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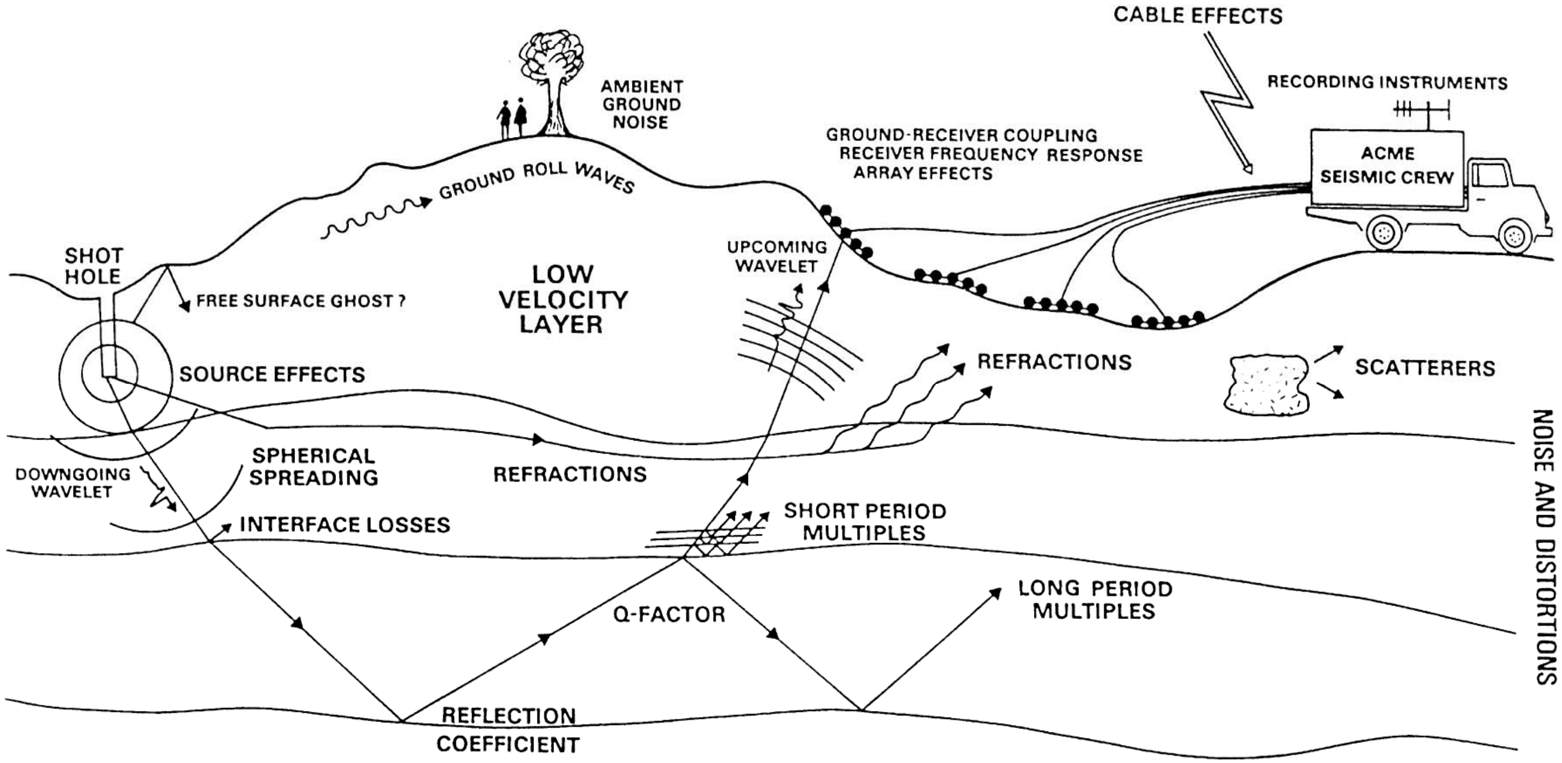
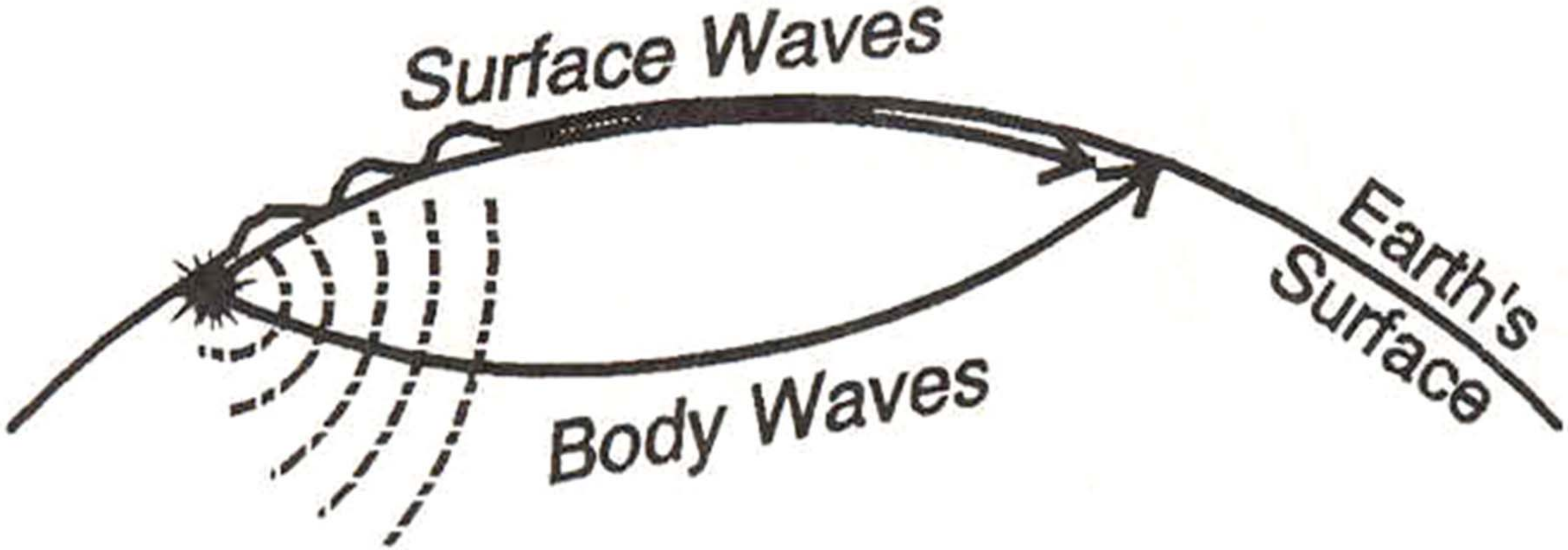
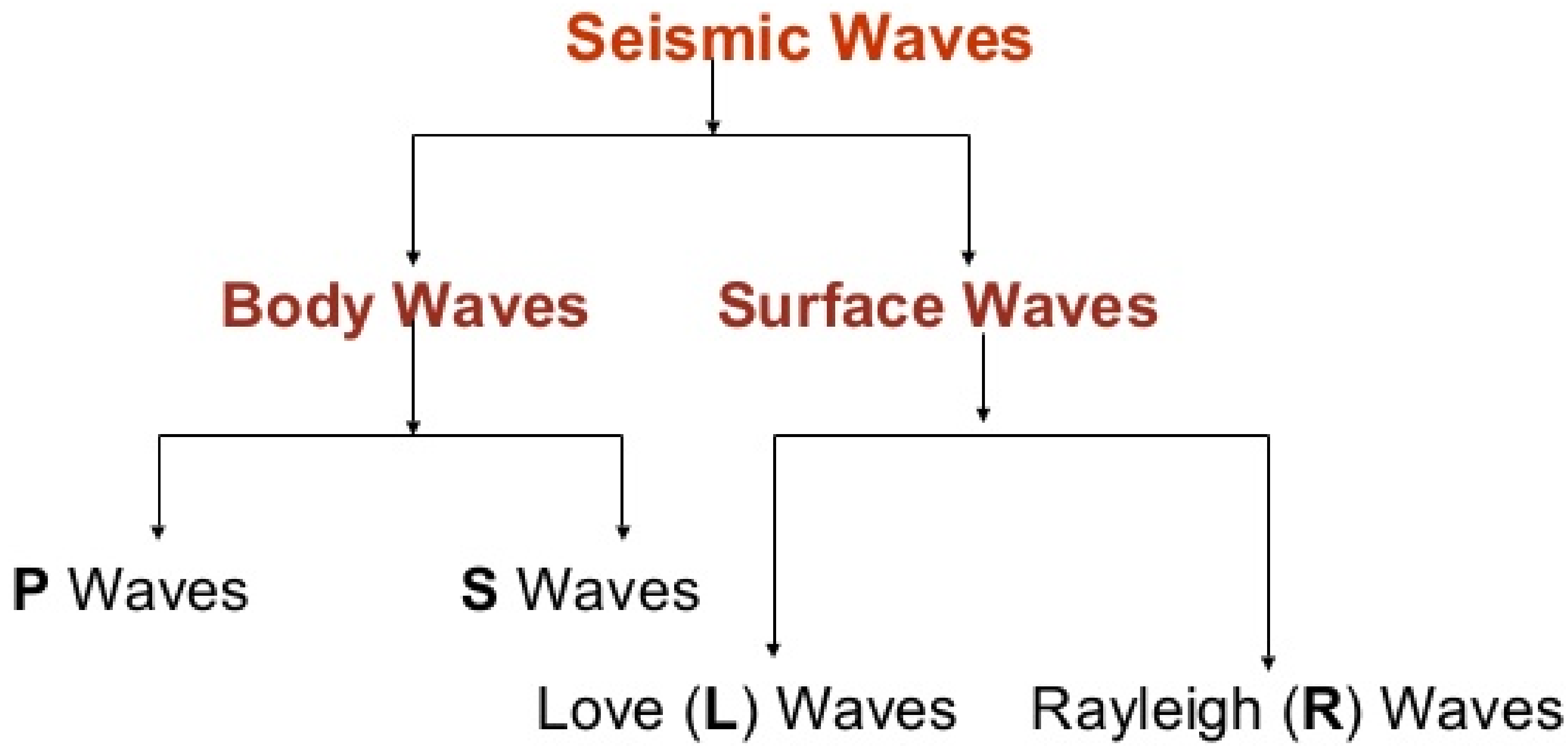
GPH 201

