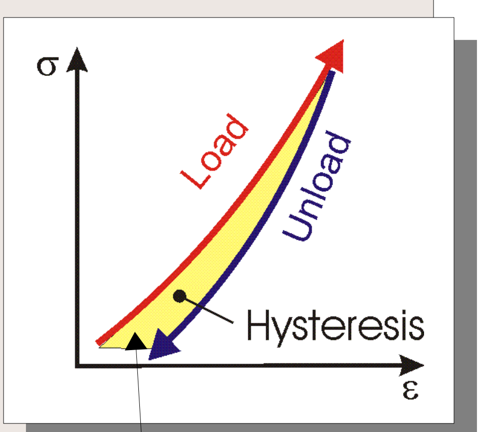
Seismic attenuation

- During propagation, seismic energy is dissipated through:
  - *Absorption* (anelastic attenuation);
  - *Scattering* (elastic attenuation).
- Attenuation is frequency-dependent and linked to *dispersion* (frequency-dependence of velocity).

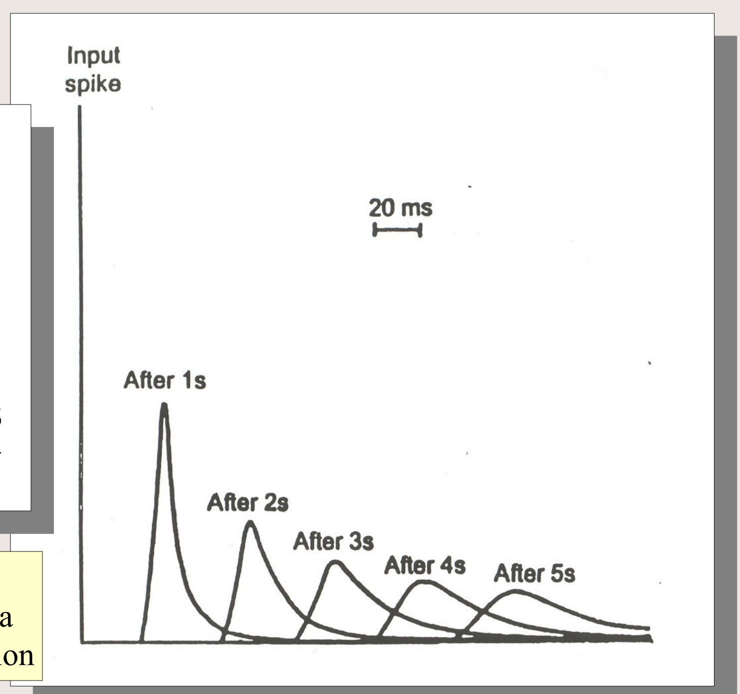
- Reading:
  - Reynolds, Section 4.4

Absorption

- When an elastic wave travels through any medium, its *mechanical* energy is progressively converted to *heat* (through friction and viscosity)
  - On grain boundaries, pores, cracks, water, gas, etc.
  - This conversion causes the amplitude to *decrease* and the pulse to *broaden*.



Area of the hysteresis curve is a measure of attenuation



Scattering

- Wavelength- dependent;
- *Scattering regime* is controlled by the ratio of the *characteristic scale length* of the *heterogeneity* of the medium, *a*, to the wavelength.
- Described in terms of *wavenumber*, $k=2\pi/wavelength$:
  - $ka << 0.01$ (quasi-homogeneous medium) - no significant scattering;
  - $ka < 0.1$ (*Rayleigh scattering*) - produces apparent *Q* and anisotropy;
  - $0.1 < ka < 10$ (*Mie scattering*) - introduces strong attenuation and discernible scattering noise in the signal.
    - typical for high-resolution seismic studies (boulder clay with 0.5-1 m boulders, $V_P \approx 2000$ m/s, $f \approx 500$ Hz

Quality Factor, *Q*

- Attenuation is measured in terms of *rock quality factor*, *Q*:
  - *Q* is (approximately) frequency-independent

$$A(t) = A(0)\exp^{-\alpha x} = A(0)\exp^{\frac{-\pi ft}{Q}}$$

$x = Vt$

  - Amplitude and energy loss per cycle (wavelength):

$$\ln\left(\frac{A(t+T)}{A(t)}\right) = \frac{-\pi fT}{Q} = \frac{-\pi}{Q}$$

$$\ln\left(\frac{E(t+T)}{E(t)}\right) = \ln\left(\frac{E(t) - \delta E}{E(t)}\right) = \frac{-\delta E}{E(t)} = \frac{-2\pi}{Q}$$

  - Thus, *Q* measures relative energy loss per oscillation cycle:

$$Q = 2\pi\frac{E}{\delta E}$$

- Typical values:
  - $Q \approx 30$ for weathered sedimentary rocks;
  - $Q \approx 1000$ for granite.

Empirical relationships for *Q*

- *Q* is thought to be sensitive to the physical state of the rock
- For sandstones with porosity ϕ % and clay content *C* %, at 1 MHz and 40 MPa:

$$Q = 179C^{-0.84\phi}$$

- Difficult to measure at seismic frequencies and *in situ*
  - *Q* measured in some refraction surveys;
  - Quite commonly, *Q* turns out to be frequency-dependent:

$$Q(f) = Q_0 f^{\eta}$$

    - This makes the story quite complicated...
  - "Absorption band" model of the Earth's mantle argues that its absorption is increased at frequencies ~0.001 – 1 Hz