Introduction to reflection and refraction seismic techniques

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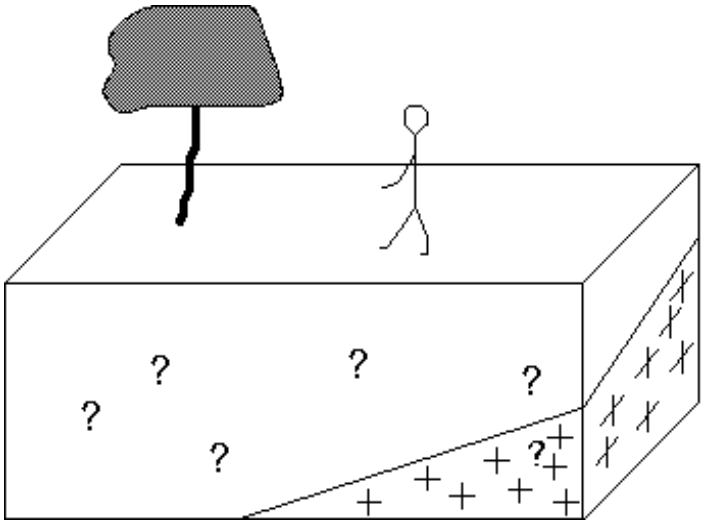
CATENA
CLIMATIC AND TECTONIC NATURAL HAZARDS IN CENTRAL ASIA

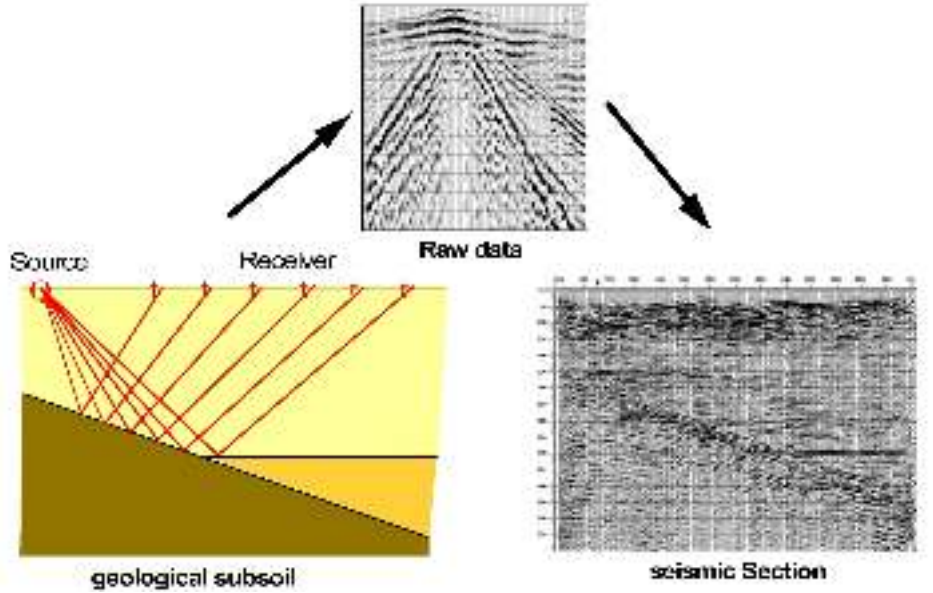
Federal Ministry of Education and Research
CLIENT II
International Partnerships for Sustainable Innovations

CaTeNA Workshop, September 24-25, 2020

Why? Goals & Motivation

- Investigating the unknown subsurface from the surface (or from borehole)
- Observing physical (here: elastic) parameters (i.e. seismic velocities)
- Infer geological structure and processes

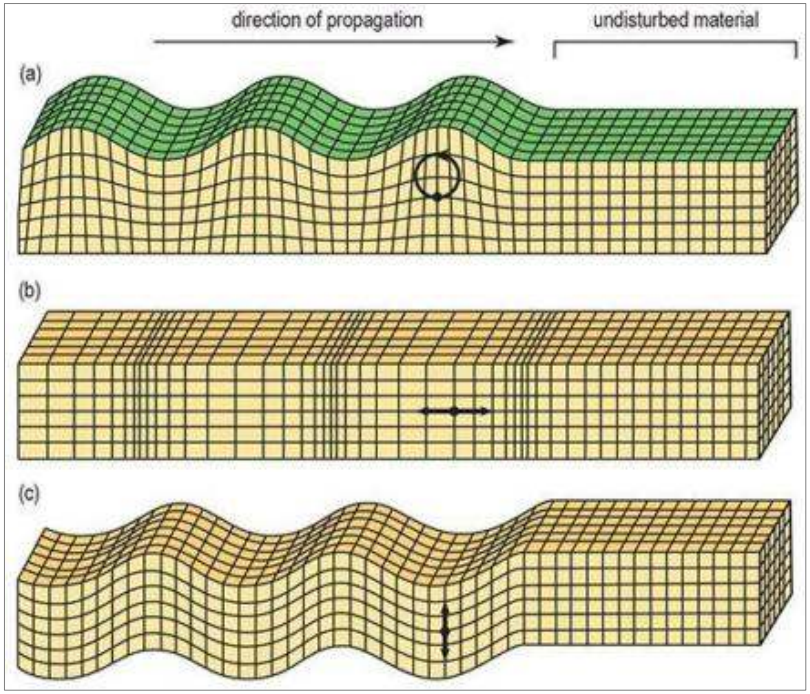




van der Kruk, 2003

Some physics

Elastic wave types



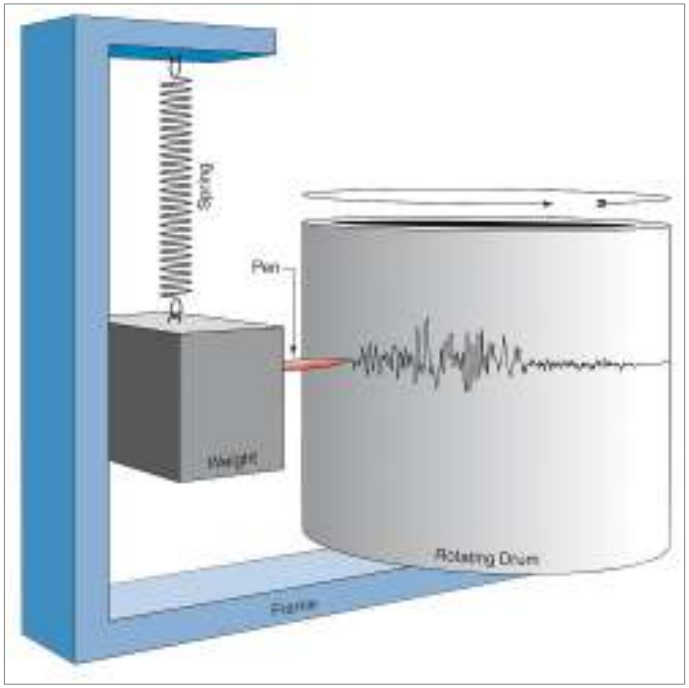
Surface wave

P-wave

S-wave

www.earthquakesreport.com

Seismometer principle

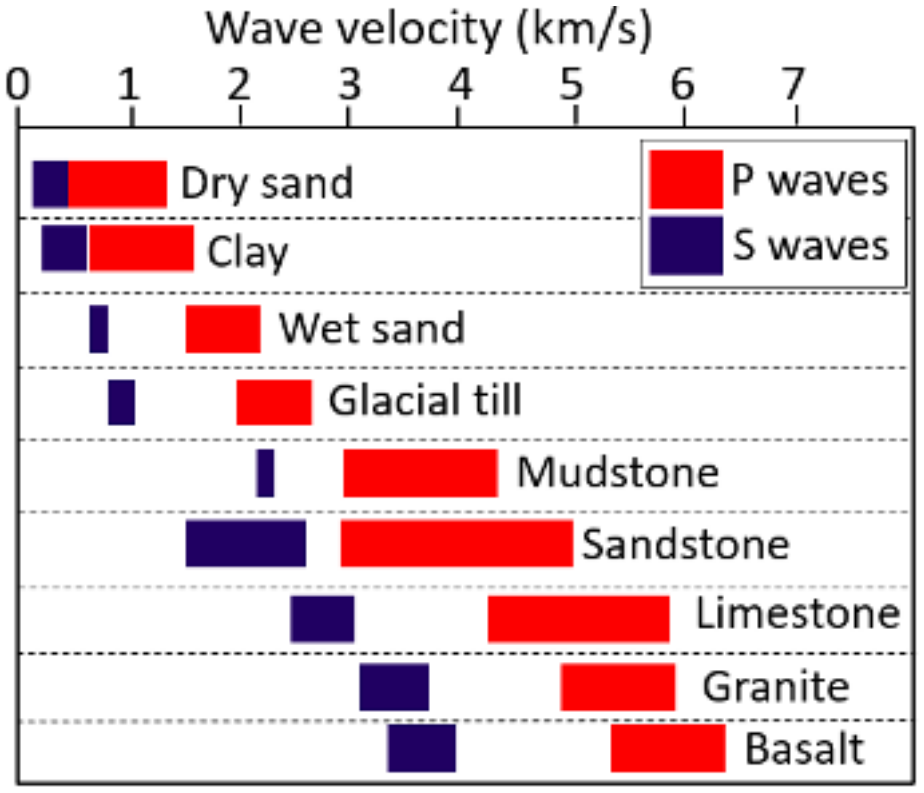


+ adding damping and electro-mechanical recording system...

www.faulhaber.com

… some more (rock) physics

	km/sec
Unconsolidated materials	
Sand (dry)	0.2–1.0
Sand (water saturated)	1.5–2.0
Clay	1.0–2.5
Glacial till (water saturated)	1.5–2.5
Permafrost	3.5–4.0
Sedimentary rocks	
Sandstones	2.0–6.0
Tertiary sandstone	2.0–2.5
Pennant sandstone (Carboniferous)	4.0–4.5
Cambrian quartzite	5.5–6.0
Limestones	2.0–6.0
Cretaceous chalk	2.0–2.5
Jurassic oolites and bioclastic limestones	3.0–4.0
Carboniferous limestone	5.0–5.5
Dolomites	2.5–6.5
Salt	4.5–5.0
Anhydrite	4.5–6.5
Gypsum	2.0–3.5
Igneous/Metamorphic rocks	
Granite	5.5–6.0
Gabbro	6.5–7.0
Ultramafic rocks	7.5–8.5
Serpentinite	5.5–6.5
Pore fluids	
Air	0.3
Water	1.4–1.5
Ice	3.4
Petroleum	1.3–1.4
Other materials	
Steel	6.1
Iron	5.8
Aluminium	6.6
Concrete	3.6



https://opentextbc.ca

Further influences by temperature, fluid/gas saturation, pressure etc.!

