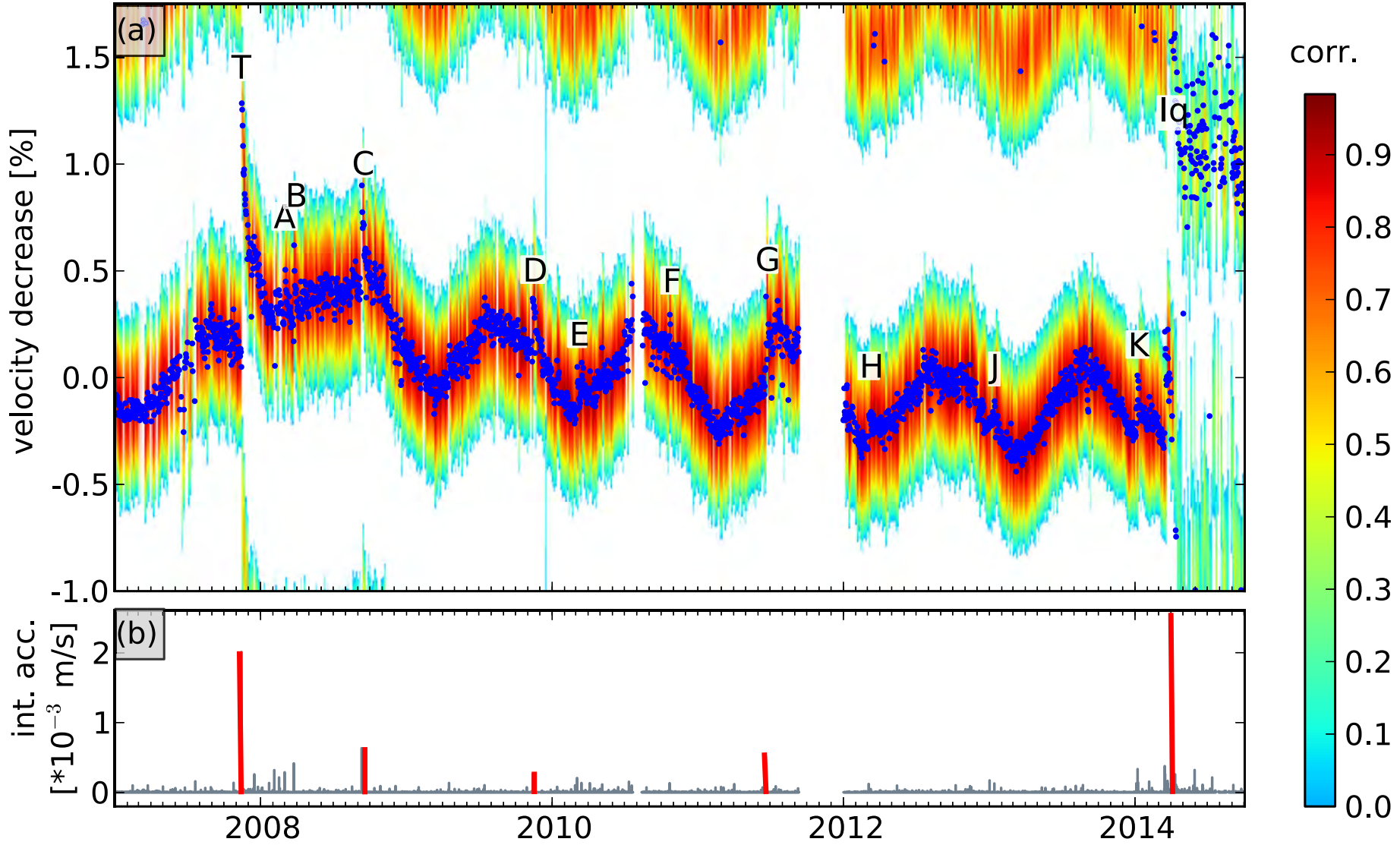
S-velocity changes with seasons



Rainfall/v_s for soft-rock sites

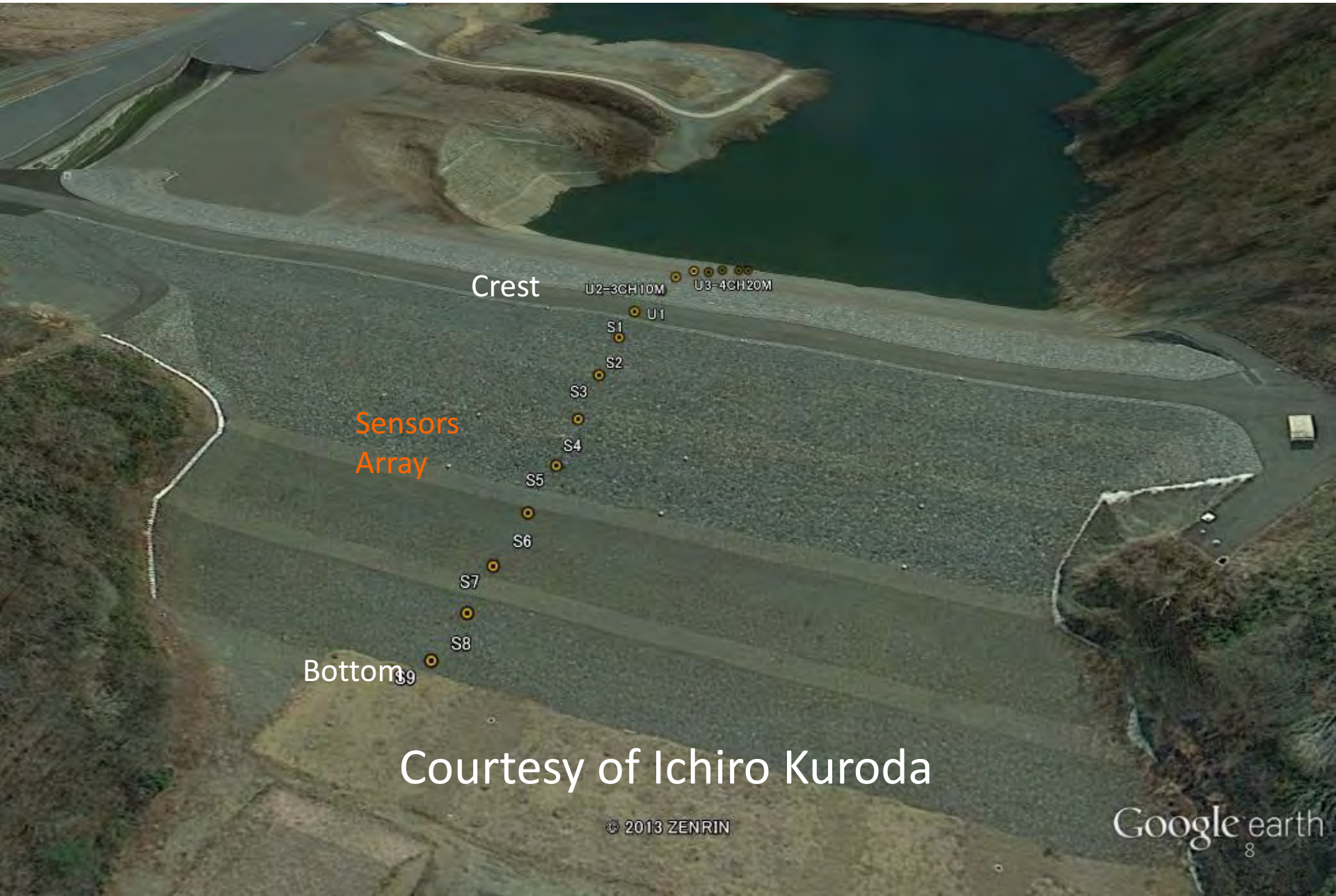


Velocity changes in Chili



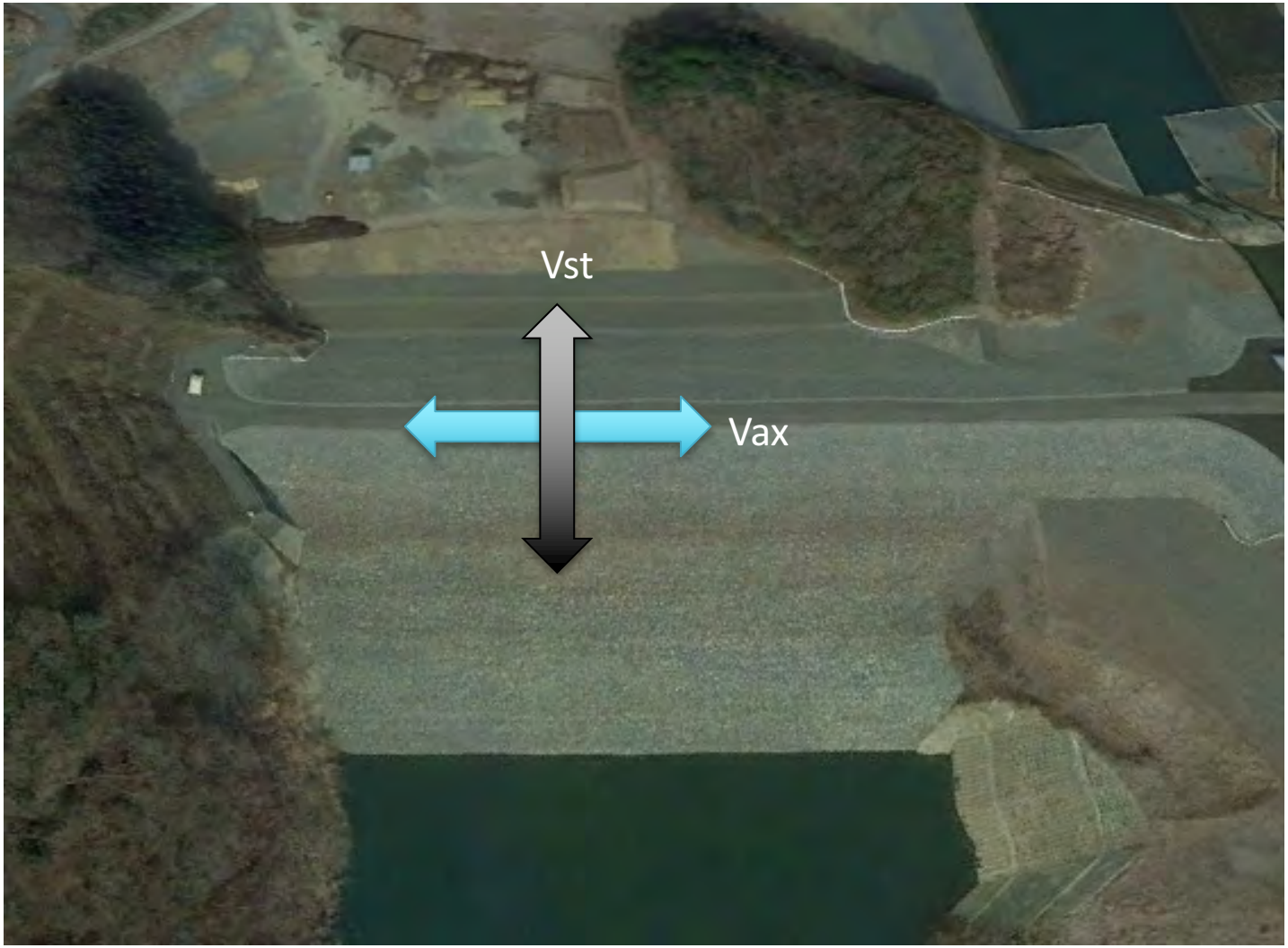
(Gassenmeier et al., Geophys. J. Int., 204, 1490-1502, 2016)

