Interpretation of Realistic Travel Time Data

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Interpretation of Realistic Travel Time Data

- With field data it is necessary to examine travel time curves carefully to decide on best method to use:

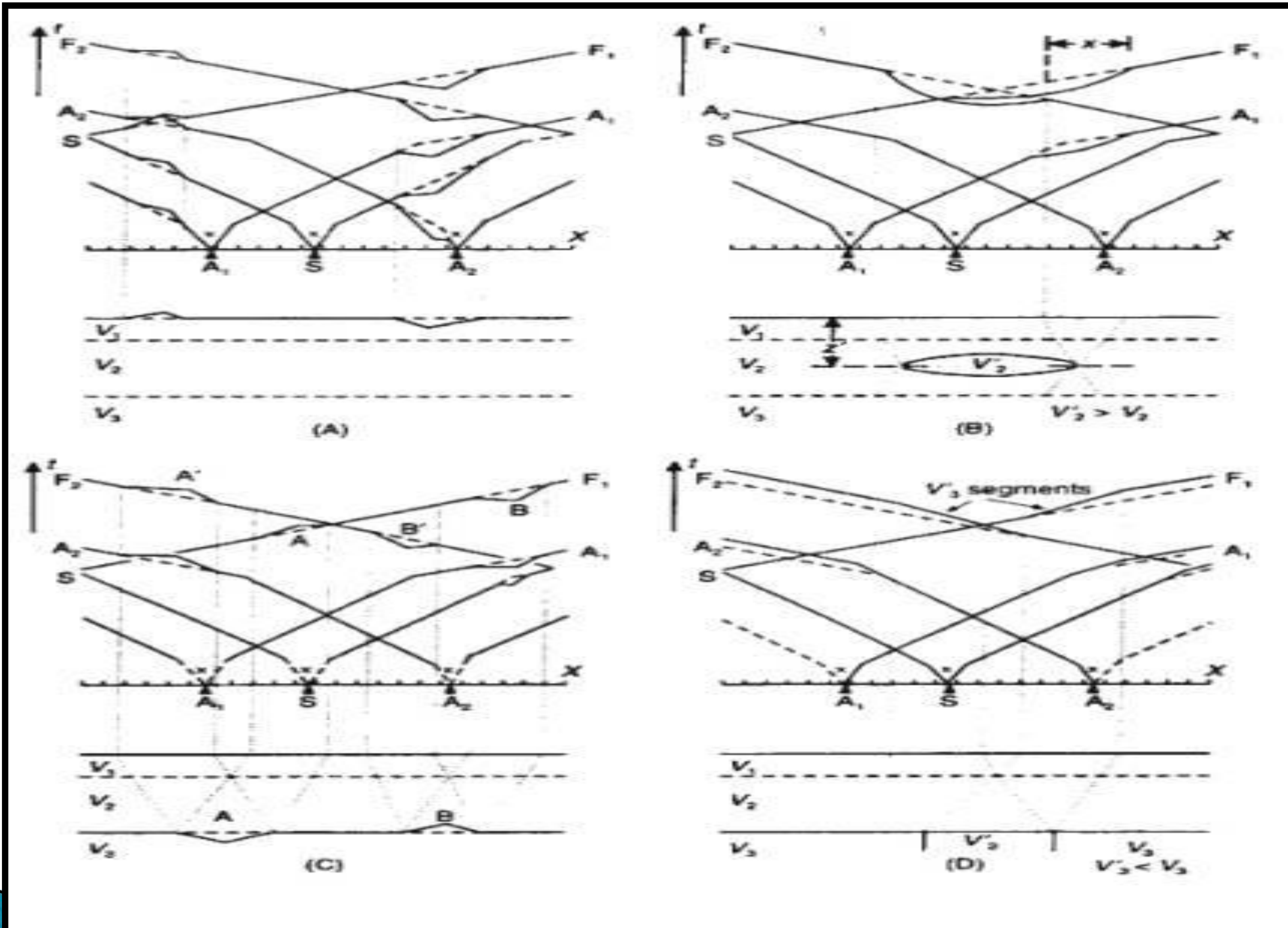
I. How many refraction branches are there, i.e. how many layers?

