Interpretation of Seismic Refraction Data

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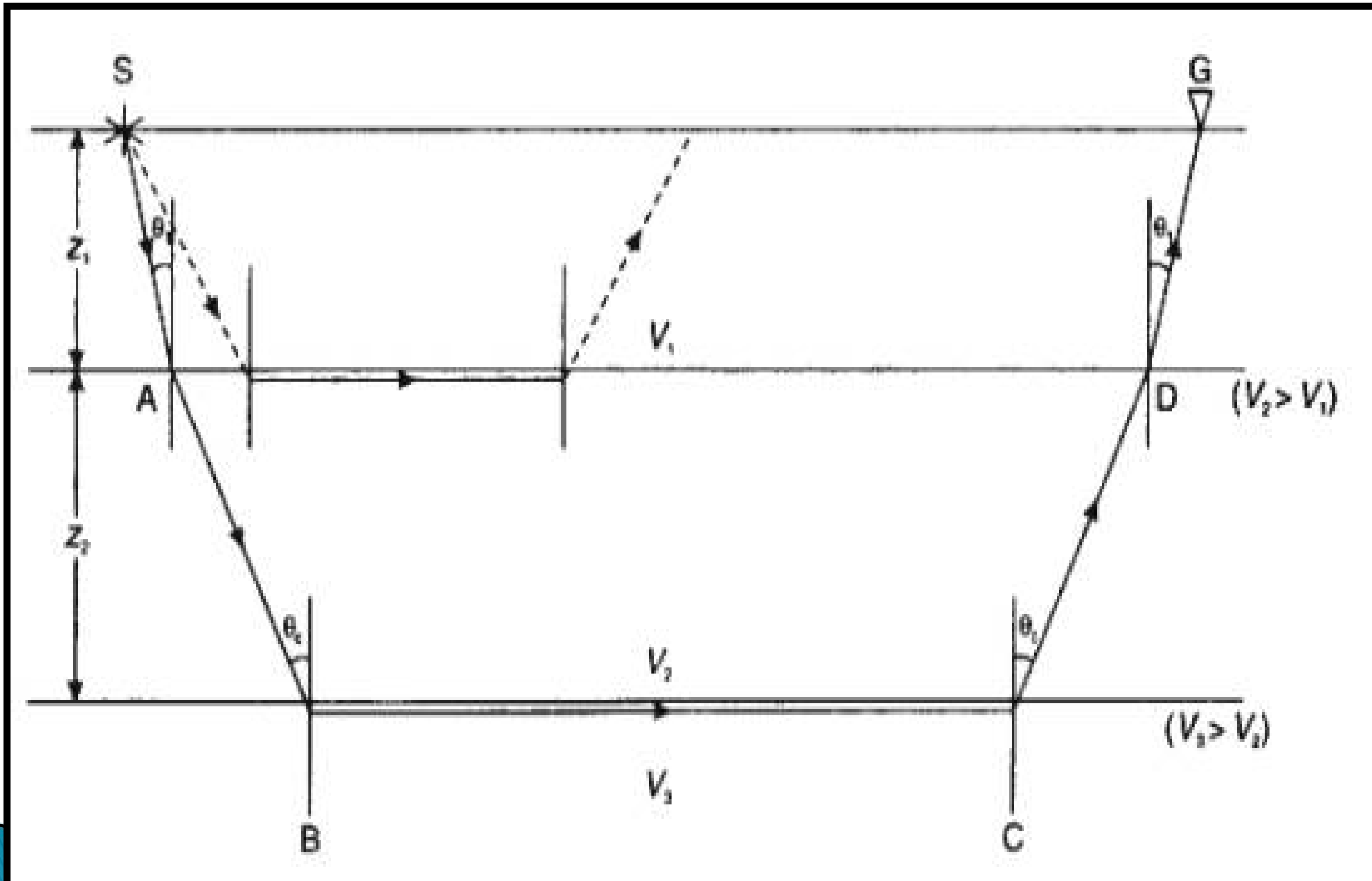
Planar Interfaces: Three Layer Case

- In same way as for 2-layer case, we can consider triangles at ends of raypath, to get expression for traveltime.
- After simplification as before:

The cosine functions can be expressed in terms of velocities using Snell's law along raypath of the critical refraction:

Planar Interfaces: Three Layer Case

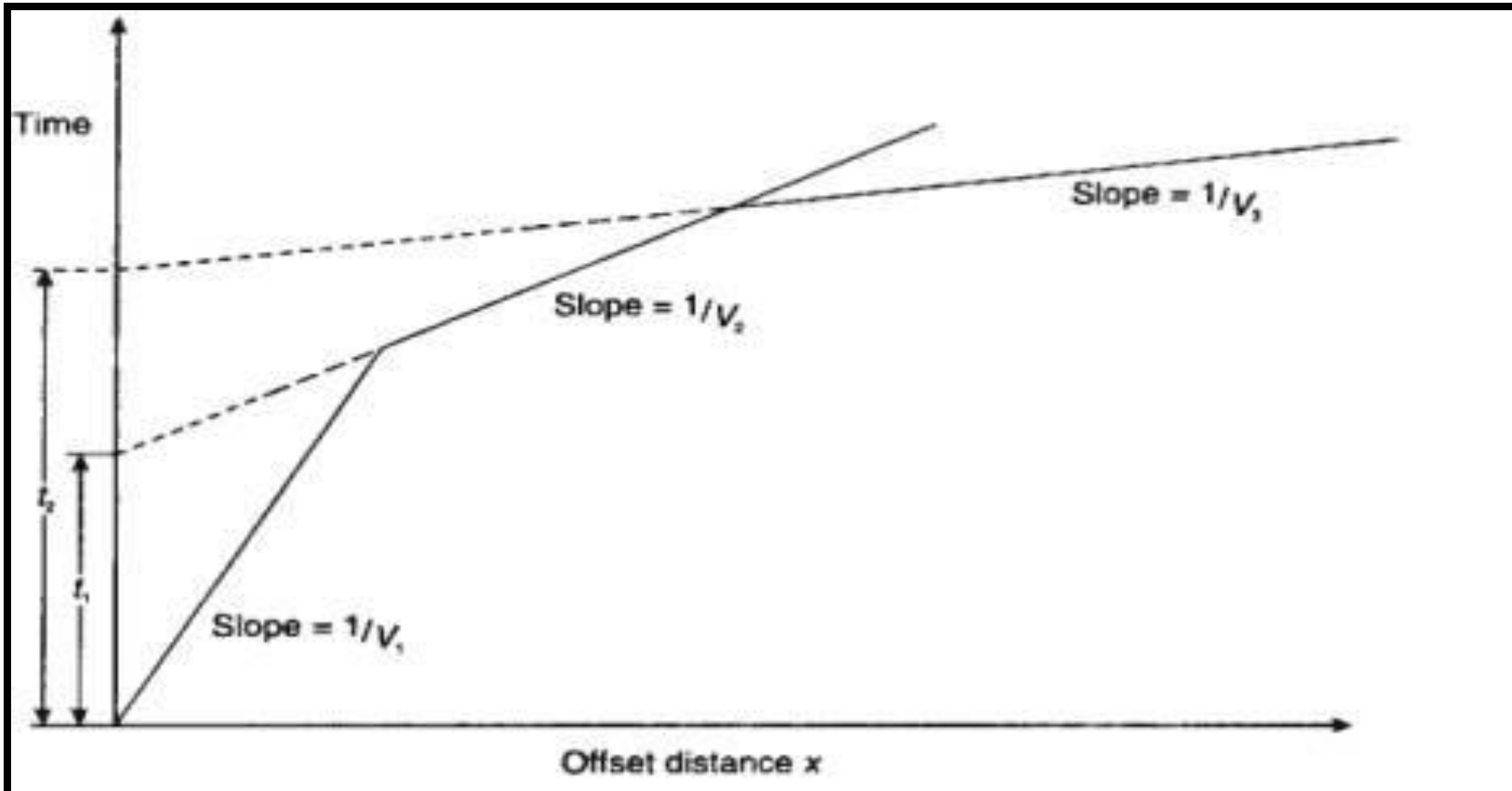


Planar Interfaces: Three Layer Case

- Again travel time equation is a straight line, with slope $1/V_3$ and intercept time t_2.
- In three layer case, the arrivals are:

1. Direct arrival in first layer
2. Critical refraction at top of seconds layer
3. Critical refraction at top of third layer

Planar Interfaces: Three Layer Case



Planar Interfaces: Three Layer Case

- Because, intercept time of travel time curve from third layer is a function of the two overlying layer thicknesses, we must solve for these first.
- Use a layer-stripping approach:

Planar Interfaces: Three Layer Case

1. Solve two-layer case using direct arrival and critical refraction from second layer to get thickness of first layer.
2. Solve for thickness of second layer using all three velocities and thickness of first layer just calculated.

