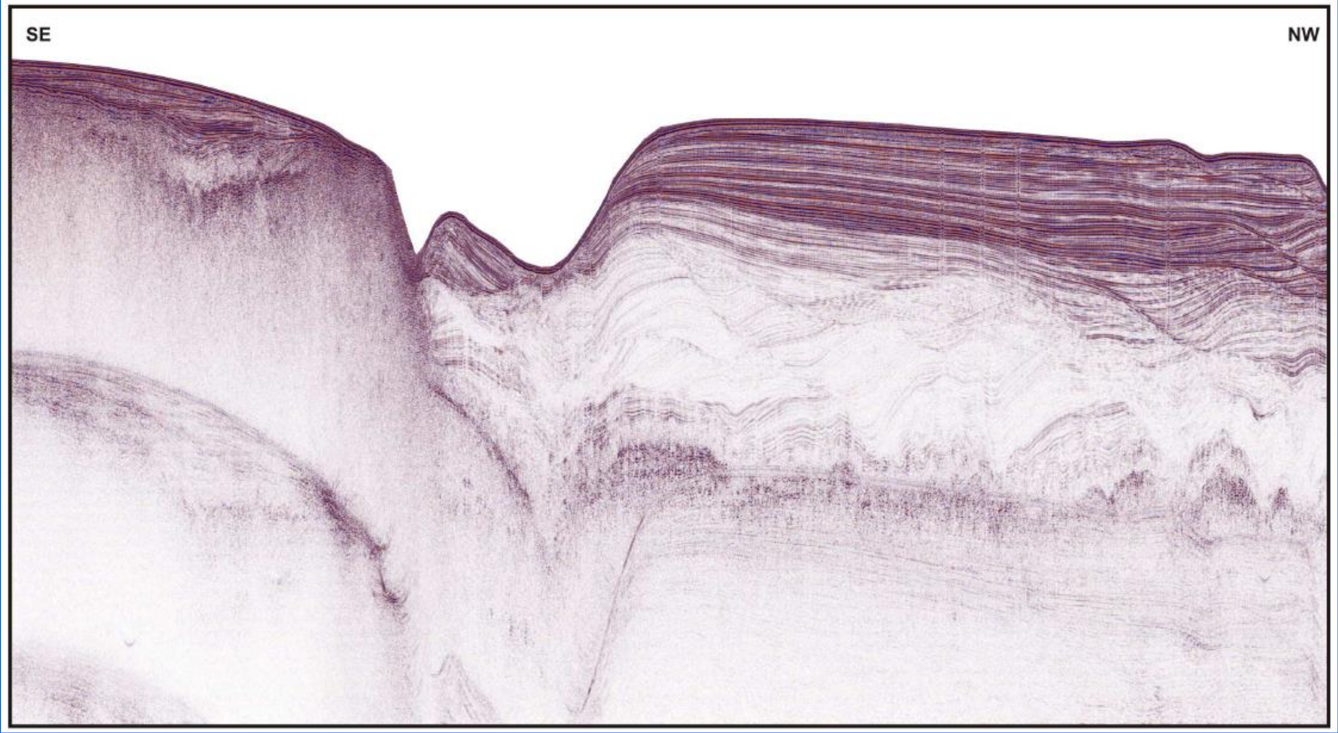
FACULTY
OF SCIENCES

DEPARTMENT OF GEOLOGY
1^{ST} & 2^{ND} MASTER OF SCIENCE IN GEOLOGY



EXPLORATION GEOPHYSICS

Refraction & reflection seismic surveying

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REFLECTION VERSUS REFRACTION SEISMICS

Increased incidence angle effects

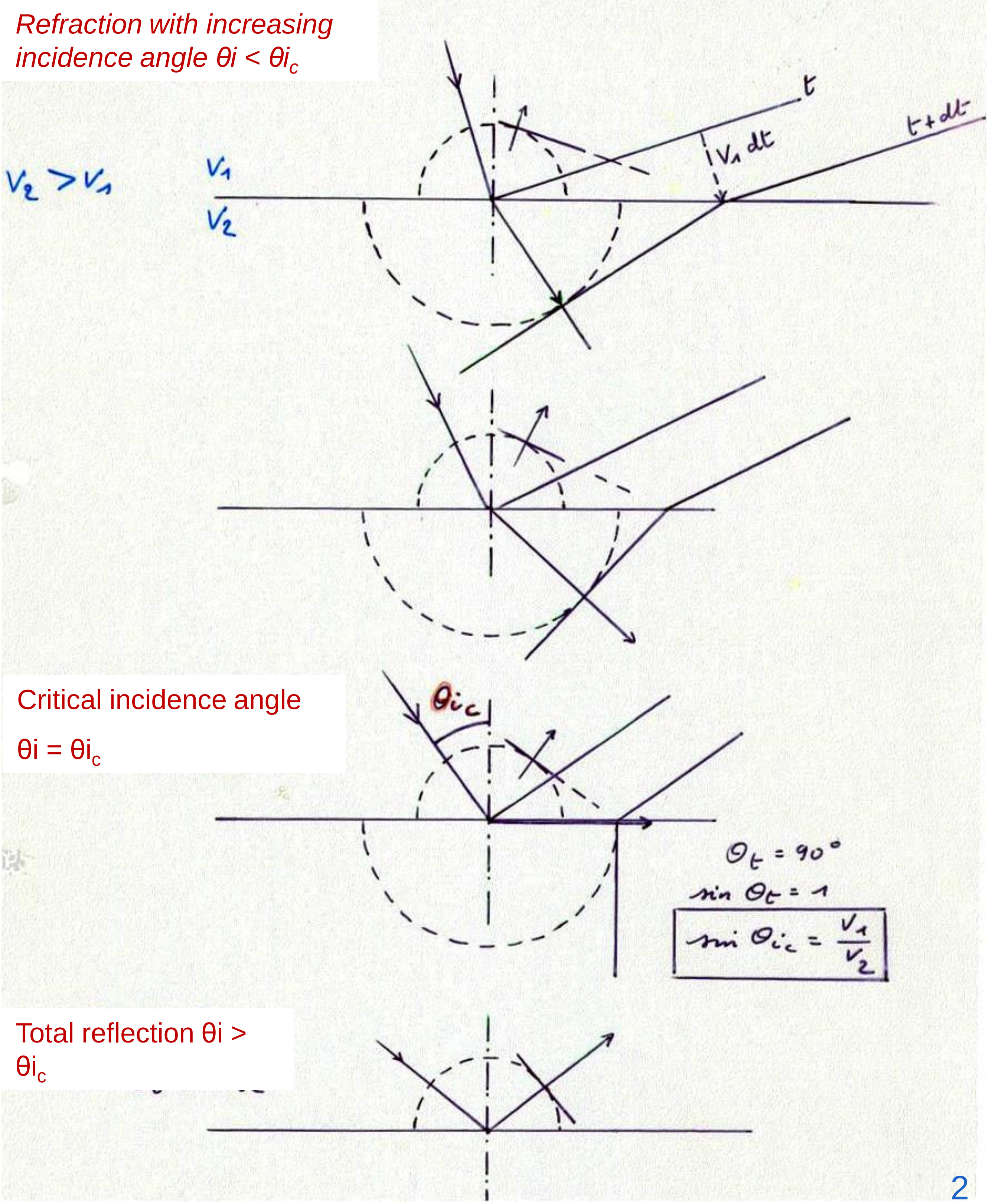
Critical incidence angle

➔ Incidence angle where refraction = 90°

- a wavefront will propagate horizontally
- on the interface of the 2 media
- with the velocity of the 2nd medium (!)

Total reflection *beyond* critical angle

- all energy will be totally reflected
- no refraction to lower medium



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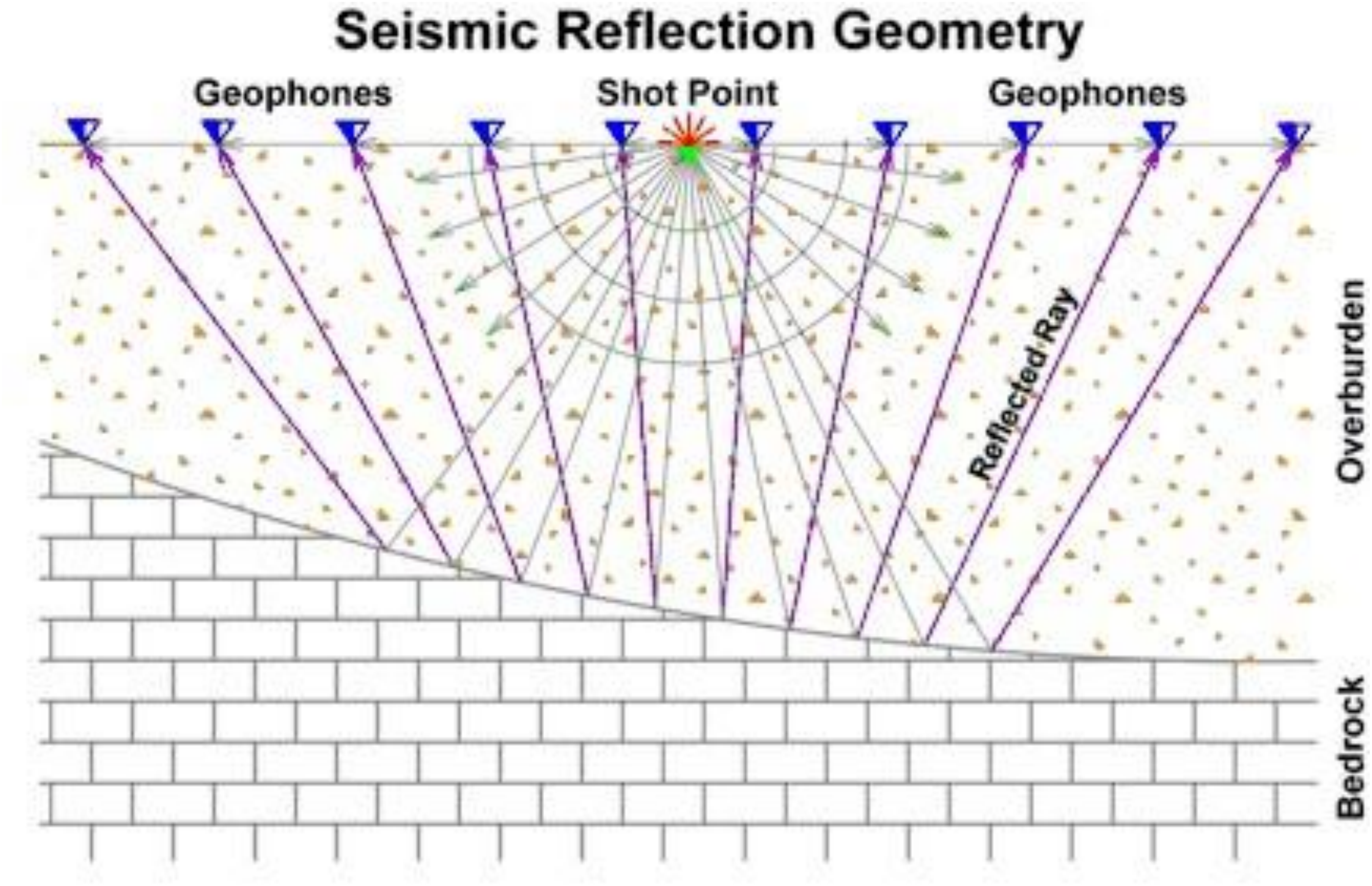
REFLECTION VERSUS REFRACTION SEISMICS