II. Are anomalous times due to mispicking or real?

III. Small anomalies can be ignored, but larger ones require other methods, e.g. Plus-Minus.

IV. Multiple source positions allow, some inference of depth of anomaly: near-surface anomalies align

- Surface Topography Intervening Velocity Anomaly



F2
F1
A2
A1
S
X
V1
V2
V3
(A)
x
V'2
V'2 > V2
(B)
A'
B
A
B'
(C)
V'3 segments
V'3
V'3 < V3
(D)

Refractor Topography and Refractor Velocity Variation

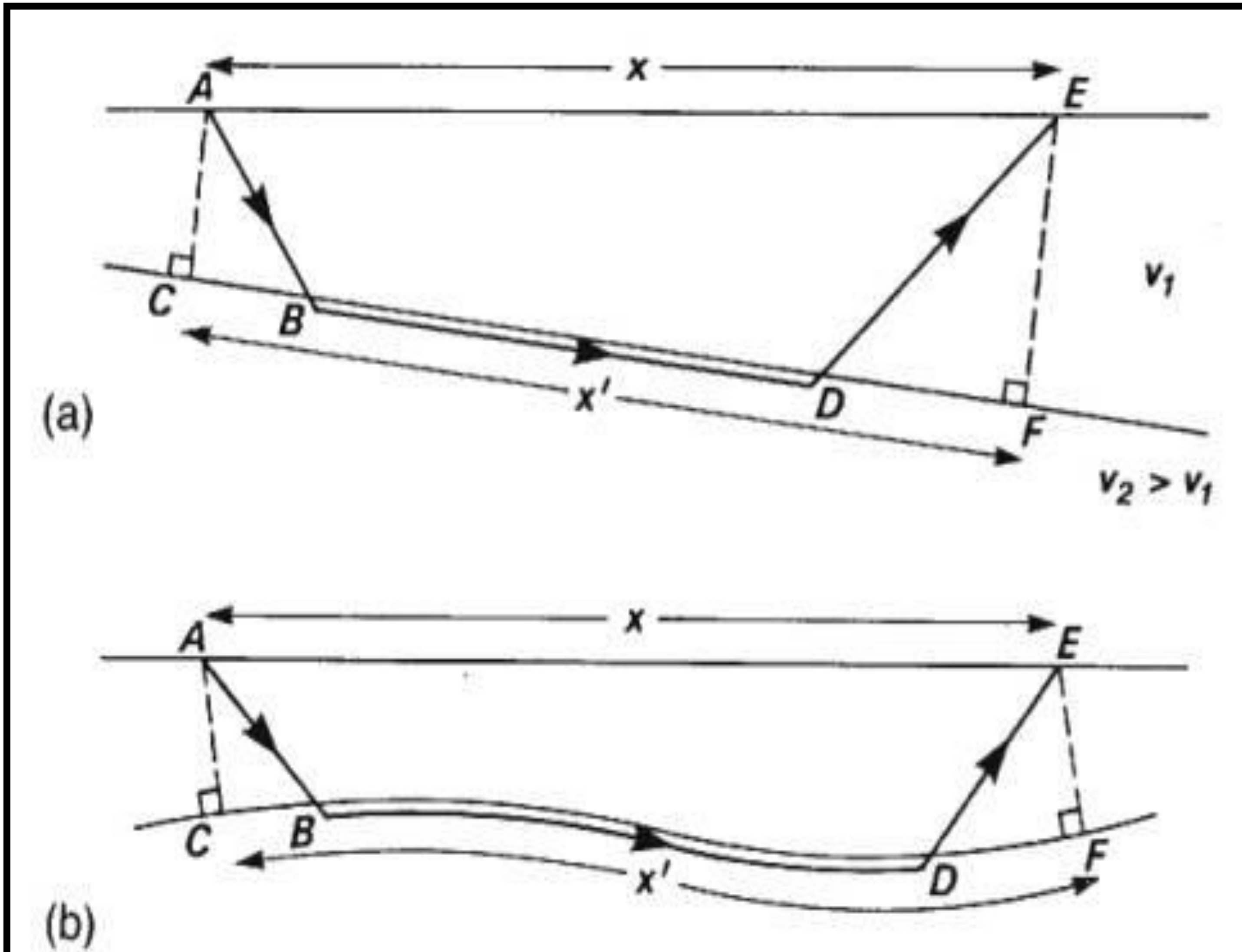
- **Delay Times**

  For irregular travel time curves, e.g. due to bedrock topography or glacial fill, much analysis is based on delay times.