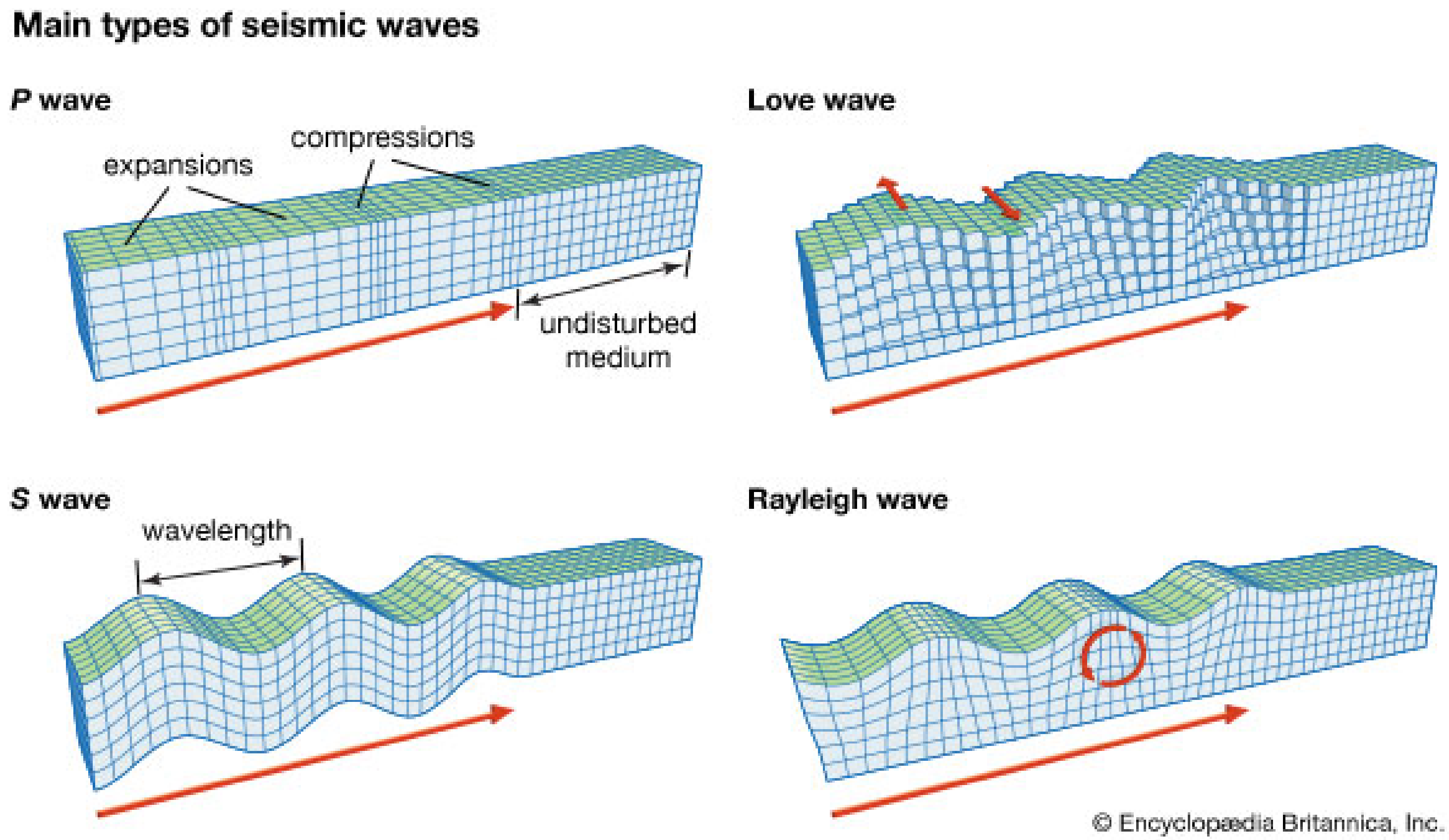
Principles of Geophysics

Dr. Sattam Abdulkareem Almadani


CABLE EFFECTS
RECORDING INSTRUMENTS
AMBIENT GROUND NOISE
GROUND-RECEIVER COUPLING
RECEIVER FREQUENCY RESPONSE
ARRAY EFFECTS
ACME SEISMIC CREW
GROUND ROLL WAVES
SHOT HOLE
FREE SURFACE GHOST ?
LOW VELOCITY LAYER
UPCOMING WAVELET
SOURCE EFFECTS
REFRACTIONS
SCATTERERS
DOWNGOING WAVELET
SPHERICAL SPREADING
REFRACTIONS
INTERFACE LOSSES
SHORT PERIOD MULTIPLES
NOISE AND DISTORTIONS
Q-FACTOR
LONG PERIOD MULTIPLES
REFLECTION COEFFICIENT


Surface Waves
Body Waves
Earth's Surface


Seismic Waves
Body Waves
Surface Waves
P Waves
S Waves
Love (L) Waves
Rayleigh (R) Waves


Main types of seismic waves
P wave
compressions
expansions
undisturbed
medium
Love wave
S wave
wavelength
Rayleigh wave
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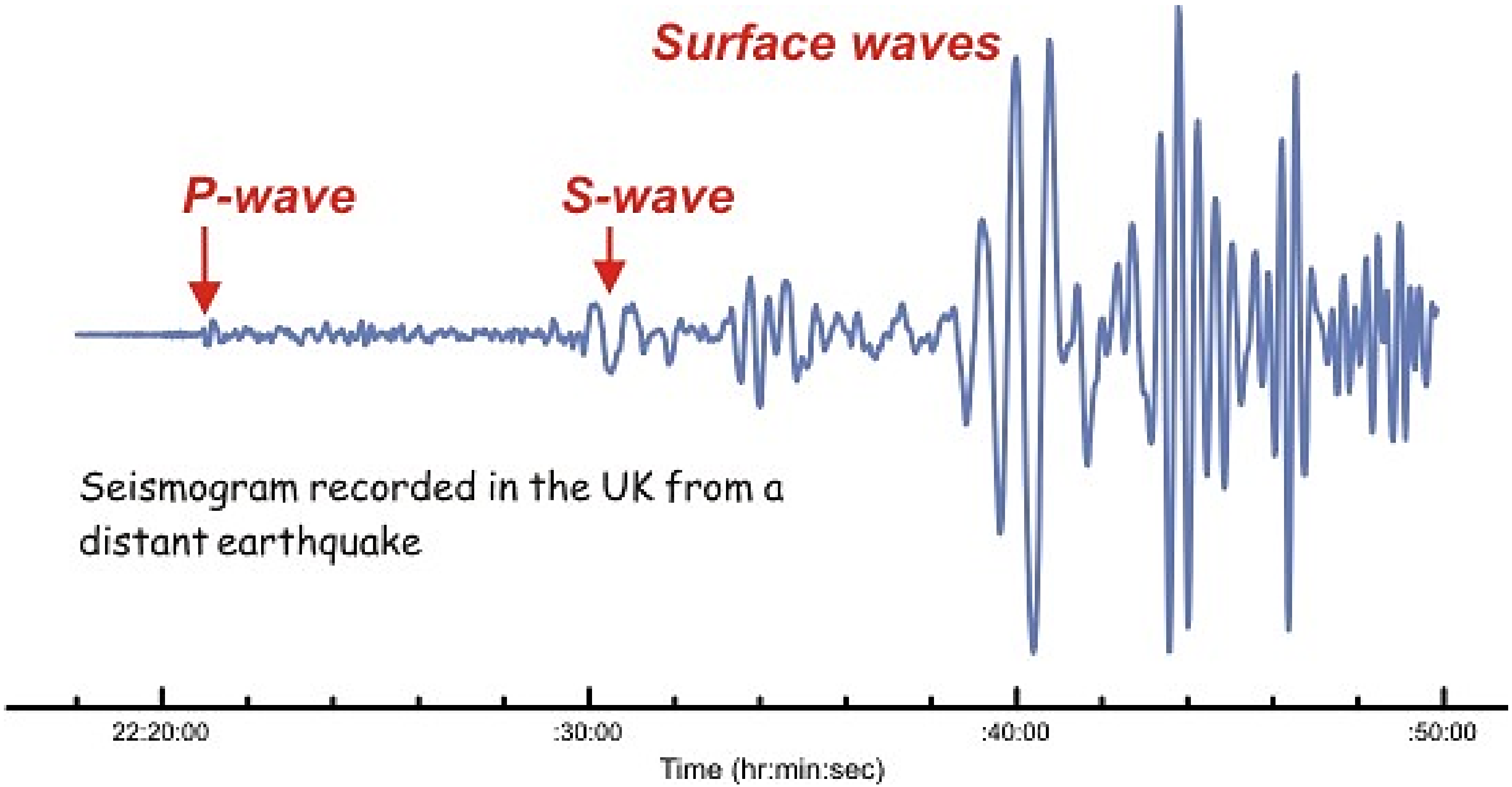

Surface waves
P-wave
S-wave
Seismogram recorded in the UK from a distant earthquake
22:20:00
:30:00
:40:00
:50:00
Time (hr:min:sec)

Relationship between Vp and Vs

Compressional Waves

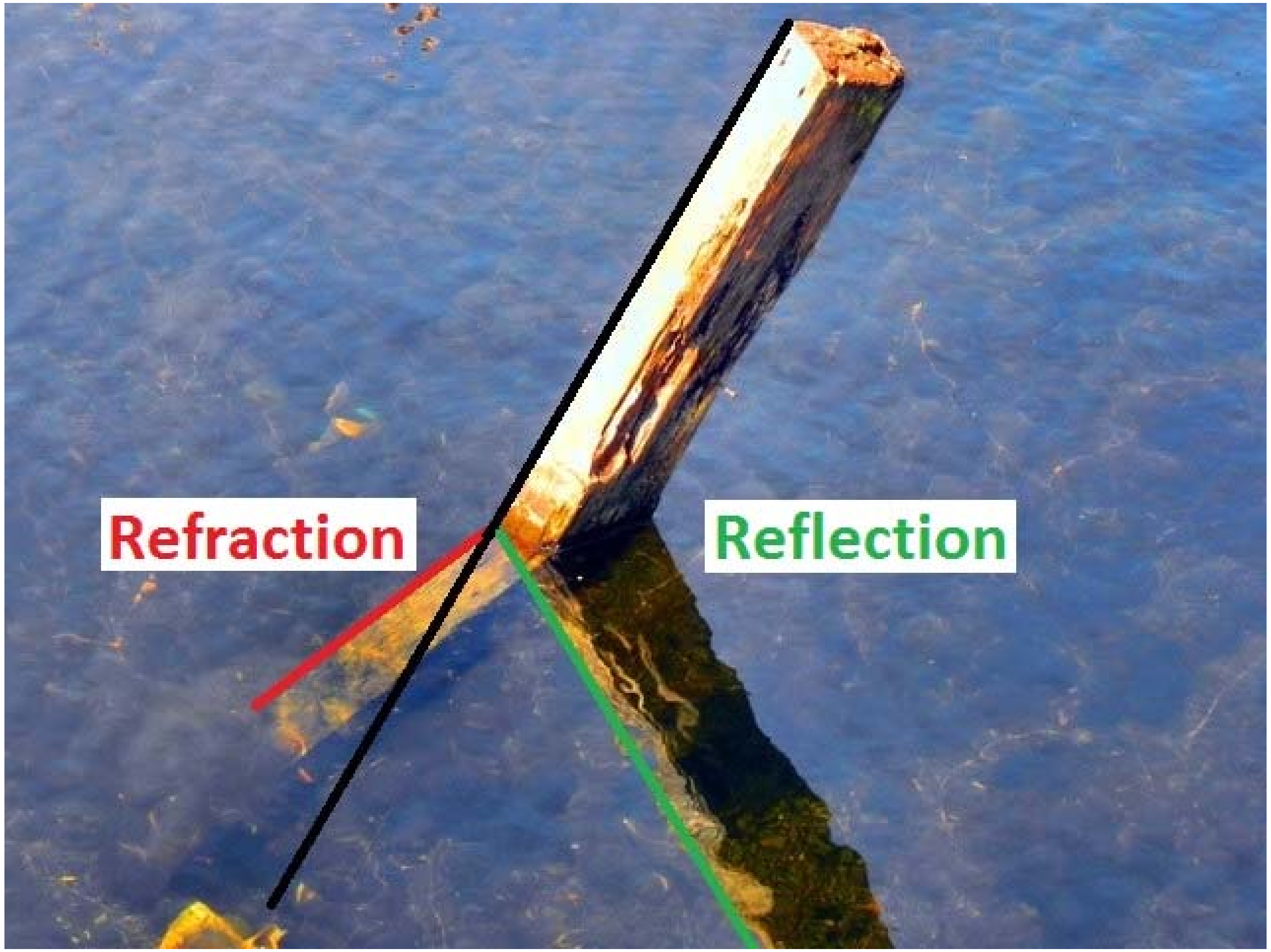
$$V_p = \sqrt{\frac{\left(\frac{4}{3}\mu + k\right)}{\rho}}$$