Reflection seismics

Analysis of all **reflected** waves and of the complete signal to achieve a 2D or 3D image

- Continuous profiles
- Larger processing time
- Short lines & all frequencies
- Superior resolution cfr. *refraction*
- Land *versus* water



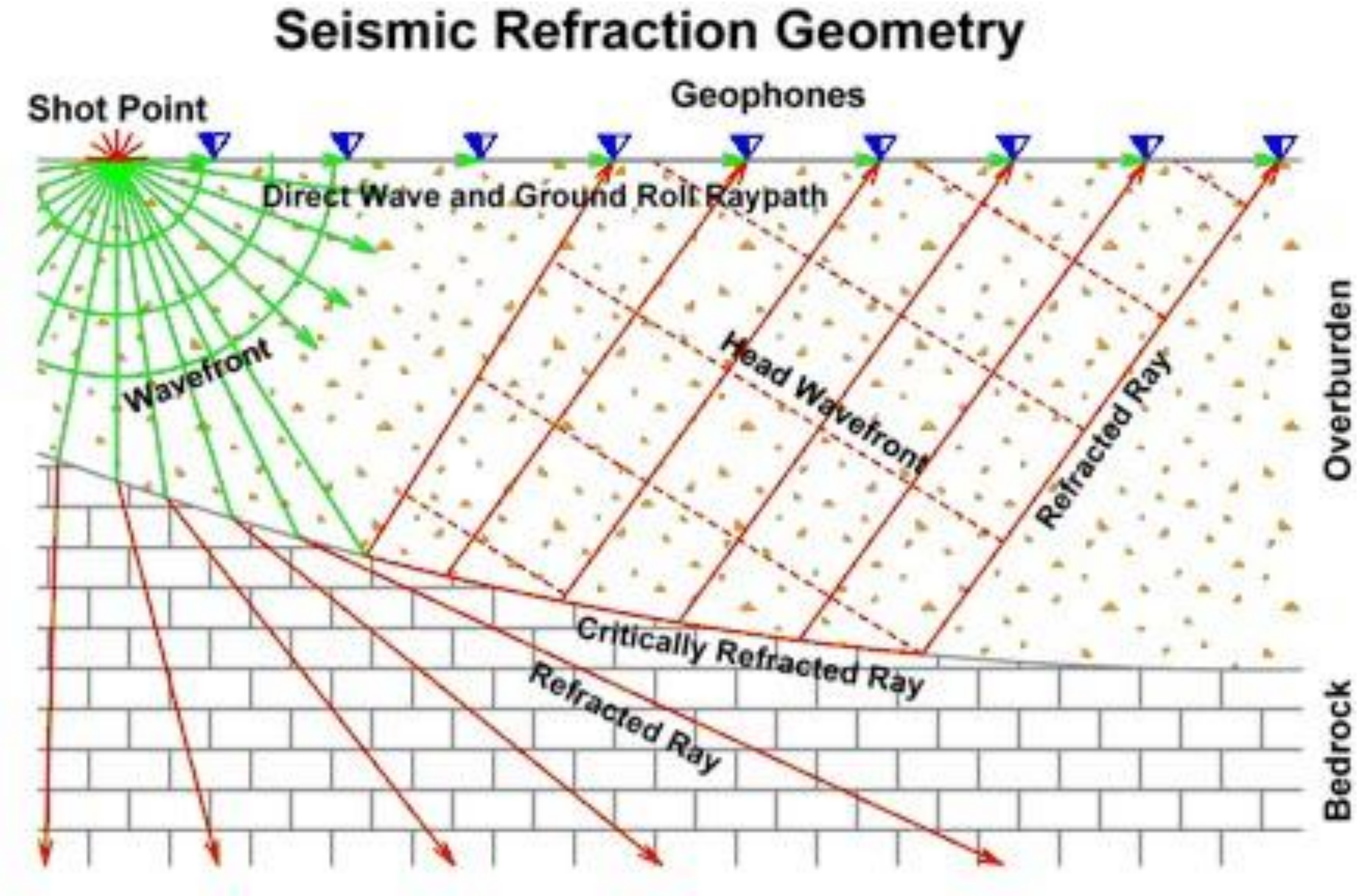
REFLECTION VERSUS REFRACTION SEISMICS

Refraction seismics

Timing of the first arrival of the quickest **refracted** wave

- Uniquely velocity information
- Large geophone array

  => 4-5 times depth
- High energy sources needed
- Practically limited
- Predominantly land seismics



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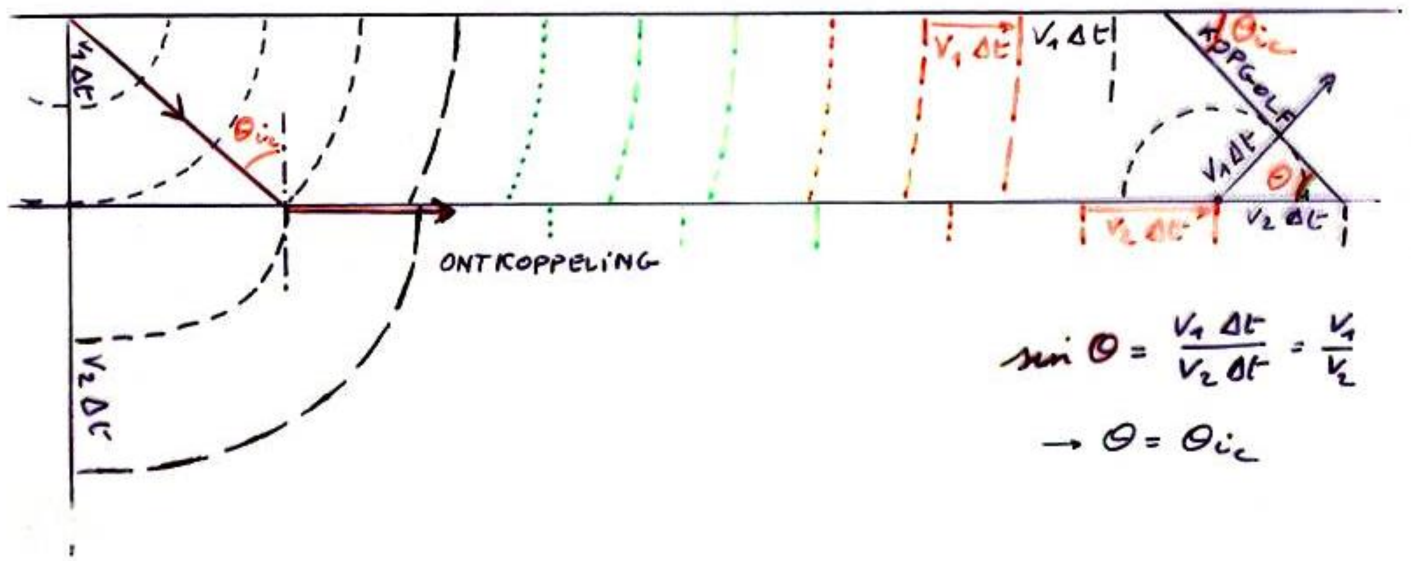
REFRACTION SEISMIC SURVEYING

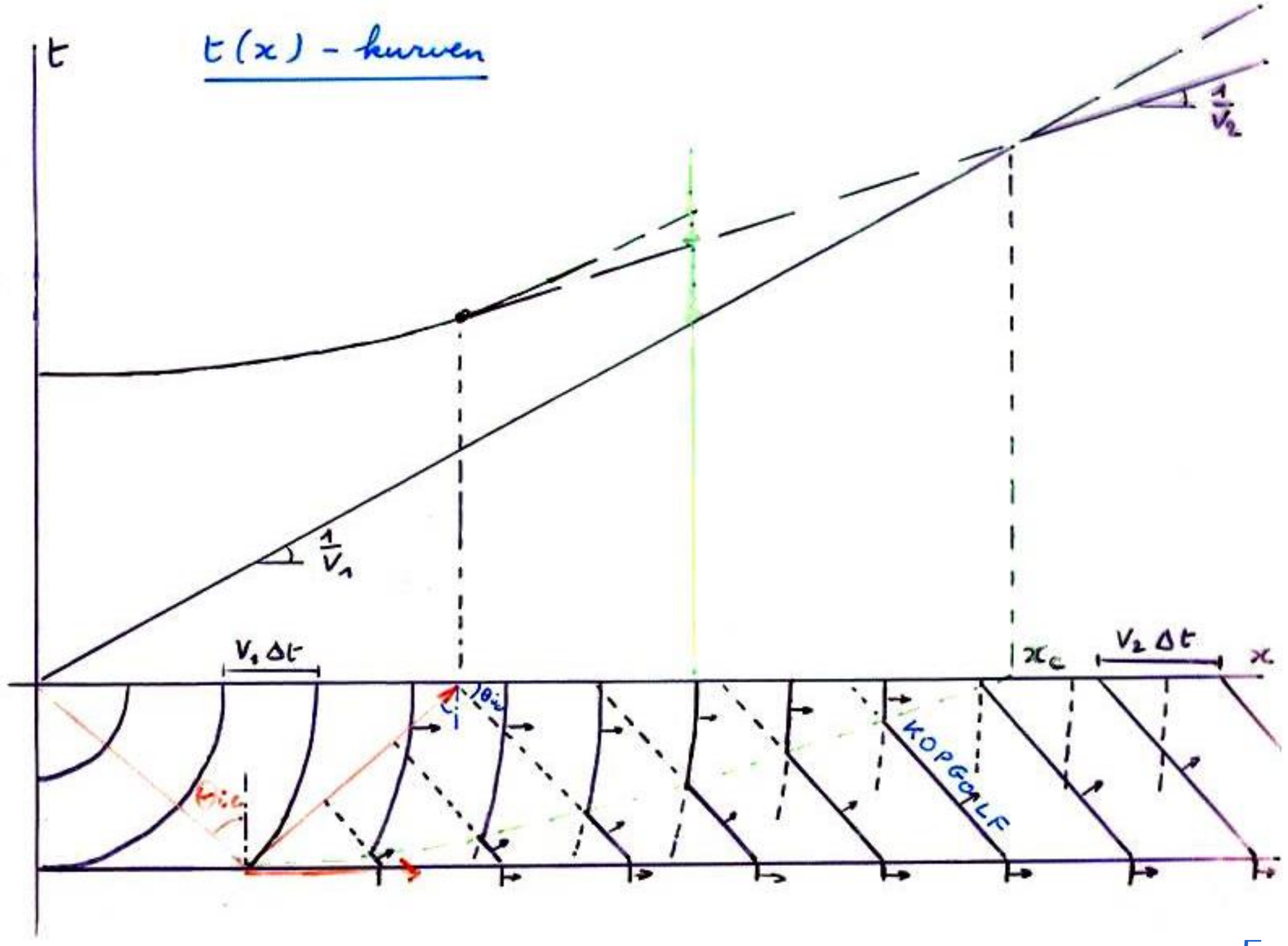
The critical angle and the head wave

Horizontally propagating wave (θt = 90°)

- “excites” all passed points on the interface
- points will act as sources (*Huyghens*)
- energy is sent to upper medium as a
  “**head wave**”
- the angle related to the head wave ray

equals the critical incidence angle!