Travel Times Calculations For A Three- Layer Case

Total travel time is:

$$T_{SG} = T_{SA} + T_{AB} + T_{BC} + T_{CD} + T_{DG}$$

where:

$$T_{SA} = T_{DG} = z_1/V_1 \cos\theta_1$$
$$T_{AB} = T_{CD} = z_2/V_2 \cos\theta_c$$
$$T_{BC} = (x - 2z_1 \tan\theta_1 - 2z_2 \tan\theta_c)/V_3 .$$

Combining these gives:

$$T_{SG} = x/V_3 + (2z_2 \cos\theta_c)/V_2 + (2z_1 \cos\theta_1)/V_1 \qquad (1)$$

$$T_{SG} = x/V_3 + t_2 \qquad (2)$$

continued

Travel Times Calculations For A Three- Layer Case

continued

where

$$\frac{\sin\theta_1}{V_1} = \frac{\sin\theta_c}{V_2} = \frac{1}{V_3} \text{ from Snell's Law.}$$

Thicknesses of refractors are given by:

$$z_1 = t_1 V_1 V_2 / 2(V_2^2 - V_1^2)^{1/2}$$

$$z_2 = t_2 V_2 V_3 / 2(V_3^2 - V_2^2)^{1/2}$$

$$- z_1 V_2 (V_3^2 - V_1^2)^{1/2} / V_1 (V_3^2 - V_2^2)^{1/2}$$

Planar Interfaces: Multi-Layer Case

❖For a subsurface of many plane horizontal layers, the planar interface travel time equation can be generalized to:

The total travel time T_{SG} in an n-layer case is given by:

$$T_{SG} = x/V_n + \sum_{i=1}^{n-1} [(2z_i \cos\theta_i)/V_i]$$

where $\sin\theta_i = V_i/V_n$.

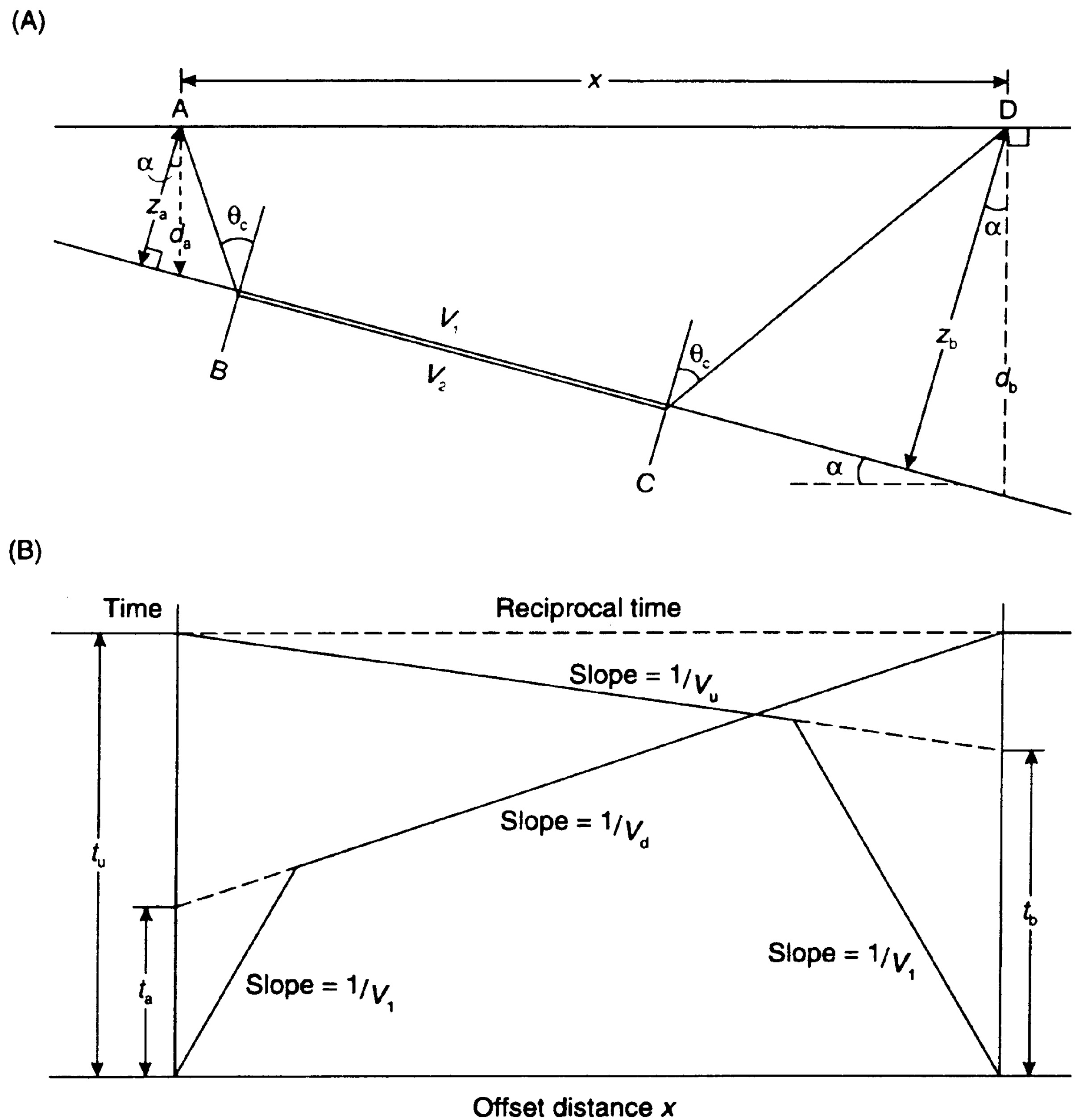
Note that θ_i are not critical angles except for θ_{n-1}.

