Bandung Train The Trainers 16th -28th May 2016

Reservoir Geomechanics – answers in-class exercises

Train The Trainers workshop , WP 1.04 WP leader Peter Fokker TNO

Auke Barnhoorn, Peter Fokker

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In-class exercise 1, 2 and 3

Stress

- $Stress = \frac{Force}{Area} = \frac{F}{A}$

- Unit of stress is Pa (Pascal) or MPa for reservoir geomechanics

- Unit of Force is N (Newton)
- Unit of Area is m^2
- 1 Pa = 1 N/m^2

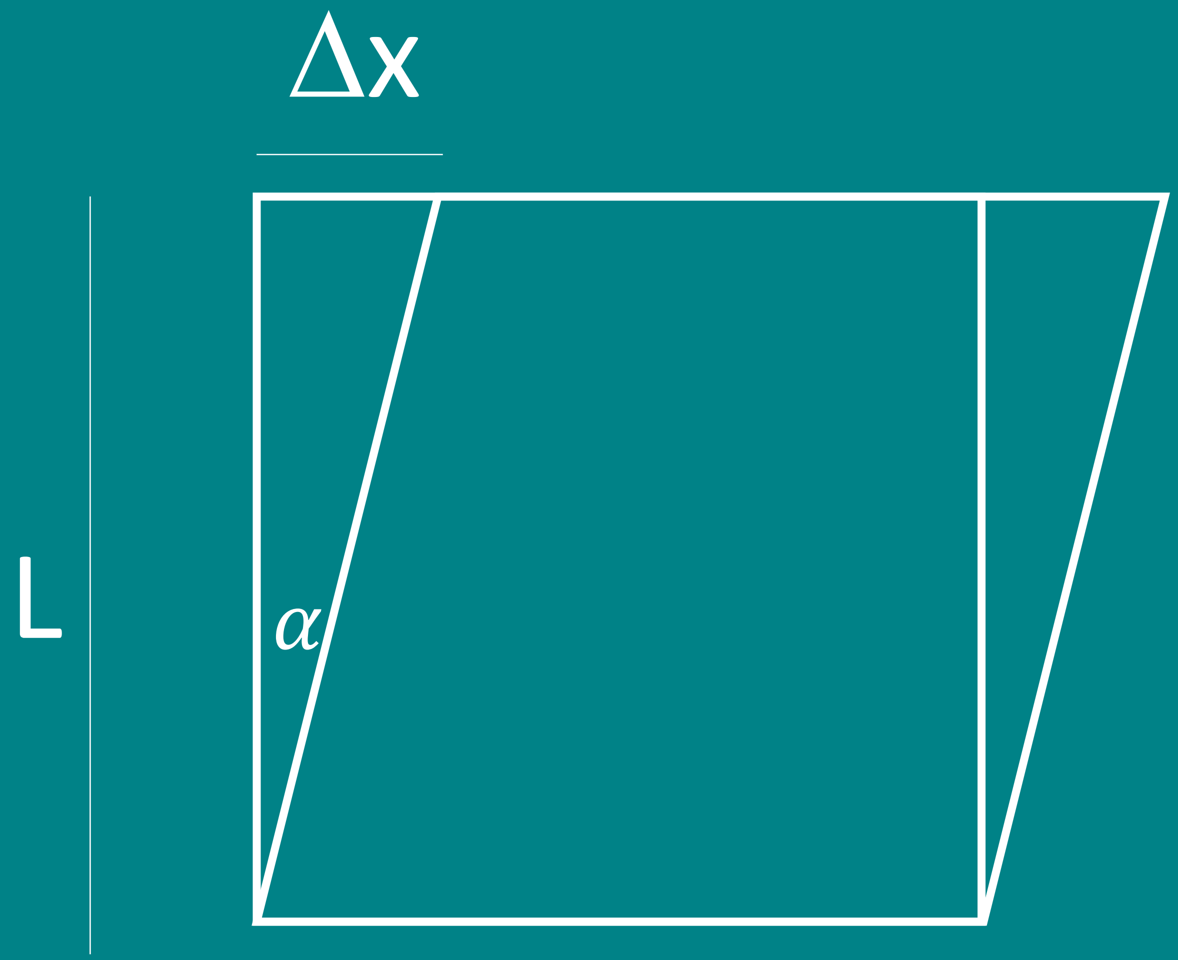
Strain

$$\varepsilon = \frac{\Delta L}{L}$$

$$\varepsilon = \frac{L_{new} - L}{L}$$

Assumption: No volume change of the body

Shear strain



$$\gamma = \frac{\Delta x}{L} = \tan\alpha$$

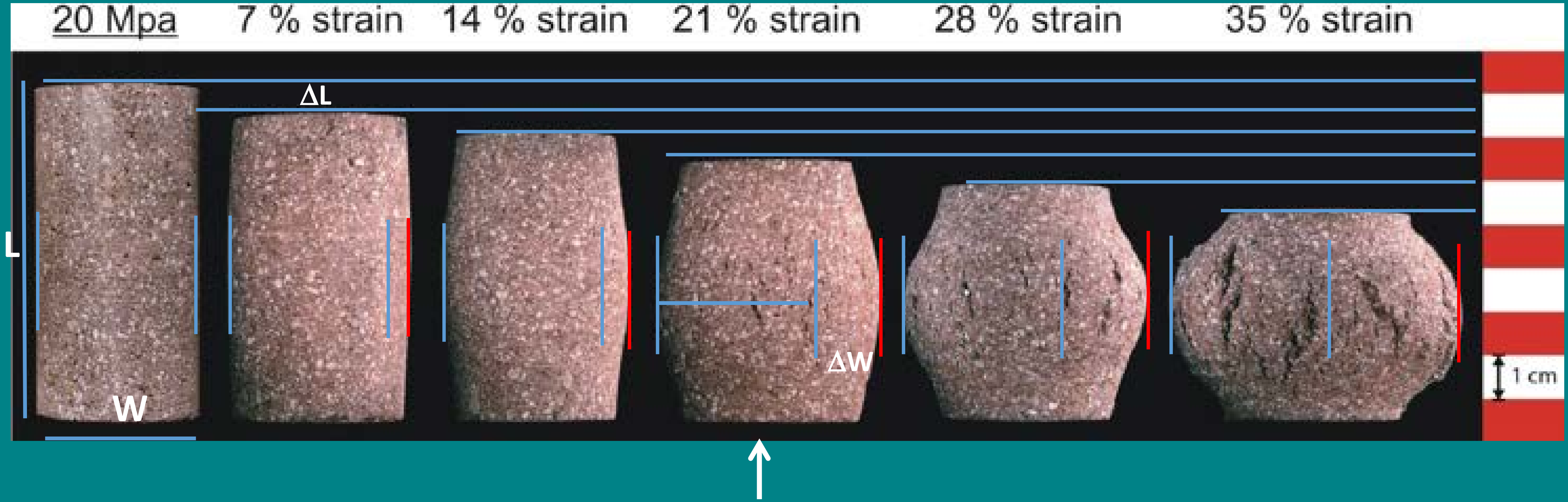
Δx = Displacement / Deformation
L = Original Length
γ = Shear strain