Analogy to medicine

Echo-Sonograph

www.lifeline.de

Reflection seismics

Reflection of signals („mirror“)

X-ray (Roentgen)

Refraction Seismics/ tomography

First "medical" X-ray, wikipedia

Transmission / refraction

Small sources

Manual hammer

Kyrgyzstan, 2019

- Impulsive source
- For shallow depths
- Engineering applications soil investigation, building ground
- Easy to use
- Highly transportible, robust

Weight drop

Weightdrop

GIPP / Haberland

FFWD-GX II;
https://geoexpert.ch

https://www.iris.edu

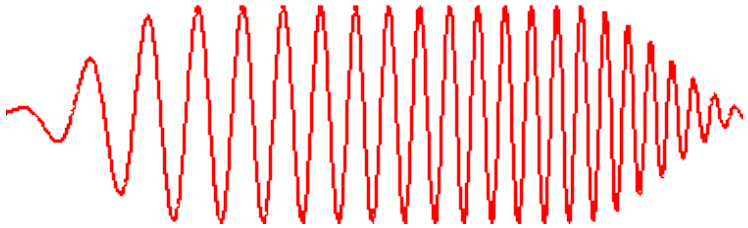
- Impulsive source
- Accellerated
- For depths <2500m
- „reservoir scale“
- Easy to handle, transportable
- robust

https://geoexpert.ch

Vibroseis

- Non-impulsive source
- Sweep signal
- Standard in **exploration** (industry; hydrocarbon)
- Frequencies controllable
- Depth range: from few meters to crustal scale
- Transportable, environmentally friendly; small footprint
- Postprocessing: Correlation (this collapses sweep into spike)

Spain 2013



http://web.ics.purdue.edu/~braile/sage/ShortCourseNotes.6.A.Vibroseis.pdf

www.leibnitz-liag.de

Big Sources...

Refraction work, 2017

- Chemical explosions
- Impulsive source
- Crustal scale, large distances
- Small charges: Exploration
- Up tp 1t / shot
- Needs drilling
- Difficulties: Permits, high costs, safety issues, environmentally critical

http://www.drillingrigts.com

Sensors/Receivers/Recording

Geophone chains

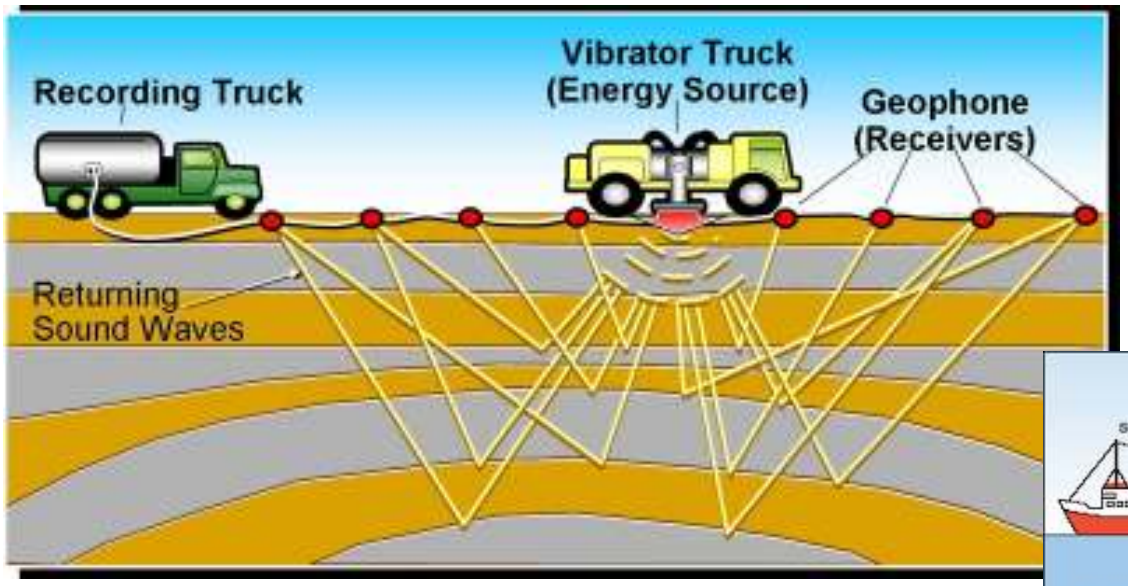
1C geophone

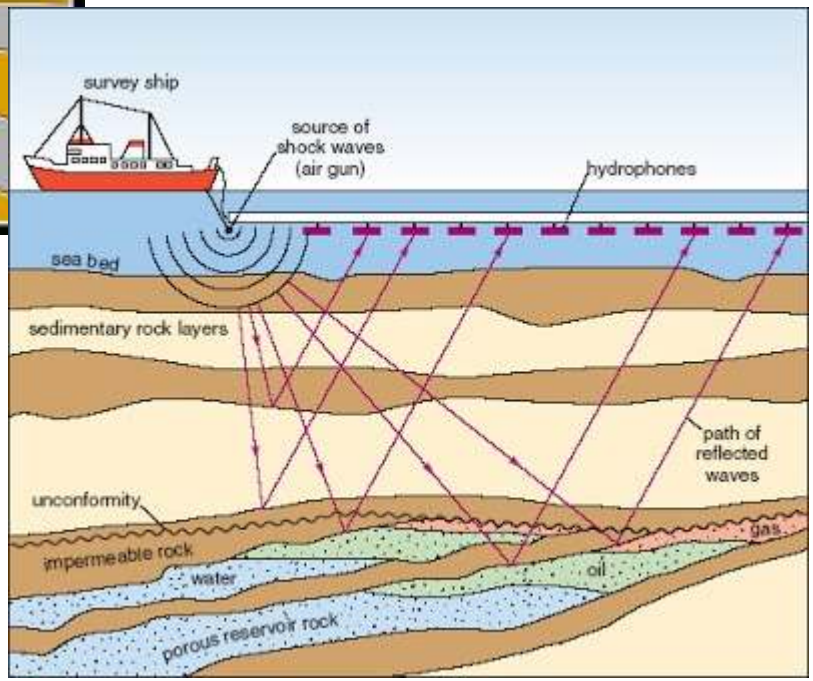
Stand-alone recorders

3C geophones

Cable-base / multichannel

Acquisition

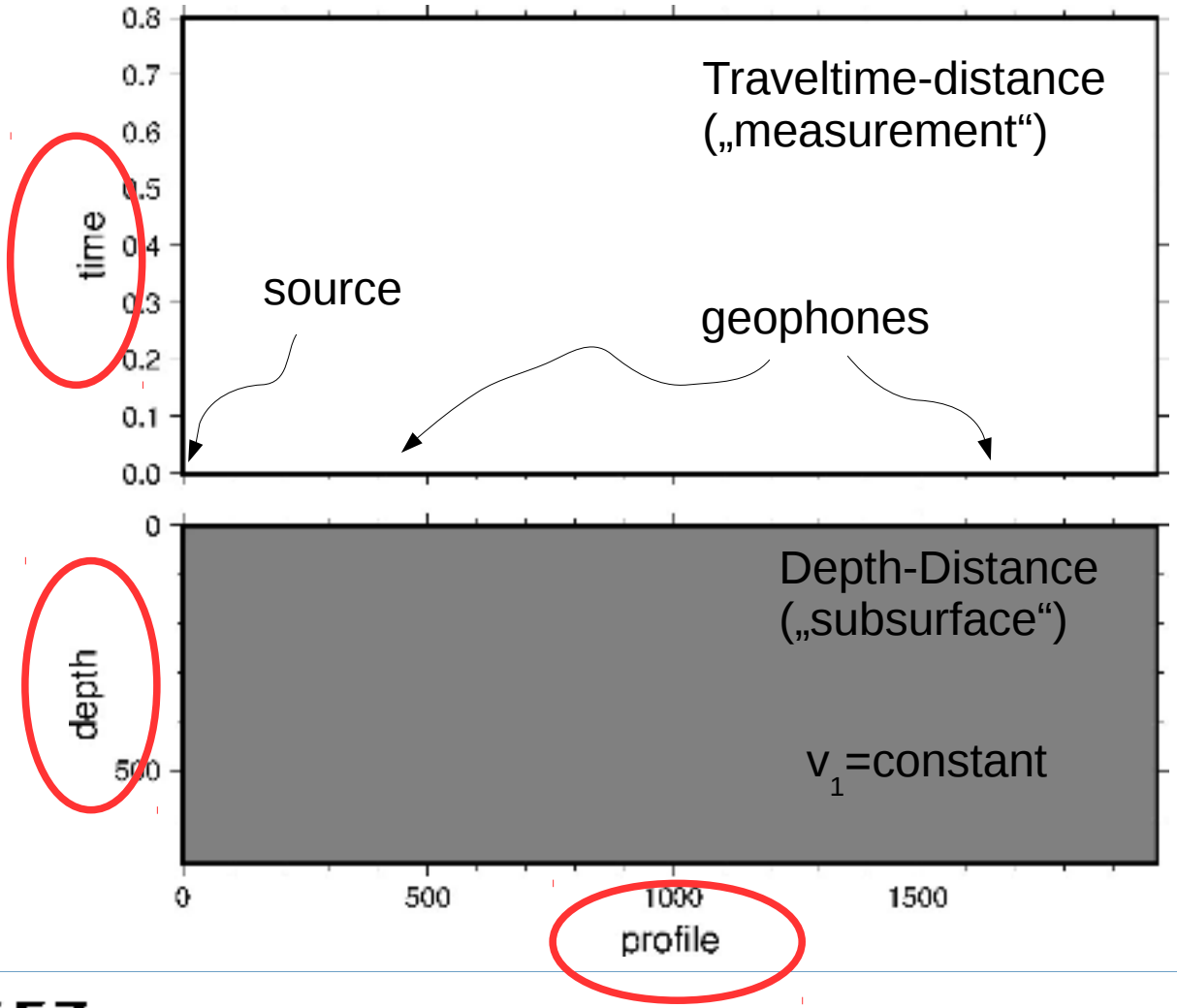




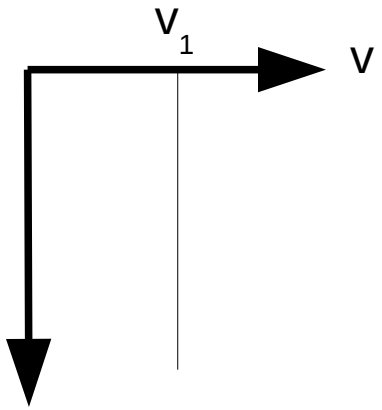
- Deployment of many receivers and (many) sources
- Linear (2-D) or areal (3-D) deployments
- Land or sea

