METODE SEISMIK BIAS

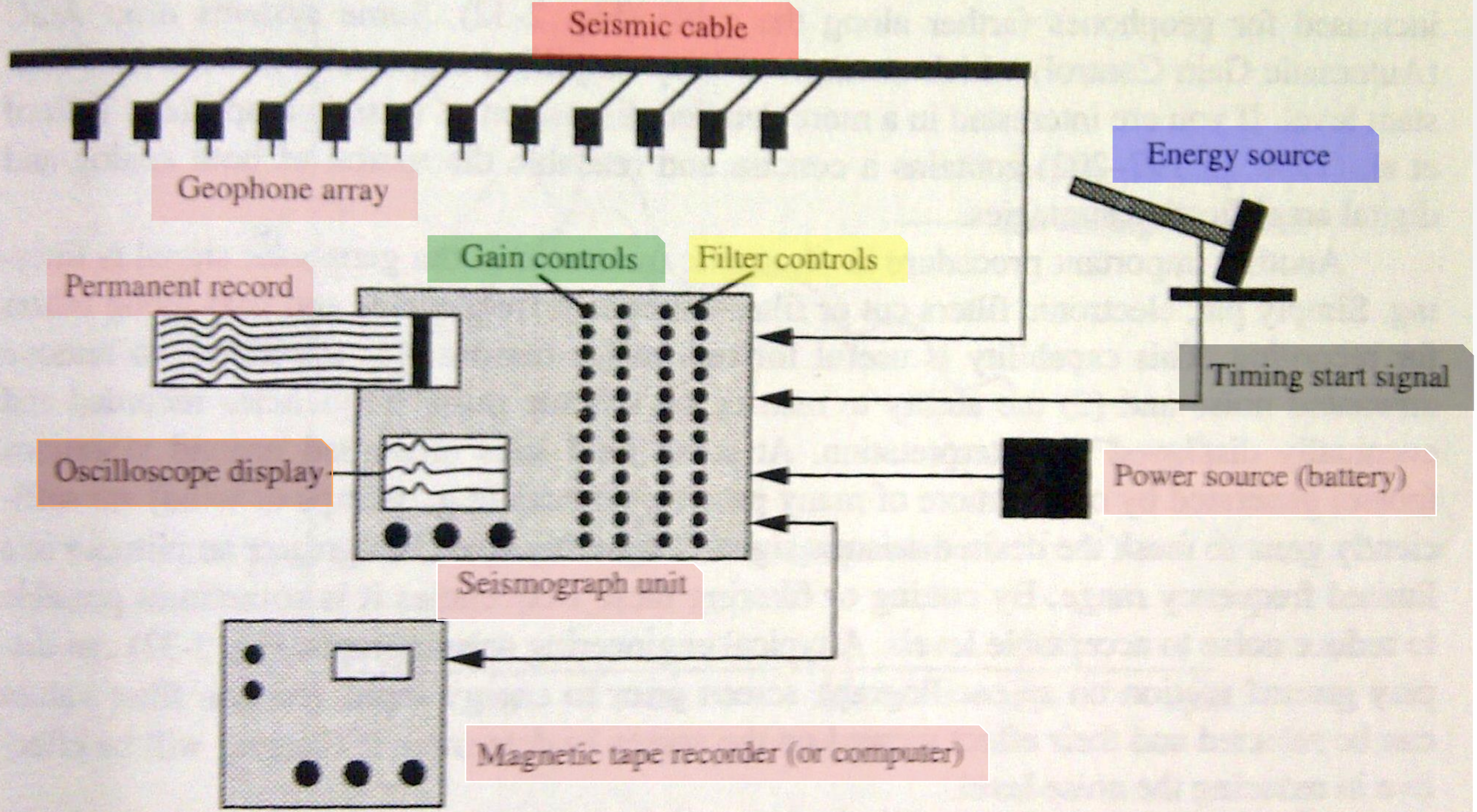
REFRACTION SEISMIC

Advance Exploration Geophysics Course

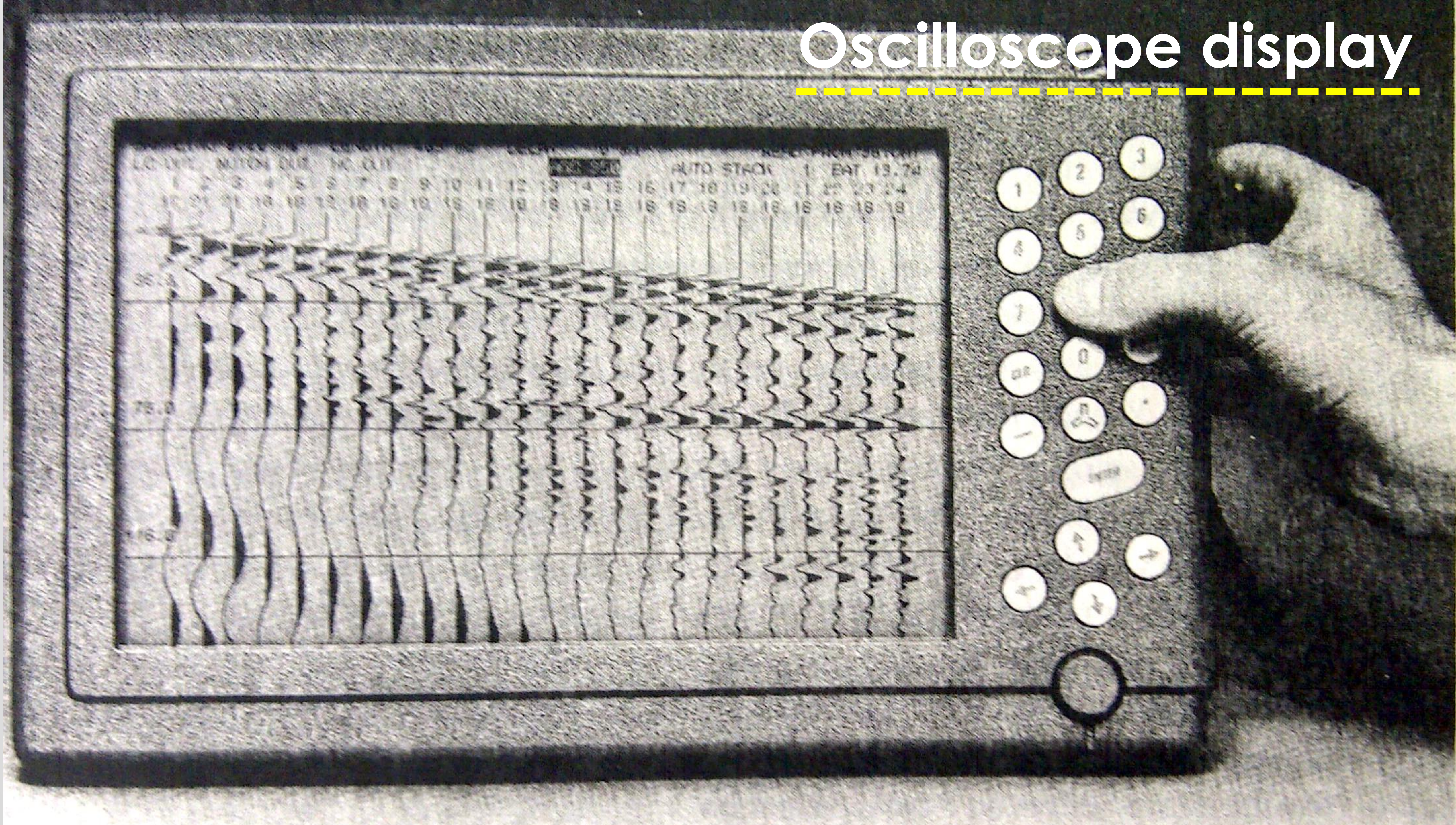
Dr. Wiwit Suryanto

Seismology, Volcanology and Geothermal Research Group

Geophysics Laboratory, Physics Department, FMNS, UGM


Seismic cable
Geophone array
Energy source
Gain controls
Filter controls
Permanent record
Timing start signal
Oscilloscope display
Power source (battery)
Seismograph unit
Magnetic tape recorder (or computer)

Oscilloscope display

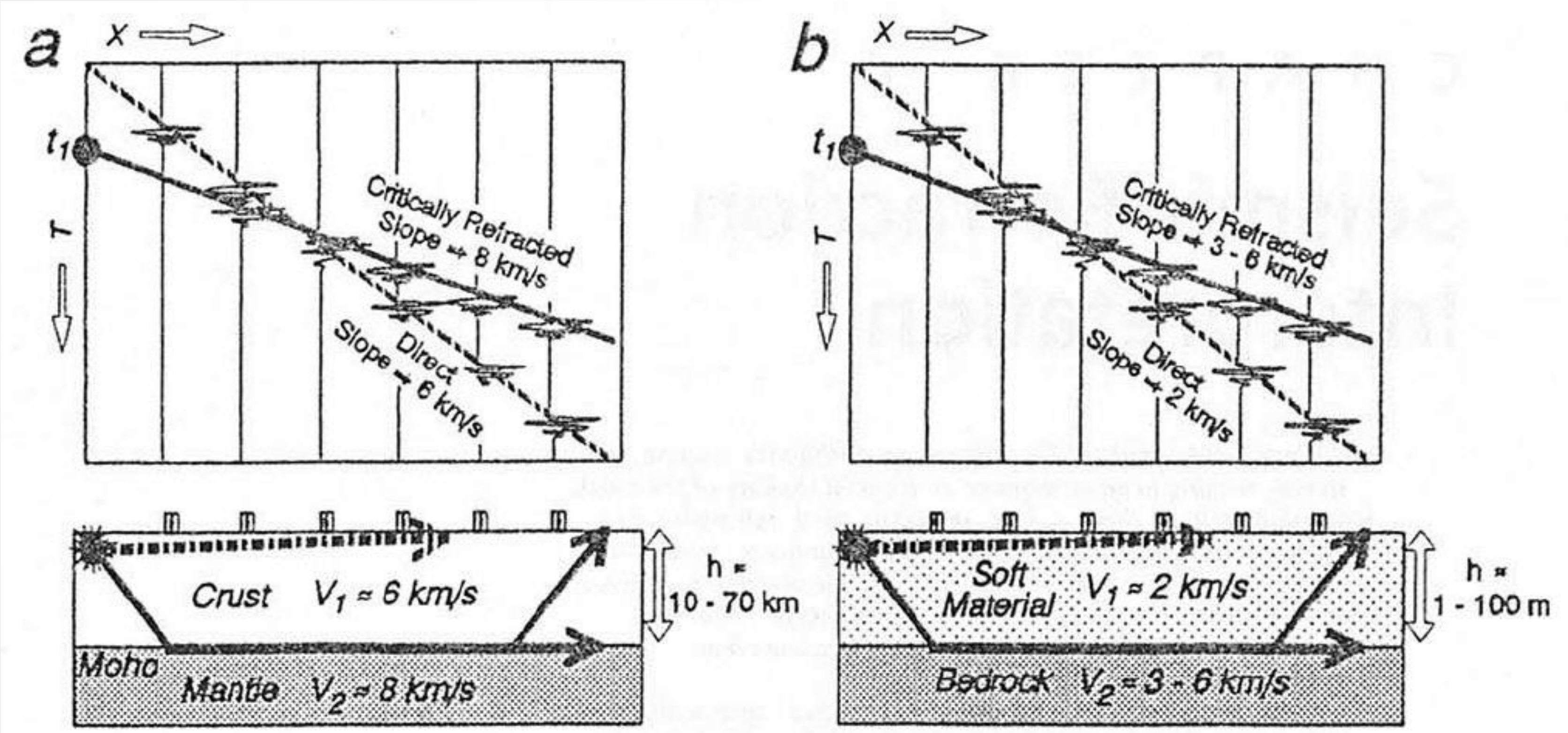



geoFact
www.geofact.de

INTRODUCTION

- Refraction seismic is most useful when abrupt increase in velocity with depth, since critically refracted P-wave eventually arrive ahead of other waves

