Introduction to Geophysics

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Reinhard Drews

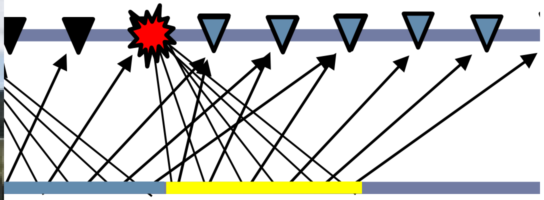
Class Schedule

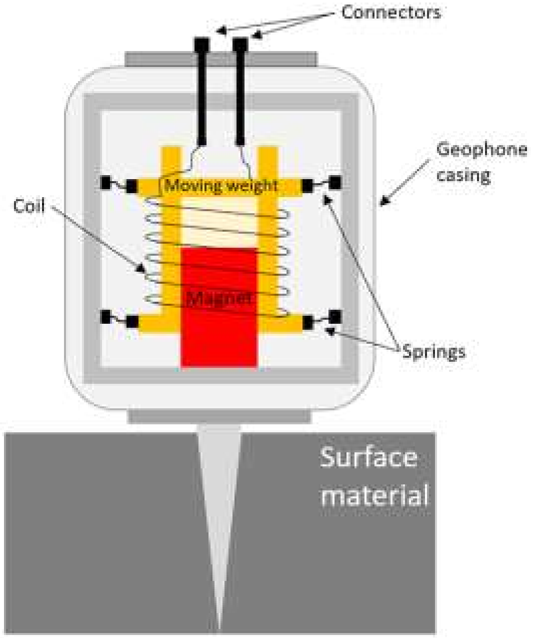
Part 1: Seismics & Seismology

Ressources: Clauser (2018) Chapter 2; Telford, Chapter 4

Lecture 1	16.04 (Schlegel)	• Introduction lecture format & scope of applied geophysics • Introduction wave-based methods (GPR, Seismics)
Lecture 2	18.04 (Schlegel, flipped)	• Wave equation and wave types (body (p,s) & surface) • Rays, refraction & reflections (fermat & huygens & snell's law)
Lecture 3	23.04 (Drews)	• Principal of seismic data aquis. & interpret of shot gathers • Horizontal one layer case (refraction)
Lecture 4	25.04 (Drews)	• Multiple and dipped layers (refraction) • Application examples
Lecture 5	30.04 (Drews)	• Reflection seismics principles • Velocity analysis
Lecture 6	02.05 (Drews)	• Imaging & migration • Application examples
Lecture 7	07.05 (Drews)	• Seismology & Earthquake location • Fault plane solutions & Application examples

Reflection seismic data acquisition





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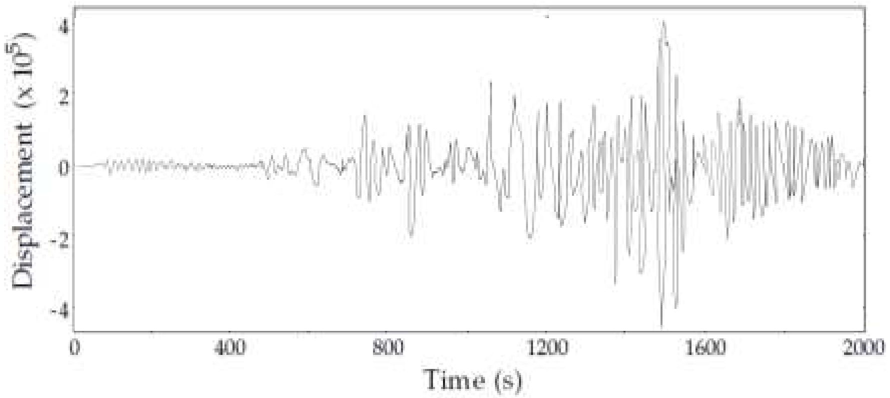
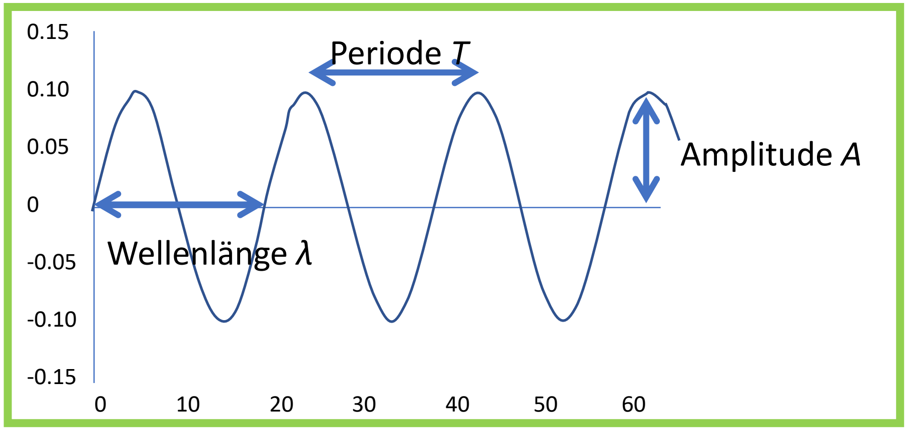
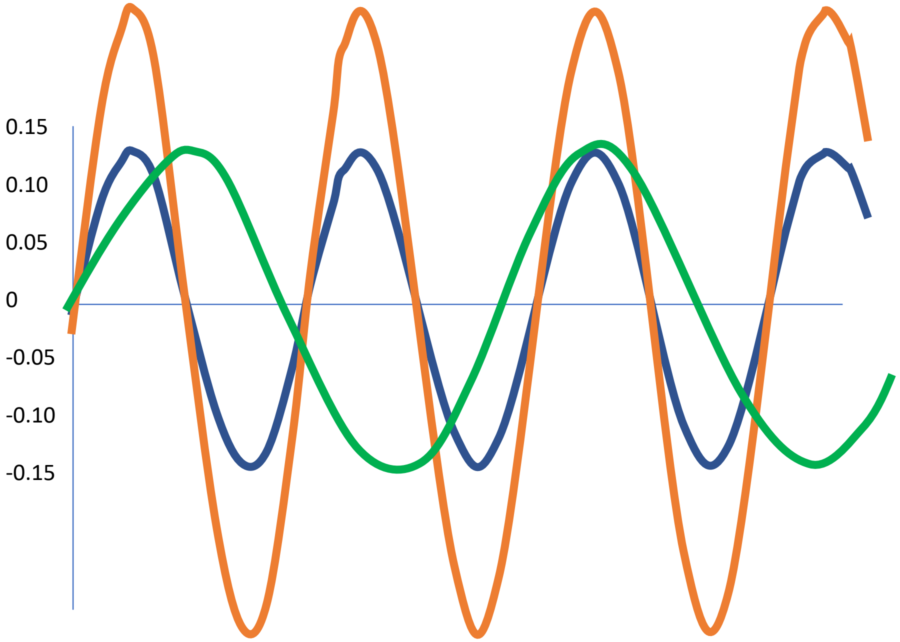
Seismische Wellen