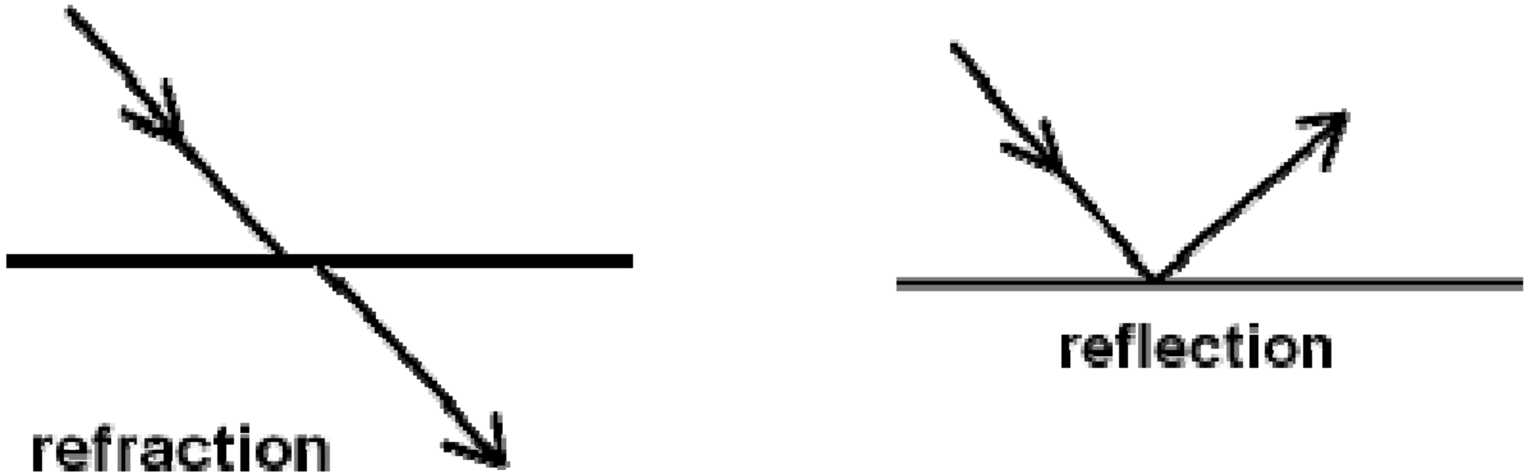
Shear Waves

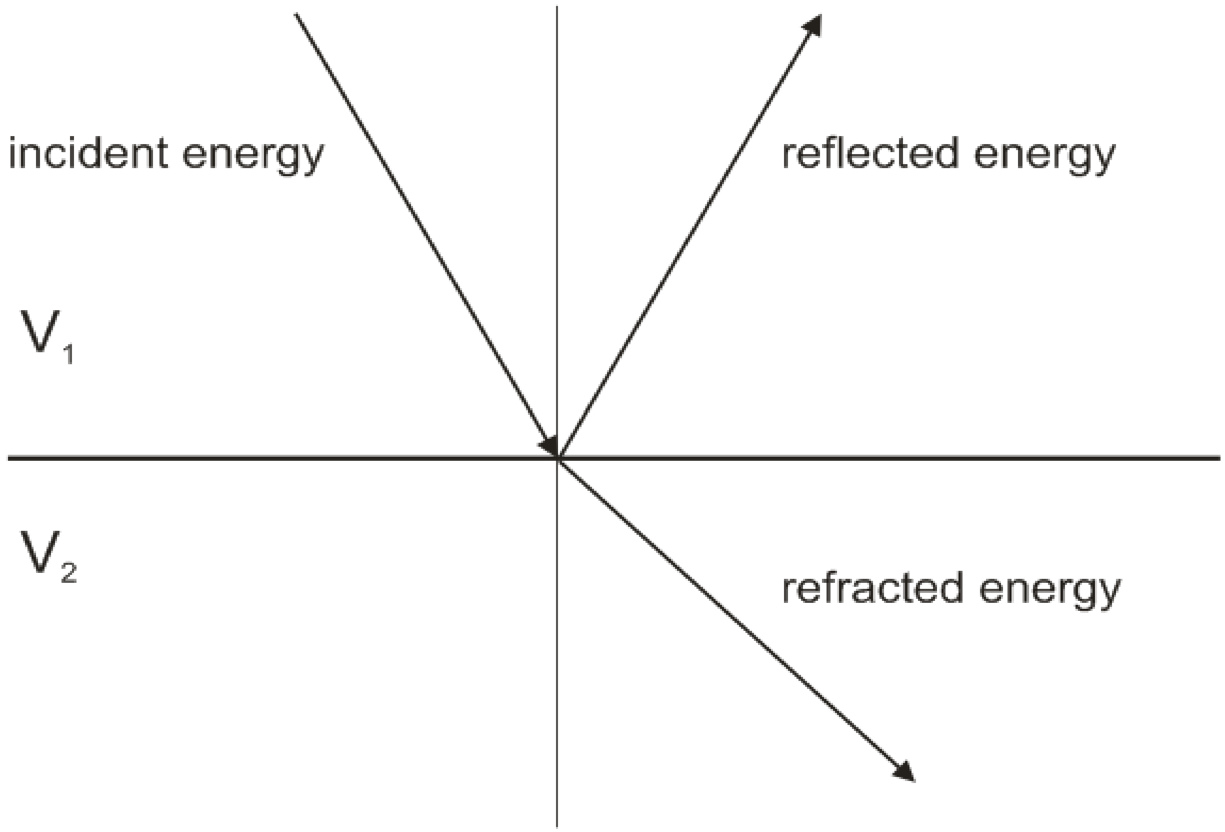
$$V_s = \sqrt{\frac{\mu}{\rho}}$$

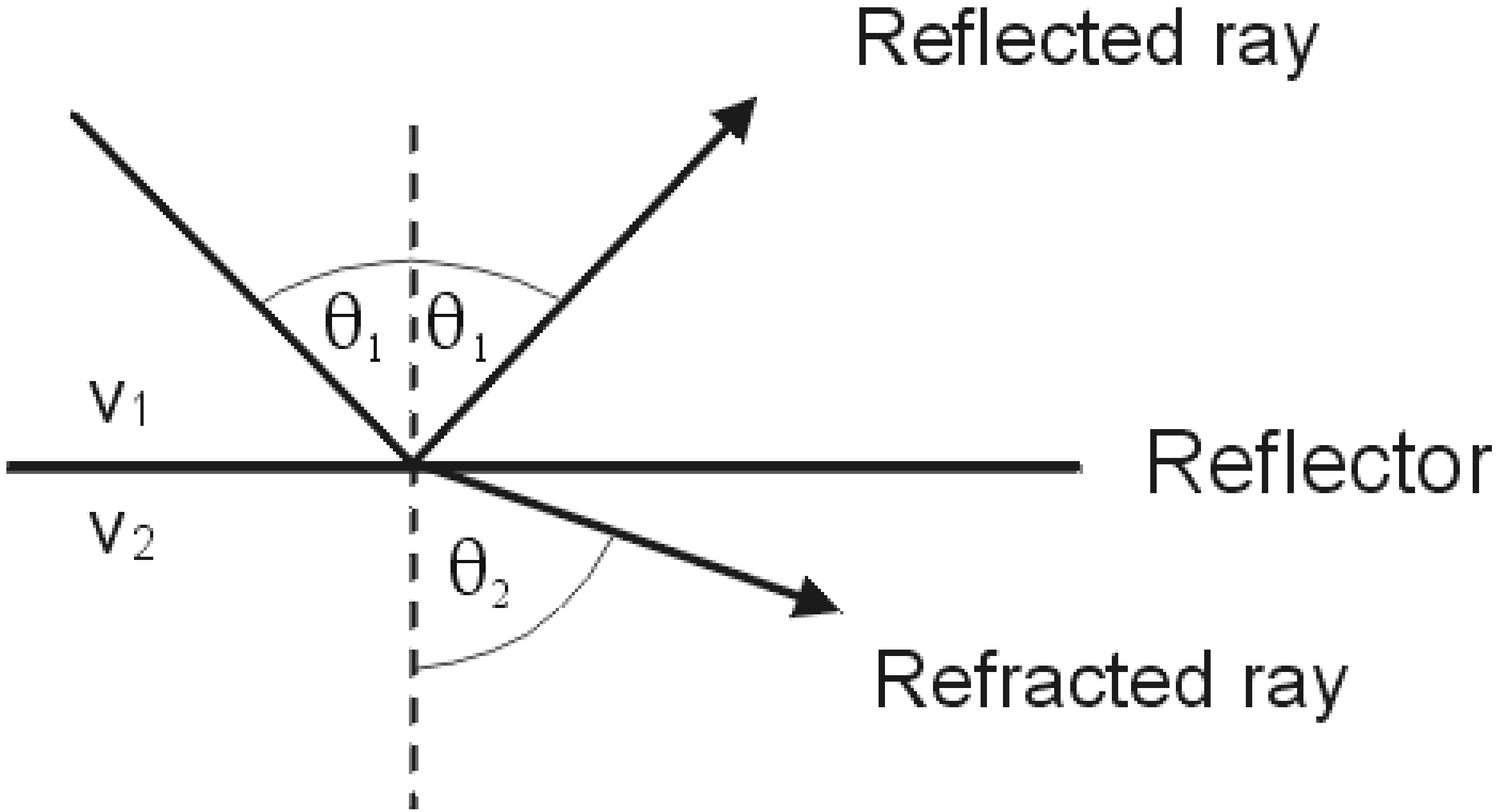
- Averaged Vp/Vs = 1.732 for the crust
- For mafic rocks, Vp/Vs = 1.81
- For felsic rocks, Vp/Vs = 1.70

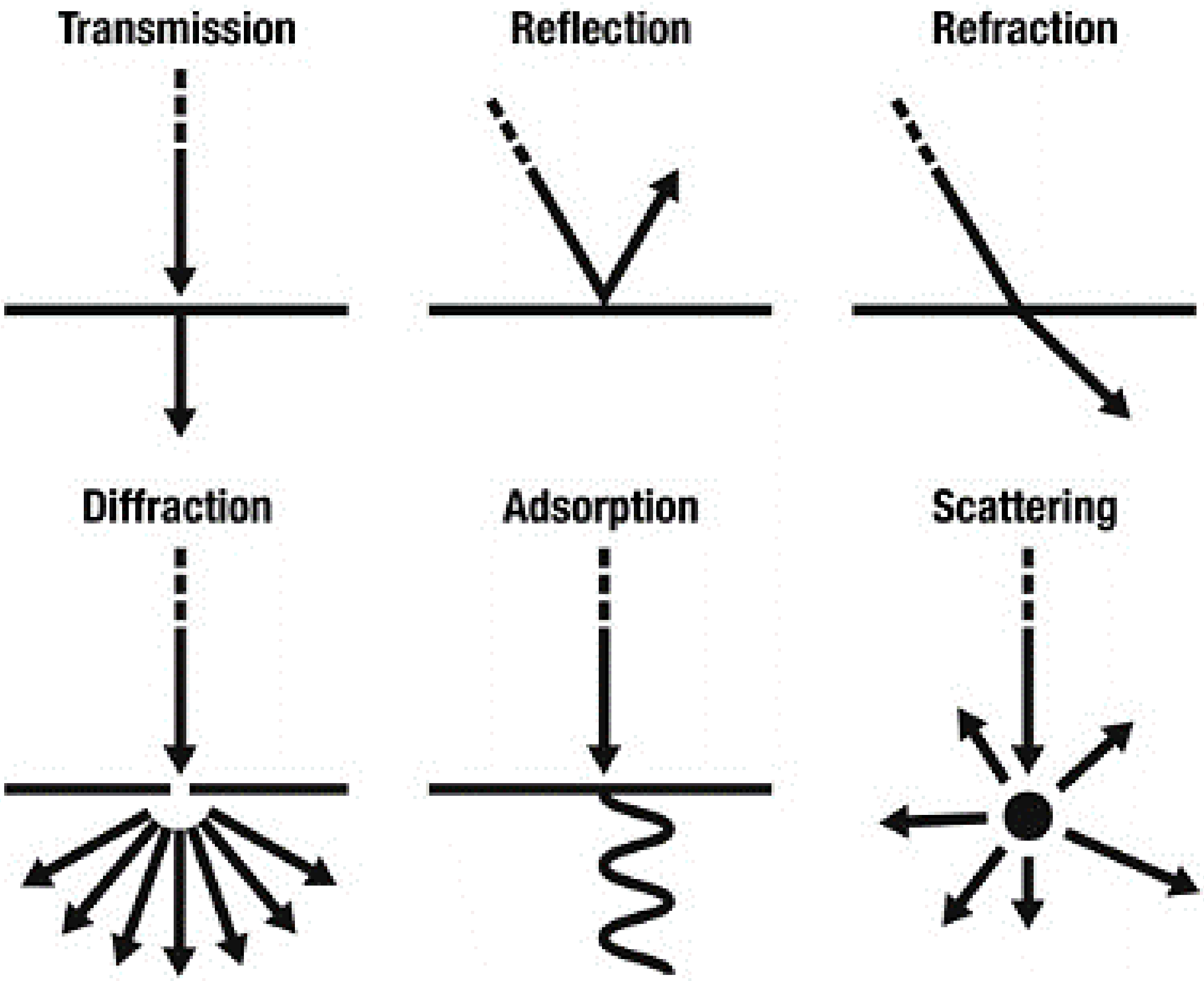
Q. What is the difference between refraction and reflection?


