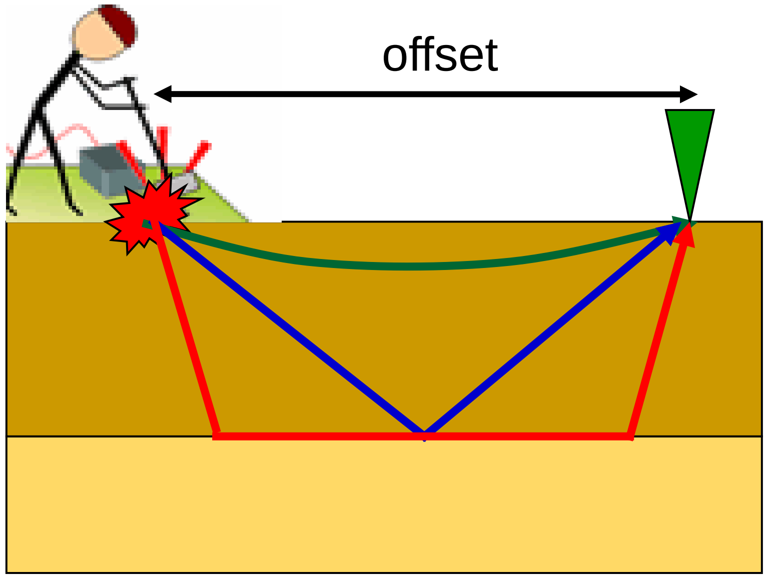
Survey

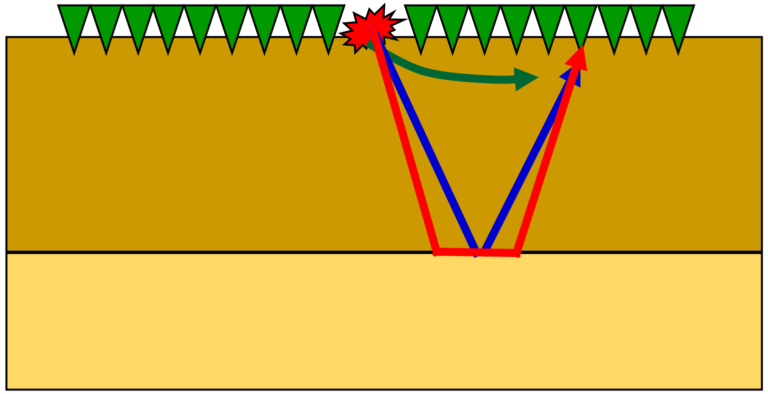
Reading on the GPG:

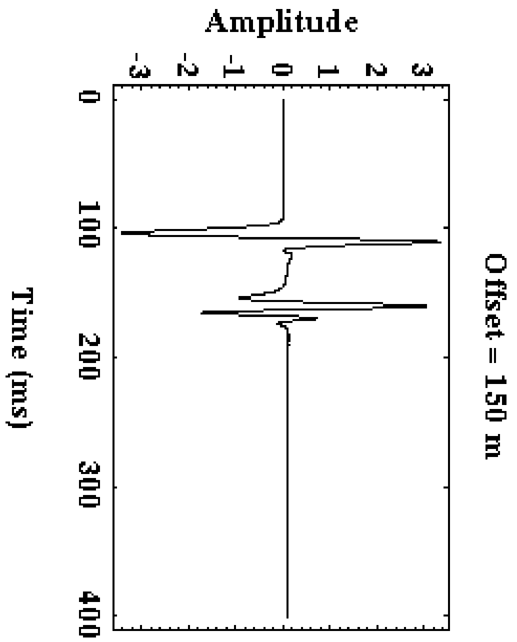
https://gpg.geosci.xyz/content/seismic/seismic_survey.html

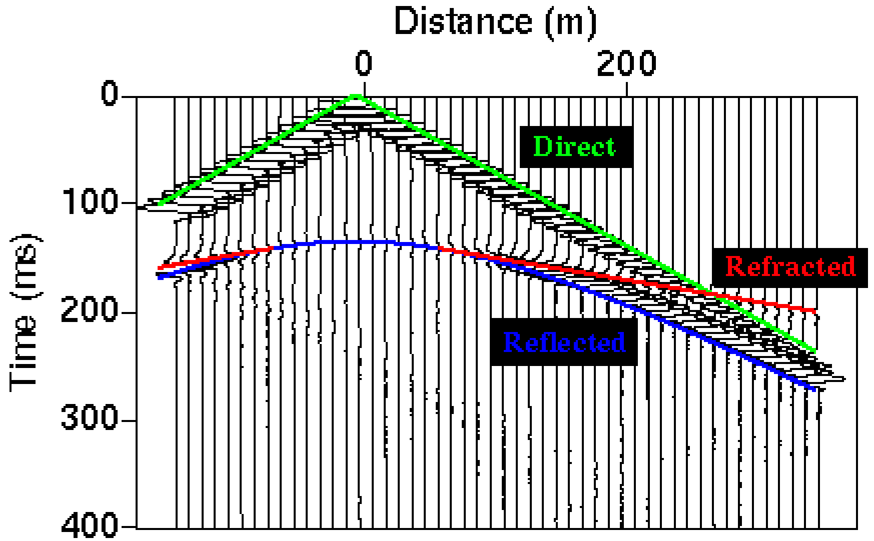
Seismic survey

- From the source energy spreads in all directions
  - Direct to geophones
  - Reflected or refracted off earth interfaces.









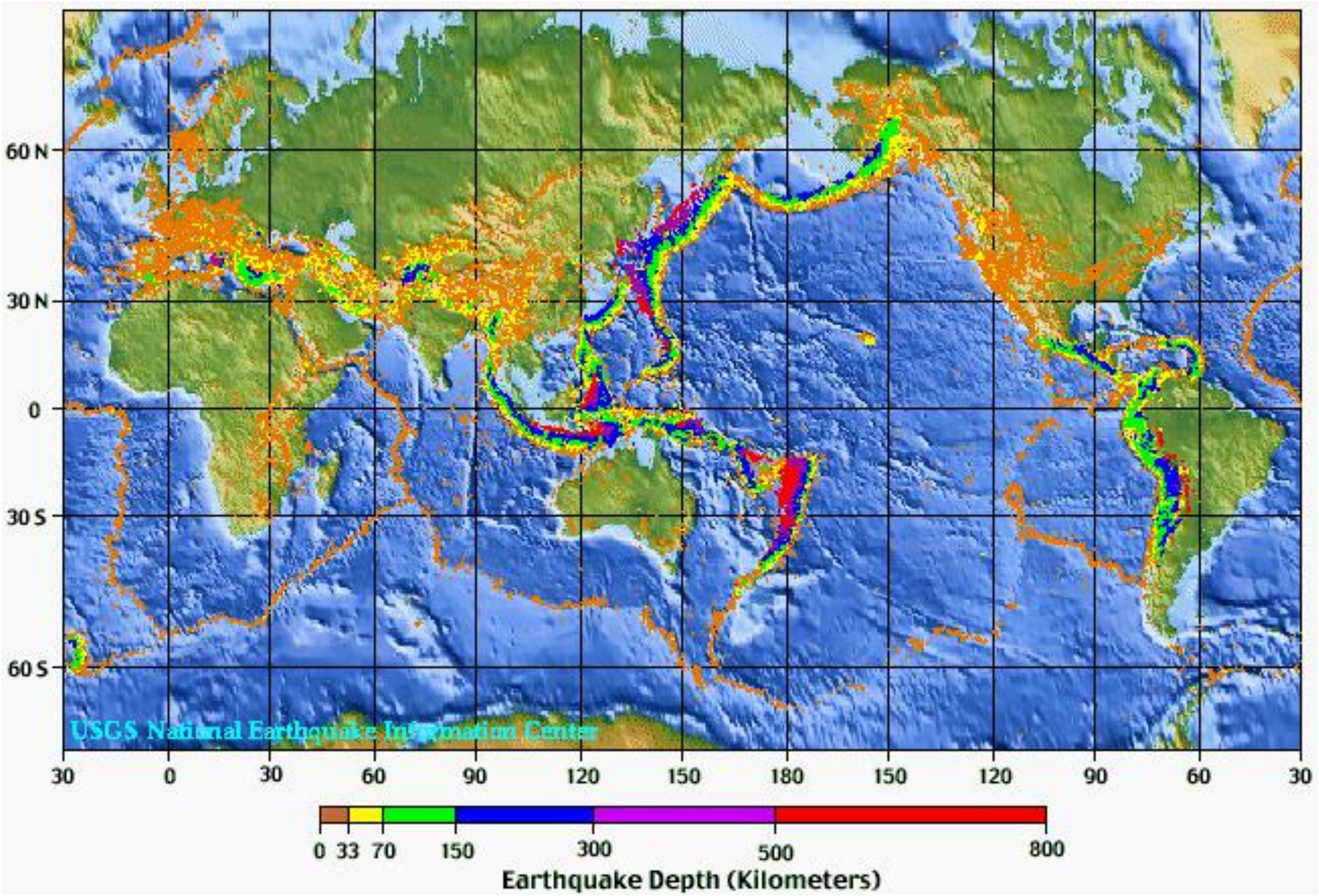
Seismic survey

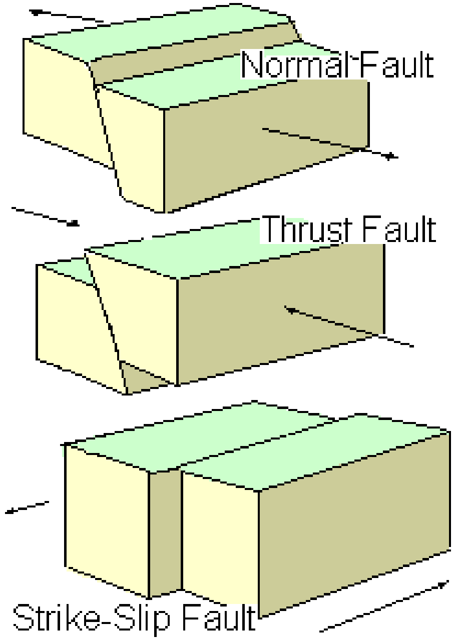
- What type of sources and receivers can we use? What kind of information do we want to collect?

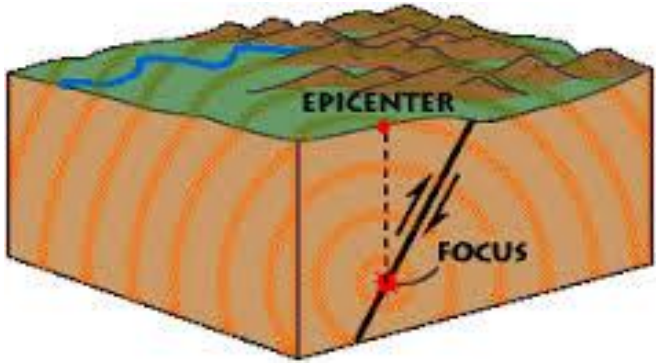
- Sources: anything that causes earth particles to move
  - Natural sources, like earthquakes
  - Man-made sources, like explosives, “hammers”, shock waves

- Receivers: record ground motion for some time following the source
  - Geophones
  - Seismometers (3 component, broadband)