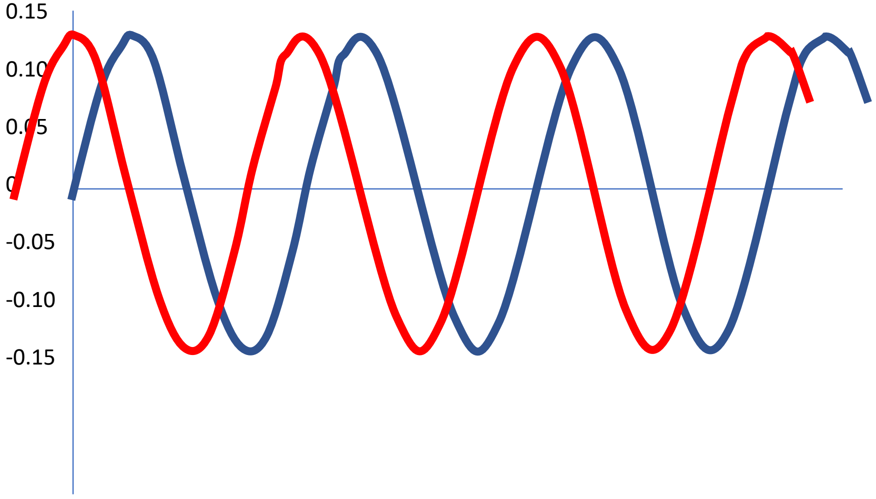
Seismische Wellen



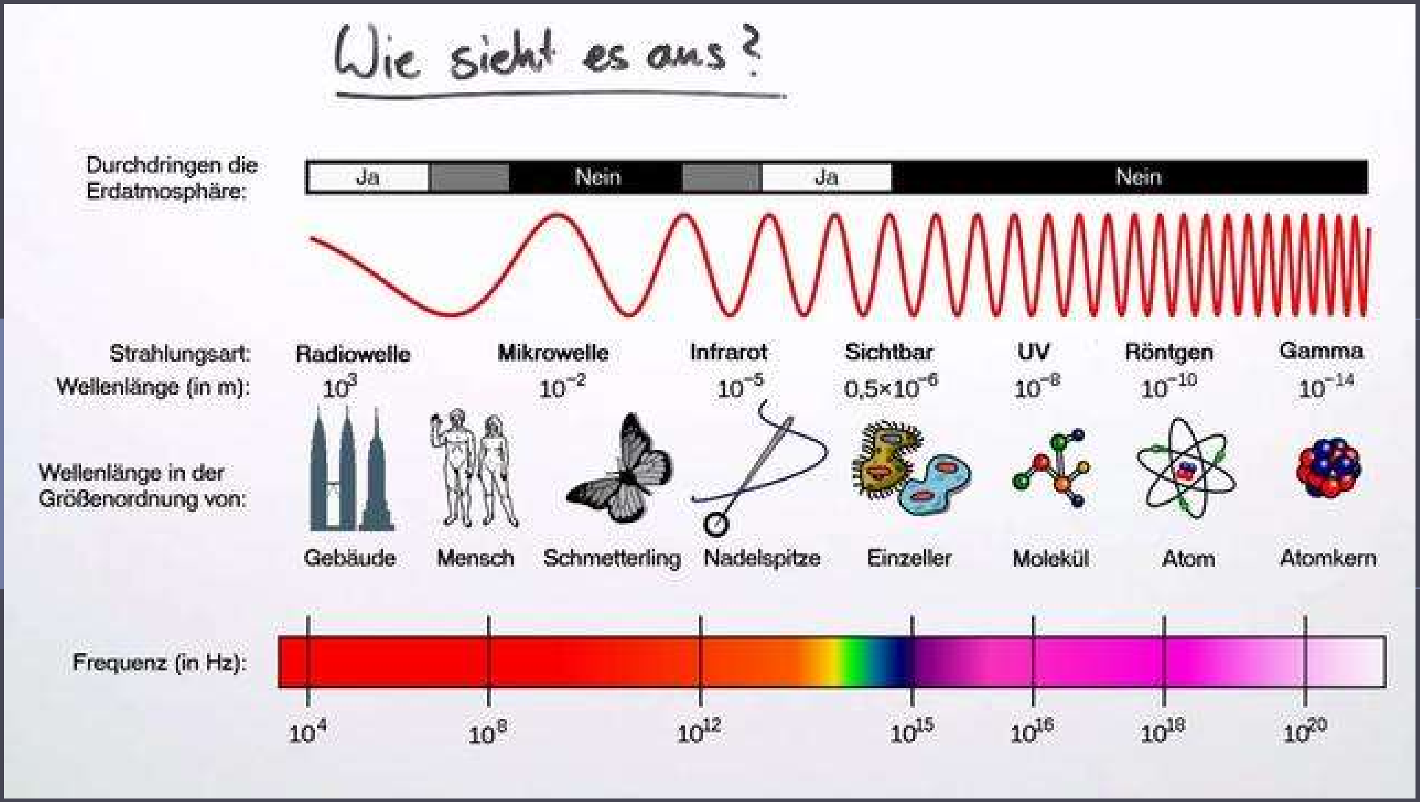
Amplitude *A*

Periode *T*

Seismische Wellen



phase φ

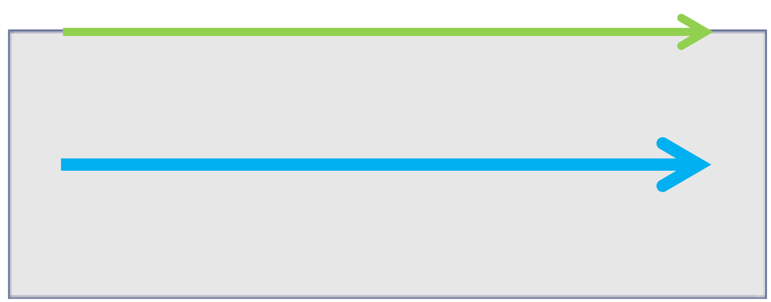

Wie sieht es aus?
Durchdringen die Erdatmosphäre:
Ja
Nein
Ja
Nein
Strahlungsart:
Wellenlänge (in m):
Radiowelle
10^3
Mikrowelle
10^{-2}
Infrarot
10^{-5}
Sichtbar
$0{,}5\times10^{-6}$
UV
10^{-8}
Röntgen
10^{-10}
Gamma
10^{-14}
Wellenlänge in der Größenordnung von:
Gebäude
Mensch
Schmetterling
Nadelspitze
Einzeller
Molekül
Atom
Atomkern
Frequenz (in Hz):
10^4
10^8
10^{12}
10^{15}
10^{16}
10^{18}
10^{20}

“Waves”

- A wave is disturbance
  - **Energy transfer without mass transfer**
  - Transfer based on elastic properties of rock or fluid

Body Waves
- P-wave
- S-wave

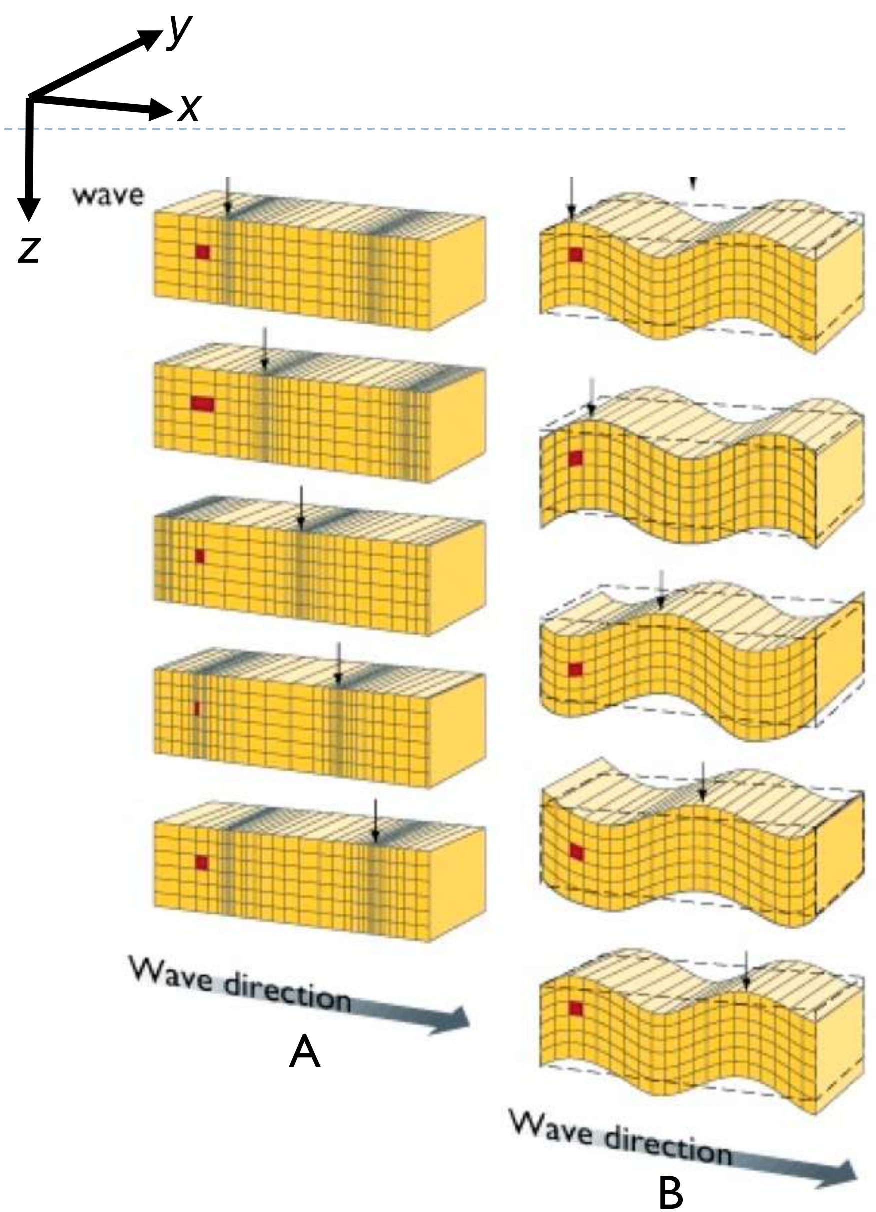
Surface Waves
- Love Waves
- **Rayleigh Waves**



Question –
What waves are shown?