- **Total Delay Time**

  Difference in travel time along actual ray path and projection of raypath along refracting interface:

$$\delta t = T_{AB} - T_{CF}$$


x
A
E
C
B
v1
x'
D
F
(a)
v2 > v1
x
A
E
C
B
x'
D
F
(b)

Refractor Topography and Refractor Velocity Variation

$$T_{CF} = \frac{CF}{V_2}$$

$$\delta t = \left(\frac{AB}{V_1} - \frac{CB}{V_2}\right) + \left(\frac{DE}{V_1} - \frac{DF}{V_2}\right) = \delta t_S + \delta t_G \approx T_{AB} - \frac{x}{V_2}$$

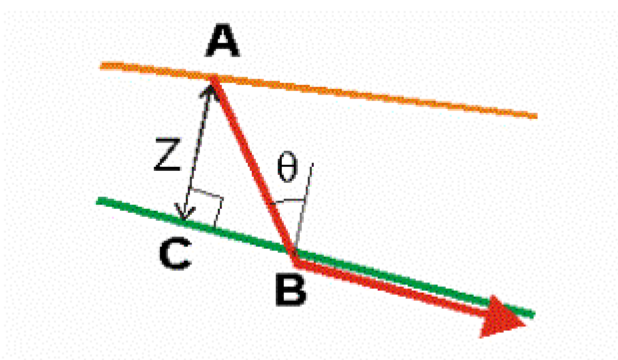
❖Total delay time is delay time at shot plus delay time at geophone:

For small dips, can assume x=x’

Refractor Topography and Refractor Velocity Variation

- **Refractor Depth from Delay Time**

If velocities of both layers are known, then refractor depth at point A can be calculated from delay time at point A:



$$\delta t_A = \frac{AB}{V_1} - \frac{BC}{V_2}$$

Refractor Topography and Refractor Velocity Variation

- Using right-angled triangle to get lengths in terms of z:

$$\delta t_A = \frac{Z}{V_1 \cos\theta} - \frac{Z \tan\theta}{V_2}$$

$$= \frac{Z}{V_1 \cos\theta}\left(1 - \frac{V_1 \sin\theta}{V_2}\right)$$

Refractor Topography and Refractor Velocity Variation

- Using Snell's law to express angles in terms of velocities:

$$\delta t_A = \frac{Z}{V_1\left(1-\frac{V_1^2}{V_2^2}\right)^{\frac{1}{2}}}\left(1-\frac{V_1^2}{V_2^2}\right)$$

Simplifying:

$$\delta t_A = \frac{Z\left(V_2^2 - V_1^2\right)^{\frac{1}{2}}}{V_1 V_2}$$

Refractor Topography and Refractor Velocity Variation

So refractor depth at A is:

$$Z = \frac{t_A V_1 V_2}{\left(V_2^2 - V_1^2\right)^{\frac{1}{2}}}$$

Plus-Minus Method

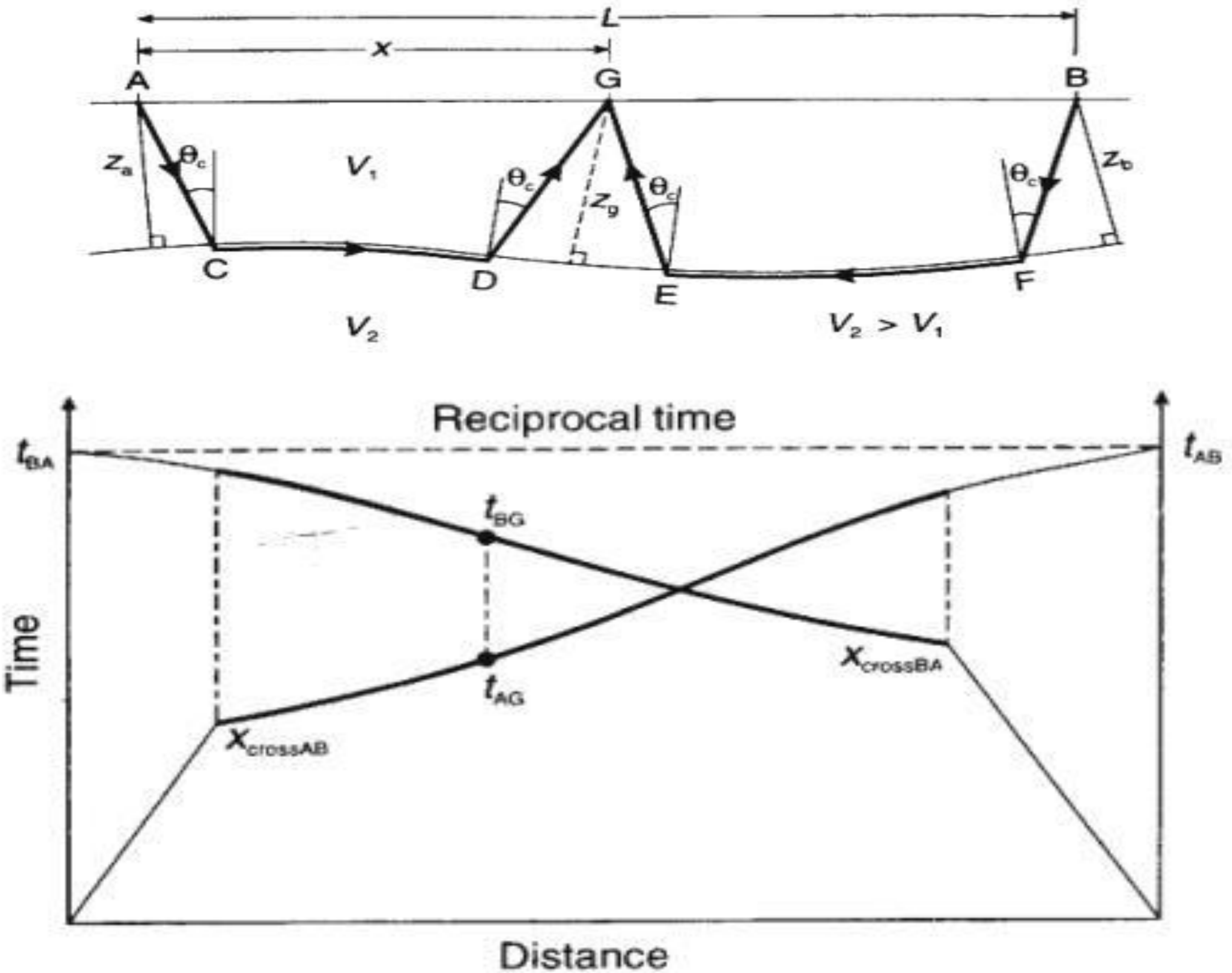
- Hagedoorn's Plus-Minus method used for more complex cases:
- Undulating interfaces
- Changes in refractor velocity along the profile
- Plus-Minus:
- Requires forward and reverse travel times at geophone location to find delay time and refractor velocity at geophone

Plus-Minus Method

- Assumes interface is planar between D and E, can result in smoothing of actual topography.
- Assumes dips less than ~10°
- Delay time at G given by:

$$0.5(T_{ACDG} + T_{GEFB} - T_{ACFB})$$

which can be found from observed data..



L
x
A
G
B
Z_a
θ_c
V_1
θ_c
Z_g
θ_c
θ_c
Z_b
C
D
E
F
V_2
$V_2 > V_1$
Reciprocal time
t_{BA}
t_{AB}
t_{BG}
Time
t_{AG}
$X_{crossBA}$
$X_{crossAB}$
Distance

Plus–Minus Method

- **Plus and Minus Terms**

Using previous figure we can write down forward/ reverse travel times:

$$t_{AG} = \frac{x}{V_2(x)} + \delta t_G + \delta t_A$$

$$t_{BG} = \frac{L - x}{V_2(x)} + \delta t_G + \delta t_B$$

Plus-Minus Method

- **Minus Term**

  Used to determine laterally varying refractor velocity, i.e. $V_2(x)$:

$$T^{-} = t_{AG} - t_{BG} = \frac{2x}{V_2(x)} - \frac{L}{V_2(x)} + \delta t_A - \delta t_B$$

•Velocity given by local slope of plot of (T^{-}) vs. x, distance along profile. Note factor of 2 compared with the plane layer method.