Crustal thickness study

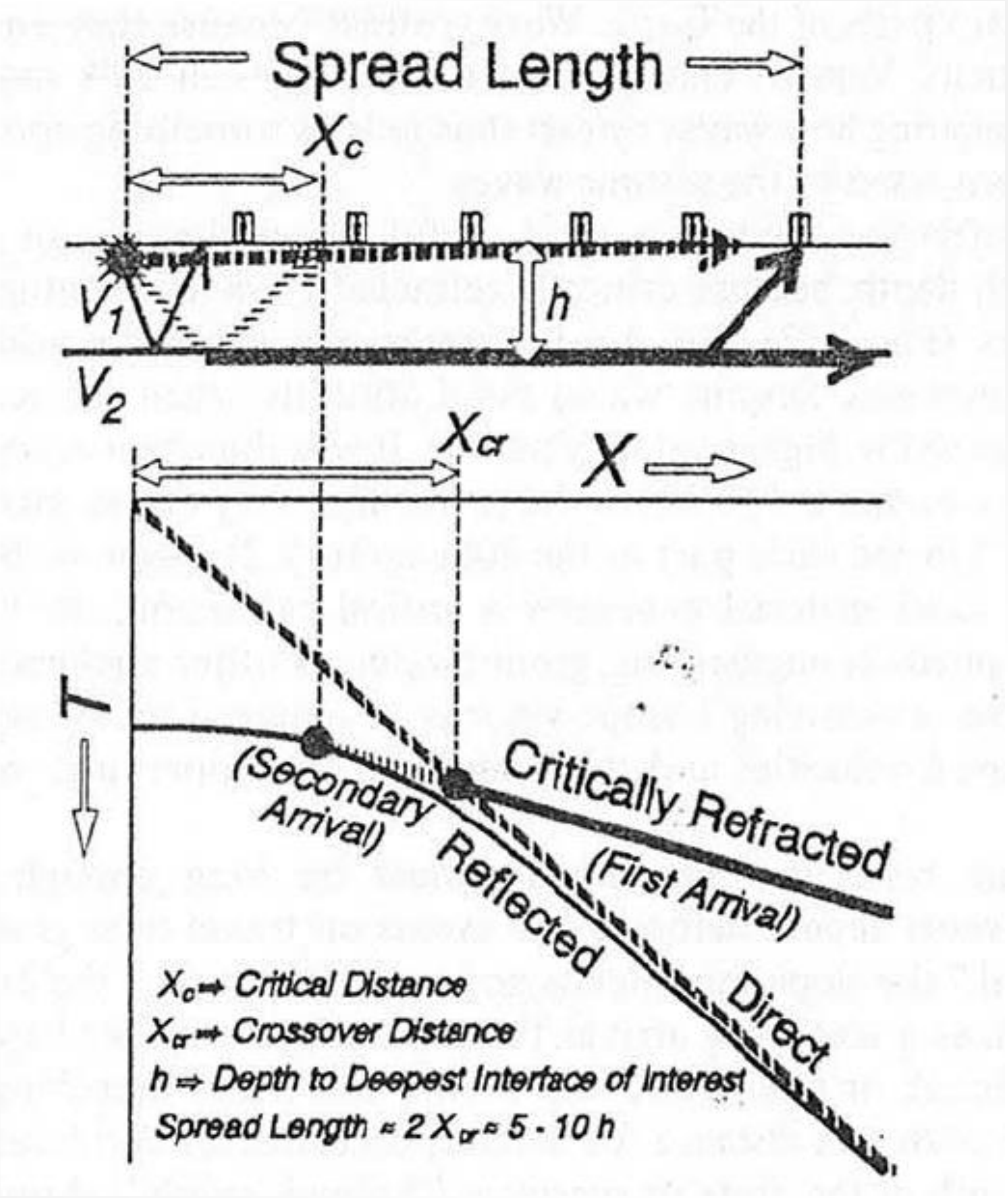


Depth to bedrock study

REFRACTION ANATOMY

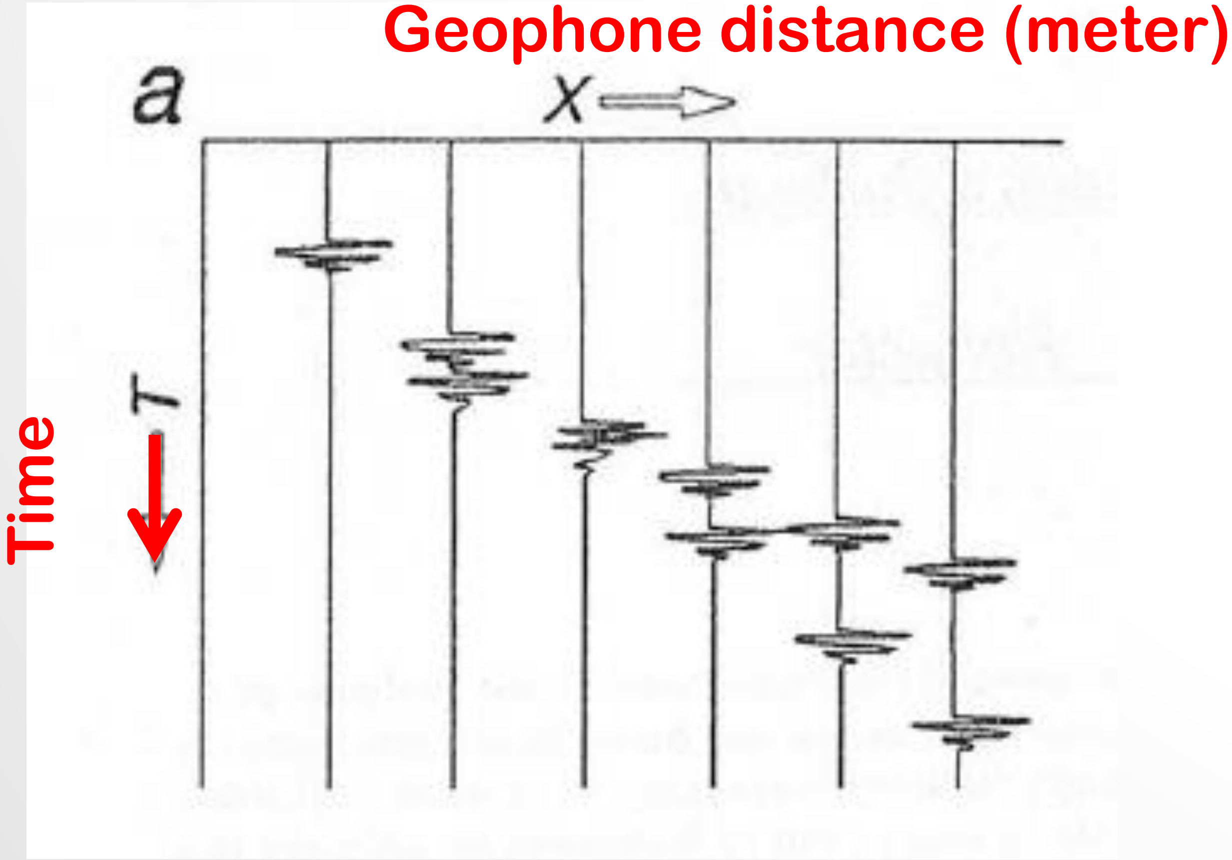
To see critical refraction clearly as a first arrival, the spread length should be at **about twice** the cross-over distance

Spread length ≈ 5 x 10 x (target depth)/2



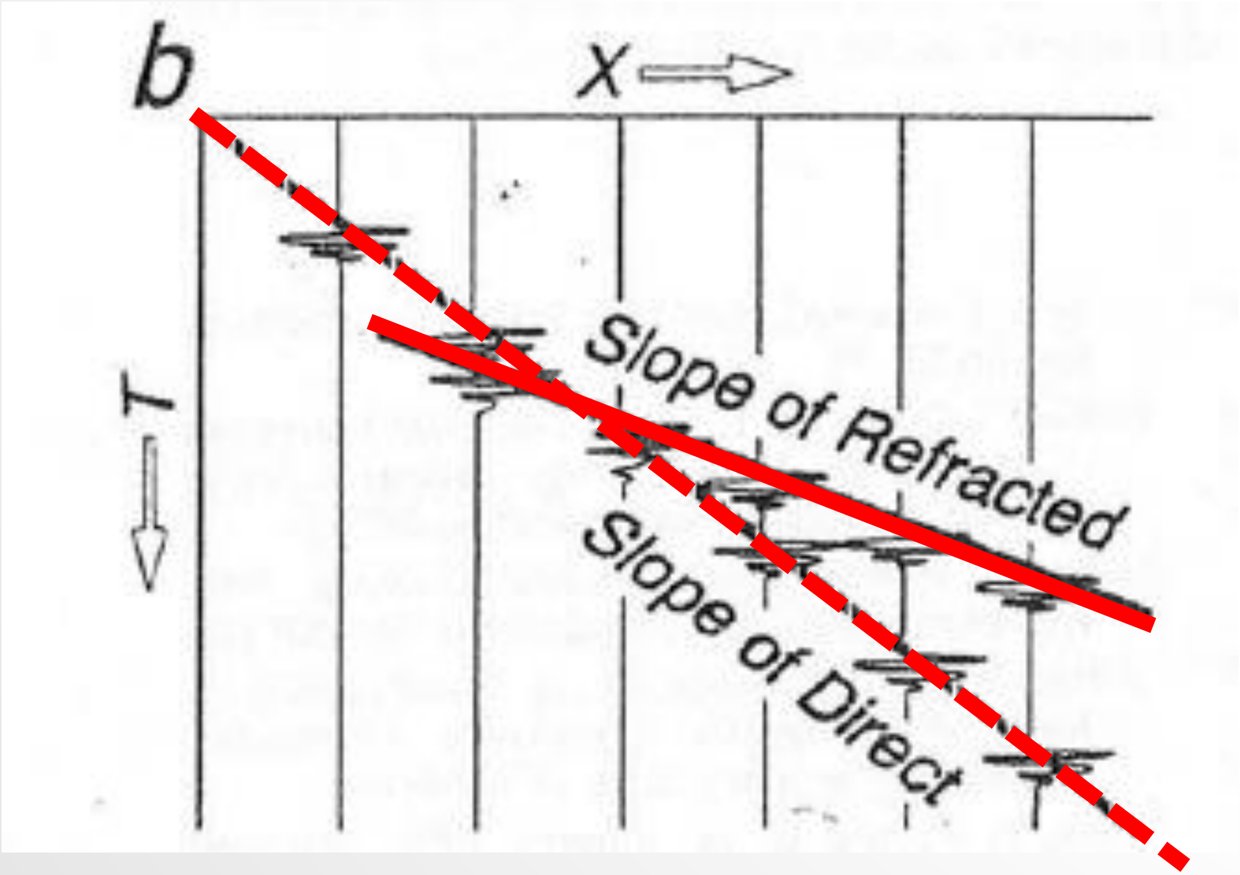
INTERPRETATION MODEL
(SINGLE HORIZONTAL INTERFACE)

- From field measurement we will obtain a seismic record of ground motions



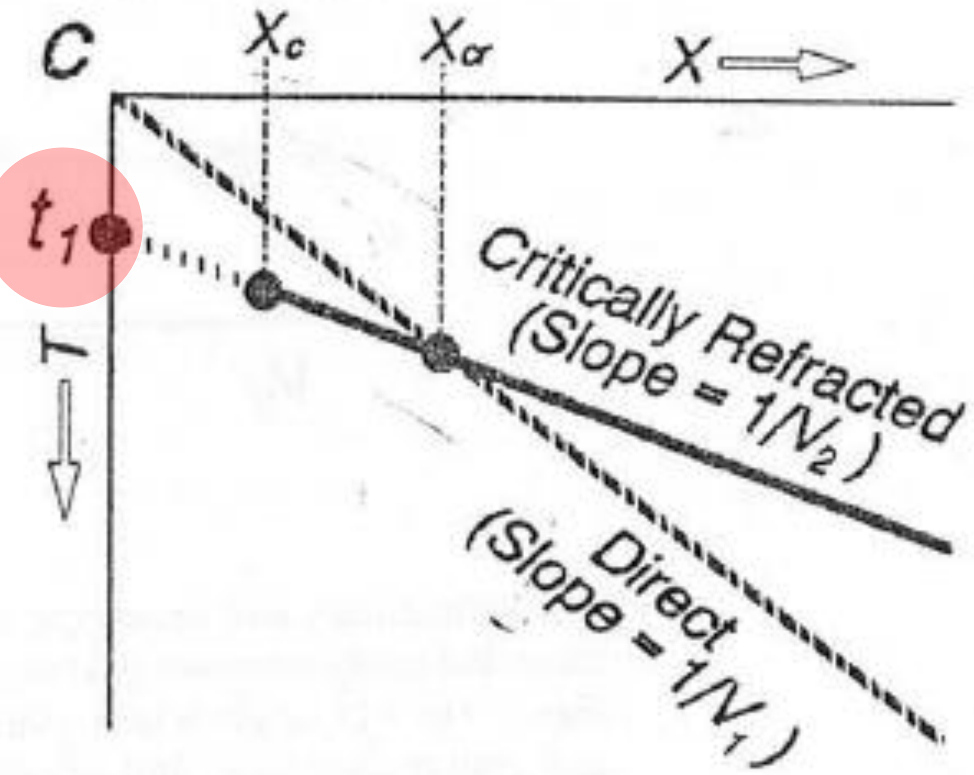
INTERPRETATION MODEL

- Pick the first arrival seismic waveform



INTERPRETATION MODEL

- Calculate the slope of each lines to find velocity of the first and second layer



$$\text{Slope of Direct} = \frac{1}{V_1} \Rightarrow V_1 = \frac{1}{\text{slope of direct}}$$

