From last time

- Direct waves

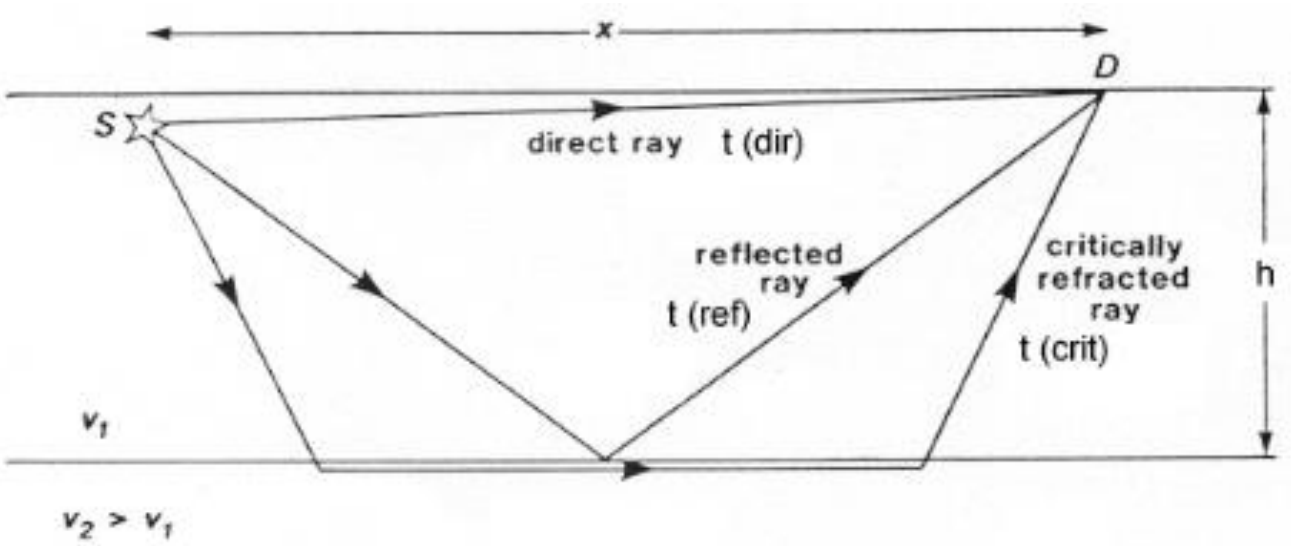
$$t_{dir} = \frac{x}{v_1}$$

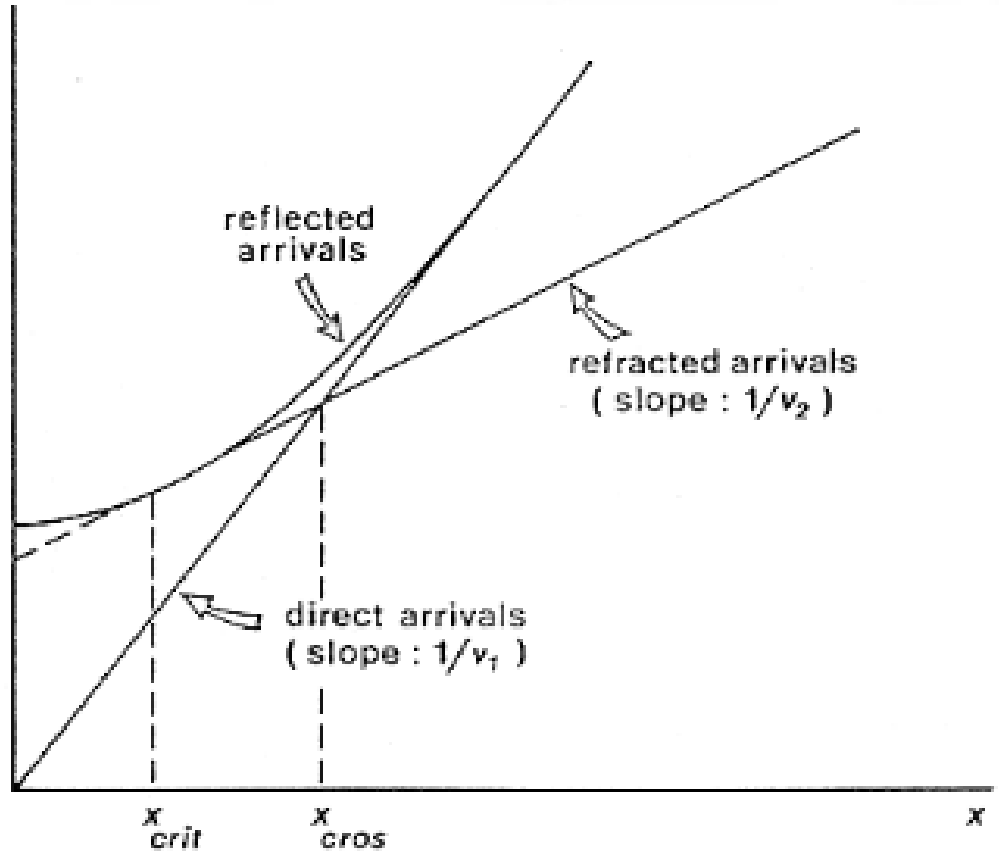
- Reflected waves

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

- Critically refracted waves (head waves)

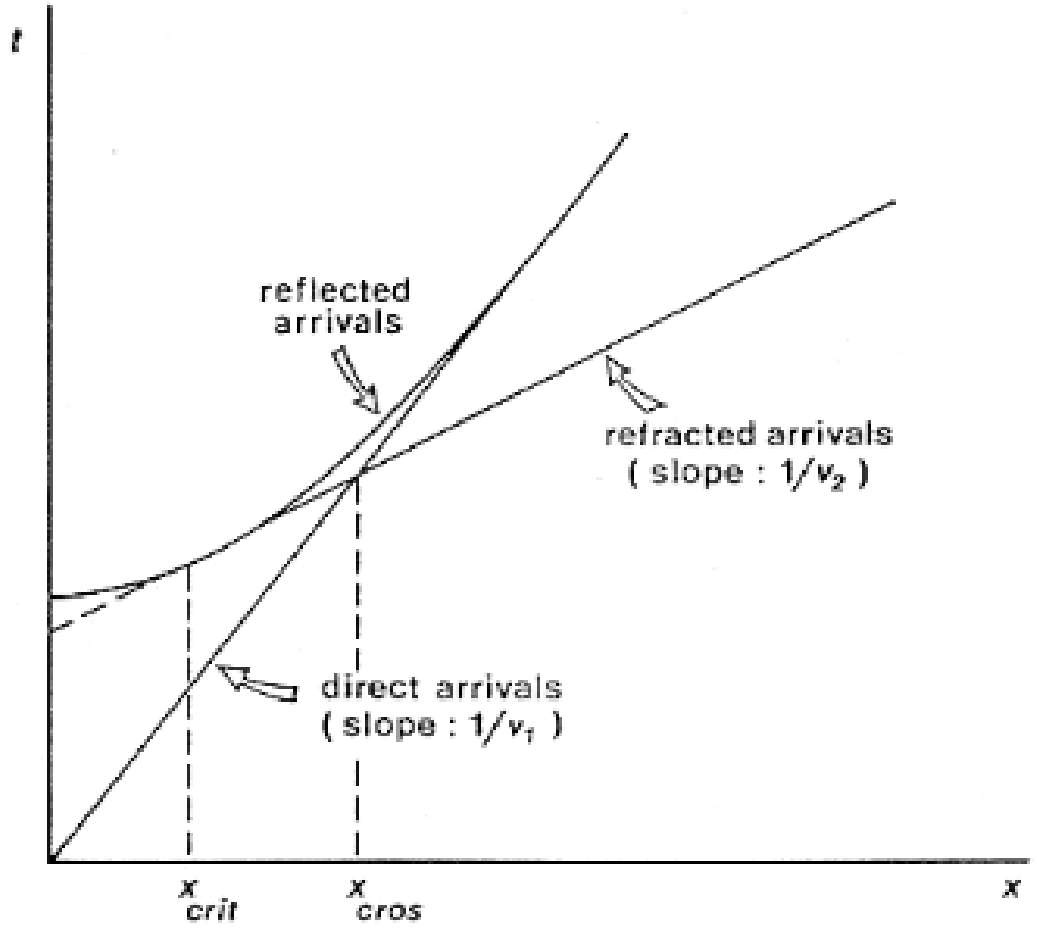
$$t_{refr} = \frac{x}{v_2} + \frac{2h\sqrt{v_2^2 - v_1^2}}{v_1 v_2}$$





From last time

- Plot the arrival times
- Identify each wave
- Use plot and equations to estimate layer velocity and thickness



Today’s Topics

- Survey
  - Basic idea
  - Sources
  - Receivers
  - Data acquisition
- Processing and Interpretation (Refraction)

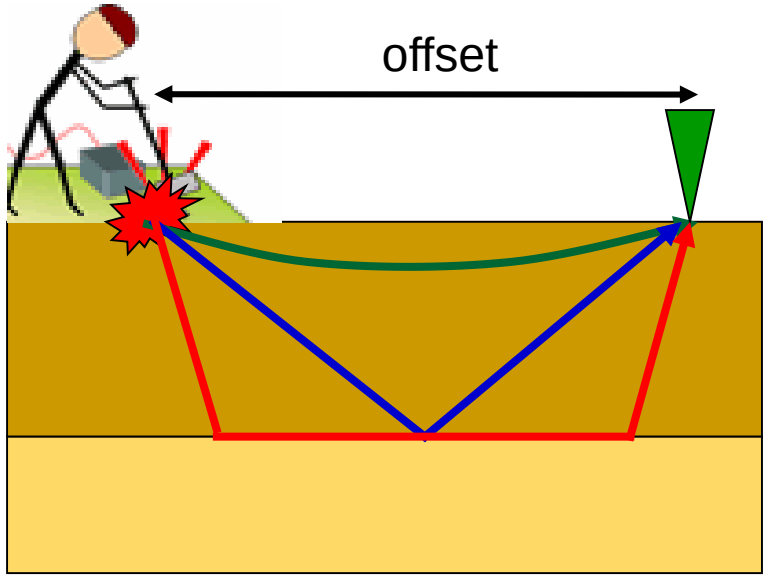
Survey

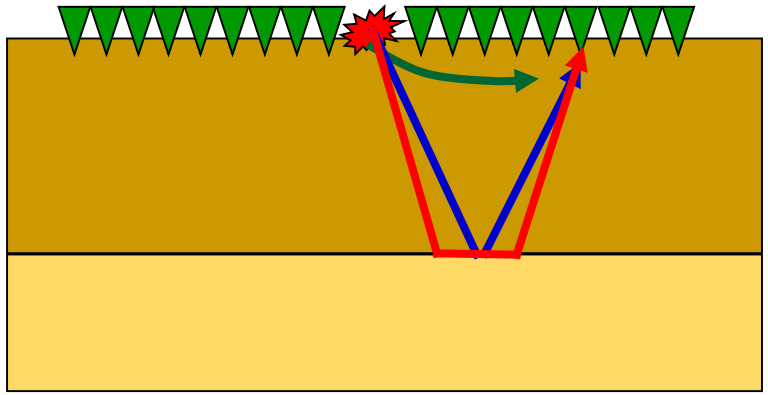
Reading on the GPG:

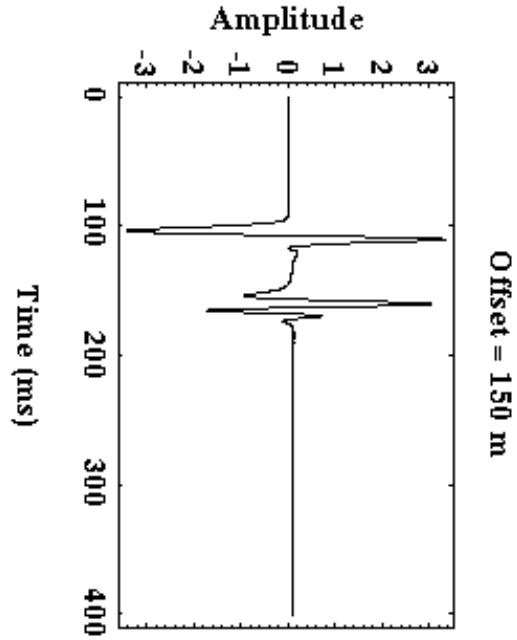
https://gpg.geosci.xyz/content/seismic/seismic_survey.html

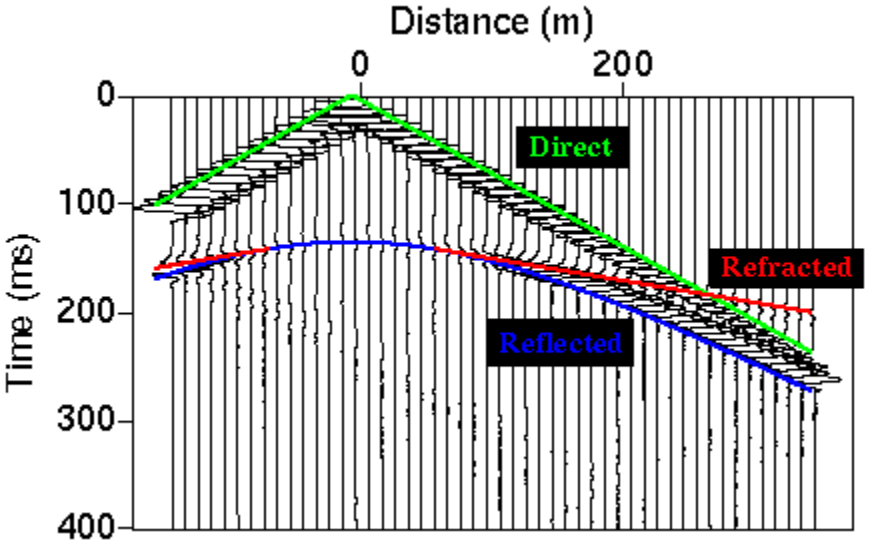
Seismic survey: Basic idea

- Source generates seismic signal
- Signal spreads in all directions
- Signal reflects, refracts and transmits at boundaries
- Geophones measure signal amplitude over time
- Raw signal turned into arrival time plot









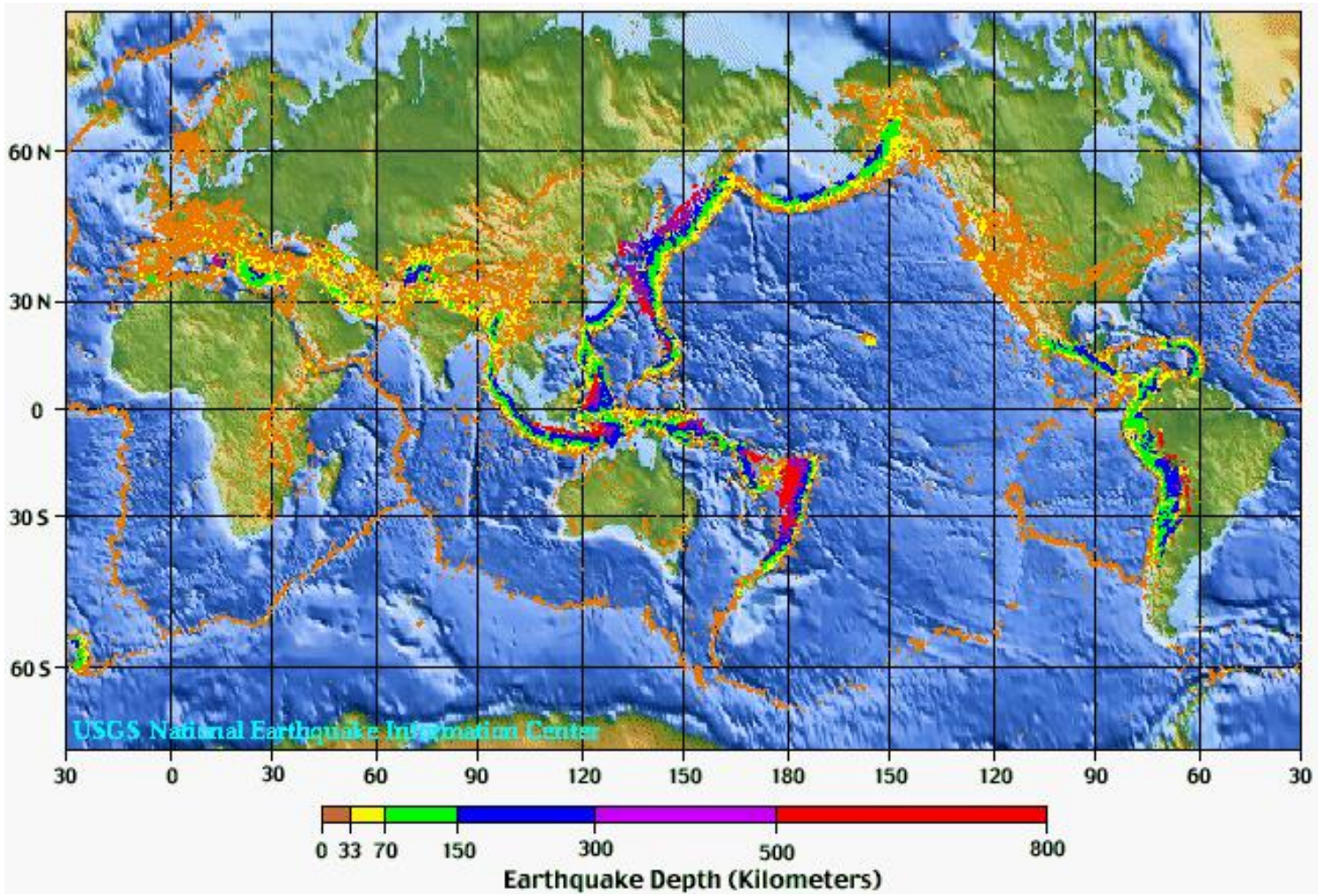
Seismic survey: Basic idea

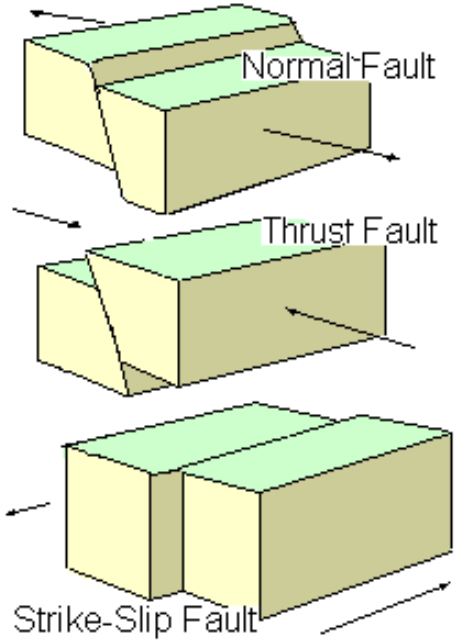
- Sources: anything that causes earth particles to move
  - Natural sources, like earthquakes
  - Man-made sources, like explosives, “hammers”, shock waves

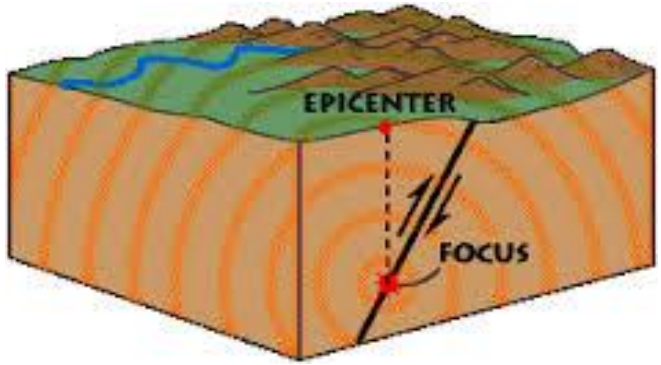
- Receivers: record ground motion for some time following the source
  - Geophones
  - Seismometers (3 component, broadband)