http://geologylearn.blogspot.com

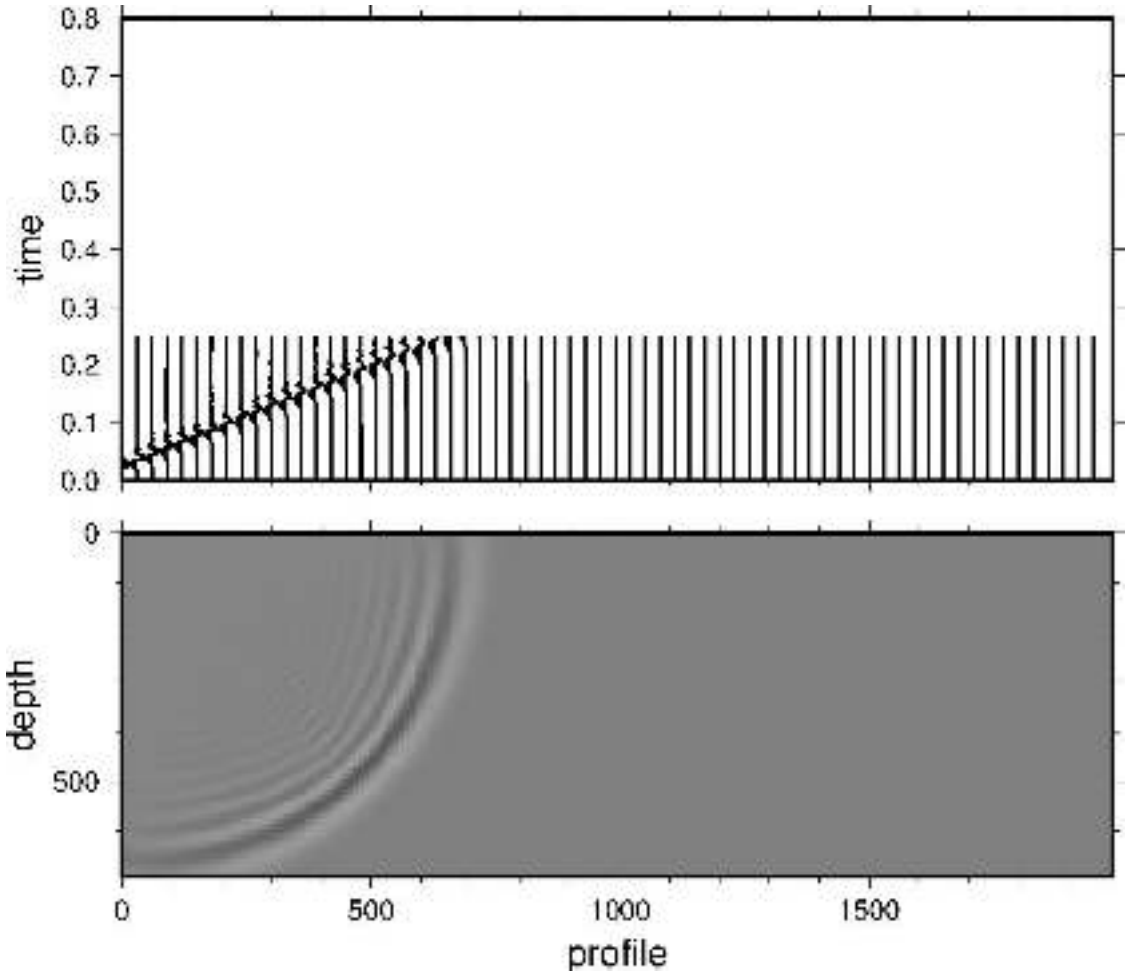
Homogeneous halfspace



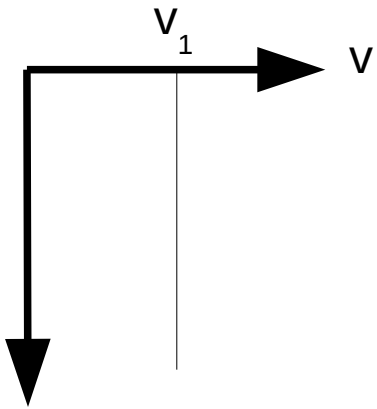
- Simple model: homogeneous halfspace
- Source at surface
- Receivers (geophones) at surface



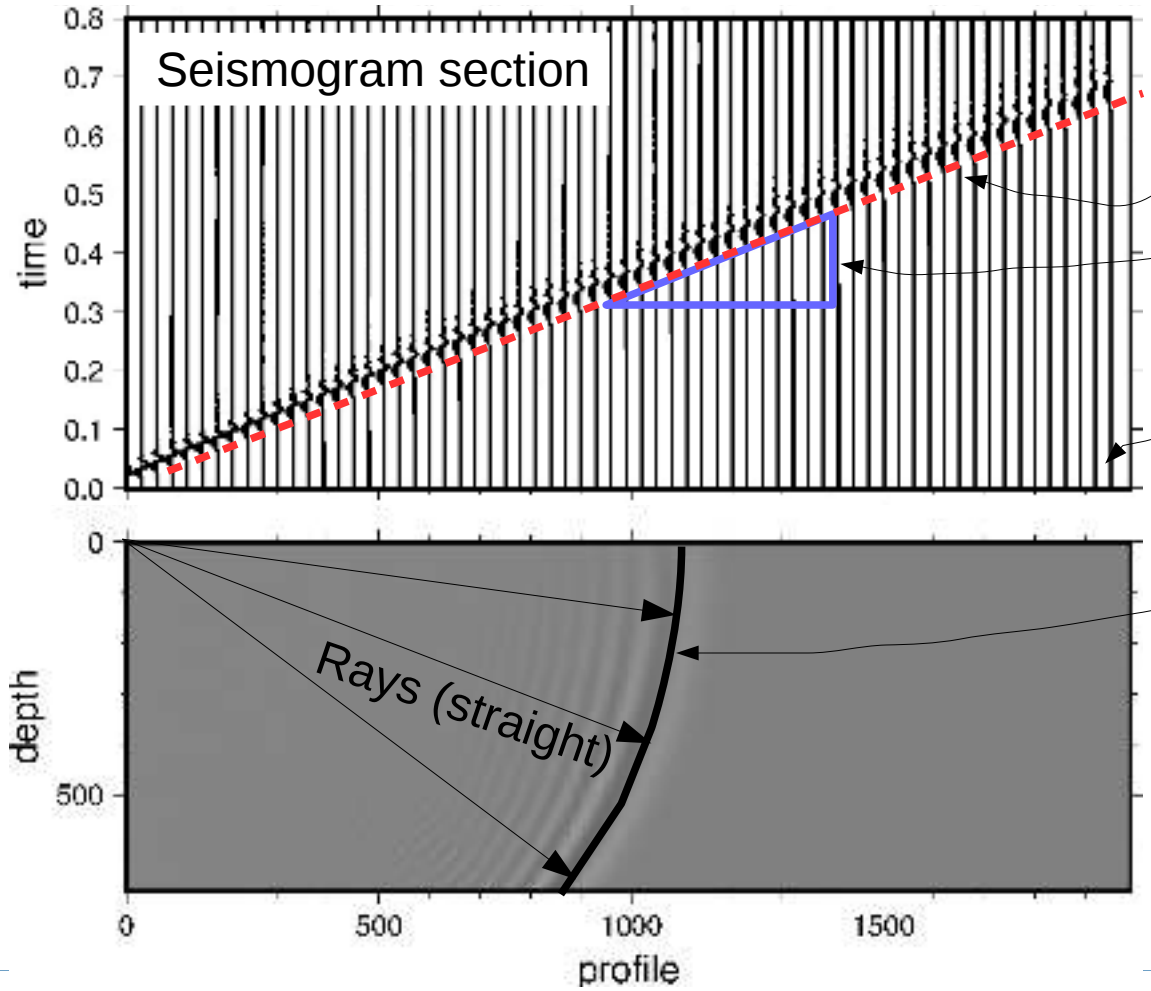
Homogeneous halfspace



- Simple model: homogeneous halfspace
- Source at surface
- Receivers (geophones) at surface
- Similar to waves on the water...