•Velocity may change along profile , so written as V_2 (x) . Different values of V_2 can be used for calculation of interface depth using plus term.

Plus-Minus Method

- **Plus Term**

  Determines refractor depth at a location from delay time there:

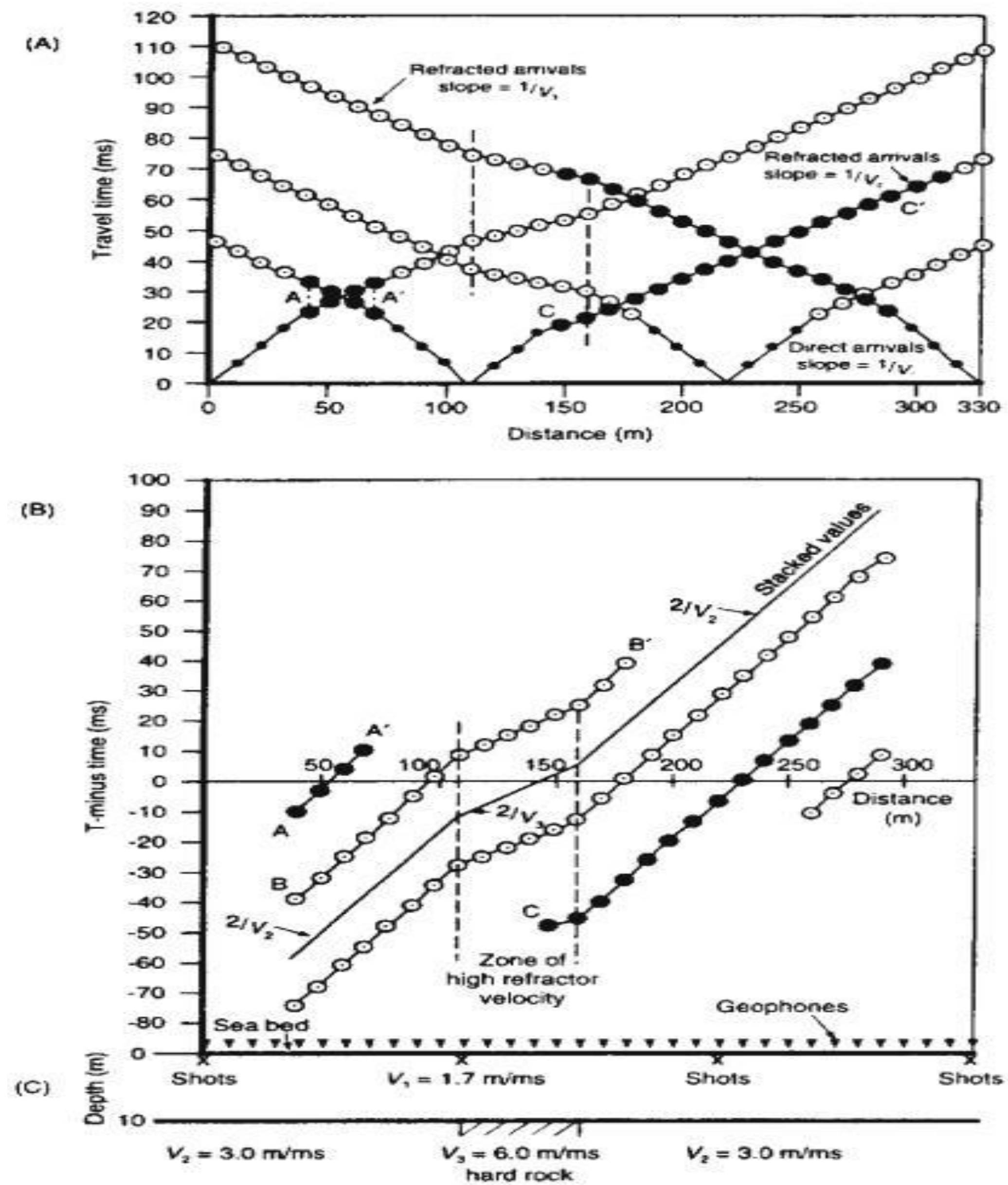
$$T^{+} = t_{AG} + t_{BG} - t_{AB} = 2\,\delta t_G$$