Sources

Natural source: earthquakes







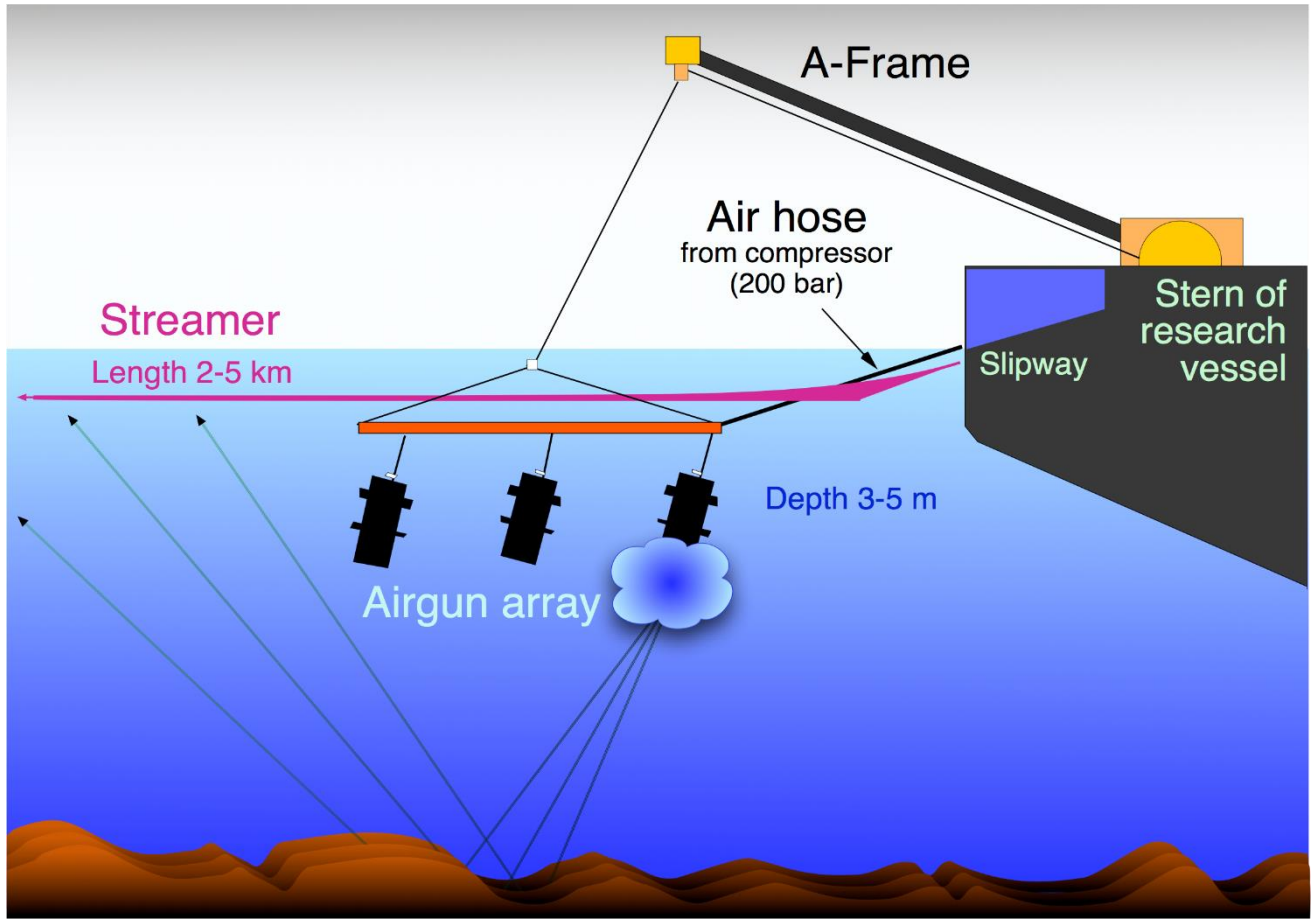
Man-made source: vibroseis truck

Single Source

Group of sources

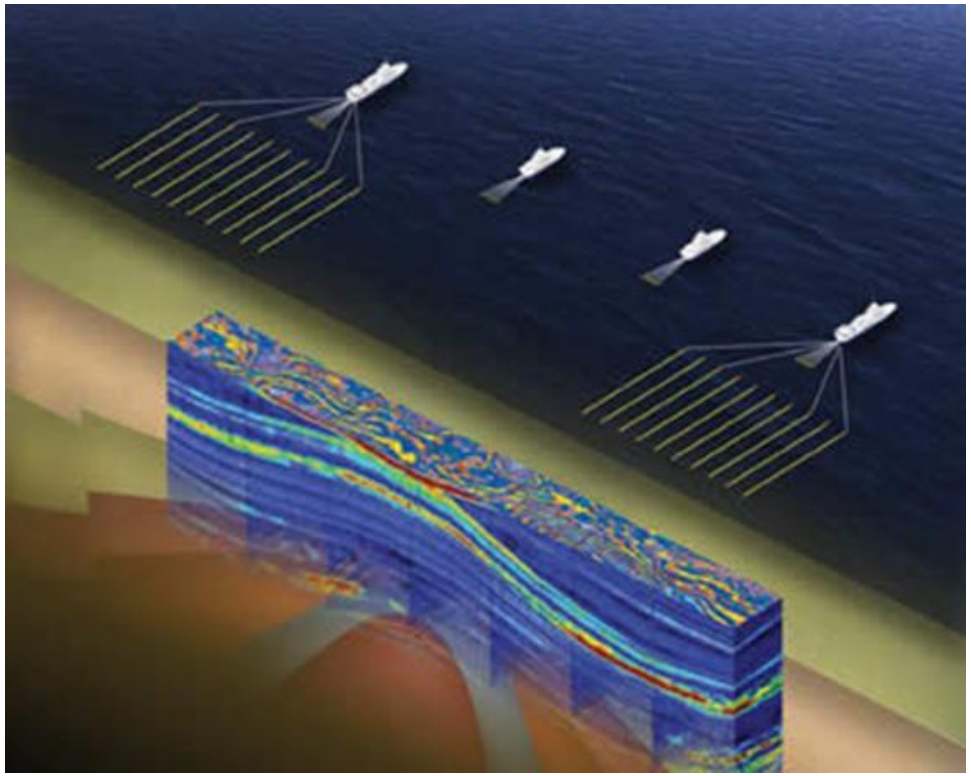
Man-made source: borehole explosion

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



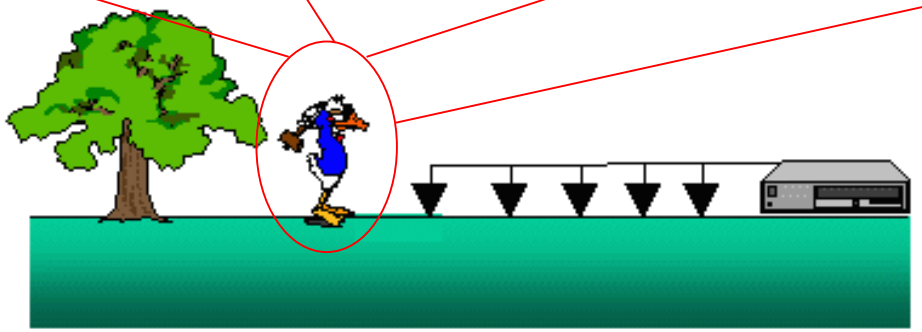
Man-made source: small-scale

Sledge Hammer

Shotgun Blast

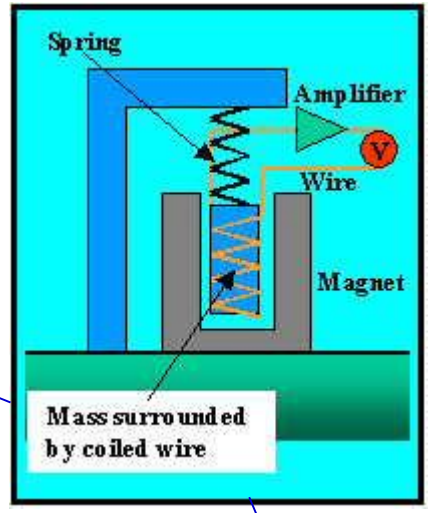
Weight Drop

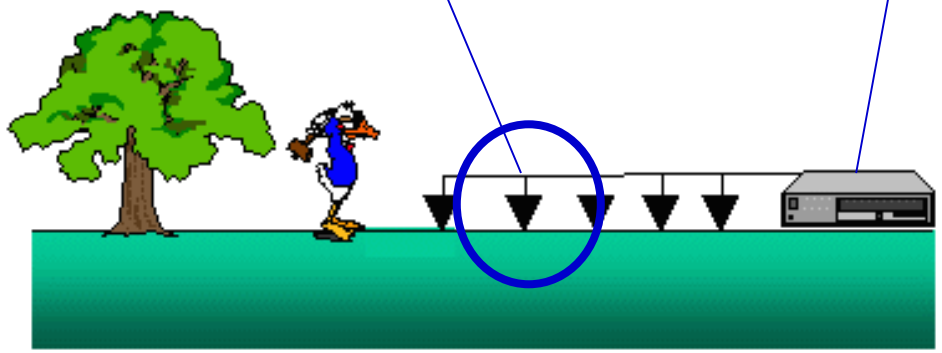
Explosives



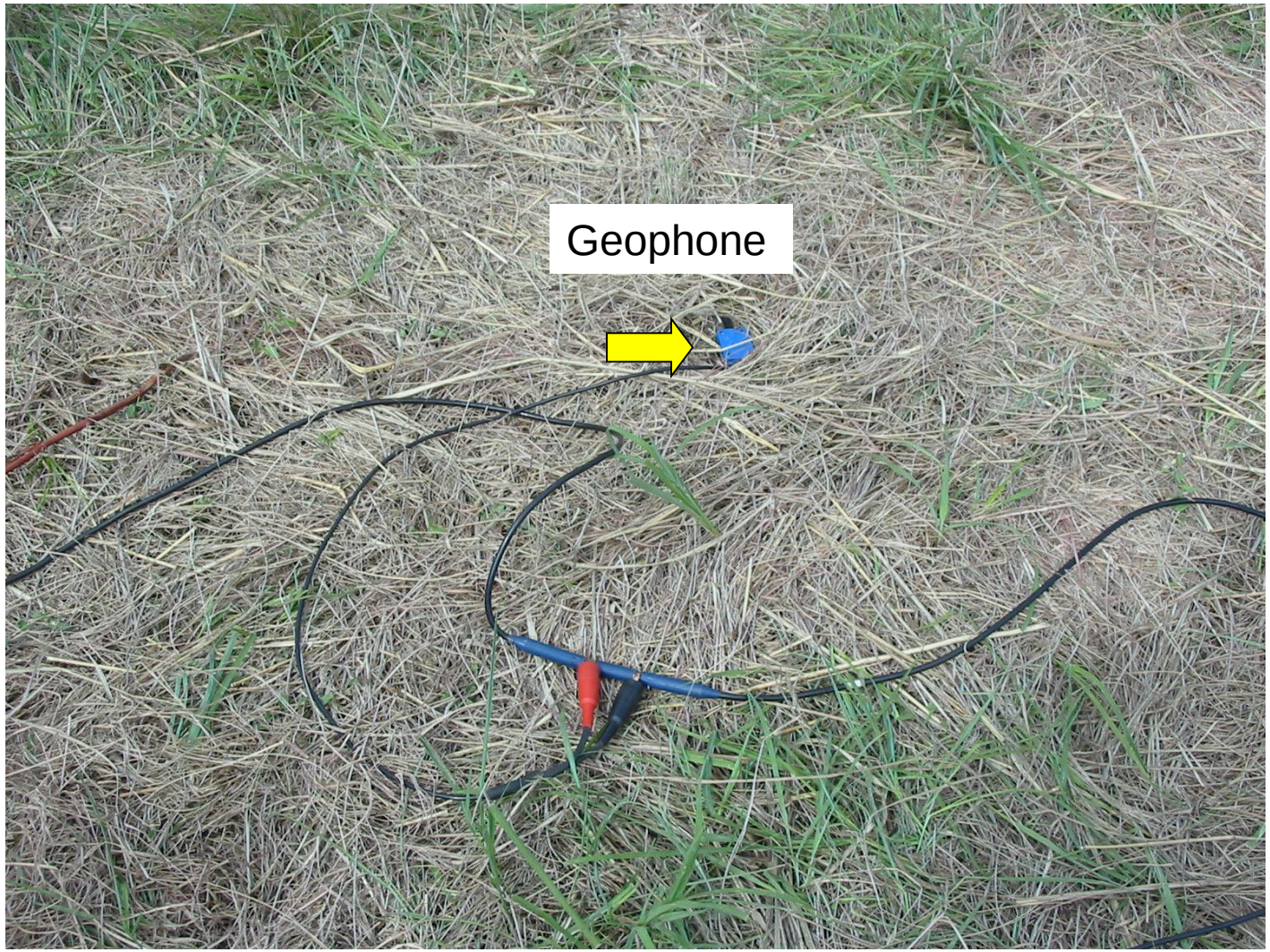
Receivers

Receivers: geophones





Set up the geophone array



Set up the geophone array

Receivers: hydrophone streamer

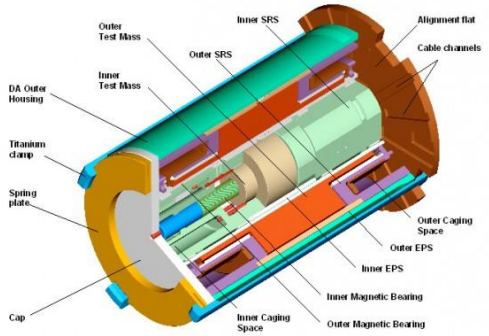
https://commons.wikimedia.org/w/index.php?curid=1468353