Homogeneous halfspace



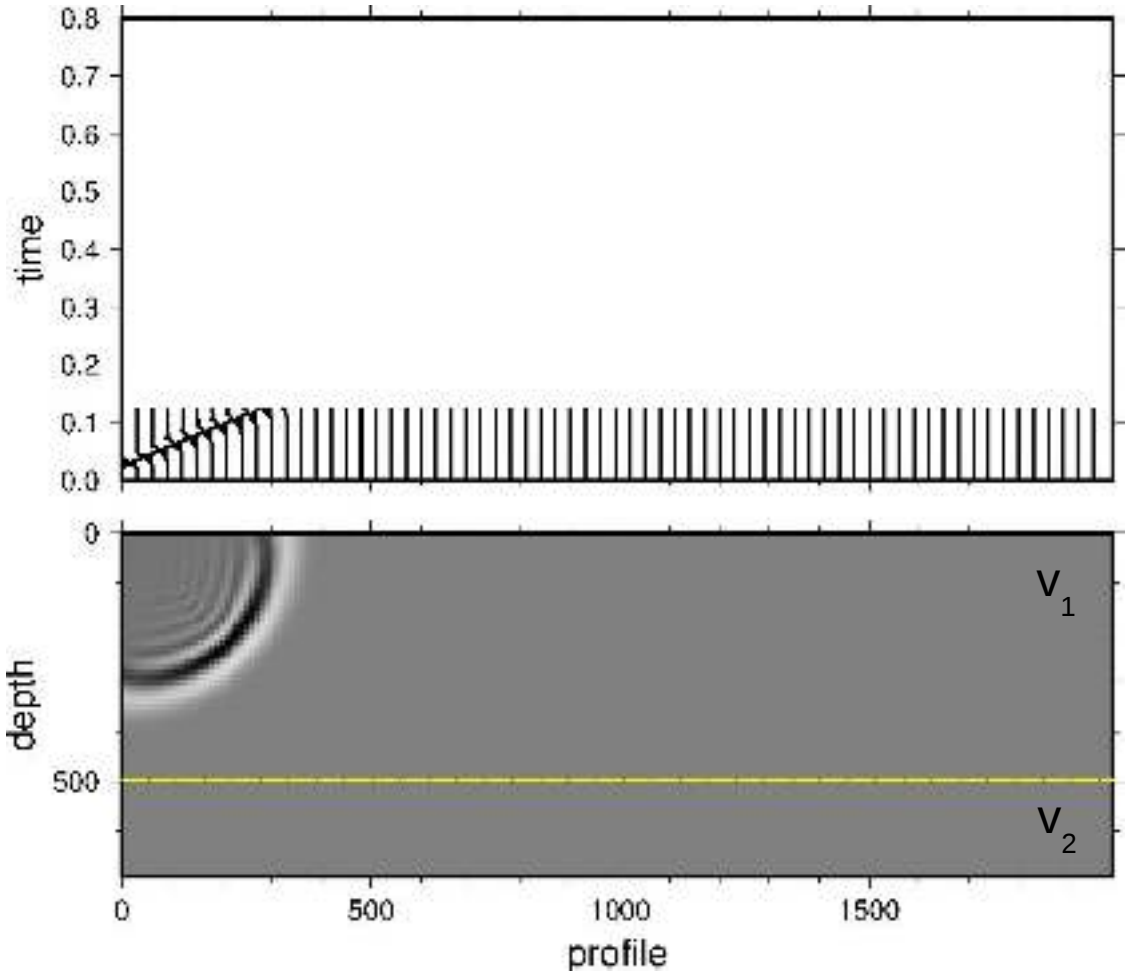
Traveltime-curve of **direct wave** (straight line)

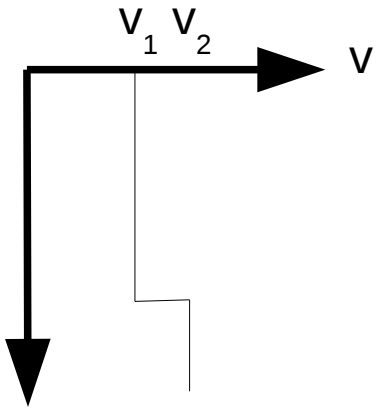
Slope == 1/velocity

Each line == seismogram

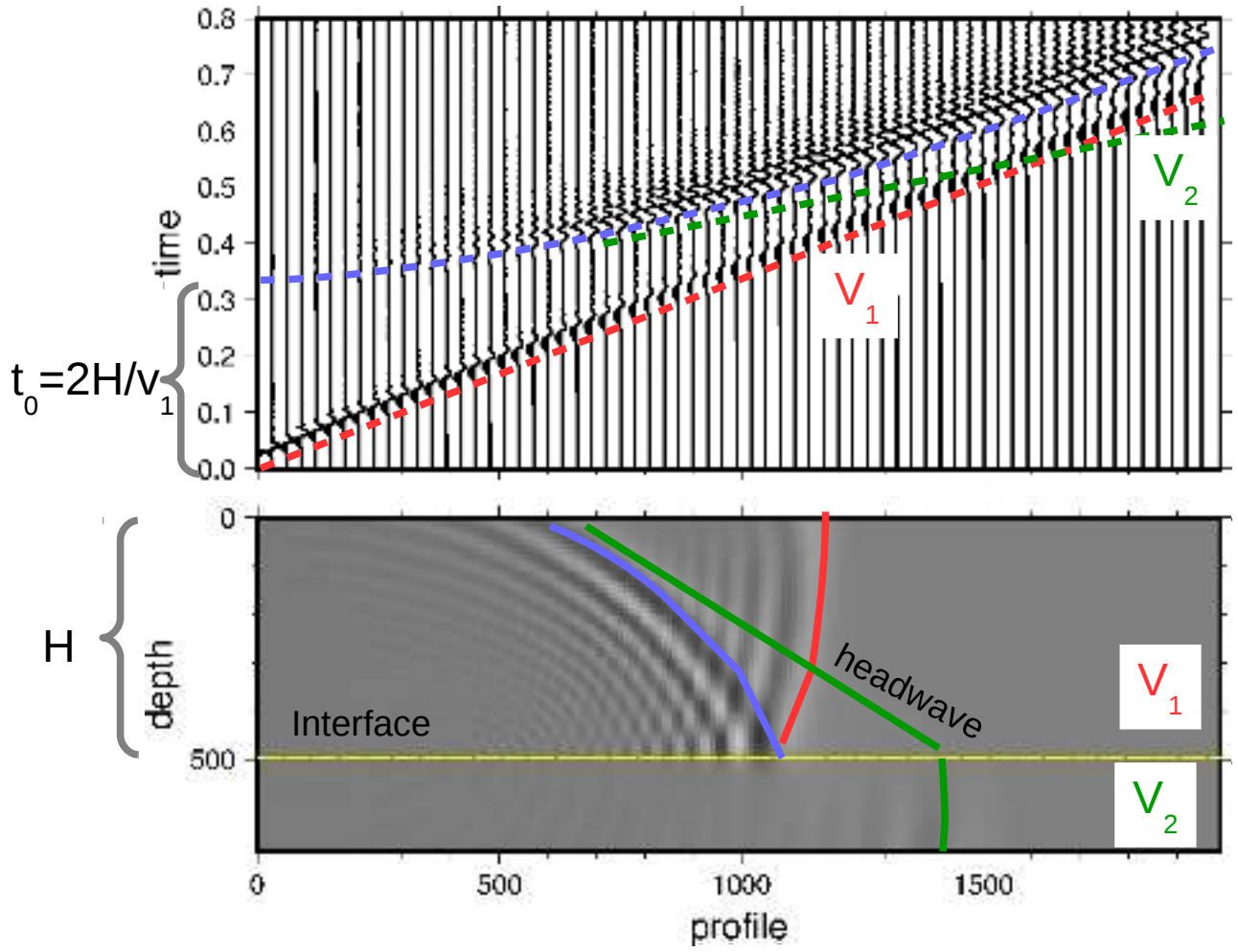
Wavefront of **direct wave** (circle/sphere)

1 Layer over halfspace





1 Layer over halfspace



Traveltime-curves...

...of **direct wave** (straight line)

...of **reflected wave** (hyperbola)

...of **refracted wave** (straight line)

Wavefronts of...

… **direct wave**

… **reflected wave**

… **refracted wave**

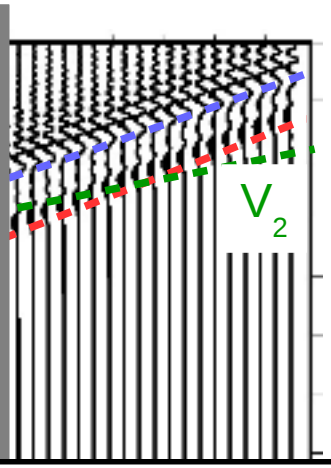
Refraction Seismics

Basics of <u>refraction seismics</u>!
Essential parameters describing the subsurface can be estimated from the measurements (slopes, t_0):