In-class stress-strain exercise - 1 10 min

Lavallee et al., 2008

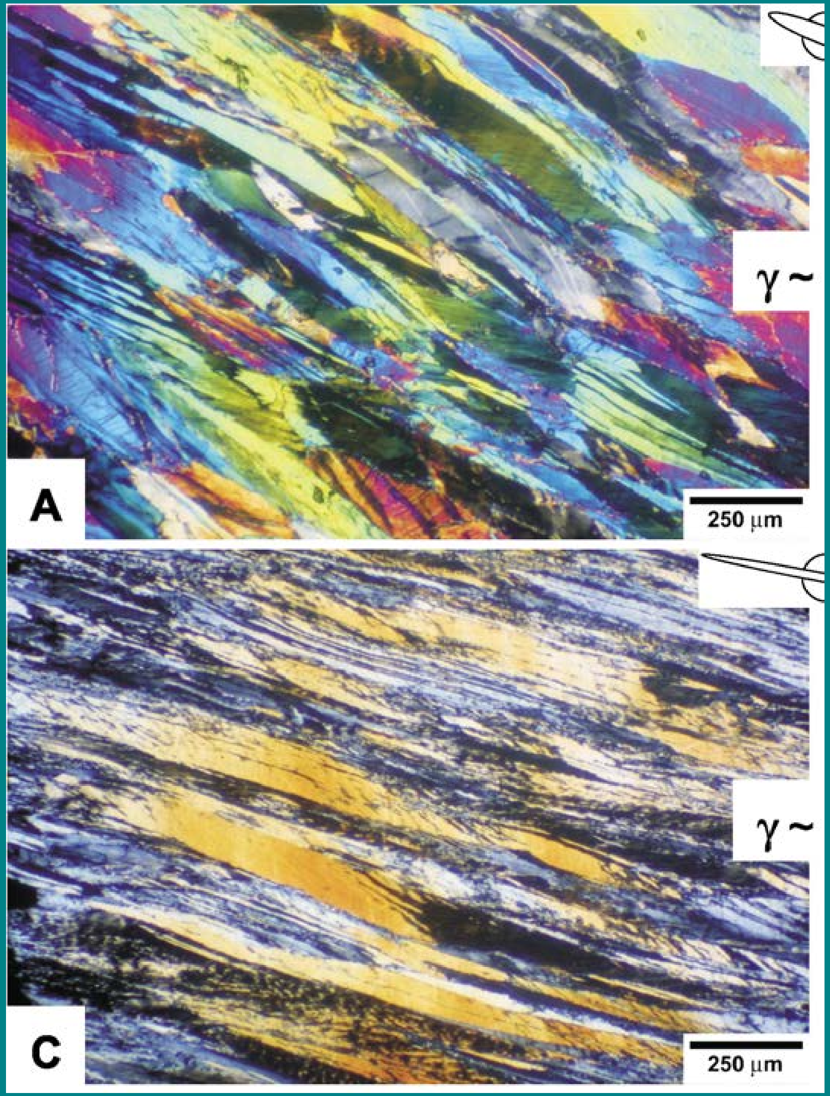
- Calculate the vertical and horizontal strain for each of these samples. The sample at the left is the original undeformed sample.

Answer



$$\varepsilon_h \sim \frac{5{,}19 - 3{,}19\ cm}{3{,}19\ cm} \sim \frac{2cm}{3{,}19\ cm}\, 0{,}68$$