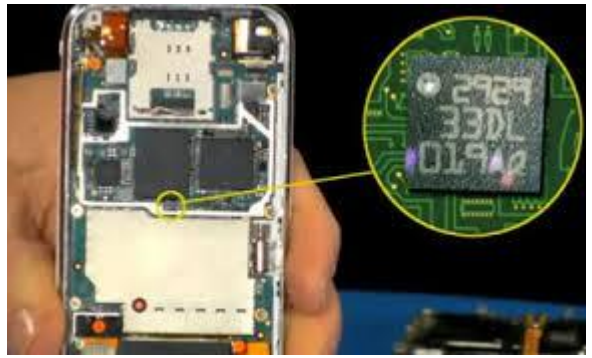
Receivers: seismometer

Smartphone example

- iPhone app: iSeismometer
- Android:

- Measure gravitational acceleration



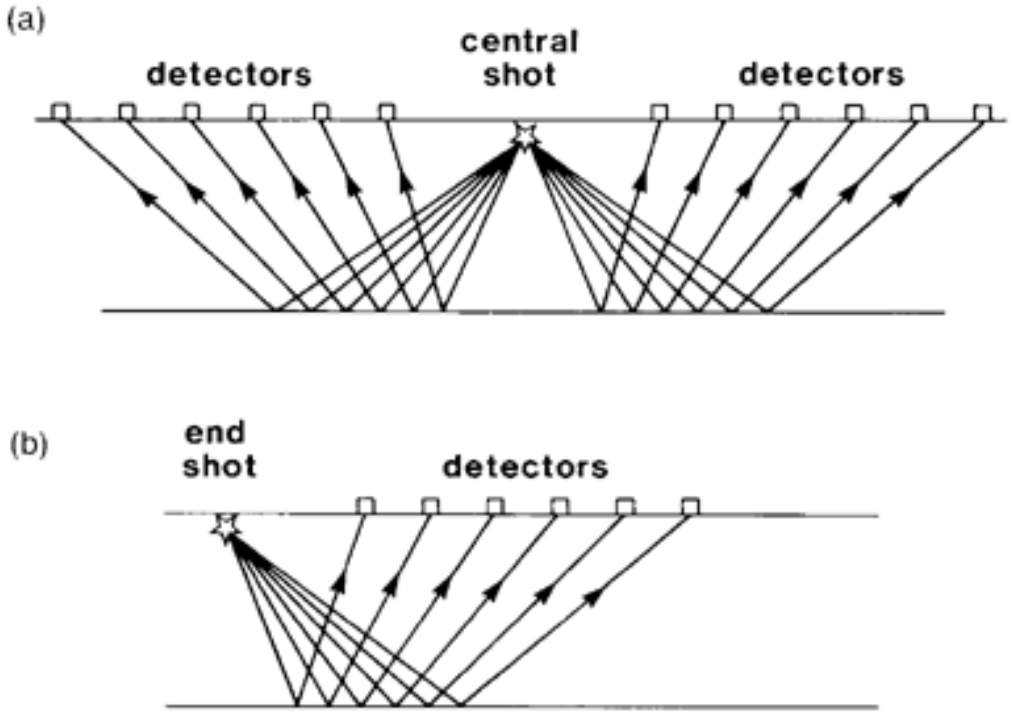


Data Acquisition

Multichannel data collection

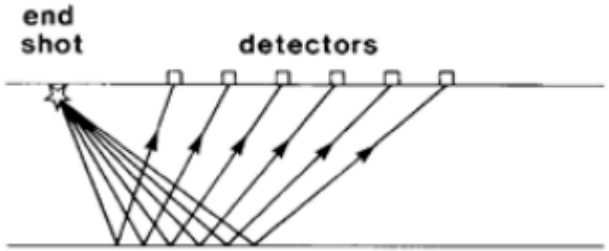
- **Split spread:** Receivers on either side of source (common for land surveys)

- **Single-ended spread:** Receivers on one side of source (common in marine surveys)

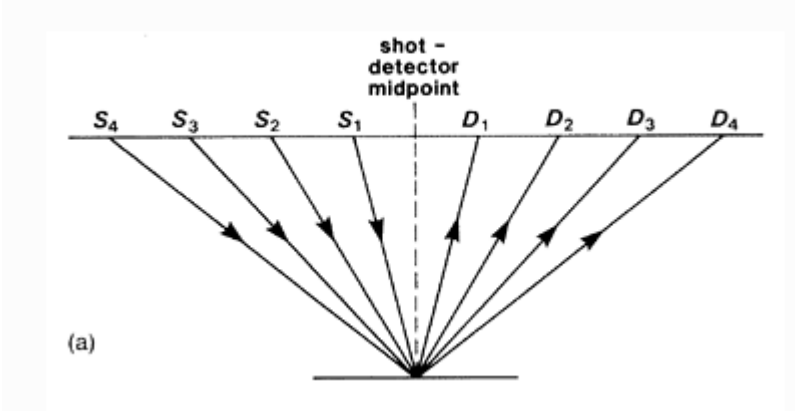


Common shot vs. common midpoint

- **Common shot gathers:**
  - Multiple receivers for each source
  - Different reflection point



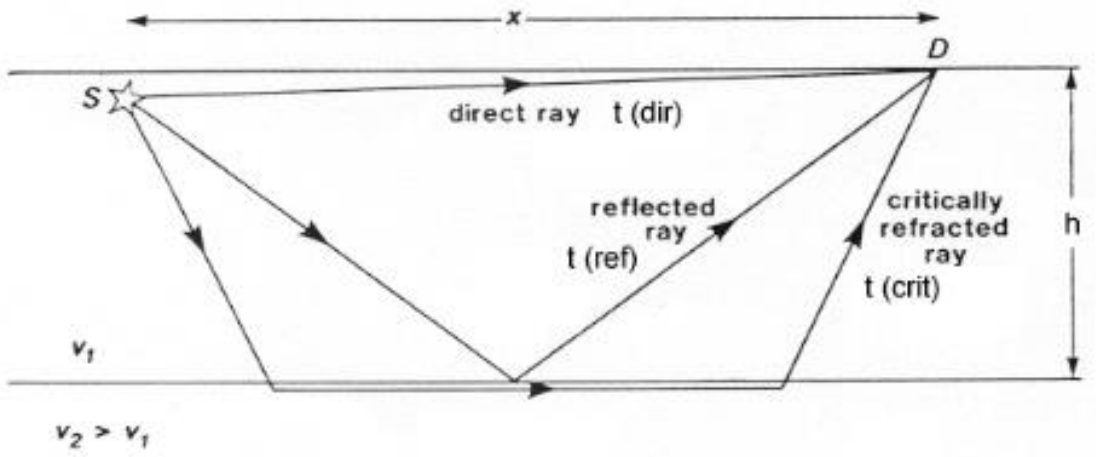
- **Common midpoint gathers:**
  - Set of sources and receivers
  - Common reflection point (if flat interface)