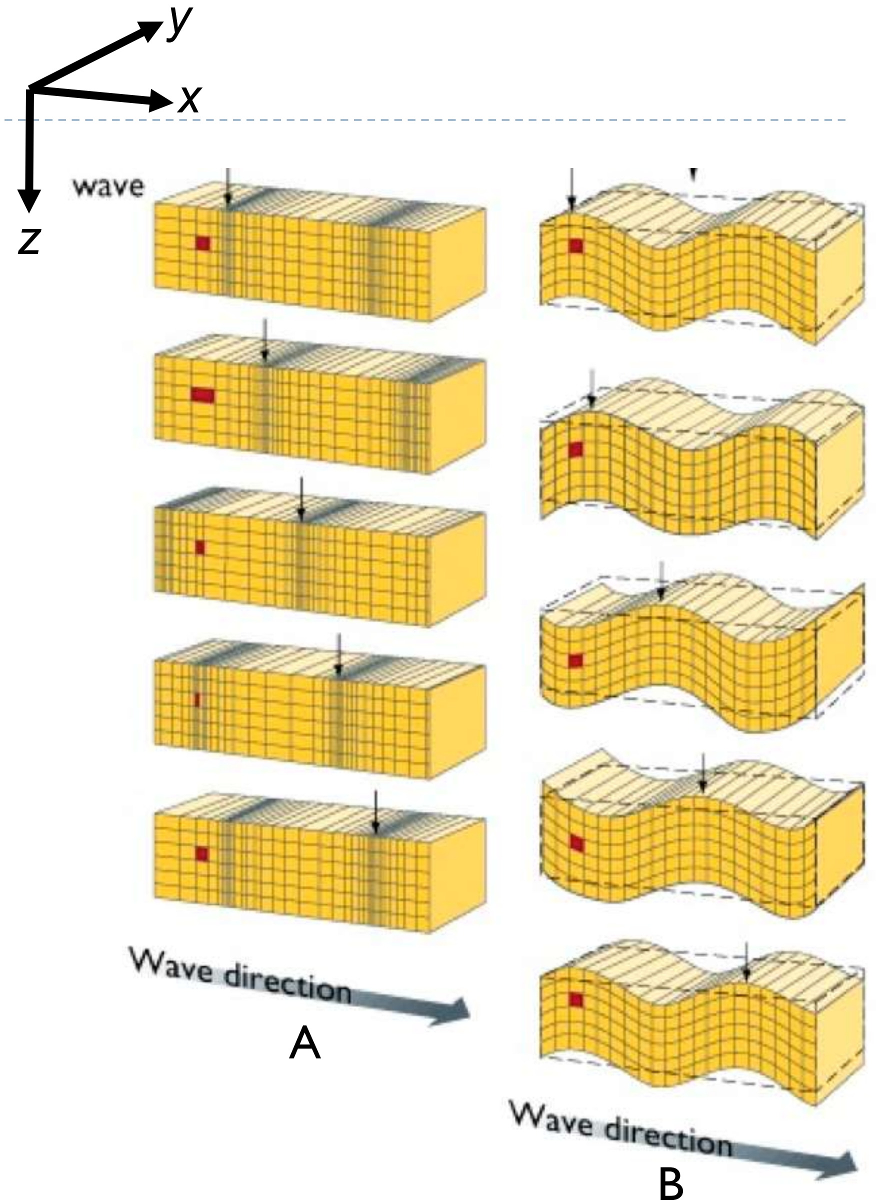
Which is correct?

a) *A* is S-wave and *B* is Love-wave
b) *A* is P-wave and *B* is Love-wave
c) *A* is Love-wave and *B* is Rayleigh-wave
d) *A* is P-wave and *B* is S-wave



Answer

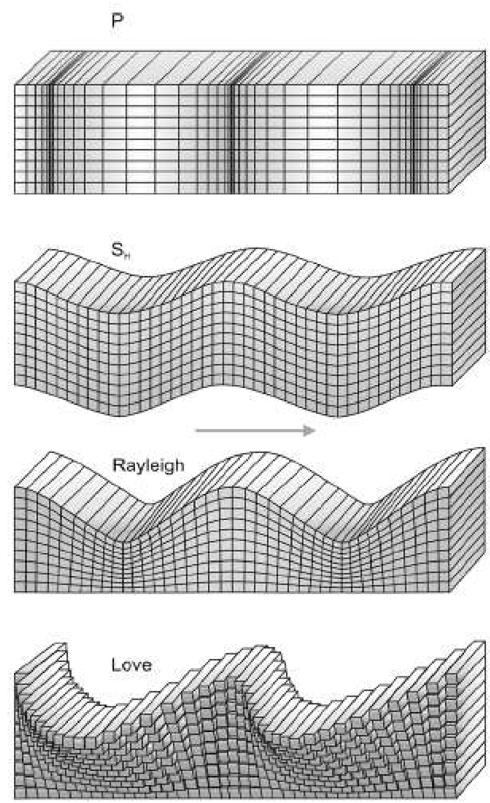
(d) *A* is P-wave and *B* is S-wave



Seismische Wellen

Ausbreitungsrichtung

Partikelbewegung



	Partikelbewegung
P-Welle	longitudinal
S-Welle	transversal
Rayleigh-Welle	Longitudinal and transversal
Love-Welle	transversal

Wavespeed equations (simpler than you'd think)

- P-waves

$$v_p = \sqrt{\frac{\kappa + \frac{4}{3}\mu}{\rho}}$$

- S-waves

$$v_s = \sqrt{\frac{\mu}{\rho}}$$

- κ = bulk modulus (or incompressibililty)
- μ = shear modulus (or rigidity)
- ρ = density

Typical wavespeeds…
the harder, the faster…

Unconsolidated material:	Dry sand	0.2 - 1.0 km/s
	Wet sand	1.5 - 2.0 km/s
	Clay	1.0 - 2.5 km/s
Sedimentary rocks:	Tertiary Sandstone	2.0 - 2.5 km/s
	Carbonate Sandstone	4.0 - 4.5 km/s
	Chalk	2.0 - 2.5 km/s
	Limestone	3.4 - 7.0 km/s
	Evaporites	4.5 - 5.0 km/s
Igneous/metamorphic rocks:	Granite	5.5 - 6.0 km/s
	Gabbro	6.5 - 7.0 km/s
	Gneiss	3.5 - 7.5 km/s

Air: 0.33 km/s; Water: 1.43-1.54 km/s; Petroleum: 1.3-1.4 km/s

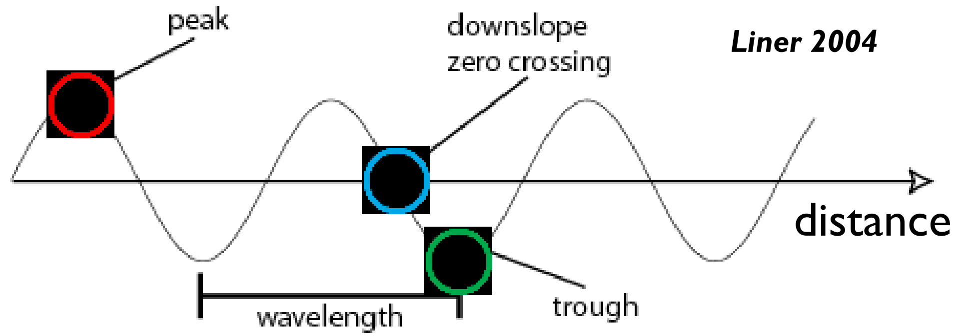
Good reference for rock properties:
"Physical Properties of Rocks: Fundamentals and Principles of Petrophysics", Schon, Elsevier)

Practical controls on wavespeed

- How do the elastic properties of rocks change?
  - ***Lithology***: most obvious factor controlling wavespeed
  - ***Fluid***: hydrocarbons and brine reduce wavespeed
  - Therefore, ***porosity*** is very important: depends on depth and pressure
  - ***Cementation, diagenesis***

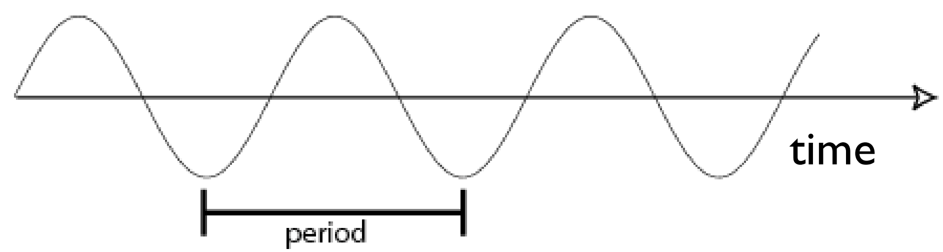
Anatomy of a waveform –
this stuff should become basic recall!