Natural source: earthquakes







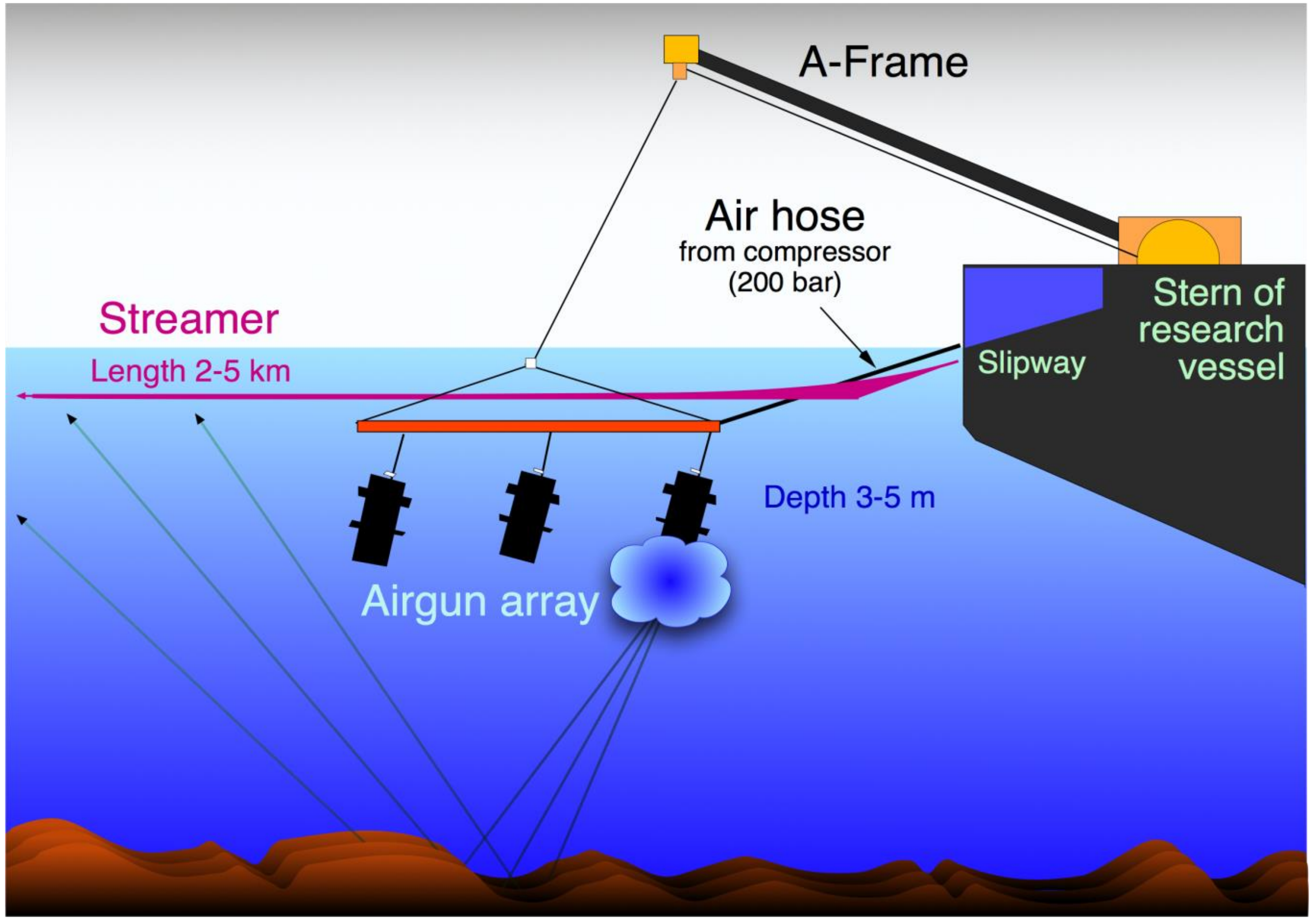
Man-made source: vibroseis truck

Single Source

Group of sources

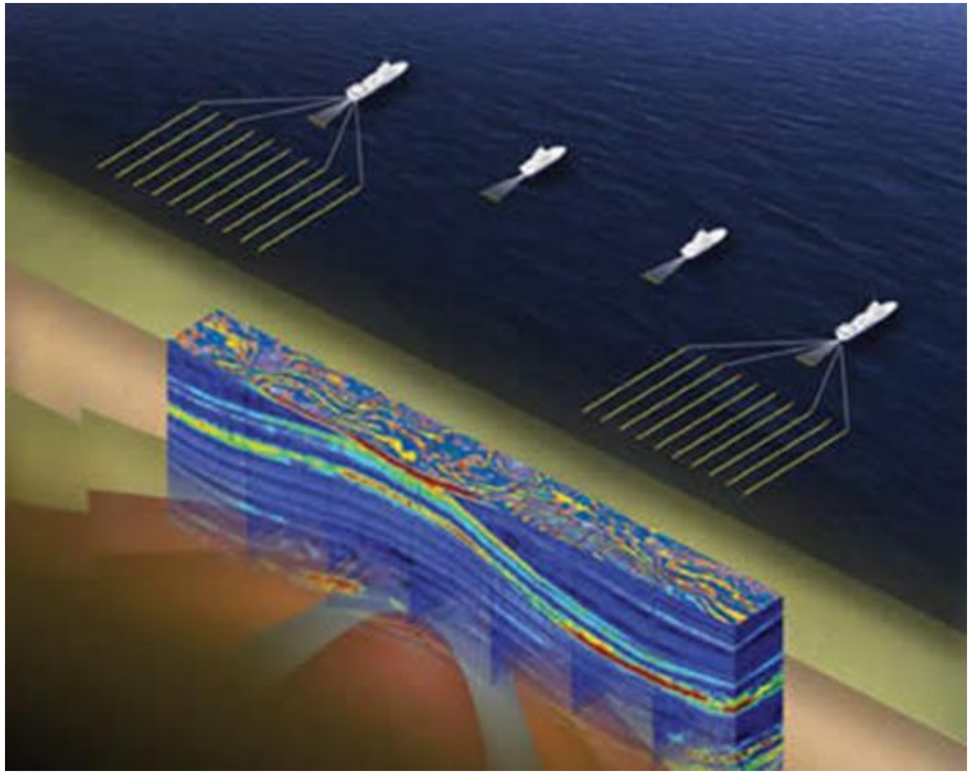
Man-made source: borehole explosion

Man-made source: in the ocean



By Hannes Grobe, Alfred Wegener Institute - Own work, CC BY-SA 2.5,
https://commons.wikimedia.org/w/index.php?curid=2270335