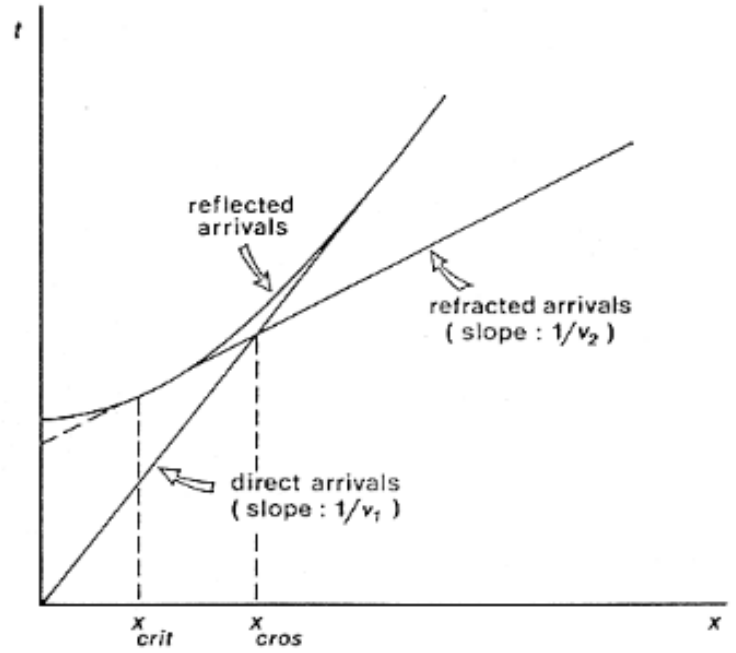
- Survey possibly comprised of both sets of information

Refraction Surveys

- Each source has multiple receivers

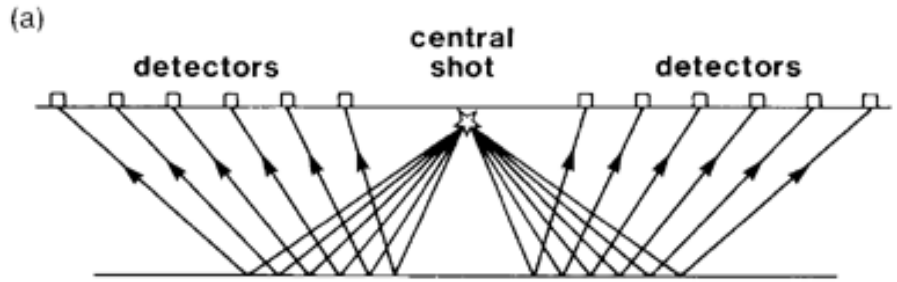


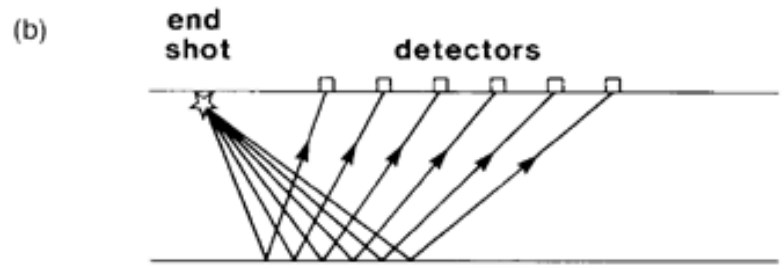
- Uses first arrivals from refracted waves to infer information about layers

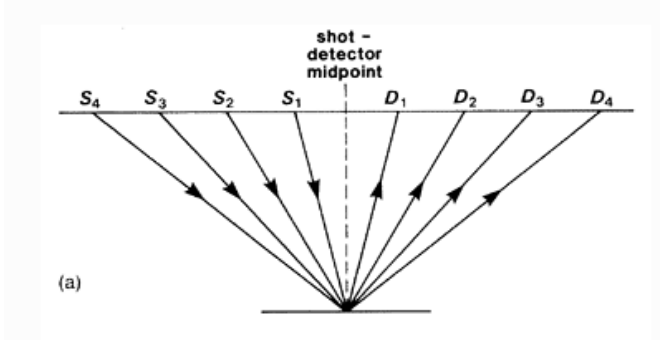


Reflection Surveys

- Use reflected waves to infer information about layers



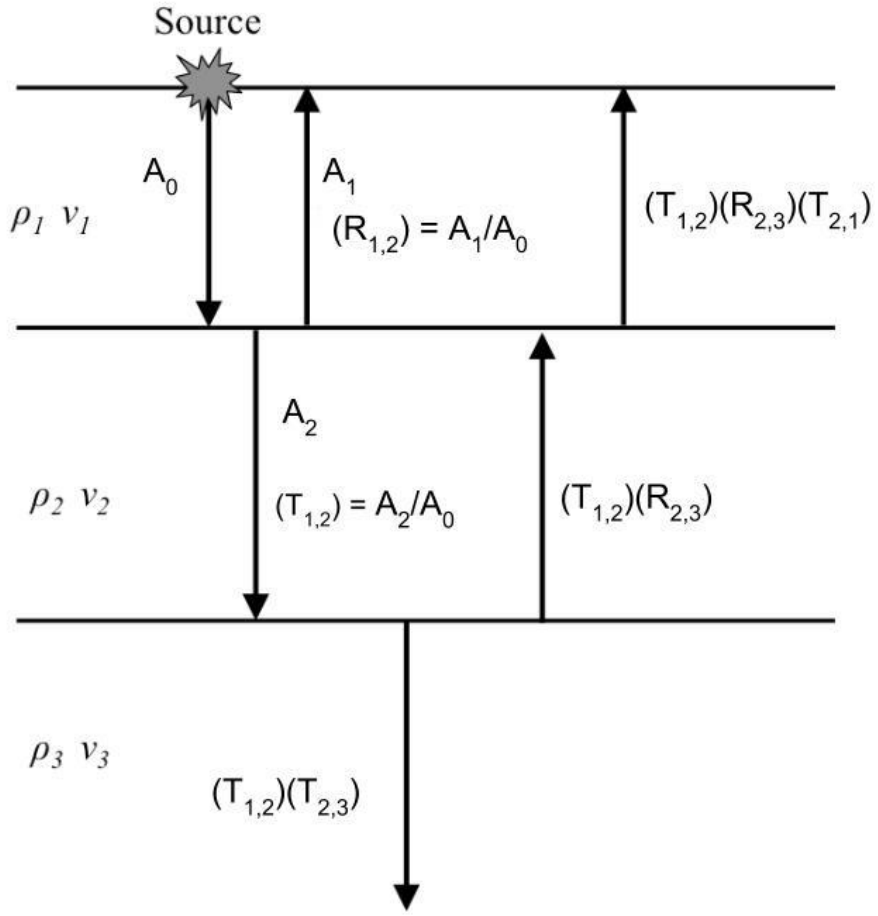




Reflection Surveys: reflection amplitude

- Reflection due to changes in acoustic impedance.

$$Z = \rho V$$

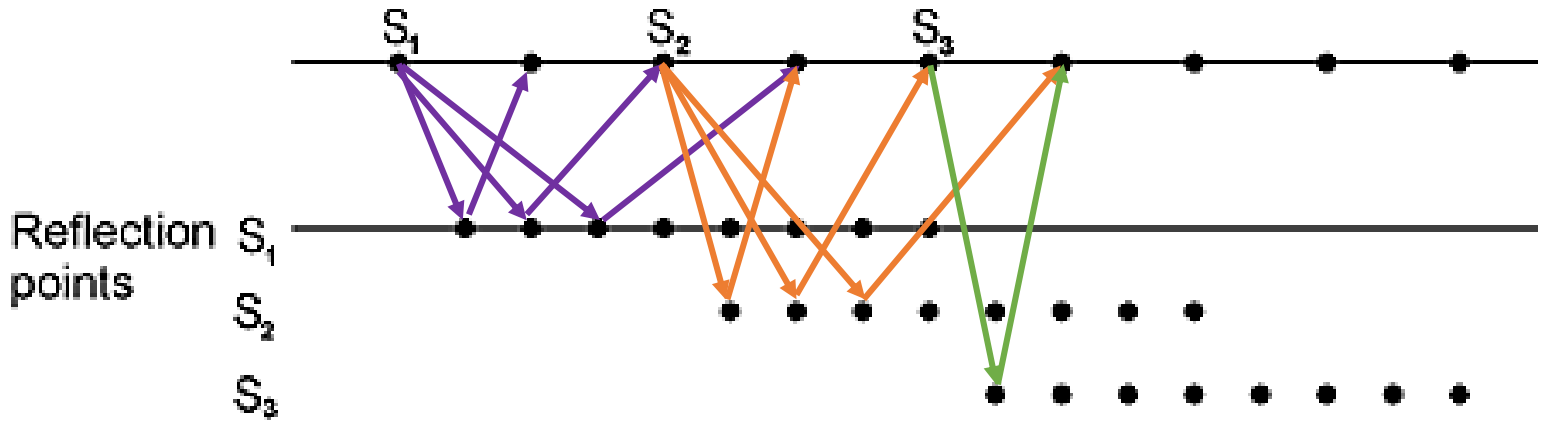


Fold

- 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?
  - $fold = \frac{8}{2*2} = 2$