- Basic Terminology:
  - Peak and trough
  - Zero crossing
  - Wavelength (λ)
  - Period (T)
  - Frequency (f)



$$f = \frac{1}{T}$$

$$V = f\lambda$$



Question time

1. The time between a successive peak and trough of a wavelet is measured to be 25 milliseconds.

   A) What is the wavelet's period?

   B) What is its frequency?

2. A wavelet with 50 Hz dominant frequency is travelling with a velocity of 4000 m/s.

   A) What is its wavelength?

   B) In what medium might the wavelet be travelling?

Answer

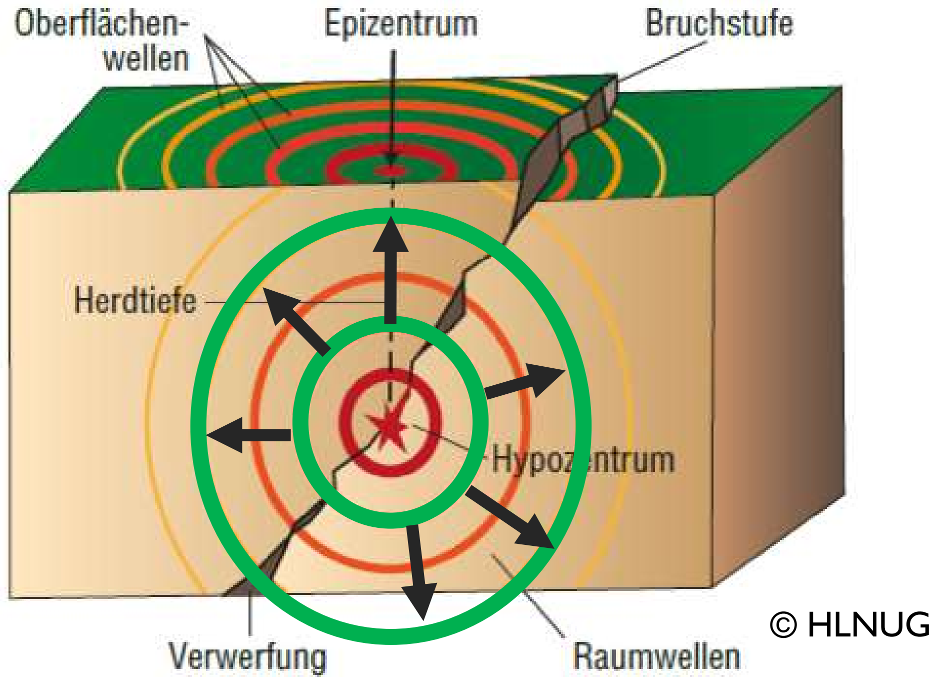
1. A wavelet with a duration between peak and trough of 25 ms has
   - Period of 50 [ms] = 0.05 [s]
   - Frequency = 1/0.05 [s] = 20 [s^{-1}] = 20 [Hz]

2. The wavelength of a 50 Hz wave travelling with a velocity of 4000 m/s
   - wavelength = velocity / frequency
   - λ = 4000 *[m/s]* / 50 *[1/s]* = 80 m

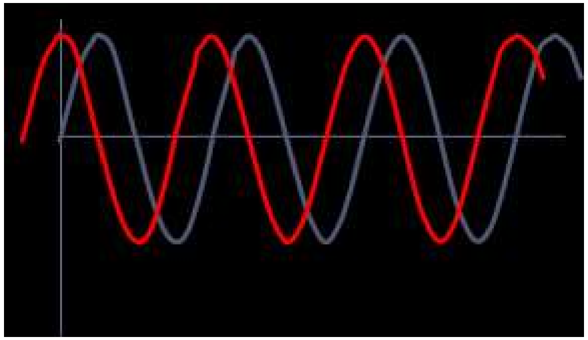
   - The medium is likely to be a consolidated sedimentary rock; arguably too slow for igneous, and much too fast for loose material. Which rock, however, is impossible to say.