So from delay time formula for depth, depth at G given by:

$$z_G = \frac{(T^{+})V_1 V_2(G)}{2\left(V_2^2(G) - V_1^2\right)^{\frac{1}{2}}}$$

Plus-Minus Method

- Depth can be determined at each geophone location where forward and reverse travel times recorded using V_2 estimated for that position



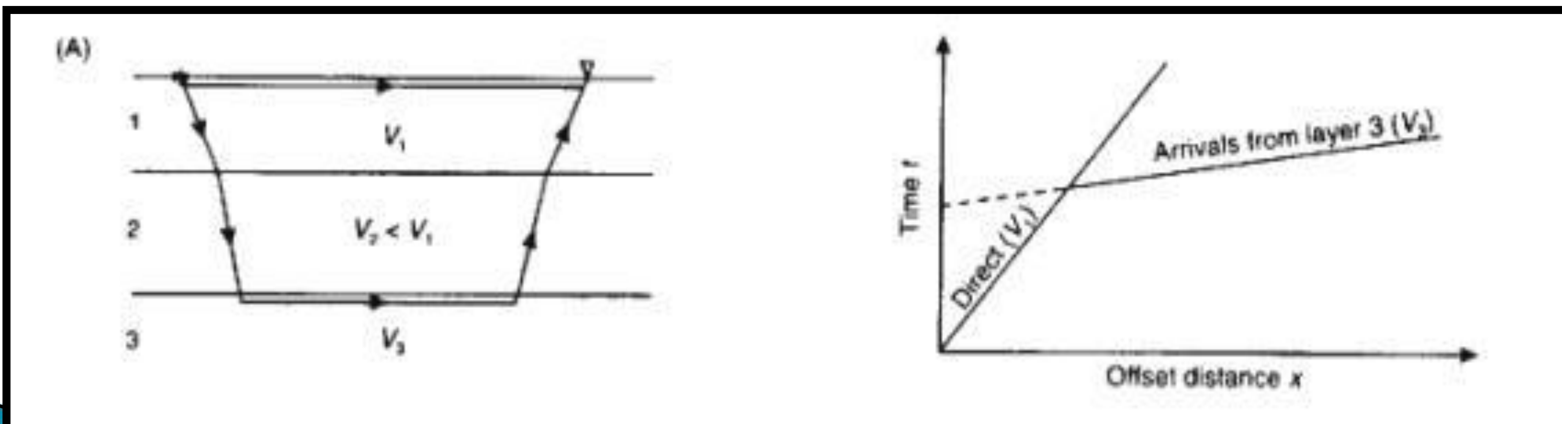
A. Composite travel time distance plots for four different shots