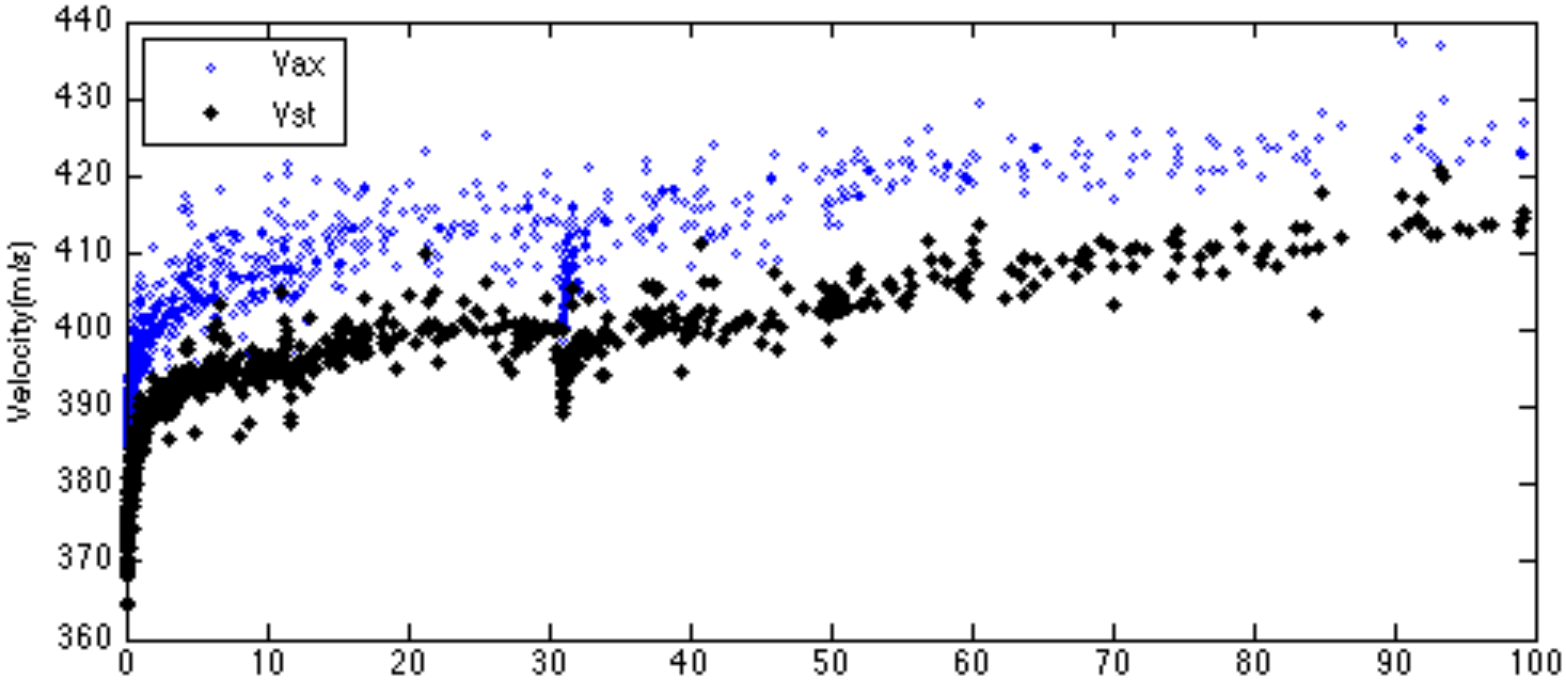
Seismic sensors array on a dam



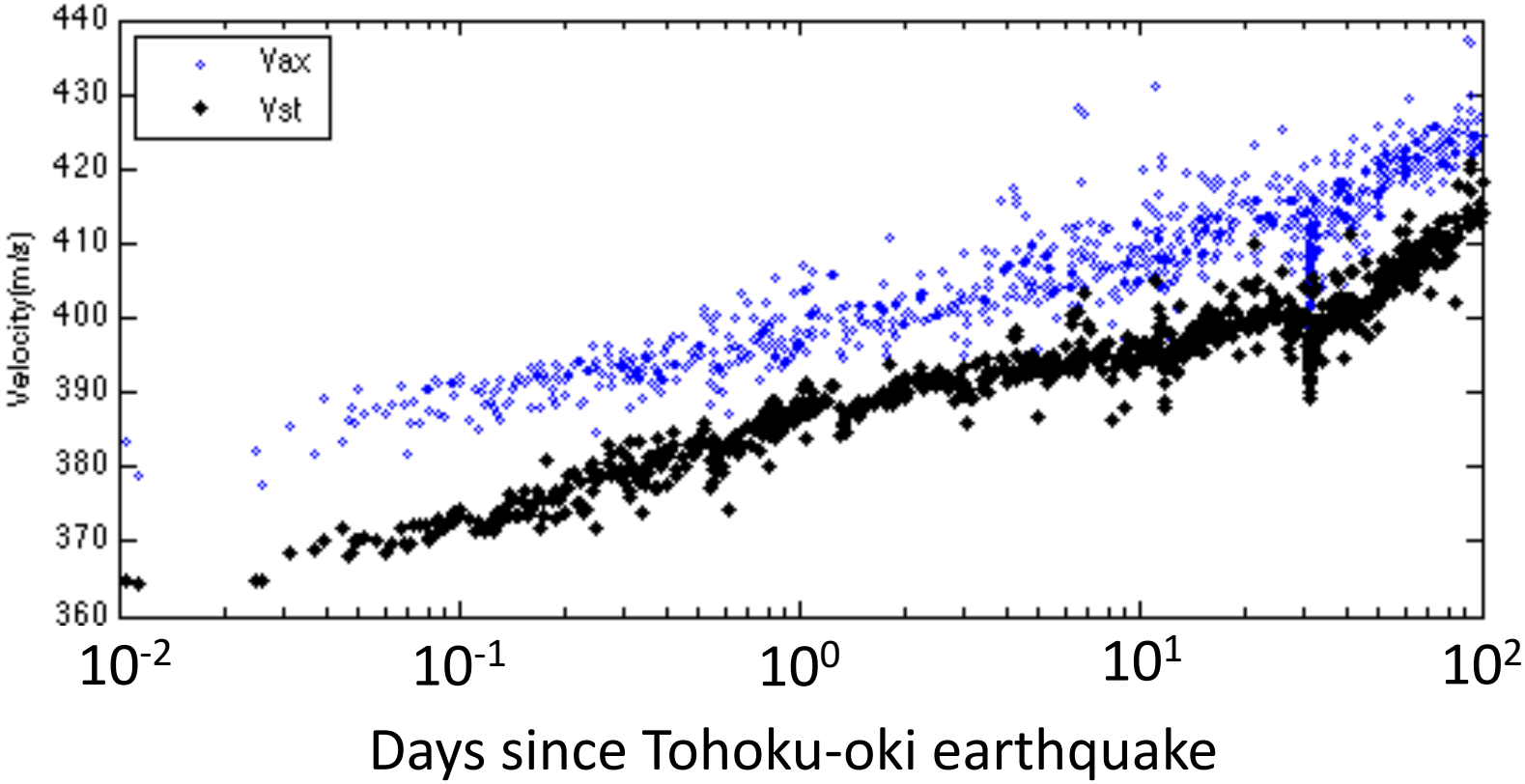
Courtesy of Ichiro Kuroda

Direction components in a dam

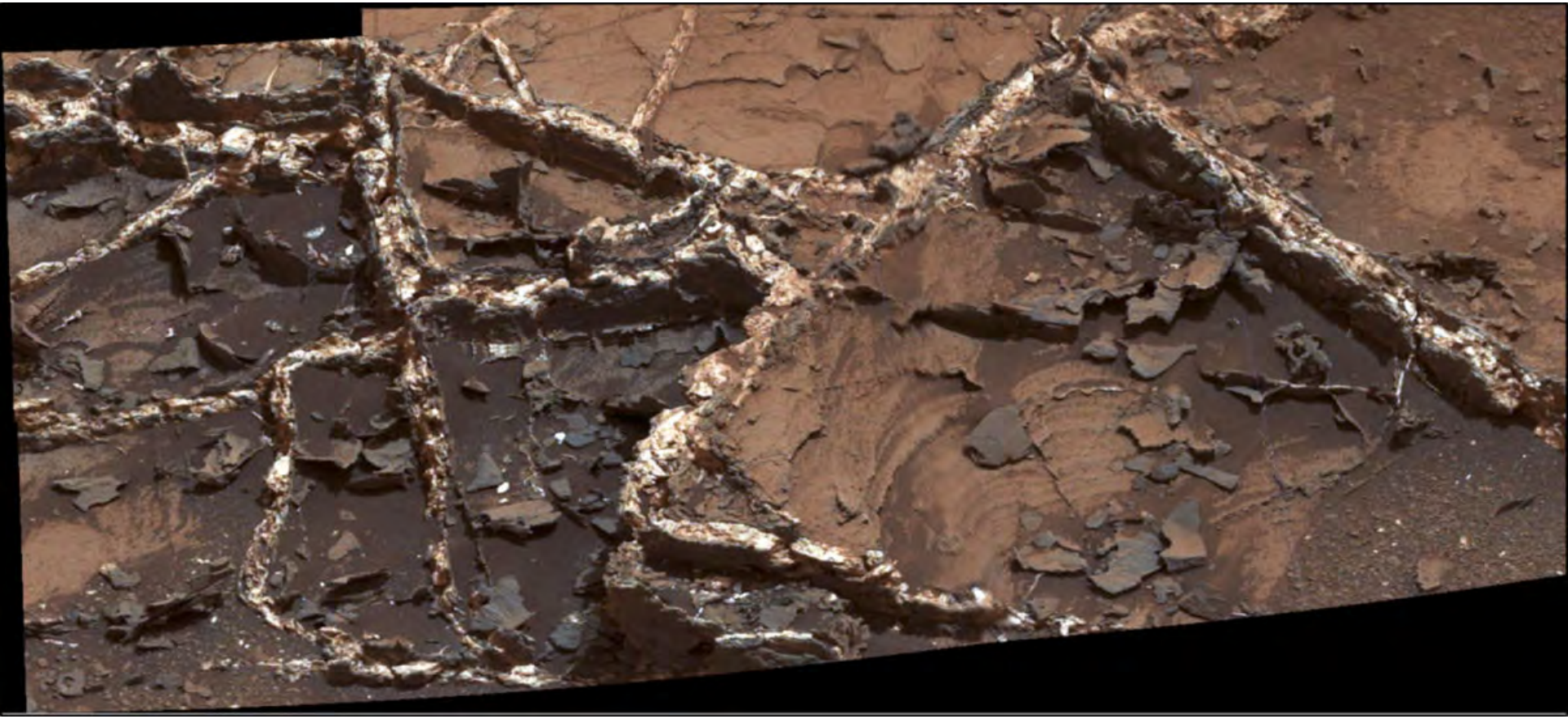




Days since Tohoku-oki earthquake

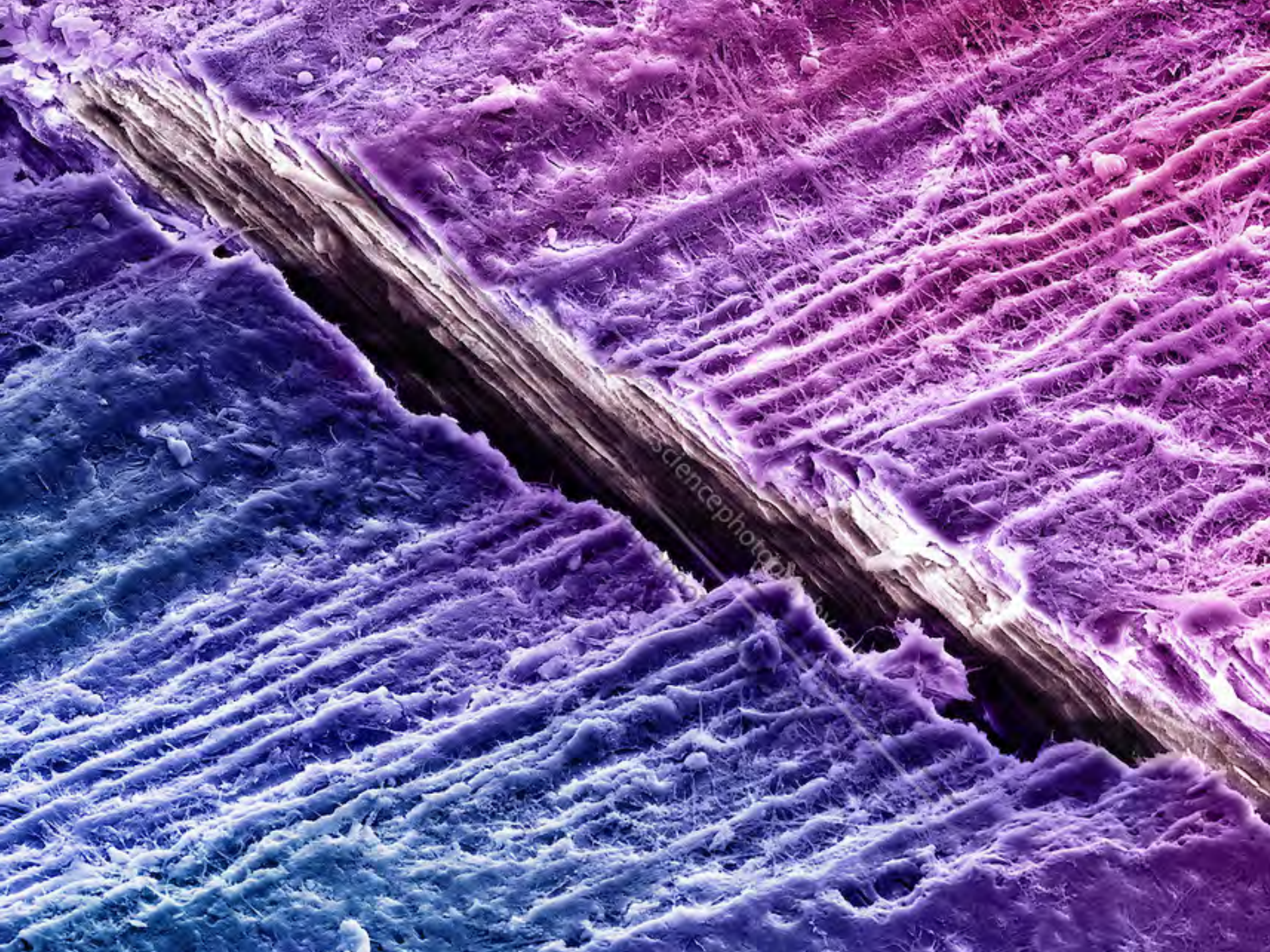

Vax
Vst
Velocity(m/s)
440
430
420
410
400
390
380
370
360
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
Days since Tohoku-oki earthquake