Multiple Sources



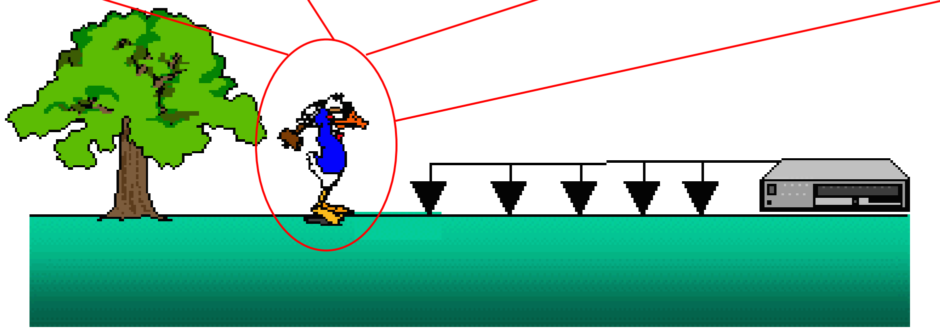
Man-made source: small-scale

Sledge Hammer

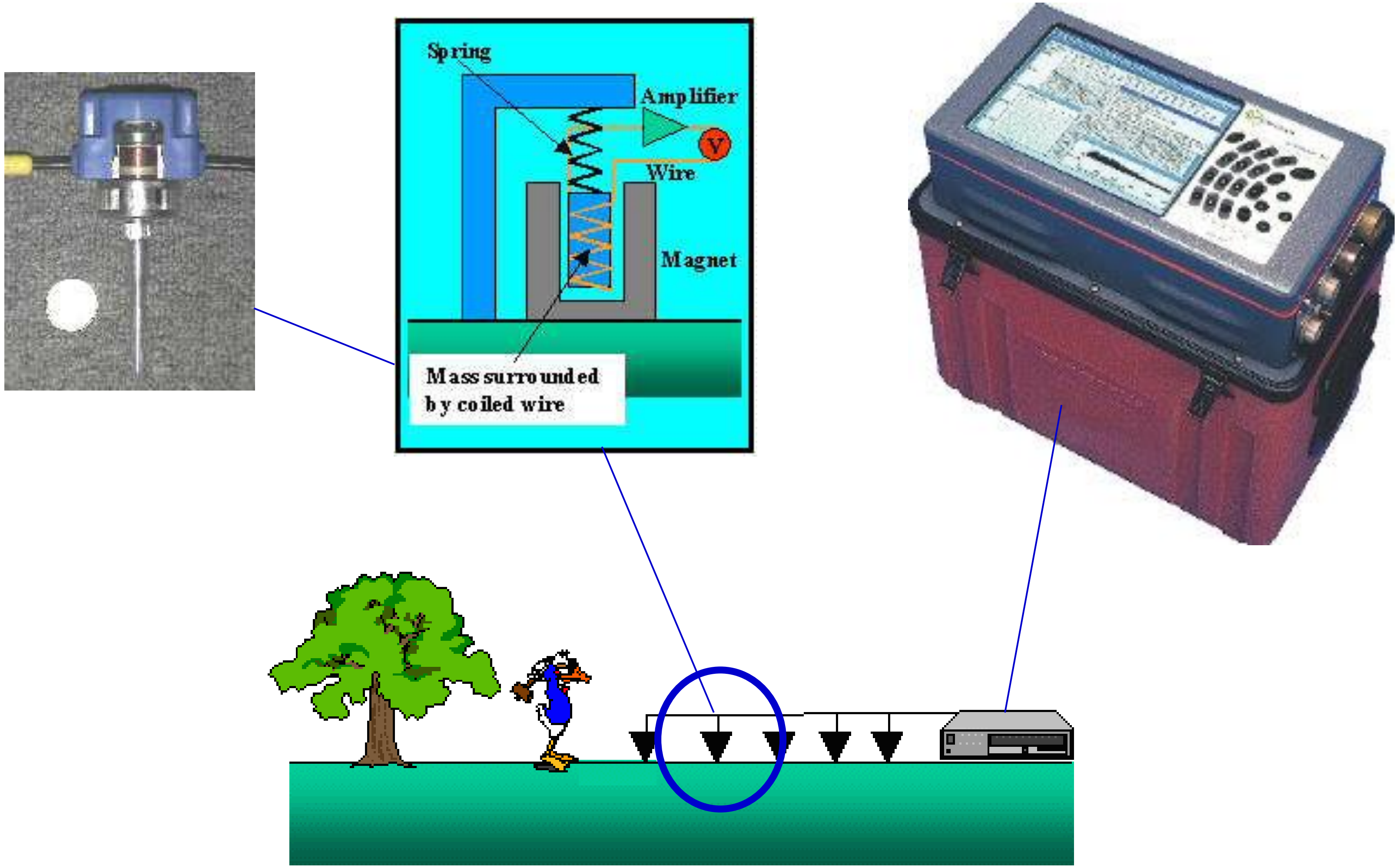
Shotgun Blast

Weight Drop

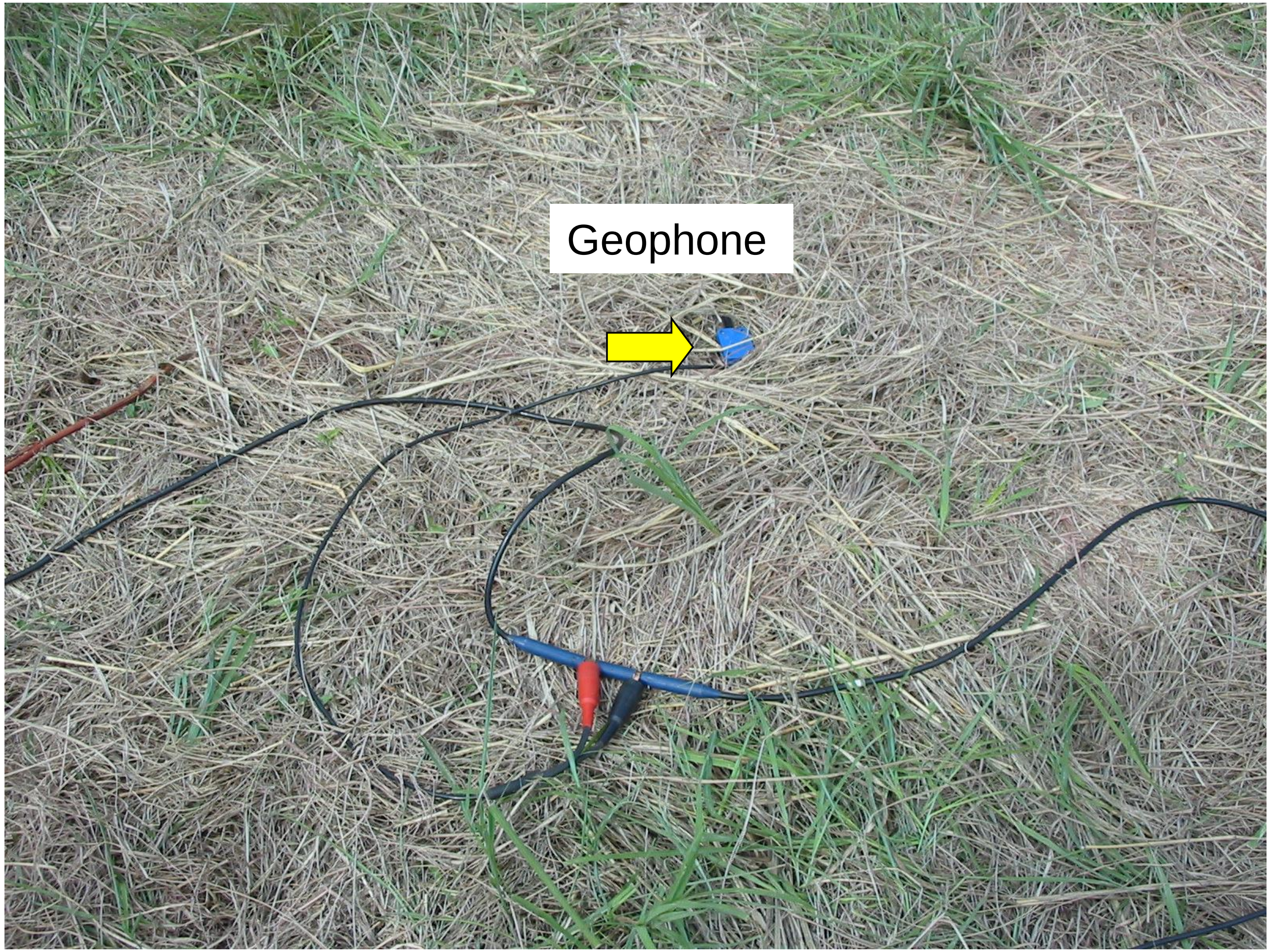
Explosives



Receivers: geophones



Set up the geophone array

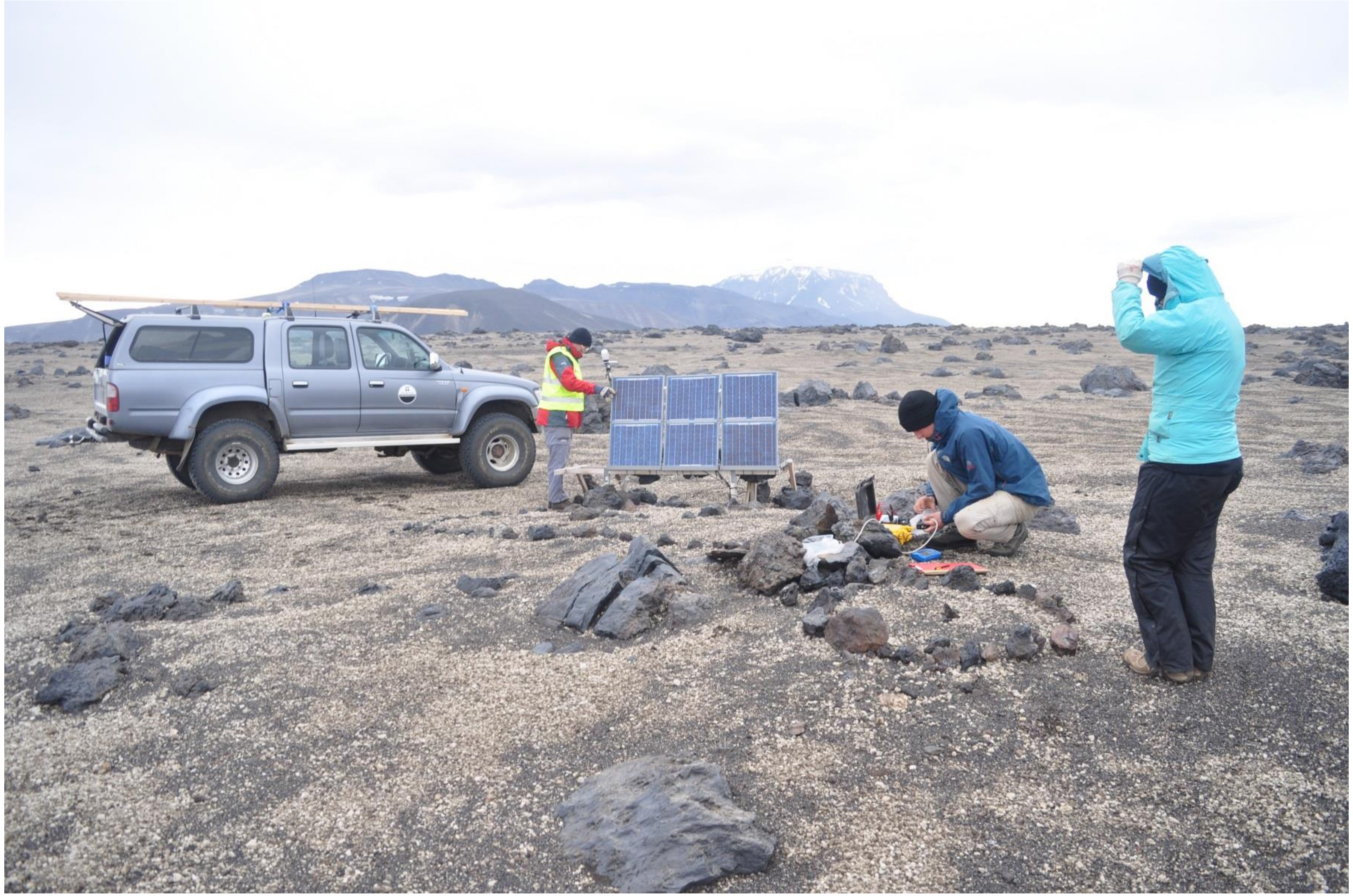


Set up the geophone array

Recievers: hydrophone streamer

https://commons.wikimedia.org/w/index.php?curid=1468353

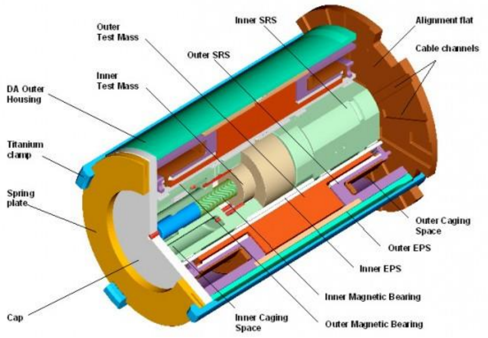
Receivers: seismometer

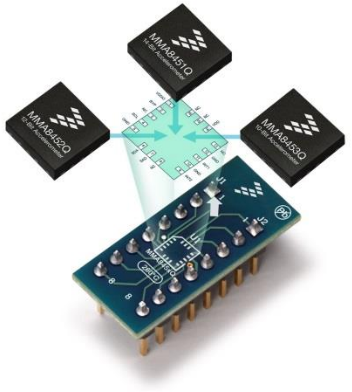


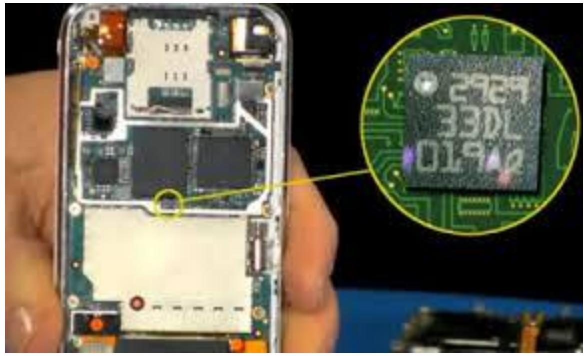
Smartphone example

- iPhone app: iSeismometer
- Android:

- Measure gravitational acceleration







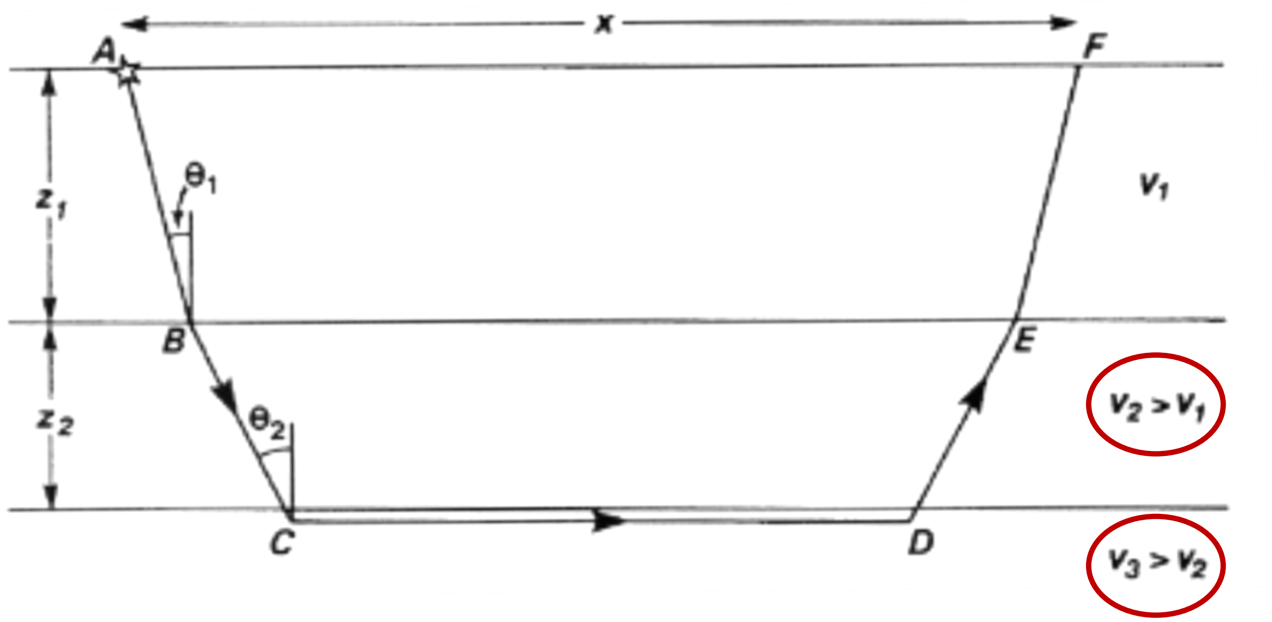
Processing: refraction

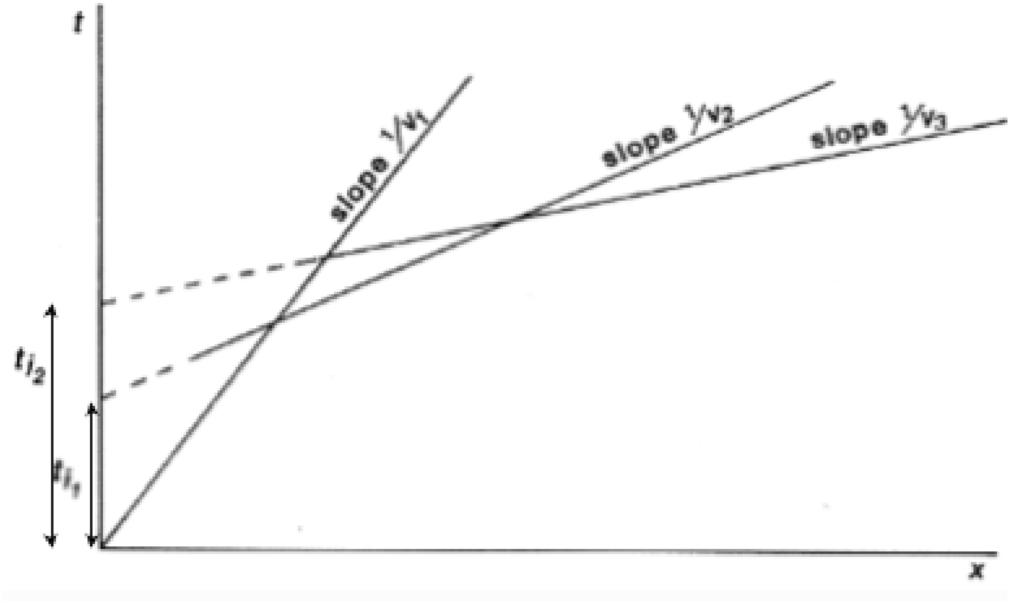
Reading on the GPG:

https://gpg.geosci.xyz/content/seismic/seismic_refraction_dipping_layers.html

https://gpg.geosci.xyz/content/seismic/seismic_refraction_irregular_layers.html

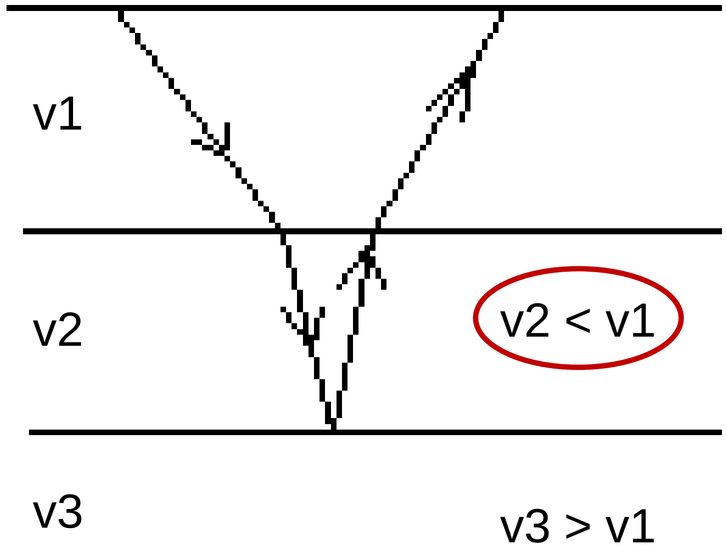
Standard refraction scenario

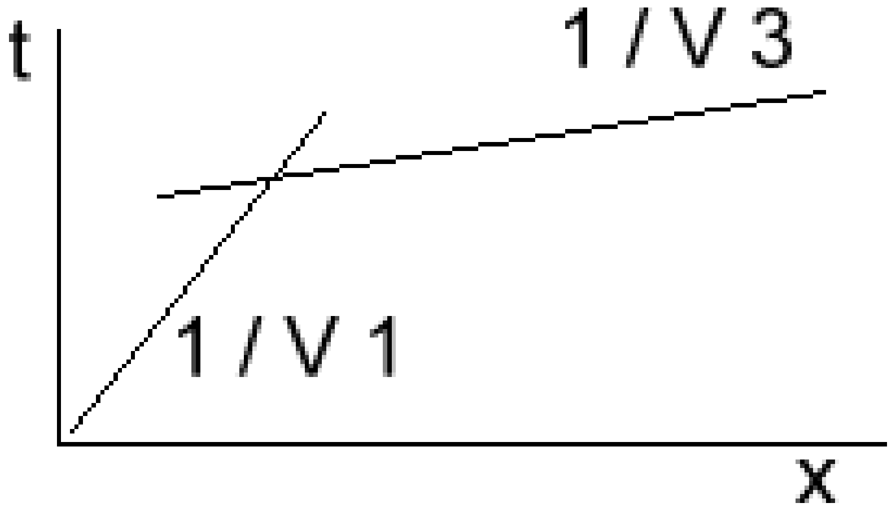




Low velocity zones

- No refracted arrival from the top of the second layer

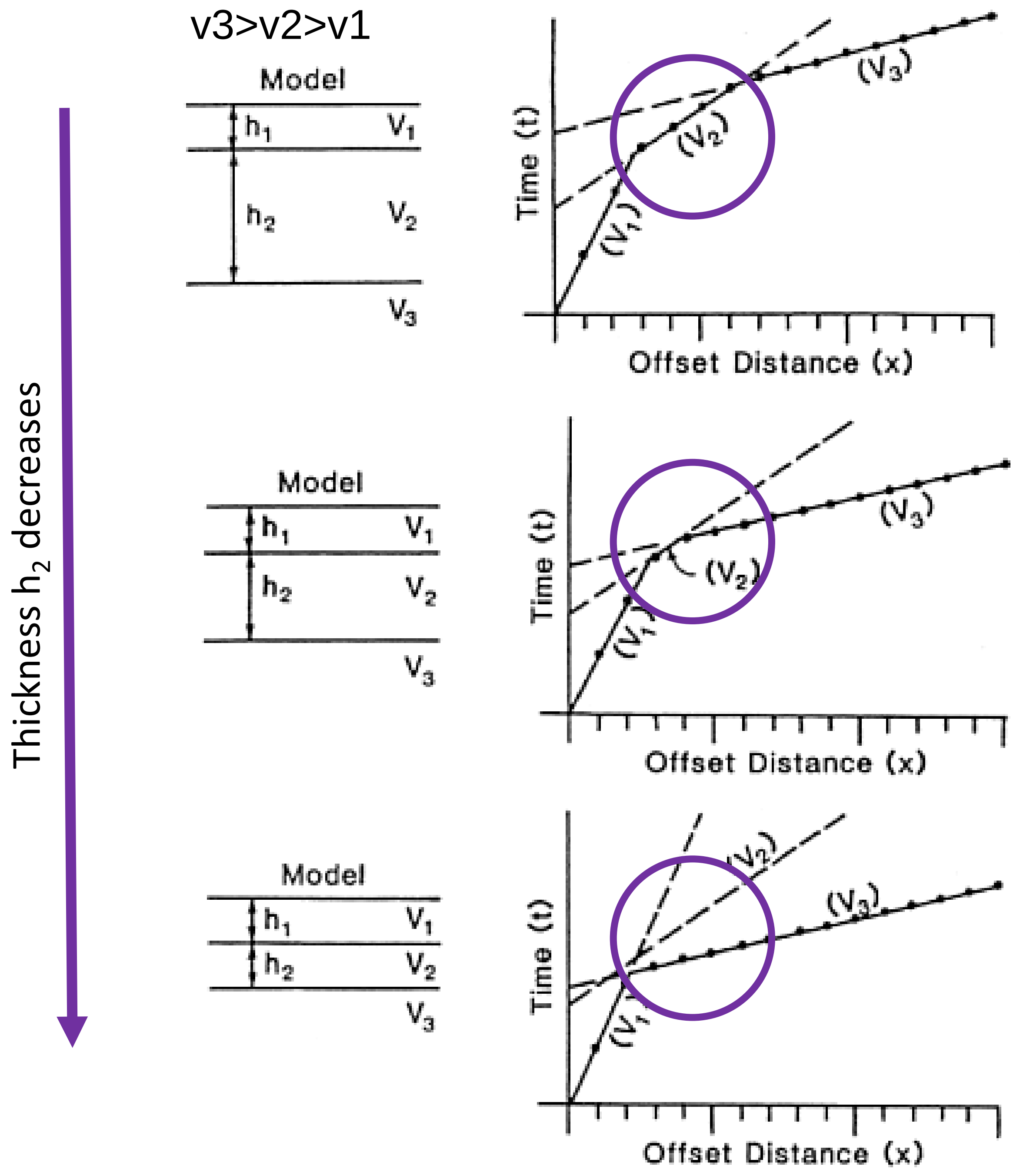




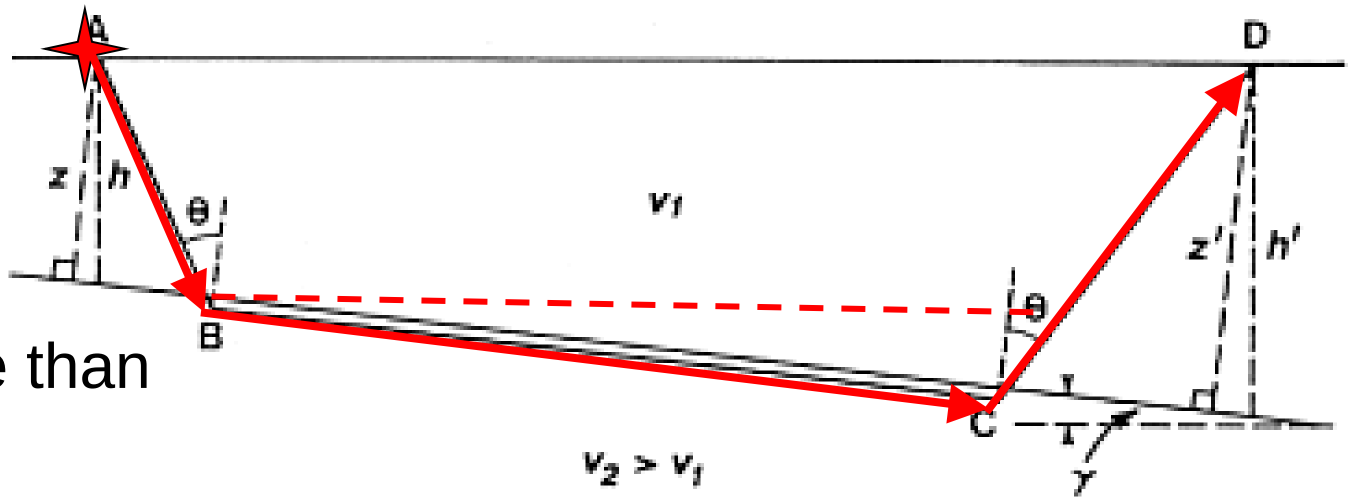
Hidden layers

- Layers that are too thin may not be seen

- Arrival from layer 3 beats that from layer 2



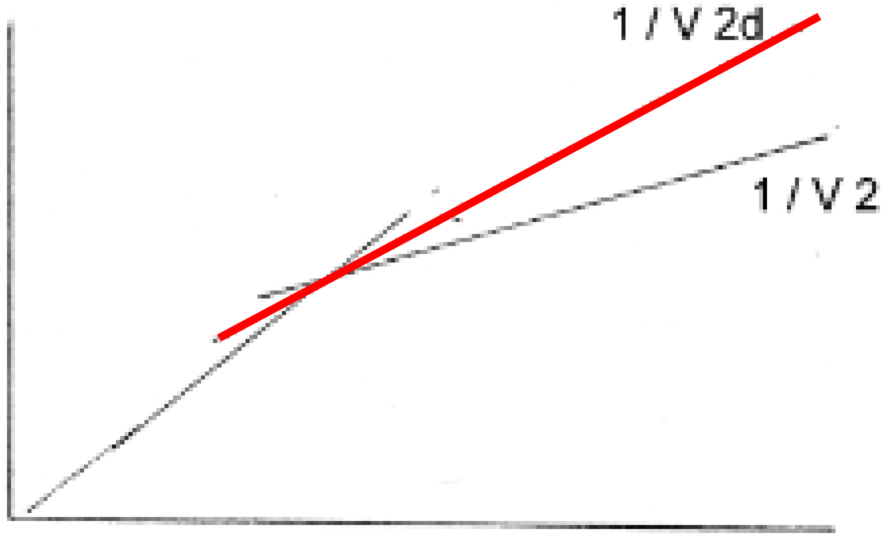
Dipping layers



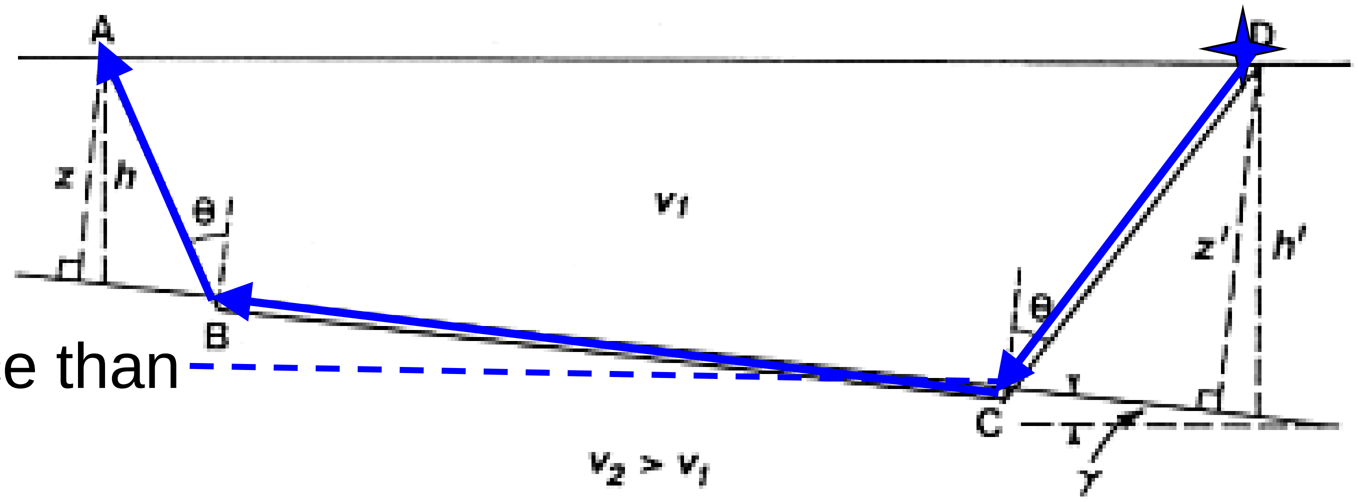
- The red refracted wave has to travel a LONGER distance than if the layer was horizontal.

- Thus the travel time is longer and the slope on the T-X plot is increased.

- The estimated velocity will be SMALLER than the actual velocity



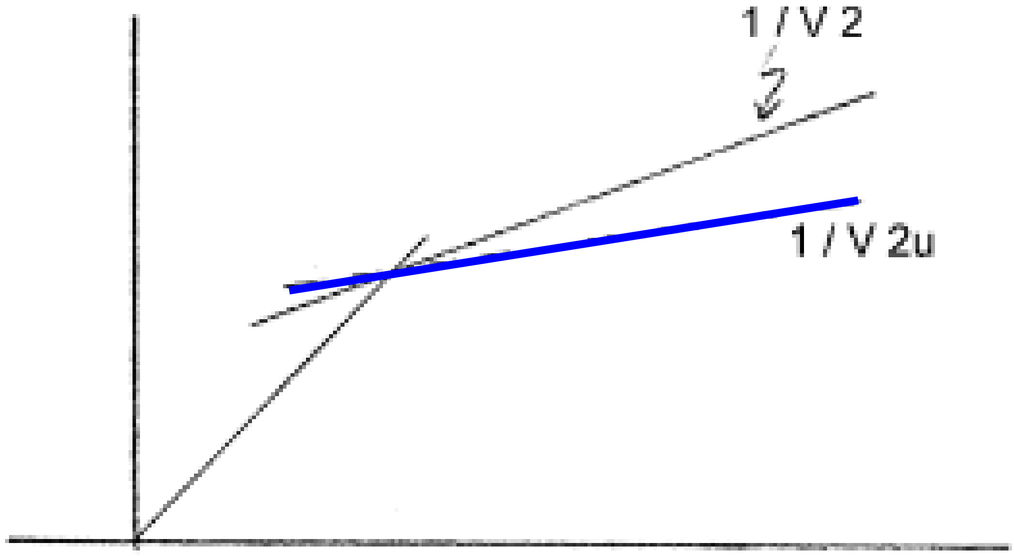
Dipping layers



- The blue refracted wave has to travel a SHORTER distance than if the layer was horizontal.

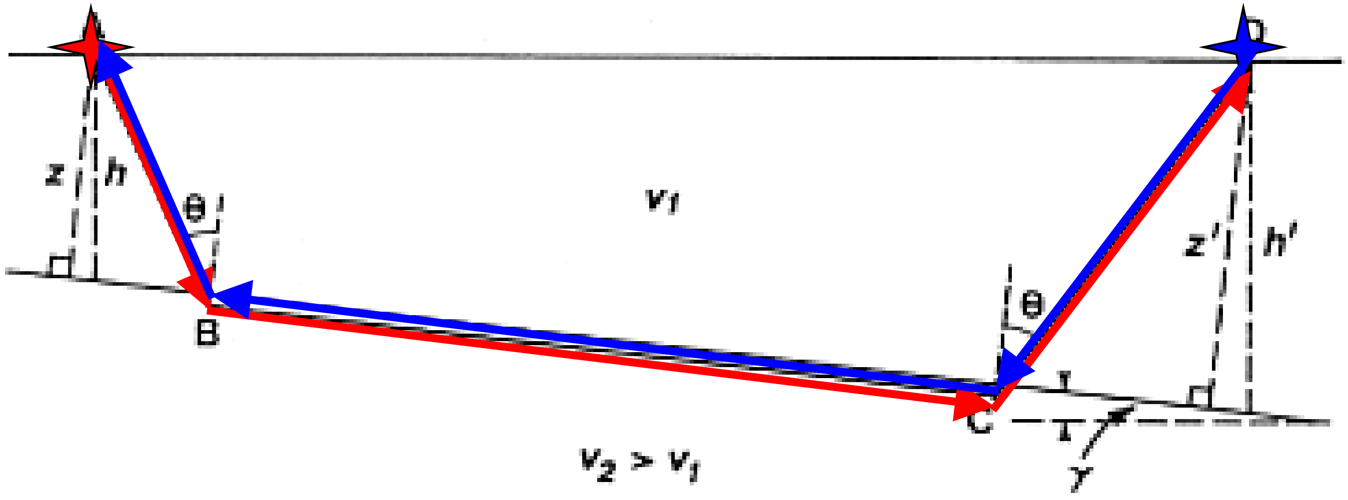
- Thus the travel time is shorter and the slope on the T-X plot is decreased.

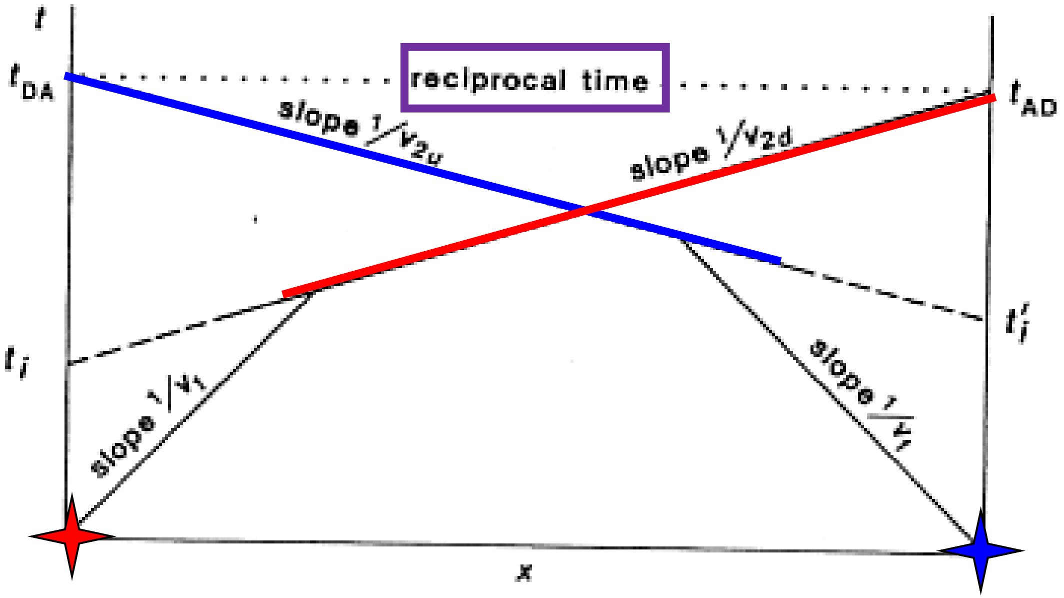
- The estimated velocity will be LARGER than the actual velocity



Dipping layers

- So this requires **TWO** shots to be able to interpret





Dipping layers

- Depth estimates
  - “Slant” depths can be obtained through the intercept times
  - True depths can be estimated using dip-angle (see GPG)

- Travel time in down-dip direction $$t_2 = \frac{x\sin(\theta+\gamma)}{v_1} + \frac{2z\cos\theta}{v_1} = \frac{x}{v_{2d}} + t_i$$

- Travel time in up-dip direction $$t_2' = \frac{x\sin(\theta-\gamma)}{v_1} + \frac{2z'\cos\theta}{v_1} = \frac{x}{v_{2u}} + t_i'$$

Irregular layers

- What happens when the boundary can no longer be approximated as a plane?