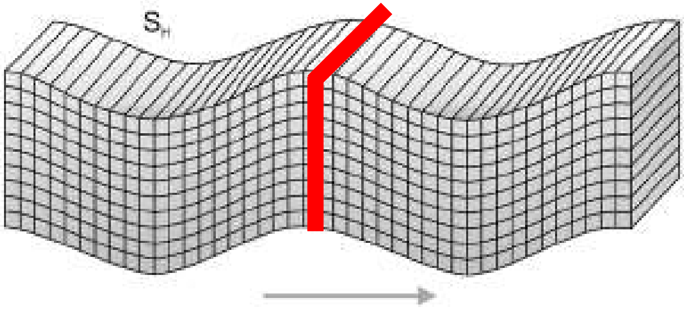
Pause

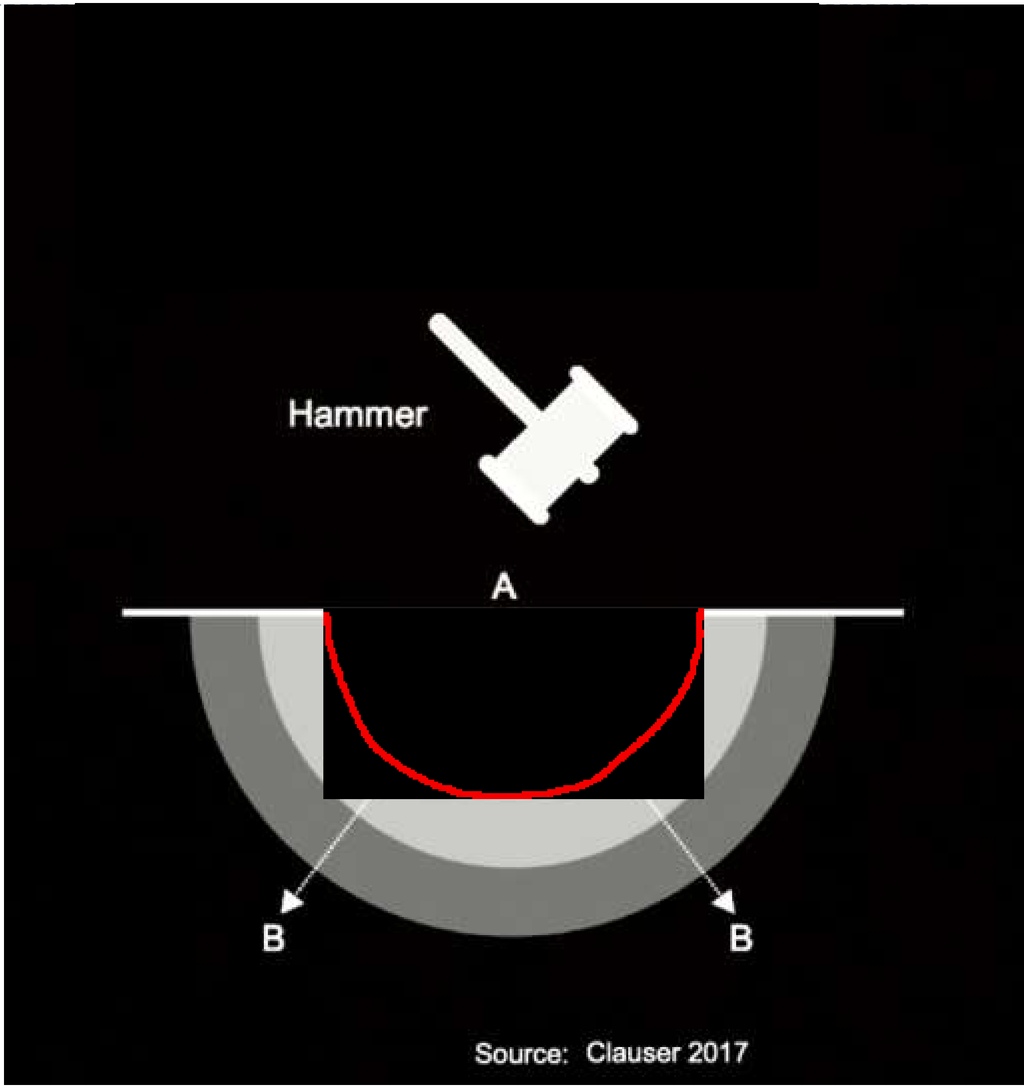
Wavefronts and Rays



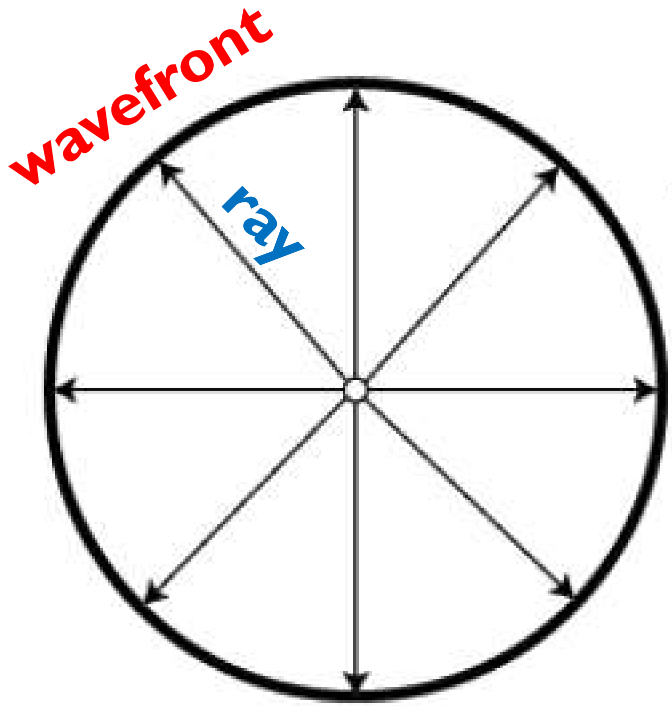
Wavefronts and Rays







Properties of waves – *Wavefronts vs. rays*

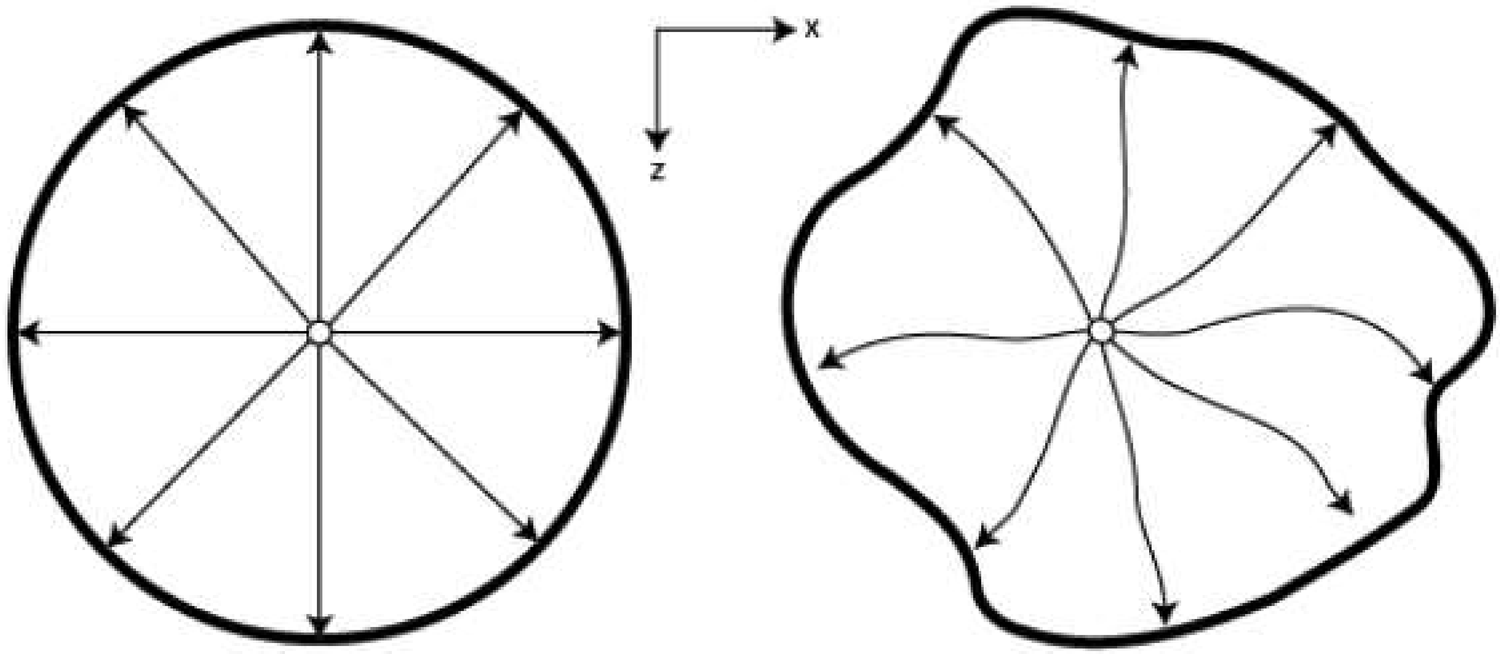


Isotropic, homogeneous

Wavefront: a surface over which the phase (or travel-time) of a traveling wave is equal (or constant)
- e.g., one ripple on a pond

Ray: the ray indicates the direction of energy transport
- e.g., the direction the ripple moves

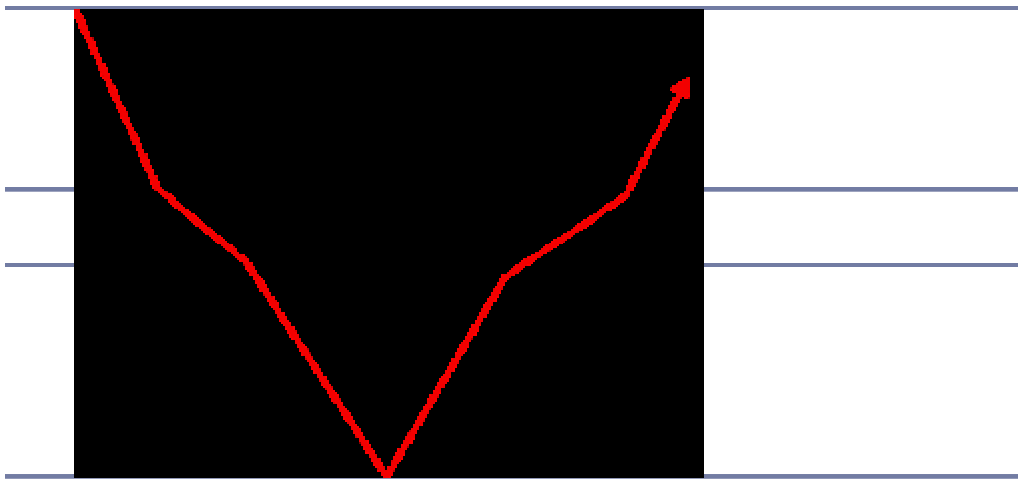
Travel time: the time for a wave to travel between two points along a ray.