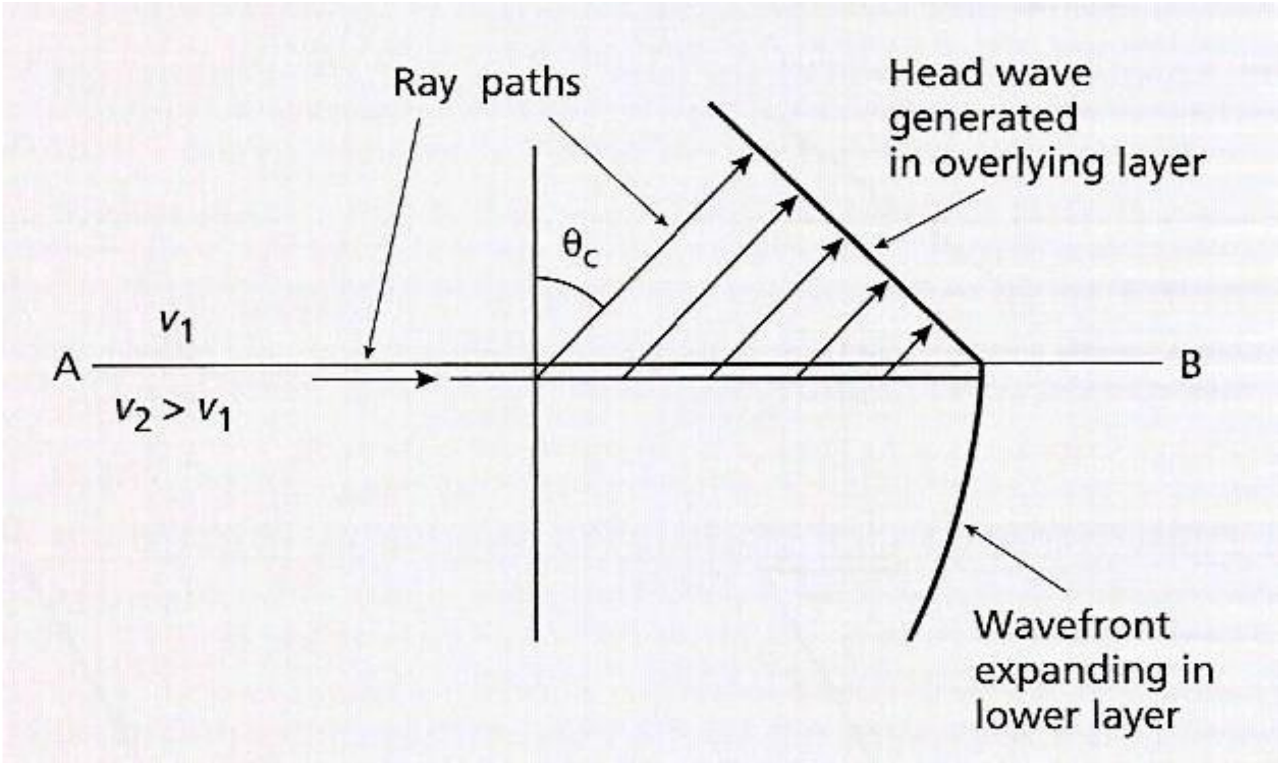


REFRACTION SEISMIC SURVEYING

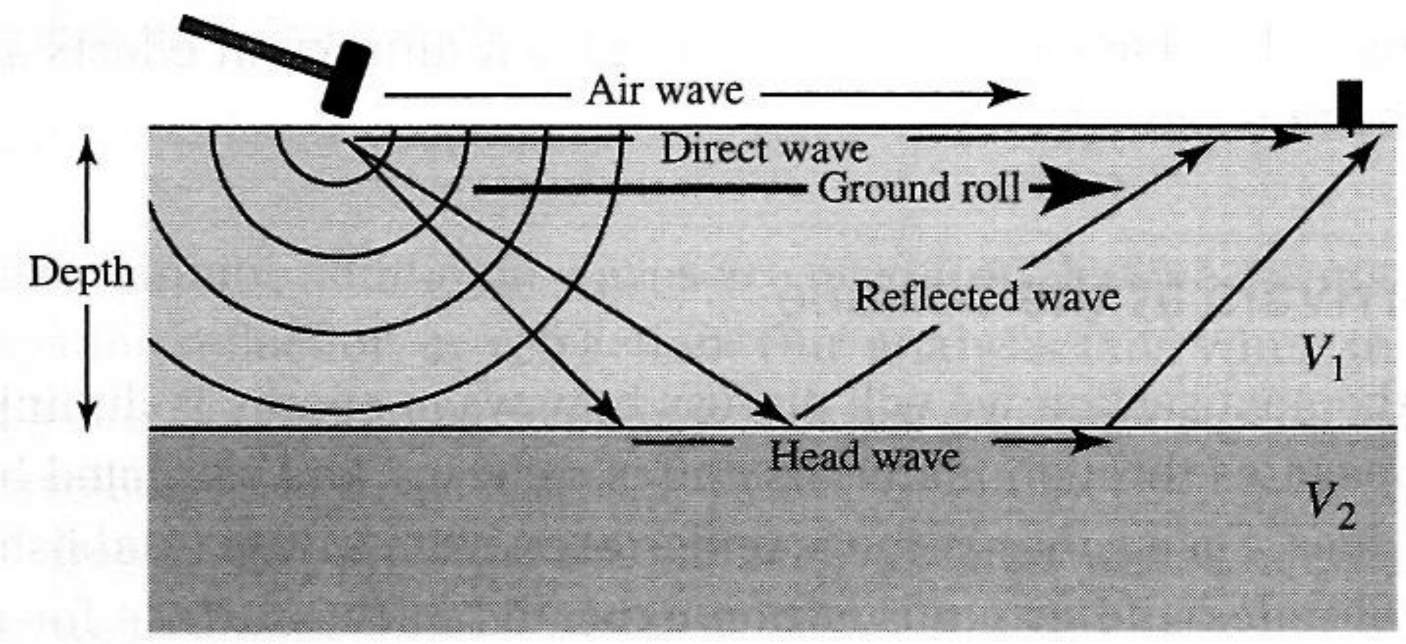
The critical angle and the head wave

The head wave is a perturbation in the upper layer, travelling with higher velocities of layer 2!

- Oblique passage through upper layer
- Any associated ray is inclined at critical angle
- Direct wave also propagates trough the slower upper layer at velocity of upper layer
- Head wave will be "*ahead*" of the direct wave over a *large* distance



Kearey *et al.* (2002)



Burger *et al.* (2006)

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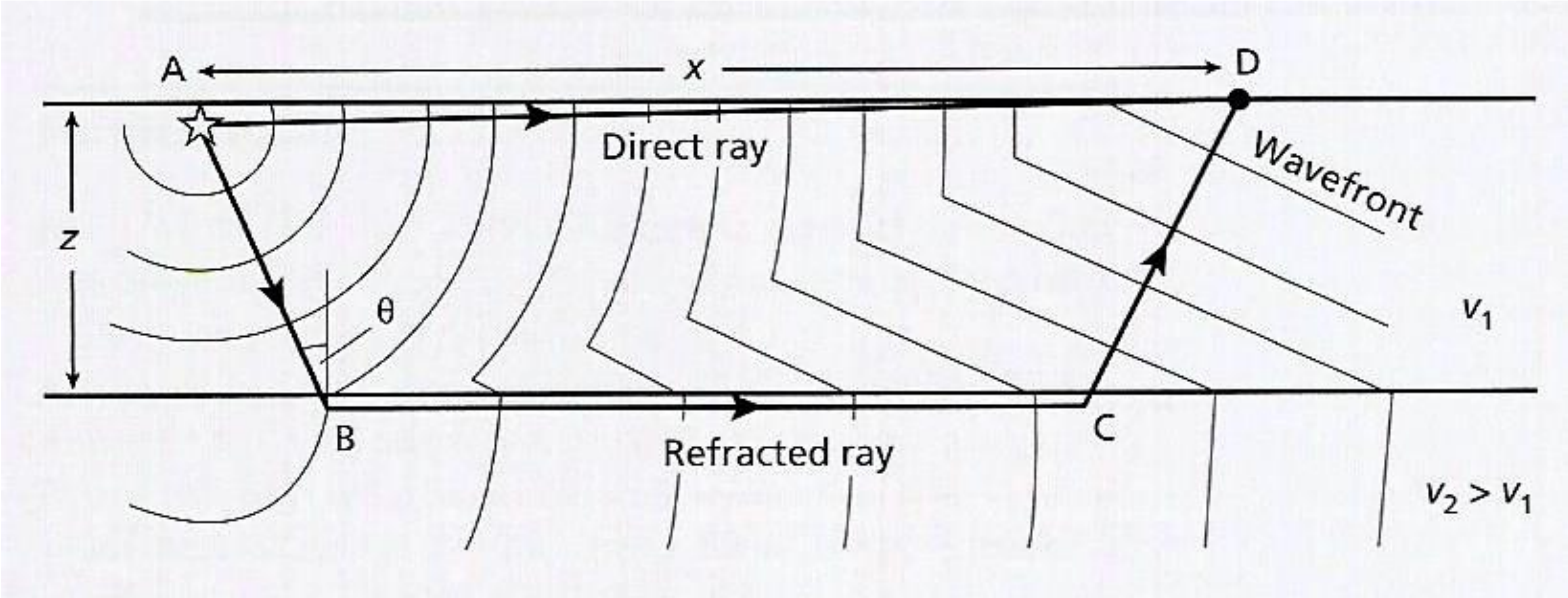
REFRACTION SEISMIC SURVEYING