Refraction
Reflection


refraction
reflection

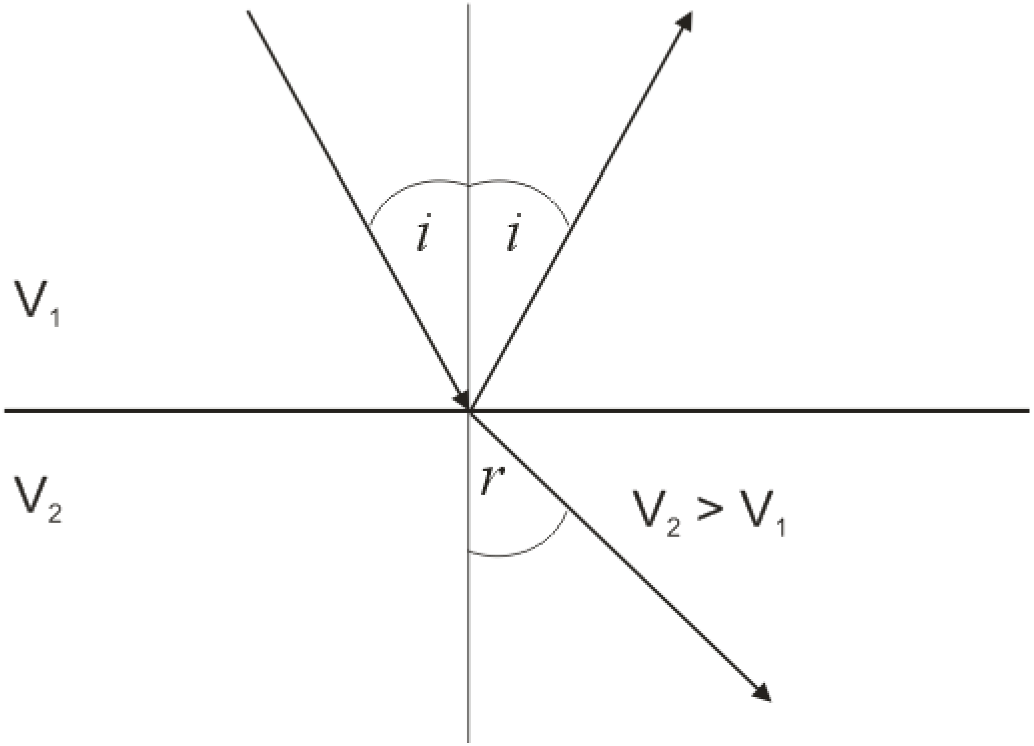

incident energy
reflected energy
V_1
V_2
refracted energy

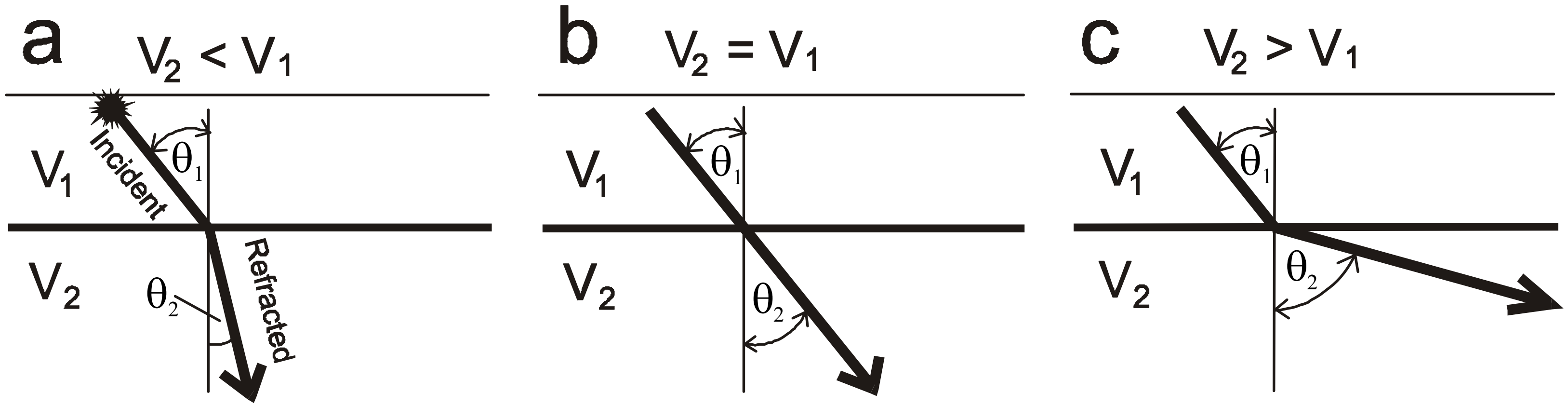

Reflected ray
θ1
θ1
v1
Reflector
v2
θ2
Refracted ray


Transmission
Reflection
Refraction
Diffraction
Adsorption
Scattering

Snell's Law

$$\frac{\sin i}{\sin r} = \frac{V_1}{V_2}$$

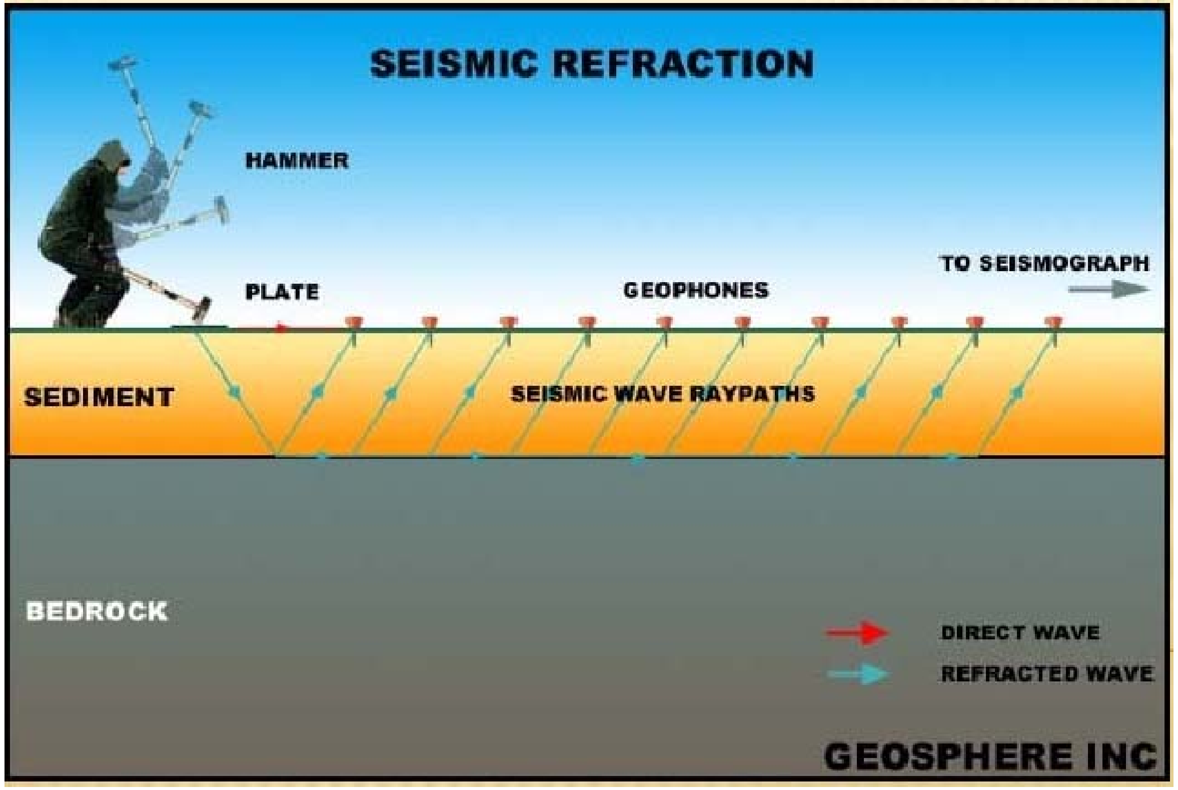




Refracted away from interface. Ray not bent. Refracted toward interface.

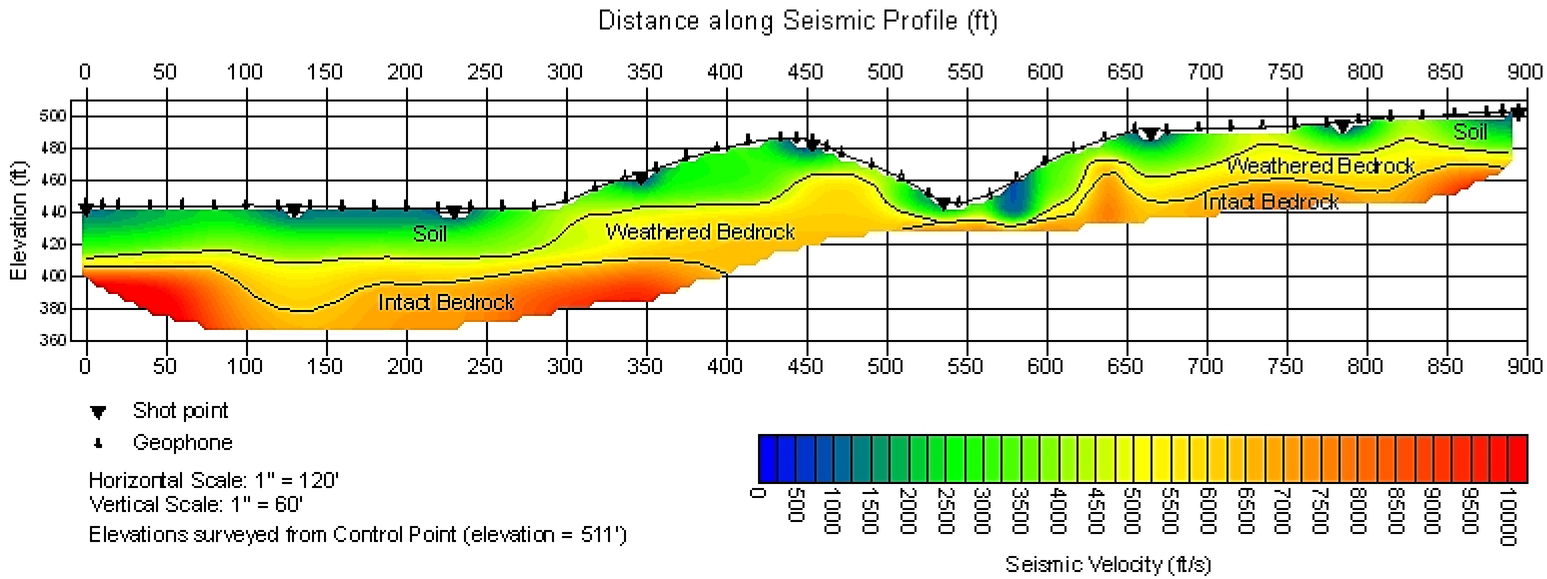
Q. What is seismic refraction?

Seismic Refraction: the signal returns to the surface by refraction at subsurface interfaces. And is recorded at distance much greater than depth of investigation.

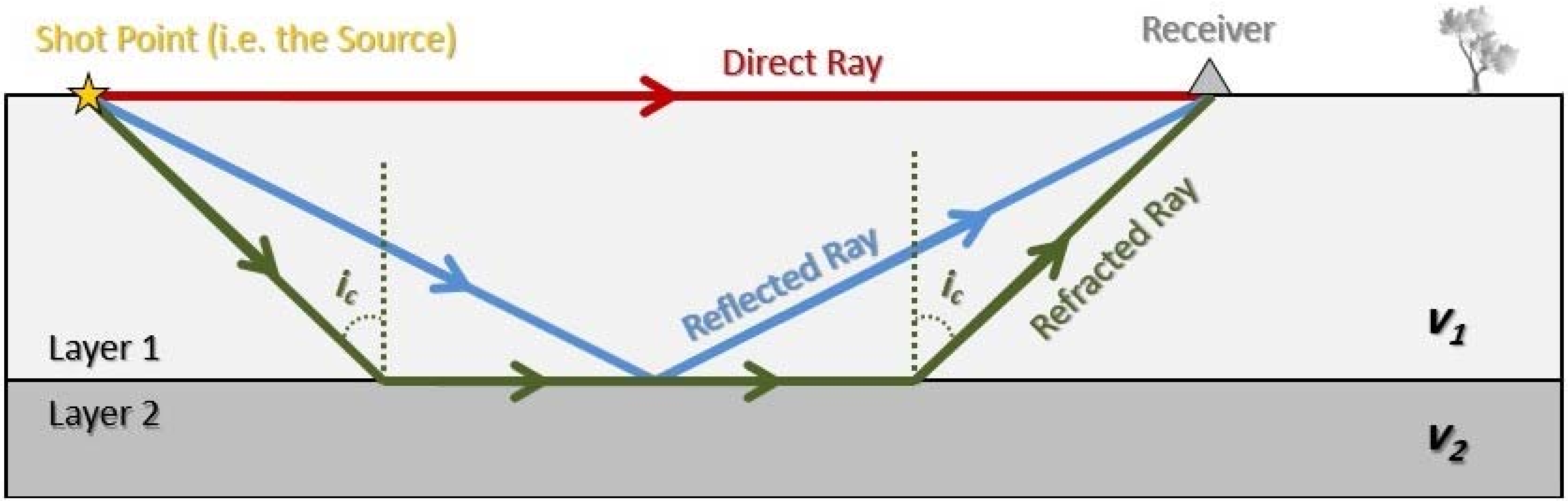


Applications for seismic refraction:

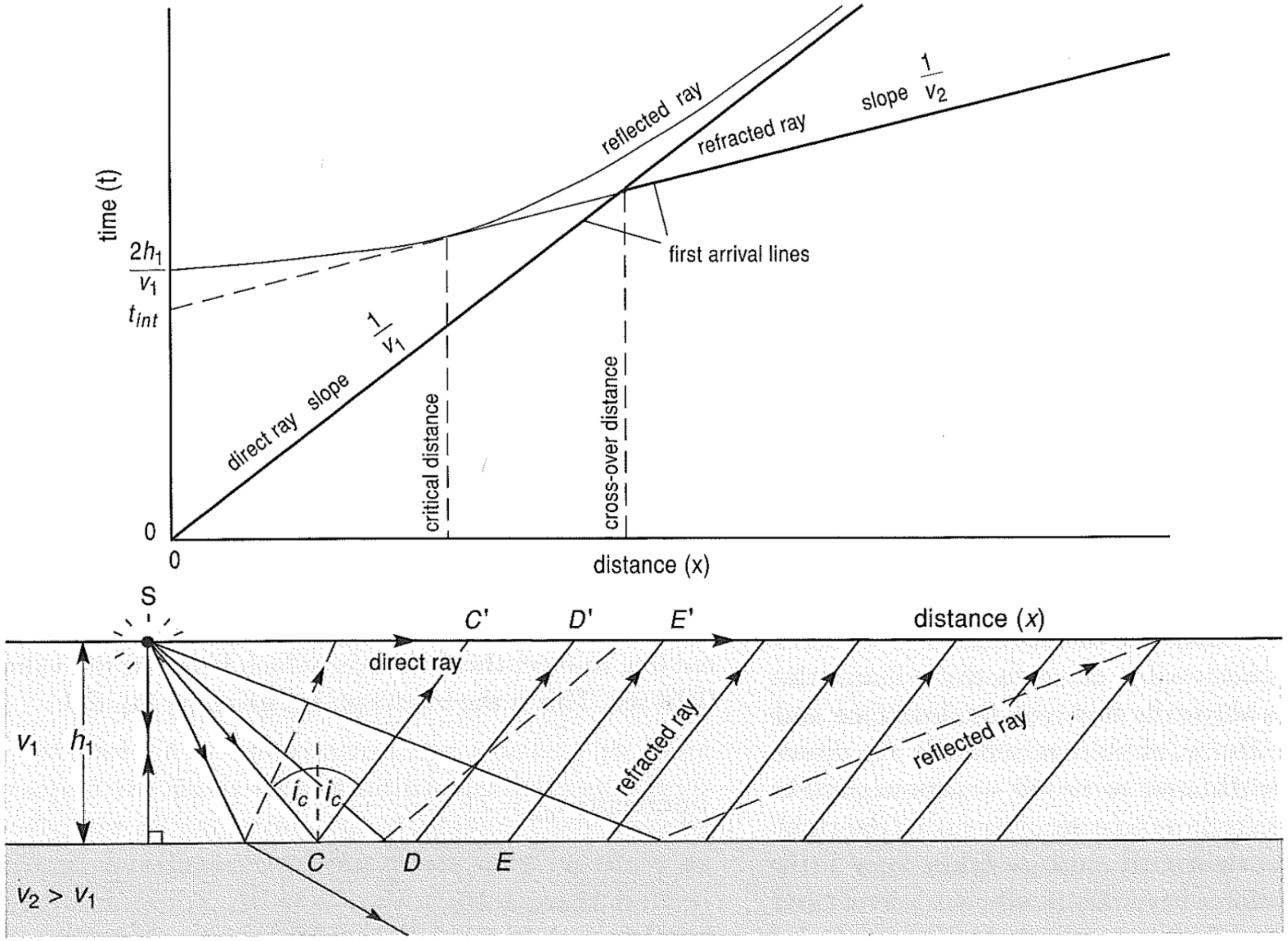
- Depth to bedrock.
- Groundwater exploration.
- Crustal structure and tectonics.



- When doing a seismic refraction survey, a recorded ray can come from three main paths:
  - The direct ray
  - The reflected ray
  - The refracted ray
- Because these rays travel different distances and at different speeds, they arrive at different times
- The direct ray and the refracted ray arrive in different order depending on distance from source and the velocity structure



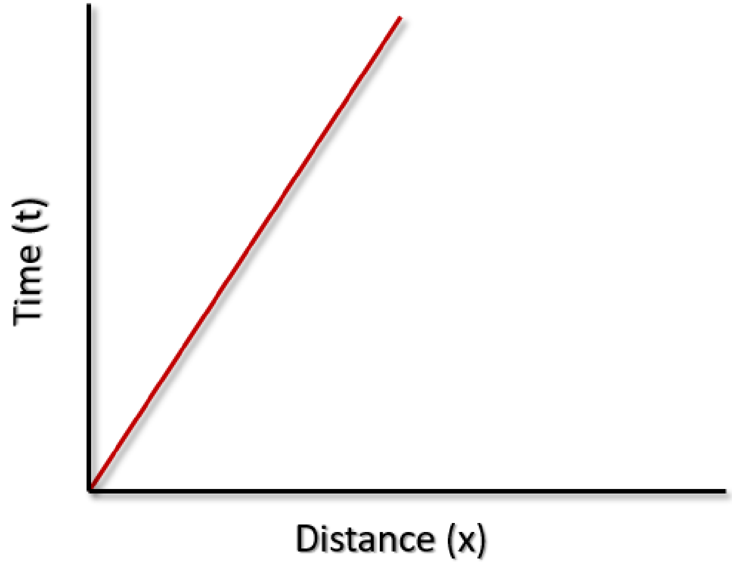
The Time-Distance (t-x) Diagram

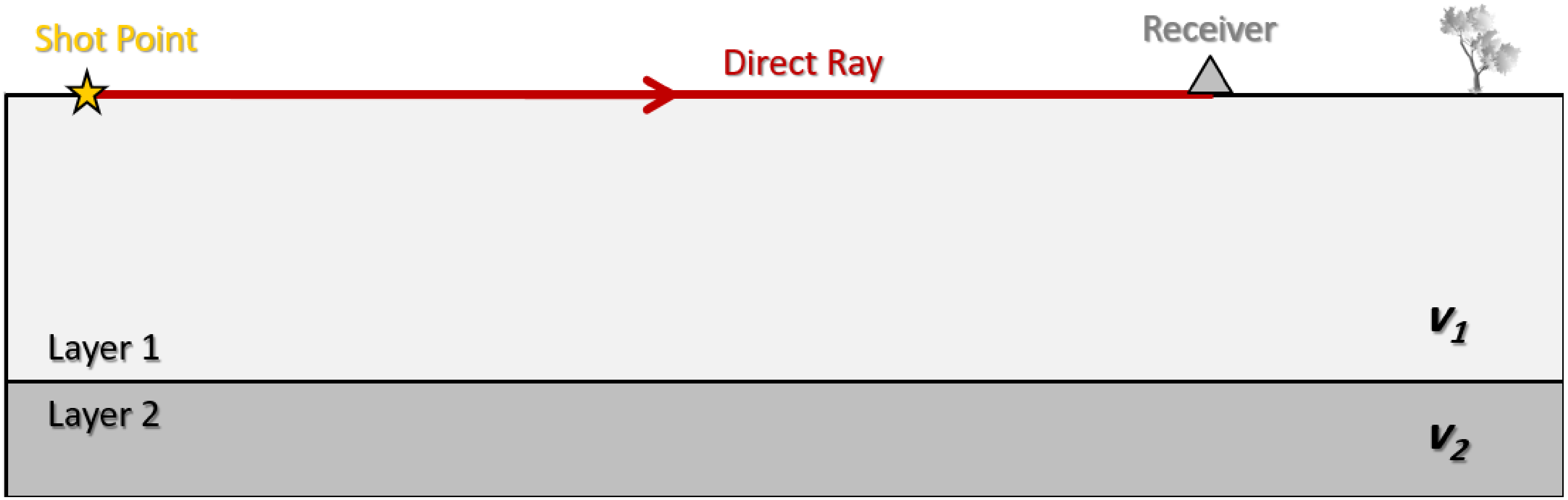


The Direct Ray

- The Direct Ray Arrival Time:
  - Simply a linear function of the seismic velocity and the shot point to receiver distance

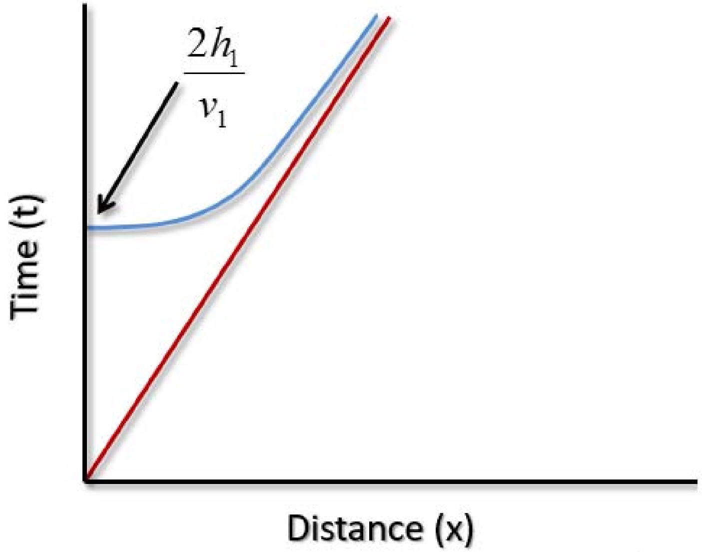
$$t_{direct} = \frac{x}{v_1}$$

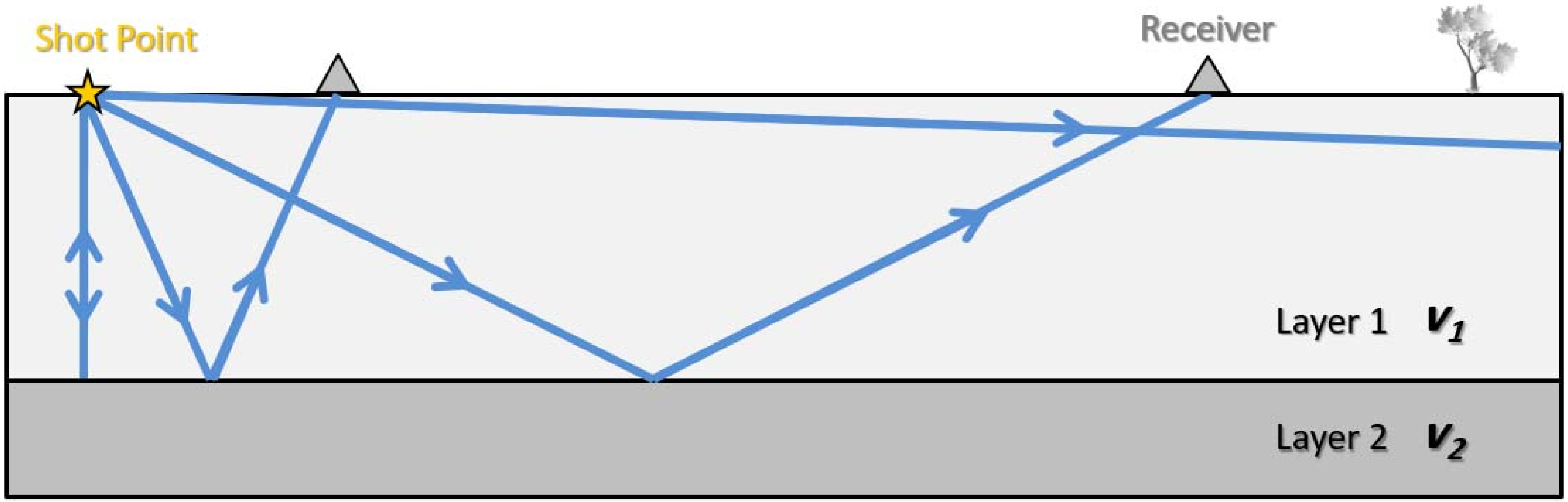




The Reflected Ray

- The Reflected Ray Arrival Time:
  - is never a first arrival
  - Plots as a curved path on t-x diagram
  - Asymptotic with direct ray
  - Y-intercept (time) gives thickness
    - Why do we not use this to estimate layer thickness?