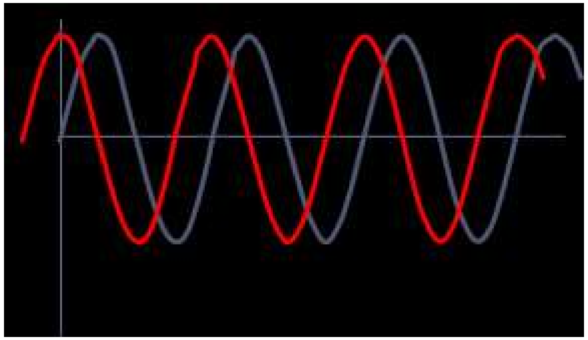
Isotropic, homogeneous

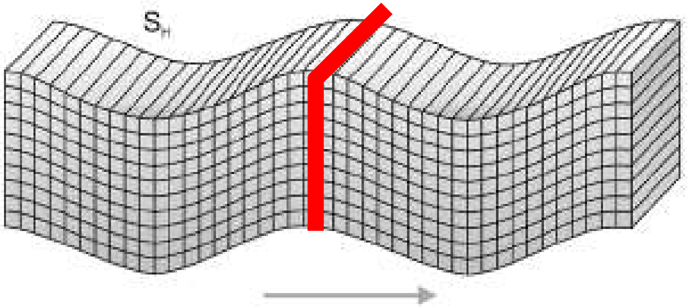
Isotropic, heterogeneous

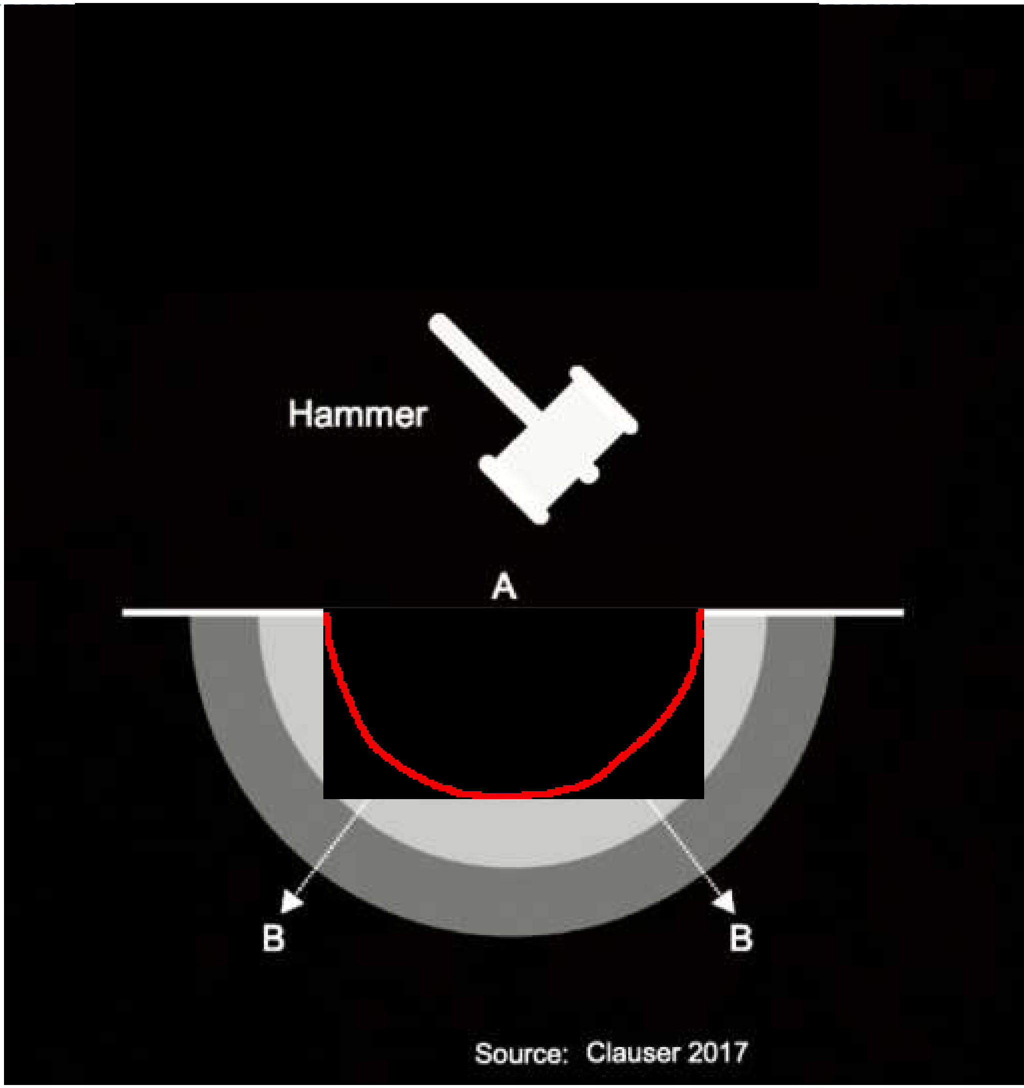
Seismic Propagation… simplified



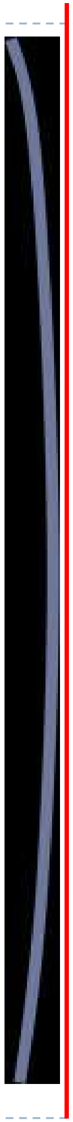
Wavefronts and Rays







Far field limit

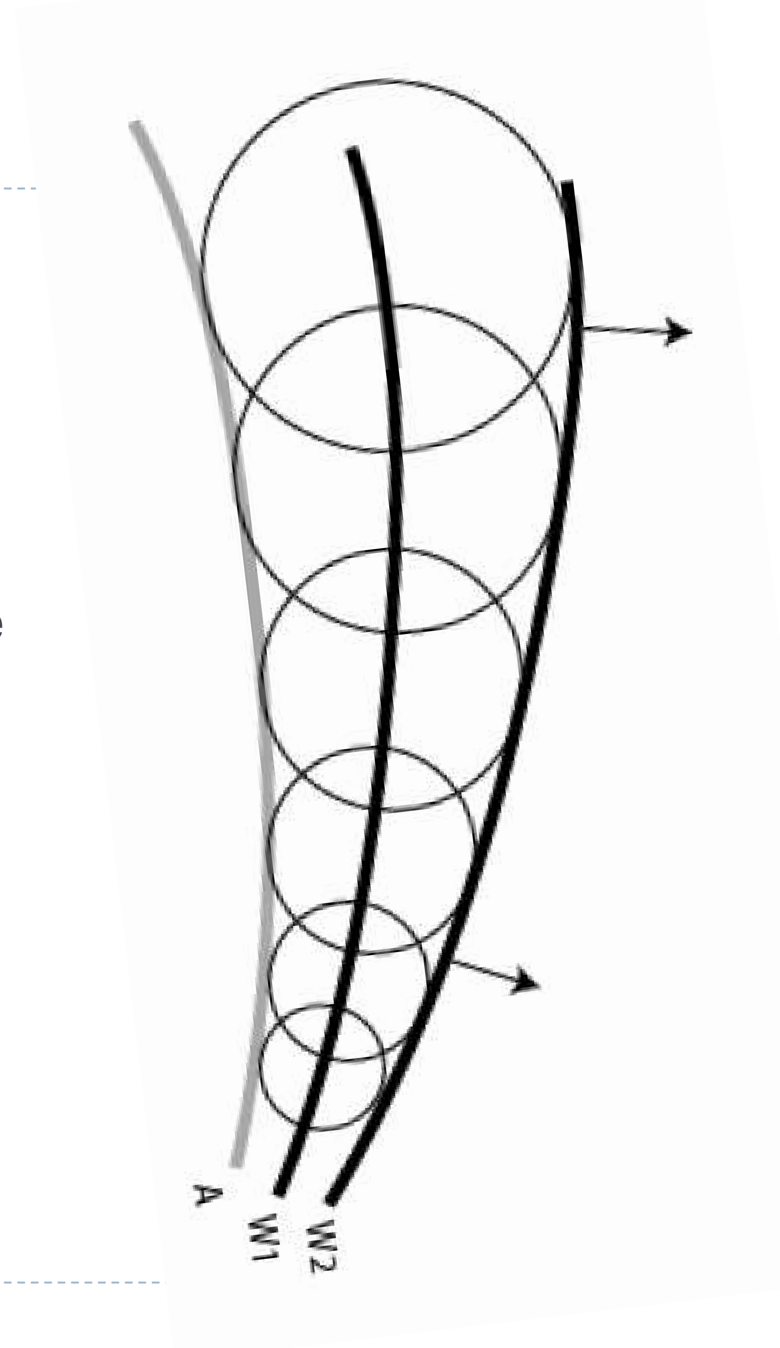


- We replace the curved wave front with straight wave fronts which basically propagate in one direction (the x-direction)