Processing and Interpretation: Refraction Surveys

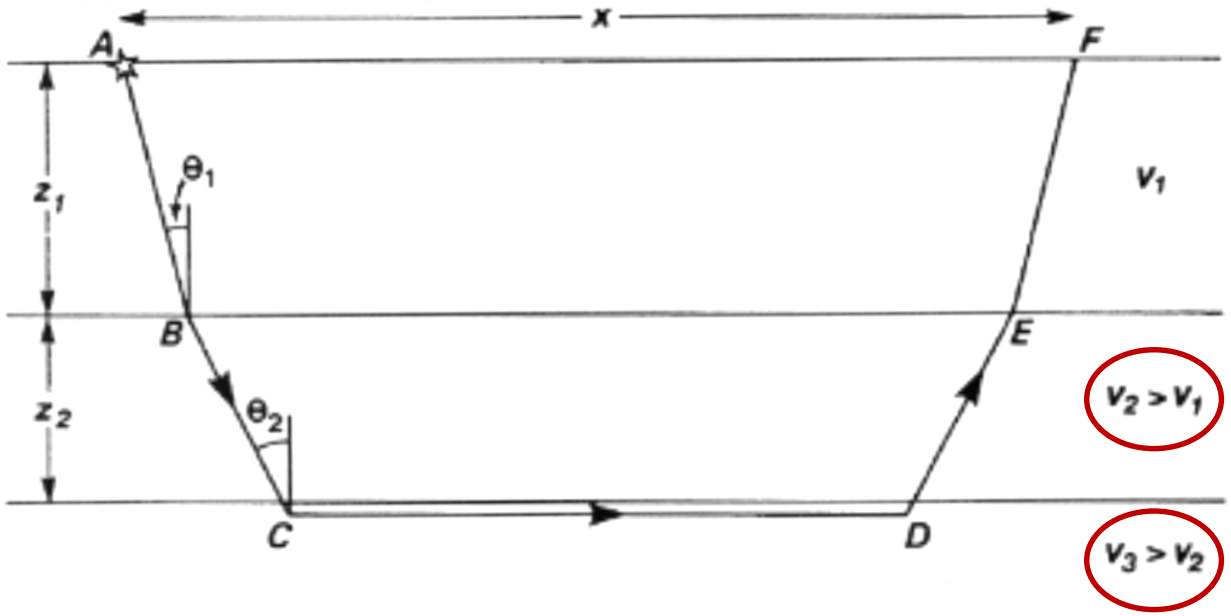
Reading on the GPG:

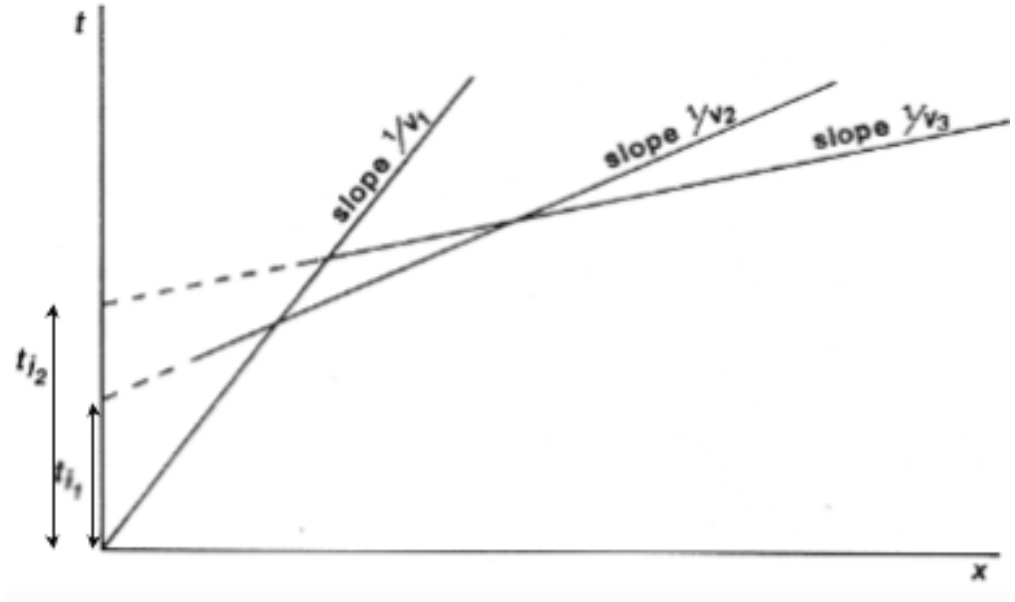
https://gpg.geosci.xyz/content/seismic/seismic_refraction_dipping_layers.html

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

Refraction Recap

- Direct, reflected and refracted waves
- Assuming flat interfaces, travel times are known
- Use travel time formulas and points to estimate layer thickness and velocity

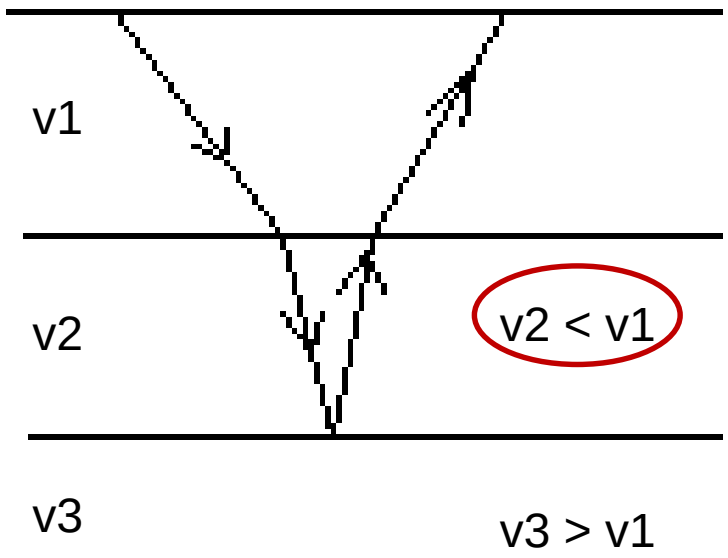


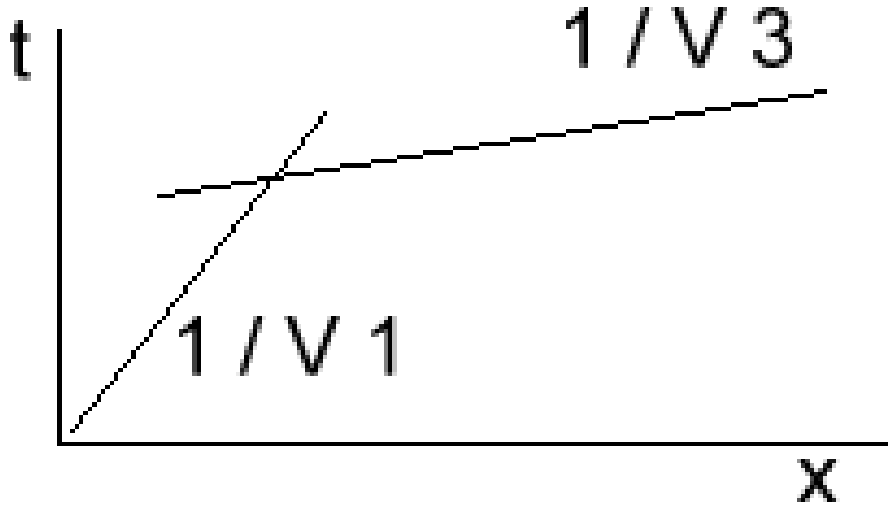


Low velocity zones

- No refracted arrival from the top of the second layer

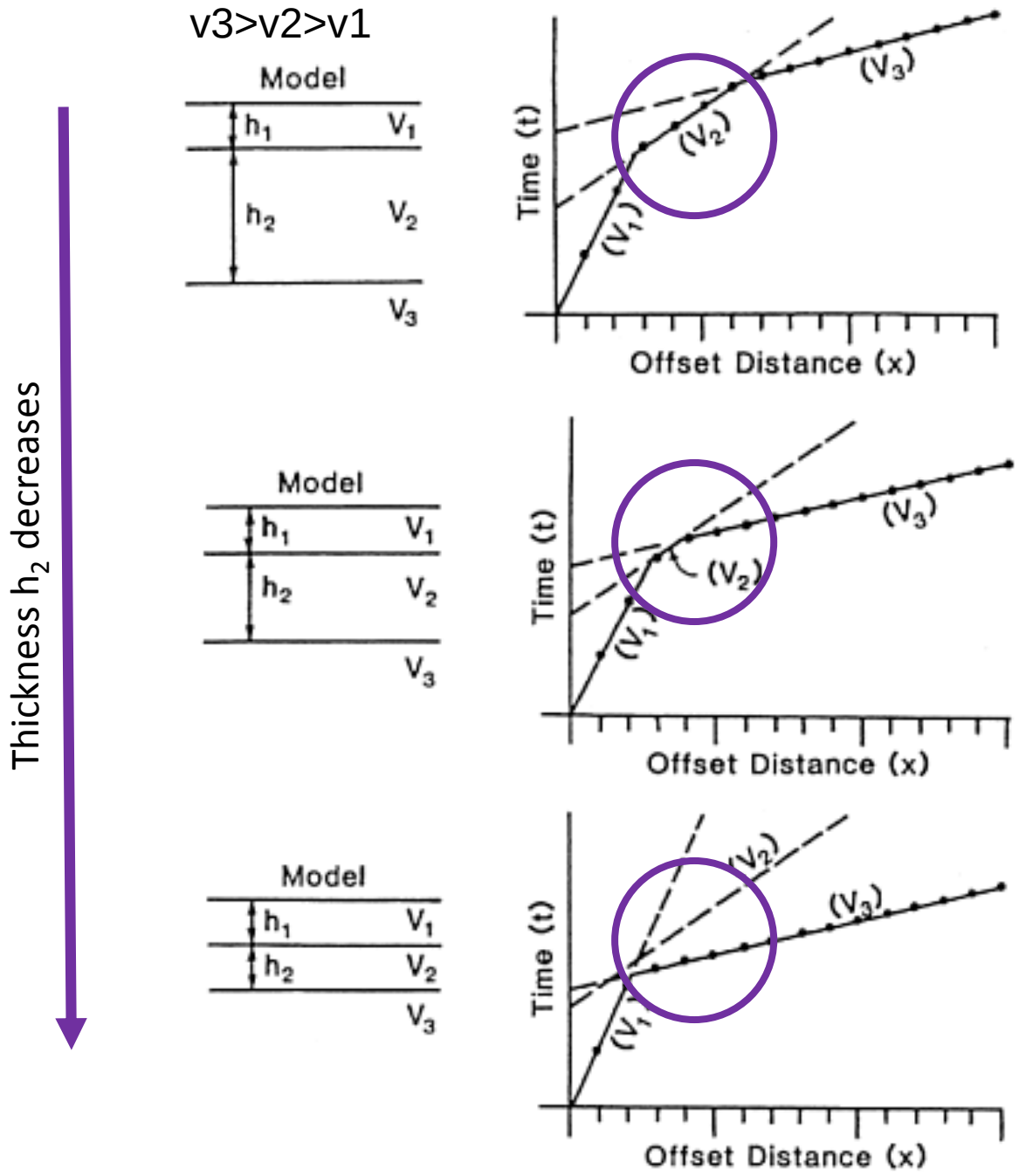
$$\frac{\sin\theta_1}{v_1} = \frac{\sin\theta_2}{v_2}$$



