

Introduction to Geophysics:

Seismic Exploration Refraction

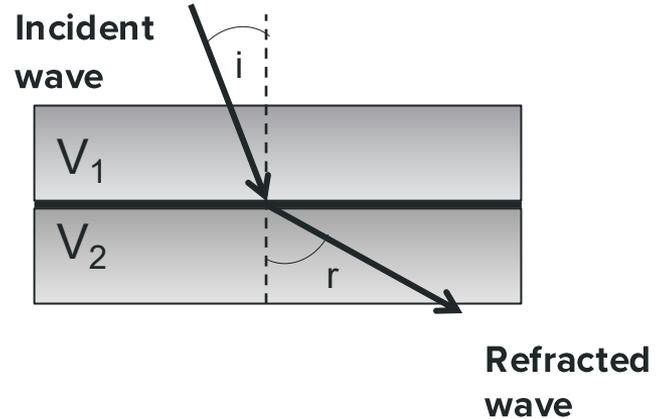
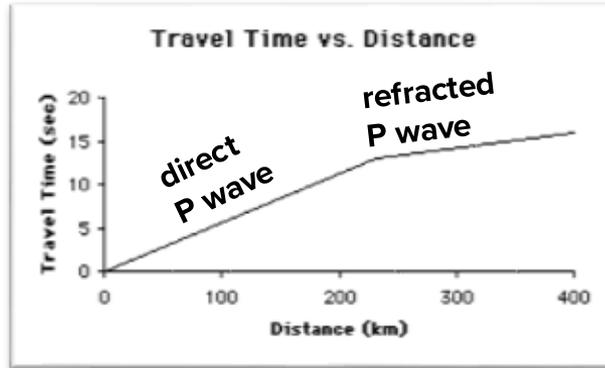
What is seismic refraction?

A method to study subsurface velocity and layered structure of the Earth's crust by analysing the first arrival times of P-waves.

A refracted wave changes direction and speed as it passes into another medium.

Snell's Law

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



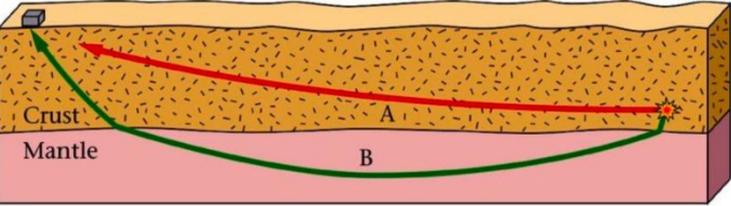
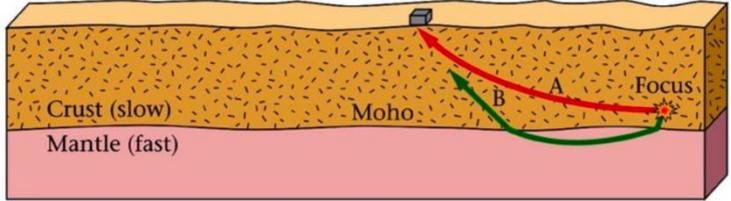
Applications of seismic refraction

Determining Moho Depth

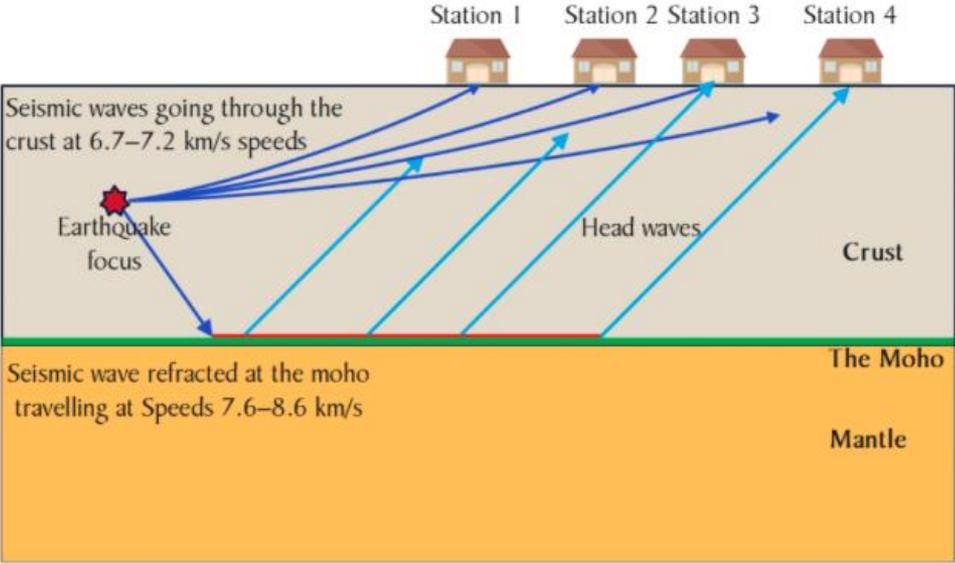
Mapping bedrock surface for construction works

Mapping depth to ground water

Identifying underground features



← Velocity in crust
← Velocity in mantle



→ Increasing distance from earthquake focus

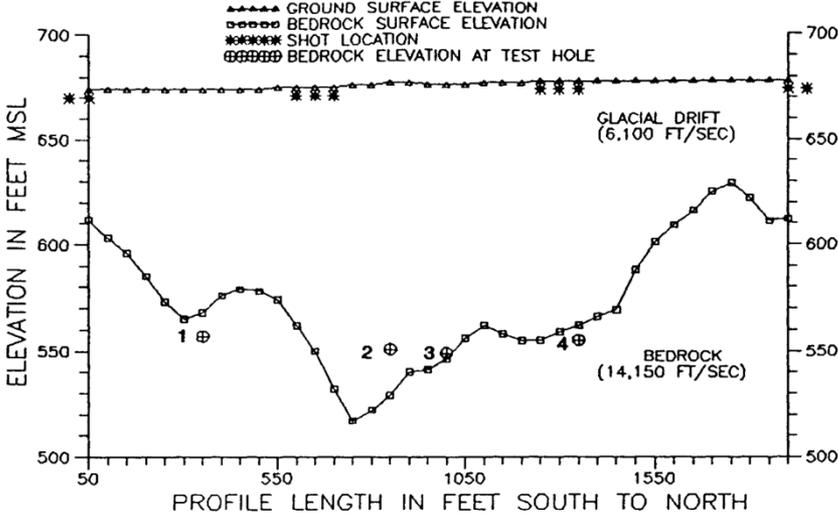
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Seismic refraction in Singapore