The crossover point

At point D, the crossover point, the *refracted* ray arrives before the *direct* ray



Kearey *et al.* (2002)

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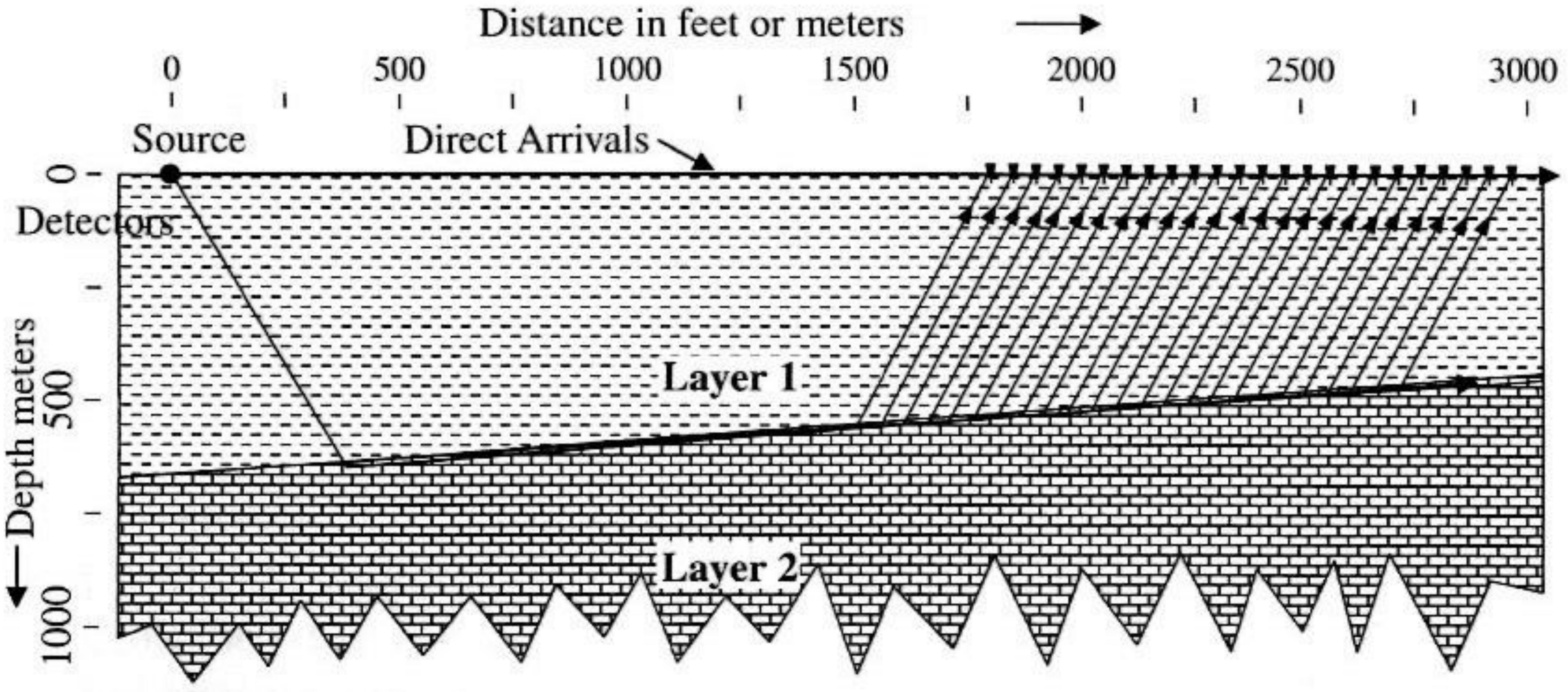
REFRACTION SEISMIC SURVEYING

Consequences of the critical angle

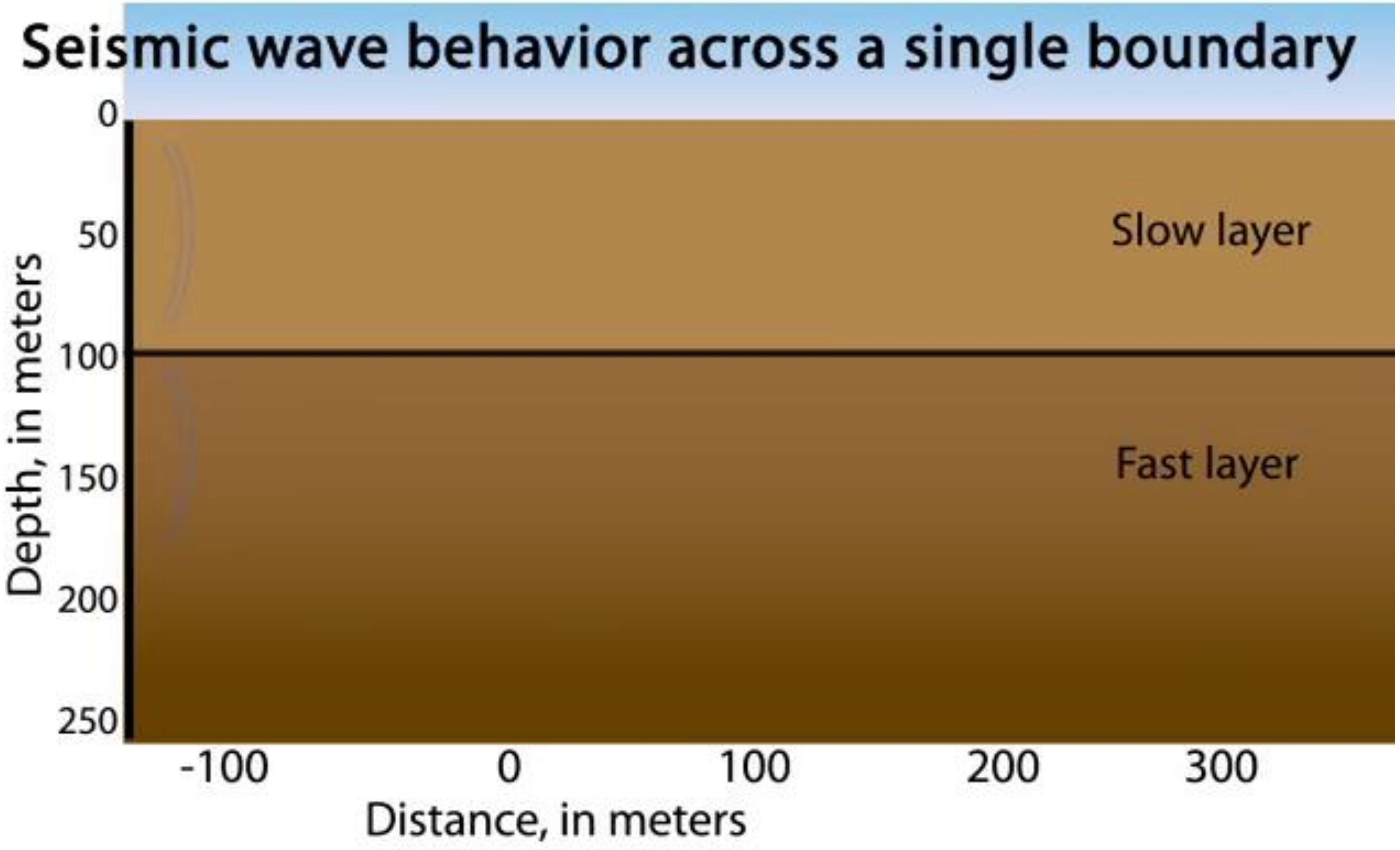
The crossover point will occur at a large distance, resulting into a long geophone array



Gadallah & Fisher (2009)