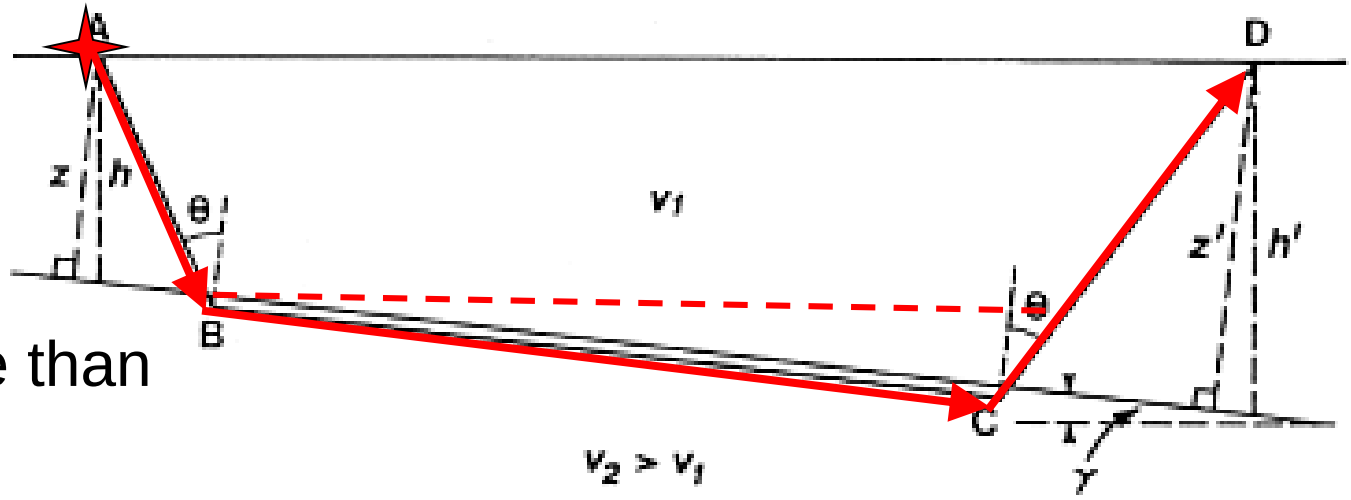


Hidden layers

- Layers that are too thin may not be seen
- Arrival from layer 3 beats that from layer 2



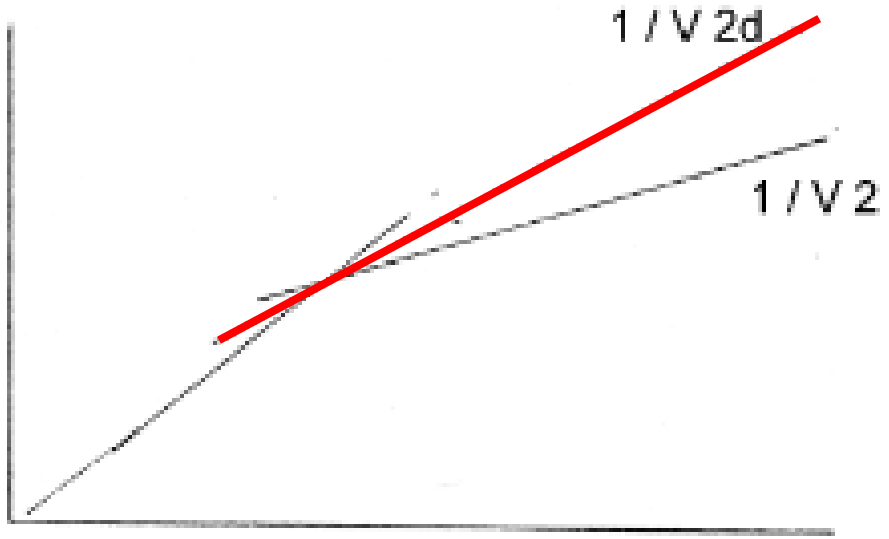
Dipping layers



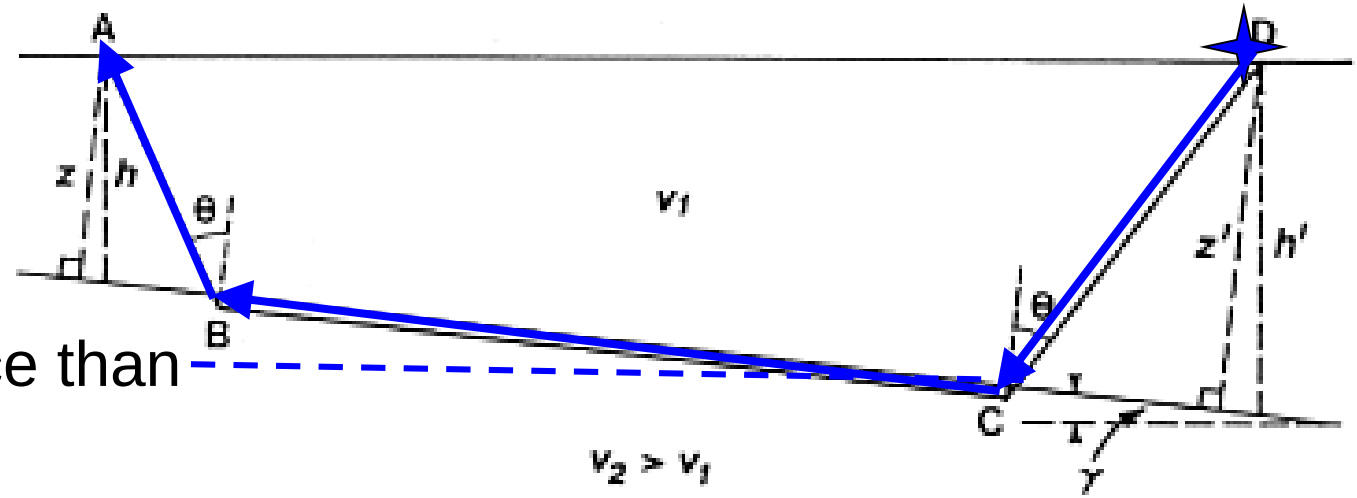
- The red refracted wave has to travel a LONGER distance than if the layer was horizontal.

- 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



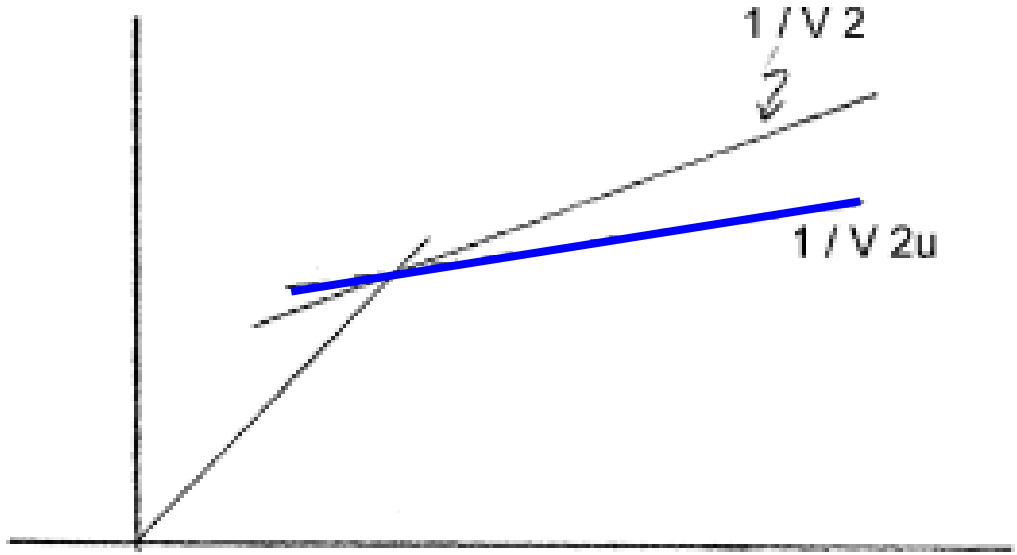
Dipping layers



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

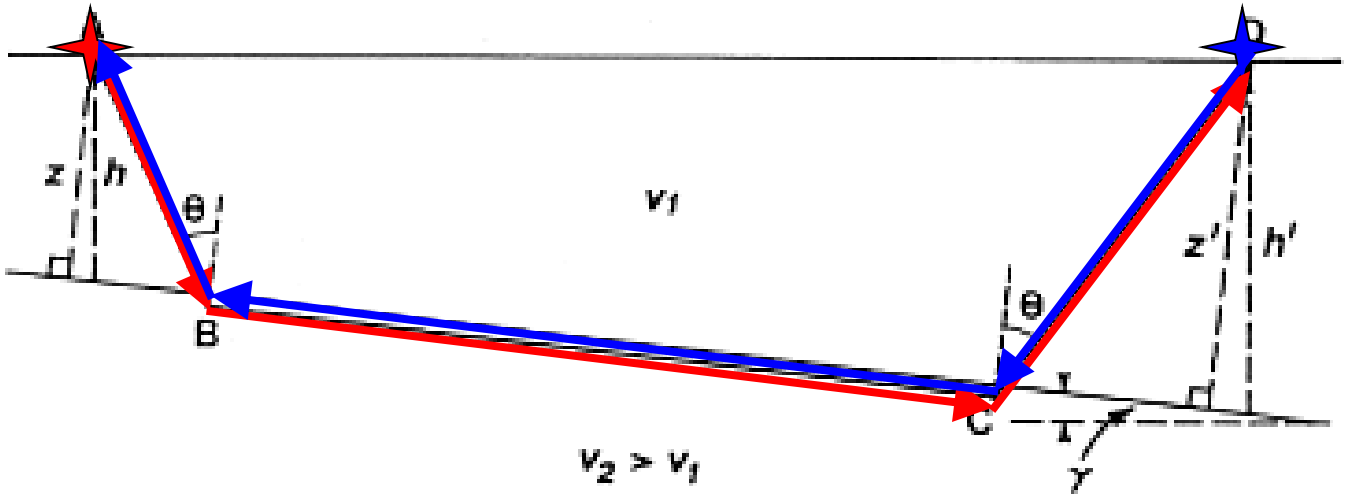
- Thus the travel time is shorter and the slope on the T-X plot is decreased.