- Depth H of interface
- Seismic velocities of the layers

$t_0=2H$

Applications: (e.g.) Engineering purposes, sledge hammer

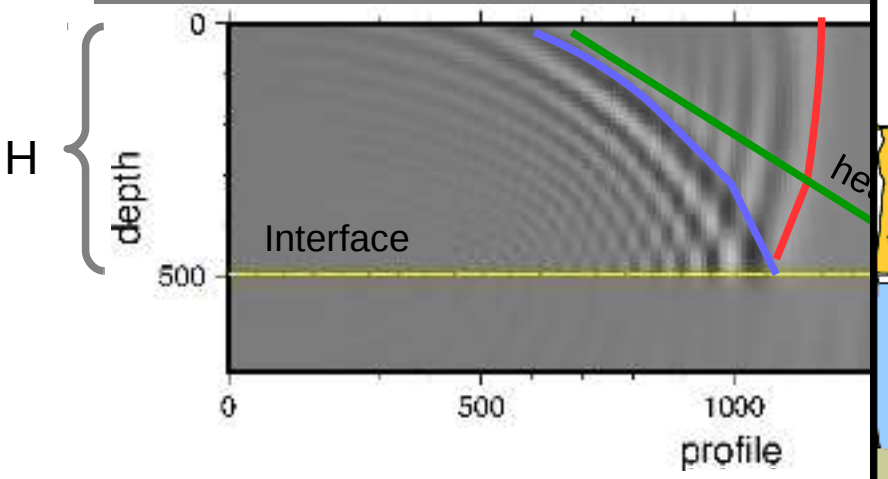


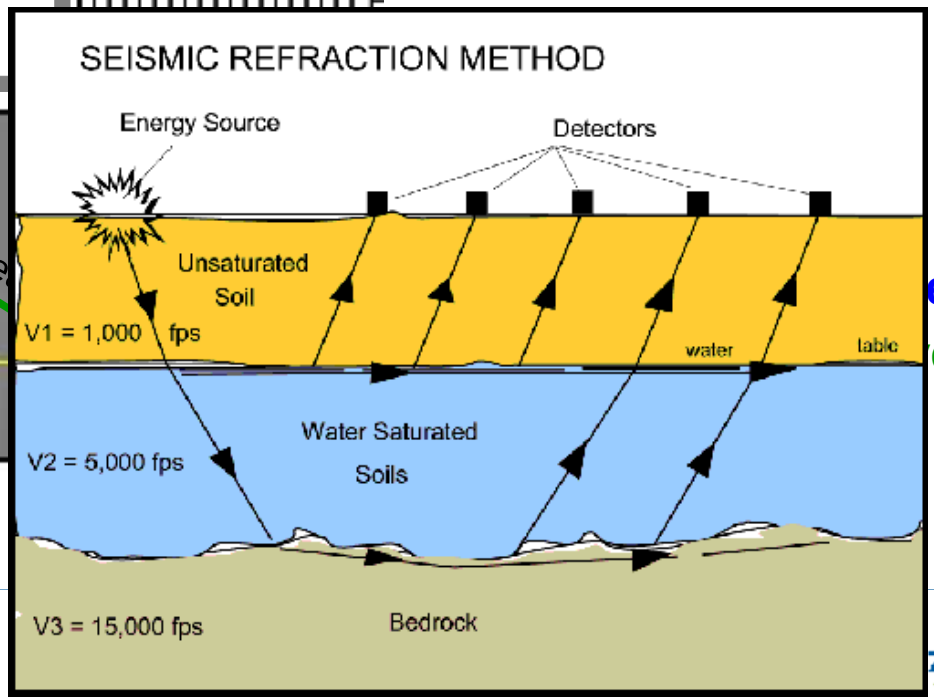
Traveltime-curves...

...of **direct wave** (straight line)

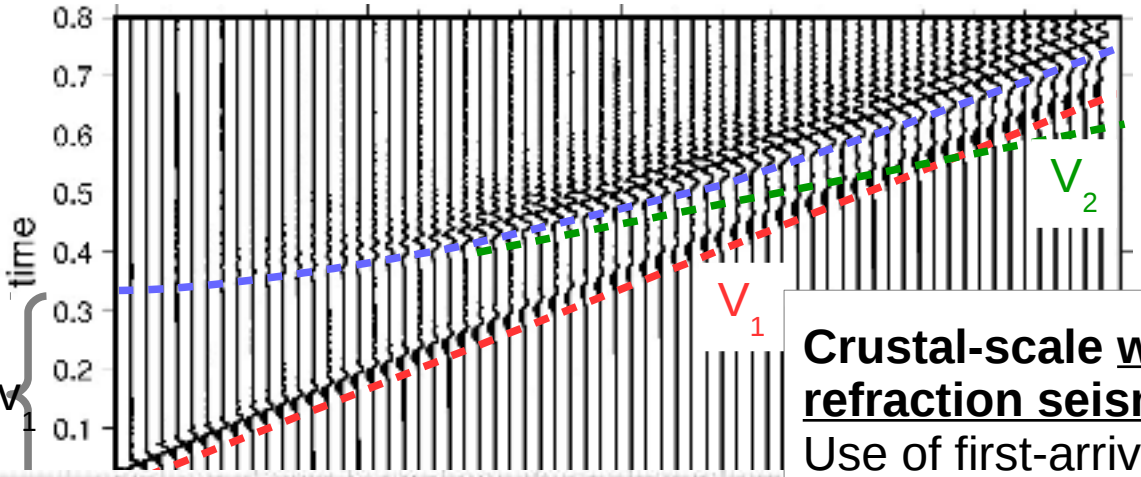
...of **reflected wave** (hyperbola)

...of **refracted wave**





Wideangle-reflection / refraction seismics



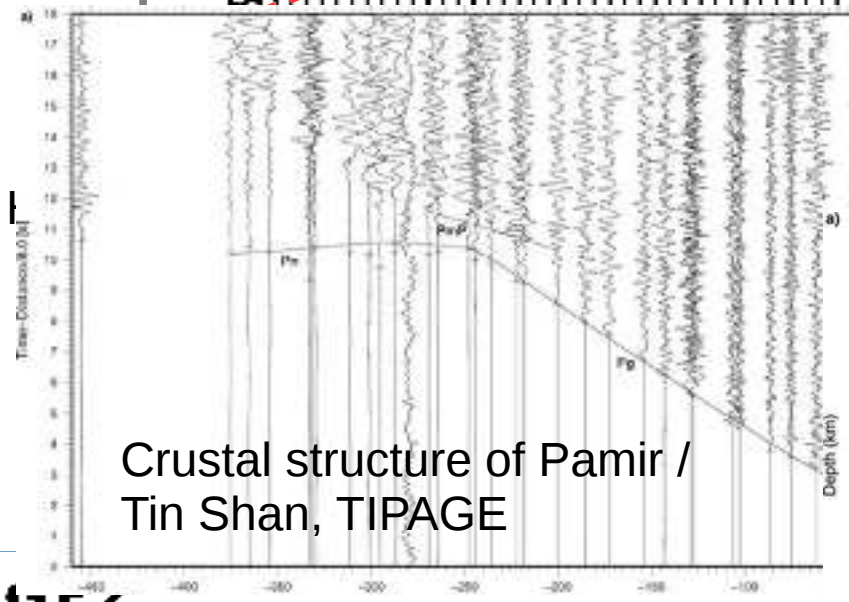
$t_0 = 2H/v_1$

Traveltime-curves...

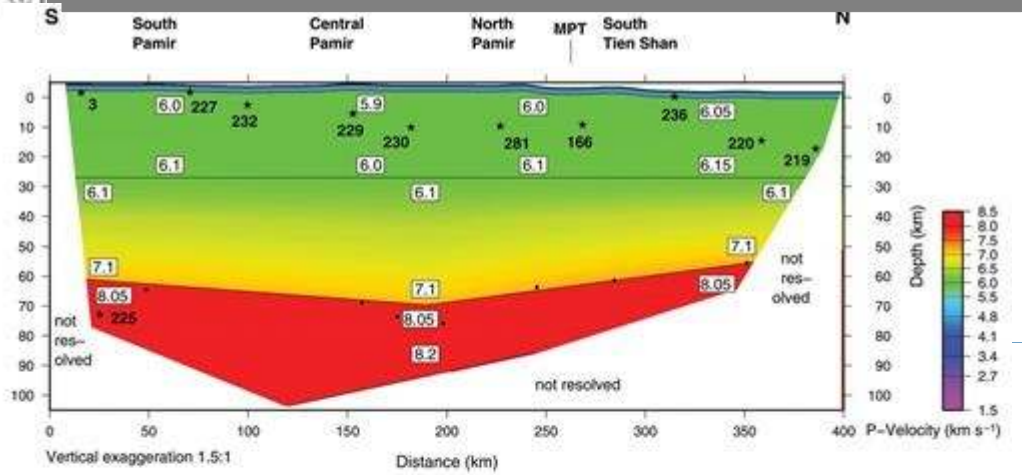
...of **direct wave** (straight line)

...of **reflected wave**

Crustal-scale <u>wideangle reflection and refraction seismics</u>!
Use of first-arrival (direct wave, refracted) and wideangle reflected waves to derive velocity model
(inversion or forward modelling)