Determining Moho Depth

Mapping bedrock surface for construction work

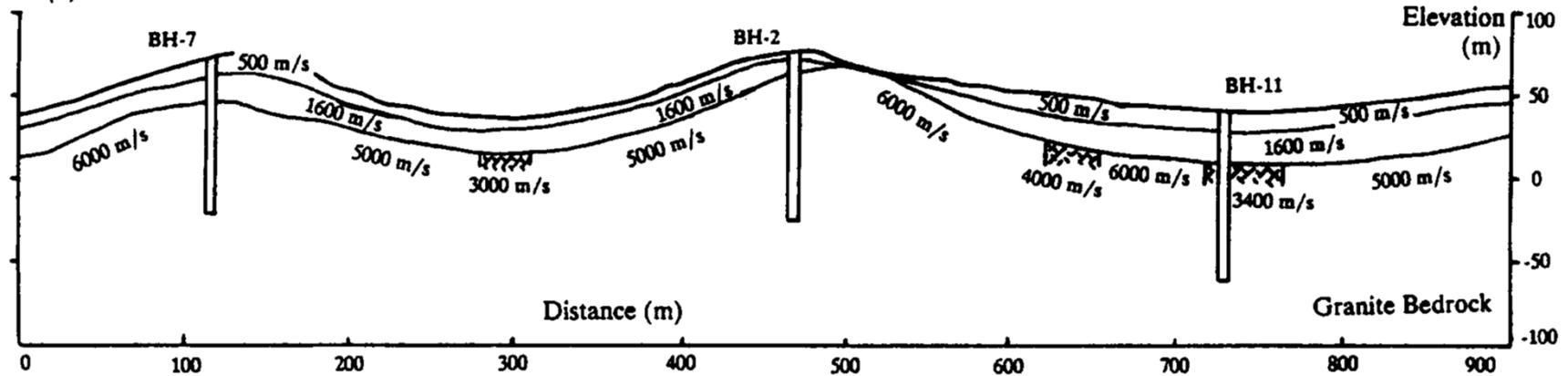
Mapping depth to ground water

Identifying underground features

Construction and Utilization of Rock Caverns in Singapore

Part A: The Bukit Timah Granite Bedrock Resource

J. Zhao



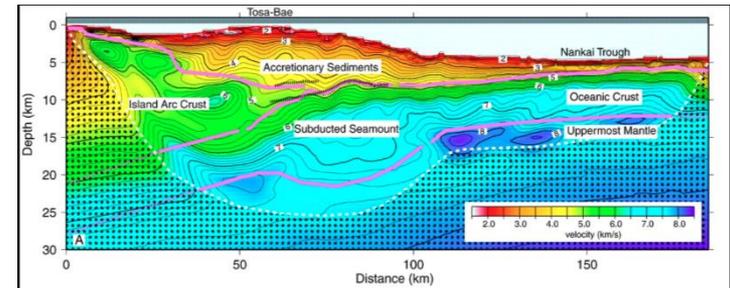
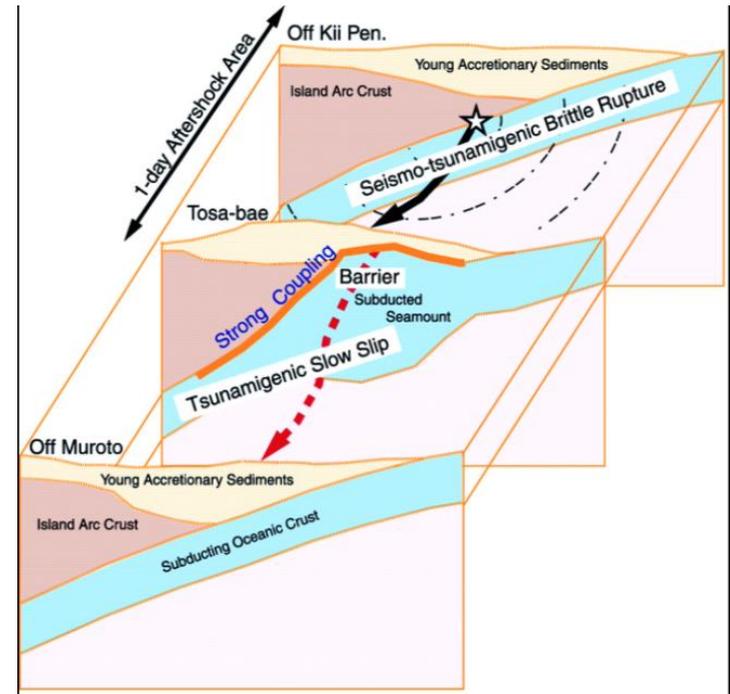
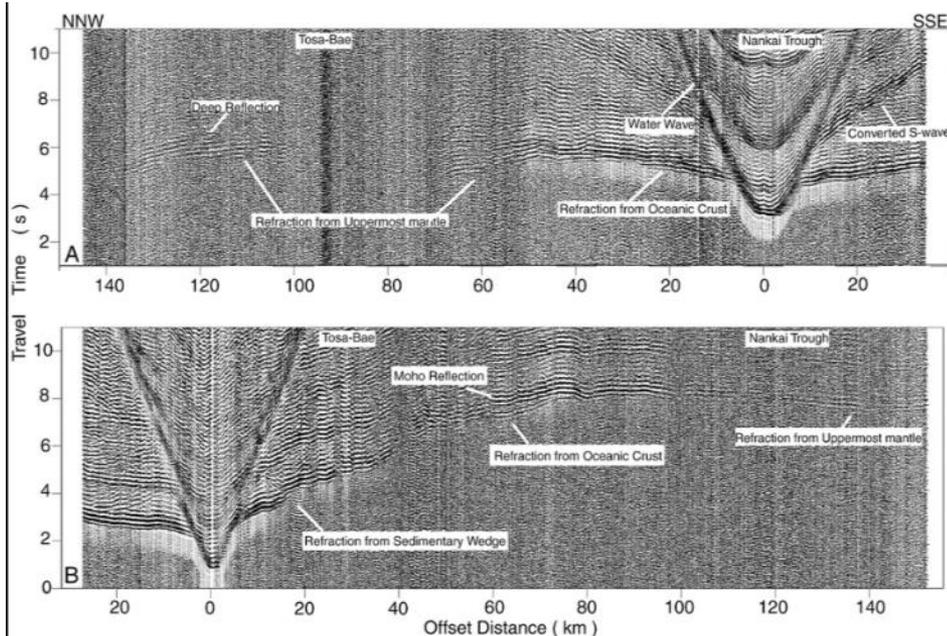
Seismic refraction in Japan

Determining Moho Depth

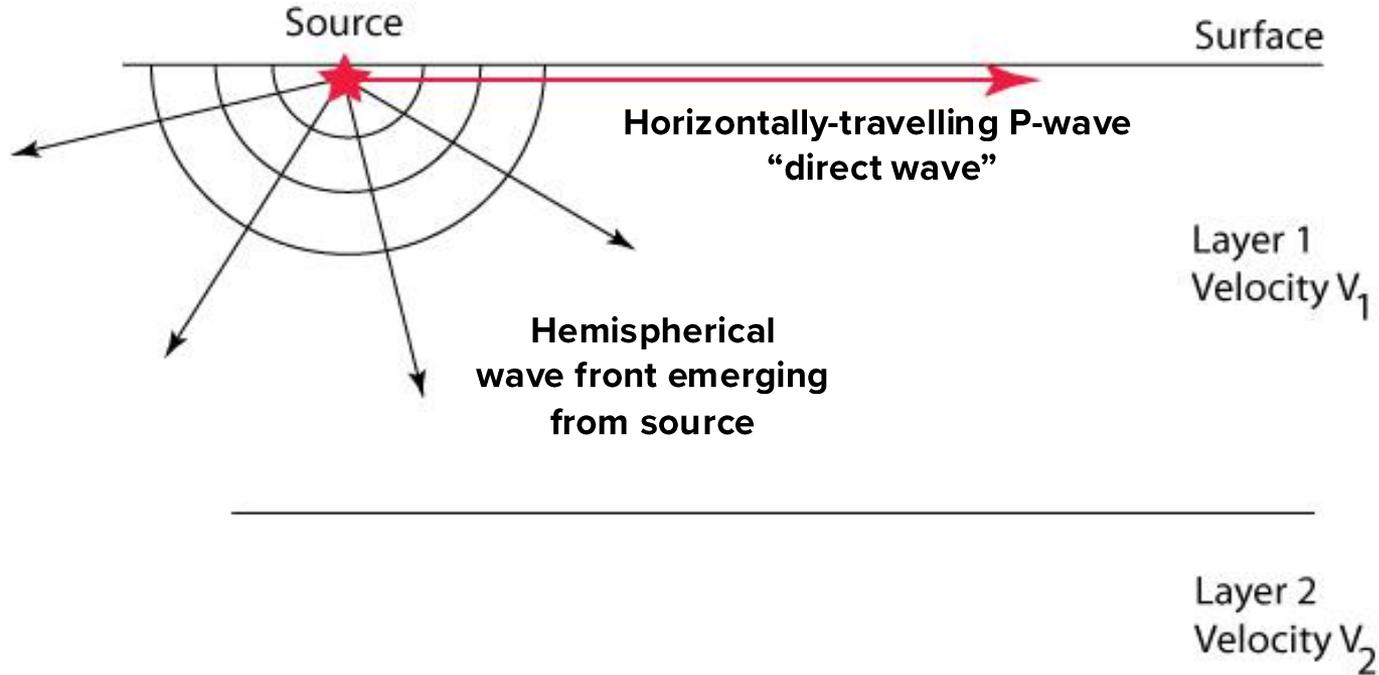
Mapping bedrock surface to understand the tectonic hazards

Mapping depth to ground water

Identifying underground features



How does this work?

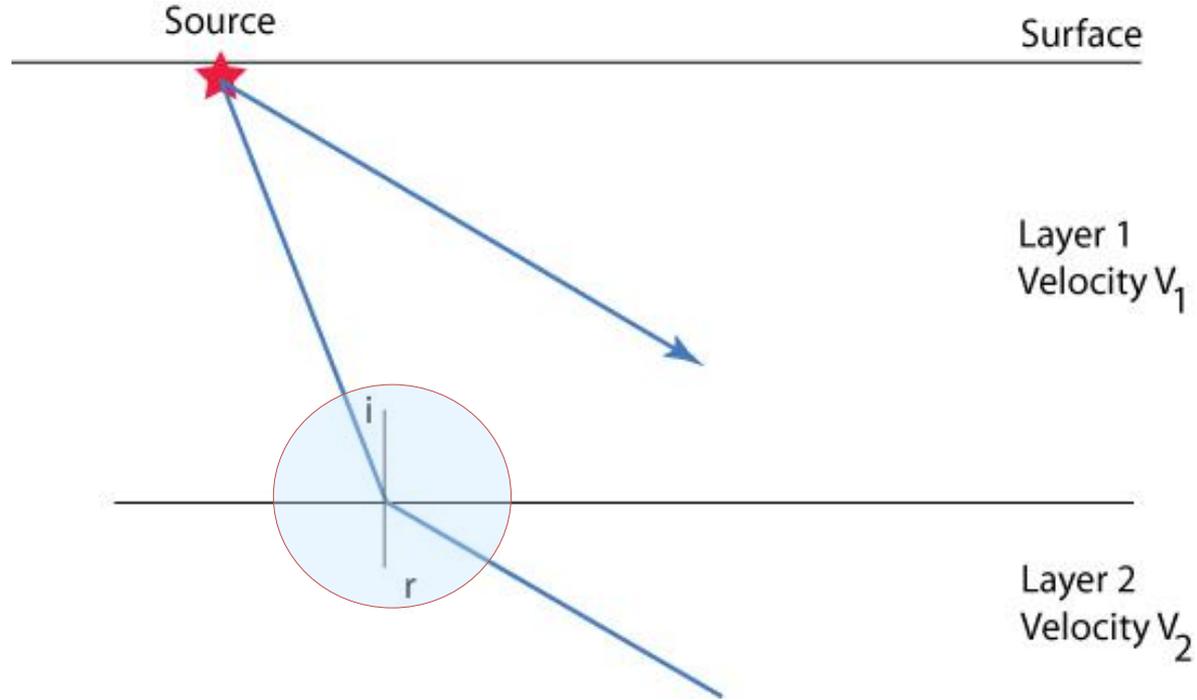


How does this work?