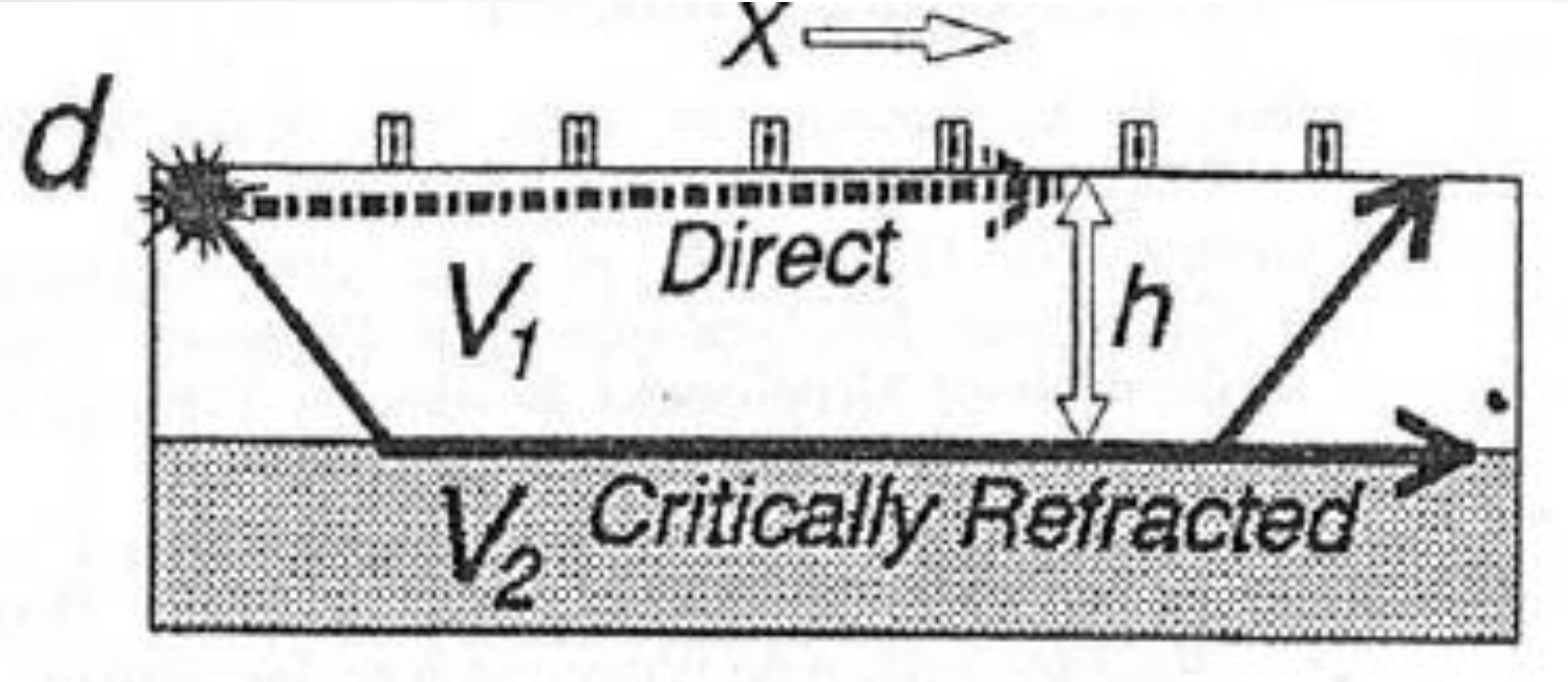
$$\text{Slope of Refracted} = \frac{1}{V_2} \Rightarrow V_2 = \frac{1}{\text{slope of refracted}}$$

$$\theta_c = \sin^{-1}\left(\frac{V_1}{V_2}\right)$$

$$t_1 = \frac{2h\cos\theta_c}{V_1} \Rightarrow h = \frac{t_1 V_1}{2\cos\theta_c}$$

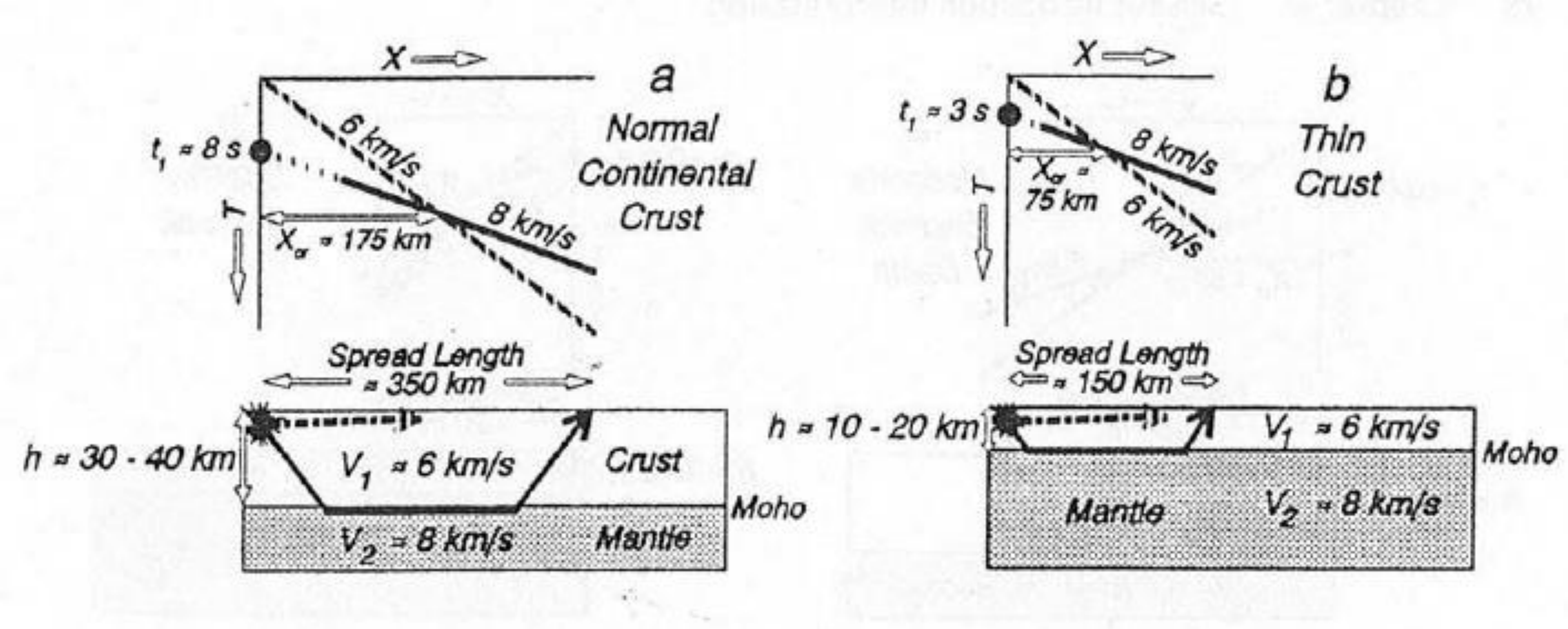
t_1 has a direct relation to depth of the interface

INTERPRETATION MODEL



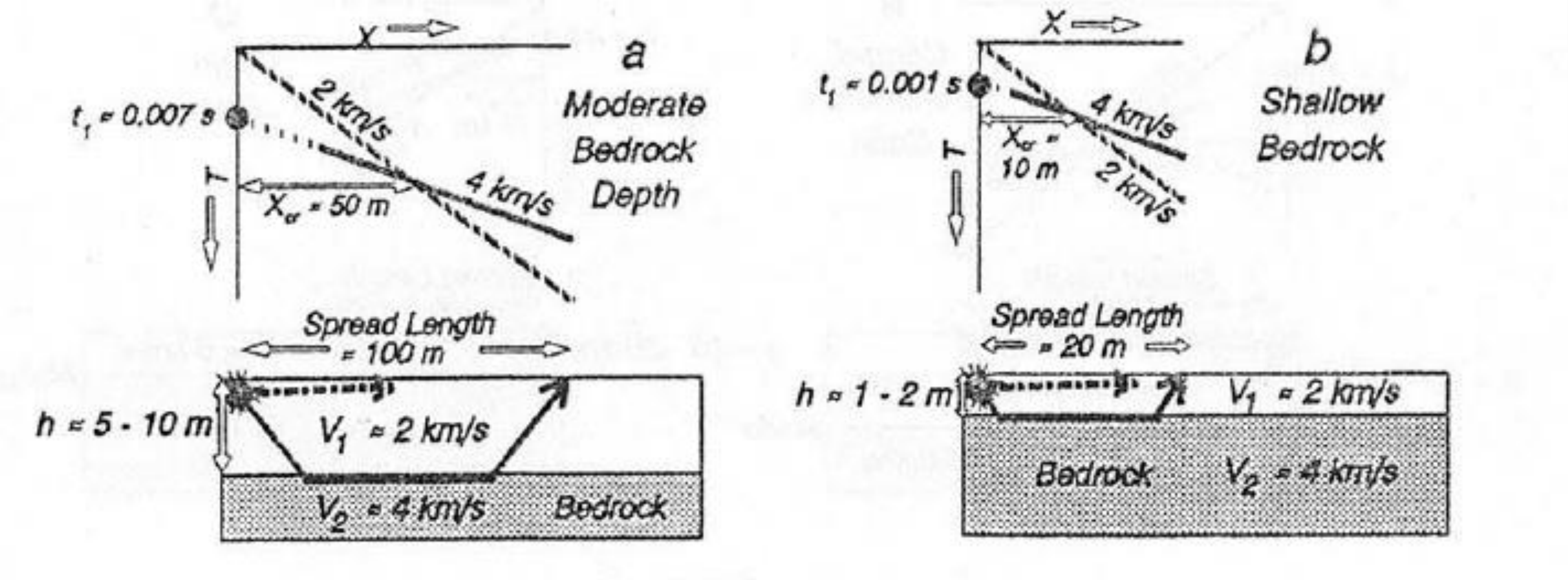
APPLICATIONS – REGIONAL SCALE

- **Crustal thickness** can be related to the delay time (T-axis intercept, t_1)