Planar Interfaces: Multi-Layer Case

- where θ_i is the angle of incidence at the ith interface, which lies at depth Z_i at the base of a layer of velocity V_i.
- The interpretation procedures of multi-layer case follow the procedures explained for a three - layer case, but are extended to the relevant total number of layers.

Dipping Planar Interfaces

- When a refractor dips, the slope of the travel time curve does not represent the "true" layer velocity:
- shooting updip, i.e. geophones are on updip side of shot, apparent refractor velocity is higher
- shooting downdip apparent velocity is lower
- To determine both the layer velocity and the interface dip, forward and reverse refraction profiles must be acquired.


(A)
x
A
D
α
z_a
d_a
θ_c
V_1
B
V_2
θ_c
C
α
z_b
d_b
α
(B)
Time
Reciprocal time
Slope = 1/V_u
Slope = 1/V_d
t_u
t_a
Slope = 1/V_1
Slope = 1/V_1
t_b
Offset distance x

Dipping Planar Interfaces

- Note: Travel times are equal in forward and reverse directions for switched, reciprocal, source/receiver positions.
- A set of equations can be produced that relate velocity, layer thickness and angle of refractor dip from which the geometry of the dipping refractor can be determined.

Dipping Planar Interfaces

- The depths (d_a and d_b) to the refractor vertically below the spread end-points can easily be calculated from the derived values of perpendicular depths (z_a and z_b) using the expression $d = z/\cos\alpha$.

Total travel time over a refractor dipping at an angle α is given by:

$$T_{ABCD} = (x \cos \alpha)/V_2 + [(z_a + z_b) \cos i_c]/V_1$$

where V_2 is the refractor velocity, and z_a and z_b are the distances perpendicular to the refractor.

The down-dip travel time t_d is given by:

$$t_d = x\,[\sin(\theta_c + \alpha)]/V_1 + t_a \qquad (1)$$

where $t_a = 2z_a(\cos\theta_c)/V_1$.

$$t_u = x\,[\sin(\theta_c - \alpha)]/V_1 + t_b \qquad (2)$$

where $t_b = 2z_b(\cos\theta_c)/V_1$.