This oblique ray reaches the base of layer 1 where P-wave speed changes from V_1 to V_2

Refraction occurs - angles described by Snells Law

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



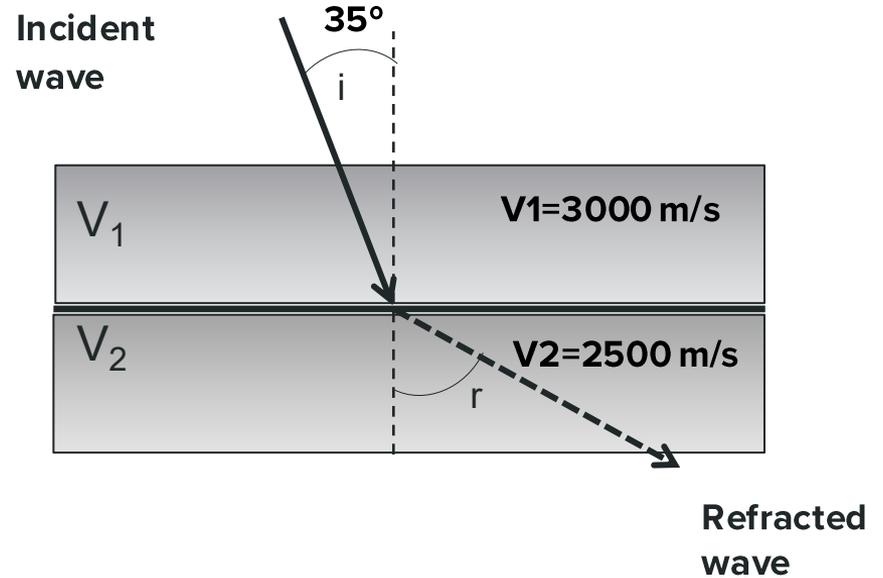
Question:

Calculate the angle of refraction
Layer 2.

After calculating the angle,
visualize and explain:

**Does the seismic wave
bend towards or away from the
surface as it moves from Layer
1 to Layer 2?**

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



Question

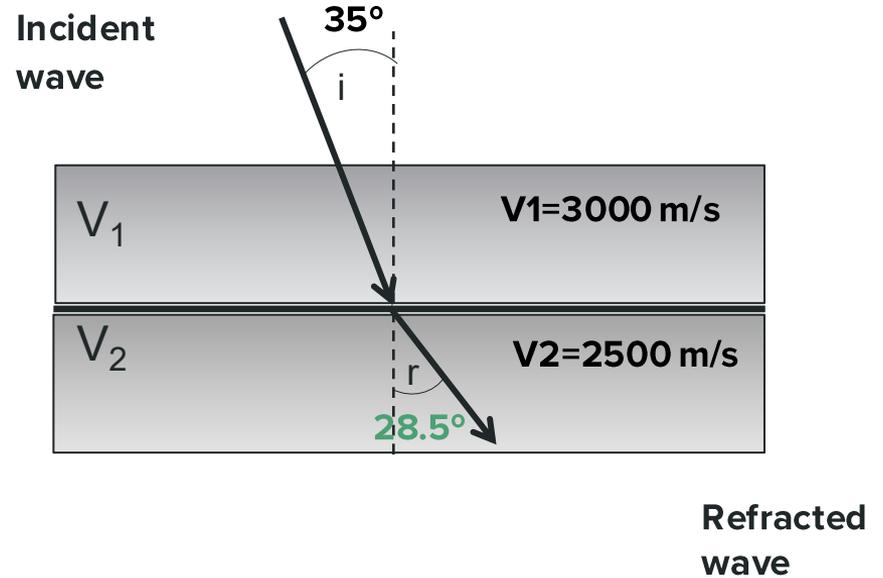
Calculate the angle of refraction in Layer 2.

After calculating the angle, visualize and explain:

Does the seismic wave bend towards or away from the surface as it moves from Layer 1 to Layer 2?

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

Since the wave travels from a faster layer (Layer 1) into a slower layer (Layer 2), it bends away from the surface (or towards the normal). This is because the wave slows down and changes direction as it enters the slower material.



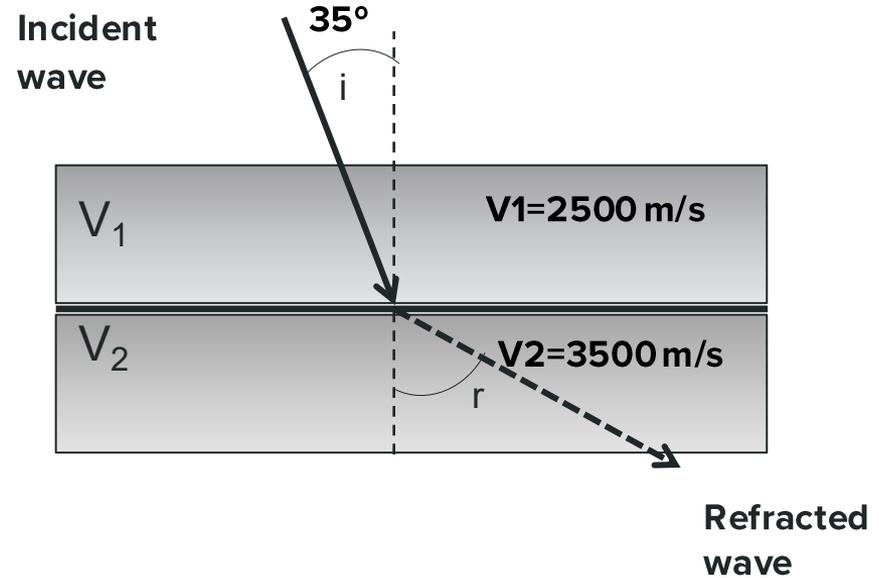
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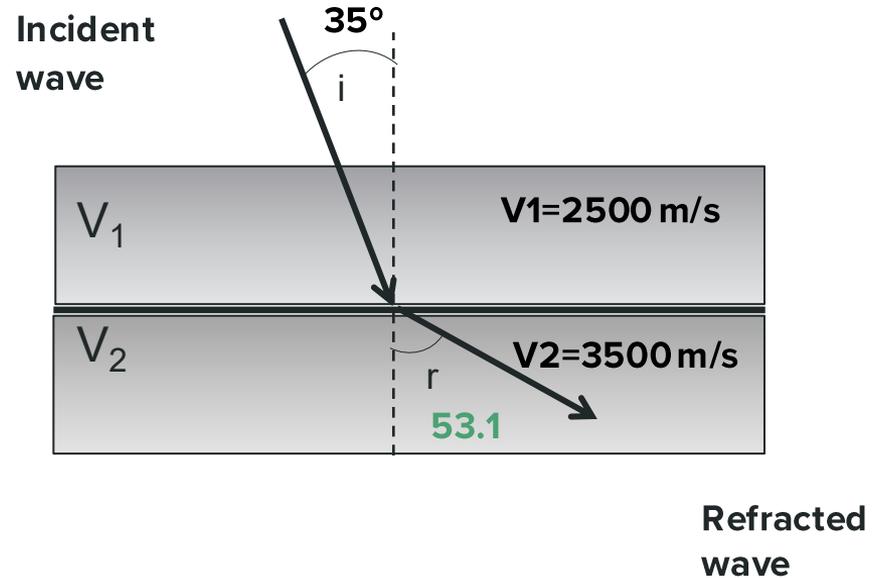
Calculate the angle of refraction in Layer 2.

After calculating the angle, visualize and explain:

Does the seismic wave bend towards or away from the surface as it moves from Layer 1 to Layer 2?

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

Since the wave travels from a slower layer (Layer 1) into a faster layer (Layer 2), it bends towards the surface (or away from the normal). This is because the wave speeds up and changes direction as it enters the faster material.