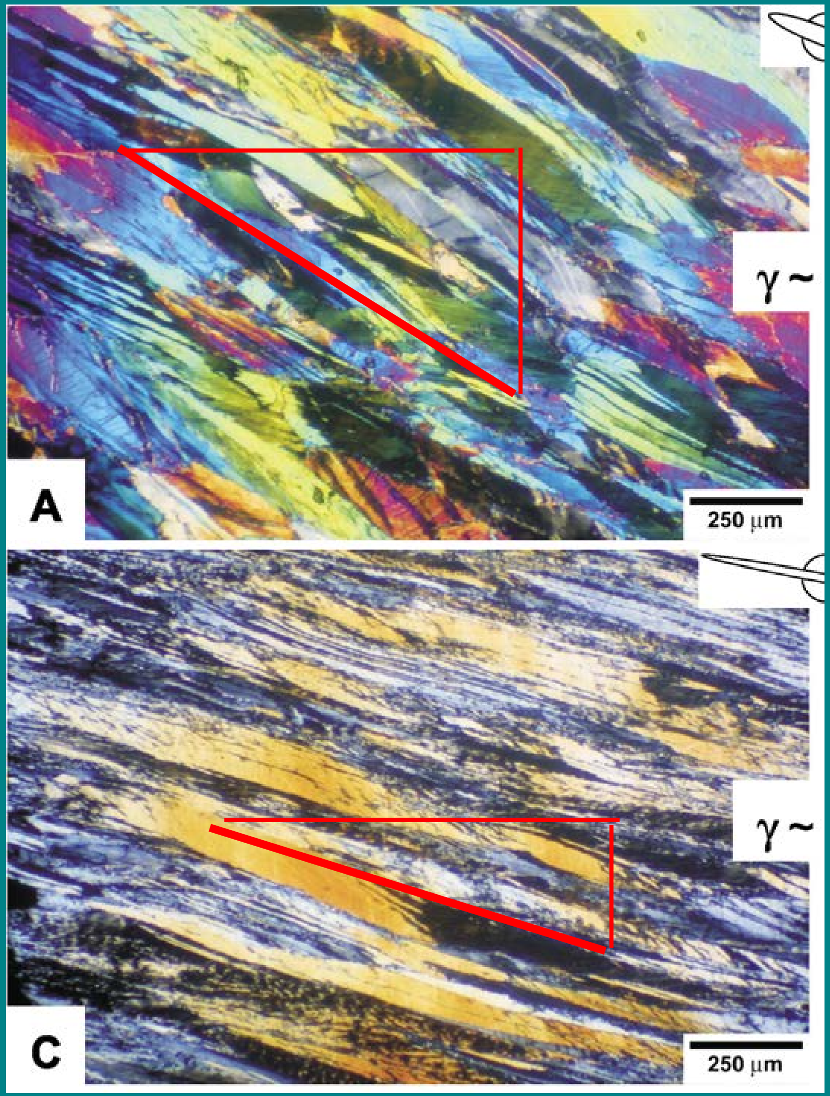
In-class stress-strain exercise - 2



Barnhoorn et al, 2004

- What is the shear strain of these 2 samples? The lineations in the images indicate the long axes of the parallelogram.