  - Plus-minus method
  - Generalized reciprocal methods
  - Ray tracing
  - Other sophisticated procedures

Processing: reflection

Reading on the GPG:

https://gpg.geosci.xyz/content/seismic/seismic_reflection_processing.html

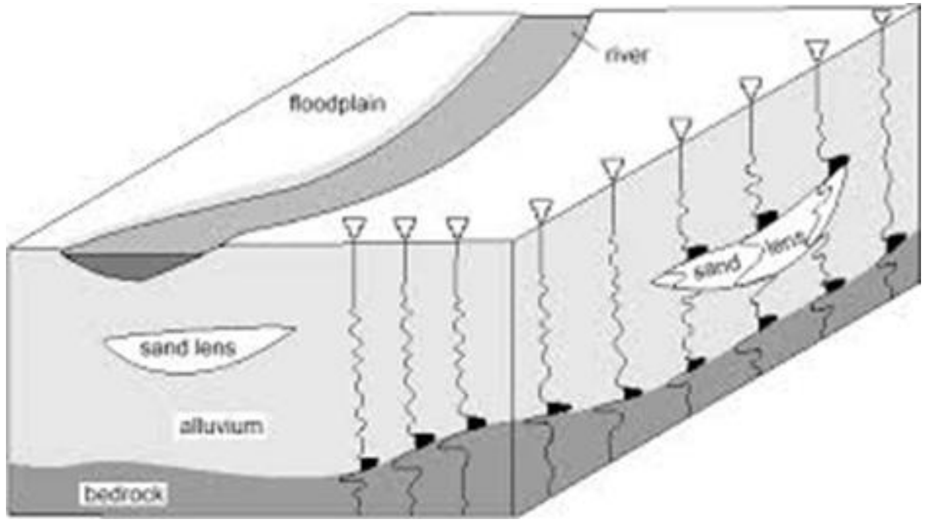
Reflection

- Seismic refraction was effective for finding interfaces and velocities
  - As long as velocity increased with depth
  - Only the first arrivals were used

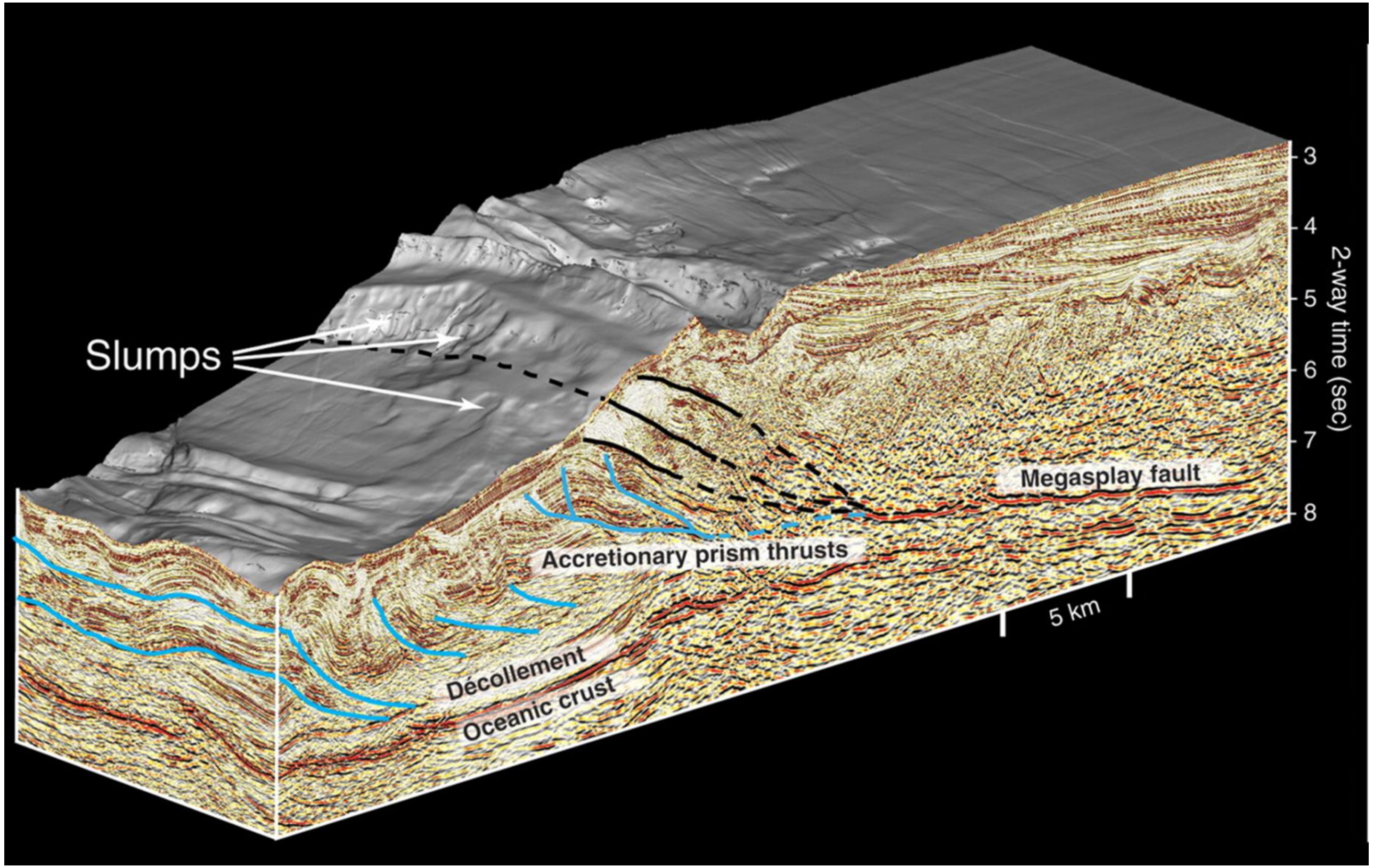
- What if we want to image something much more complicated?

- Impedance contrasts gives reflections

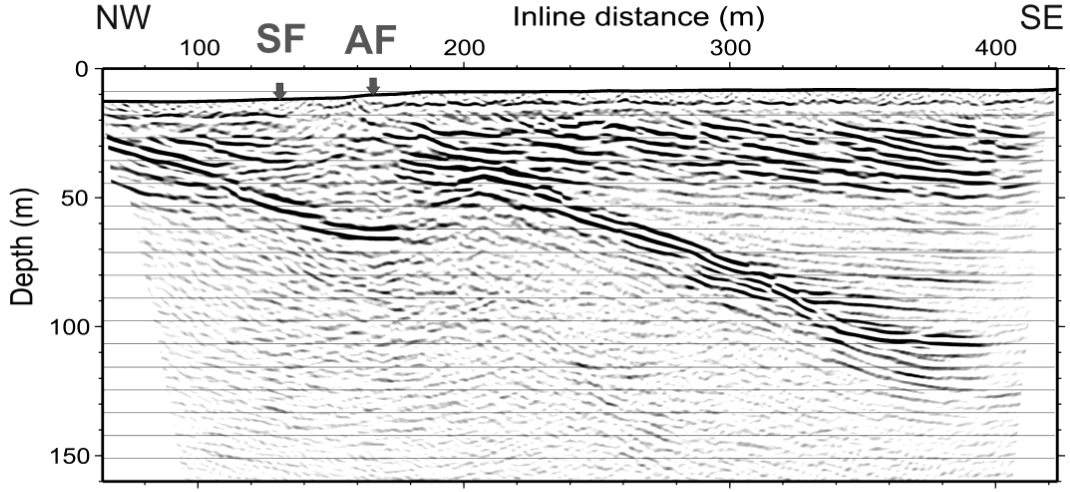
- Generate an image made from normal incidence seismograms

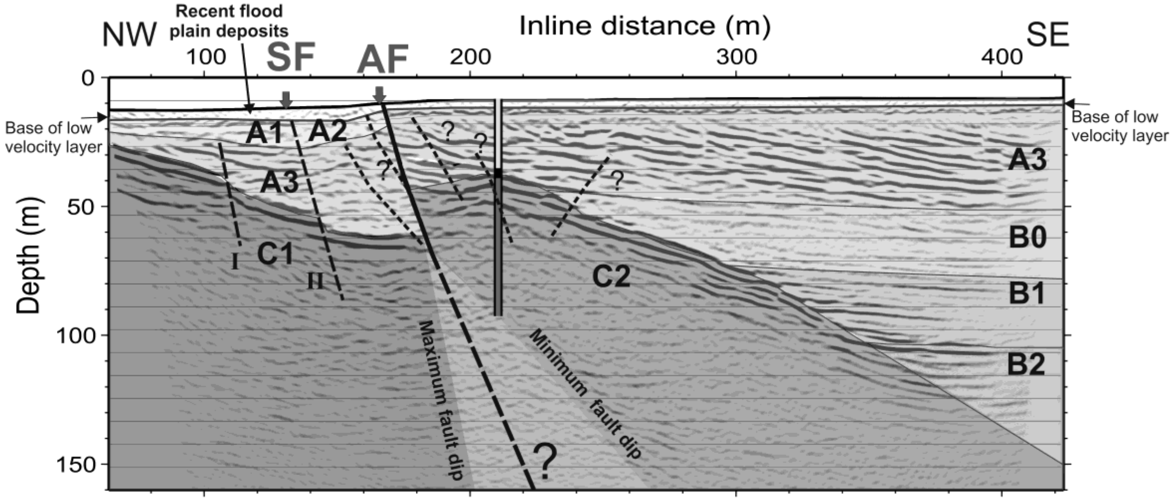


Seismic image with geologic information



Smaller scale seismic reflection





Main uses for seismic reflection

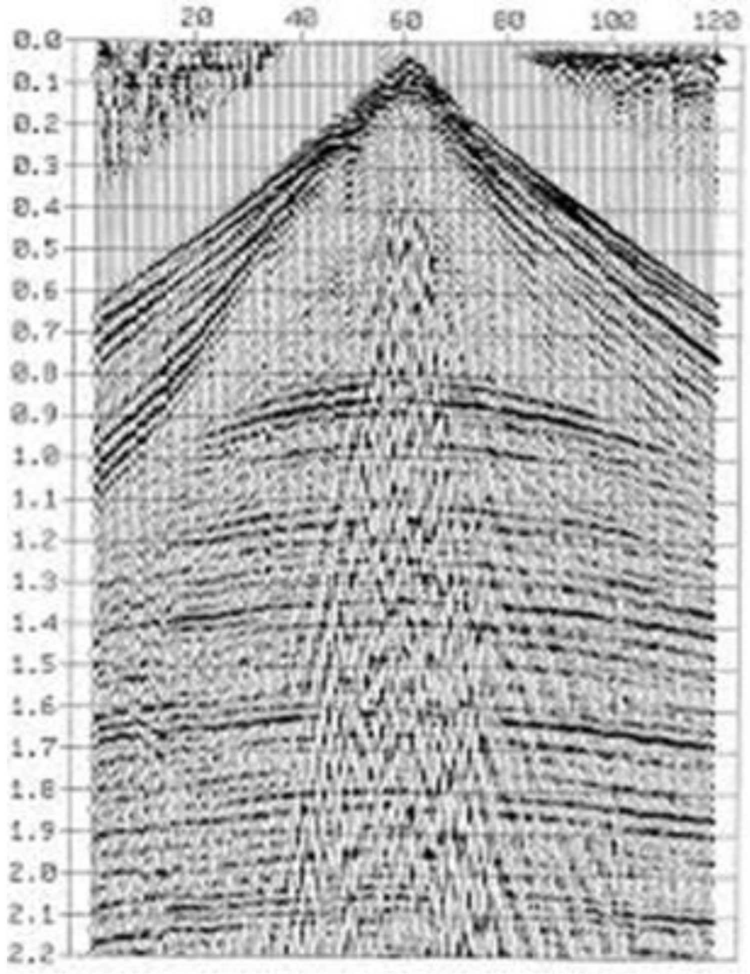
- Hydrocarbon exploration!!!

- General earth structure
  - Whole earth
  - Continental scale (lithoprobe)
  - Regional scales

- Local structure
  - Geotechnical work
  - Environmental work

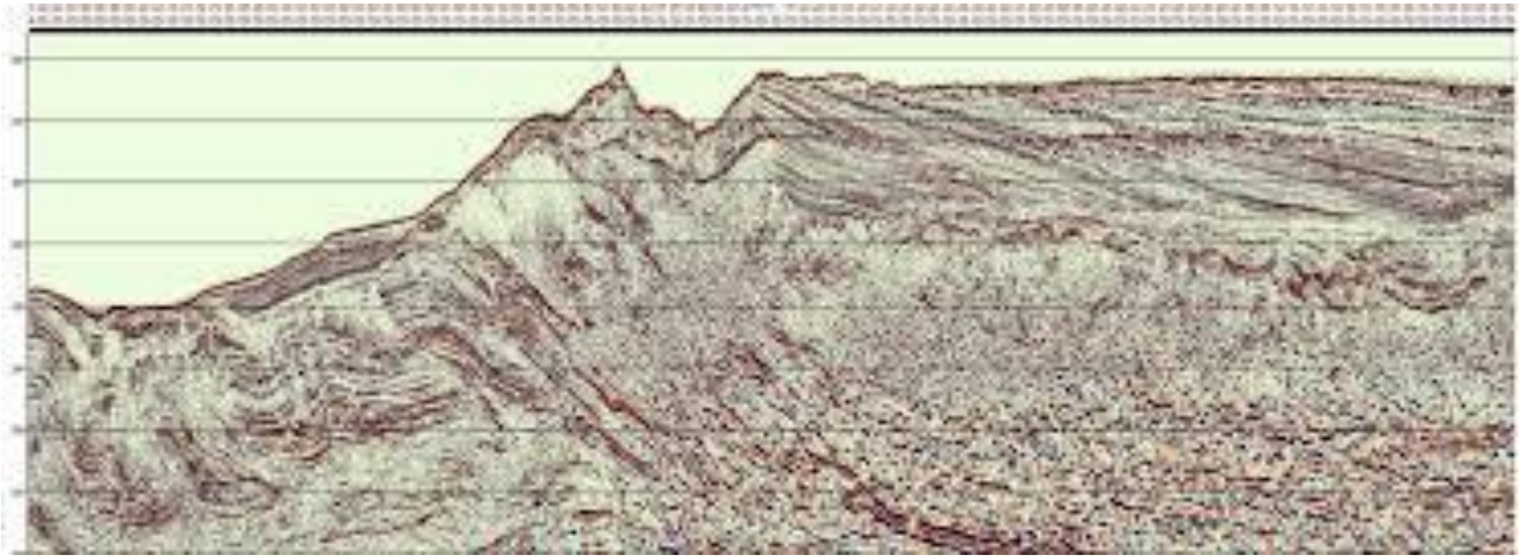
Let’s think

- What precisely is the ideal seismogram?
- How to collect and process seismic data to make these ideal traces?
- Data from a single shot is shown.
  - Seismic surveys consist of many shots
  - Need to convert into a suite of ideal seismograms



Seismic images

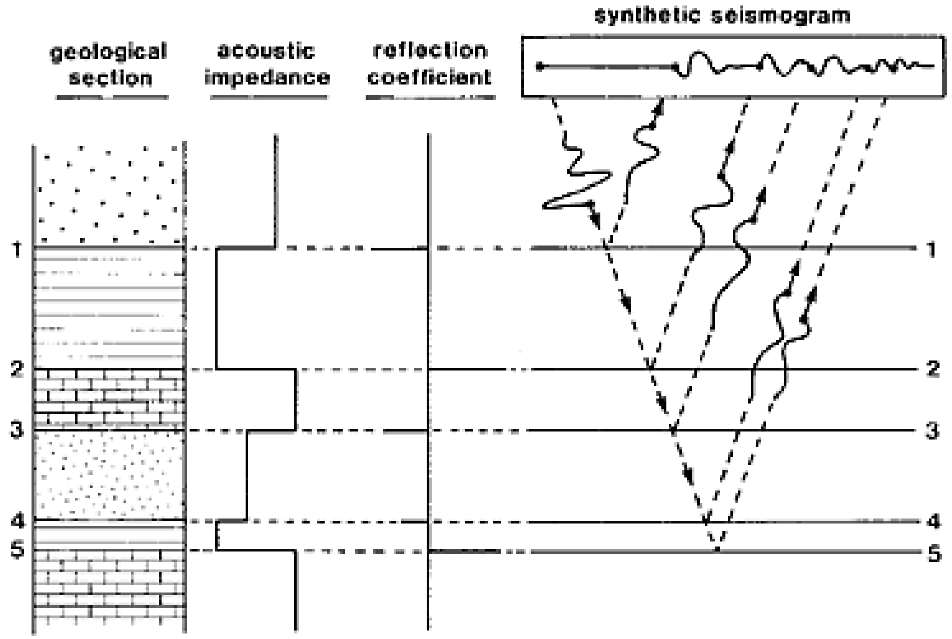
- Each trace is an ideal reflection seismogram of a wave that …
  - Travels vertically downward
  - Reflects off of boundaries
  - And arrives back at the surface along the same vertical path
- Plotting many such traces yields an image in which structure can be observed