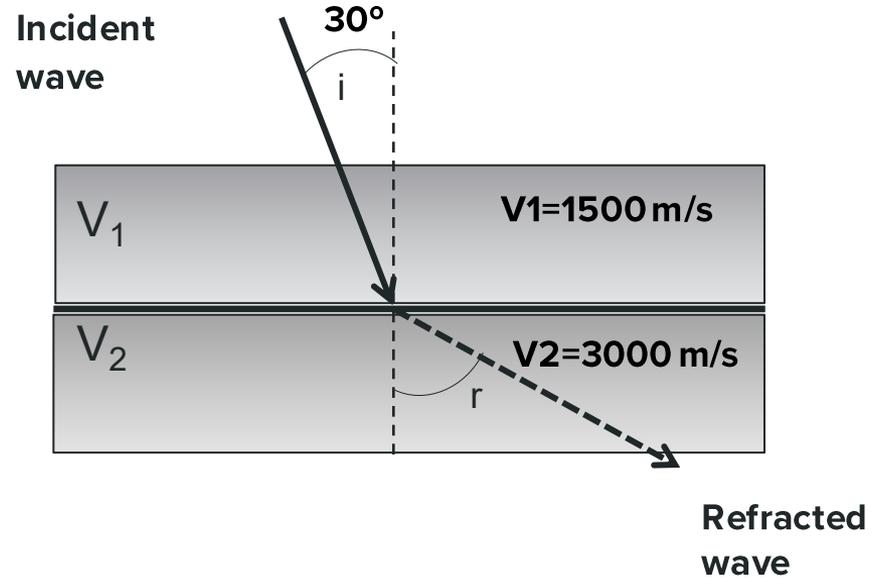
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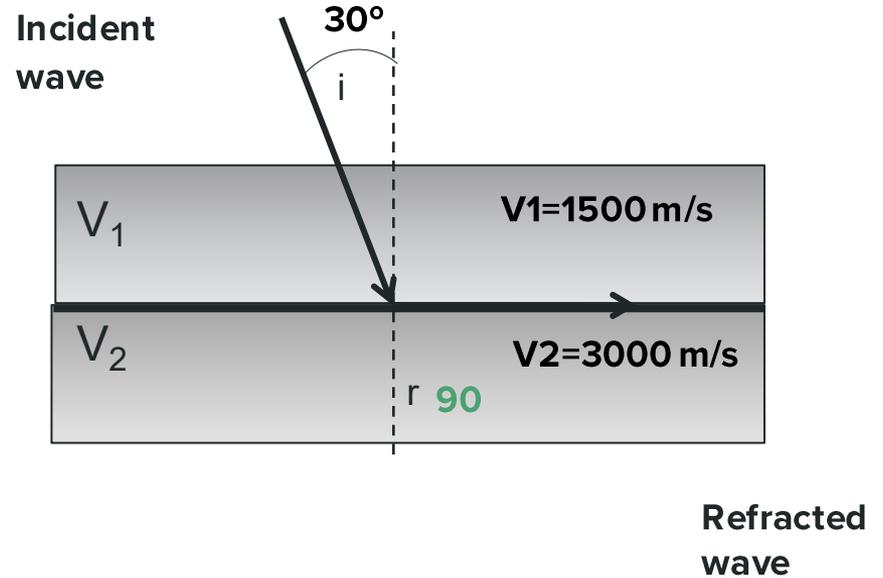
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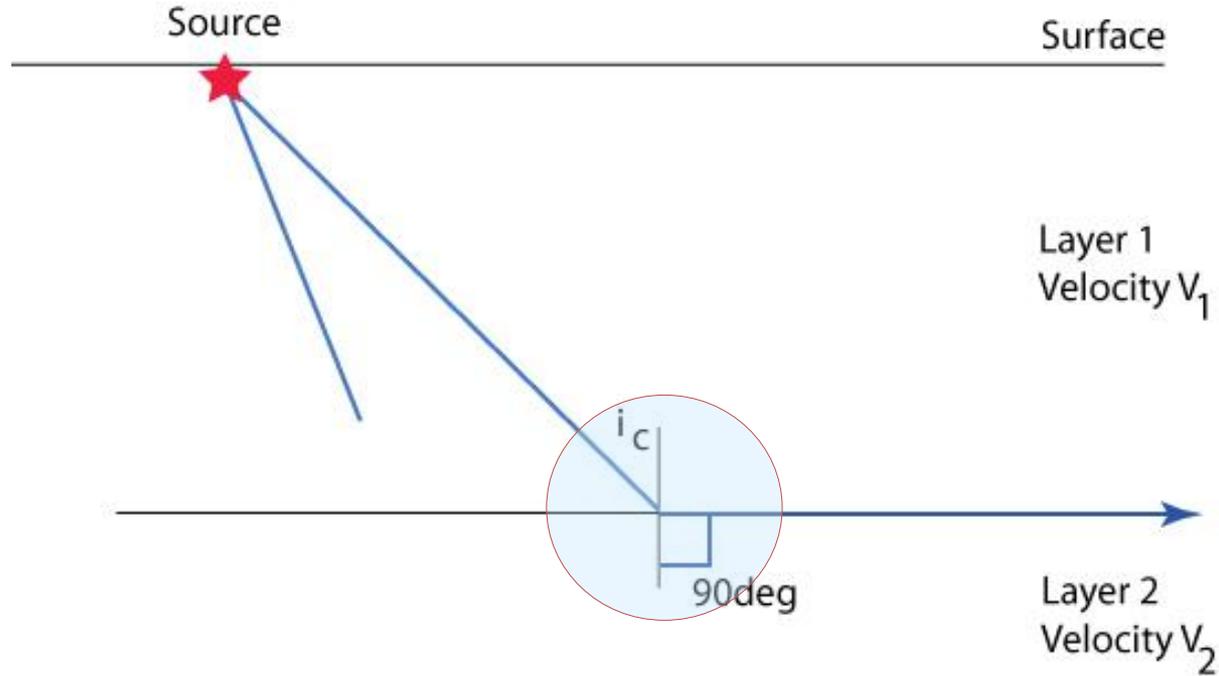
$$\frac{\sin i}{\sin r} = \frac{V_1}{V_2}$$



Special case!

Critical Refraction

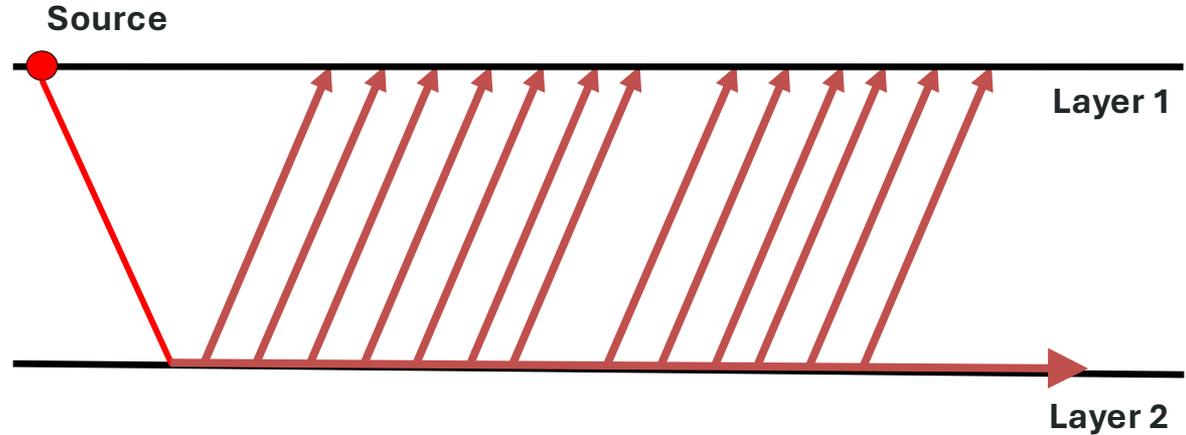
This oblique ray reaches the base of layer 1 at an angle such that $r = 90^\circ$. This is called **Critical Refraction**. The angle of incidence i_c that produces it is the **Critical Angle**