Answer



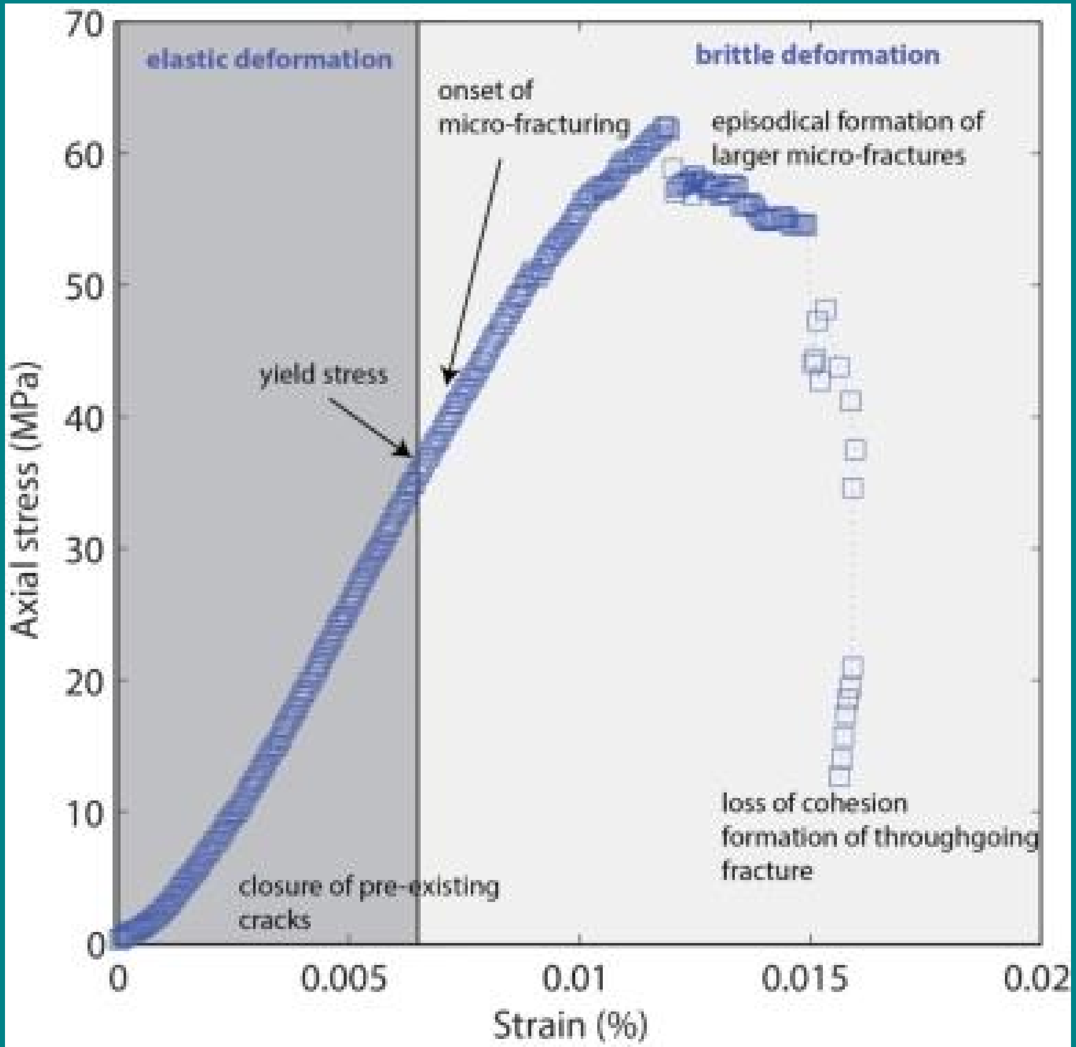
Barnhoorn et al, 2004

- What is the shear strain of these 2 samples? The lineations in the images indicate the long axes of the parallelogram.