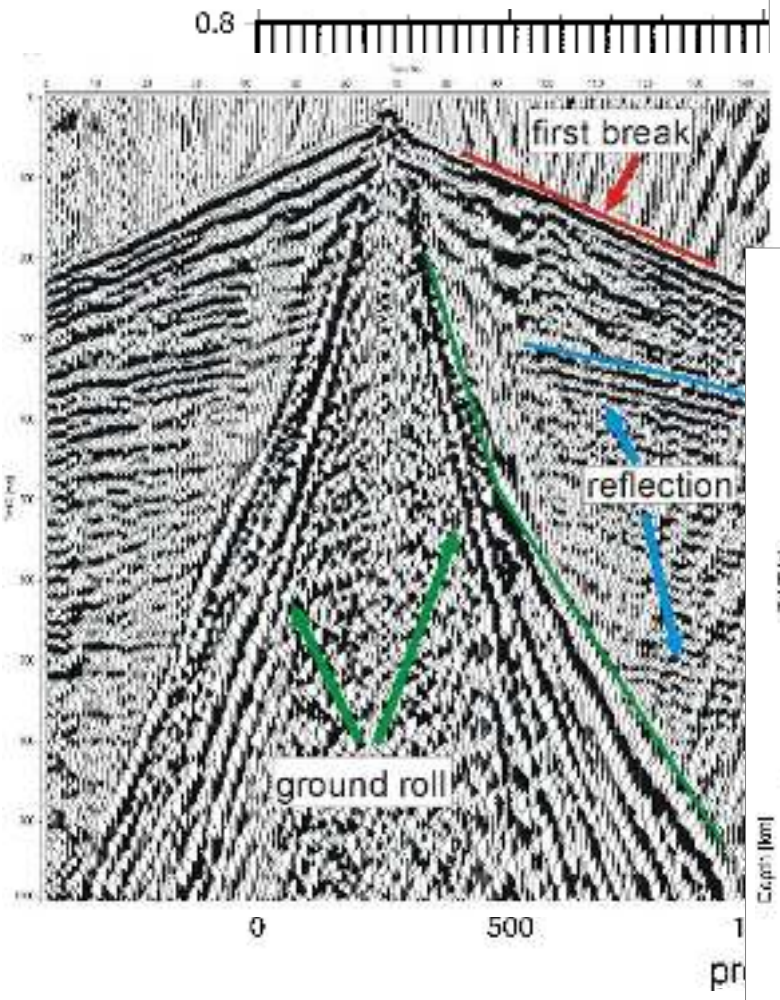


Crustal structure of Pamir / Tin Shan, TIPAGE



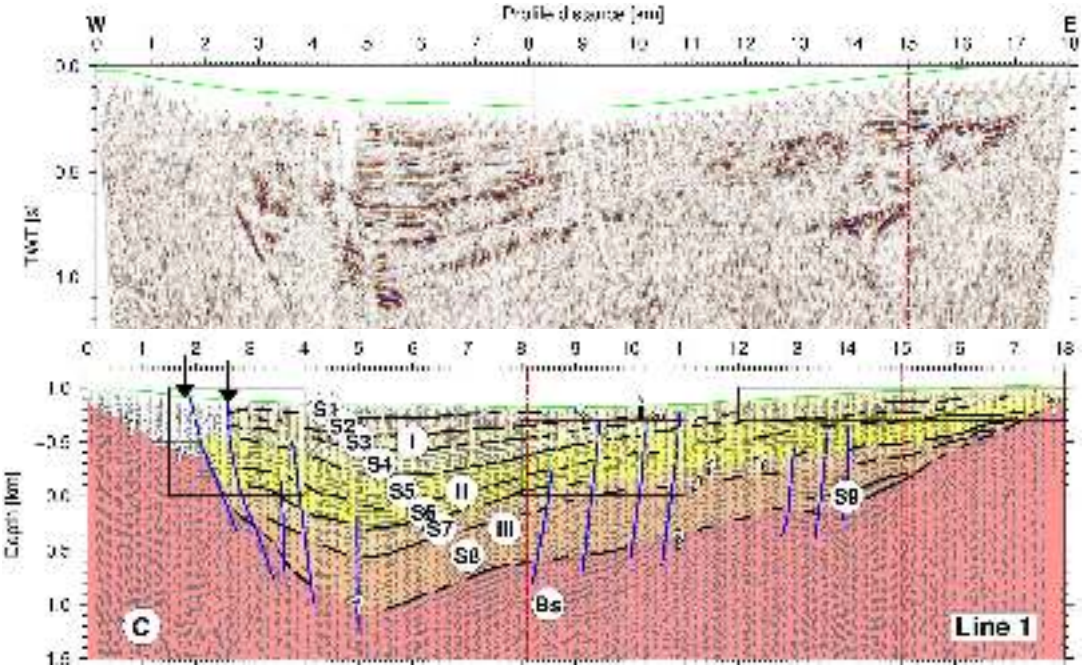
Mechie et al., 2012

Reflection seismics



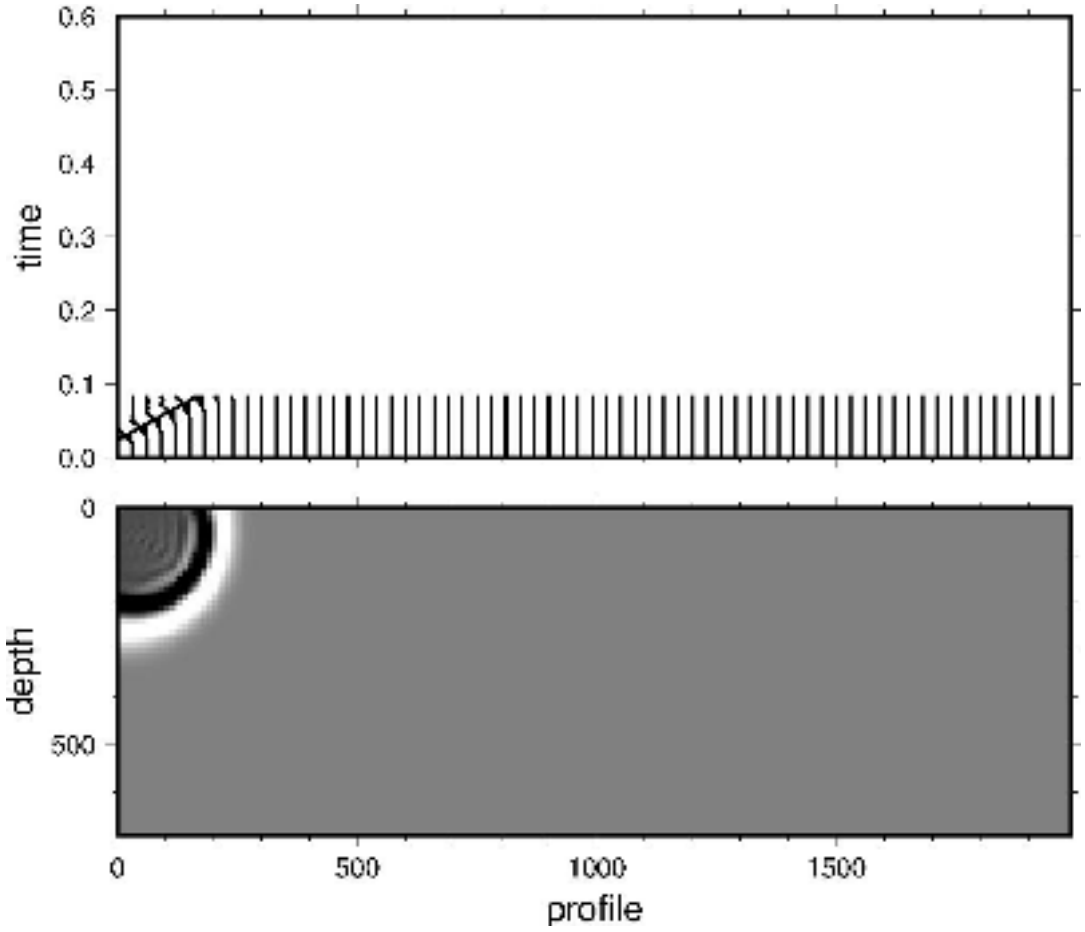
Reflection seismics
Using reflections from short offsets to image subsurface

Imaging of sedimentary basin structure

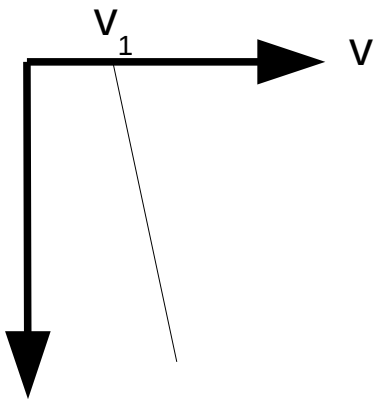


Haberland et al., 2017, Tectonophysics

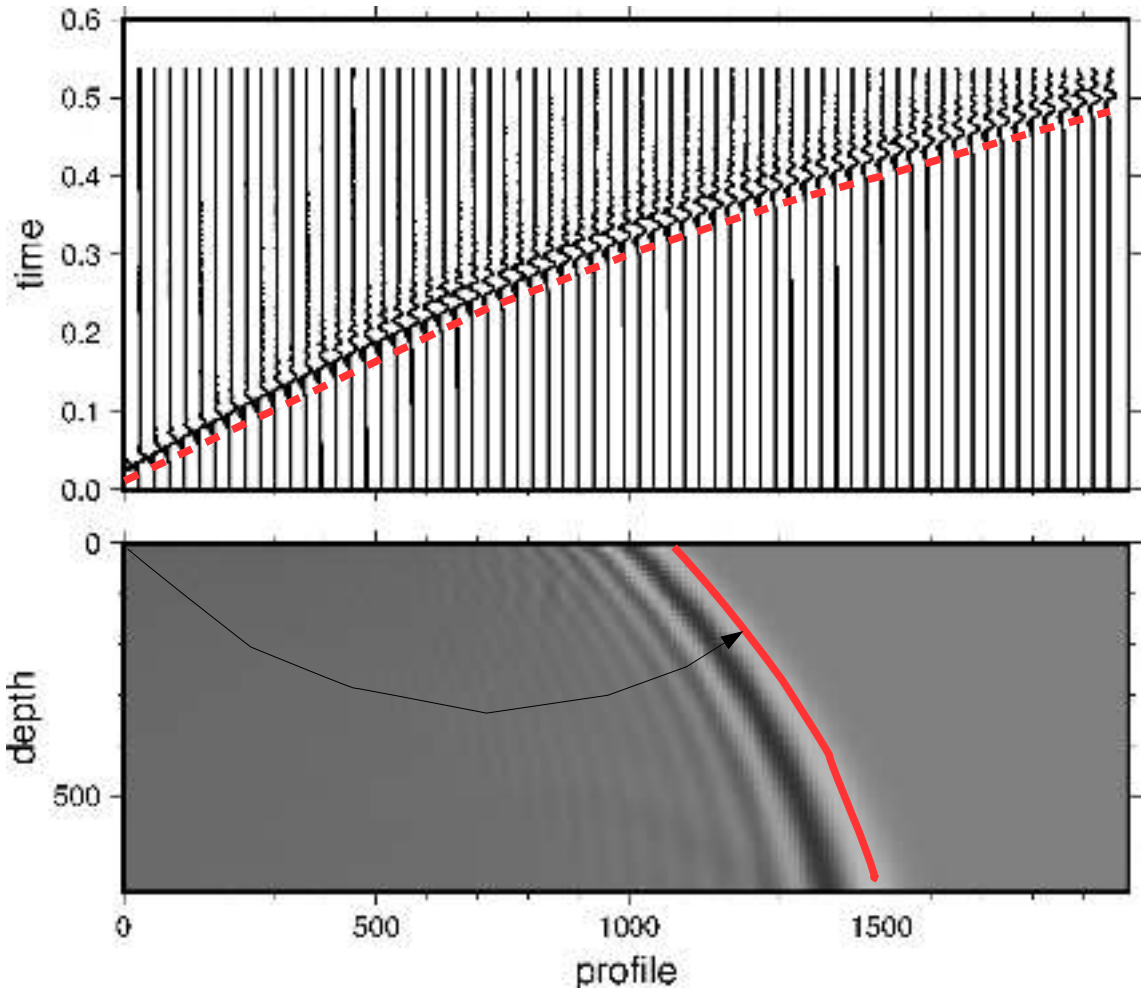
Gradient



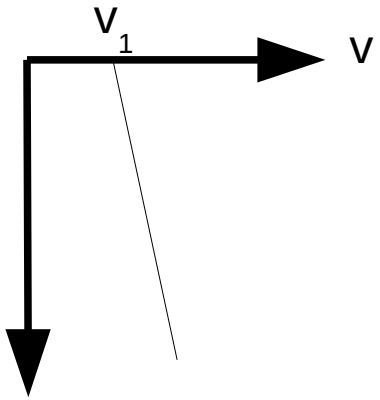
- Gradual increase of velocity (e.g. linear)