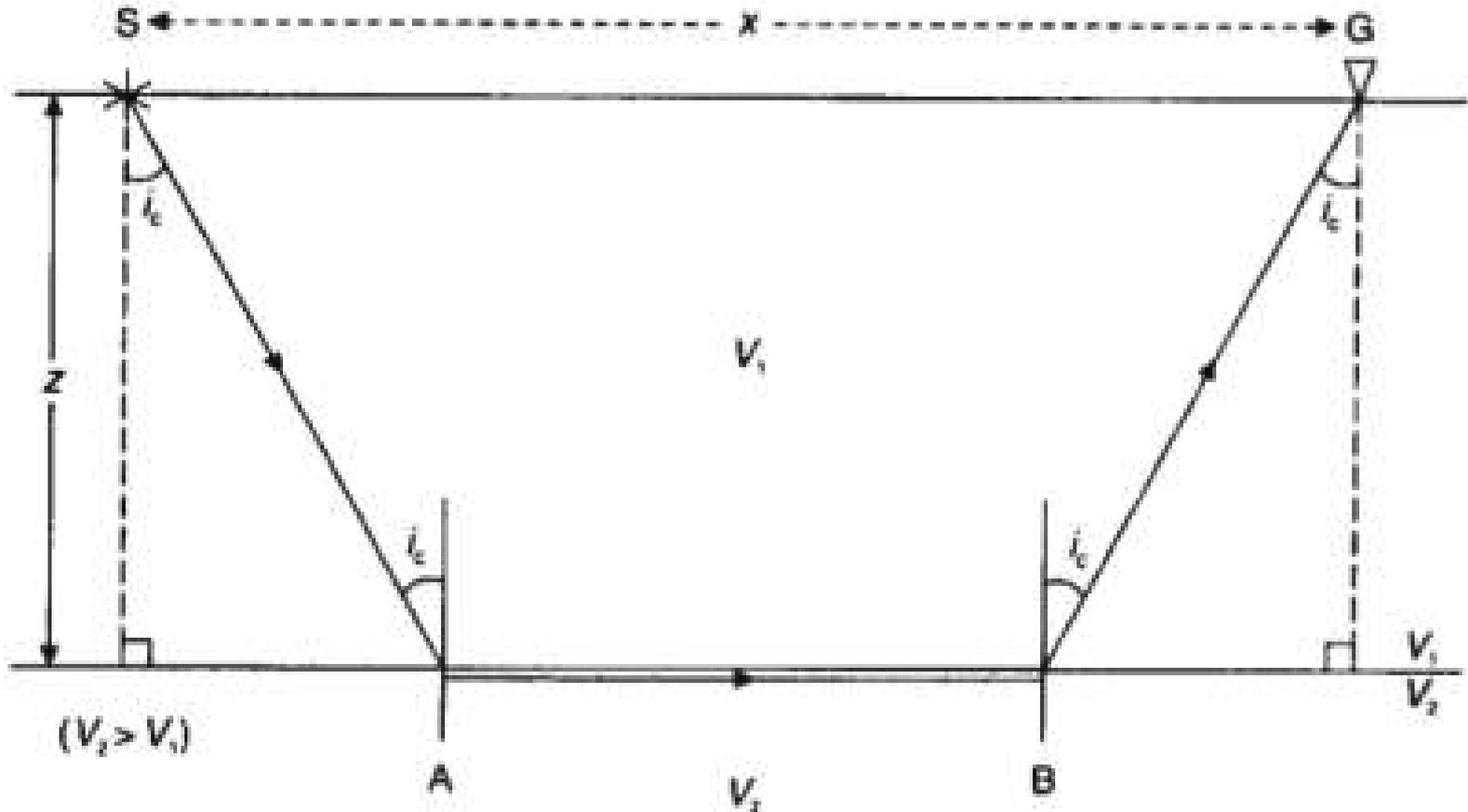
Critical Refraction

As the critically-refracted ray travels along at the top of layer 2, it's re-radiating energy upwards - by Snell's Law, the up-going rays emerge at the critical angle

$$\sin i_c = \frac{V_1}{V_2}$$



Refracted wave travel time



Two layer model

Direct wave: $T = \frac{x}{V_1}$

Refracted wave: $T_{refrac} = T_{SG} = T_{SA} + T_{AB} + T_{BG}$

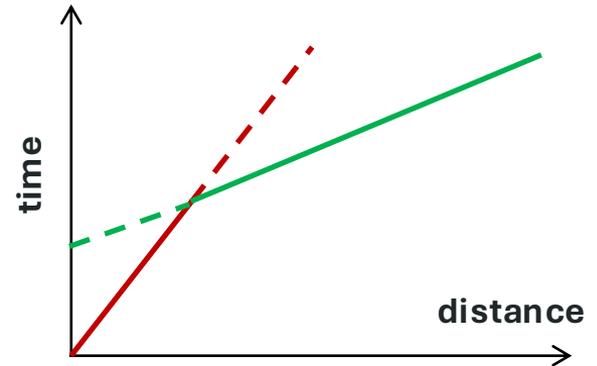
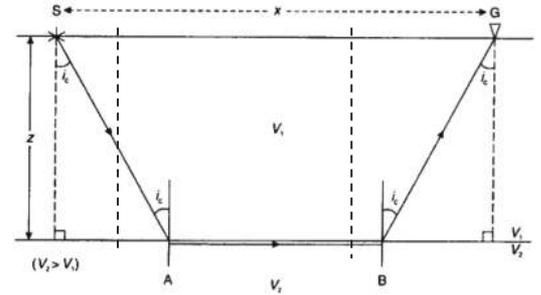
$$= \frac{x}{V_2} + \frac{2z \cos \theta}{V_1}$$

$$T_{SG} = \frac{x}{V_2} + \frac{2z}{V_1} \sqrt{1 - \frac{V_1^2}{V_2^2}}$$

$y = mx + c$

gradient = $m = \frac{1}{V_2}$

intercept = $c = \frac{2z}{V_1} \sqrt{1 - \frac{V_1^2}{V_2^2}}$ $z = \frac{c V_1 V_2}{2 \sqrt{V_2^2 - V_1^2}}$



Multi-layer model

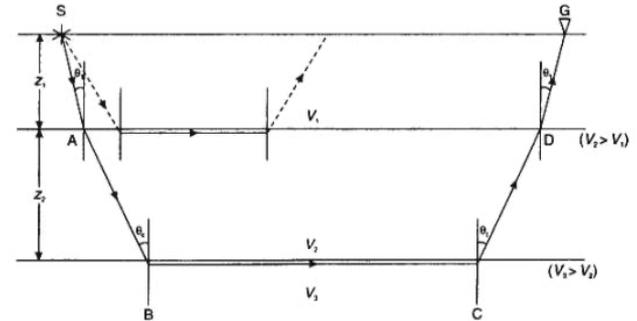
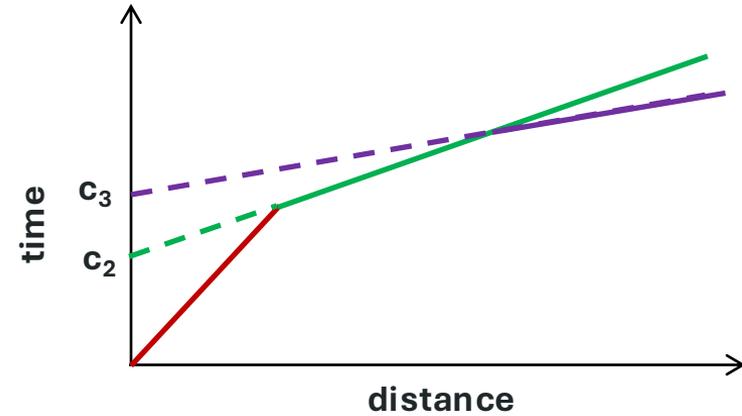
Apply same process to determine velocity and layer thickness sequentially from the top down

Head wave from layer 2

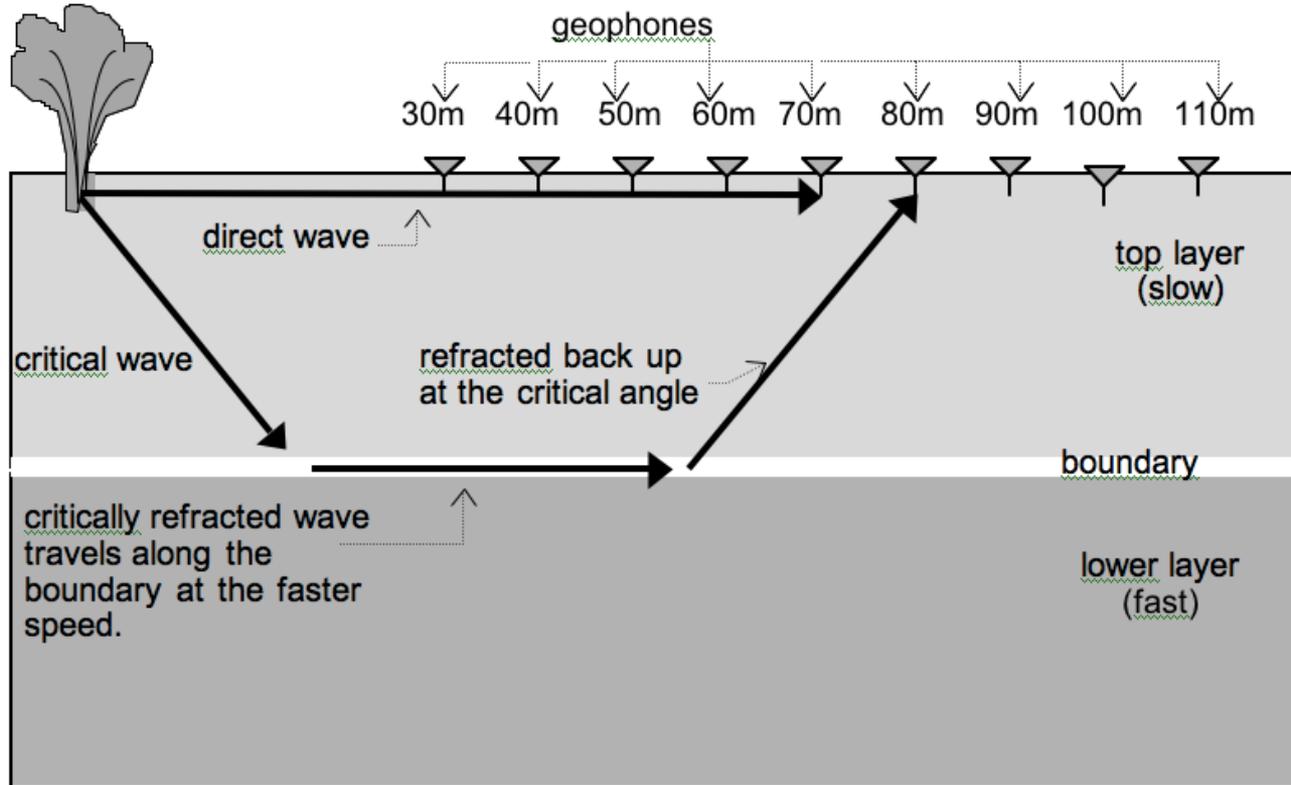
$$T_{SG} = \frac{x}{V_2} + \frac{2z}{V_1} \sqrt{1 - \frac{V_1^2}{V_2^2}}$$