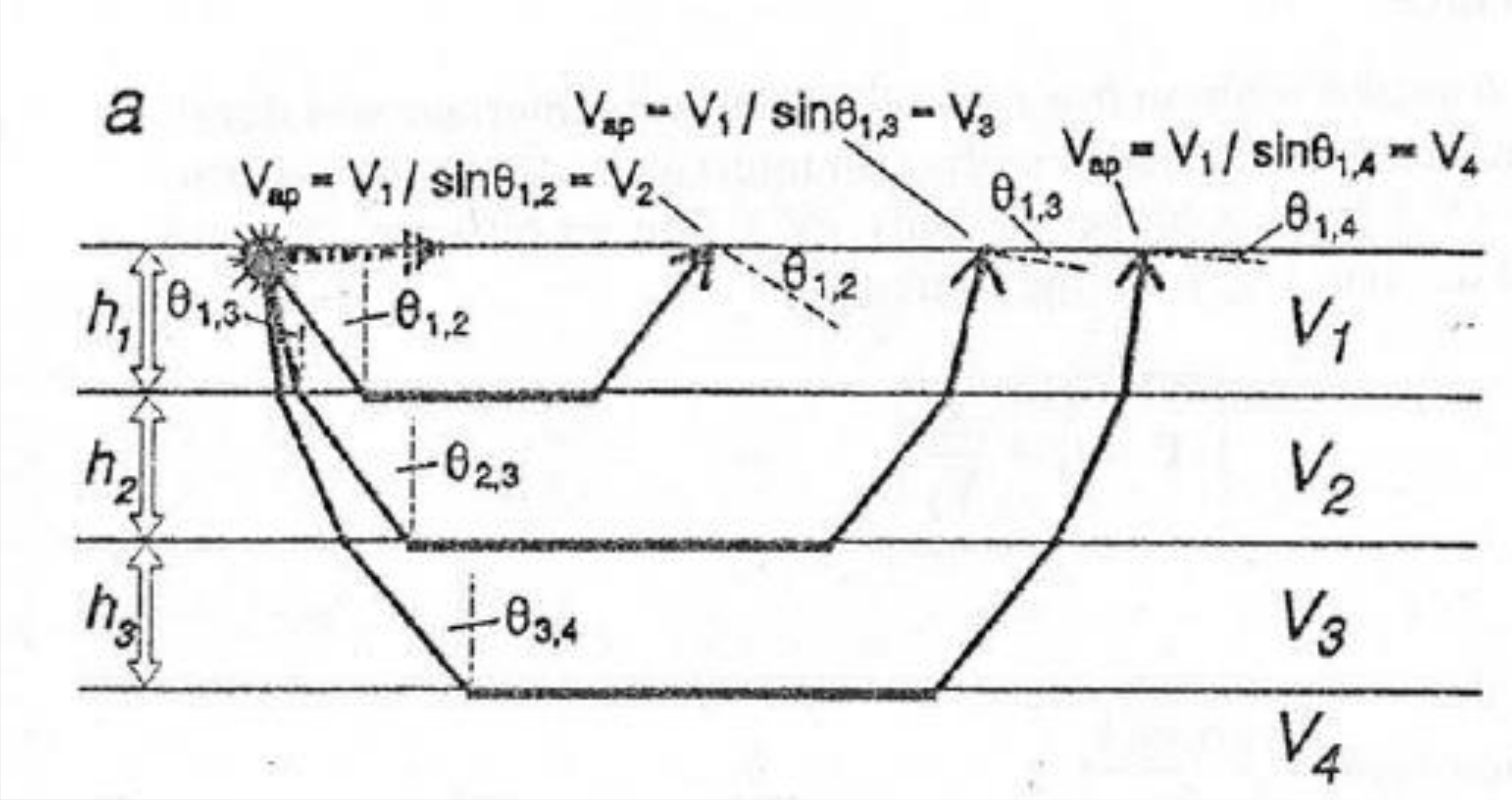


APPLICATIONS – LOCAL SCALE

- **Depth to bedrock**



SEVERAL HORIZONTAL INTERFACES



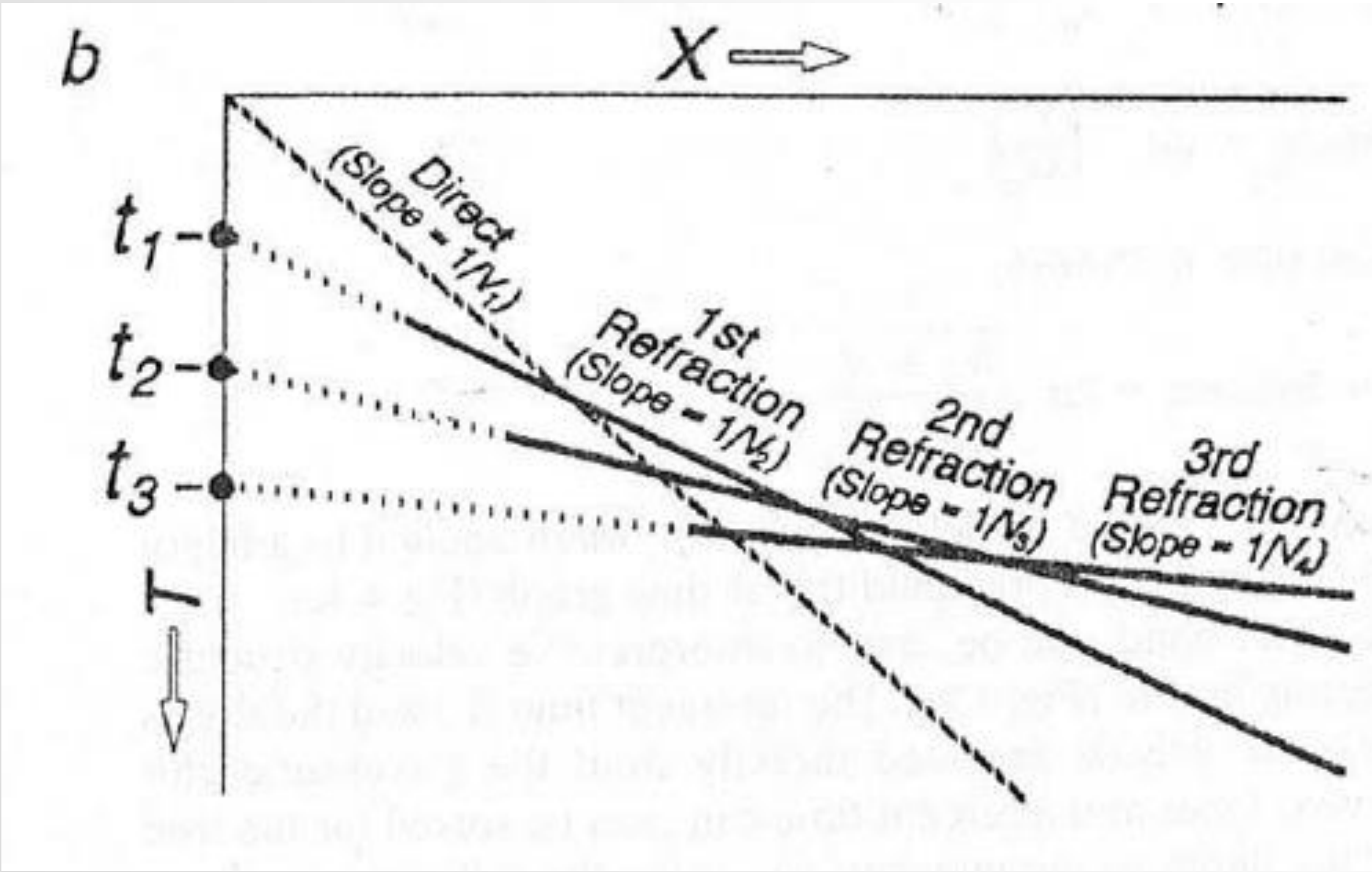
$$V_{ap2} = \frac{V_1}{sin\,\theta_{1,2}} = V_2$$

$$V_{ap3} = \frac{V_1}{sin\,\theta_{1,3}} = V_3$$

$$V_{ap4} = \frac{V_1}{sin\,\theta_{1,4}} = V_4$$

$V_4 > V_3 > V_2 > V_1$

SEVERAL HORIZONTAL INTERFACES



first critical refraction:

$$\sin\theta_{1,2} = V_1/V_2$$

second critical refraction:

$$\sin\theta_{1,3} = V_1/V_3$$

$$\sin\theta_{2,3} = V_2/V_3$$

third critical refraction:

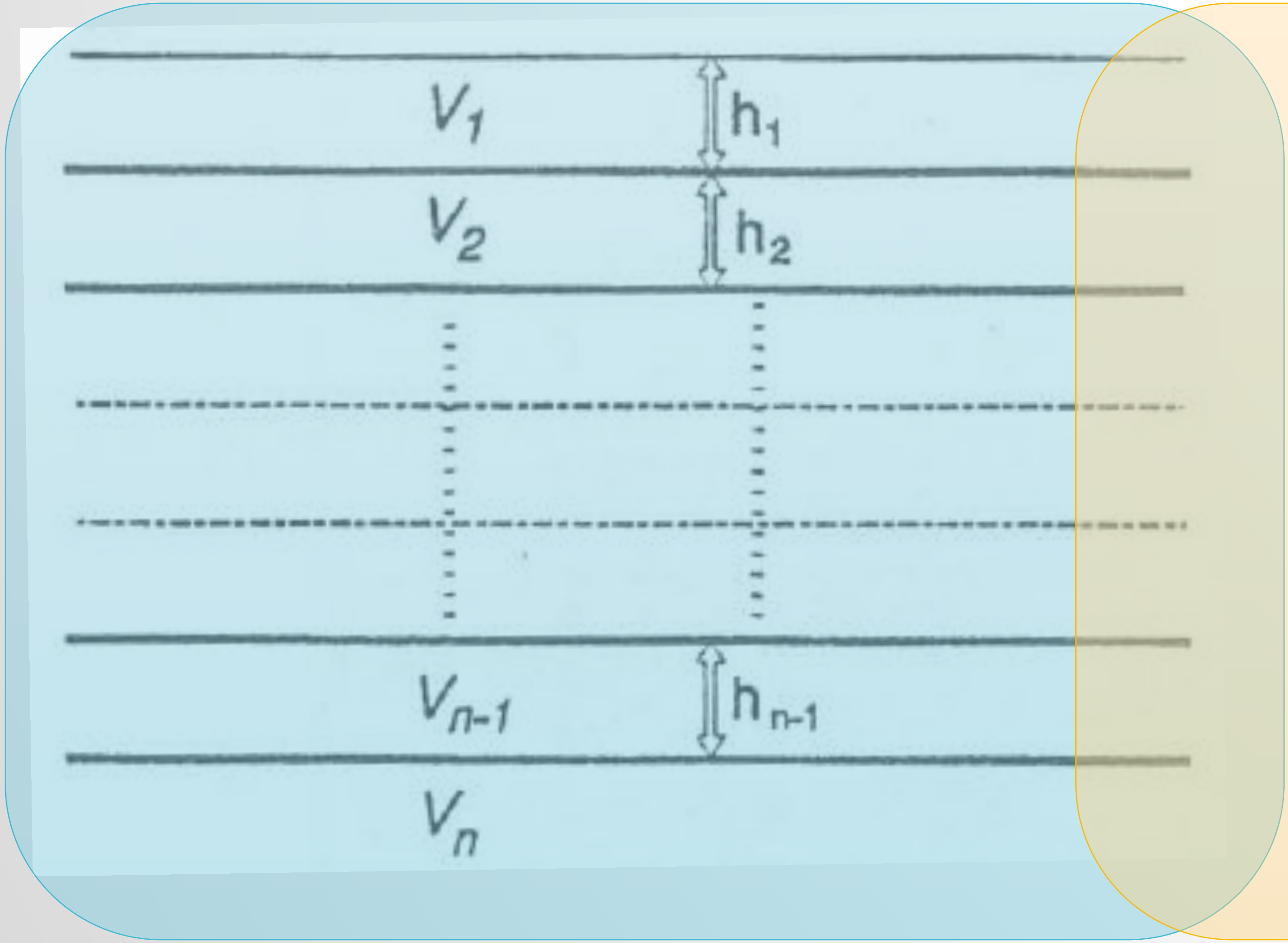
$$\sin\theta_{1,4} = V_1/V_4$$

$$\sin\theta_{2,4} = V_2/V_4$$

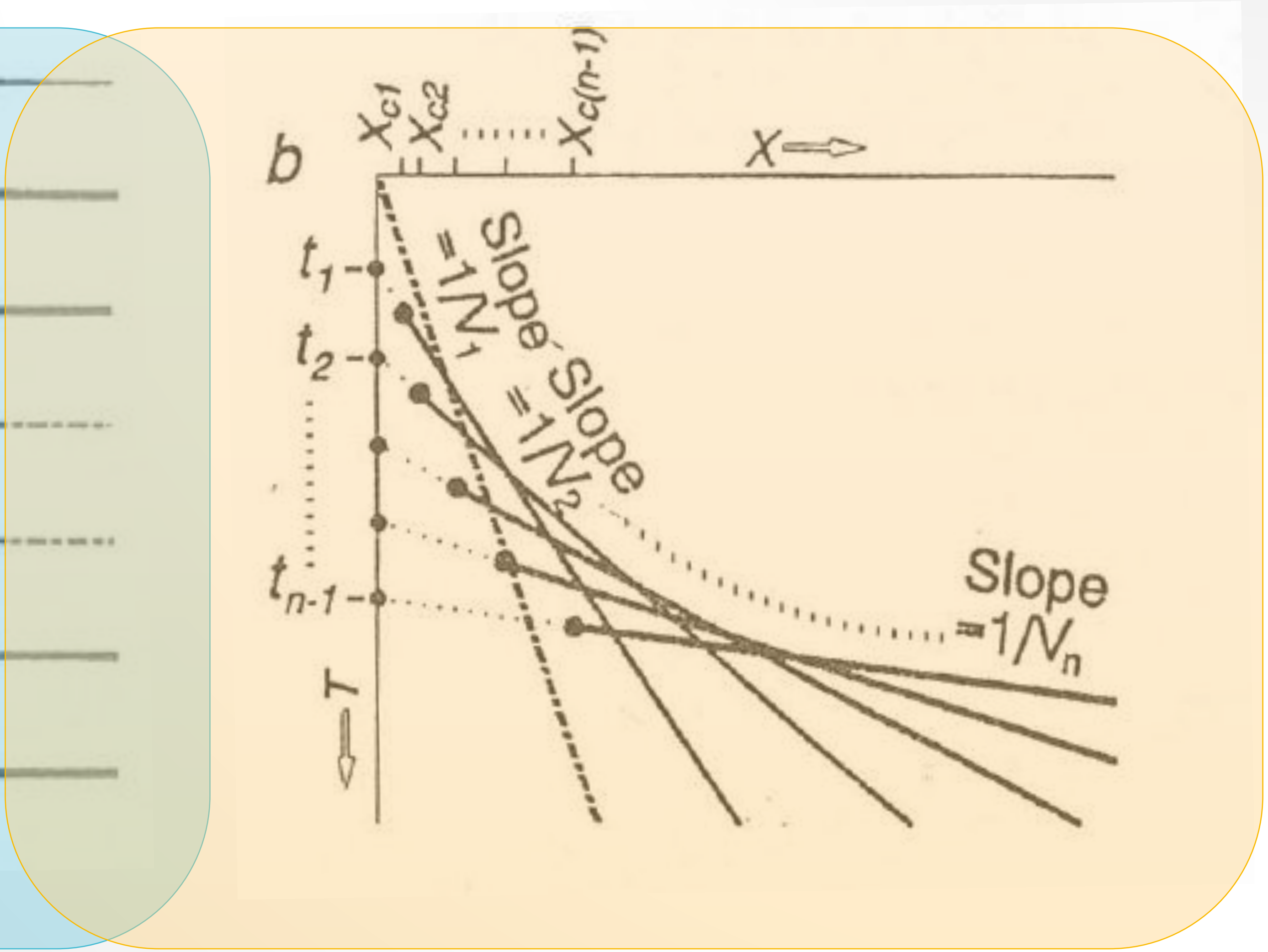
$$\sin\theta_{3,4} = V_3/V_4$$

$$V_4 > V_3 > V_2 > V_1$$

N-LAYERS

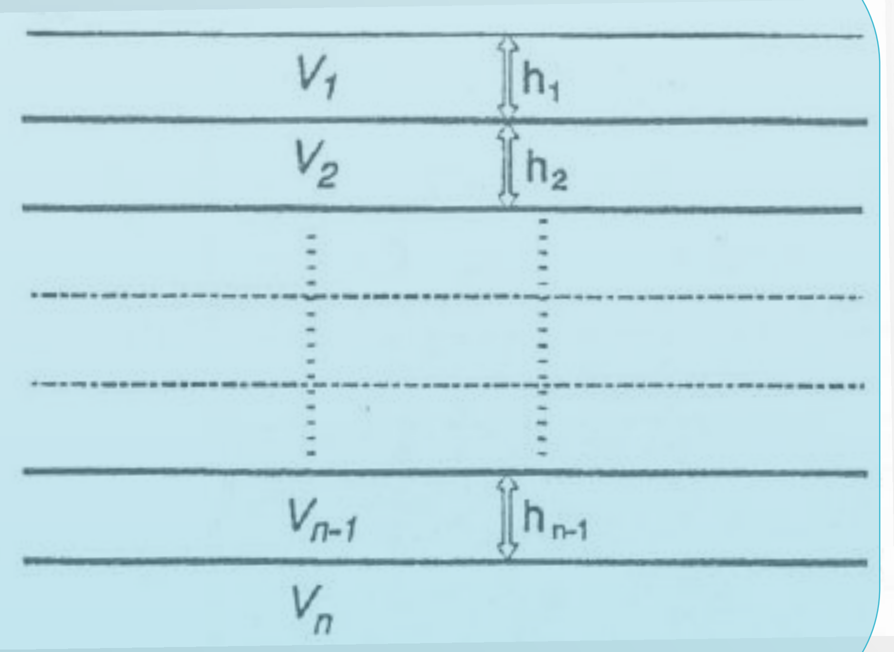


V_1
h_1
V_2
h_2
V_{n-1}
h_{n-1}
V_n



b
X_{c1}
X_{c2}
$X_{c(n-1)}$
X
t_1
t_2
t_{n-1}
T
Slope $=1/V_1$
Slope $=1/V_2$
Slope $=1/V_n$