REFRACTION SEISMIC SURVEYING

Summary of reflection, refraction and head wave formation



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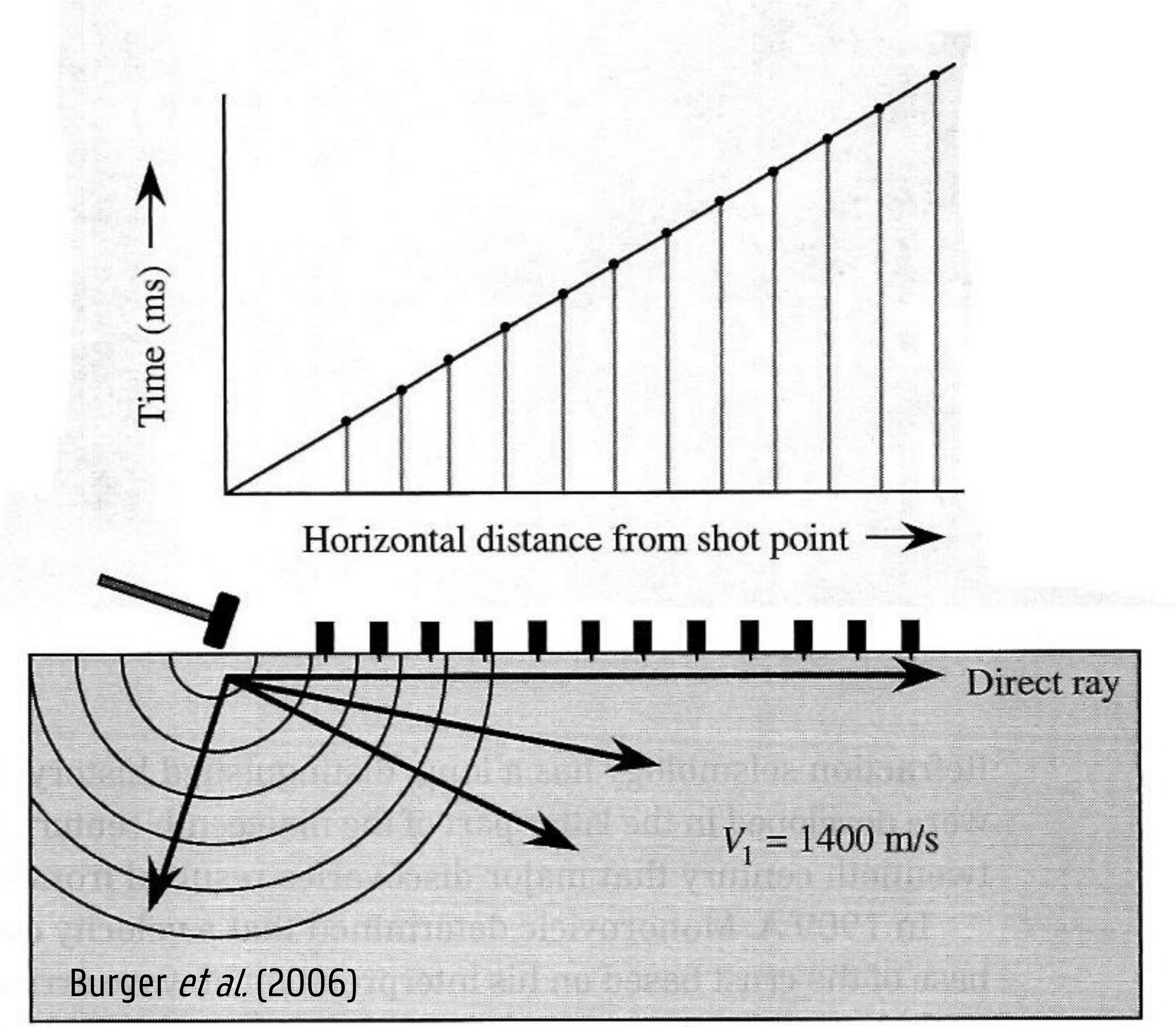
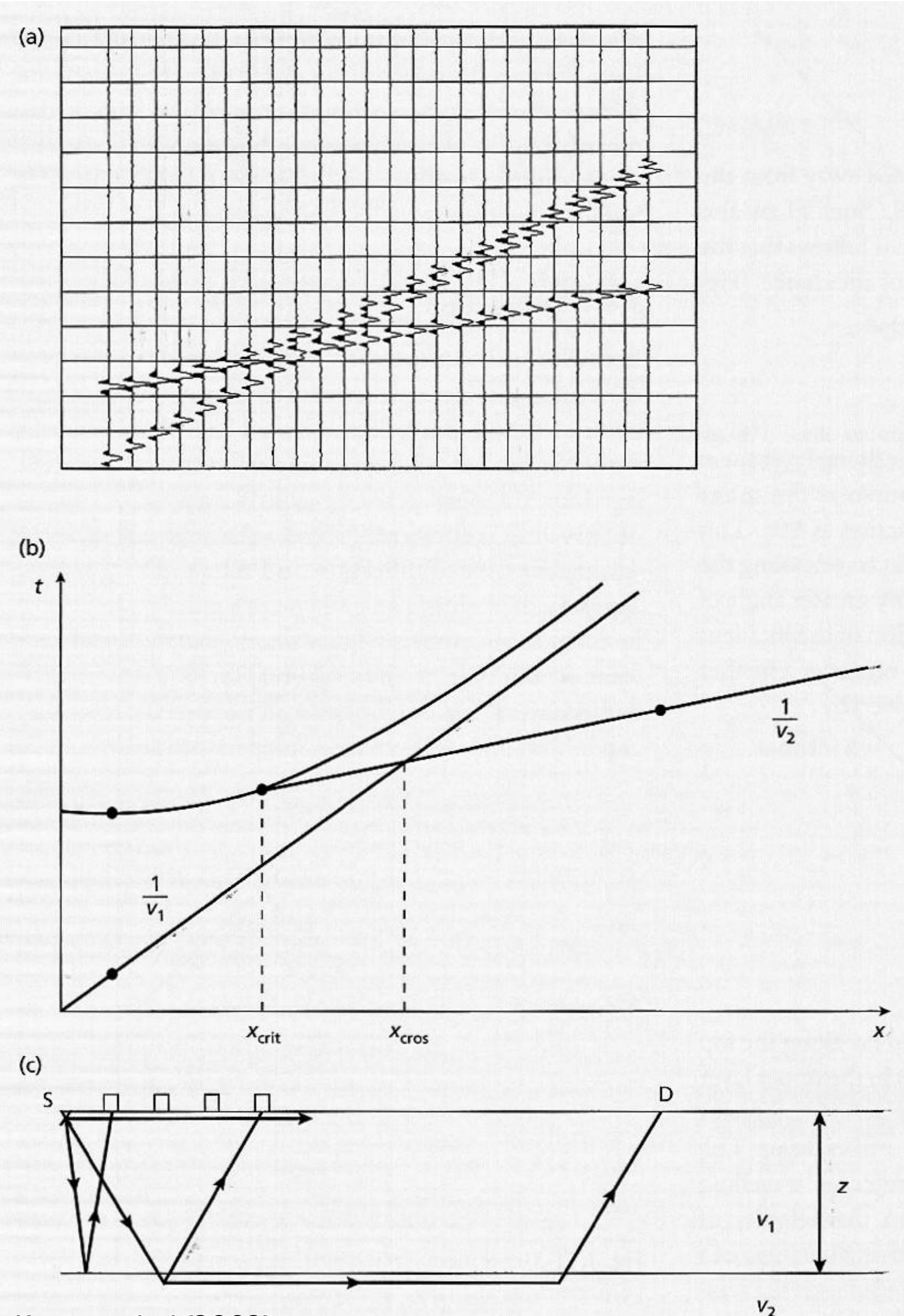
REFRACTION SEISMIC SURVEYING

Refraction seismogrammes and t(x) curves

Direct wave expression



Burger *et al.* (2006)

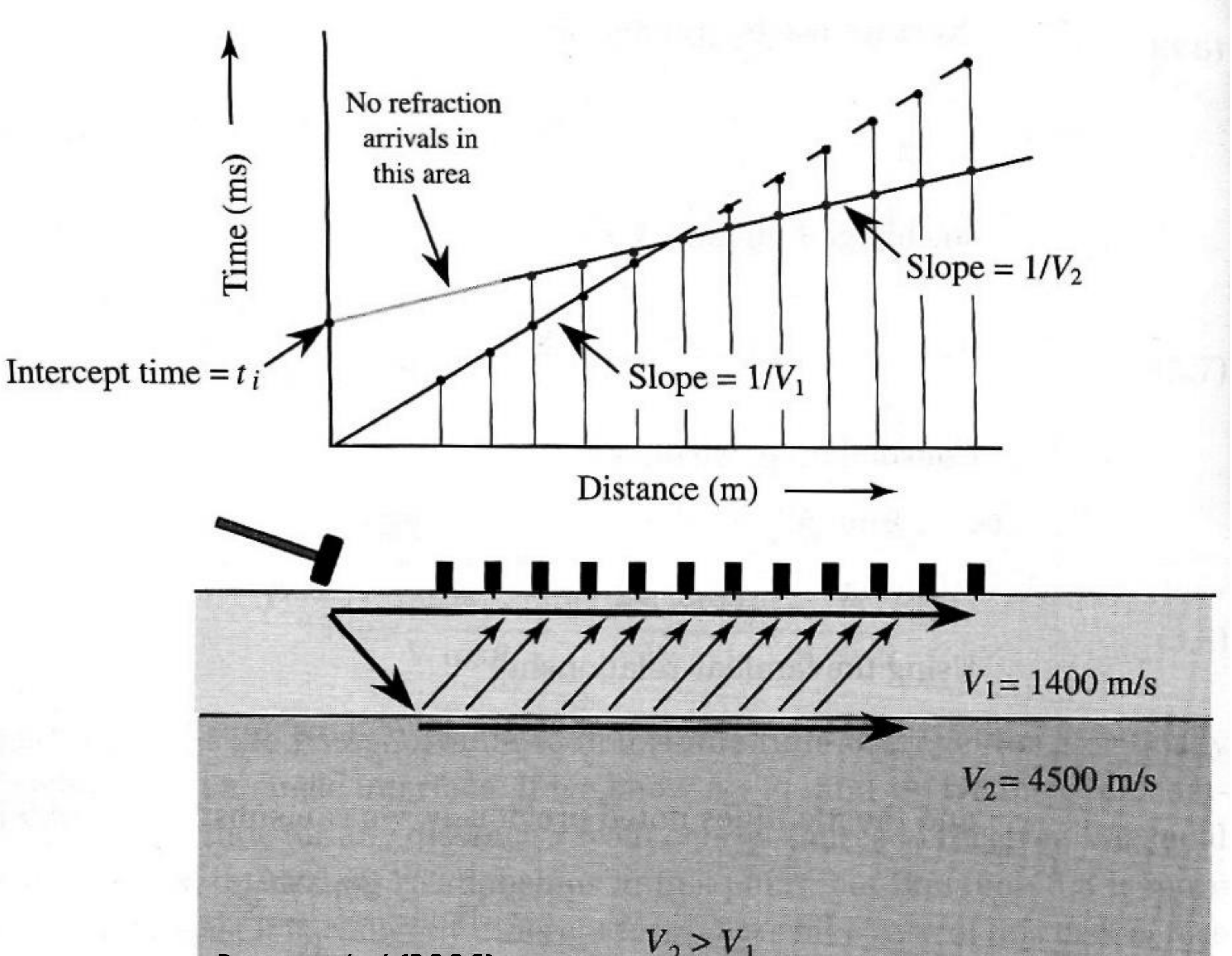


Kearey *et al.* (2002)