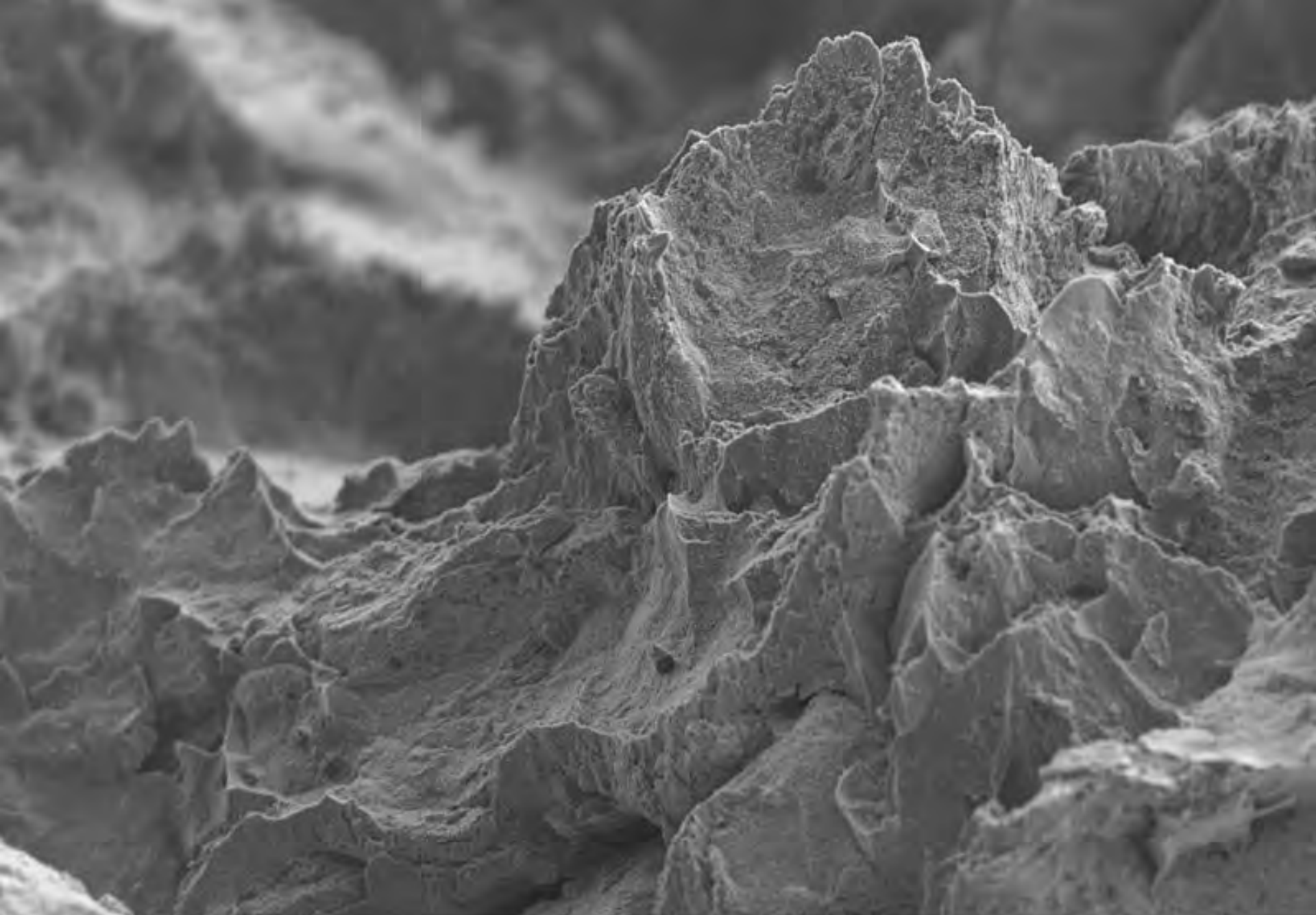
Mineralized fractures

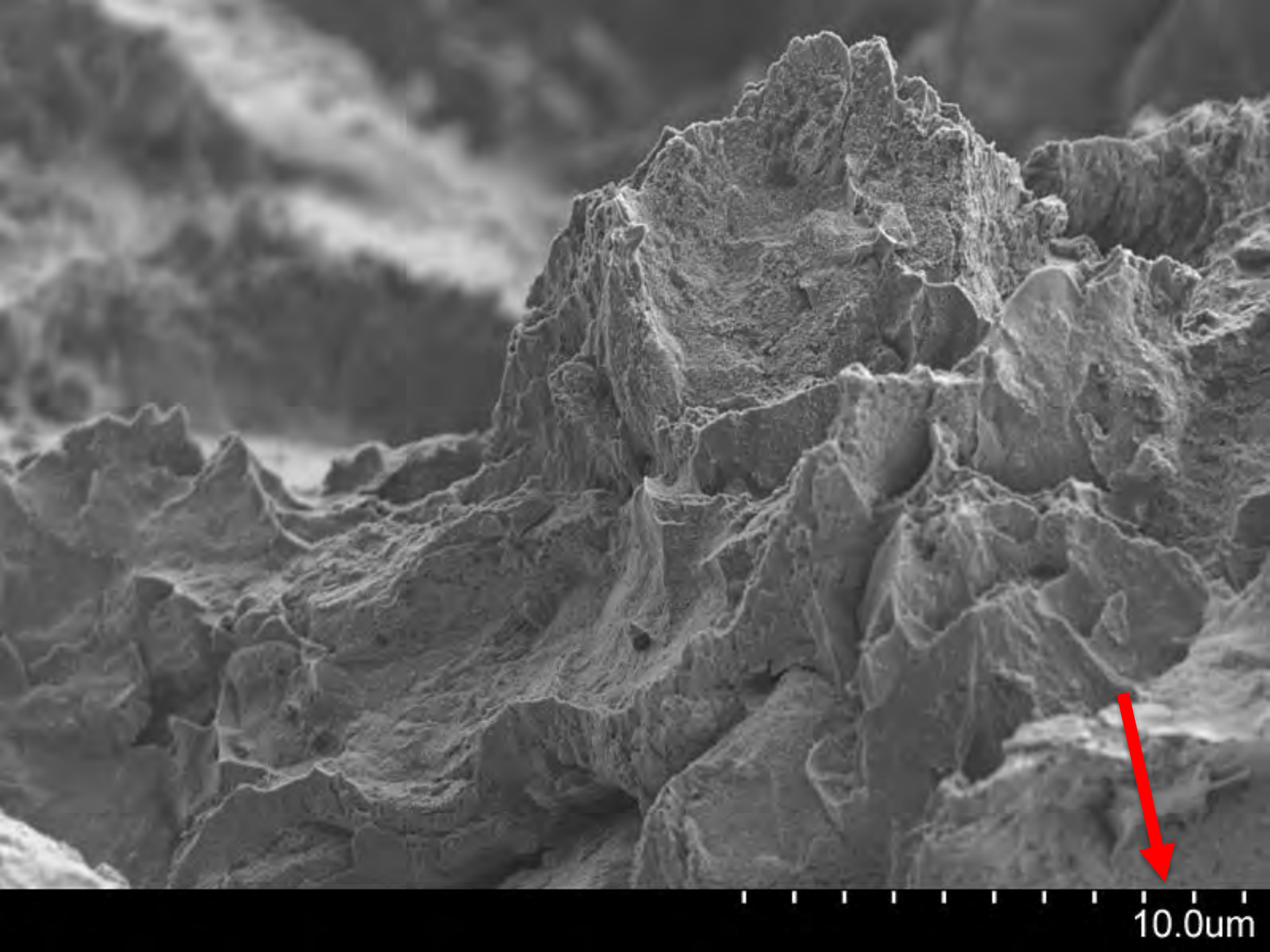


(Credit: NASA/JPL-Caltech/MSSS)