Head wave from layer 3

$$T_{SG} = \frac{x}{V_3} + \frac{2z_1}{V_1} \sqrt{1 - \frac{V_1^2}{V_3^2}} + \frac{2z_2}{V_2} \sqrt{1 - \frac{V_2^2}{V_3^2}}$$



Critical Distance and Cross-Over Distance

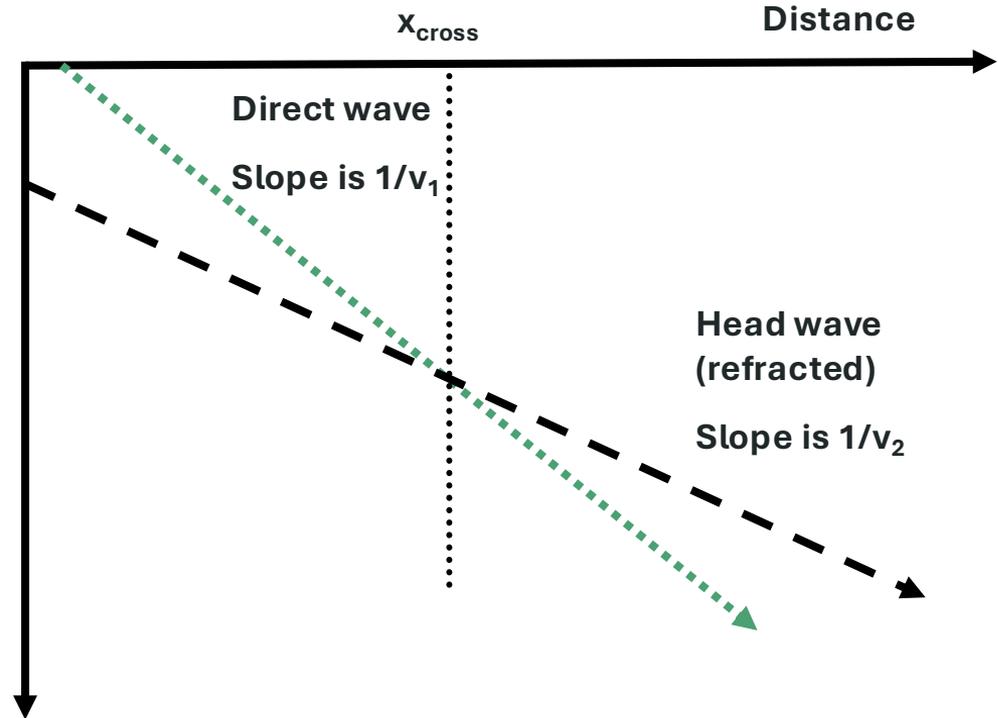


How to determine the depth to the interface/boundary?

The “intercept time”, t_i , of the refracted wave
Or the “c” in “ $y=mx+c$ ”

$$\textit{intercept time} = \frac{2z}{v_1} \sqrt{1 - \frac{v_1^2}{v_2^2}}$$

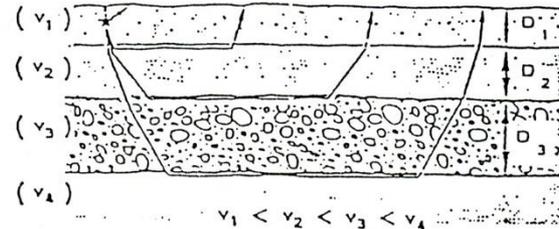
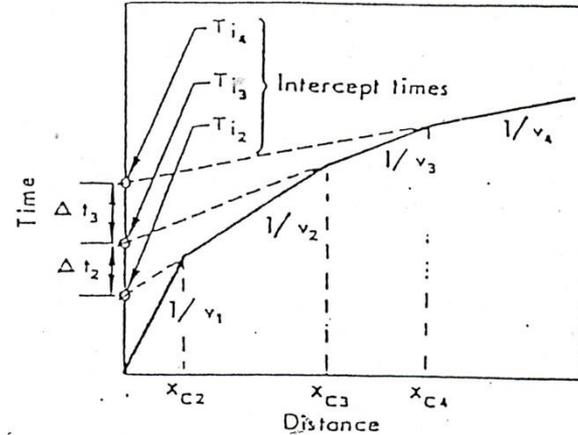
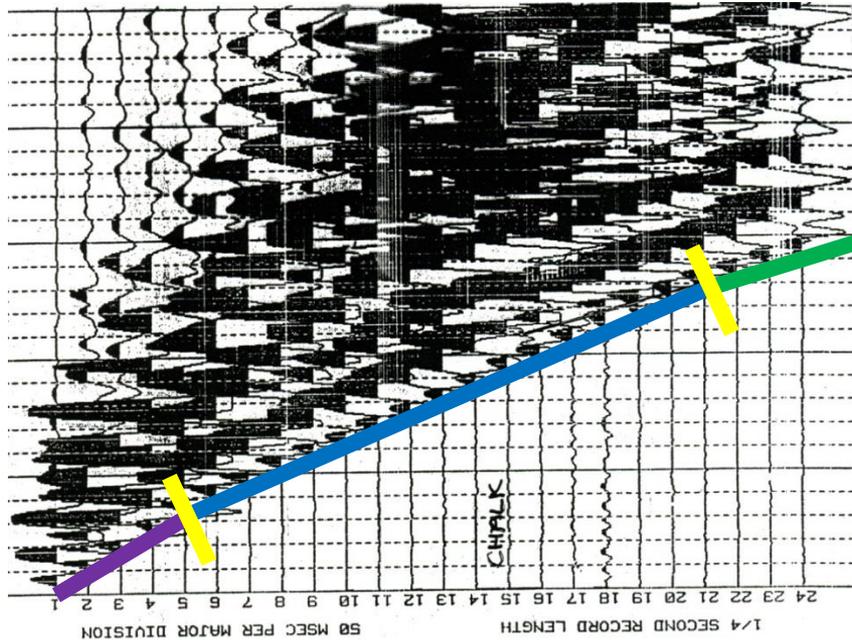
The cross-over distance, x_{cross} , is related to the depth to the boundary!



More complex cases: Multiple Layers

Each layer gives its 'own' linear segment on the TX plot

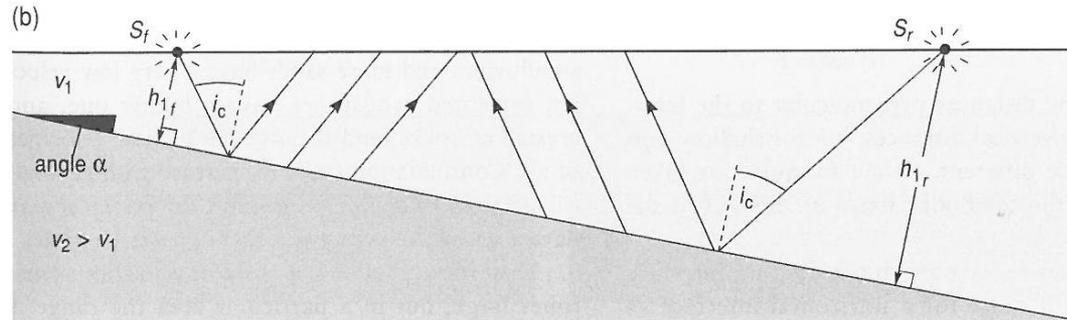
Velocities found from slopes, layer thicknesses from intercept times



Example from England: soil, over glacial clay, over chalk.