N-LAYERS



$$\boxed{T_n = t_{n-1} + \frac{X}{V_n}}$$

where:

T_n = travel time down from the source, horizontally along the top of layer n, and back up to a receiver at X

t_{n-1} = T-axis intercept for the refraction from layer n:

$$t_{n-1} = \sum_{i=1}^{n} \frac{2h_i \cos\theta_{i,n}}{V_i}$$

X = horizontal distance from the source to the receiver

V_n = velocity of layer n.

EXAMPLE: 4-LAYERS

$$\boxed{T_n = t_{n-1} + \frac{X}{V_n}}$$

$$t_{n-1} = \sum_{i=1}^{n} \frac{2h_i \cos\theta_{i,n}}{V_i}$$

n = 1 ⇒ Direct Arrival

travel time: $T_1 = \frac{X}{V_1}$

T-Axis intercept: 0

critical distance: 0

n = 2 ⇒ 1st Refraction

travel time: $T_2 = t_1 + \frac{X}{V_2}$

T-Axis intercept: $t_1 = \frac{2h_1 \cos\theta_{1,2}}{V_1}$

critical distance: $X_{c1} = 2h_1 \tan\theta_{1,2}$

n = 3 ⇒ 2nd Refraction

travel time: $T_3 = t_2 + \frac{X}{V_3}$

T-Axis intercept: $t_2 = \frac{2h_1 \cos\theta_{1,3}}{V_1} + \frac{2h_2}{}$

critical distance: $X_{c2} = 2h_1 \tan\theta_{1,3} + 2h$

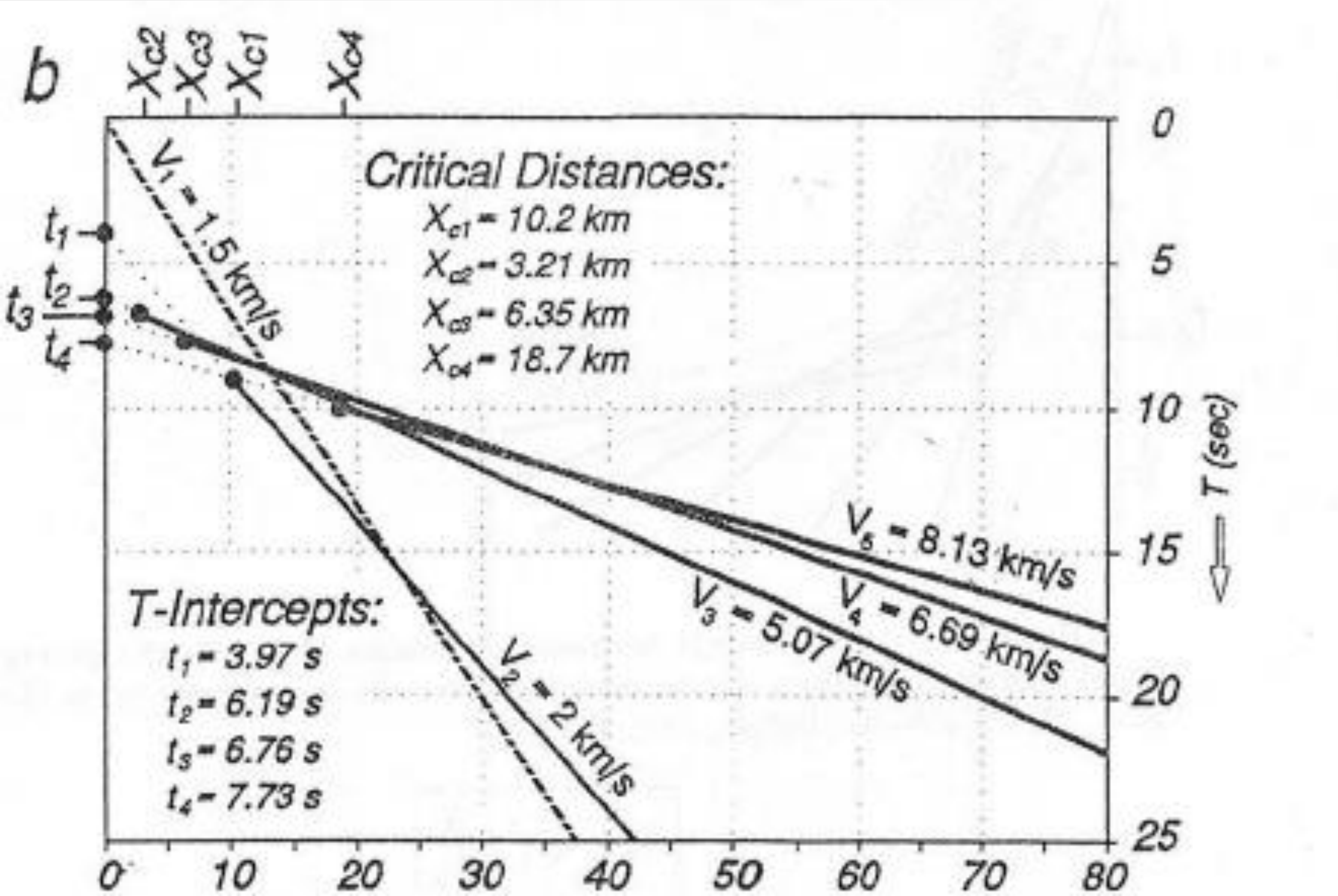
n = 4 ⇒ 3rd Refraction

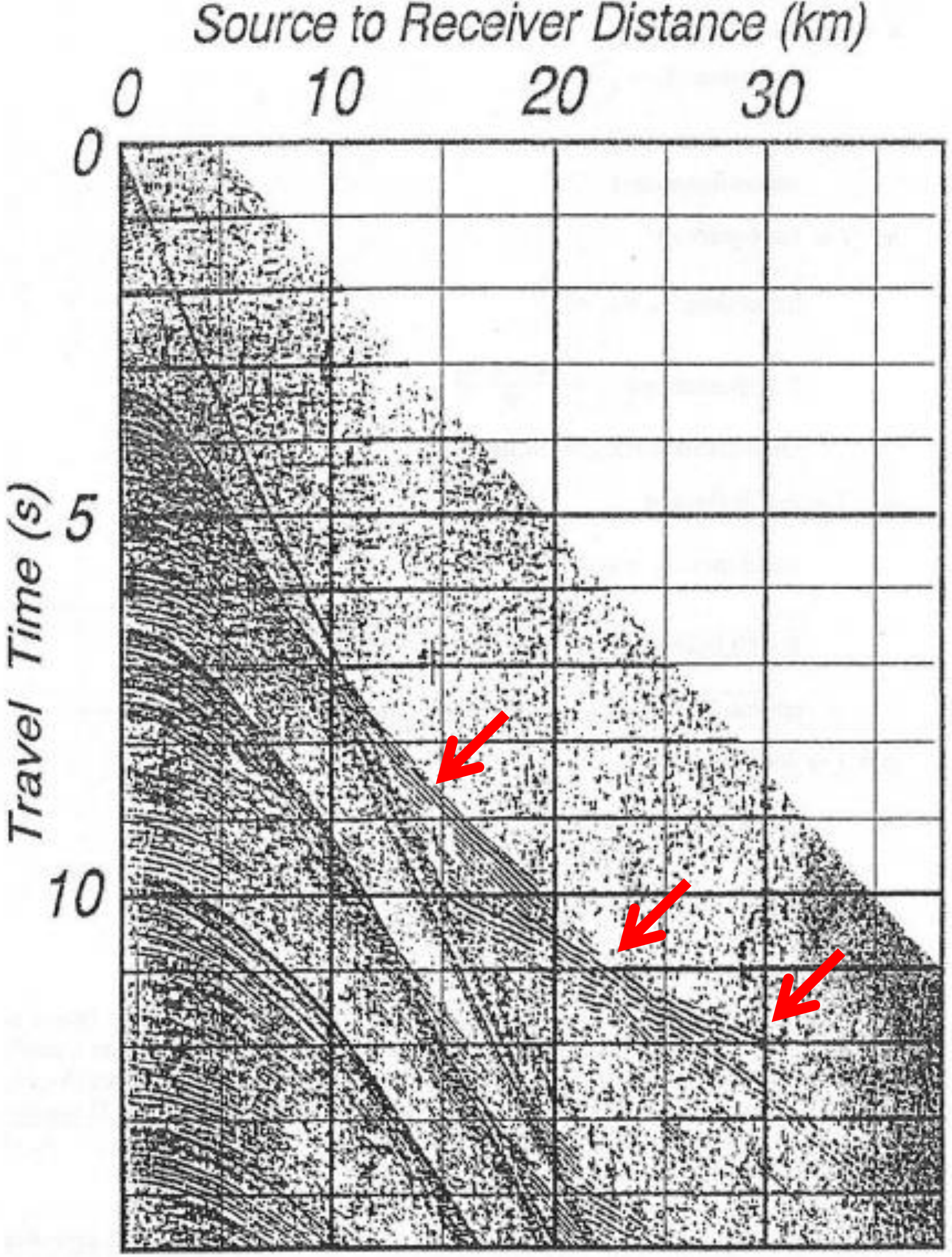
travel time: $T_4 = t_3 + \frac{X}{V_4}$

T-Axis intercept: $t_3 = \frac{2h_1 \cos\theta_{1,4}}{V_1} + \frac{2h_2 \cos\theta_{2,4}}{V_2} + \frac{2h_3 \cos\theta_{3,4}}{V_3}$

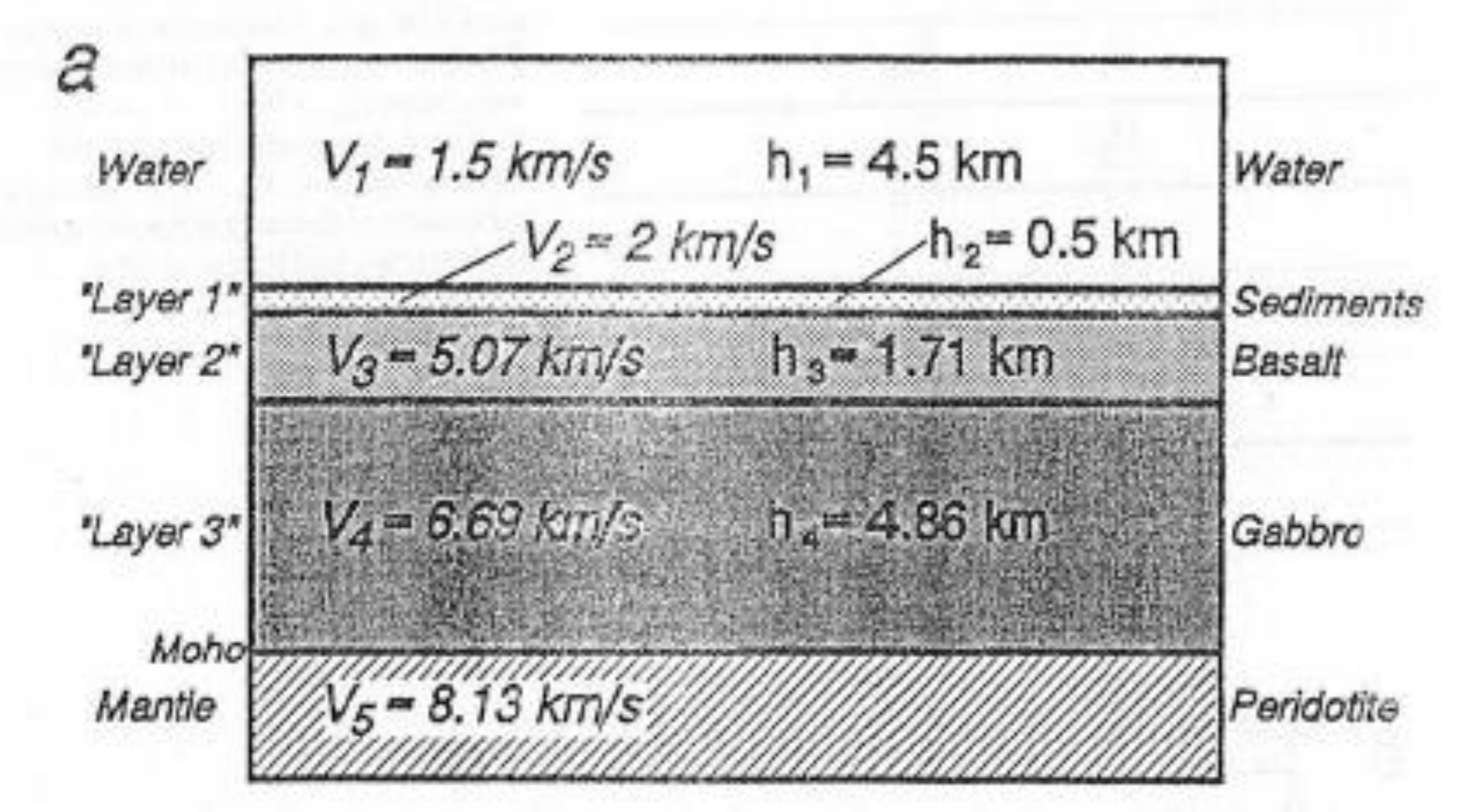
critical distance: $X_{c3} = 2h_1 \tan\theta_{1,4} + 2h_2 \tan\theta_{2,4} + 2h_3 \tan\theta_{3,4}$