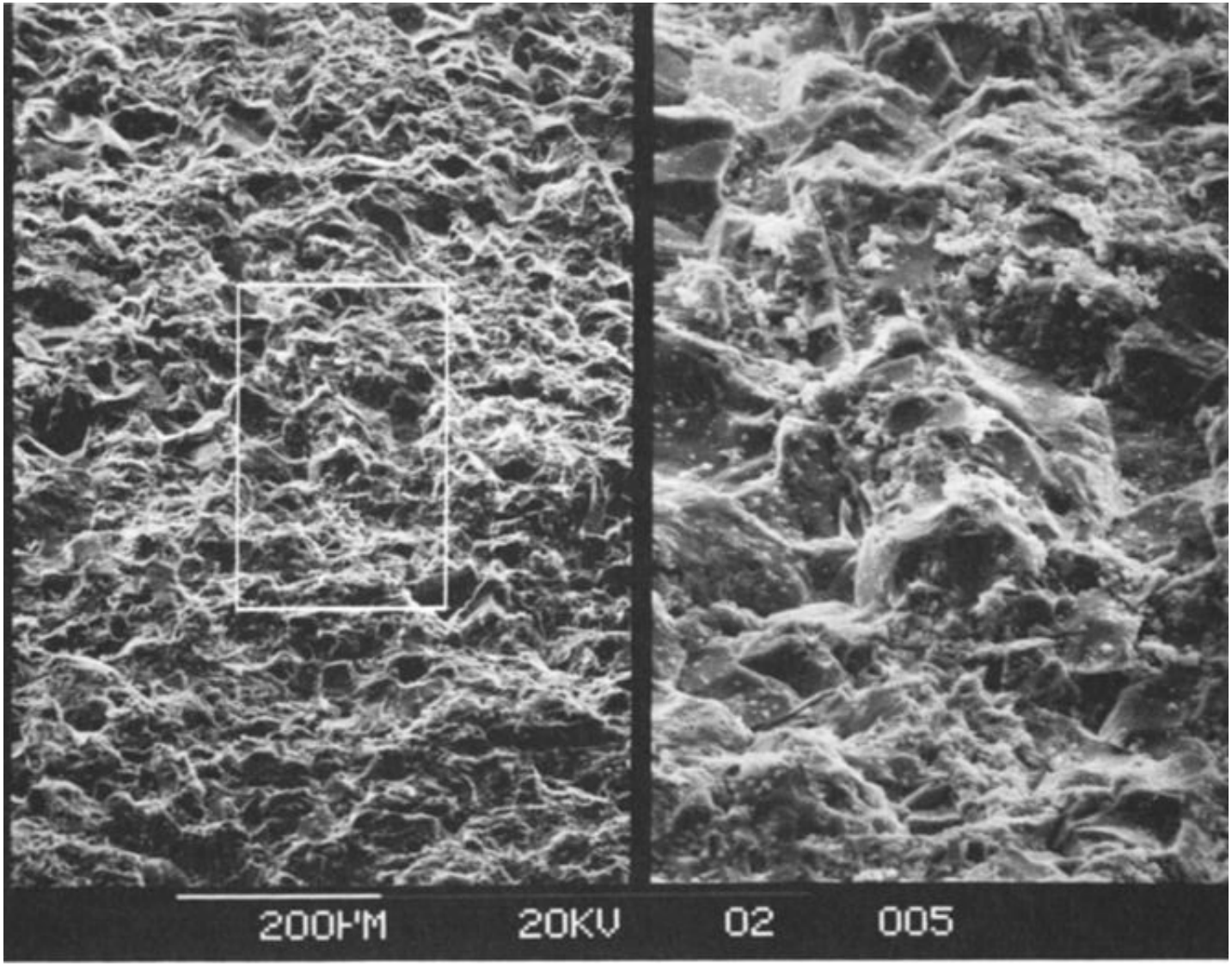
Intrusion by a dike





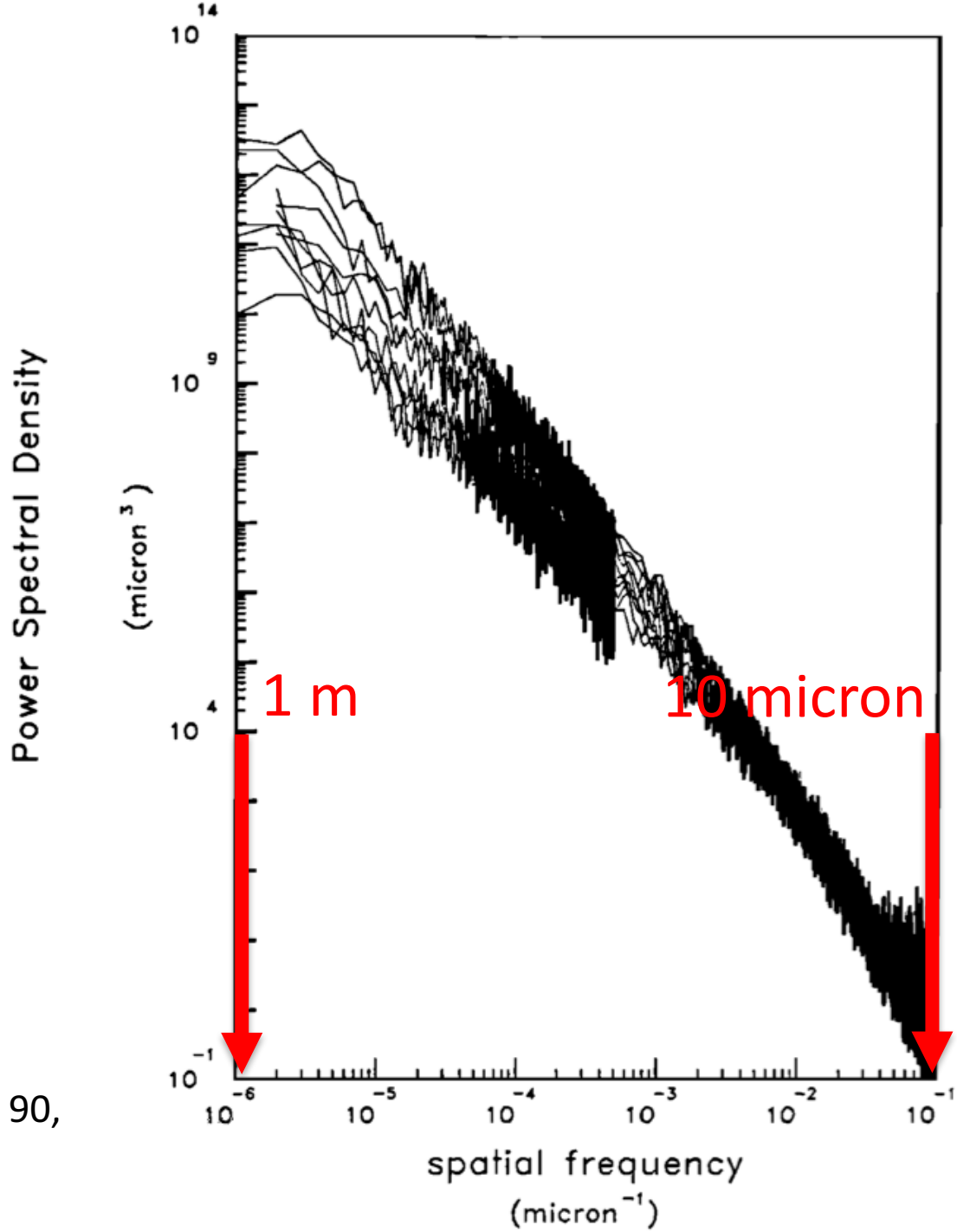

10.0um

Micro-structure of a rock fracture



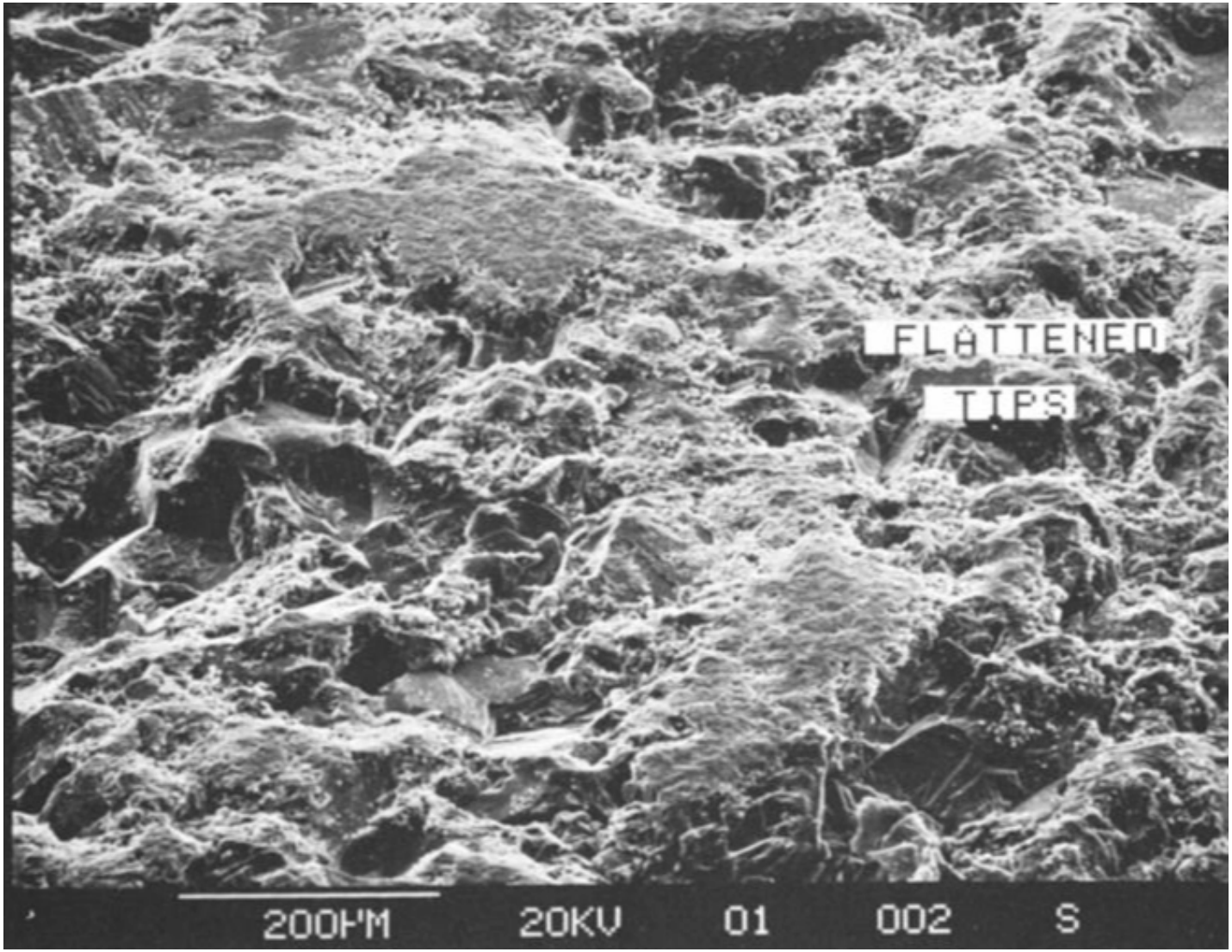
(Brown and Scholz, J. Geophys. Res., 91, 4939-4948, 1986)

Power spectrum of rock surface



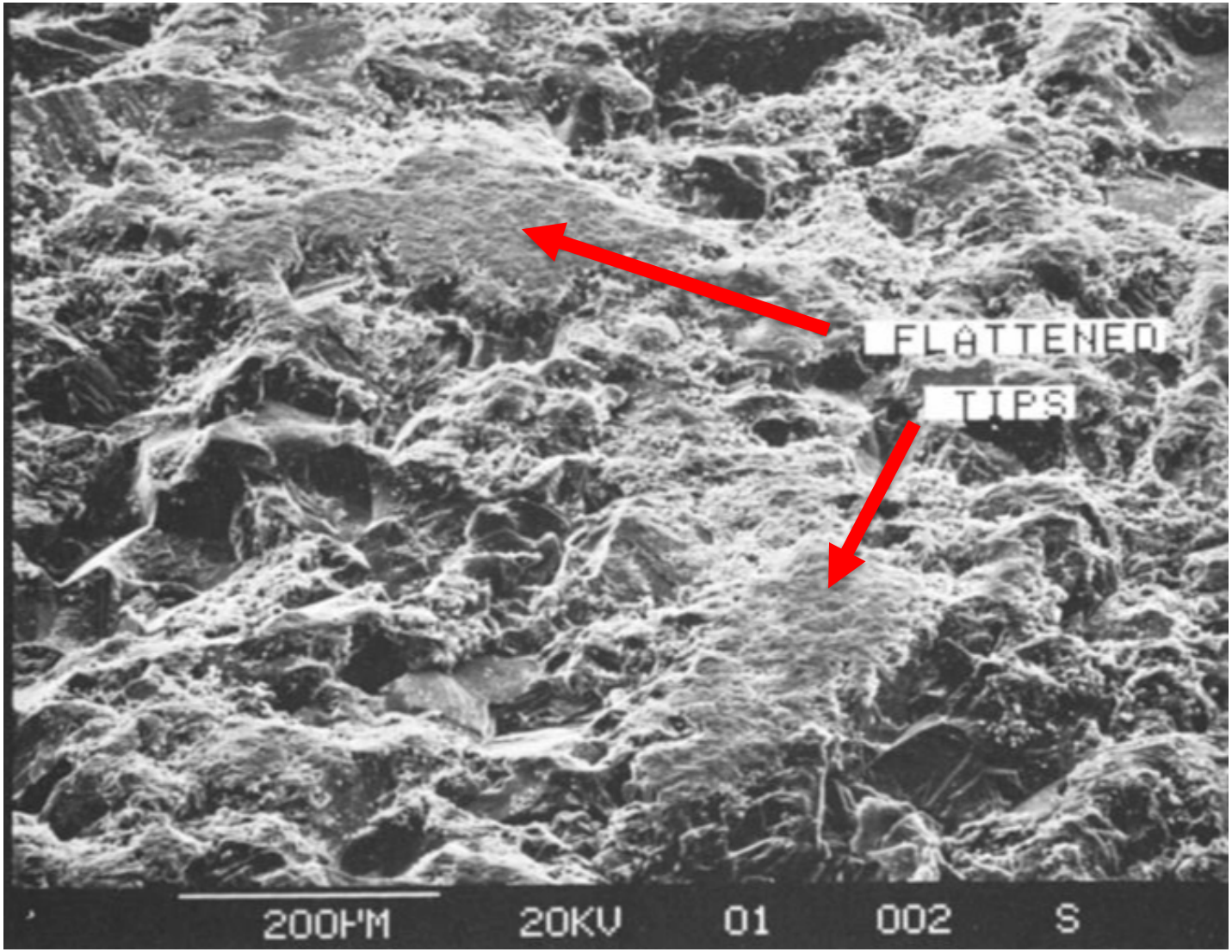
(Brown and Scholz, J. Geophys. Res., 90, 12575-12582, 1985)

Healing of a fracture



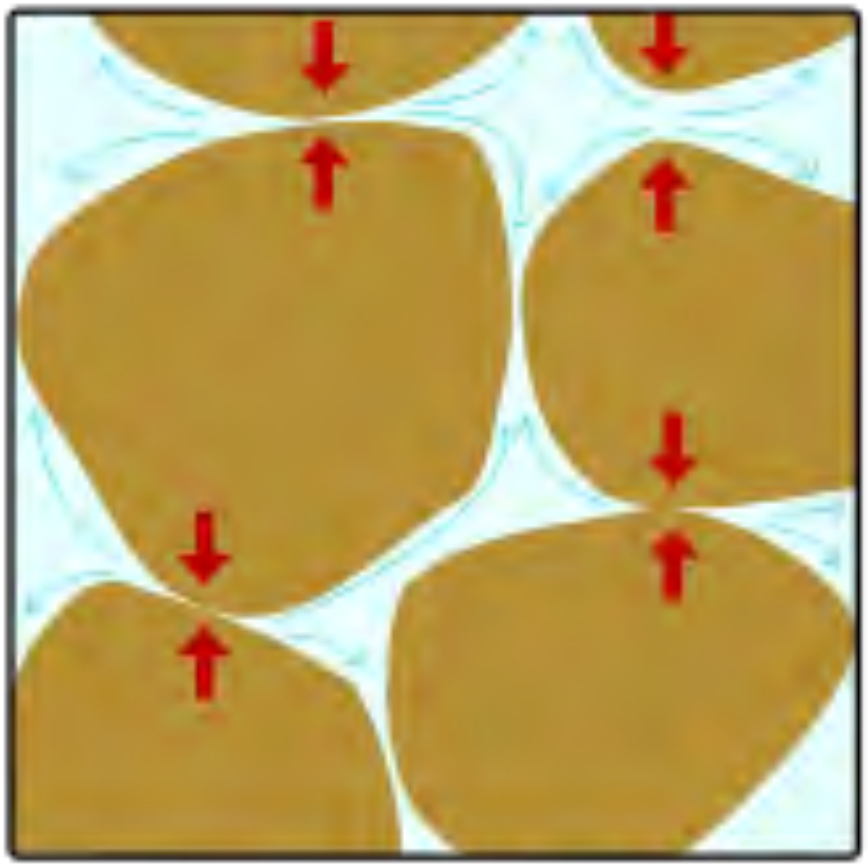
(Brown and Scholz, J. Geophys. Res., 91, 4939-4948, 1986)