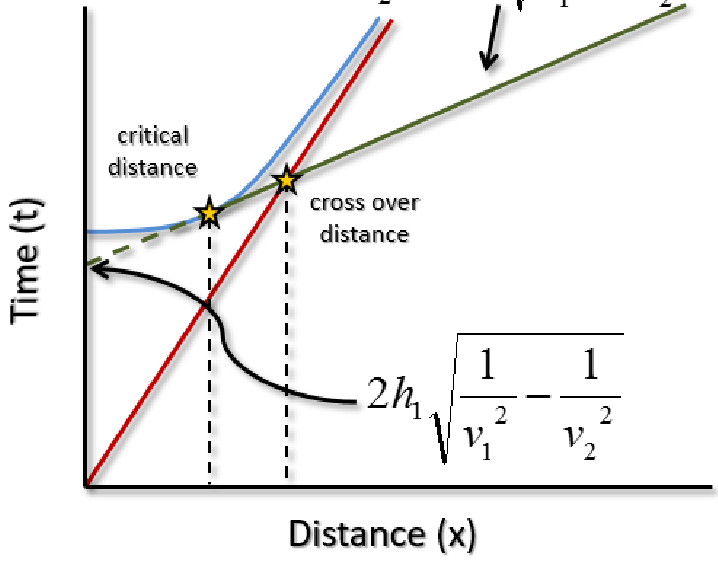


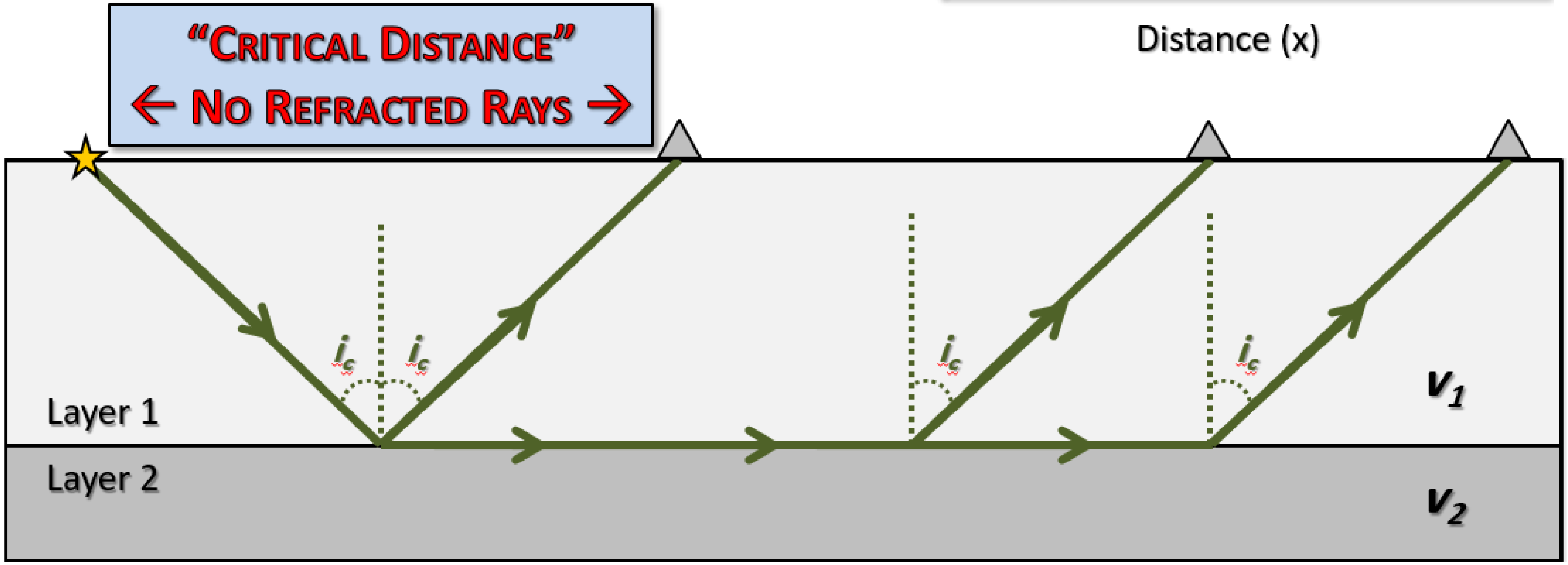


The Refracted Ray

$$t = \frac{x}{v_2} + 2h_1\sqrt{\frac{1}{v_1^{\,2}} - \frac{1}{v_2^{\,2}}}$$

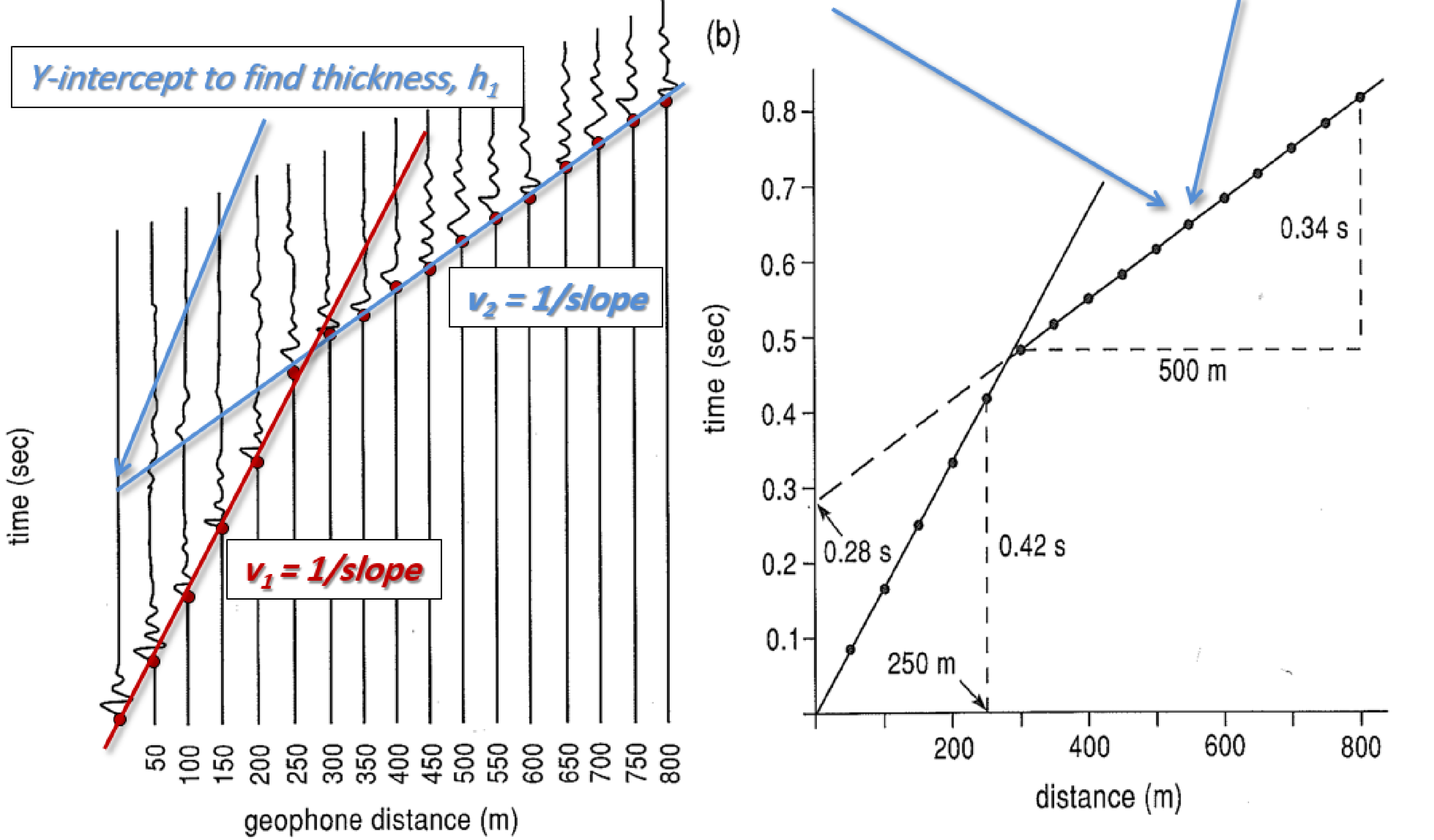
- The Refracted Ray Arrival Time:
  - Plots as a linear path on t-x diagram
    - Part travels in upper layer (constant)
    - Part travels in lower layer (function of x)
  - Only arrives after **critical distance**
  - Is first arrival only after **cross over distance**
    - Travels long enough in the faster layer





Making a t-x Diagram

Refracted Ray Arrival Time, t $t = \frac{x}{v_2} + 2h_1\sqrt{\frac{1}{v_1^{\,2}} - \frac{1}{v_2^{\,2}}}$ or $t = \frac{x \sin i_c}{v_1} + \frac{2h_1 \cos i_c}{v_1}$



Refraction…What is it Good For?

- Seismic refraction surveys reveal two main pieces of information
  - Velocity structure
    - Used to infer rock type
  - Depth to interface
    - Lithology change
    - Water table

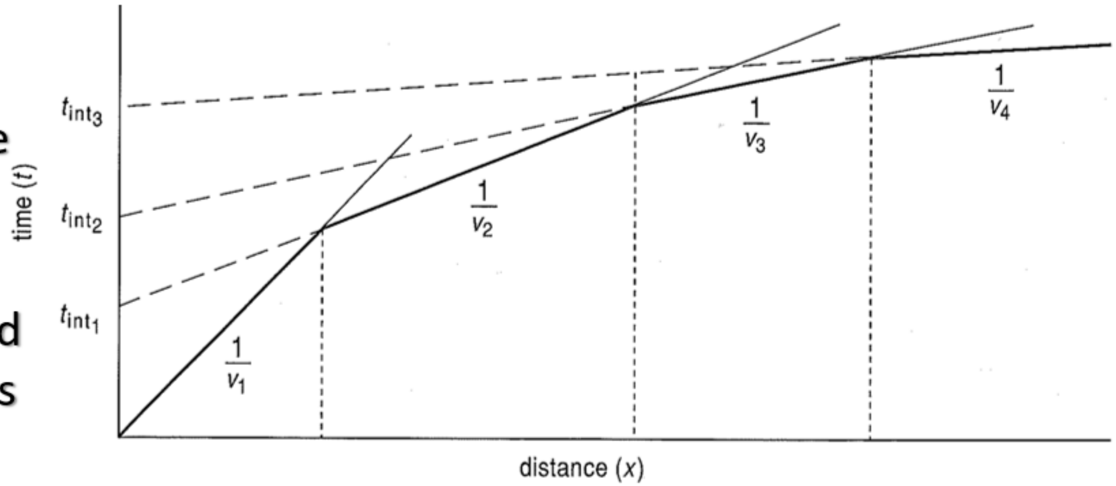
Table 6.1 Seismic velocities for rocks

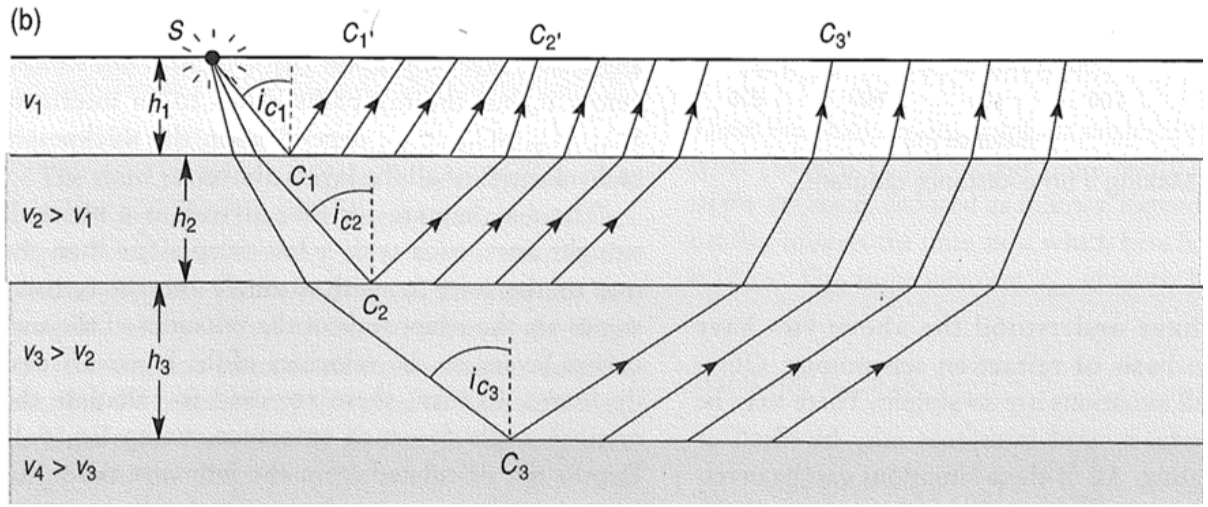
Rock type	v_p (km/sec)
Unconsolidated sediments	
clay	1.0–2.5
sand, dry	0.2–1.0
sand, saturated	1.5–2.0
Sedimentary rocks	
anhydrite	6.0
chalk	2.1–4.5
coal	1.7–3.4
dolomite	4.0–7.0
limestone	3.9–6.2
shale	2.0–5.5
salt	4.6
sandstone	2.0–5.0
Igneous and metamorphic rocks	
basalt	5.3–6.5
granite	4.7–6.0
gabbro	6.5–7.0
slate	3.5–4.4
ultramafic rocks	7.5–8.5
Other	
air	0.3
natural gas	0.43
ice	3.4
water	1.4–1.5
oil	1.3–1.4

Ranges of velocities, which are from a variety of sources, are approximate.