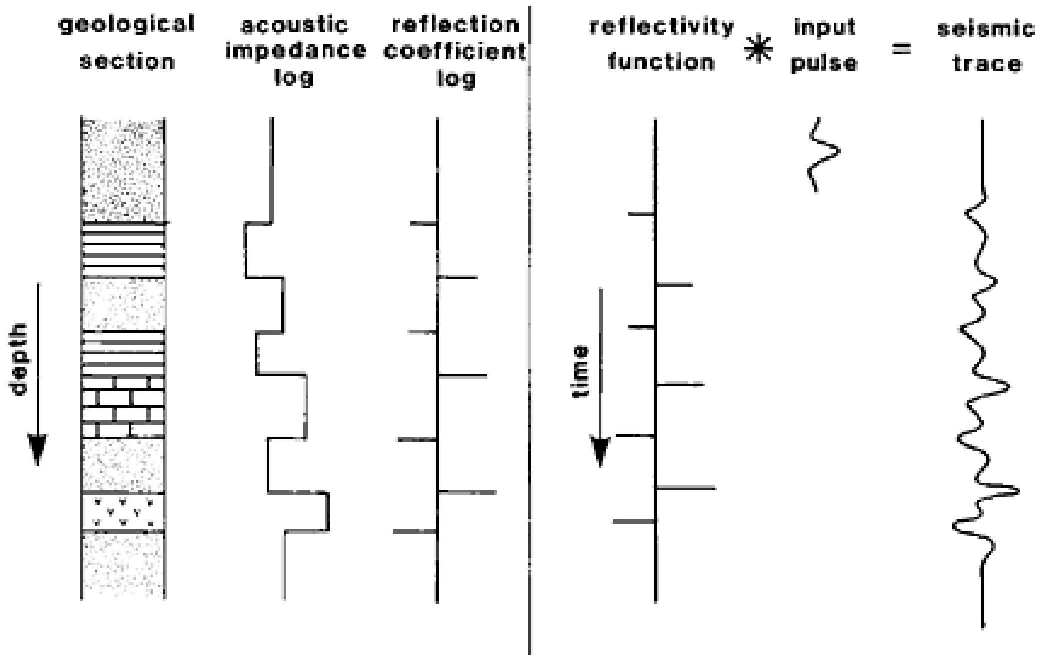


Ideal seismogram

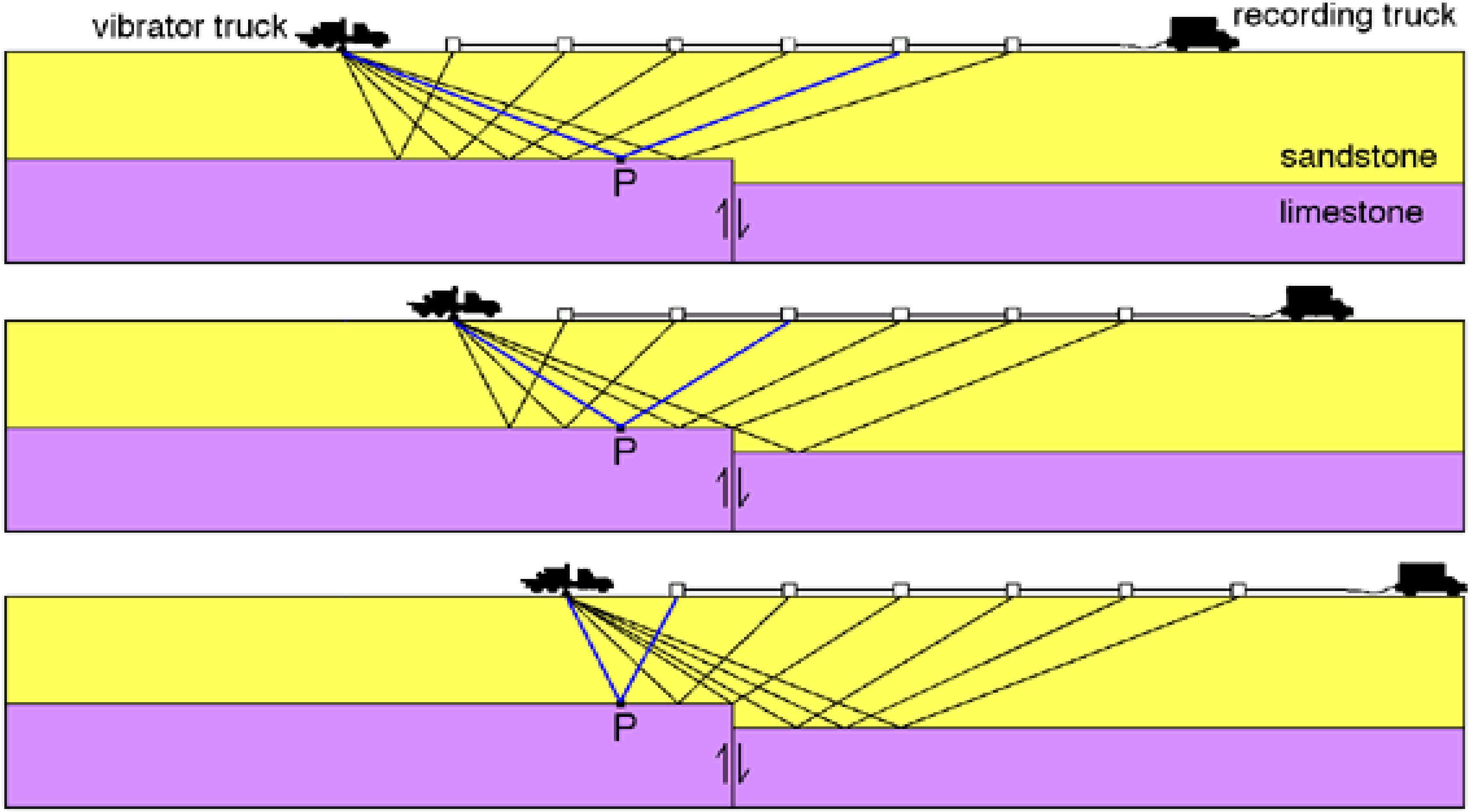
Ray travels straight down and back up.

- Assumes 0m offset and normal incidence



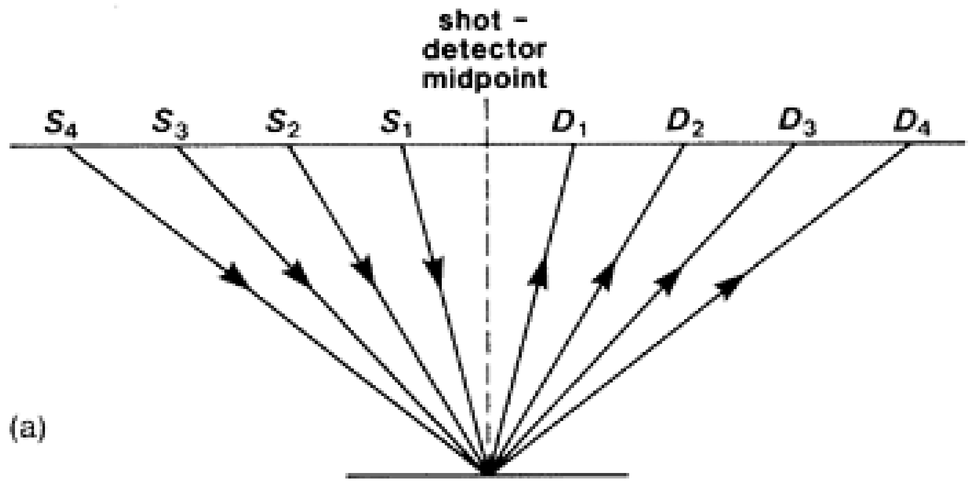


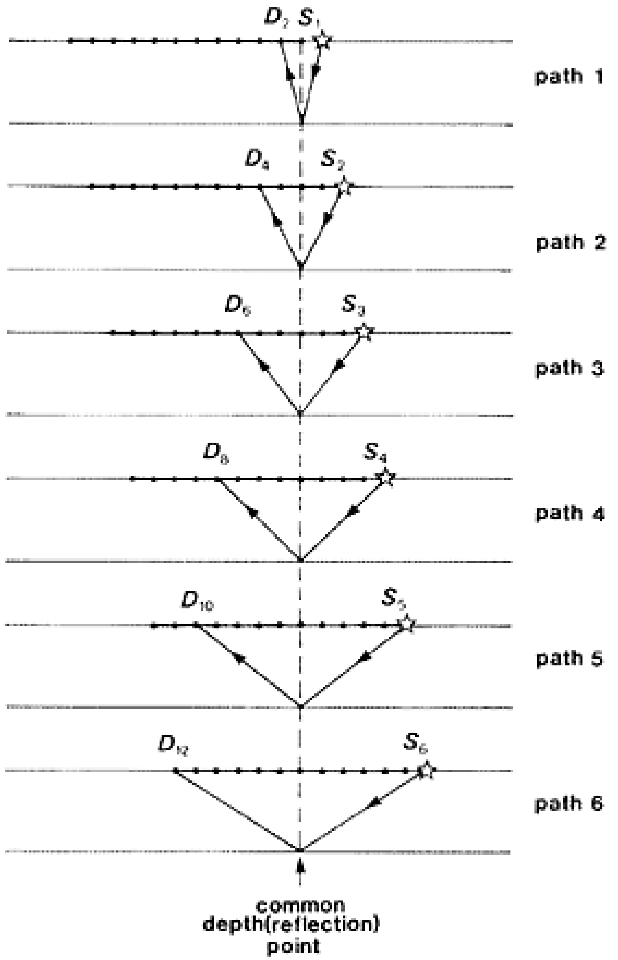
Seismic reflection acquisition



Survey basics

- Collect common shot gathers (CSG)
- Reorder to collect common midpoint (CMP) gathers





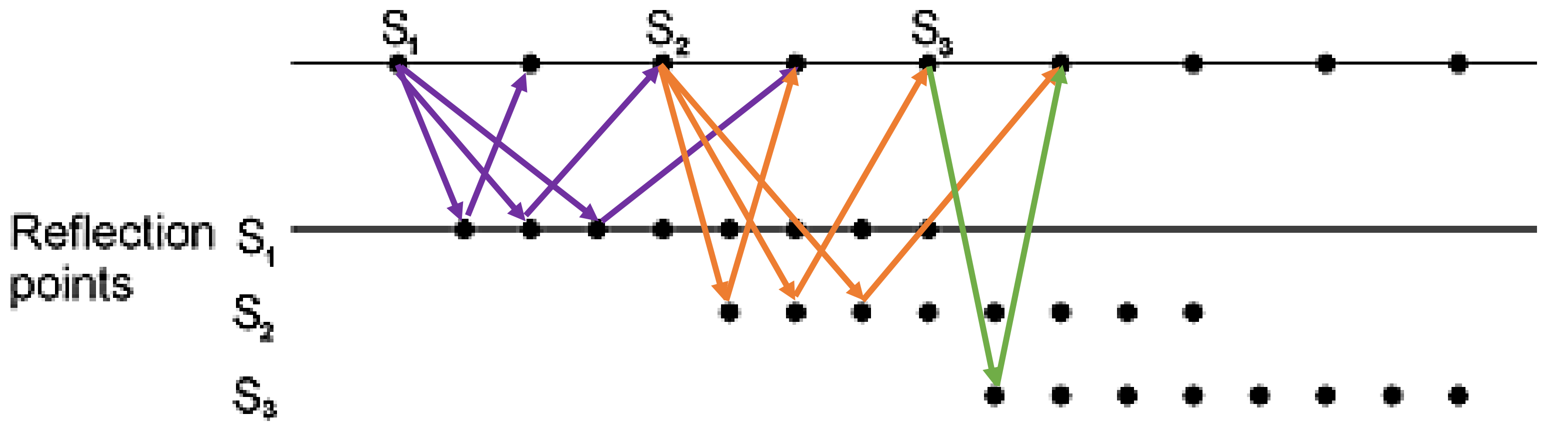
A series of six shots and associated receivers that would have reflections from a common point. When the layers are plane and horizontal then this common reflection point lies midway between the source and receiver

Fold

- How times a subsurface point is sampled by pull-along arrays
  - N = number of geophones
  - n = move up number (shot spacing / geophone spacing)
    - Example:
      - Geophones places every 2 m
      - Source shots every 4 m
      - n = 4 / 2 =2

$$fold = \frac{N}{2n}$$

- Example:
  - 8 geophones
  - Move up of 2
  - What is the fold?
  - $fold = \frac{8}{2*2} = 2$