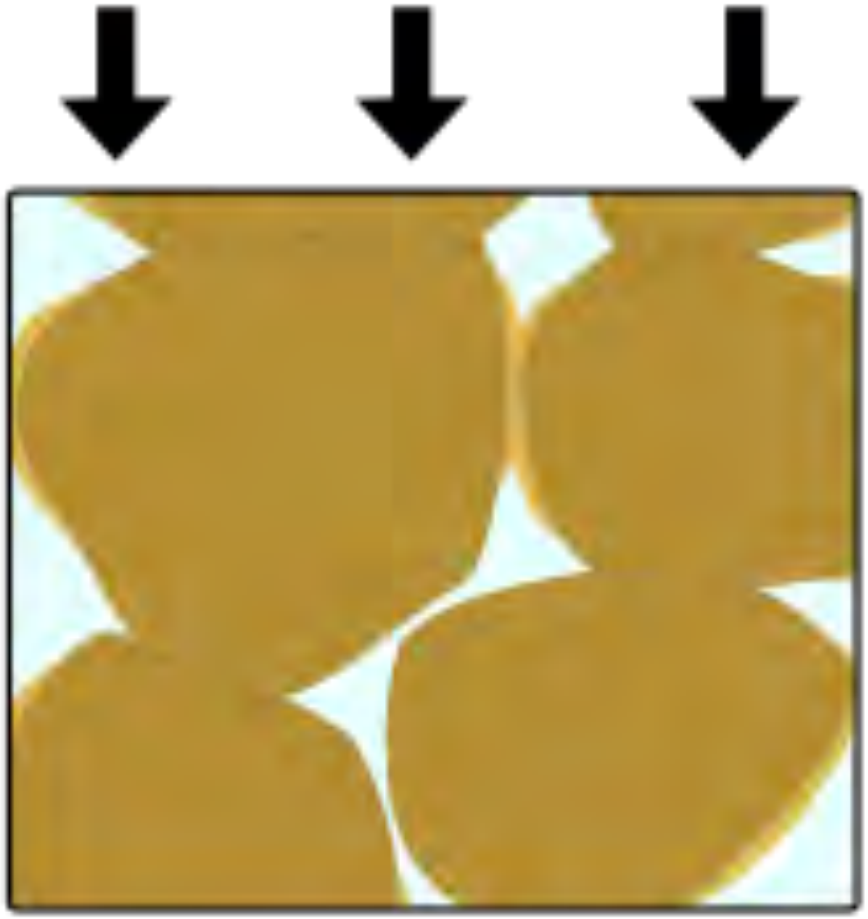
Healing of a fracture



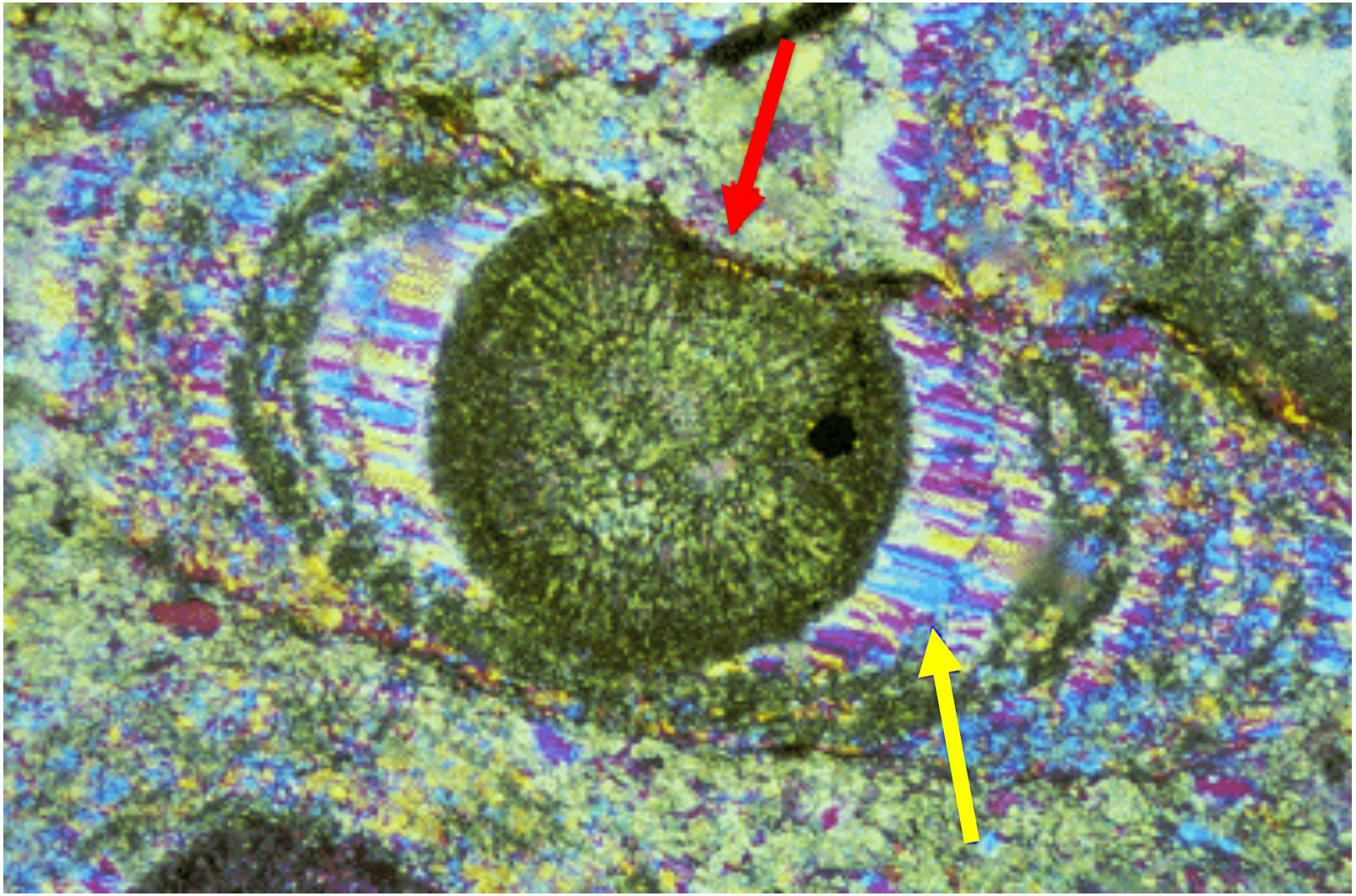
(Brown and Scholz, J. Geophys. Res., 91, 4939-4948, 1986)