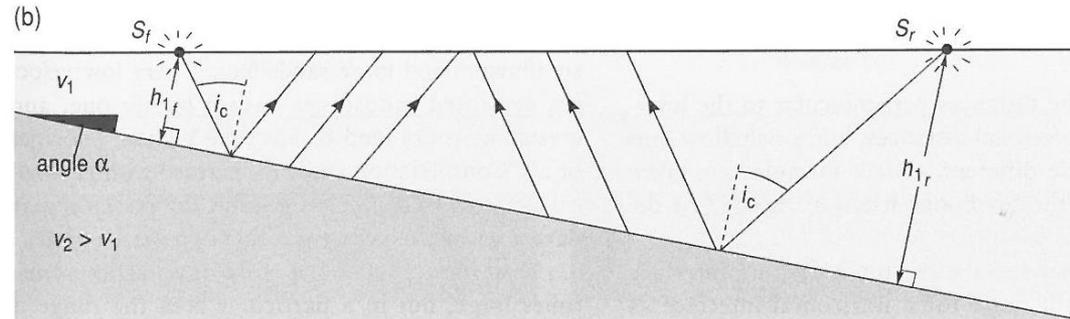
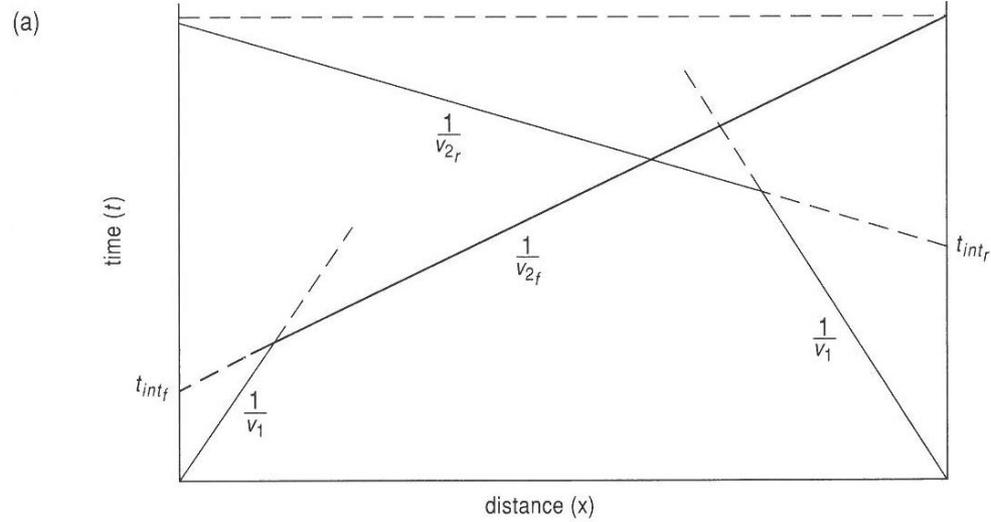
More complex cases: Dipping Layers

What is the shape of the the travel-time curve?



More complex cases: Dipping Layers

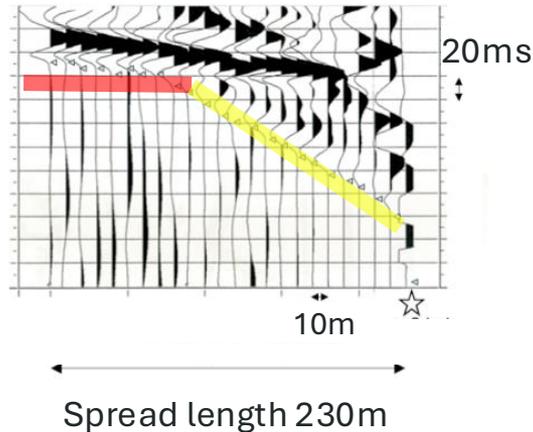
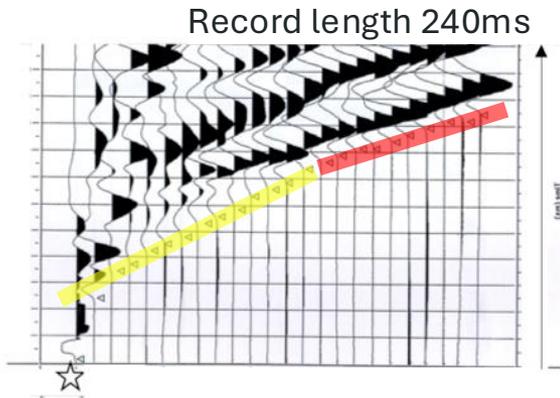
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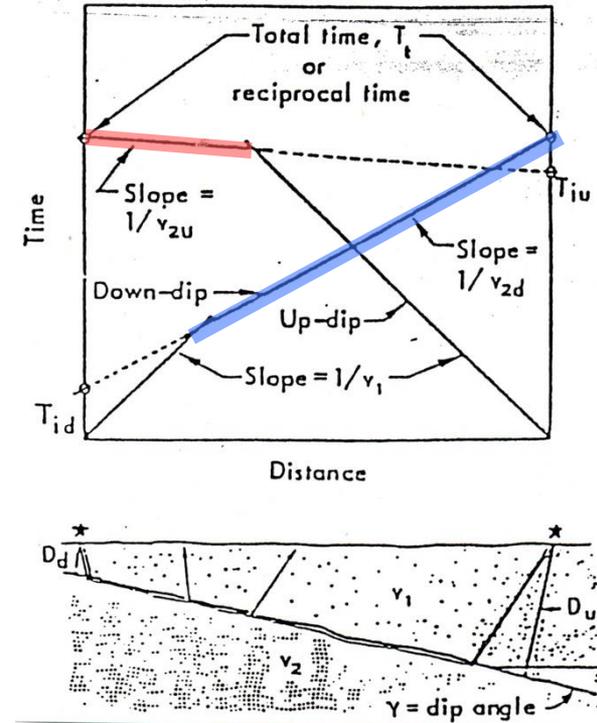
More complex cases: Dipping Layers

Take separate shots at **both** ends of the geophones
Refracted arrivals have different apparent velocities for each shot

Take shots at both ends of a line of geophones, **otherwise dip is not recognized**

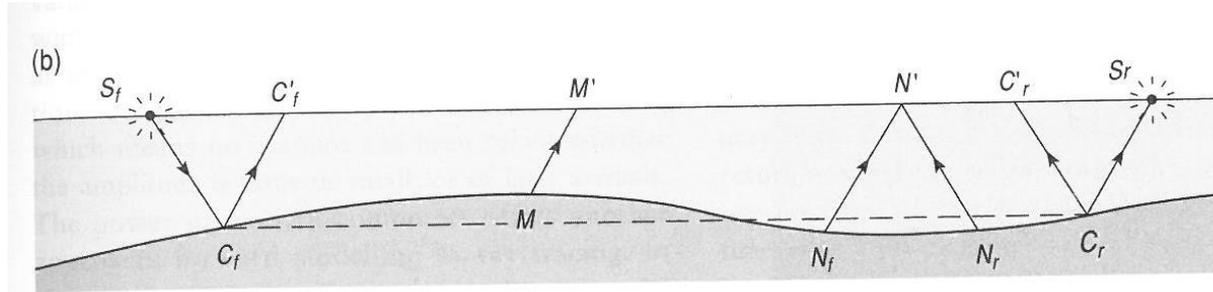


Example England: the refracting boundary is a horizontal water table beneath a steeply-dipping hillside.



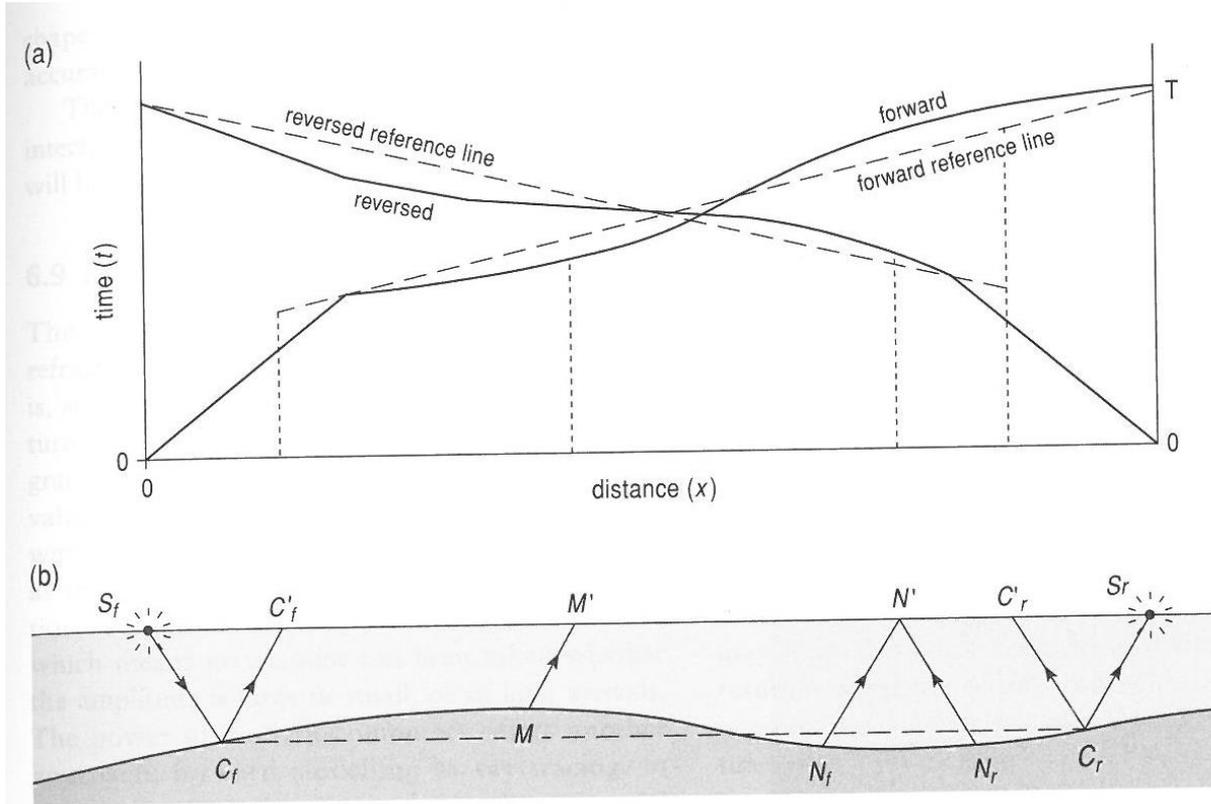
More complex cases: Undulating Layers

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More complex cases: Undulating Layers