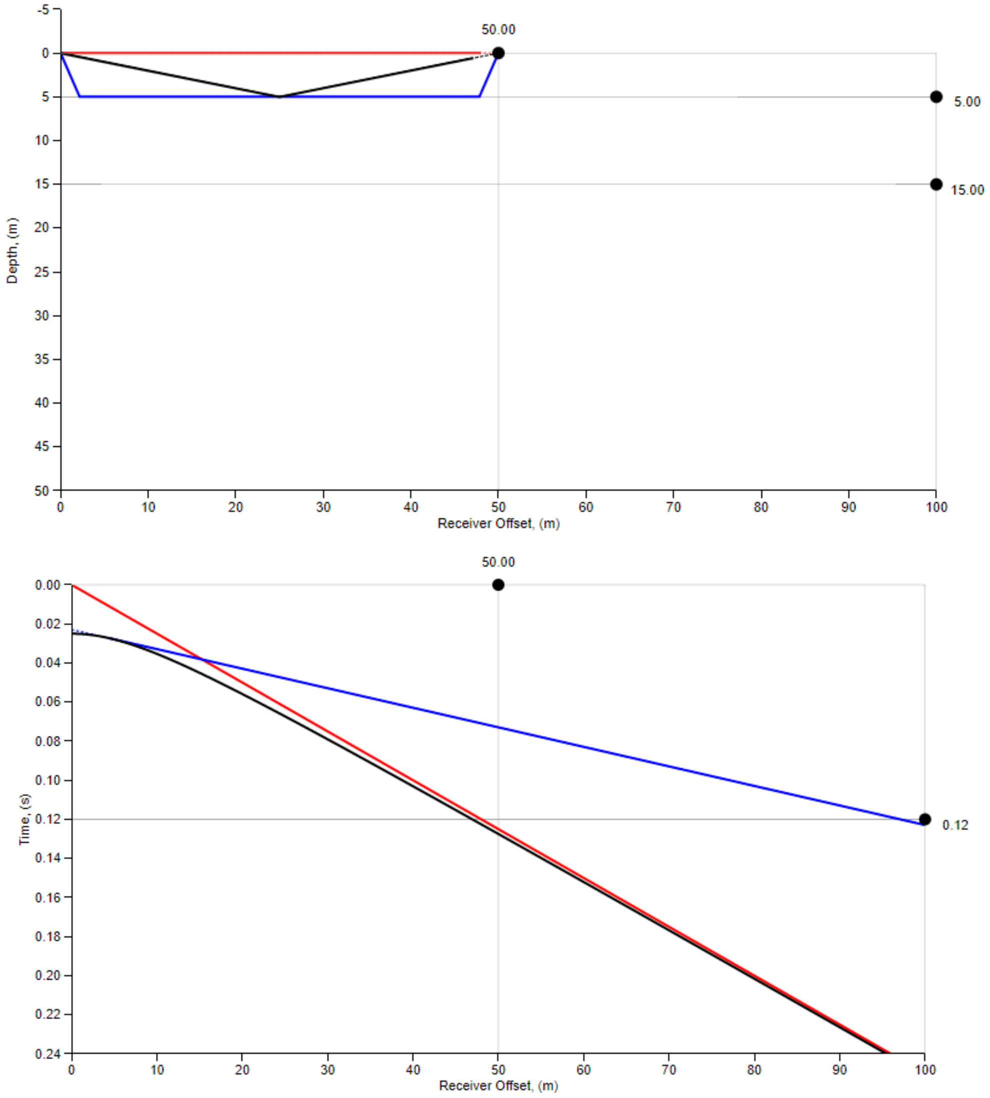


Travel time

- Recall that travel time for a reflected wave is

$$t_{refl} = \frac{\sqrt{x^2 + 4h^2}}{v_1}$$

- Which is a hyperbola

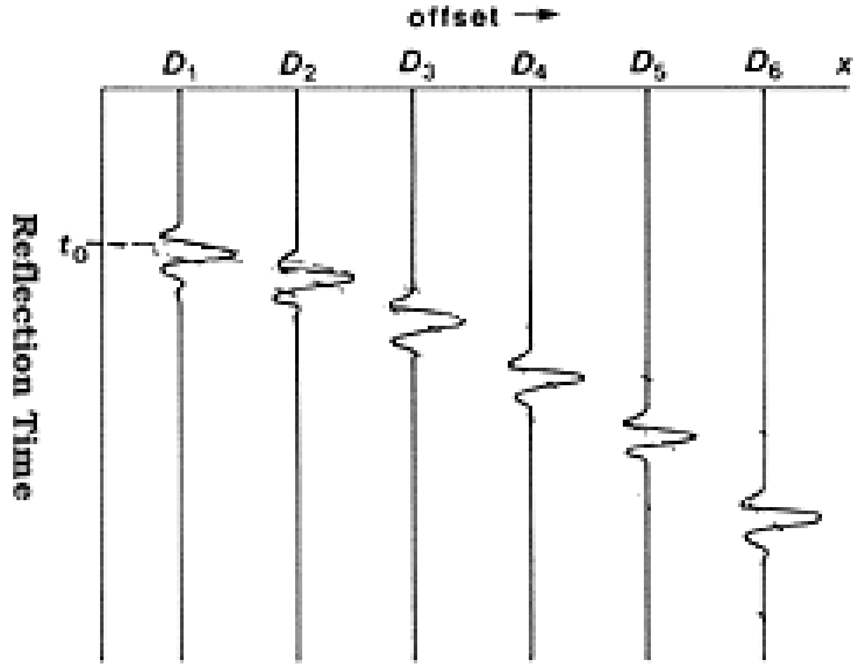


Normal move-out (NMO) correction

- Imagine recording 6 seismic traces from one source

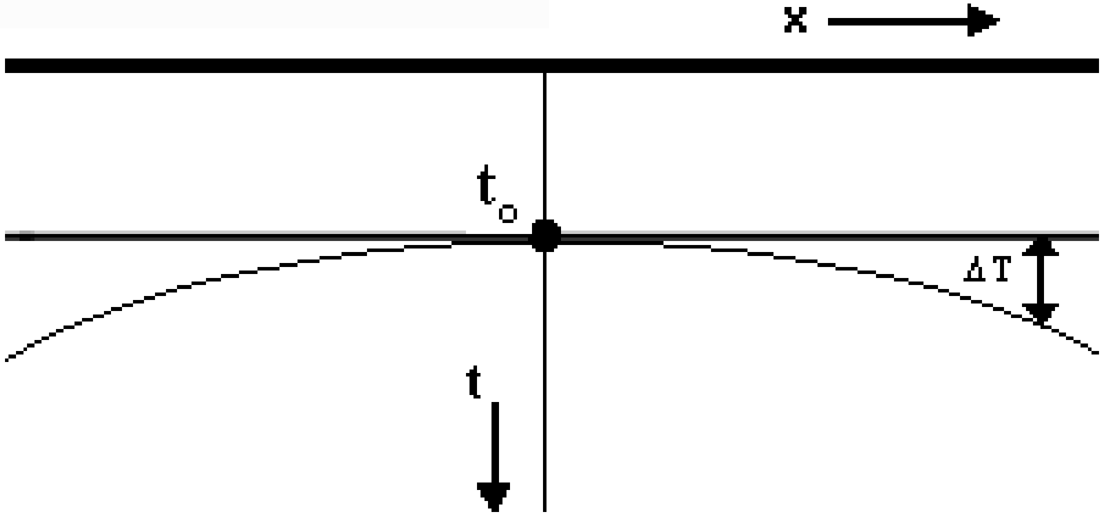
- Travel time plot will show that arrival time increases as source-receiver distance increases

- Let’s go through the steps



Normal move-out (NMO)

- Travel time: $$t = \frac{(x^2 + 4z^2)^{\frac{1}{2}}}{v}$$



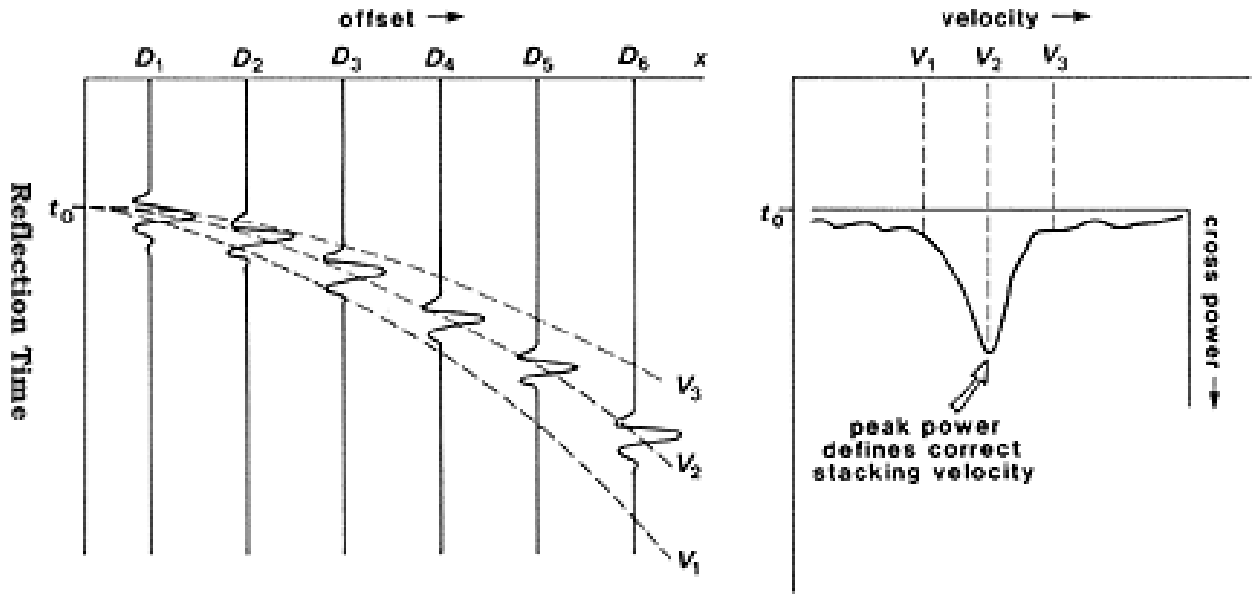
- Normal move out: $\triangle t = t - t_0$

NMO correction

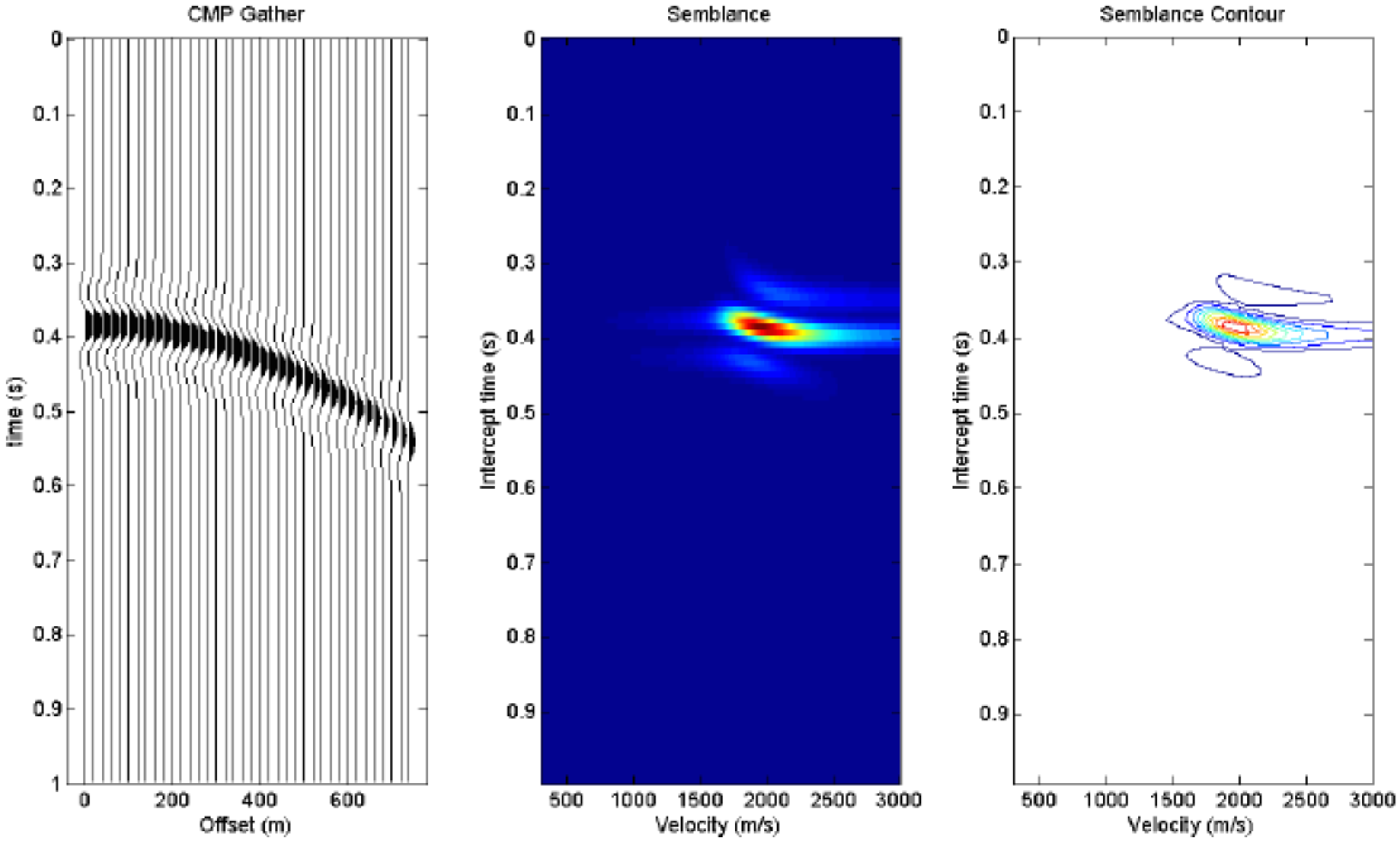
- Travel time: $$t^2(x) = t_0^2 + \frac{x^2}{v_{st}^2}$$

v_{st} is a “stacking” velocity, or sometimes called the Normal Moveout Velocity, v_{nmo}

- For each reflection event, perform velocity analysis to find v_{st}
  - First choose t_0 and a trial velocity v_1
  - Generate the associated travel time hyperbola
  - Sum the energy of the seismic traces and plot this value
  - Repeat with different trial velocities
  - Choose v_{st} as the velocity that yields the largest energy