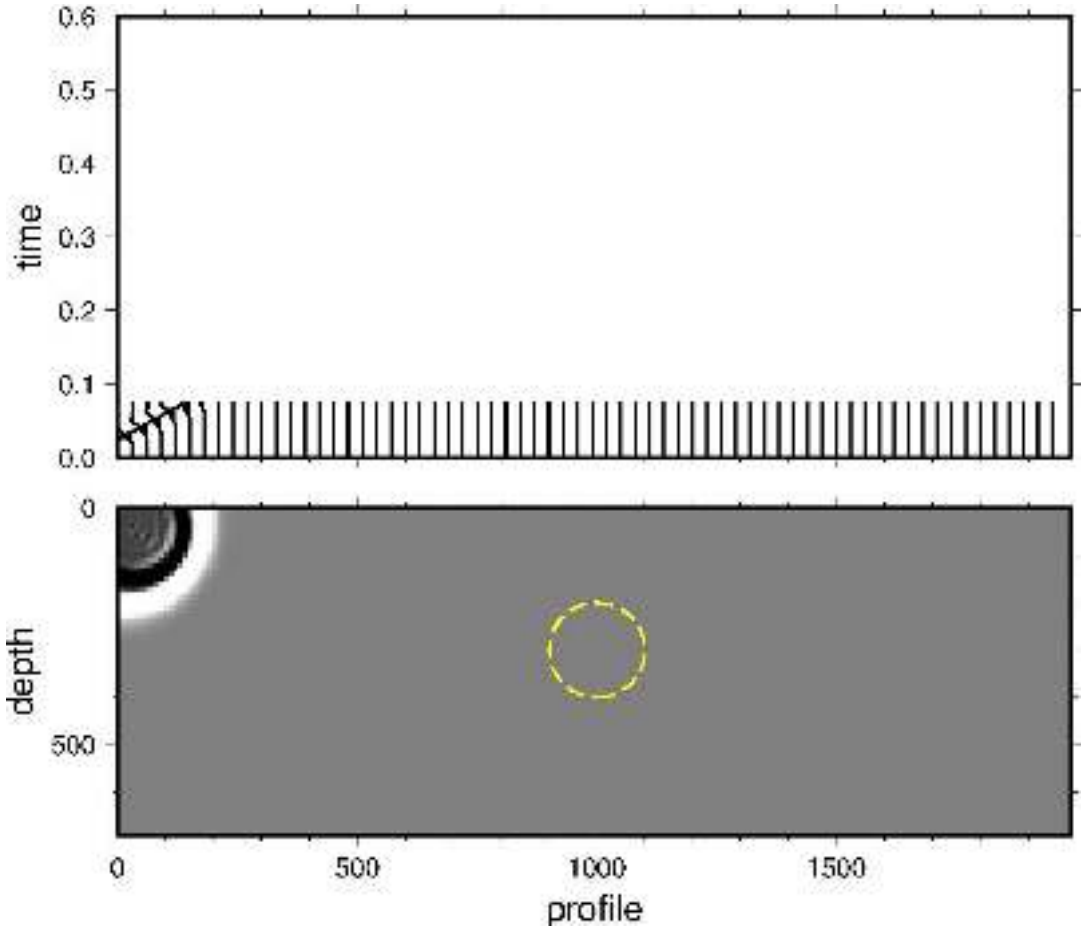
Gradient



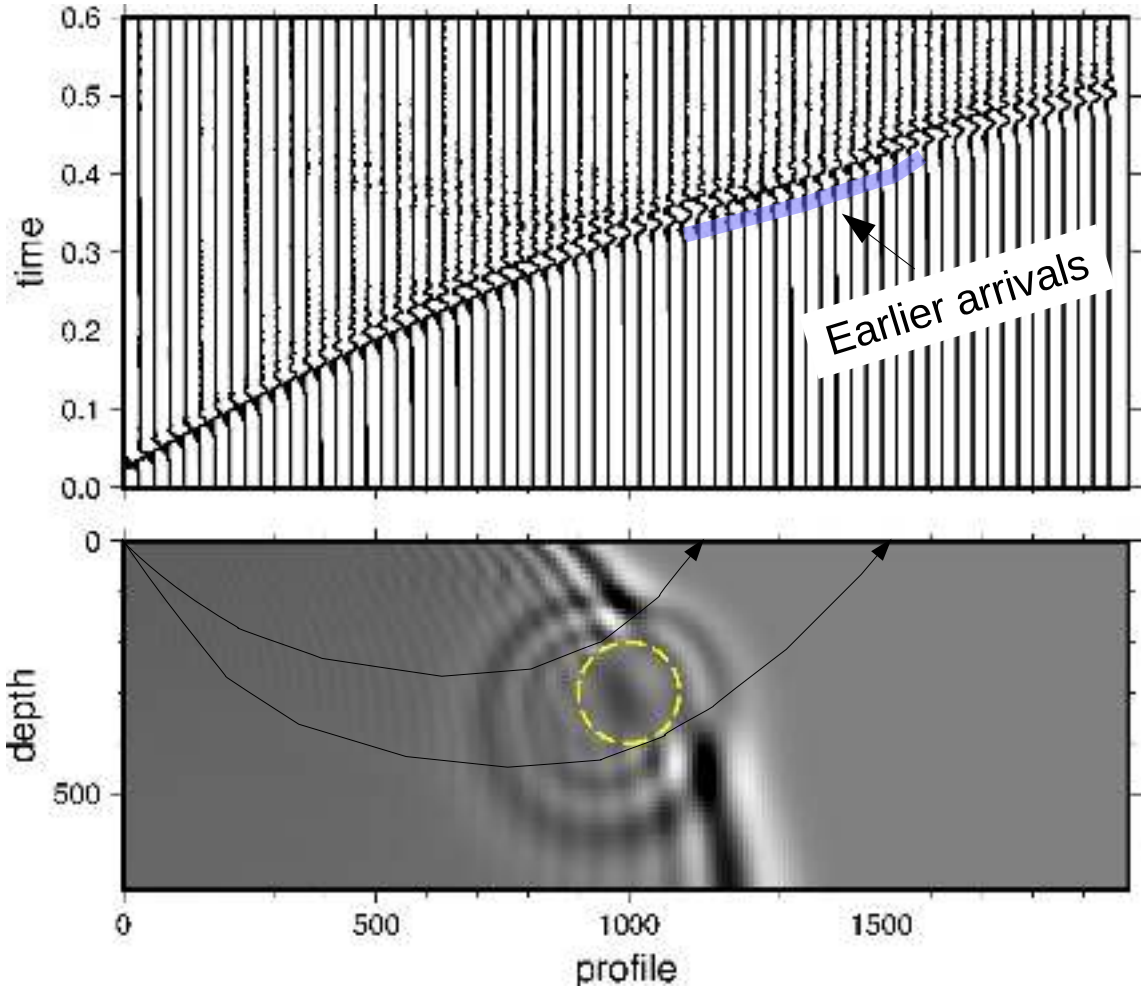
- Curved travel-time curve of direct wave
- Non-circular (spherical) wavefronts
- Curved rays