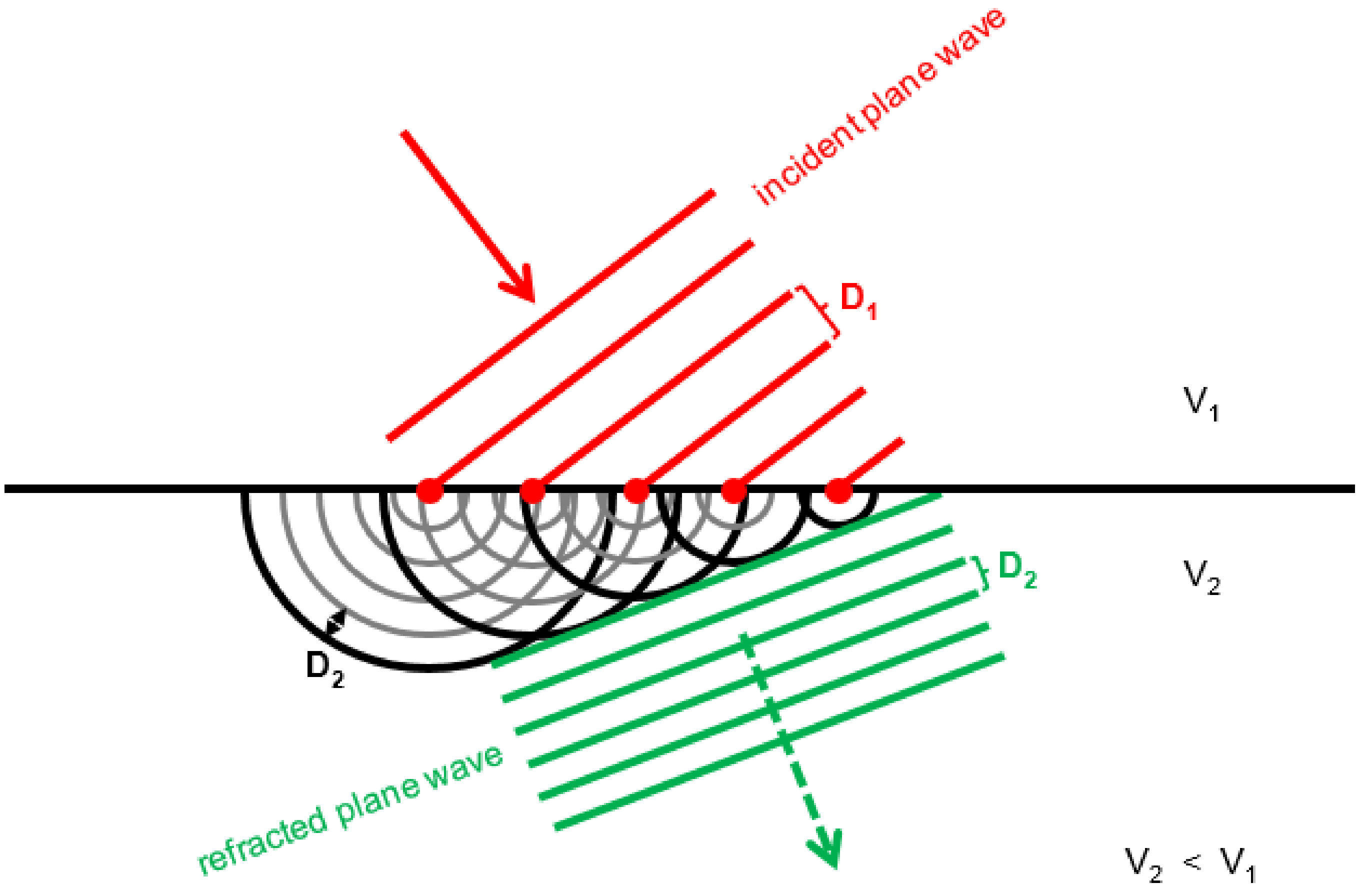
How do waves propagate? - Huygen's Principle

Huygen's principle states:

- Every point on a wavefront may be considered as a center of a secondary disturbance.
- This gives to spherical waves and the envelope of those wavelets is the wavefront at any later time



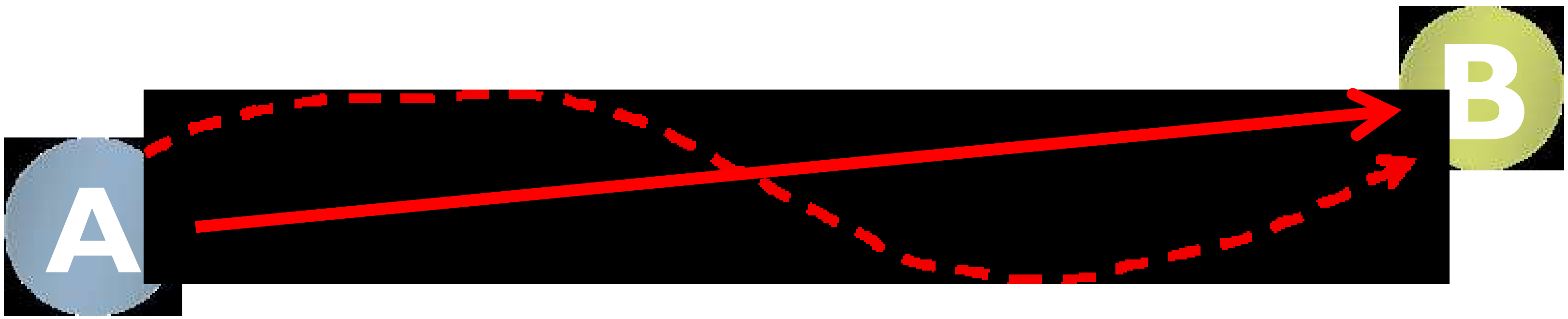
Liner 2004



SEG wiki

Defining Raypaths
- Fermat's principle

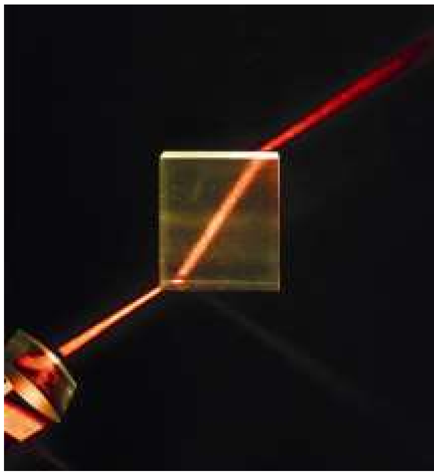
- Fermat's principle states that the path taken by a beam of light between two points is the one that takes the least travel-time.

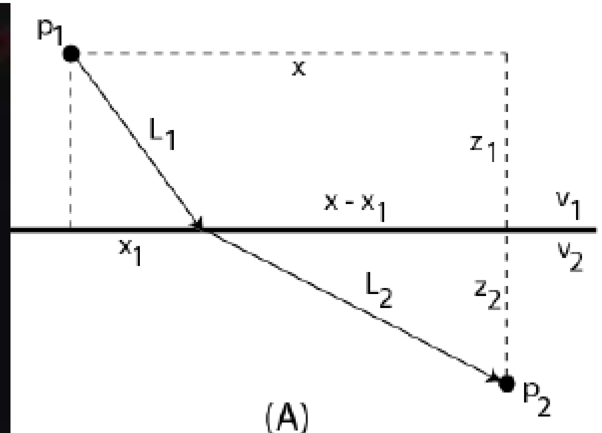


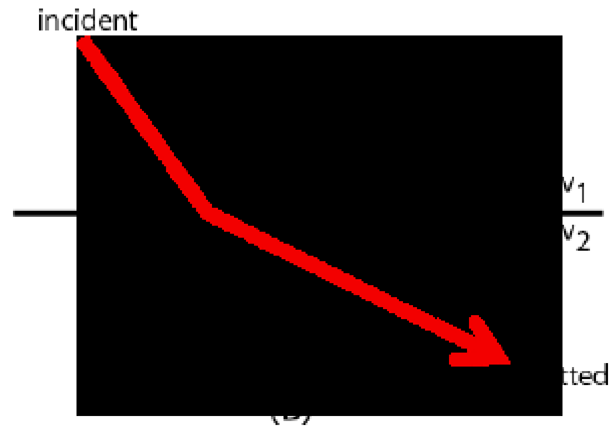
- The same holds for seismic energy; the raypaths we define are minimum travel paths.