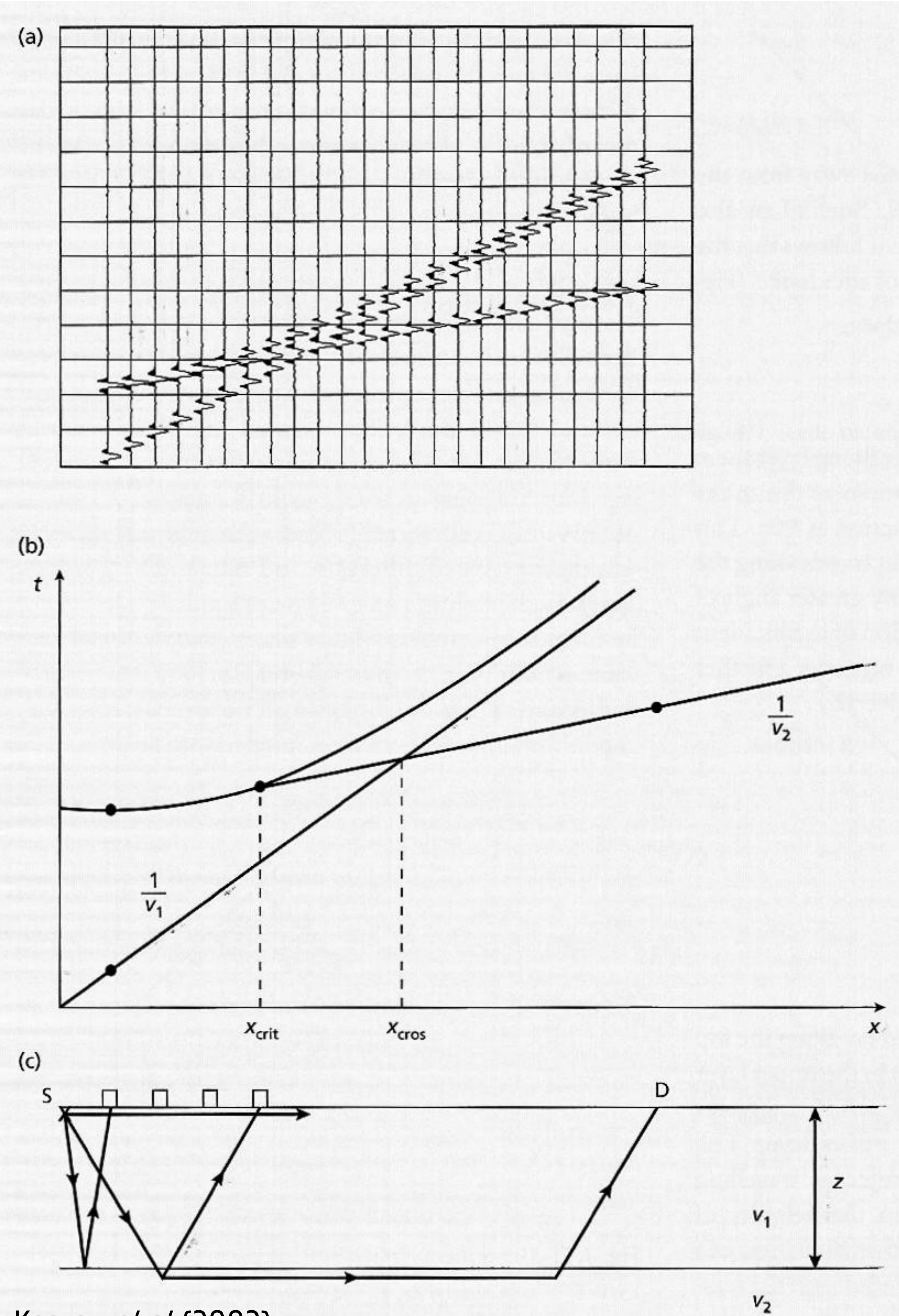
REFRACTION SEISMIC SURVEYING

Refraction seismogrammes and t(x) curves

Direct wave + 1 refracted wave expression



Burger *et al.* (2006)

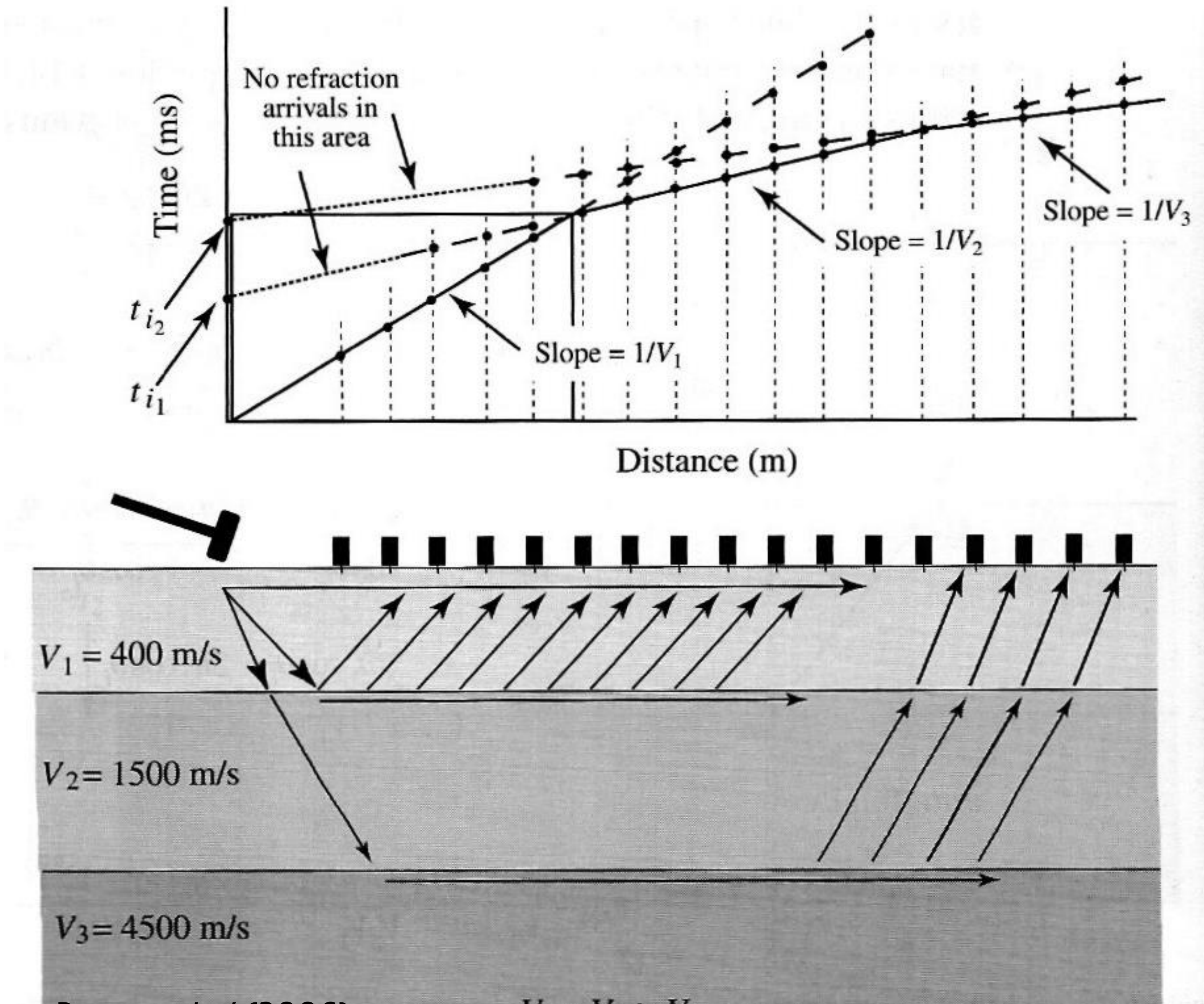


Kearey *et al.* (2002)