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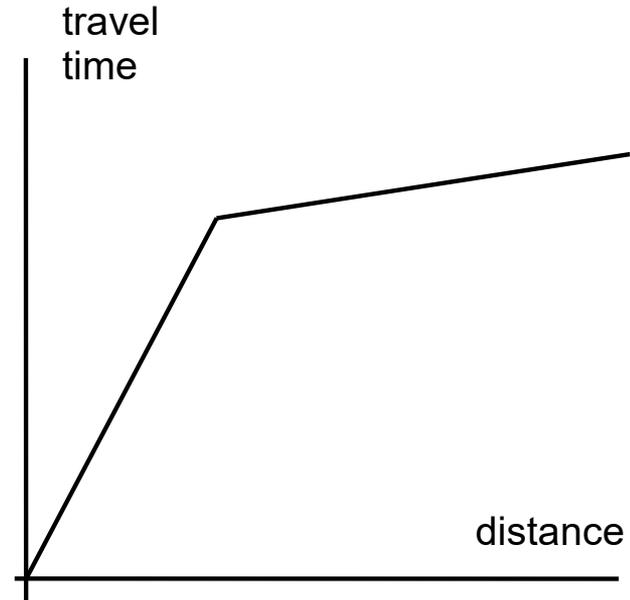
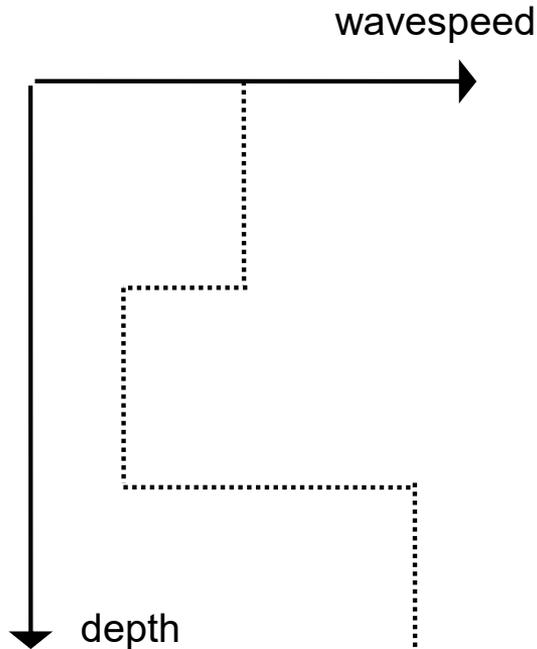


What if velocity decreases with depth?

Critical refraction cannot happen

The **slow layer** will be **invisible** in the TX plot

All results at/below this layer will appear systematically too deep

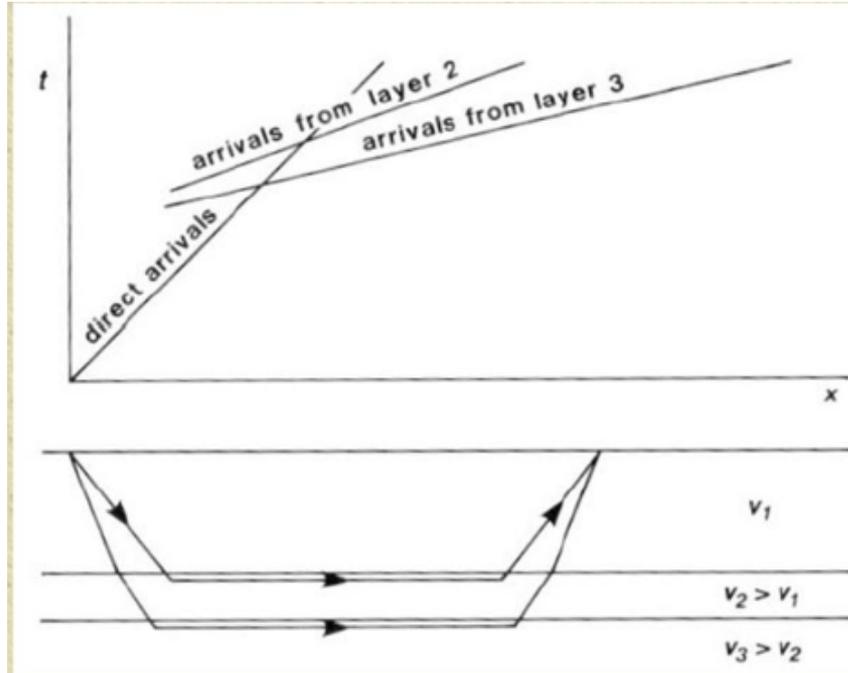


What if there are thin layers?

Critical refraction from the base of the layers always overtakes that from the top

The **thin layer** will be invisible in the **TX plot**

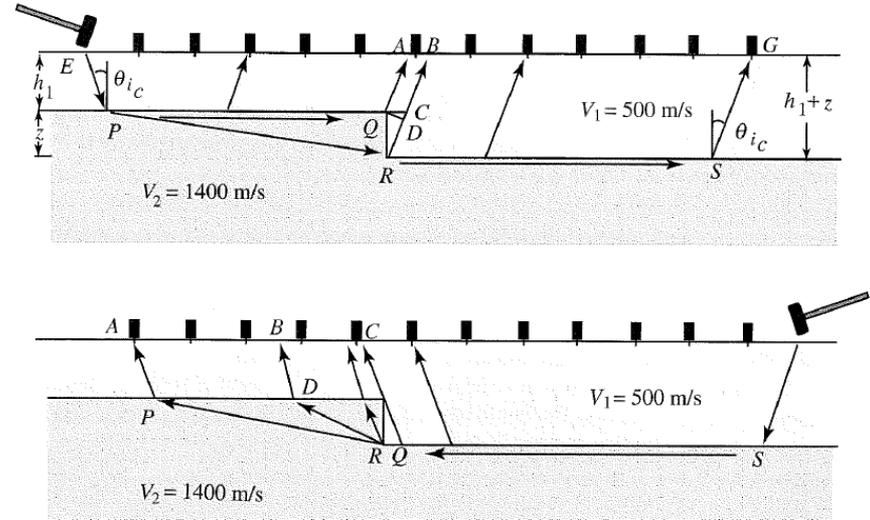
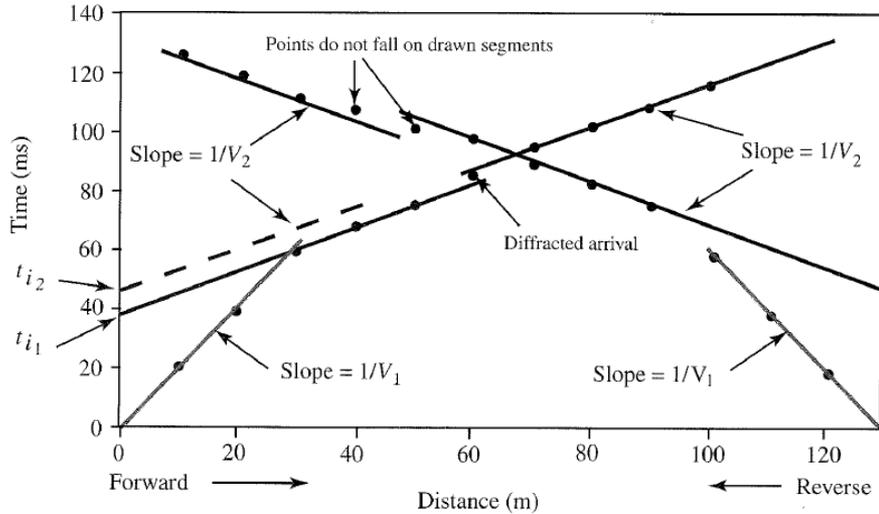
All results at/below this layer will appear systematically too shallow



Offsets in velocity interface

Sharp offsets in travel time curves are indicative of some kind of discontinuity or faults. You can determine fault throw from these offsets:

Look at the difference between the two intercept time.



Continuously increasing velocities with depth

Rays are continuously refracted to follow a **curved ray path**.