Equations (1) and (2) above can be written in terms of the apparent up-dip velocity (V_u) and down-dip velocity (V_d) such that:

$$t_d = x/V_d + t_a, \qquad \text{where } V_d = V_1/\sin(\theta_c + \alpha)$$

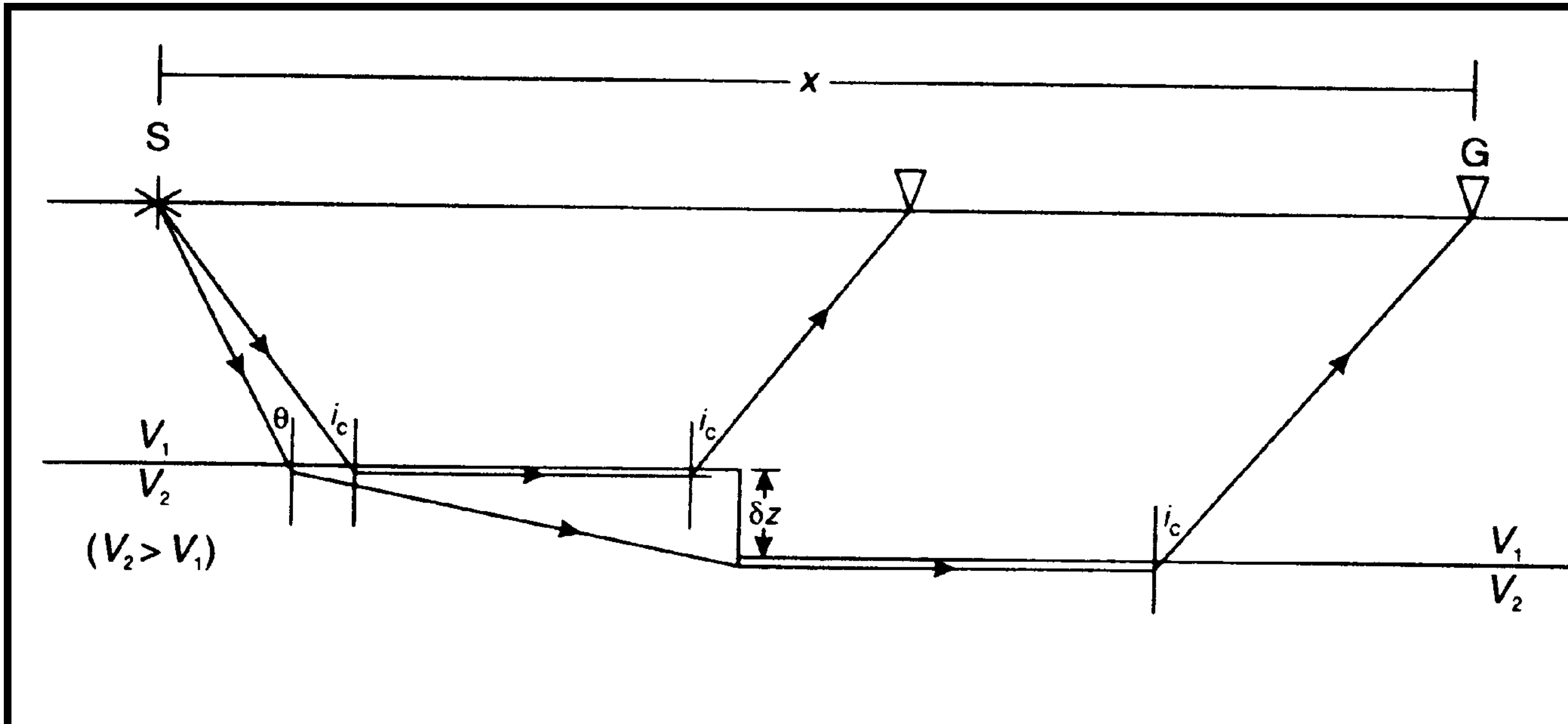
$$t_u = x/V_u + t_b, \qquad \text{where } V_u = V_1/\sin(\theta_c - \alpha).$$