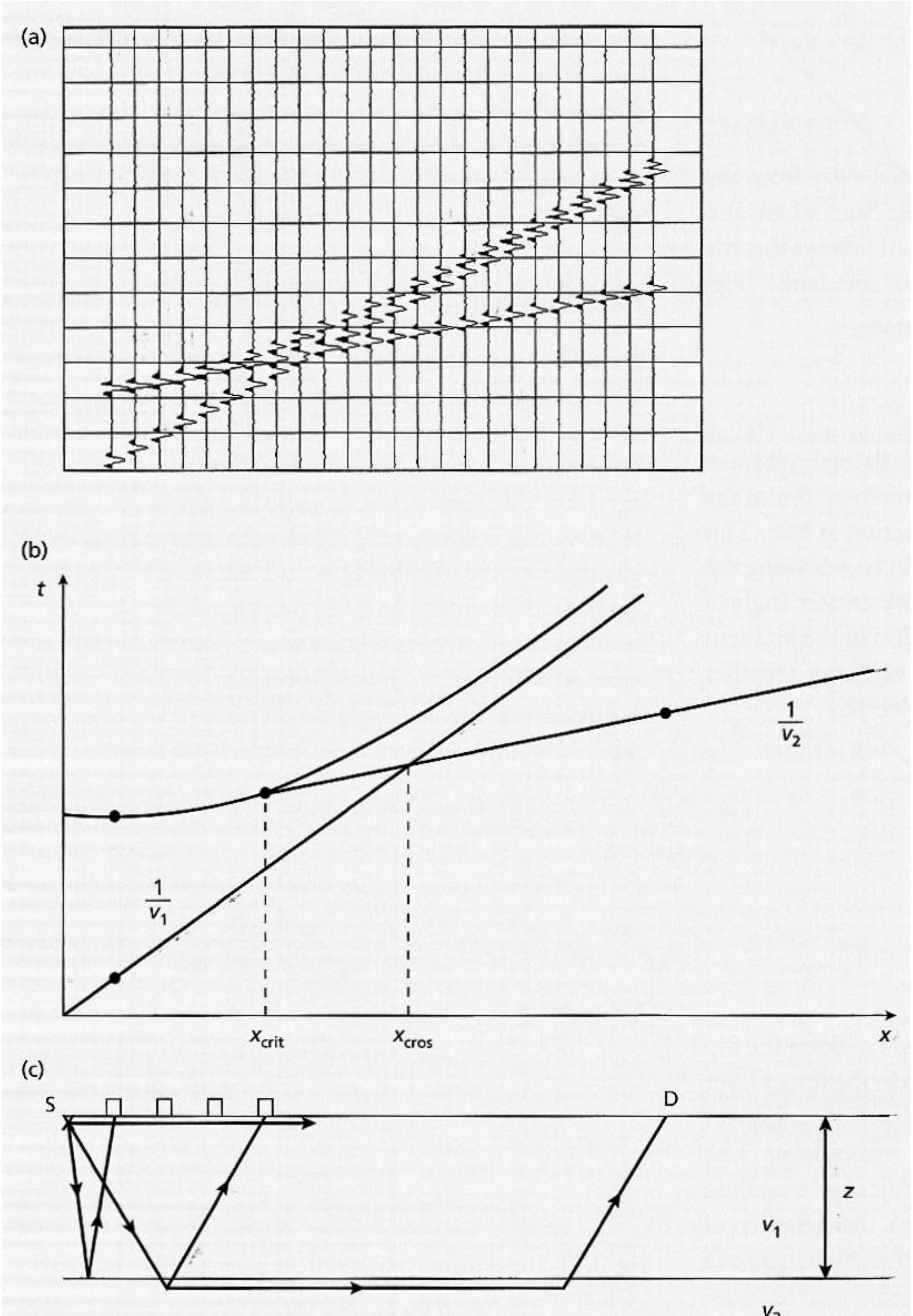
REFRACTION SEISMIC SURVEYING

Refraction seismogrammes and t(x) curves

Direct wave + 2 refracted waves expression



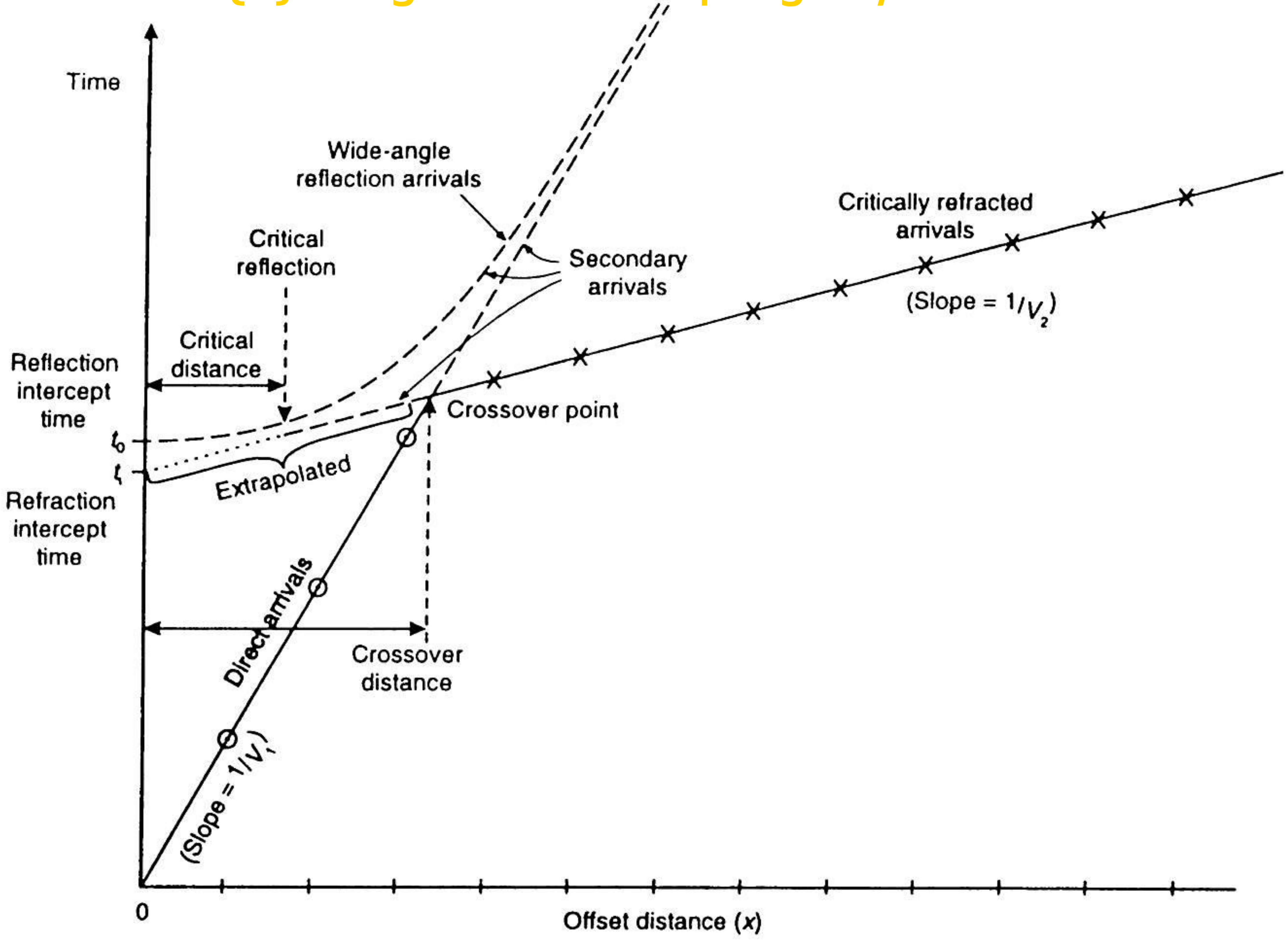
Burger *et al.* (2006)



Kearey *et al.* (2002)

REFRACTION SEISMIC SURVEYING

Interpretation of a t(x) diagram for sloping layers



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REFRACTION SEISMIC SURVEYING

Travel time equations: a single horizontal layer

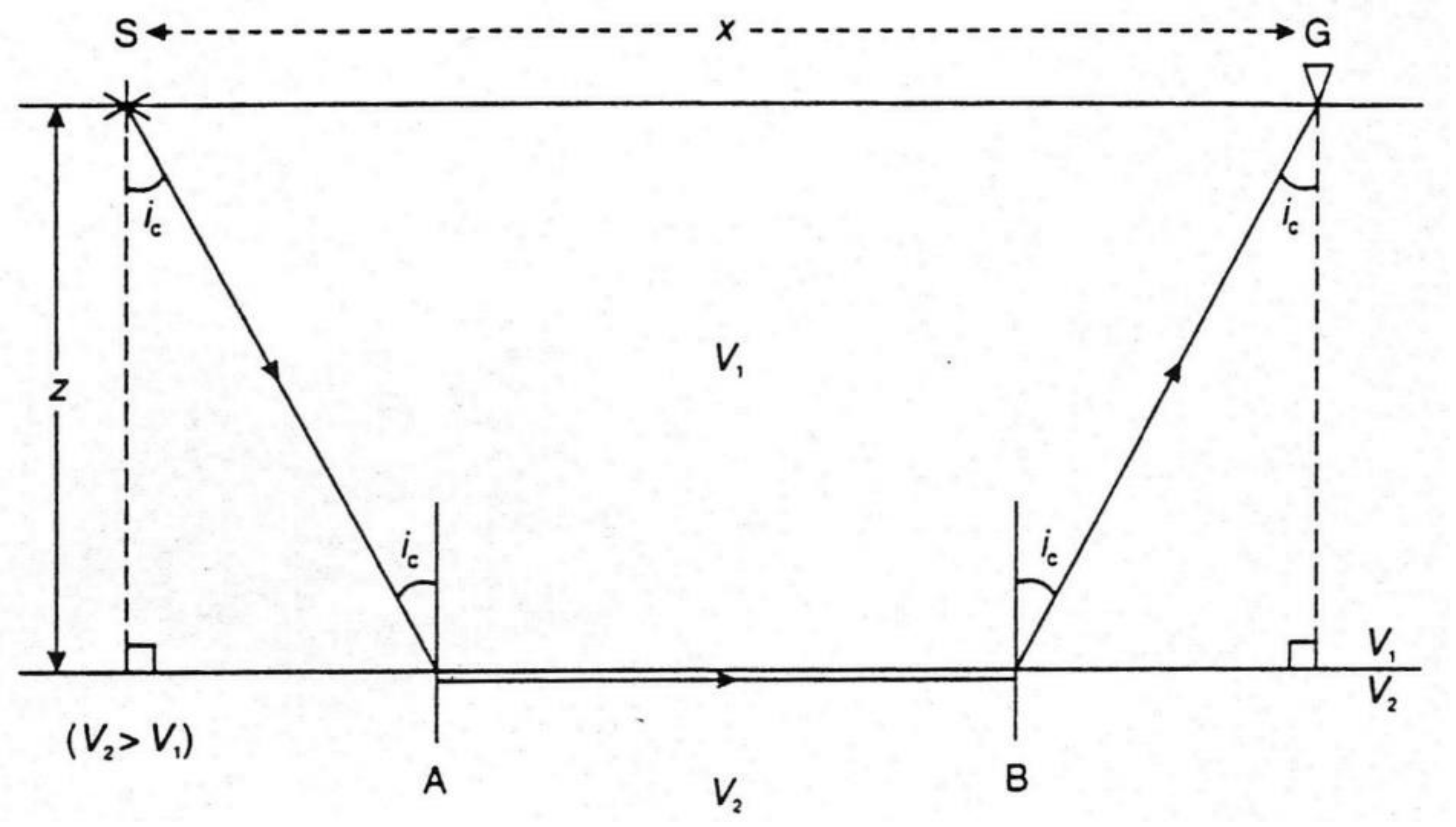
Starting from basic goniometric relationships:

$$\tan i_c = \frac{\left({(x - AB)}/{2} \right)}{z}$$

$$\cos i_c = \frac{z}{SA}$$

$$\sin i_c = \frac{V_1}{V_2} \quad (Snell's\ Law)$$

$$\cos^2 i_c + \sin^2 i_c = 1$$



Direct wave versus refracted wave

$$T_{SG} = T_{SA} + T_{AB} + T_{BG}$$

REFRACTION SEISMIC SURVEYING

Travel time equations: a single horizontal layer

$$T_{SG} = \frac{AB}{V_2} + \frac{2SA}{V_1}$$

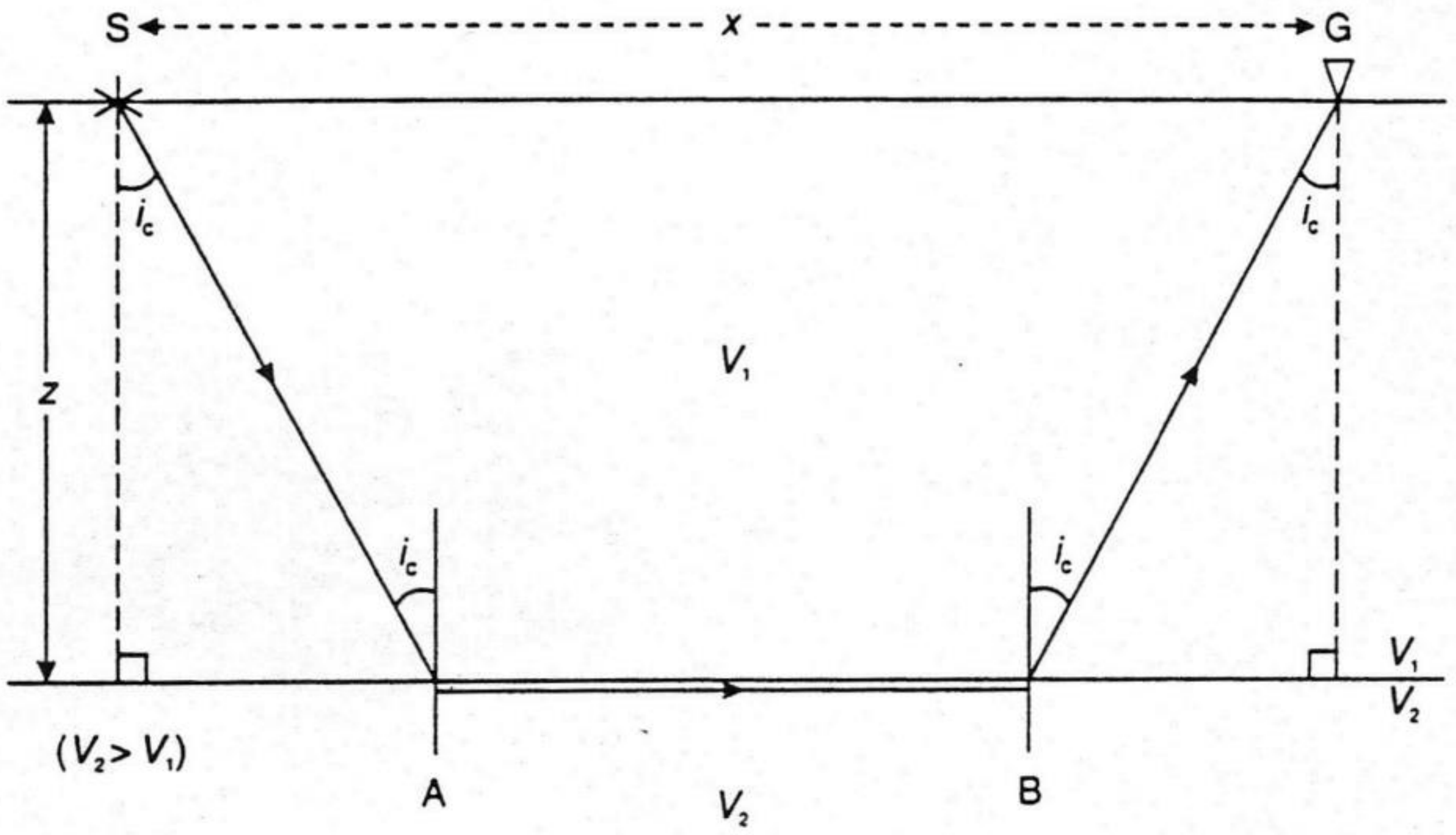
$$T_{SG} = \frac{x - 2z.\tan i_c}{V_2} + \frac{2z}{V_1.\cos i_c}$$