$$\gamma = \frac{\Delta x}{L} \sim \frac{5.23}{3.29} \sim 1{,}6$$

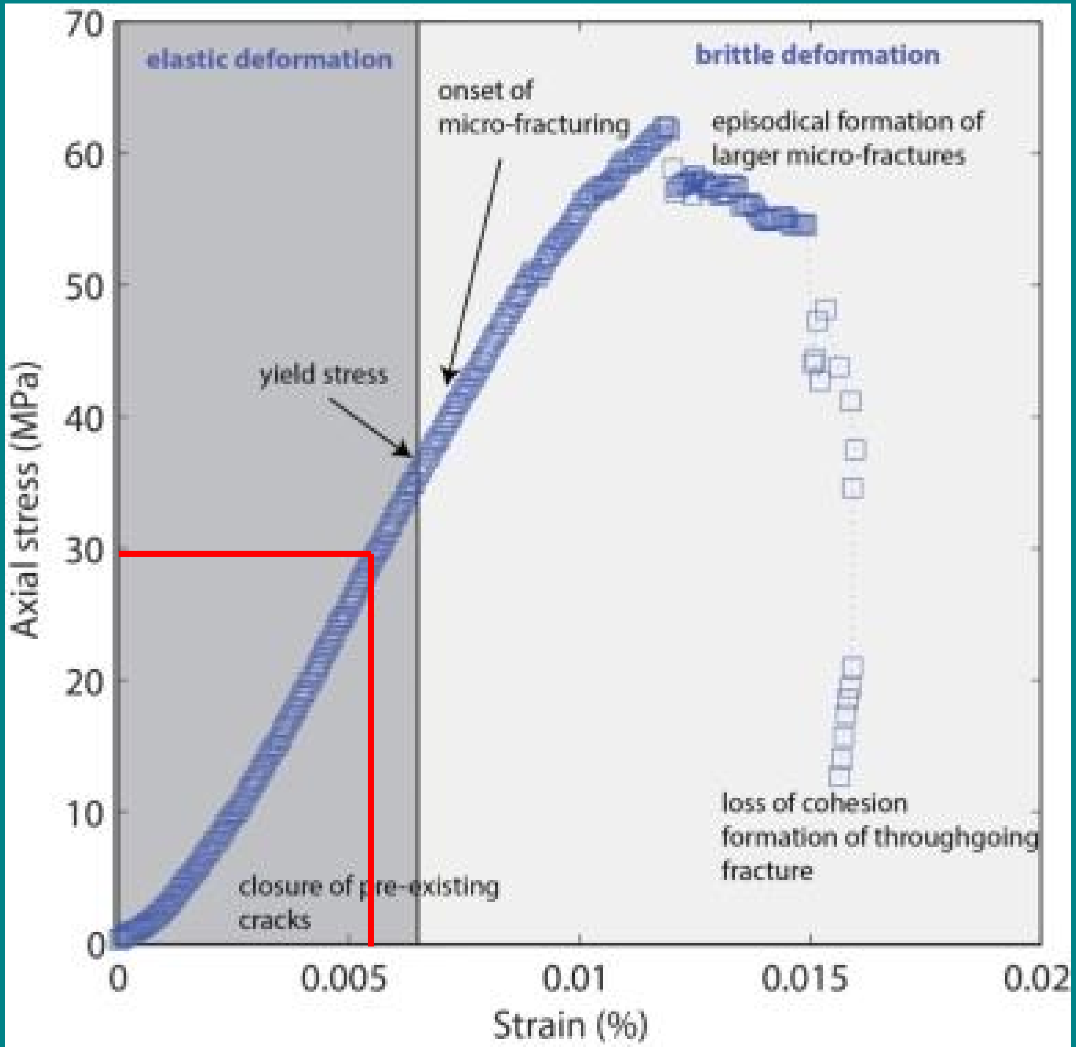
$$\gamma = \frac{\Delta x}{L} \sim \frac{5.23}{1.63} \sim 3{,}2$$