Pressure solution

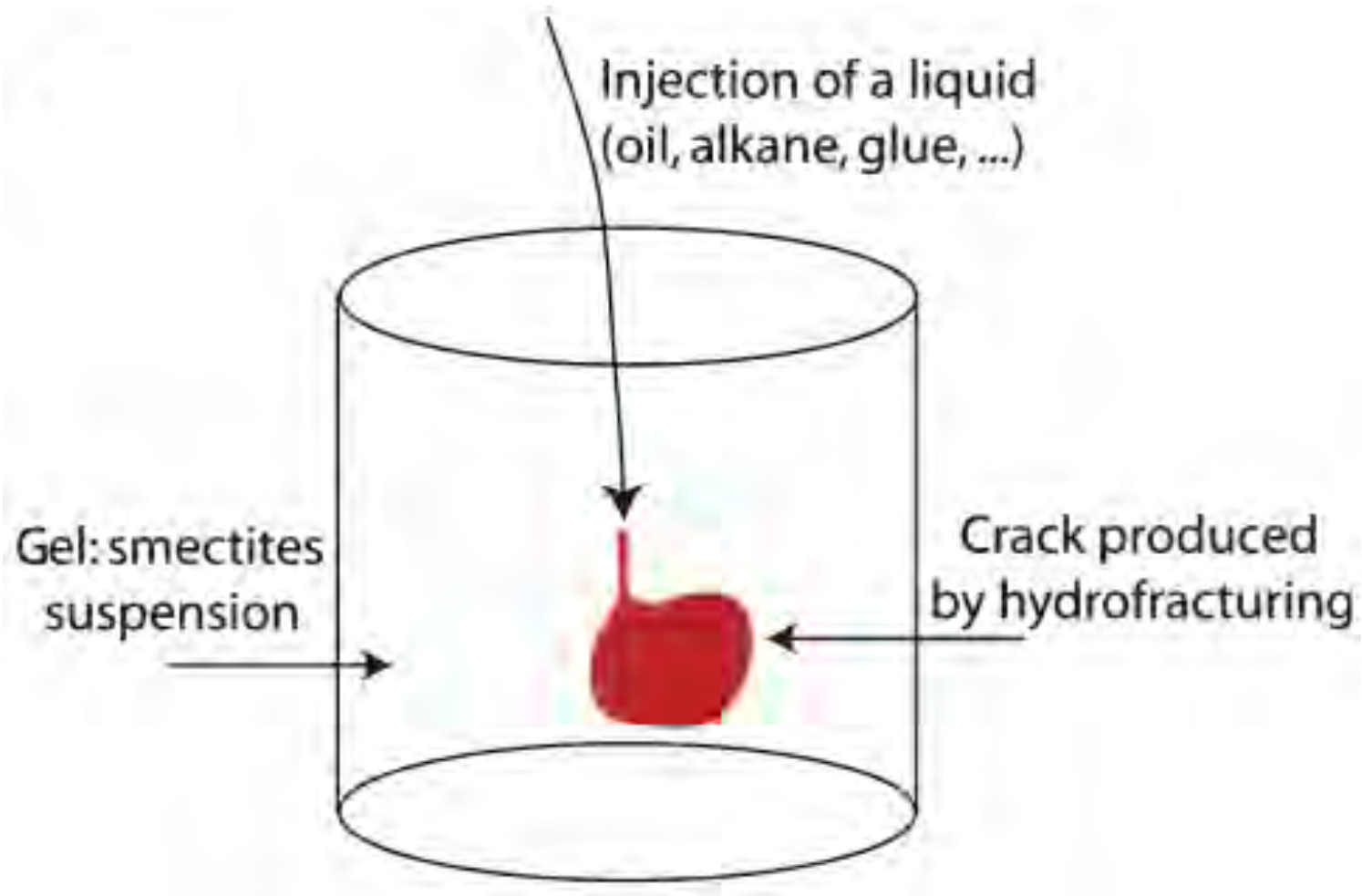




Pressure solution of oolitic limestone

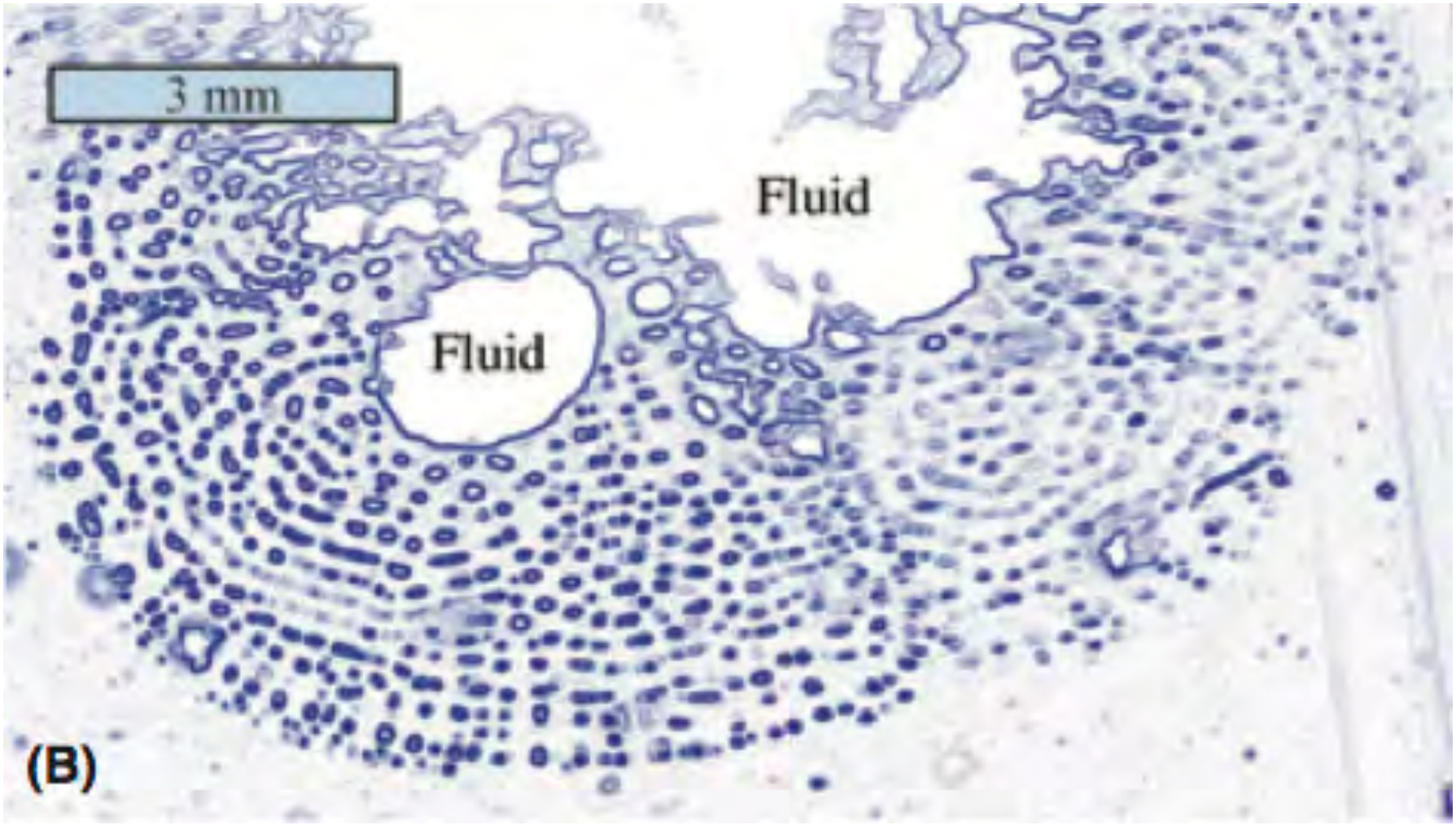


Analogue model for cracks



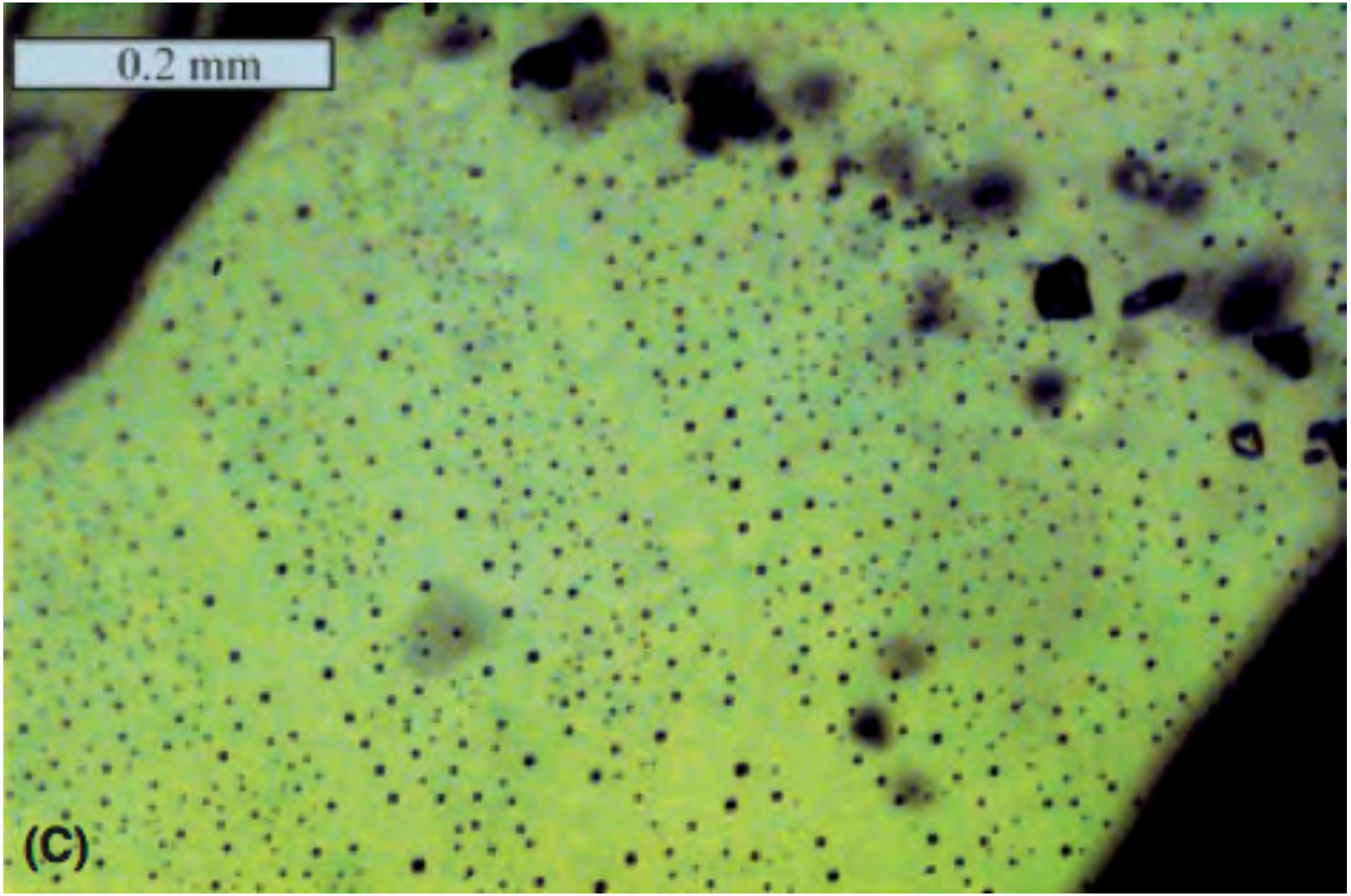
(Renard et al., Geofluids, 9, 365-372, 2009)

A healing crack in a gel



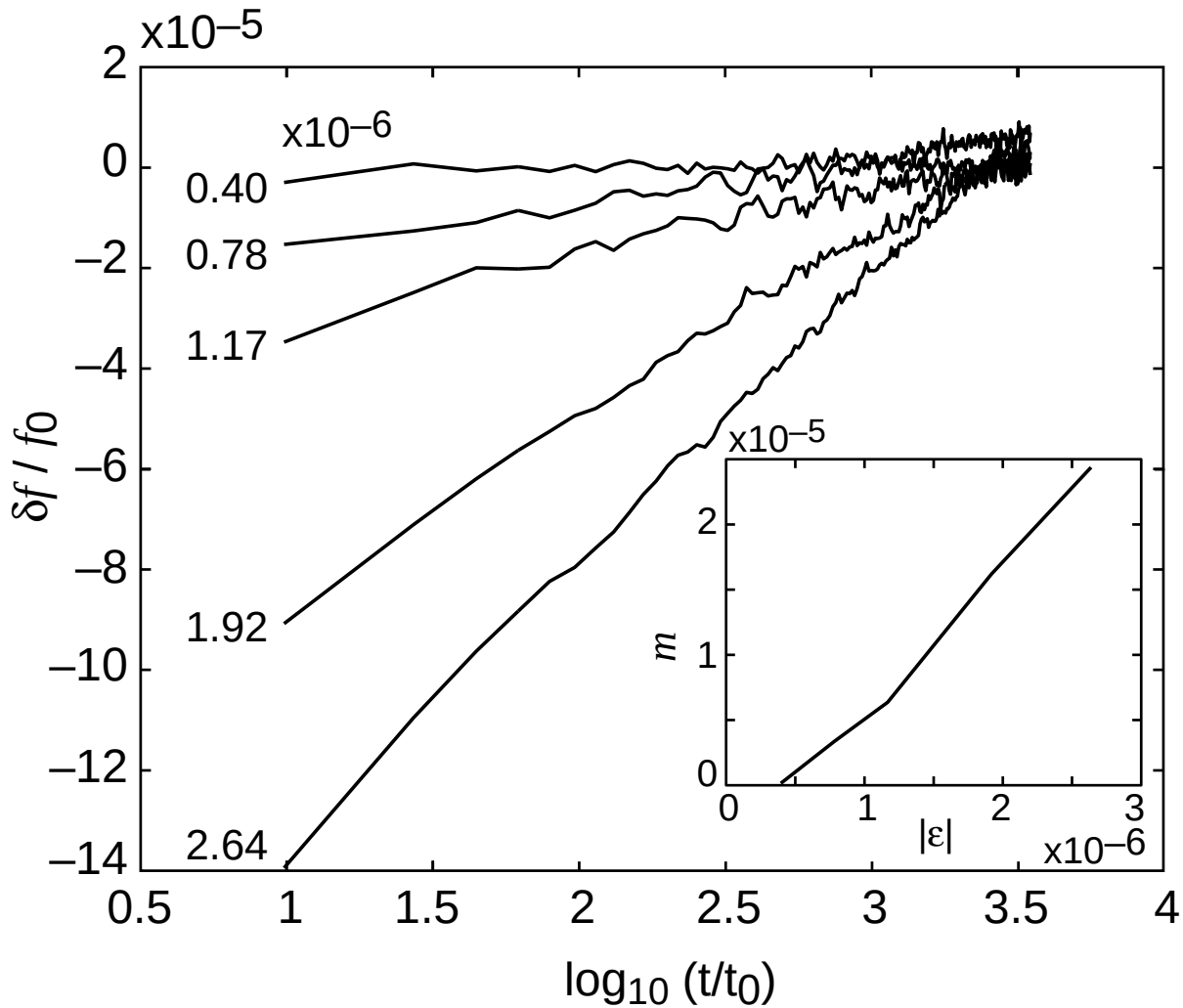
(Renard et al., Geofluids, 9, 365-372, 2009)

A healing crack in a quartz



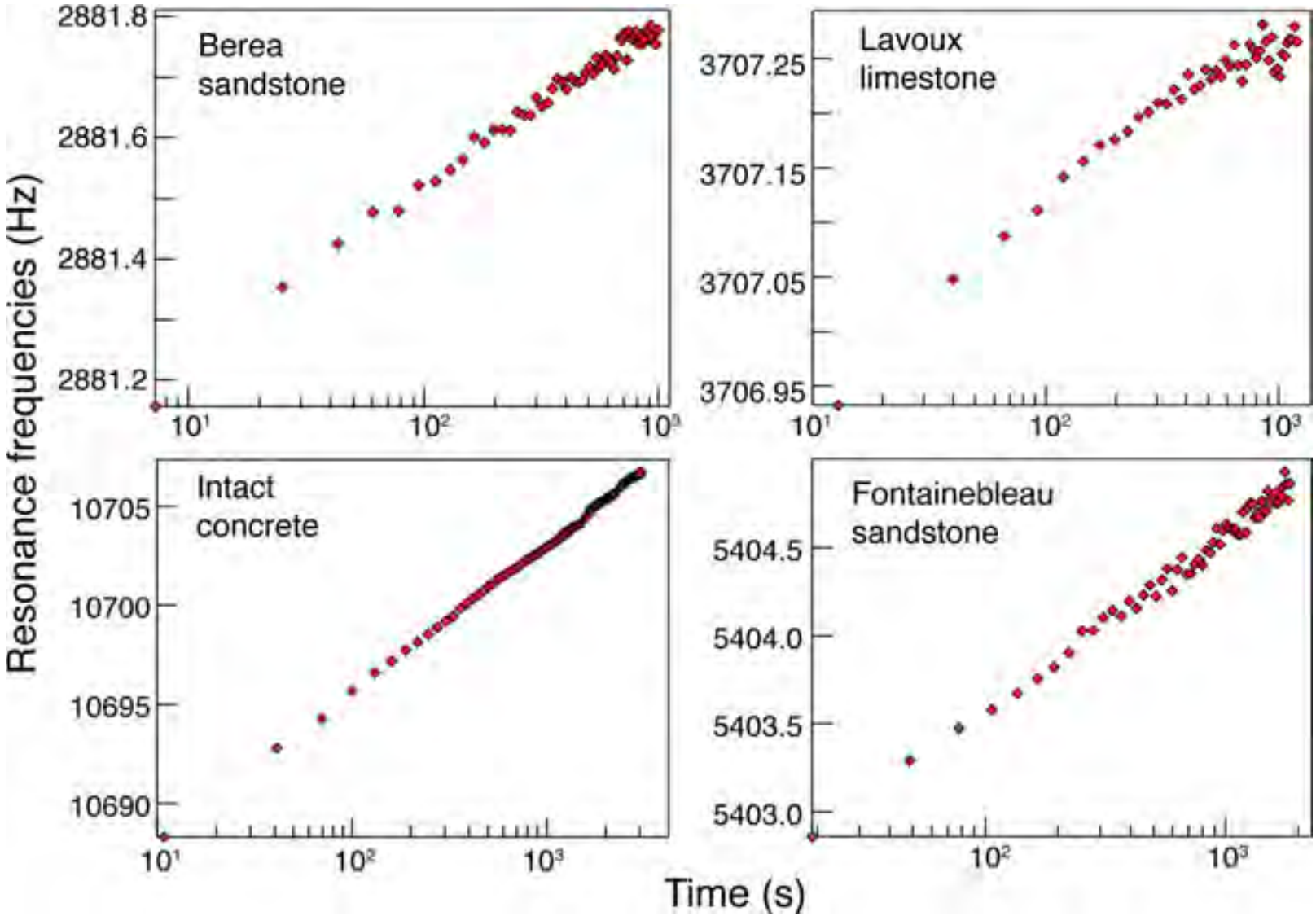
(Renard et al., Geofluids, 9, 365-372, 2009)