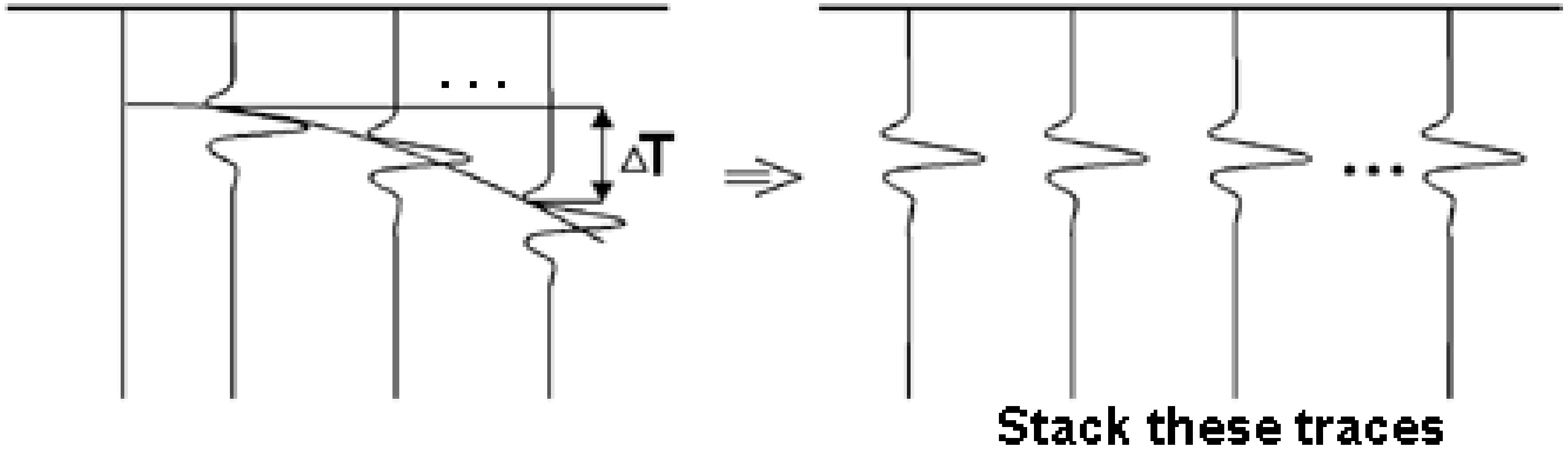


Semblance analysis: Finding v_{st} and t_o



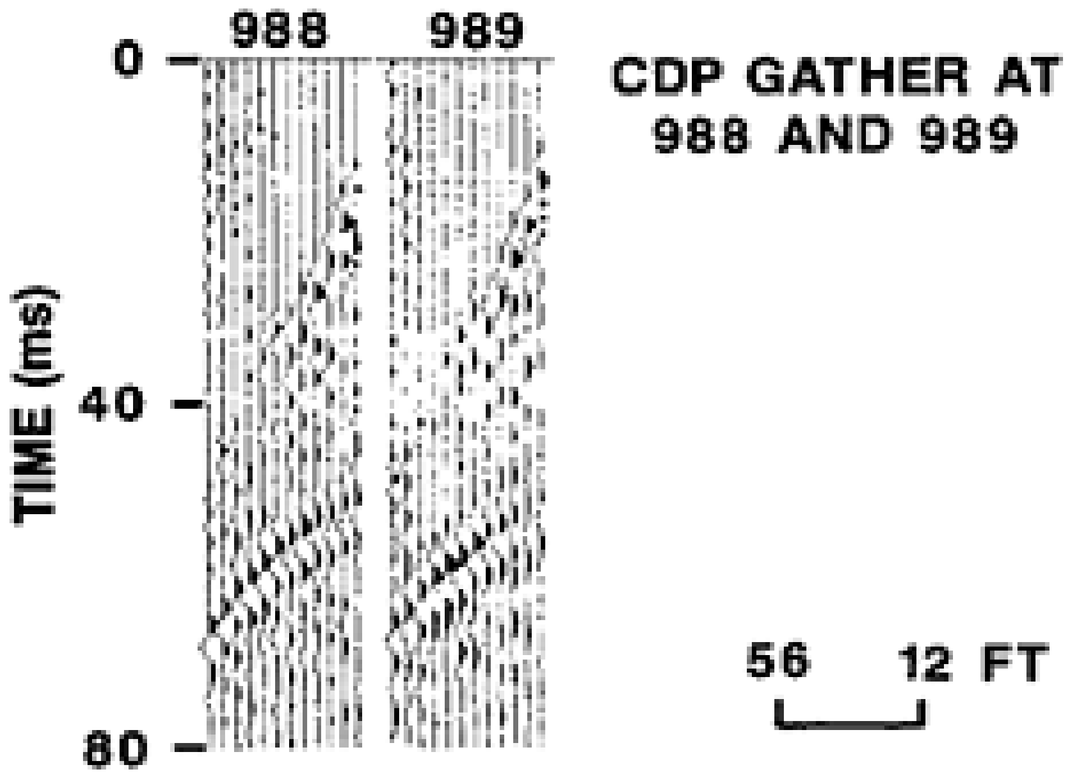
NMO correction

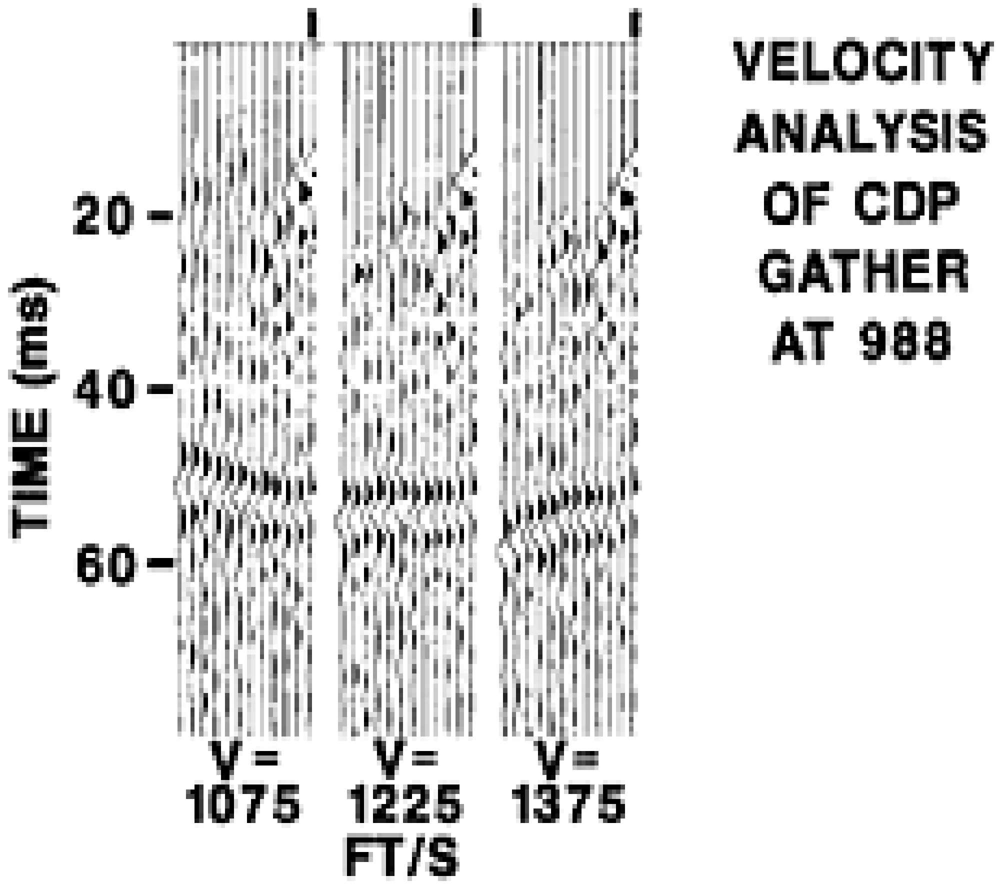
- Then, using the hyperbola corresponding to v_{st}:
  - Compute the normal moveout for each trace
  - Adjust the reflection time by ΔT
- Stack the normal moveout corrected traces to generate a single trace



Example

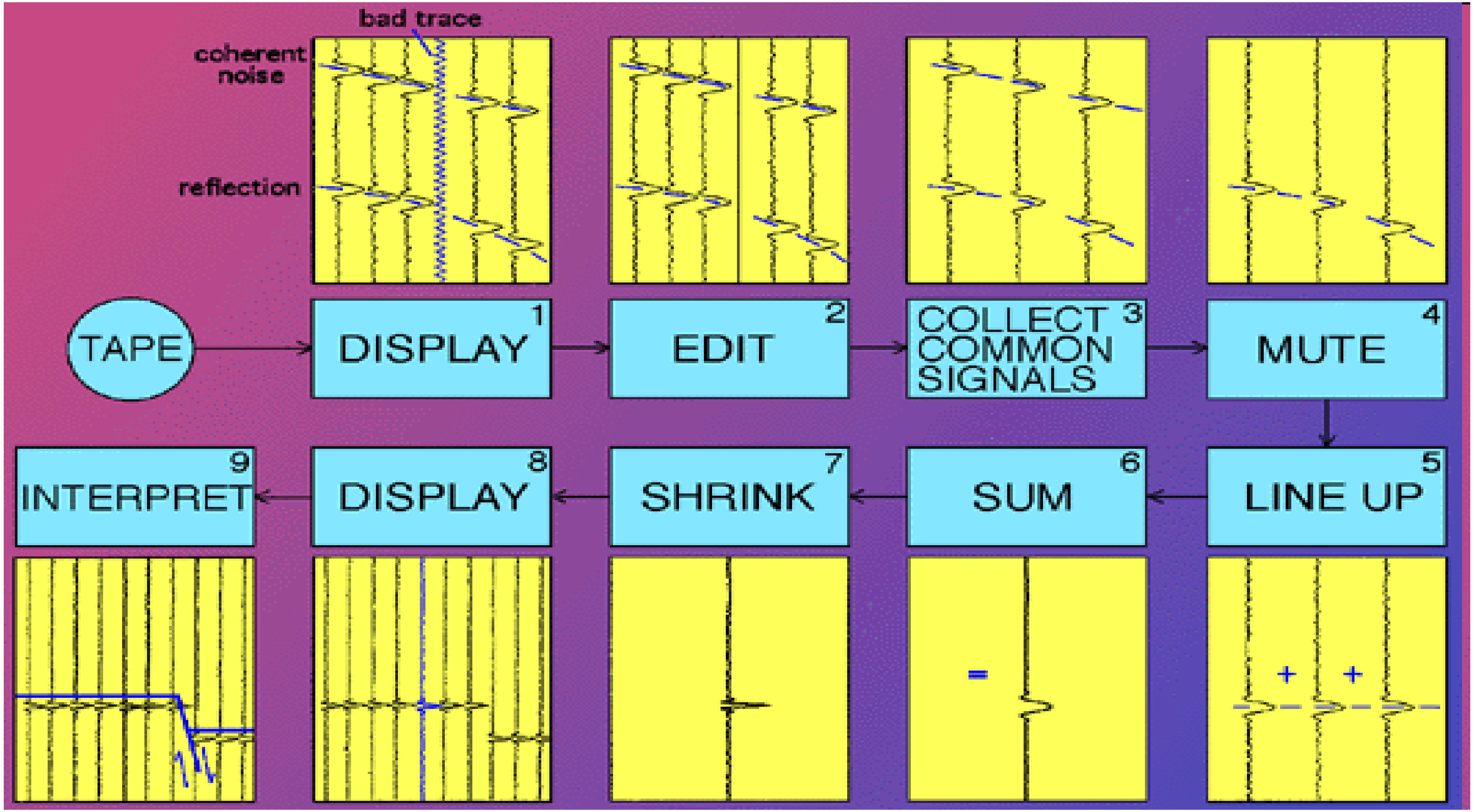
NMO correction for 988



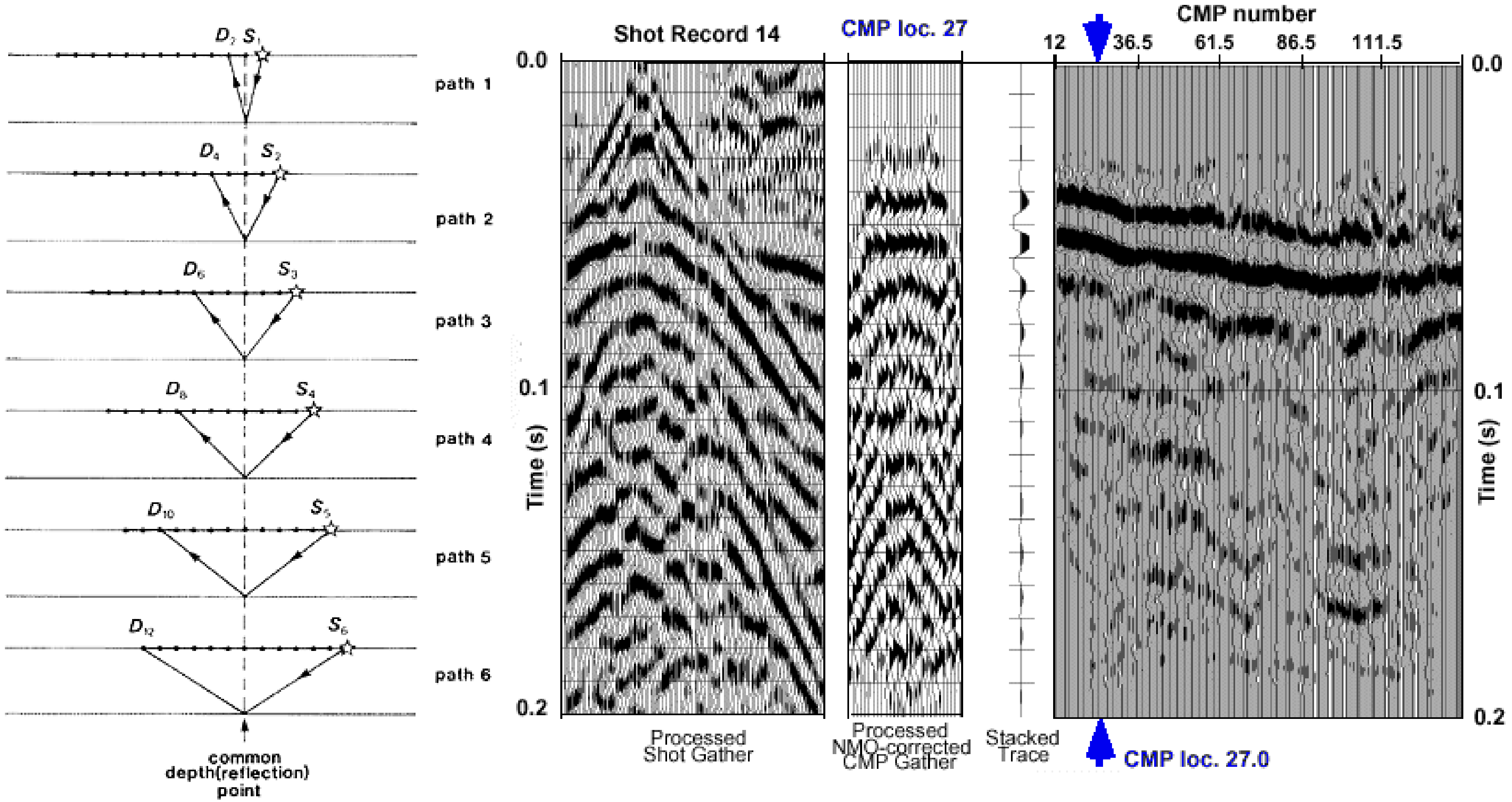


• Stacking these signals will produce a high quality reflection signal

Summary of CMP processing



CSG → CMP → Zero Offset Trace



CSG = common shot gather
CMP = common midpoint gather