In-class stress-strain exercise - 3



- What is the stress-strain ratio $\left({}^{\Delta\sigma}/_{\Delta\varepsilon}\right)$ of this experimentally deformed shale sample? Determine the stress-strain ratio only in the gray part of the diagram. The unit of the stress-strain ratio is in GPa.

Answer



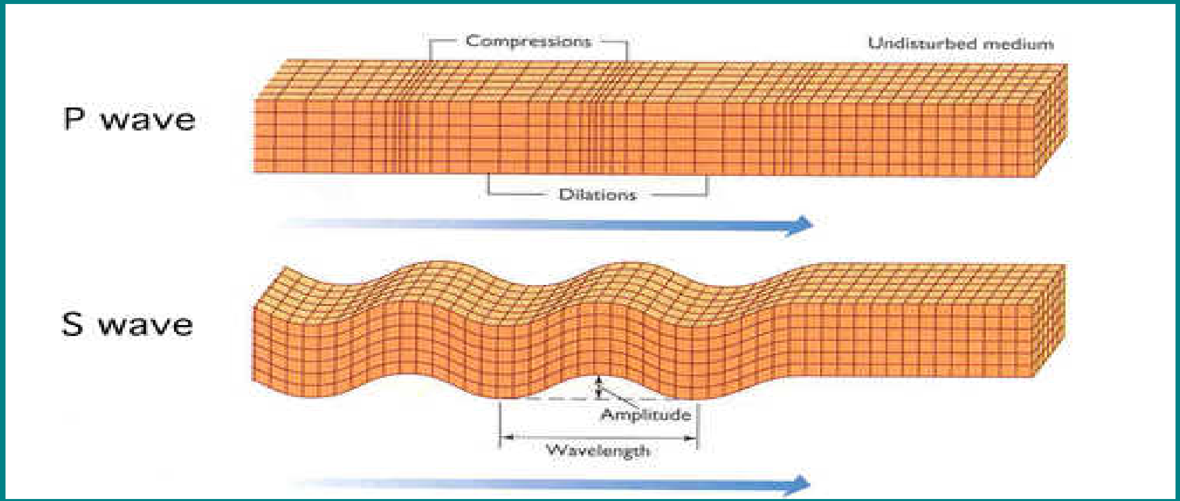
$$\frac{stress}{strain} = \frac{\sigma}{\varepsilon} \sim \frac{30\ MPa}{0{,}0055} \sim 5.45e9\ Pa = 5.45\ \text{GPa}$$