Multiple Layers

- Seismic refraction can detect multiple layers
- The velocities are easily found from the slopes on the t-x diagram

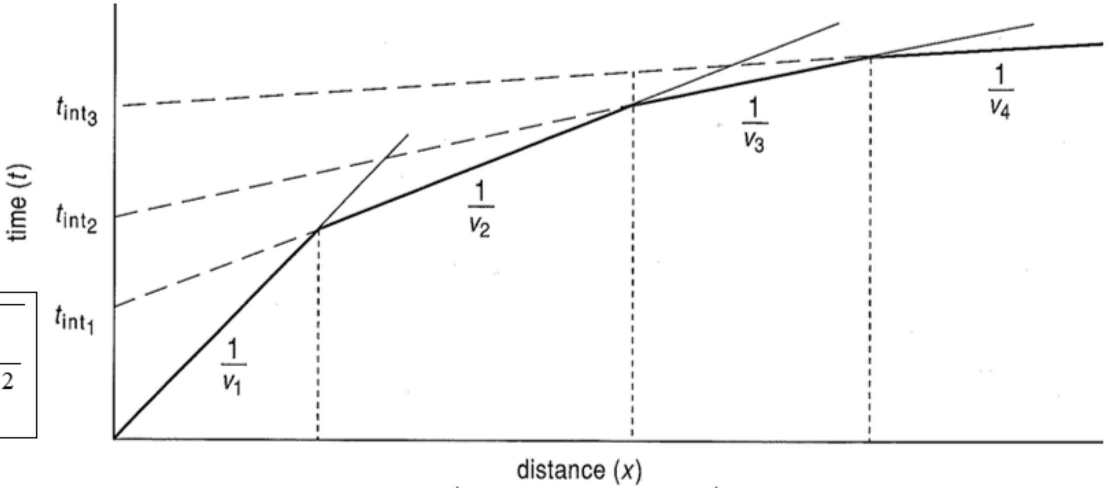




Multiple Layers

- The layer thicknesses are not as easy to find
- Recall…

$$t = \frac{x}{v_2} + 2h_1\sqrt{\frac{1}{v_1^2} - \frac{1}{v_2^2}}$$



$$t_{int_1} = 2h_1\sqrt{\frac{1}{v_1^2} - \frac{1}{v_2^2}}$$ Solve for h_1…→ $$h_1 = \frac{t}{2\sqrt{\frac{1}{v_1^2} - \frac{1}{v_2^2}}} = \frac{t}{2\sqrt{\frac{v_2^2 - v_1^2}{v_1^2 v_2^2}}}$$

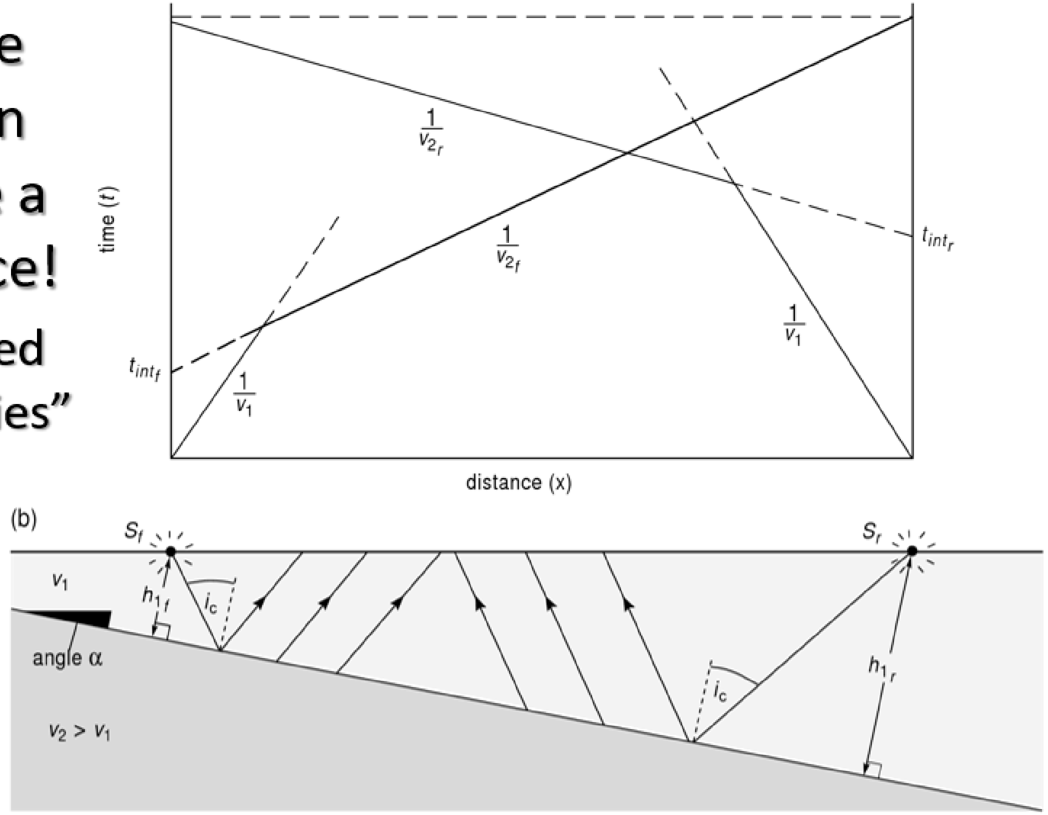
Now, plug in h1 and solve the remaining layers one at a time…

$$t_{int_2} = 2h_1\sqrt{\frac{1}{v_1^2} - \frac{1}{v_2^2}} + 2h_2\sqrt{\frac{1}{v_2^2} - \frac{1}{v_3^2}}$$

BEWARE!!! h_1, h_2, are layer thicknesses, not depth to interfaces.
So, depth to bottom of layer 3 /top of layer 4 = $h_1 + h_2 + h_3$

Dipping Interfaces

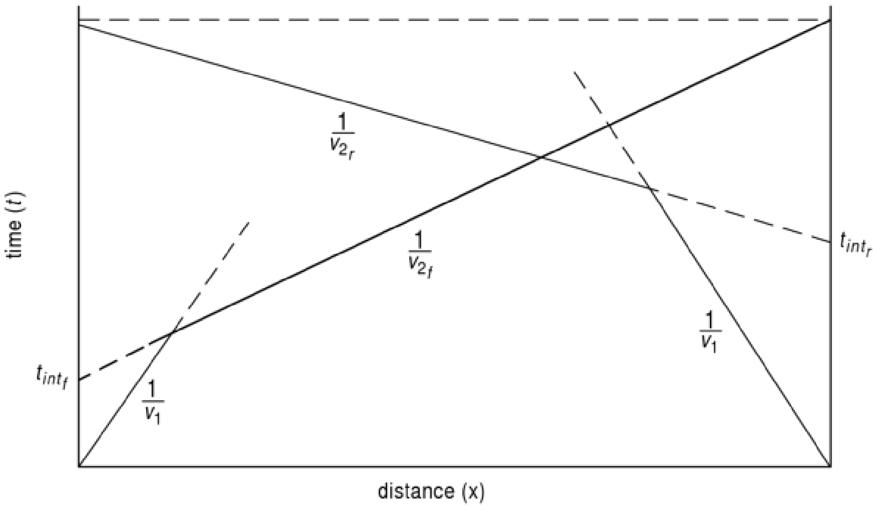
- What if the critically refracted interface is not horizontal?
- A dipping interface produces a pattern that looks just like a horizontal interface!
  - Velocities are called "apparent velocities"
- What do we do?

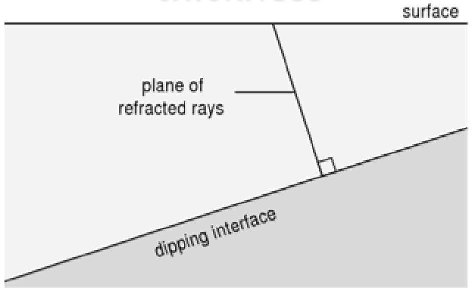


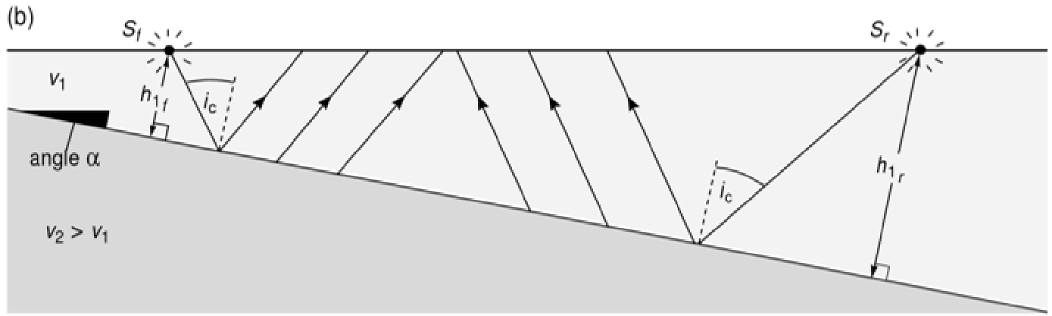
In this case, velocity of lower layer is underestimated

Dipping Interfaces

- To determine if interfaces are dipping…
- Shoot lines forward and reversed
- If dip is small (< 5°) you can take average slope
- The intercepts will be different at both ends
  - Implies different thickness



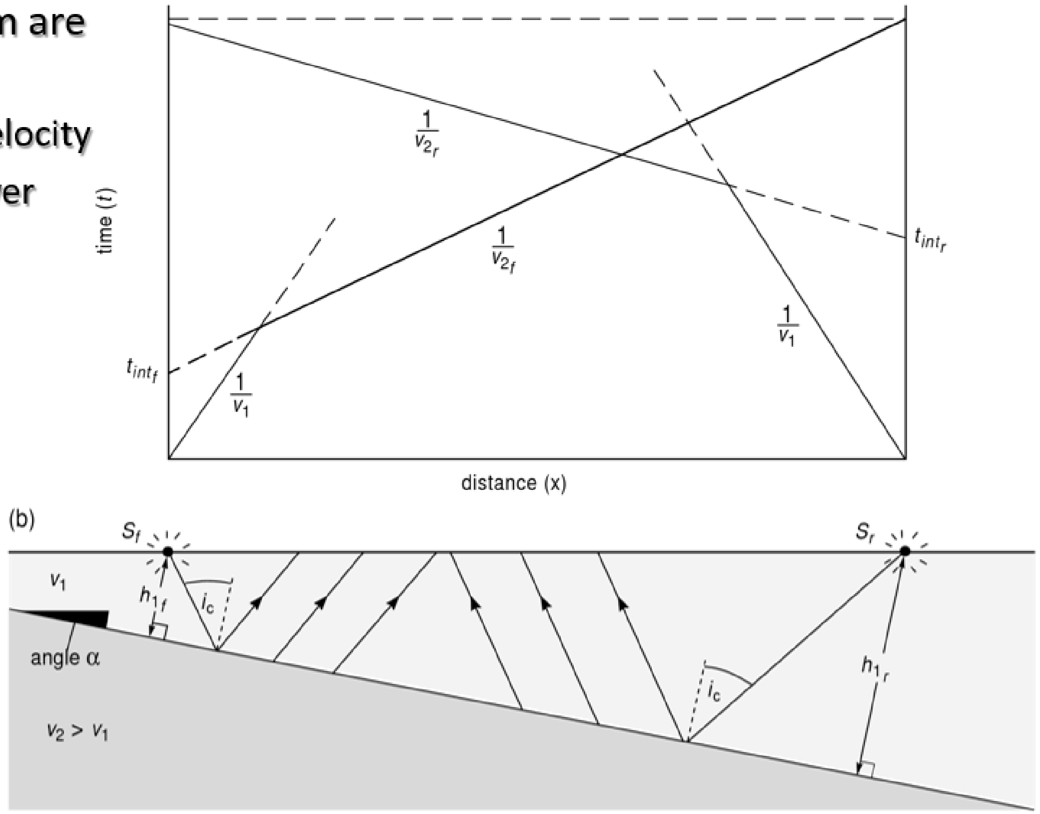




Beware: the calculated thicknesses will be perpendicular to the interface, not vertical

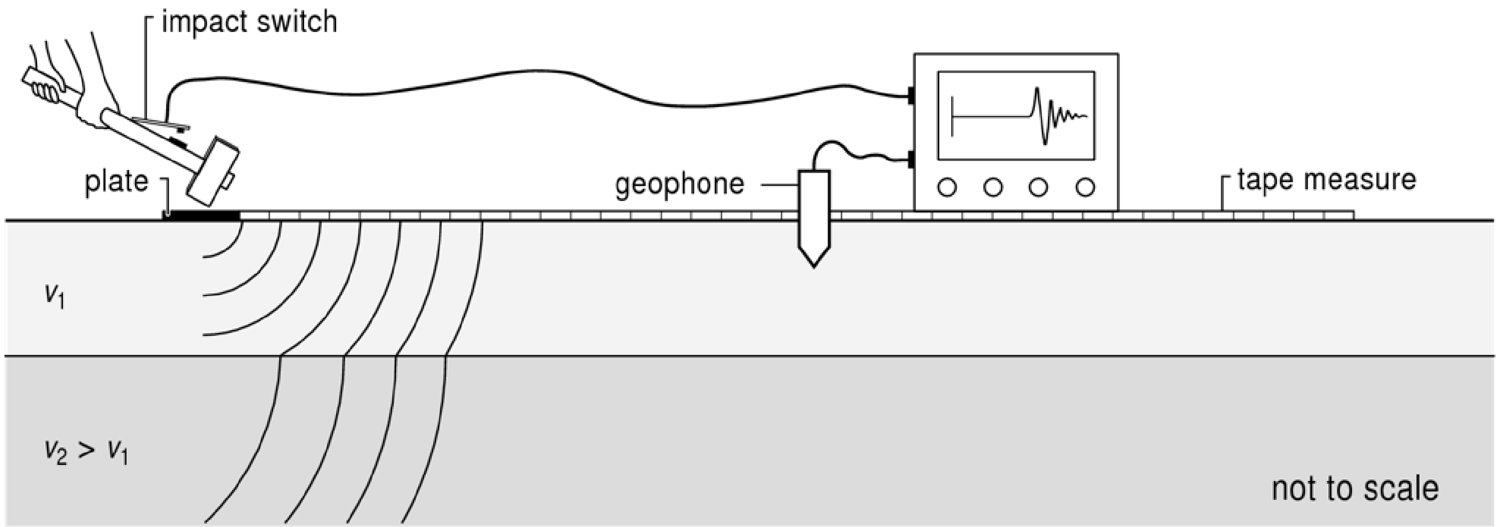
Dipping Interfaces

- If you shoot down-dip
  - Slopes on t-x diagram are too steep
    - Underestimates velocity
  - May underestimate layer thickness
- Converse is true if you shoot up-dip
- In both cases the calculated direct ray velocity is the same.
- The intercepts t_{int} will also be different at both ends of survey