EXAMPLE: REFRACTION SURVEY FOR OCEANIC CRUST





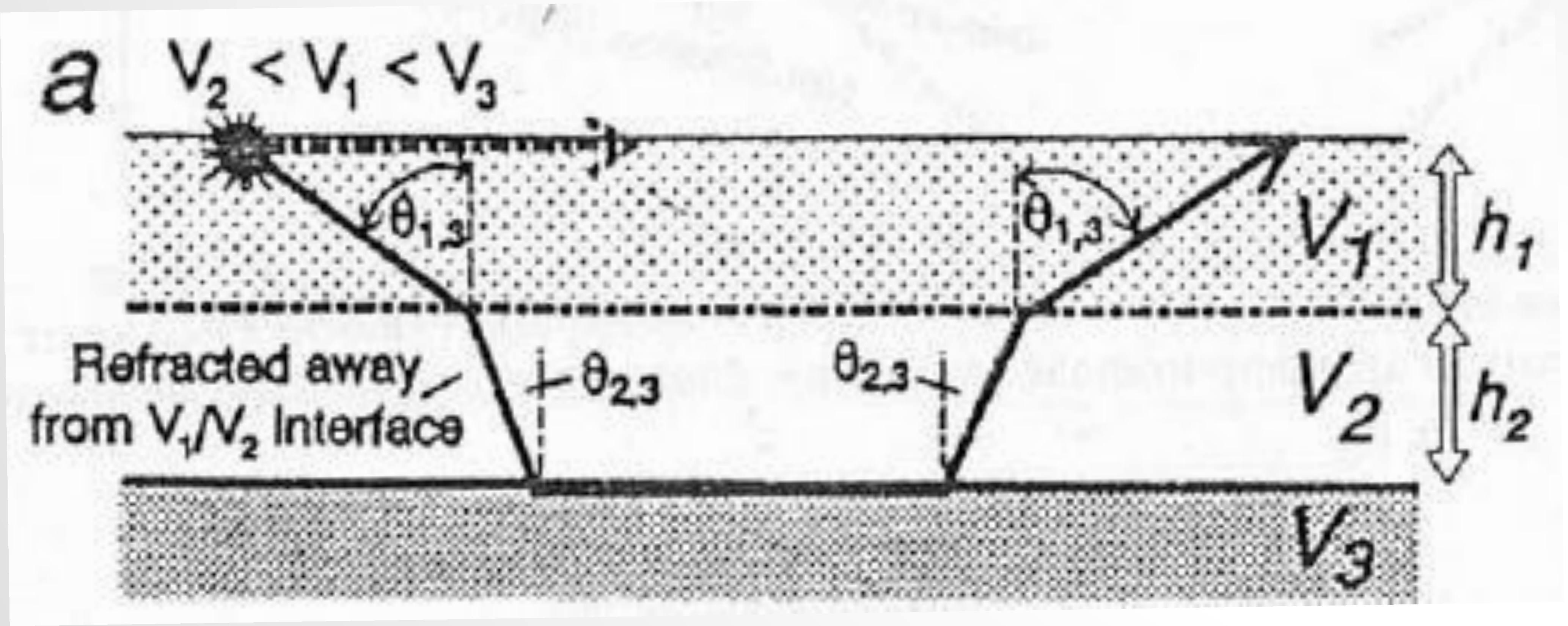
EXAMPLE: REFRACTION SURVEY FOR OCEANIC CRUST



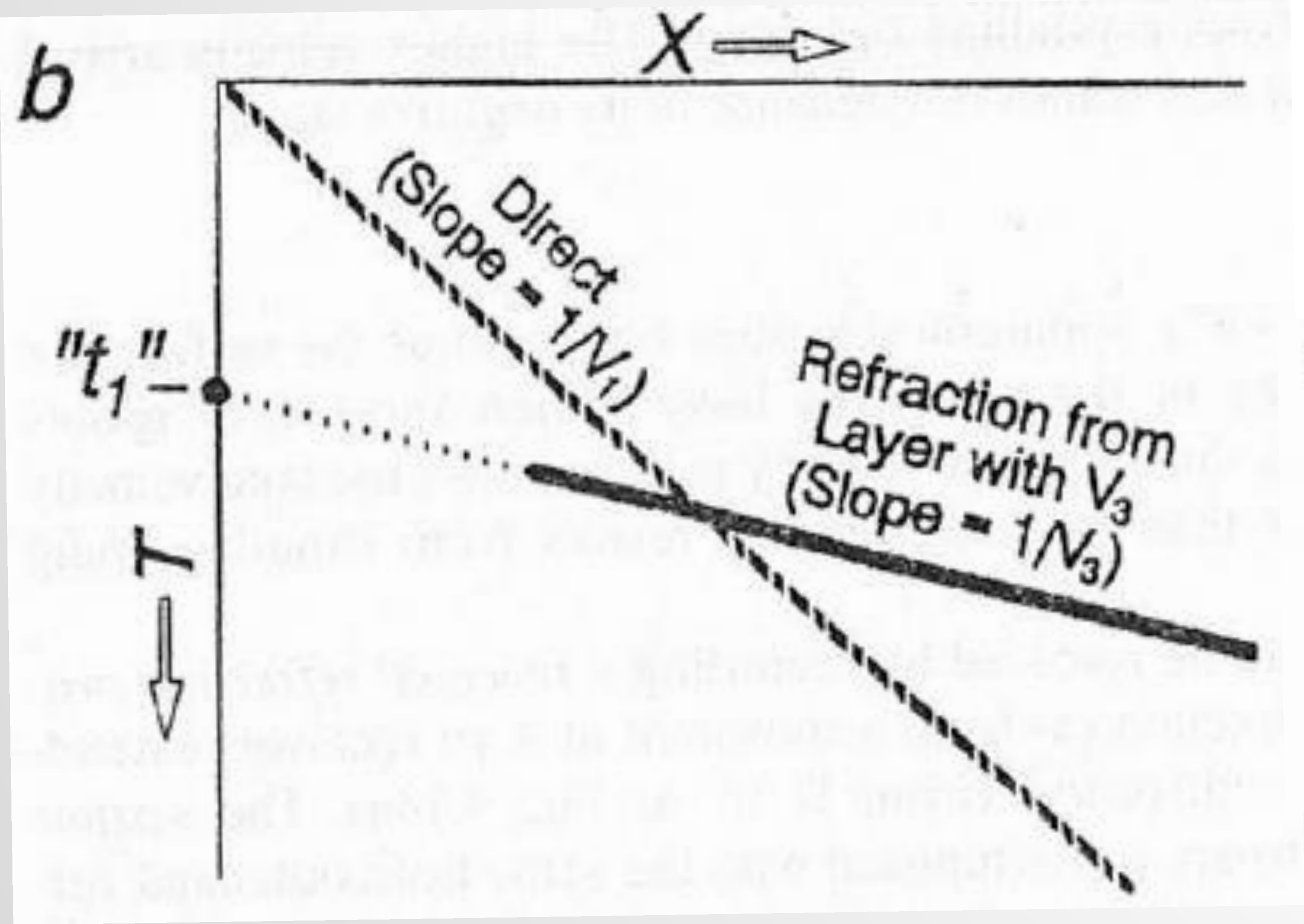
PROBLEM FOR REFRACTION SEISMIC

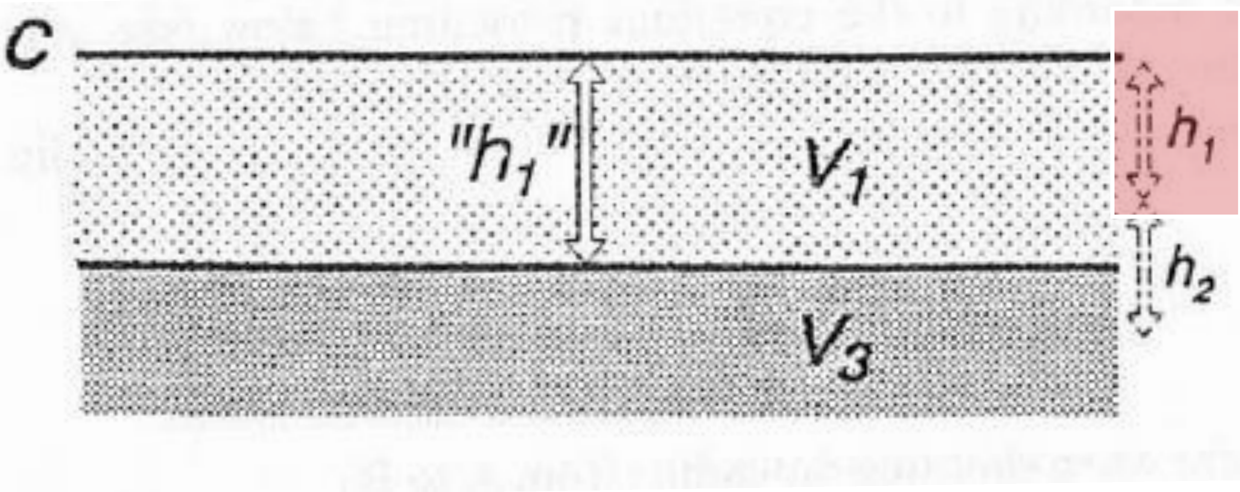
1. Low velocity layer ($V_2 < V_1 < V_3$) there will be no critical refraction from the layer with velocity V_2. From the travel time graph, V_3 lies directly below layer V_1. The equation will yield no V_2 and the layer V_1 will be too tick.
2. Thin layer ($V_3 > V_2 > V_1$, but h_2 very small), the refraction from this thin layer never observed as first arrival.
3. Dipping interface