Log(time) behavior in resonance



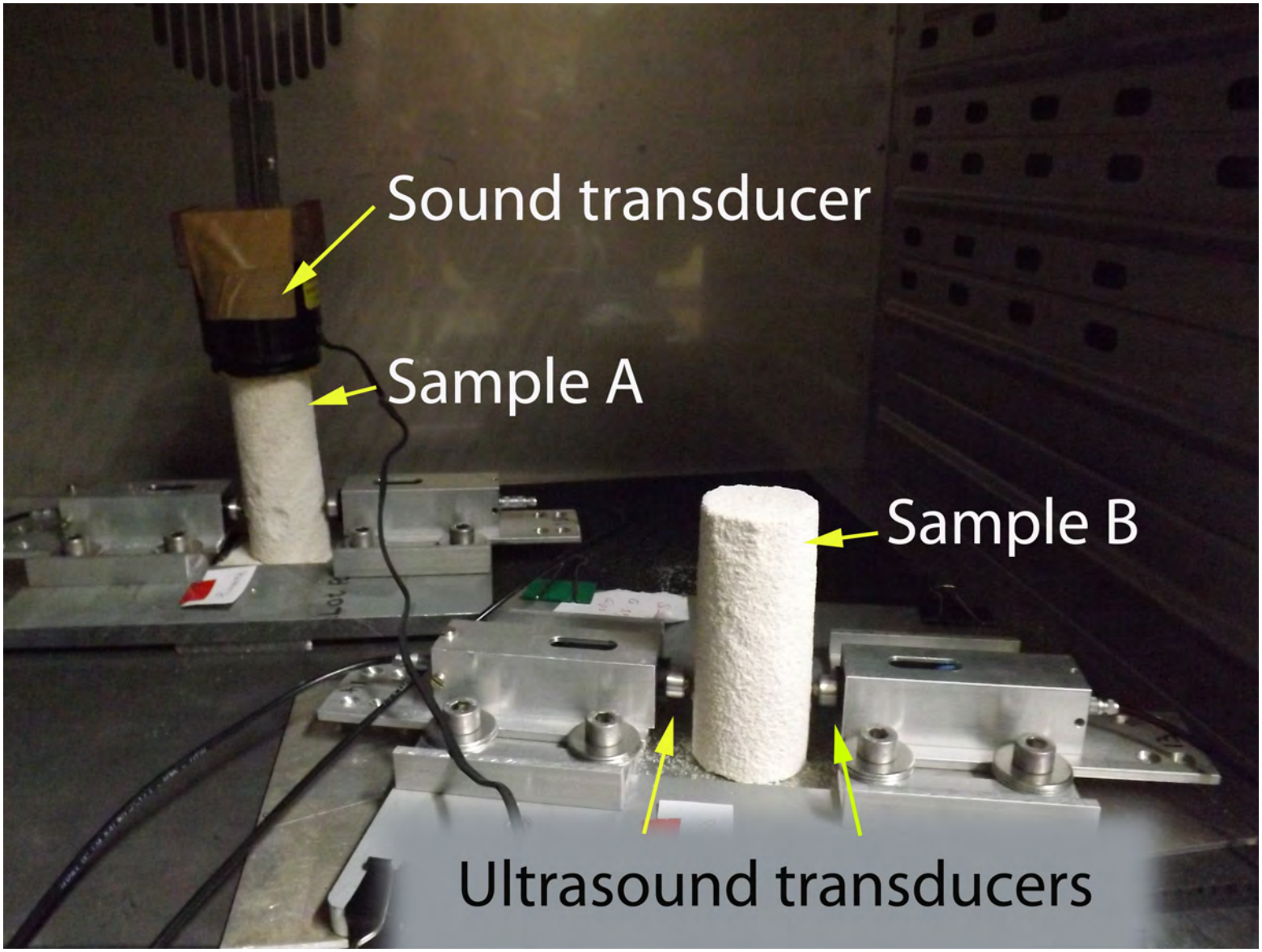
(Ten Cate et al., Phys. Rev. Lett., 85, 1020-1023, 2000)

Log(time) behavior in resonance



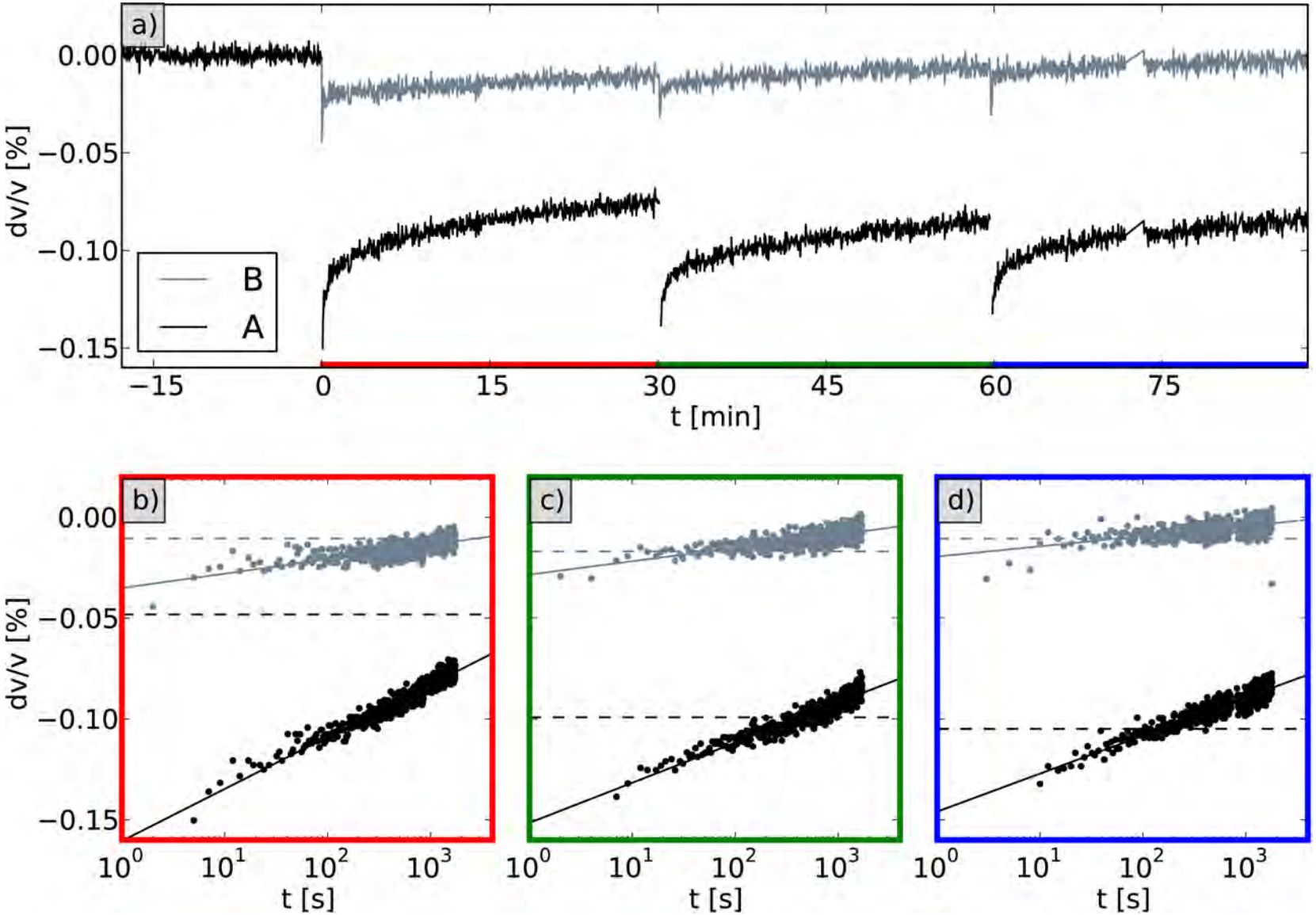
(Ten Cate et al., Pure Appl. Geophys, 168, 2211-2219, 2011)

Perturbing samples



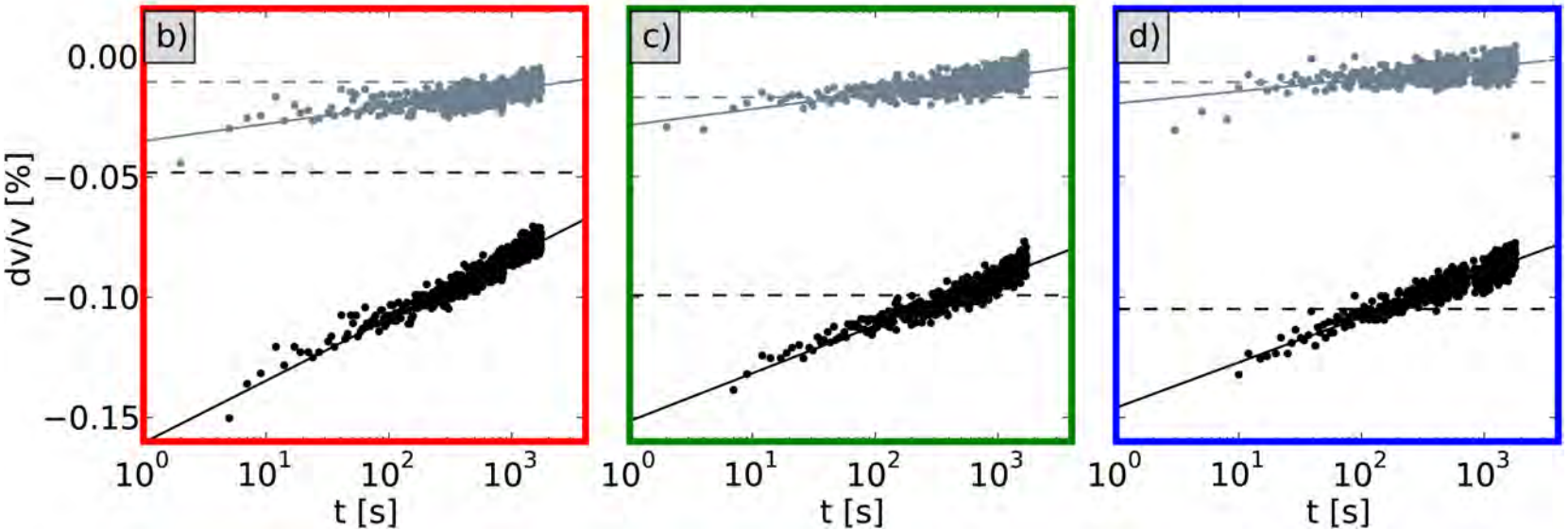
(Gassenmeier, 2015, PhD thesis, Universität Leipzig)

Healing of rock samples



(Gassenmeier, 2015, PhD thesis, Universität Leipzig)

So rock healing clearly goes as log-time



Logarithm means there is no time-scale

$$\ln(t/\tau) = \ln(t) - \ln(\tau)$$

any time-scale corresponds to an offset

Relaxation process for one relaxation time

$$R(t) = e^{-t/\tau}$$

(Snieder, R., C. Sens-Schoenfelder, and R. Wu, Geophys. J. Int., 208, 1-9, 2017)

Relaxation process for one relaxation time

$$R(t) = e^{-t/\tau}$$

Superposition of relaxation processes

$$\boxed{R(t) = \int_{\tau_{min}}^{\tau_{max}} \frac{1}{\tau} e^{-t/\tau} d\tau}$$

$\frac{1}{\tau}$ follows from Arrhenius' law

How to get log-time behavior?

$$R(t) = \int_{\tau_{min}}^{\tau_{max}} \frac{1}{\tau} e^{-t/\tau} d\tau$$

How to get log-time behavior?