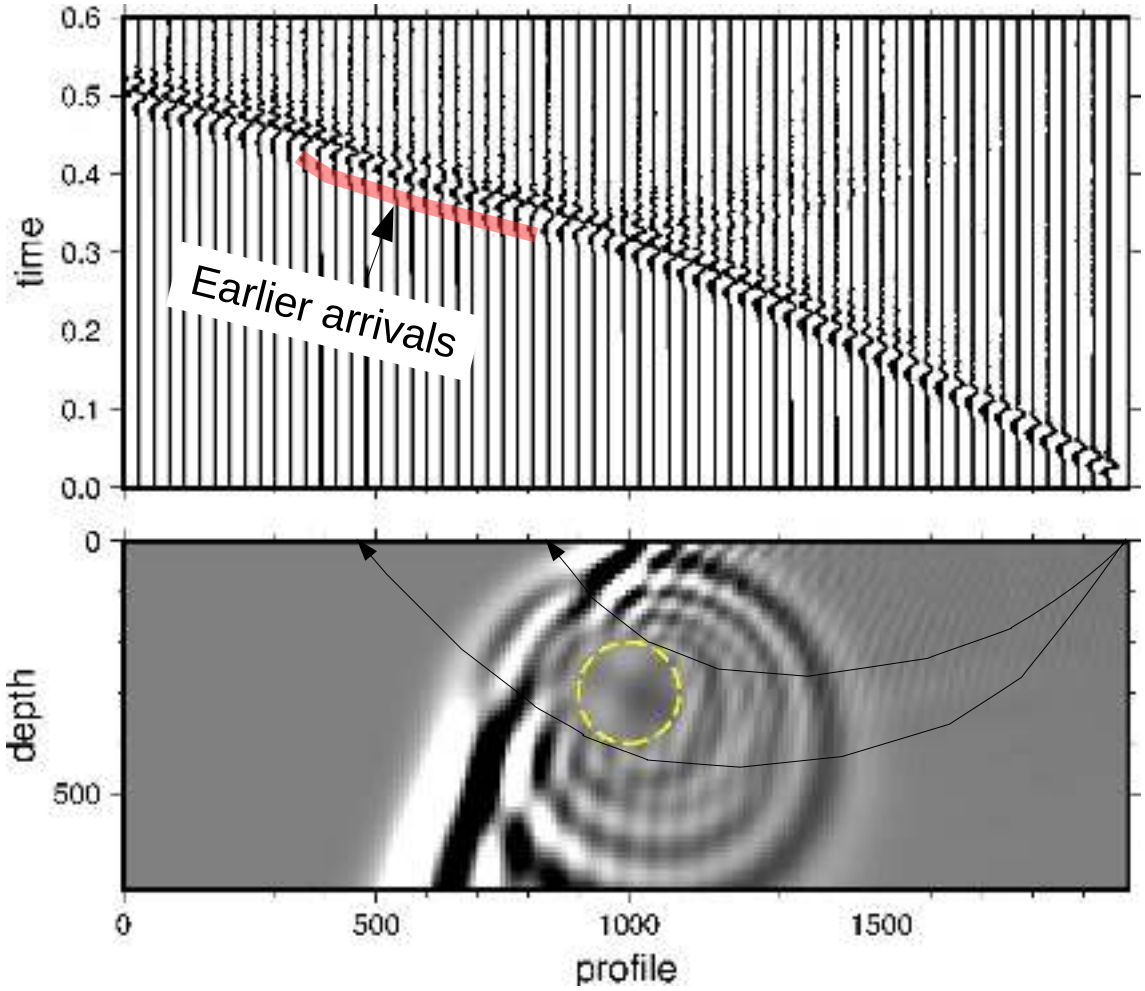
Gradient with anomaly - 1



Gradient with anomaly - 1

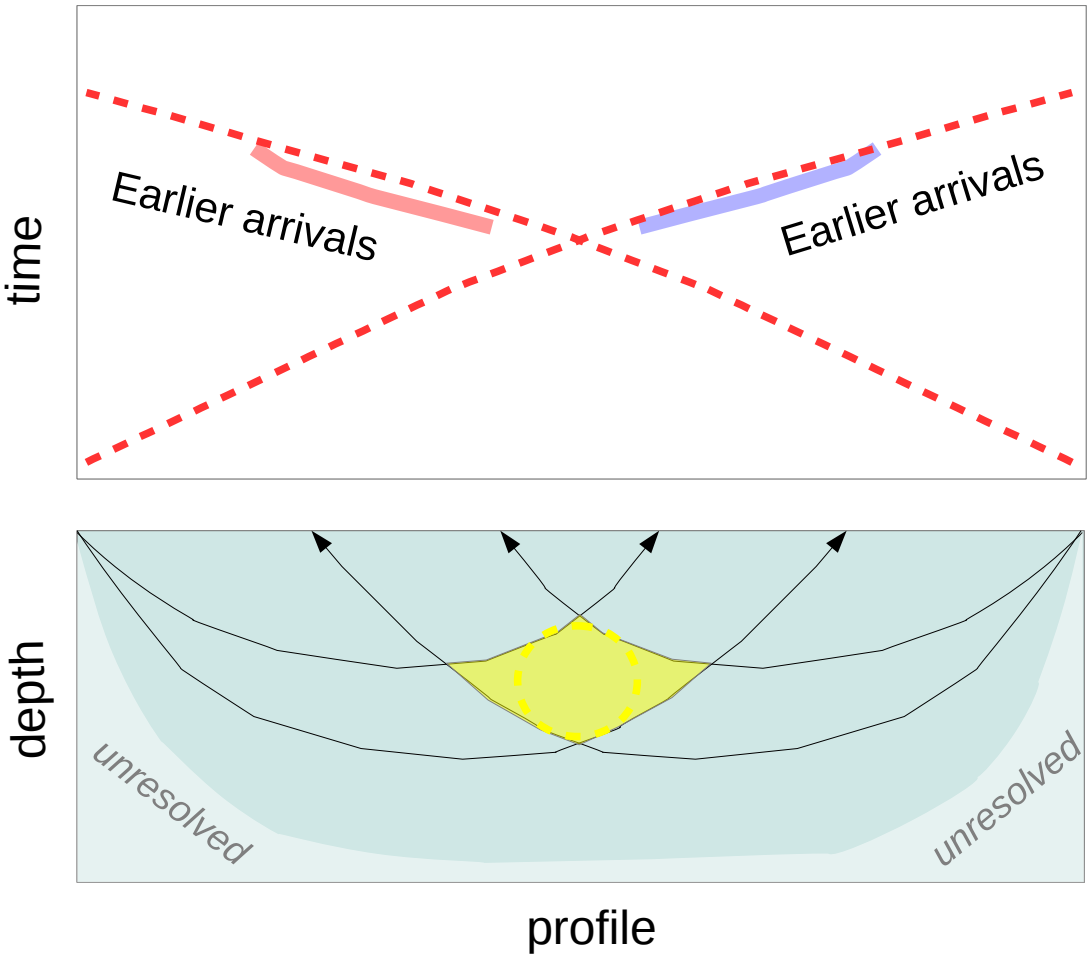


Gradient with anomaly - 2



„Reverse shot“

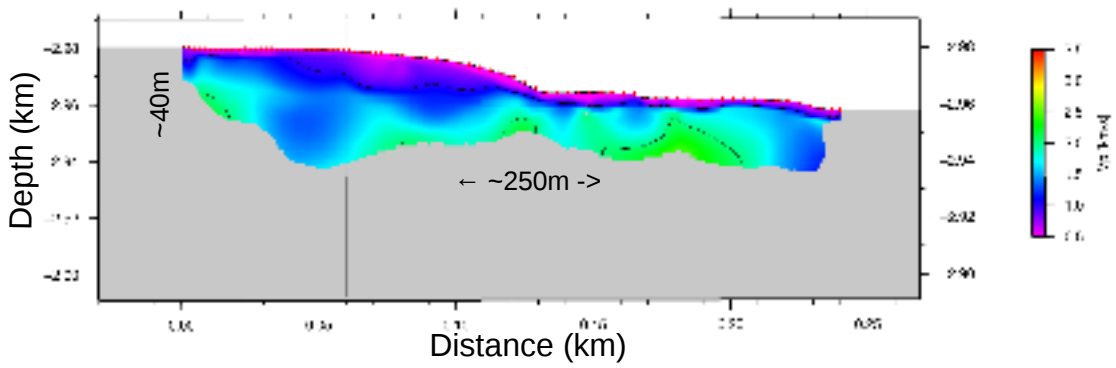
That‘s tomographic imaging!



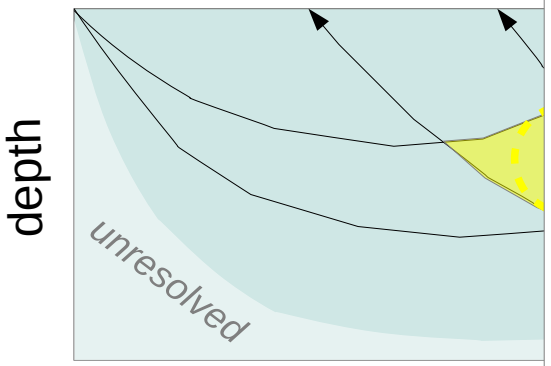
- Tomographic inversion reconstructs the position of the anomaly (using position and time delays of earlier arrivals)
- Mathematical procedure (computer program)
- Smearing can occurr
- Large number of sources and receivers increase the spatial resolution
- There remain unresolved regions
- Resolution has to be checked

That's tomographic imaging!

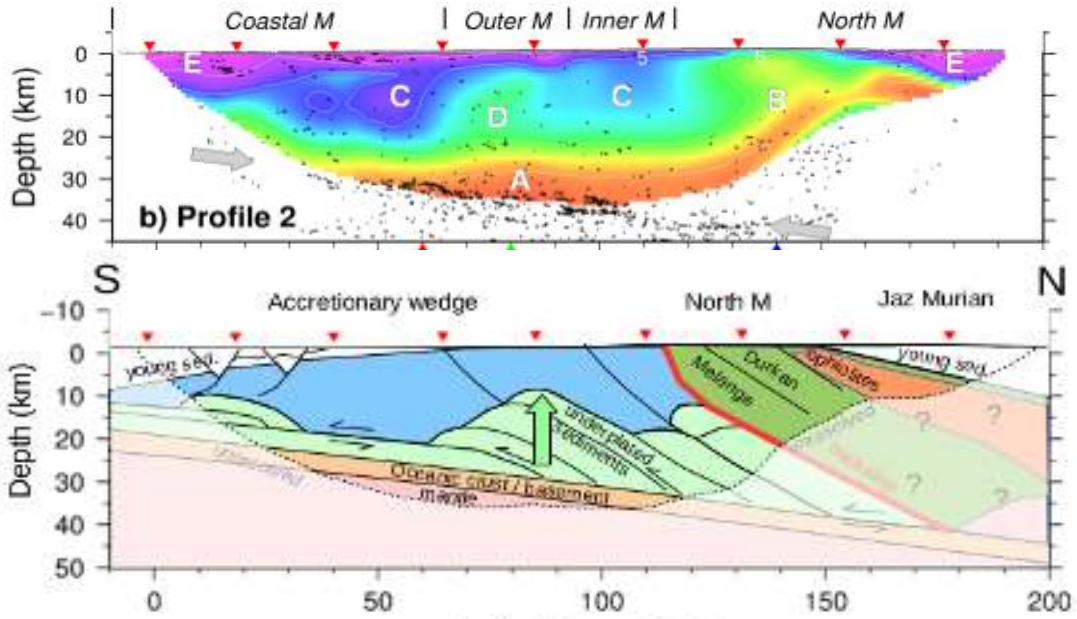
Alai valley, shallow tomography (tomorrow...)



Tomographic inversion reconstructs the position of the anomaly (using position and time delays of earlier arrivals)
Mathematical procedure



Crustal structure of accretionary wedge western Makran



Haberland et al., 2020, Geology

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Helmholtz Zentrum Potsdam

Conclusions

- Powerful methods to image subsurface from the surface
- Usage of different wave types, direct, reflected, refracted
- All scales, from meter-scale to lithospheric scale
- Potentially high resolution; applicable in areas without high earthquake activities
- Big potential for studies in Central Asia
- Tomorrow presentation of shallow study in Alai Valley

Thank you for your attention!