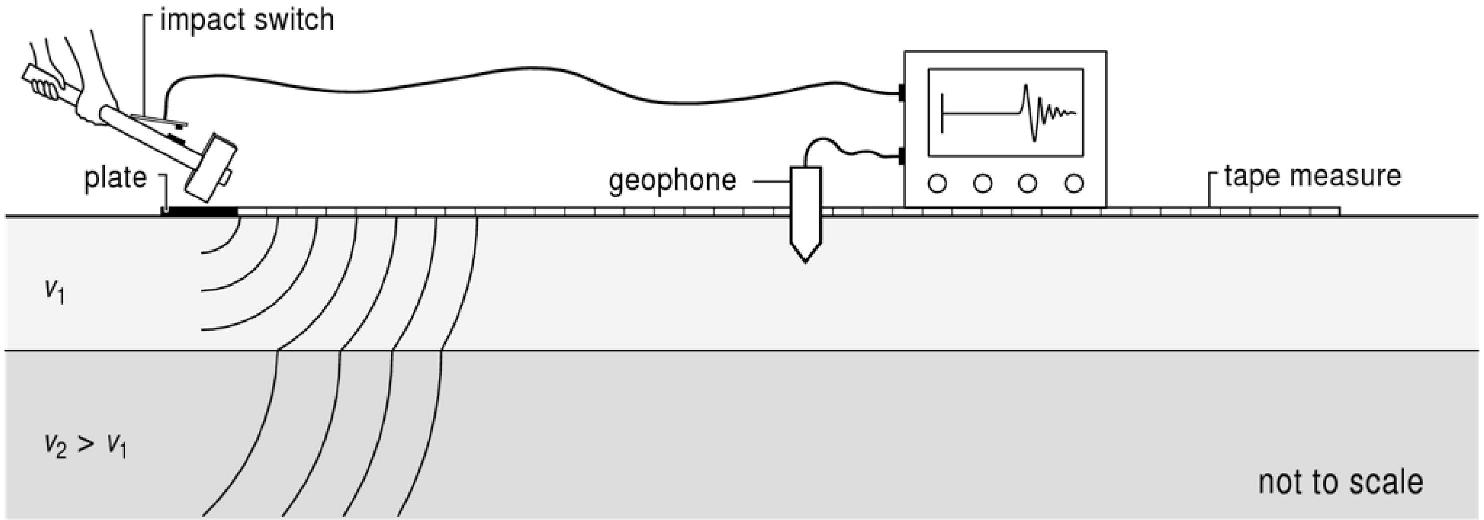
Survey Types

- The simplest (and cheapest) type of survey is called a hammer seismic survey
  - A sledgehammer is whacked into a steel plate
  - Impact switch tells time=0
  - First arrivals are read digitally or inferred from seismogram
  - Because swinging a hammer is free, only one geophone is needed
    - More can be used, but single geophones must be along a linear transect



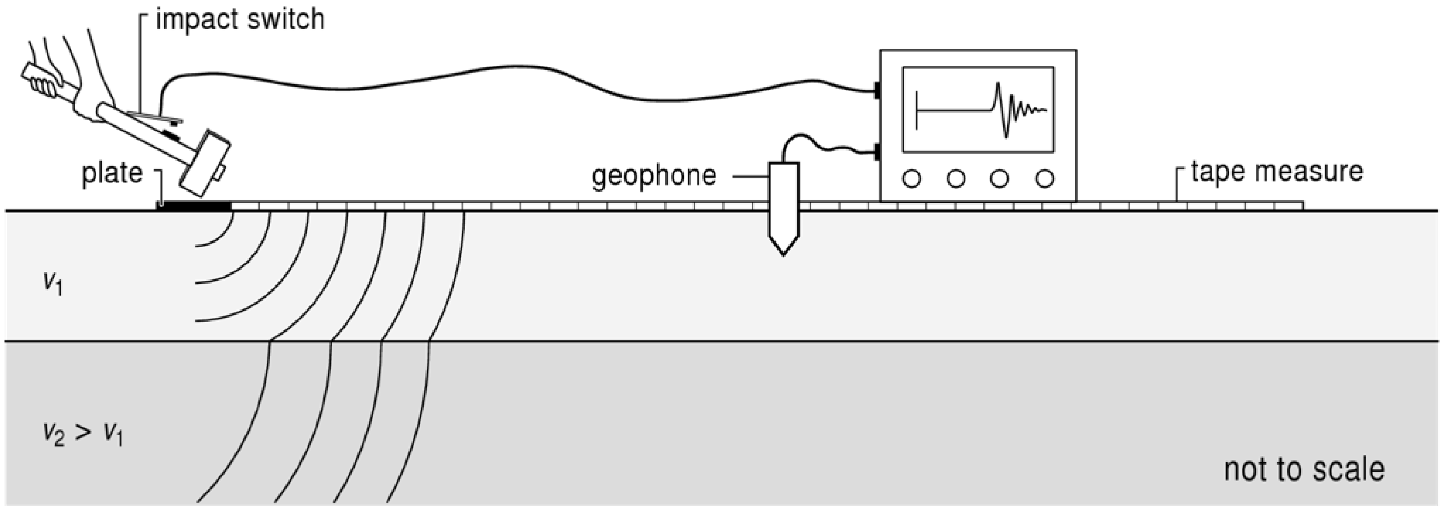
Survey Types

- The maximum workable distance depends on:
  - The sensitivity of the system
  - The strength of the sledgehammer whacks
  - The amount of noise
    - Wind shakes trees, etc…
    - Cars, footsteps, HVAC, traffic, etc…
    - Surveys may be done at night to minimize noise



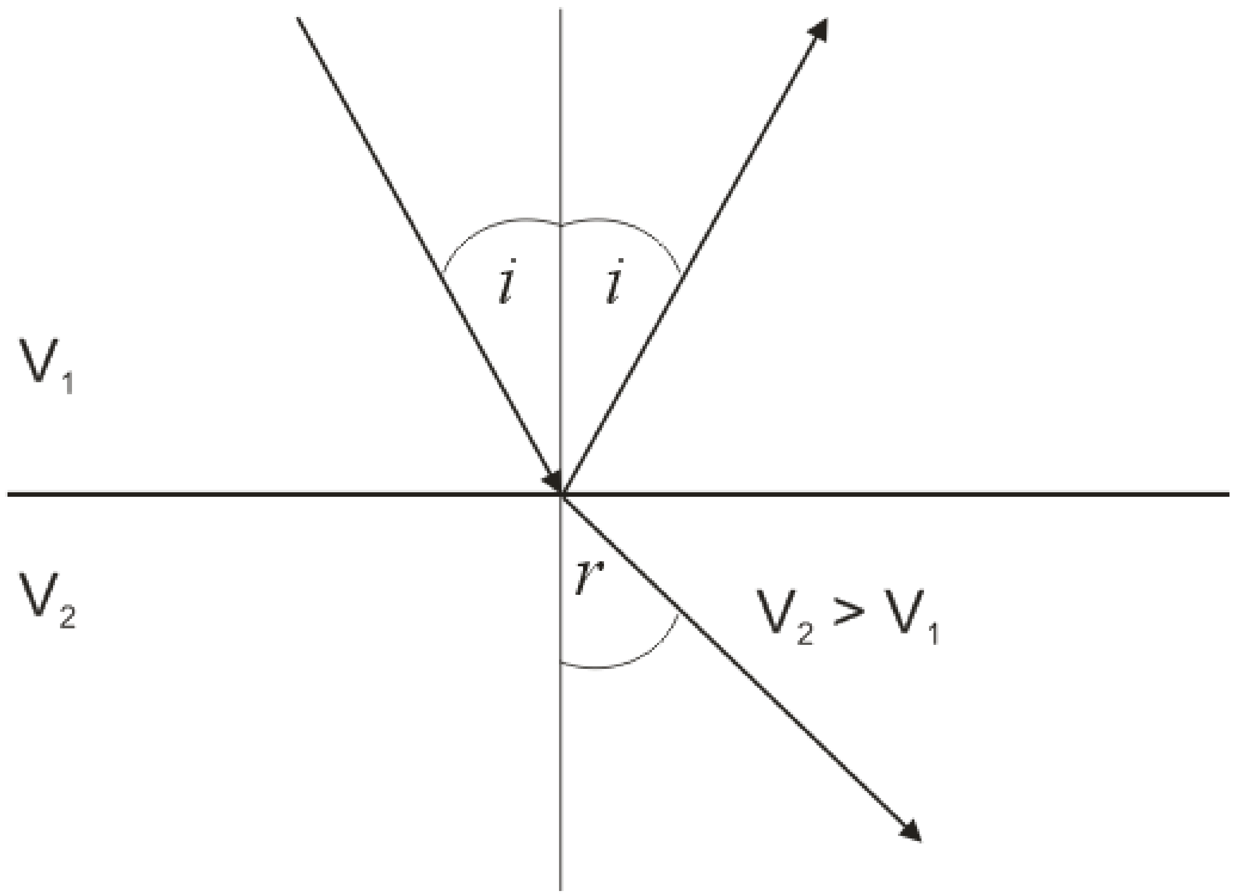
Survey Types

- Often the signal to noise ratio is very poor:
  - Stacking is often used to help delineate first arrivals
- General rule of thumb:
  - Geophone array should be about 10x the depth to interface
  - 100 meters is the typical upper limit on length of hammer seismic transect
    - So hammer seismics are best for shallow interfaces (< 10 m)

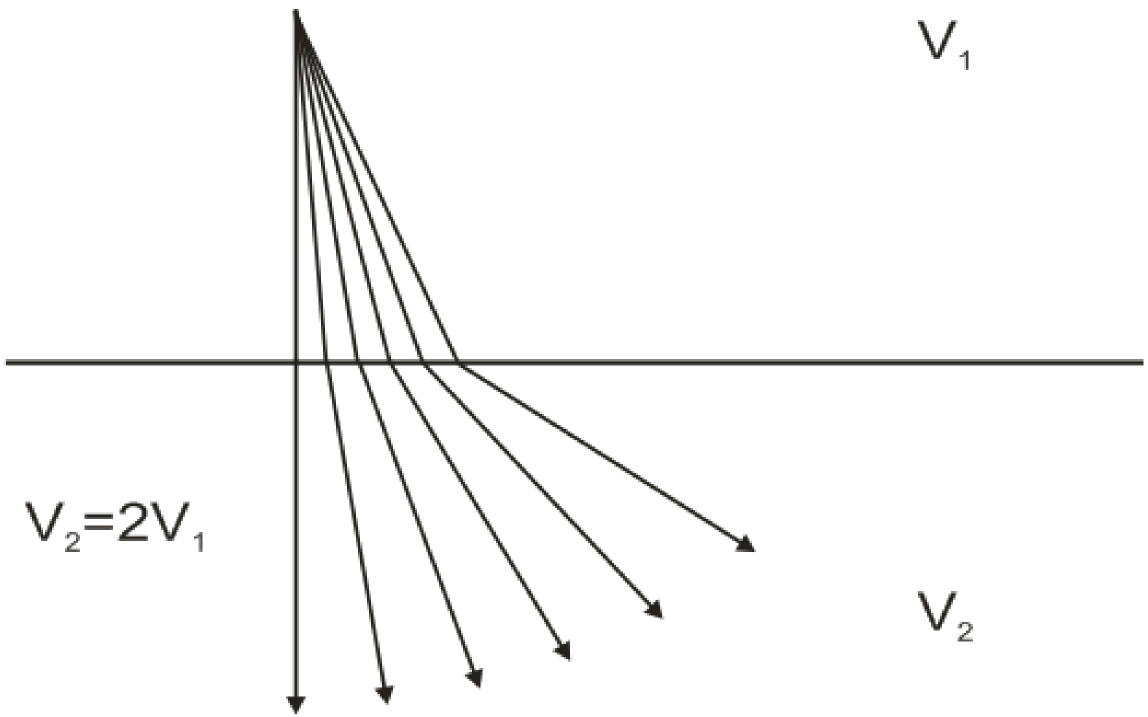


Other Survey Types

- Explosion seismics
  - Offers a much stronger signal
    - Can detect deeper features
    - Often involves water explosions (much cheaper)
    - Geophones / Seismometers are often linked wirelessly (RF / radio waves)
- Marine Surveys
  - Sometimes use explosives, compressed air, high voltage charges, or many other types.
  - Usually use hydrophones
    - Respond to pressure changes (p-waves)
    - Surveying is often done while the ship is moving, so very long transects can be done at a lower cost


i
i
V1
V2
r
V2 > V1

If $V_2 > V_1$, then as i increases, r increases faster



Critical Refraction

At Critical Angle of incidence i_c, angle of refraction $r = 90^o$