$$R(t) = \int_{\tau_{min}}^{\tau_{max}} \frac{1}{\tau} e^{-t/\tau} d\tau = \int_{t/\tau_{max}}^{t/\tau_{min}} \frac{1}{u} e^{-u} du$$

$$u = t/\tau$$

How to get log-time behavior?

$$R(t) = \int_{\tau_{min}}^{\tau_{max}} \frac{1}{\tau} e^{-t/\tau} d\tau = \int_{t/\tau_{max}}^{t/\tau_{min}} \frac{1}{u} e^{-u} du$$

$$u = t/\tau$$

$$\frac{dR(t)}{dt} = \frac{1}{t}\left(e^{-t/\tau_{min}} - e^{-t/\tau_{max}}\right)$$

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when $\tau_{min} \ll t \ll \tau_{max}$

$$\frac{dR(t)}{dt} = \frac{1}{t}(0 - 1) = -\frac{1}{t}$$

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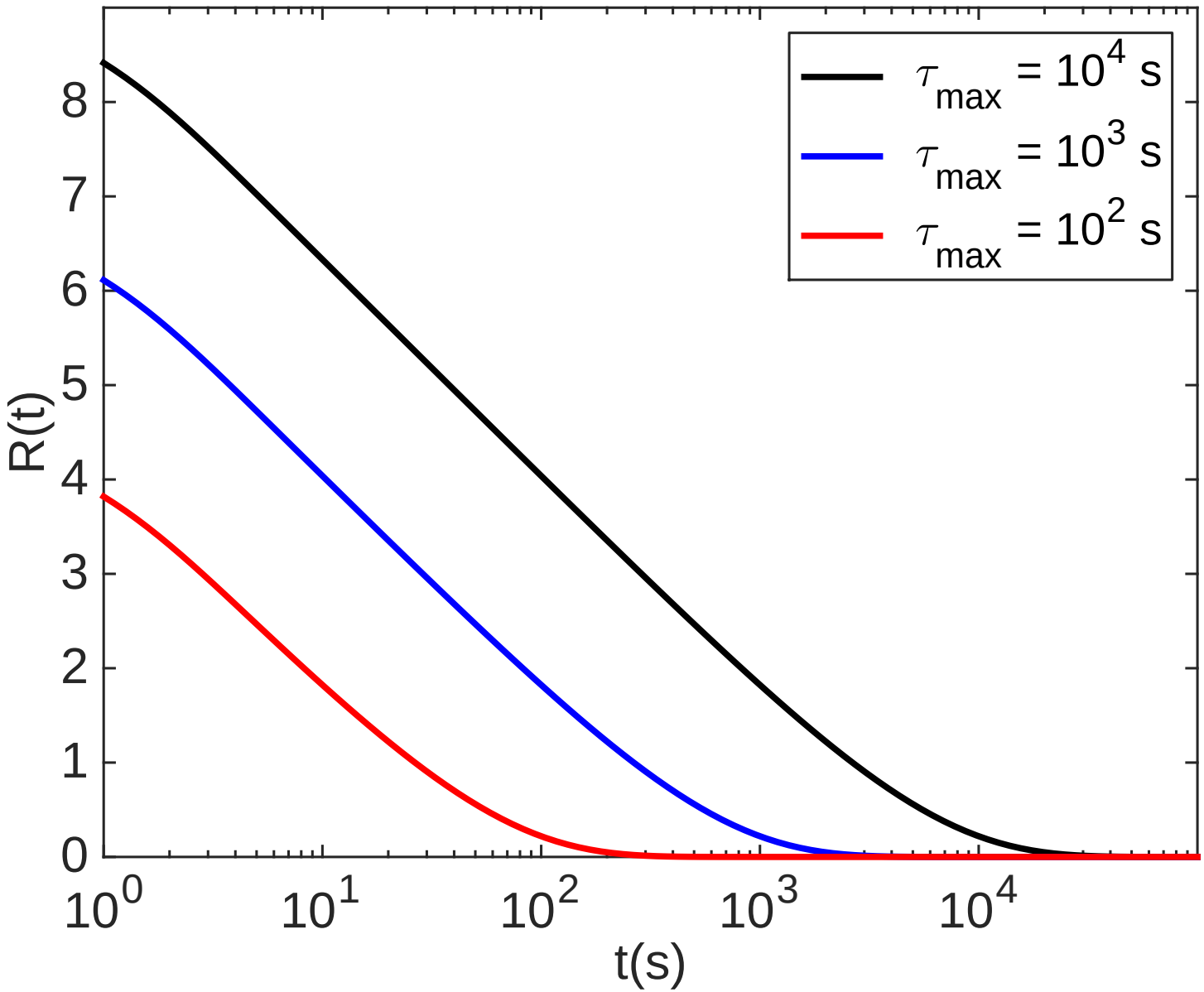
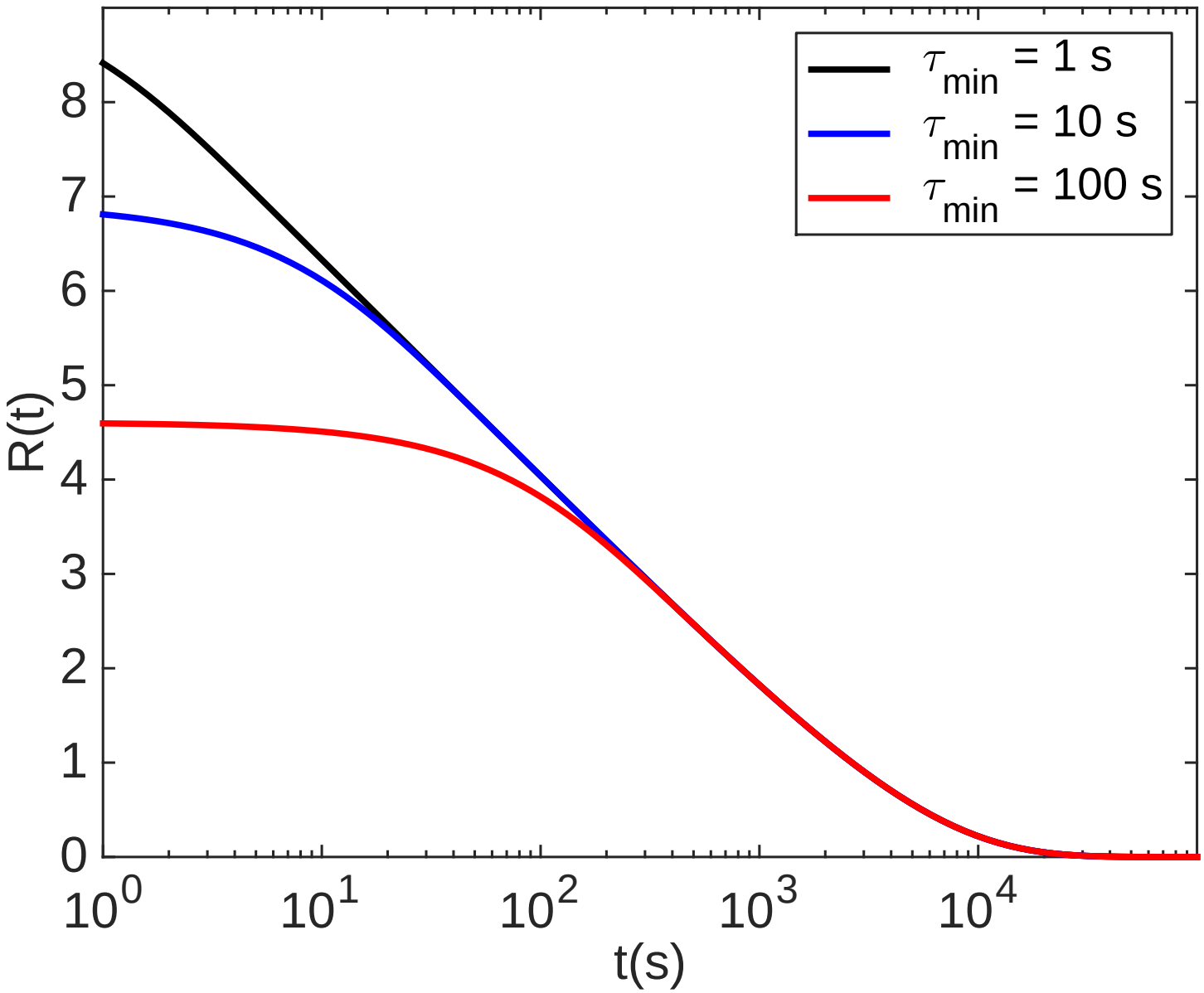
$$\frac{dR(t)}{dt} = \frac{1}{t}(0 - 1) = -\frac{1}{t}$$

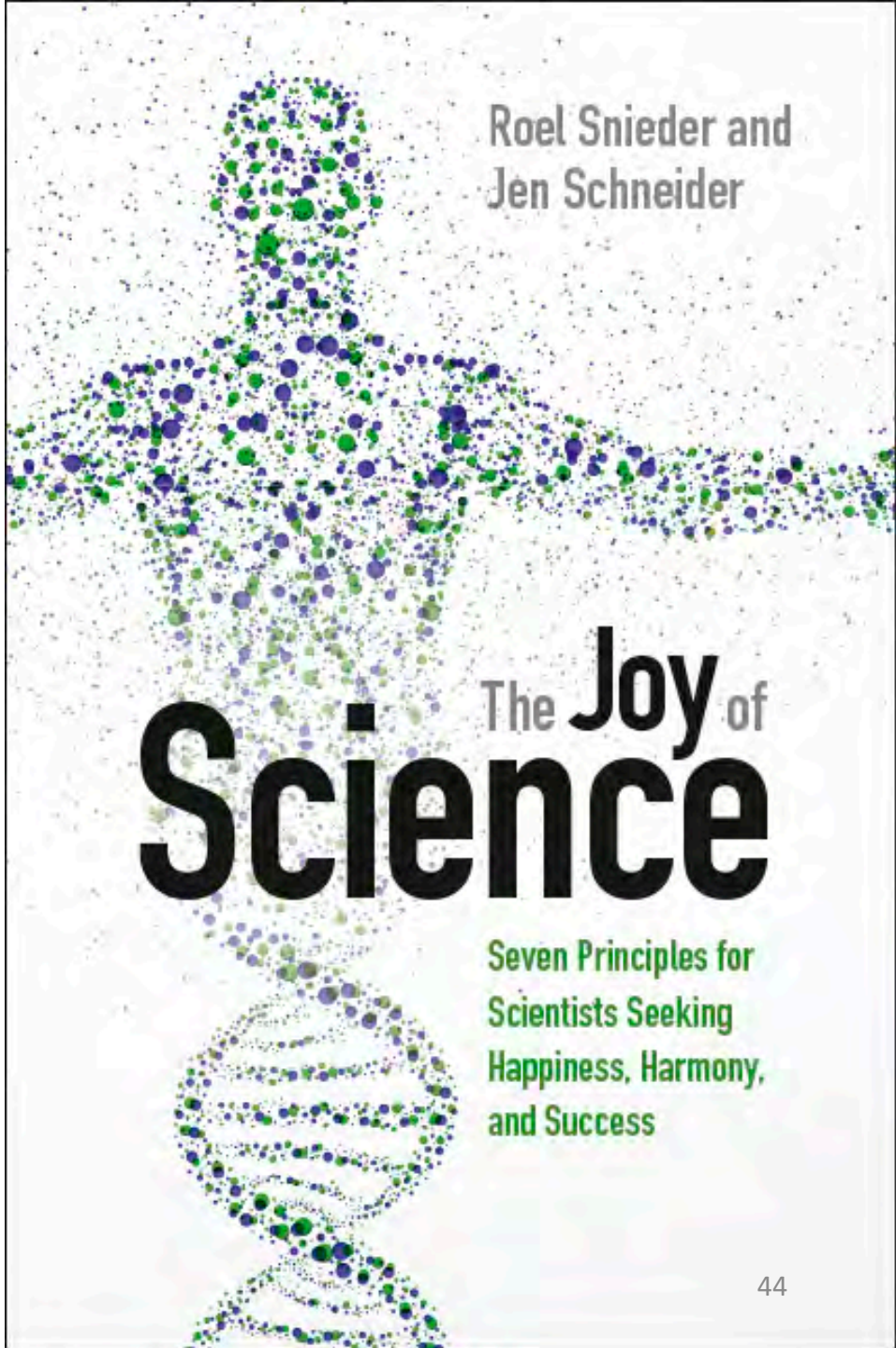
$$R(t) = B - \ln(t)$$

Relaxation function



Relaxation function




Roel Snieder and
Jen Schneider
The Joy of
Science
Seven Principles for
Scientists Seeking
Happiness, Harmony,
and Success

Once a semester, I will engage in a professional or personal activity that frightens me a little but which makes me feel alive.