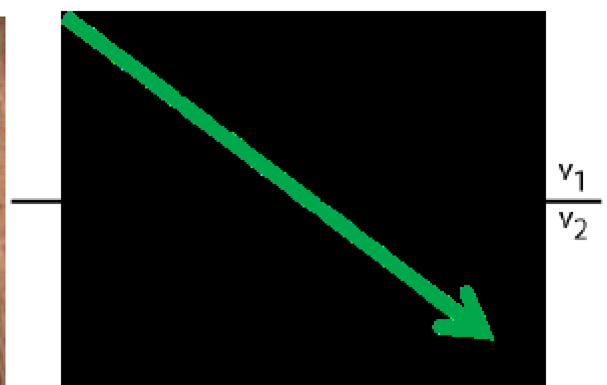
Rays at interfaces – Snell's Law

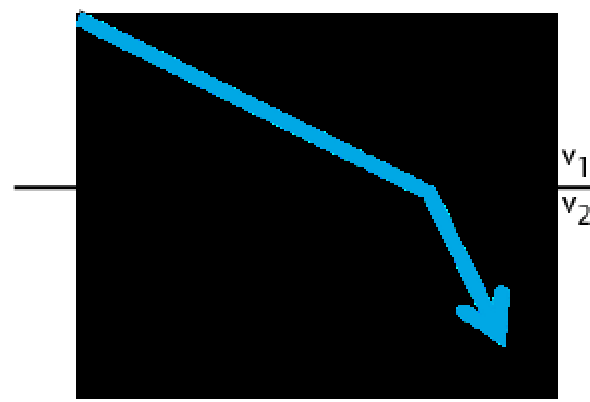
$$\frac{\sin\theta_1}{V_1} = \frac{\sin\theta_2}{V_2}$$





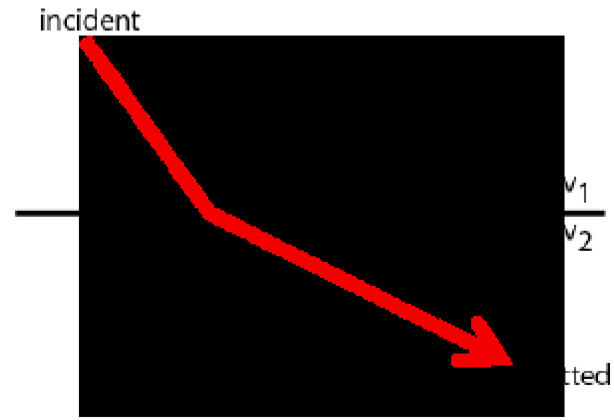




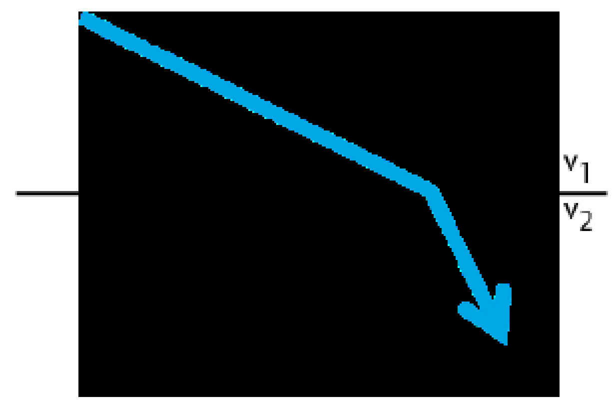


Velocity contrasts control refraction

- **Case 1: Velocity increases - $V_2 > V_1$**
  - Ray bends *away* from normal – $\theta_2 > \theta_1$
  - Rays diverge away from high velocity



- **Case 2: Velocity decreases - $V_2 < V_1$**
  - Ray bends *toward* normal – $\theta_2 < \theta_1$
  - Rays cluster into low velocity zones



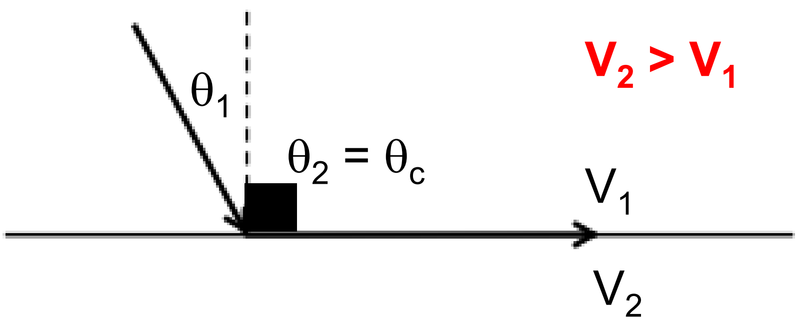
Critical Refraction, or *Headwave*

- Special case of refraction where a ray approaches at such a θ_1 that $\theta_2 = 90°$.

- In this case, θ_1 is the "critical angle", θ_c.

$$\frac{\sin\theta_c}{V_1} = \frac{\sin 90^0}{V_2} = \frac{1}{V_2}$$

$$\theta_c = \sin^{-1}\left(\frac{V_1}{V_2}\right)$$



Another Question Time…

$$\frac{\sin\theta_1}{V_1} = \frac{\sin\theta_2}{V_2}$$

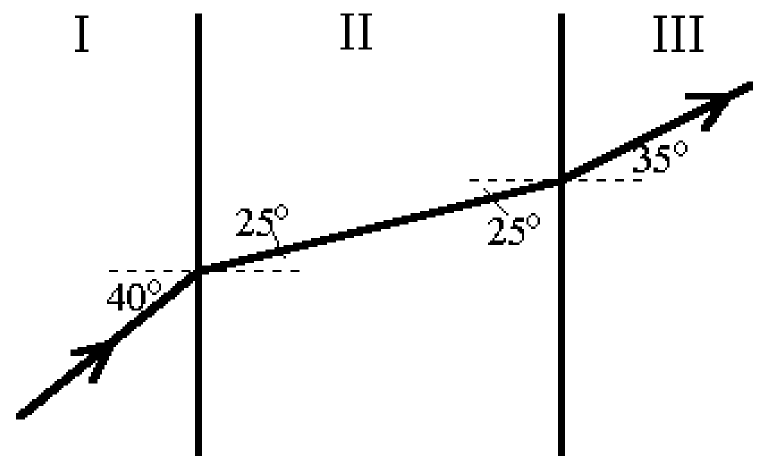
- A ray of light passes through 3 regions labeled I, II, and III, as shown. How do the velocities of regions I and III compare?

a) $V_I > V_{III}$

b) $V_I = V_{III}$

c) $V_I < V_{III}$

d) Impossible to tell



$$\frac{\sin\theta_1}{V_1} = \frac{\sin\theta_2}{V_2}$$

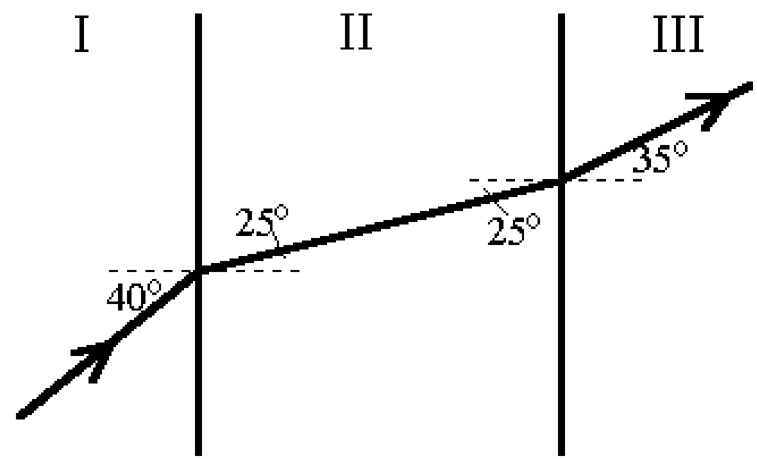
Answer

(a) $V_I > V_{III}$

$$\frac{\sin 40^0}{V_I} = \frac{\sin 25^0}{V_{II}} = \frac{\sin 35^0}{V_{III}}$$

$$\frac{\sin 40^0}{V_I} = \frac{\sin 35^0}{V_{III}}$$

$$\frac{V_I}{V_{III}} = \frac{\sin 40^0}{\sin 35^0} \approx 1.12$$



To-do

- Aufgabenblatt