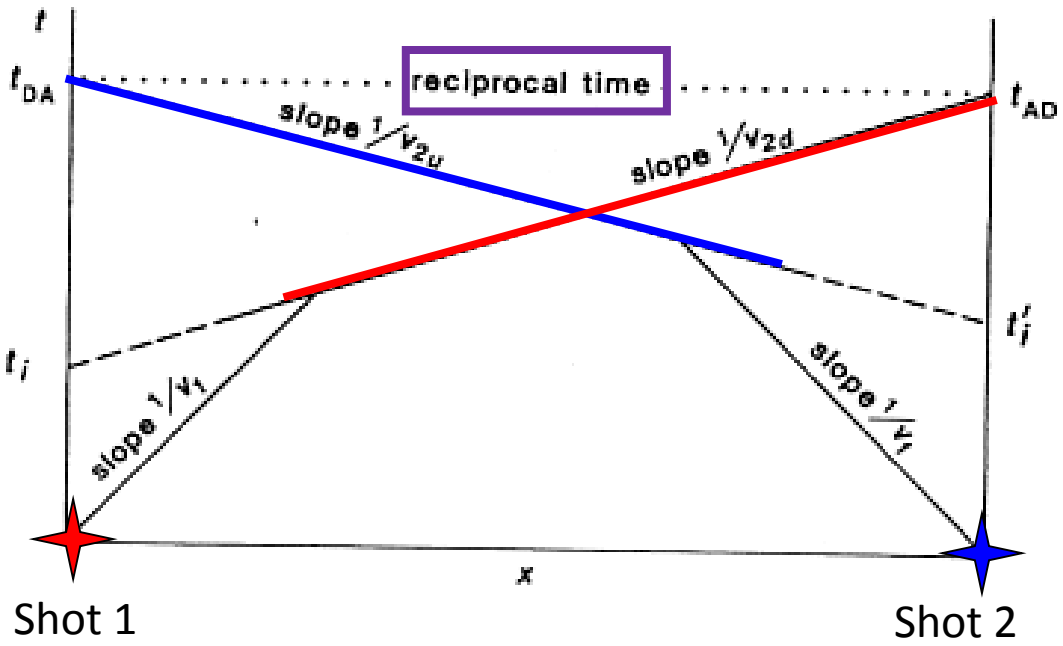
- The estimated velocity will be LARGER than the actual velocity



Dipping layers

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





Shot 1

Shot 2

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

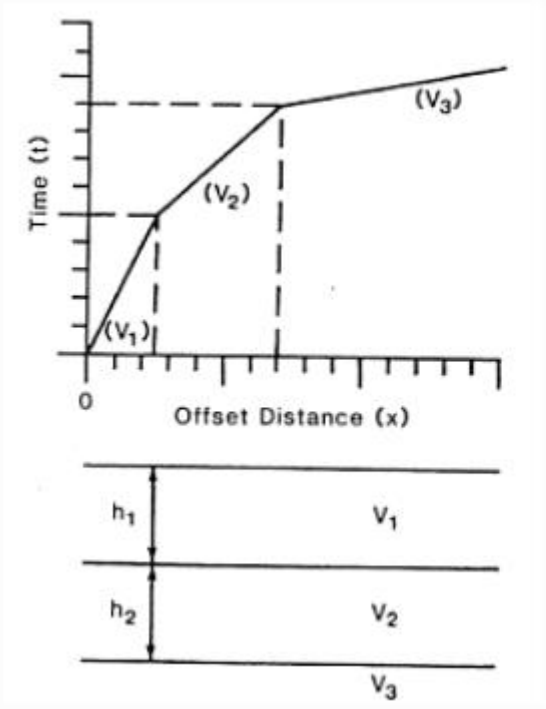
- What happens when the boundary can no longer be approximated as a plane?

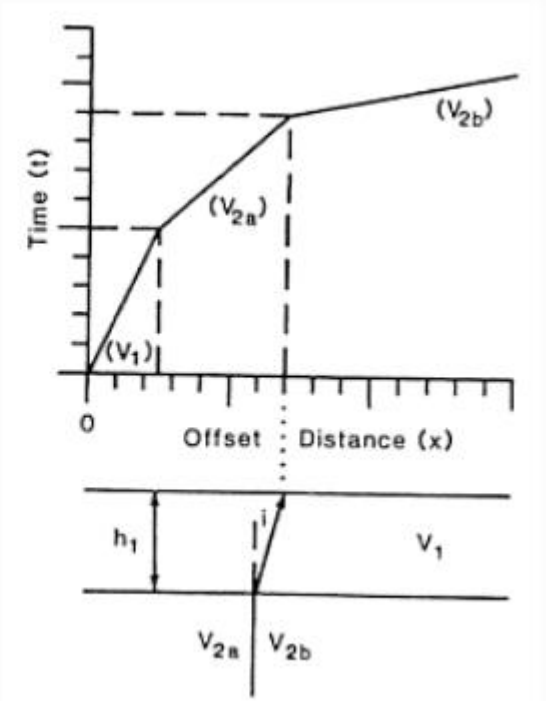
  - Plus-minus method
  - Generalized reciprocal methods
  - Ray tracing
  - Other sophisticated procedures

Lateral Velocity Changes

- Critically refracted wave travels at v_{2a} then at v_{2b}

- Seismograms looks like 3 layer case



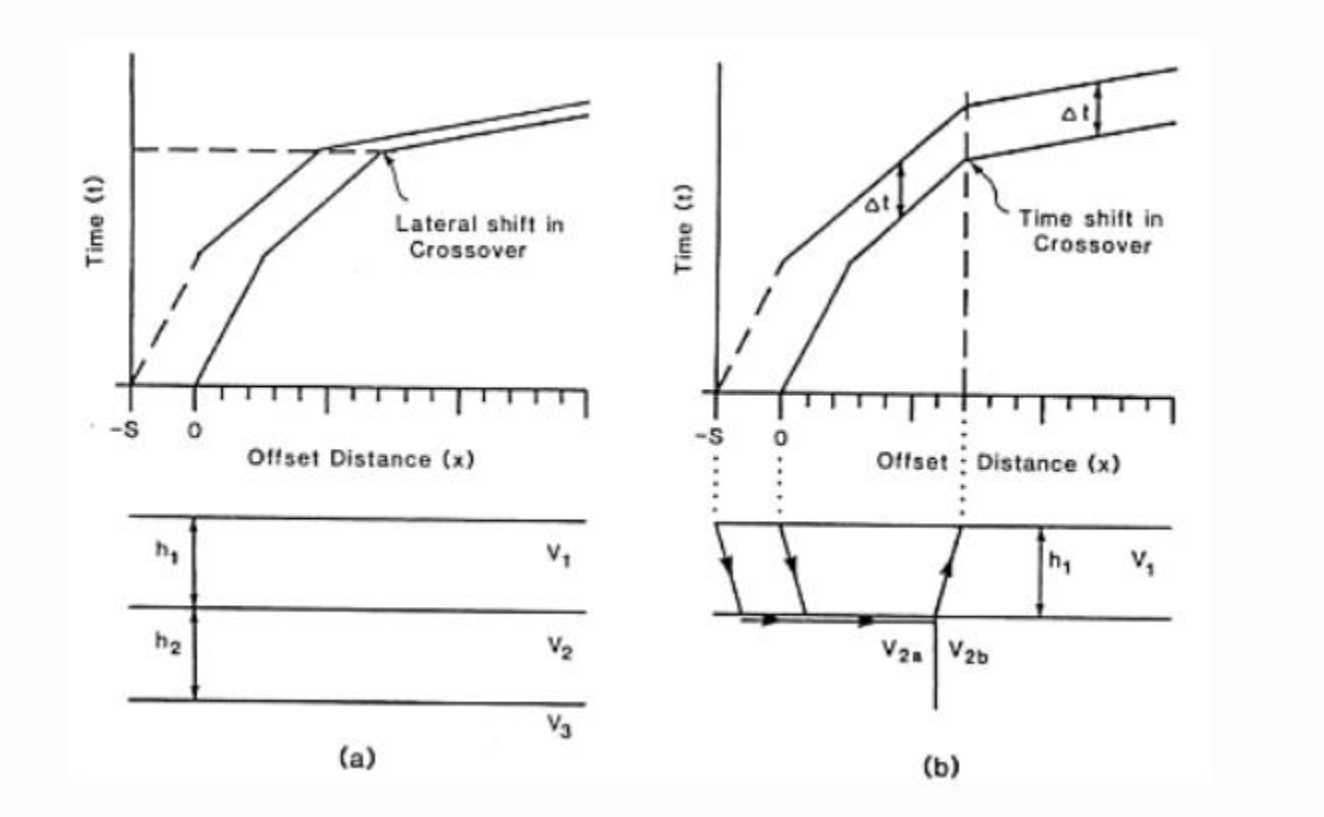


Lateral Velocity Changes

- Examine seismogram from shifted common shot gather

- If layer
  → Horizontal shift

- If lateral change
  → Vertical shift



Recap

- Refraction survey good when layer velocity increases with depth
- Low velocity zones and thin layers no visible
- Need shots from two sides to resolve dipping layers

Unit Activities

- **Labs: (Seismic I)**
  - Monday, September 30th
  - Tuesday, October 1st
- **Labs: (Seismic II)**
  - Monday, October 7th
  - Tuesday, October 8th
- **TBL:**
  - Monday, October 7th
- **Quiz:**
  - Monday, October 7th