(1) LOW VELOCITY LAYER

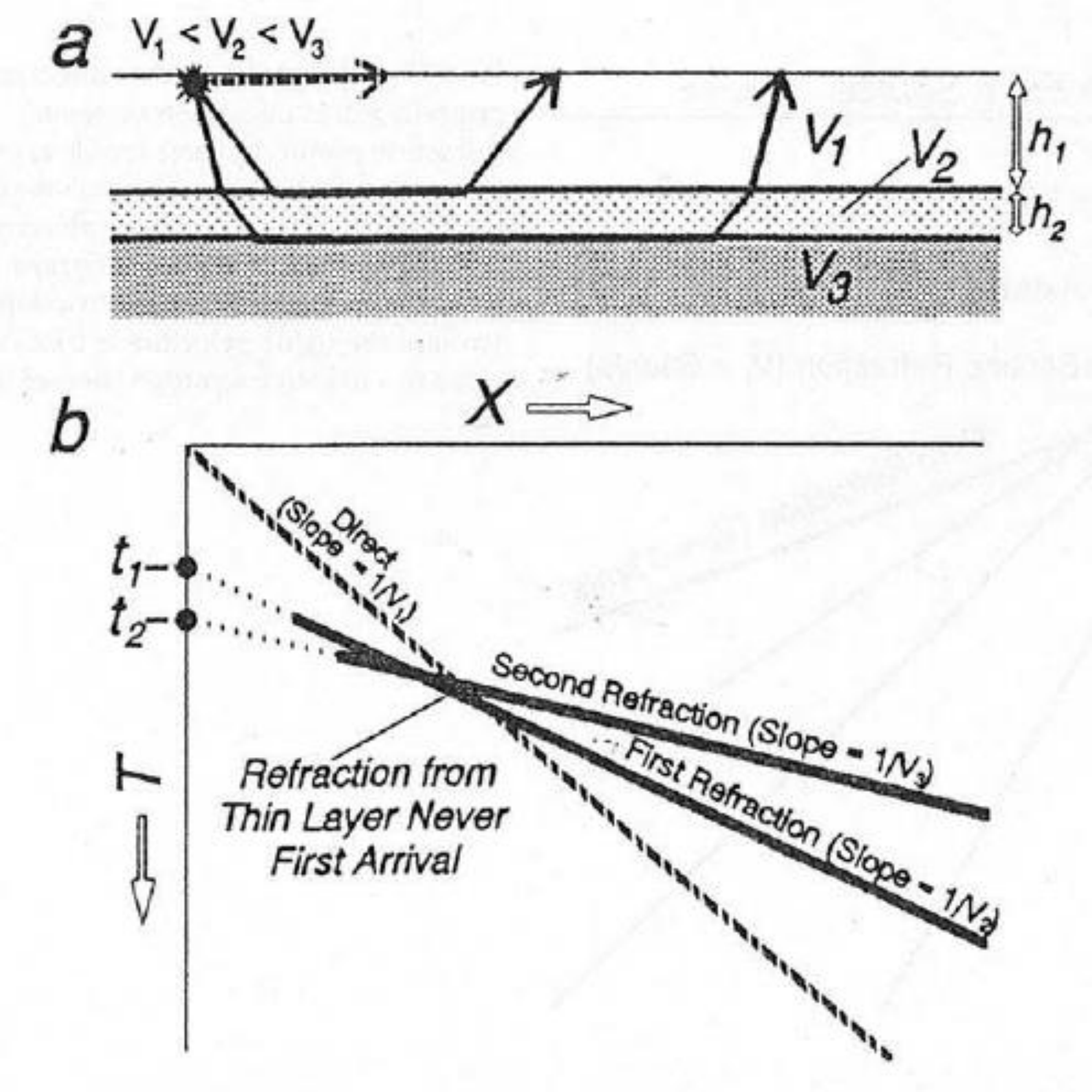


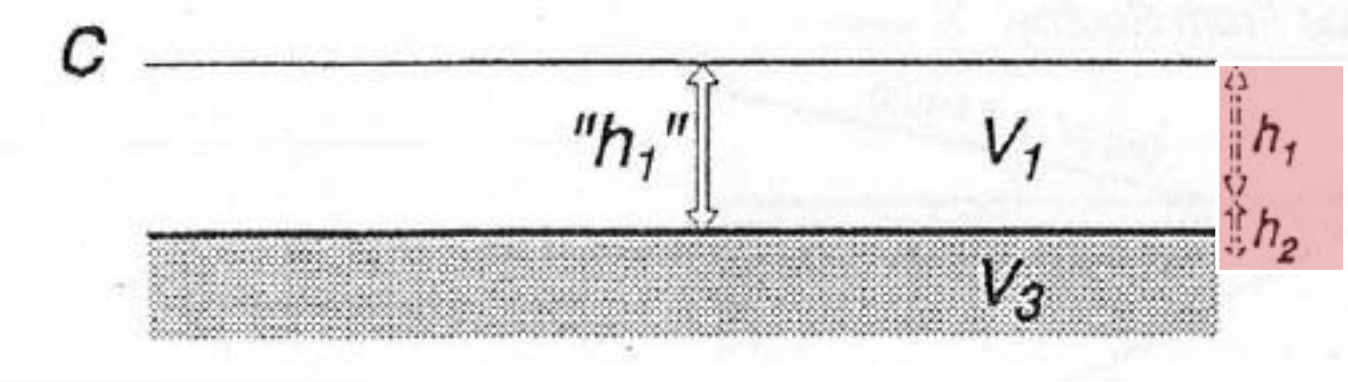
(1) LOW VELOCITY LAYER





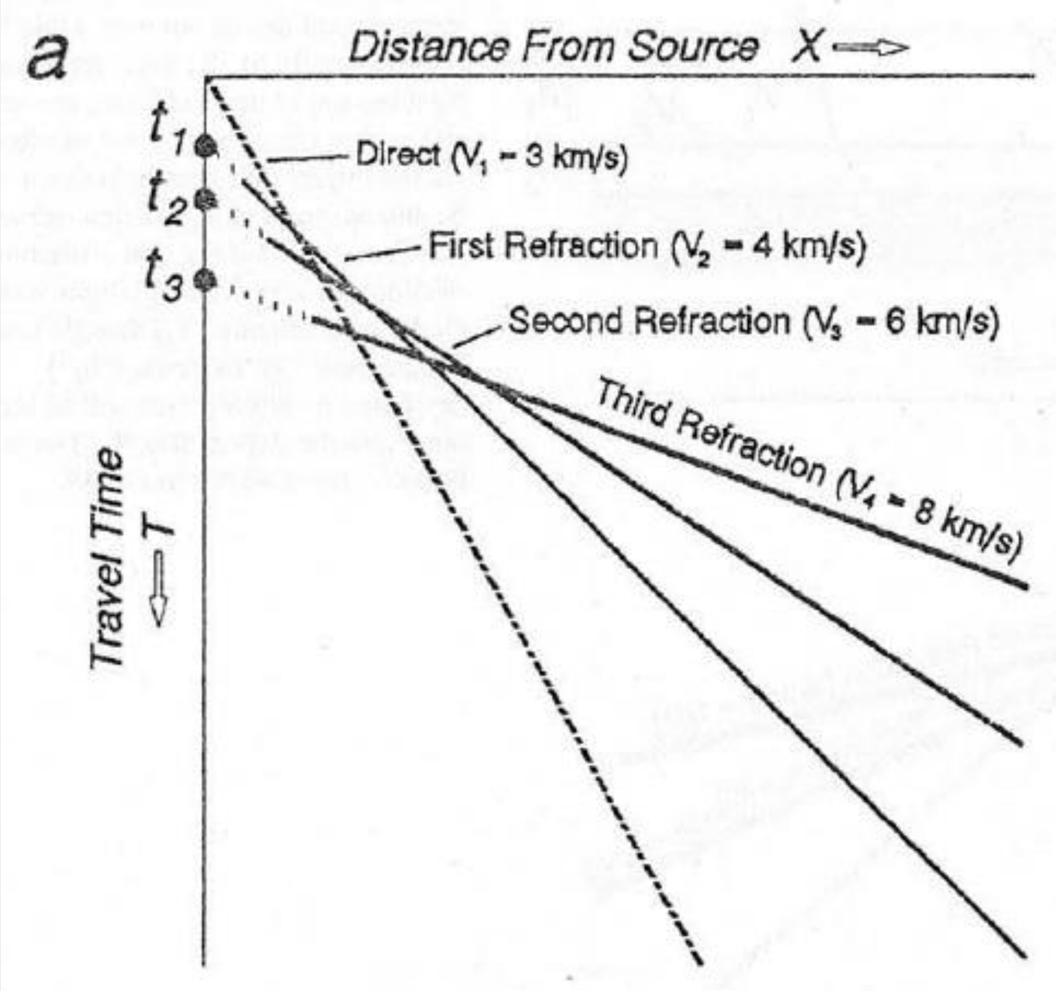
(2) THIN LAYER

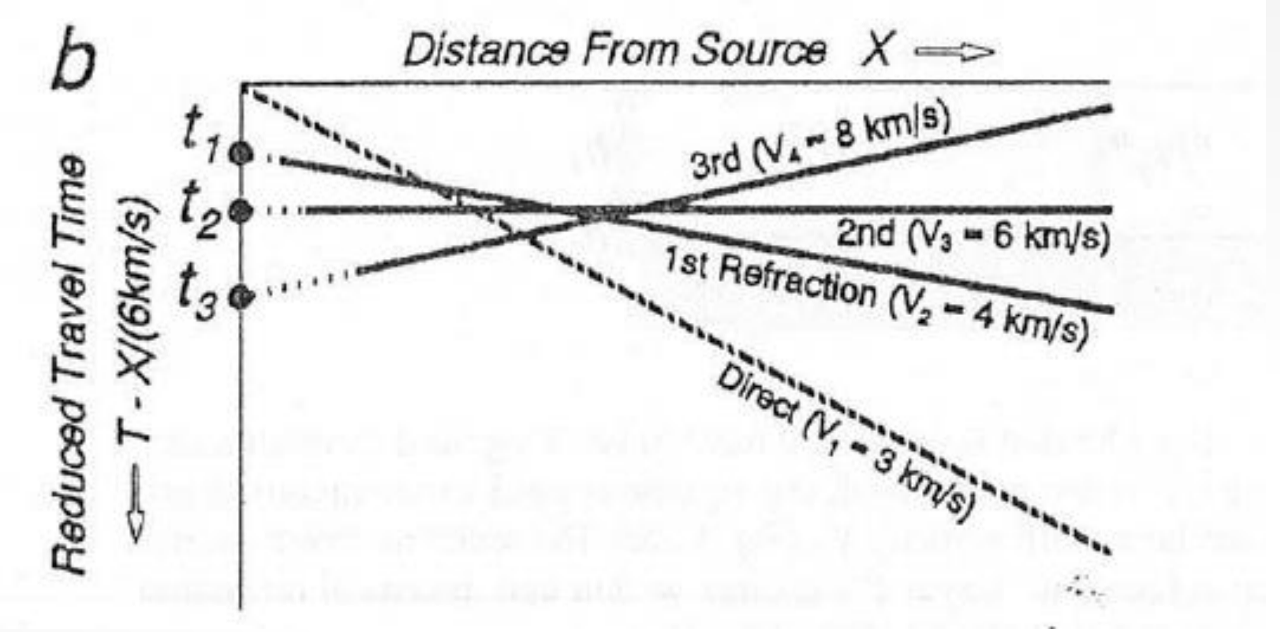

a
V1 < V2 < V3
V1
V2
V3
h1
h2
b
X
T
t1
t2
Direct (Slope = 1/V1)
Second Refraction (Slope = 1/V3)
First Refraction (Slope = 1/V2)
Refraction from Thin Layer Never First Arrival