An approximate relationship between true and apparent velocities for shallow angles of dip ($\alpha < 10°$) is given by:

$$V_2 \approx (V_d + V_u)/2.$$

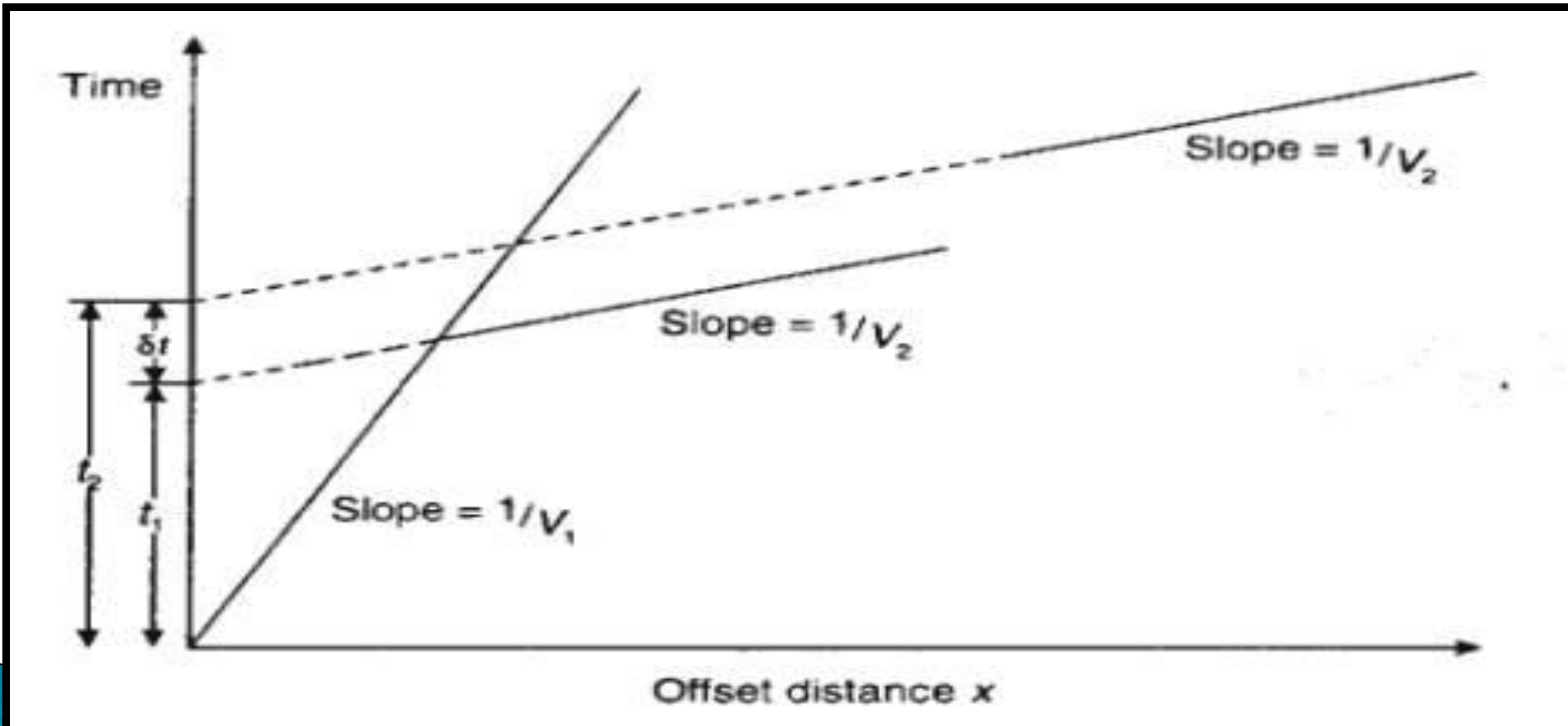
Faulted Planar Interface

- So far the refractor has been assumed to be planar and continuous.
- There are situations where a step discontinuity may occur in the refractor (the refractor faulted).
- If the step discontinuity has been caused by a normal , there may be an additional complication of the refractor velocity having different magnitudes across the fault plane.


x
S
G
θ
i_c
i_c
V_1
V_2
$(V_2 > V_1)$
δz
i_c
V_1
V_2

Faulted Planar Interface

- If refractor faulted, then there will be a sharp offset in the travel time curve:



Faulted Planar Interface

Can estimate throw on fault from offset in curves, i.e. difference between two intercept times, from simple formula:

The step size (δz) in a discontinuity in a refractor is given by:

$$\delta z = \delta t\, V_1 V_2 / (V_2^2 - V_1^2)^{1/2}.$$

Textbook

Kearey, P., Brooks, M. and Hill, I. (2002) An introduction to Geophysical Exploration. 3rd edition, Blackwell Science Ltd, UK, 261p.