Vp and Vs

$$\mu = v_s^2 \rho$$

$$K_b = (v_p^2 - \frac{4}{3} v_s^2)\rho$$

$$\nu = \frac{v_p^2 - 2v_s^2}{2(v_p^2 - v_s^2)}$$



Measurement of Vp, Vs and density

Elastic relationships in isotropic materials

K	E	λ	ν	M	μ
$\lambda + 2\mu/3$	$\mu \frac{3\lambda + 2\mu}{\lambda + \mu}$	—	$\frac{\lambda}{2(\lambda + \mu)}$	$\lambda + 2\mu$	—
—	$9K \frac{K - \lambda}{3K - \lambda}$	—	$\frac{\lambda}{3K - \lambda}$	$3K - 2\lambda$	$3(K - \lambda)/2$
—	$\frac{9K\mu}{3K + \mu}$	$K - 2\mu/3$	$\frac{3K - 2\mu}{2(3K + \mu)}$	$K + 4\mu/3$	—
$\frac{E\mu}{3(3\mu - E)}$	—	$\mu \frac{E - 2\mu}{(3\mu - E)}$	$E/(2\mu) - 1$	$\mu \frac{4\mu - E}{3\mu - E}$	—
—	—	$3K \frac{3K - E}{9K - E}$	$\frac{3K - E}{6K}$	$3K \frac{3K + E}{9K - E}$	$\frac{3KE}{9K - E}$
$\lambda \frac{1 + \nu}{3\nu}$	$\lambda \frac{(1 + \nu)(1 - 2\nu)}{\nu}$	—	—	$\lambda \frac{1 - \nu}{\nu}$	$\lambda \frac{1 - 2\nu}{2\nu}$
$\mu \frac{2(1 + \nu)}{3(1 - 2\nu)}$	$2\mu(1 + \nu)$	$\mu \frac{2\nu}{1 - 2\nu}$	—	$\mu \frac{2 - 2\nu}{1 - 2\nu}$	—
—	$3K(1 - 2\nu)$	$3K \frac{\nu}{1 + \nu}$	—	$3K \frac{1 - \nu}{1 + \nu}$	$3K \frac{1 - 2\nu}{2 + 2\nu}$
$\frac{E}{3(1 - 2\nu)}$	—	$\frac{E\nu}{(1 + \nu)(1 - 2\nu)}$	—	$\frac{E(1 - \nu)}{(1 + \nu)(1 - 2\nu)}$	$\frac{E}{2 + 2\nu}$

Mavko, 2003

In-class exercise 4

In-class elastic moduli exercise 4 - 10 min

- Sandstone ρ = 2.65 g/cm3, Vp = 5491 m/s. Vs = 3463 m/s
- Limestone ρ = 2.71 g/cm3, Vp = 6417 m/s. Vs = 3444 m/s
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- Wat are Kb, μ, E and ν for these 2 rock types?

Answer

- Sandstone ρ = 2.65 g/cm3, Vp = 5491 m/s. Vs = 3463 m/s
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- Wat are Kb, μ, E and ν for these 2 rock types?

Density (g/cm3)	Density (kg/m3)	Vp (m/s)	Vs(m/s)	mu (Pa)	mu (Gpa)	Kb (Pa)	Kb (Gpa)	E(Gpa)	poissons ratio
2,65	2650	5491	3463	3,18E+10	31,78	3,75E+10	37,54	74,36	0,17
2,71	2710	6417	3444	3,21E+10	32,14	6,87E+10	68,74	83,43	0,30

Contact Details

Auke Barnhoorn

Department of Geoscience and Engineering

Faculty of Civil Engineering and Geosciences

Delft University of Technology

The Netherlands

More information or questions:

www.citg.tudelft.nl/aukebarnhoorn or auke.barnhoorn@tudelft.nl

@AukeBarnhoorn