c
"h1"
V1
V3
h1
h2

REDUCED TRAVEL-TIME PLOT

$$T_{red} = T - \frac{X}{V_{red}}$$



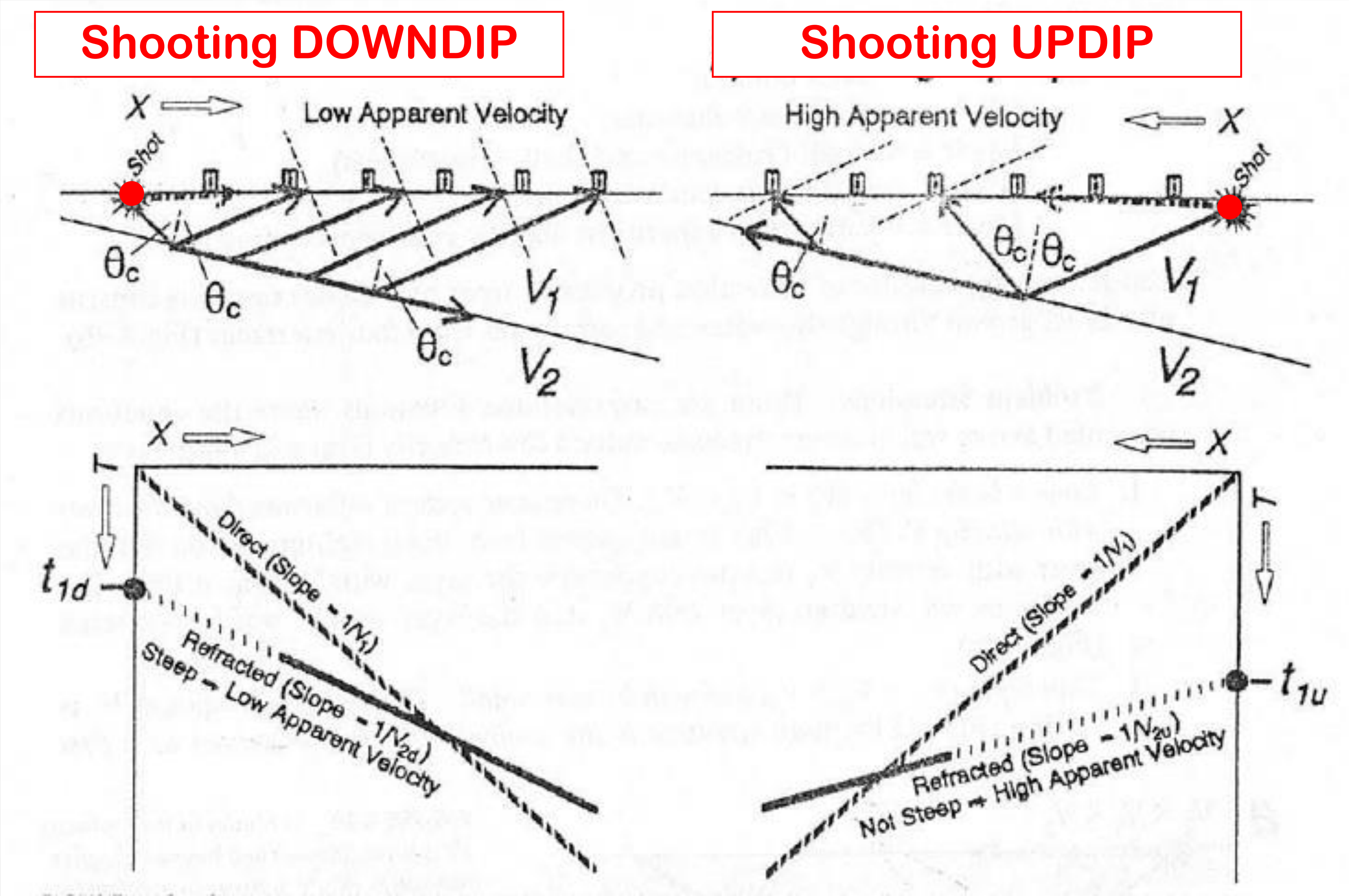


$$T_{red} = T - \frac{X}{6\ km/s}$$

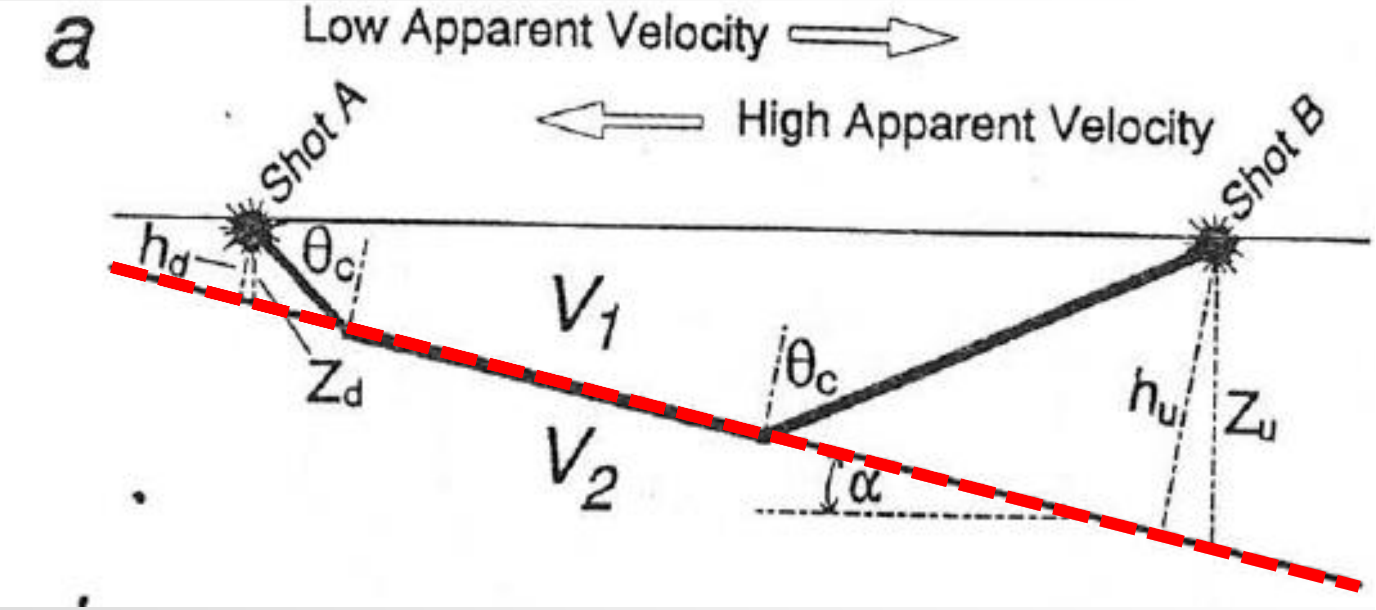
(3) DIPPING INTERFACE

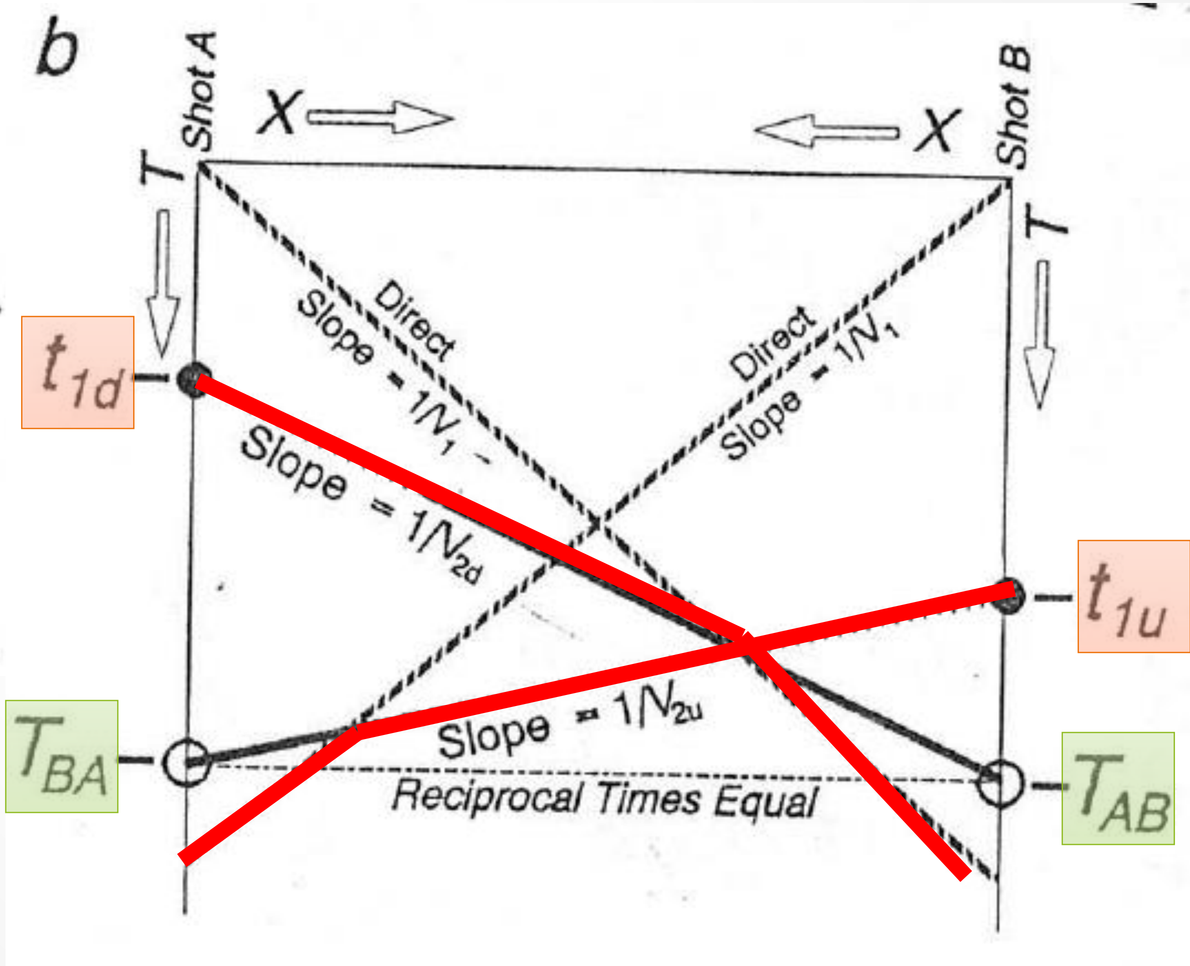
- For a dipping interface apparent velocities observed at the surface are not equal to the true velocity of the refracting layer.
- When the source shoots down-dip toward the receiver, the apparent velocity is lower than the true velocity
- When the source shoots up-dip toward the receiver, the apparent velocity is higher than the true velocity
- The dipping interface can be resolved by recording a reversed refraction profile

DIPPING INTERFACE



REVERSED REFRACTION





1. Intercept time are not equal
2. Reciprocal times must be equal

REVERSED REFRACTION

The apparent velocities for downdip and updip shooting

$$V_{2d} = \frac{V_1}{\sin(\theta_c + \alpha)}$$

$$V_{2u} = \frac{V_1}{\sin(\theta_c - \alpha)}$$

$$\alpha = \frac{\sin^{-1}(V_1/V_{2d}) - \sin^{-1}(V_1/V_{2u})}{2}$$

$$\theta_c = \frac{\sin^{-1}(V_1/V_{2d}) + \sin^{-1}(V_1/V_{2u})}{2}$$

$$V_1 = \frac{1}{\text{slope of direct arrival}}$$

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

V_{2d} = apparent velocity shooting downdip
V_{2u} = apparent velocity shooting updip
V_1 = velocity of the overlying layer
θ_c = critical angle
α = dip of the interface.

REVERSED REFRACTION

- Travel time to receiver at horizontal distance (X), shooting downdip (T_d) and updip (T_u) are:

$$T_d = t_{1d} + \frac{X}{V_{2d}} \qquad \text{where} \qquad t_{1d} = \frac{2h_d \cos\theta_c}{V_1}$$

$$T_u = t_{1u} + \frac{X}{V_{2u}} \qquad\qquad t_{1u} = \frac{2h_u \cos\theta_c}{V_1}$$

h_d = *perpendicular* distance to interface when shooting downdip:

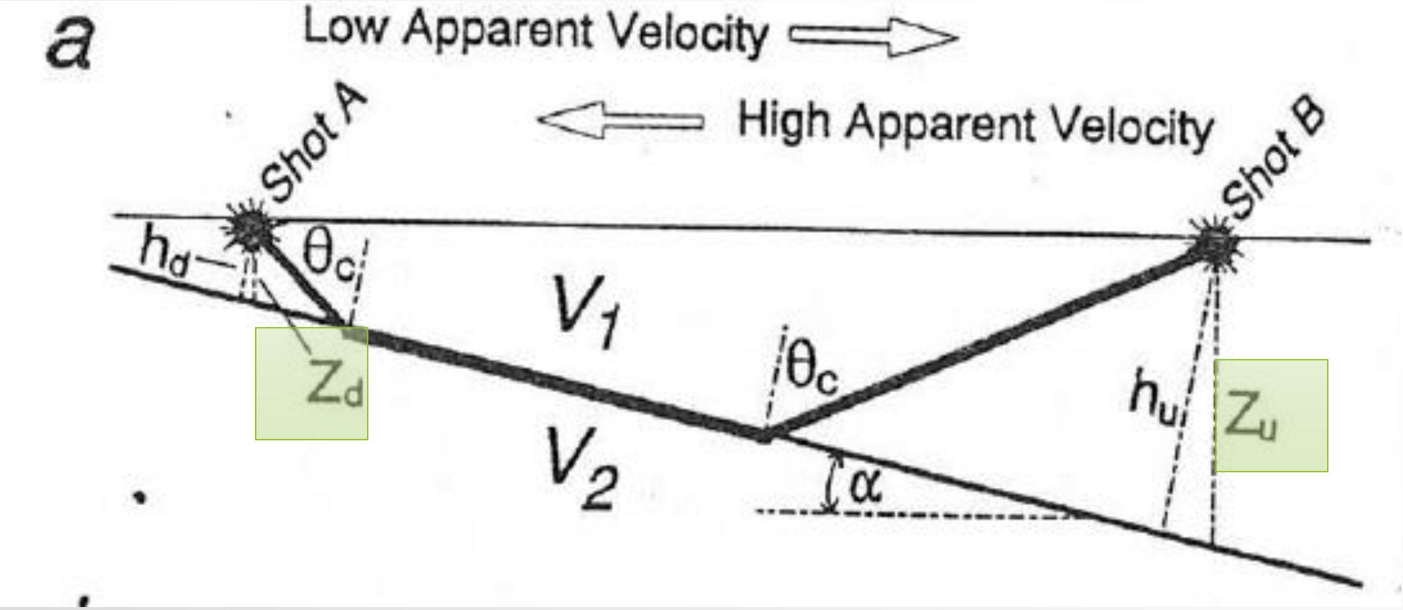
$$h_d = \frac{V_1 t_{1d}}{2\cos\theta_c}$$

h_u = *perpendicular* distance to interface when shooting updip:

$$h_u = \frac{V_1 t_{1u}}{2\cos\theta_c}$$

REVERSED REFRACTION

- The vertical **depth to the interface** below point A and B



$$Z_d = \frac{h_d}{\cos\alpha}$$

$$Z_u = \frac{h_u}{\cos\alpha}$$

QUIZ

① Buat perkiraan *velocity* di bawah permukaan

Distance from Shot (m)	Arrival Times (ms)	
	Direct Wave	Refracted Wave
0	0.00	13.58
3	2.14	14.24
6	4.29	14.91
9	6.43	15.58
12	8.57	16.24
15	10.71	16.91
18	12.86	17.58
21	15.00	18.24
24	17.14	18.91
27	19.29	19.58
30	21.43	20.24
33	23.57	20.91
36	25.71	21.58
39	27.86	22.24
42	30.00	22.91
45	32.14	23.58
48	34.29	24.24
51	36.43	24.91
54	38.57	25.58
57	40.71	26.24
60	42.86	26.91
63	45.00	27.58
66	47.14	28.24
69	49.29	28.91