B. Plot of Minus Terms: note lateral changes in refractor velocity

Hidden Layer Problem

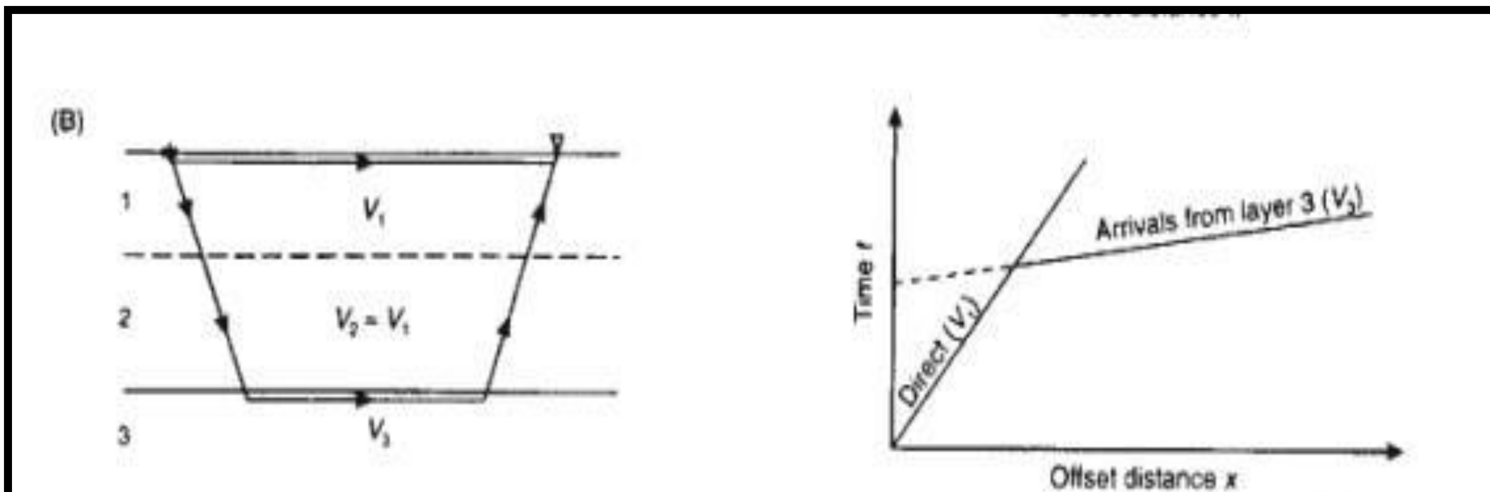
- Layers may not be detected by first arrival analysis:

A. Velocity inversion produces no critical refraction from layer 2



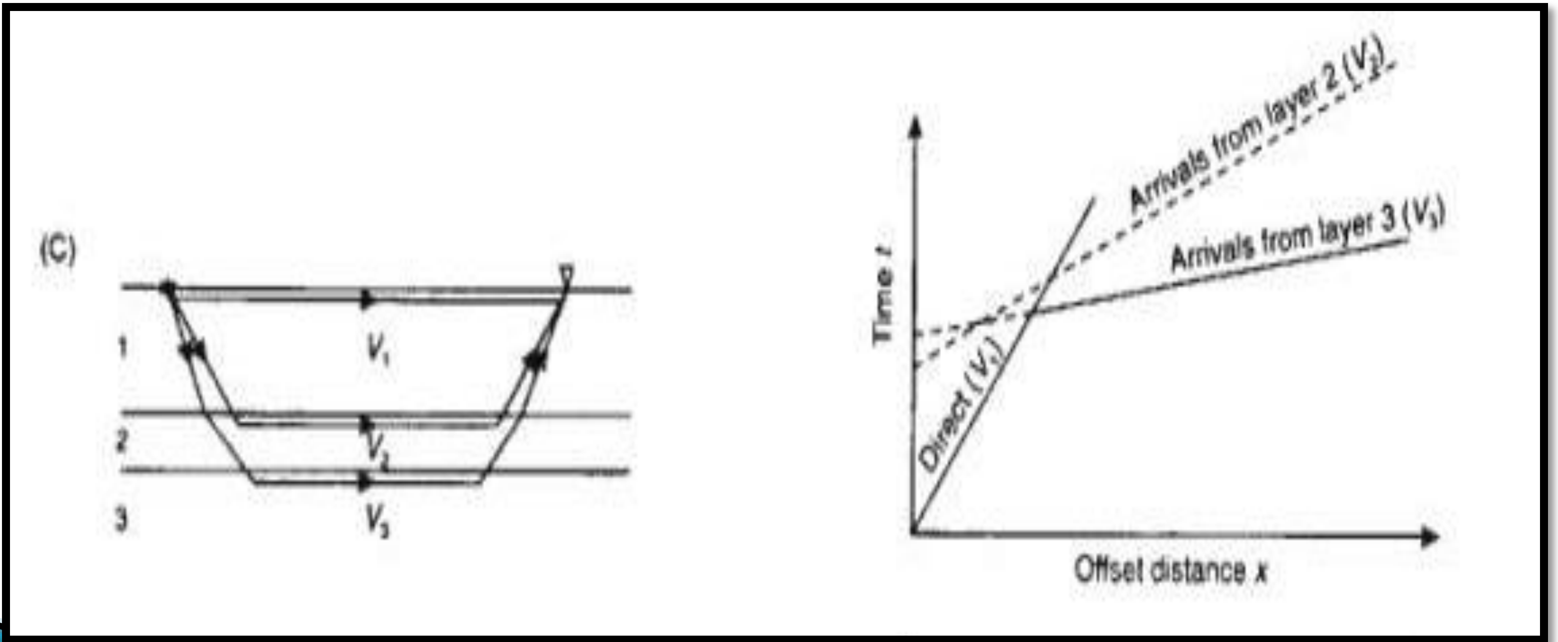
Hidden Layer Problem

B. Insufficient velocity contrast makes refraction difficult to identify



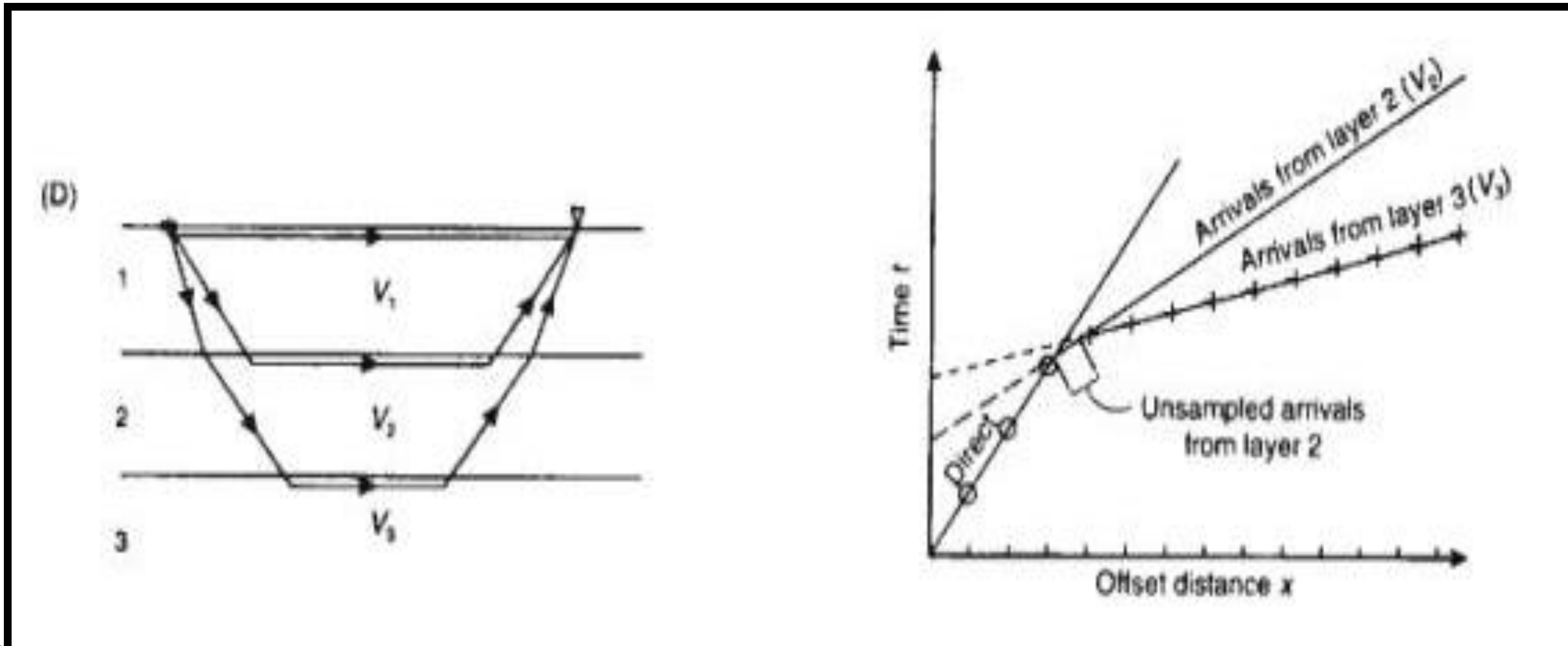
Hidden Layer Problem

C. Refraction from thin layer does not become first arrival



Hidden Layer Problem

D. Geophone spacing too large to identify second refraction



Textbook

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