$$T_{SG} = \frac{x}{V_2} + \frac{2z}{V_1.\cos i_c} - \frac{2z.\sin i_c}{V_2.\cos i_c}$$

$$T_{SG} = \frac{x}{V_2} + \frac{2z}{V_1.\cos i_c} - \frac{2V_1.z.\sin i_c}{V_1.V_2.\cos i_c}$$

$$T_{SG} = \frac{x}{V_2} + \frac{2z}{V_1.\cos i_c}\left(1 - \frac{V_1}{V_2}\sin i_c\right)$$

$$T_{SG} = \frac{x}{V_2} + \frac{2z.\cos i_c}{V_1}$$



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Travel time equations: a single horizontal layer

The final equation fits with **y = ax + b**

Where a = gradient

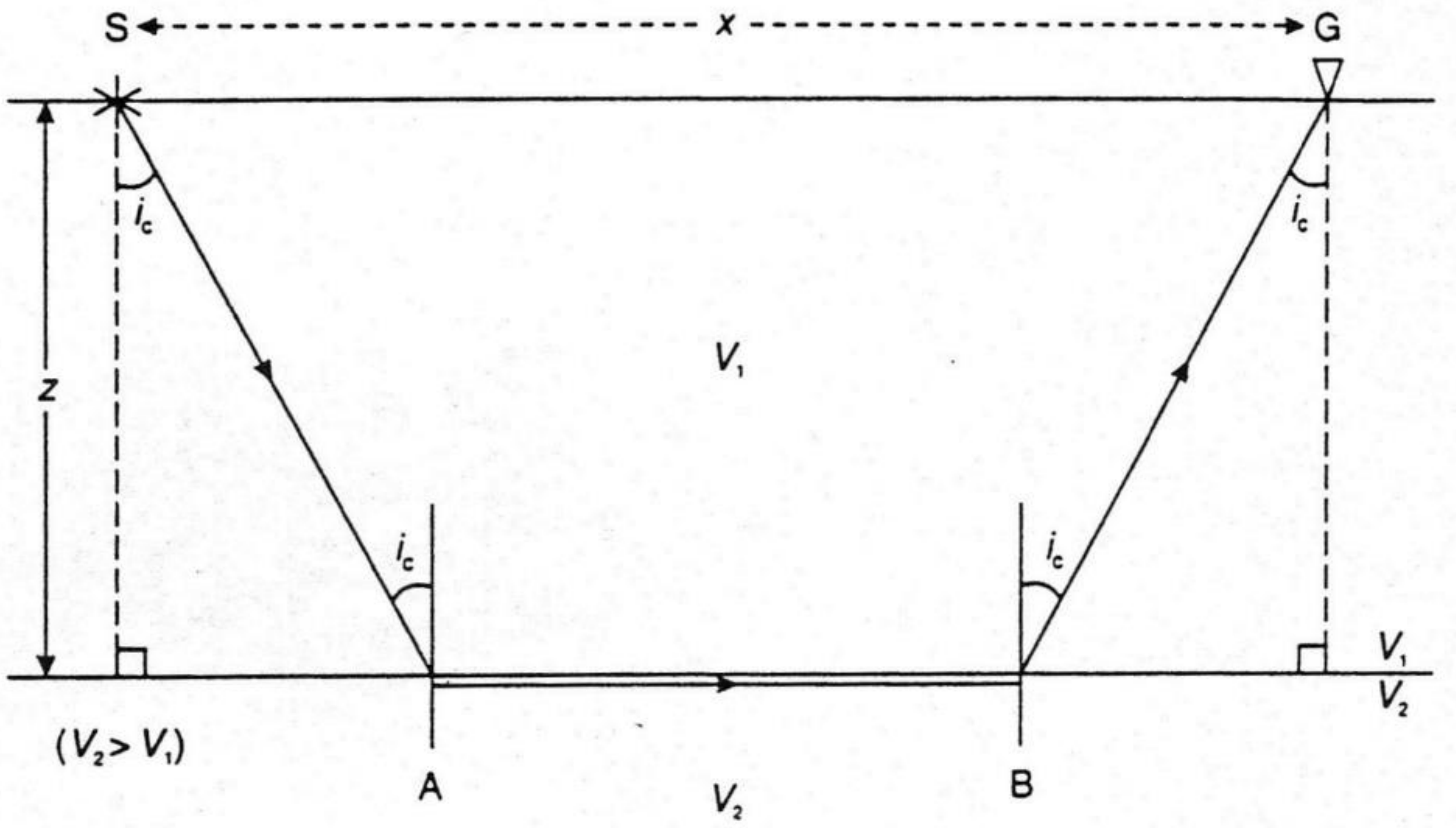
b = interception on Y axis

Otherwise put:

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

$$interception\ time = \frac{2z.\cos i_c}{V_1}$$

$$=> T_{SG} = \frac{x}{V_2} + t_i$$



$$T_{SG} = \frac{x}{V_2} + \frac{2z.\cos i_c}{V_1}$$

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REFRACTION SEISMIC SURVEYING

Travel time equations: a single horizontal layer

Calculation of the interception time t_i and depth z

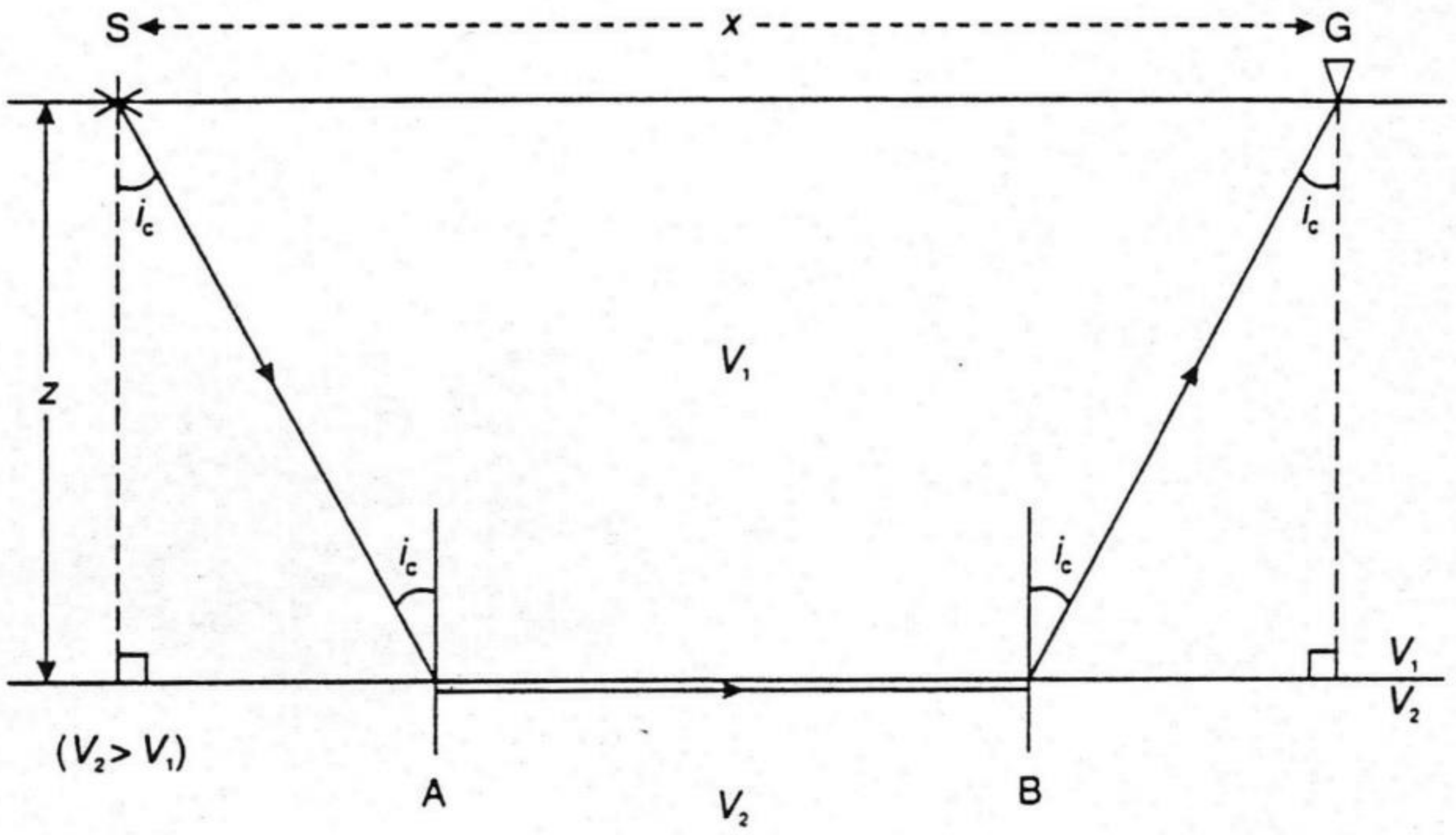
$$(1)\ \sin i_c = \frac{V_1}{V_2}$$

$$(2)\ \sin^2 i_c + \cos^2 i_c = 1$$

As a consequence :

$$\cos^2 i_c = 1 - \sin^2 i_c$$

$$\cos i_c = \sqrt{1 - \frac{V_1^2}{V_2^2}}$$



$$t_i = \frac{2z.\cos i_c}{V_1}$$

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REFRACTION SEISMIC SURVEYING

Travel time equations: a single horizontal layer

Calculation of the interception time t_i and depth z

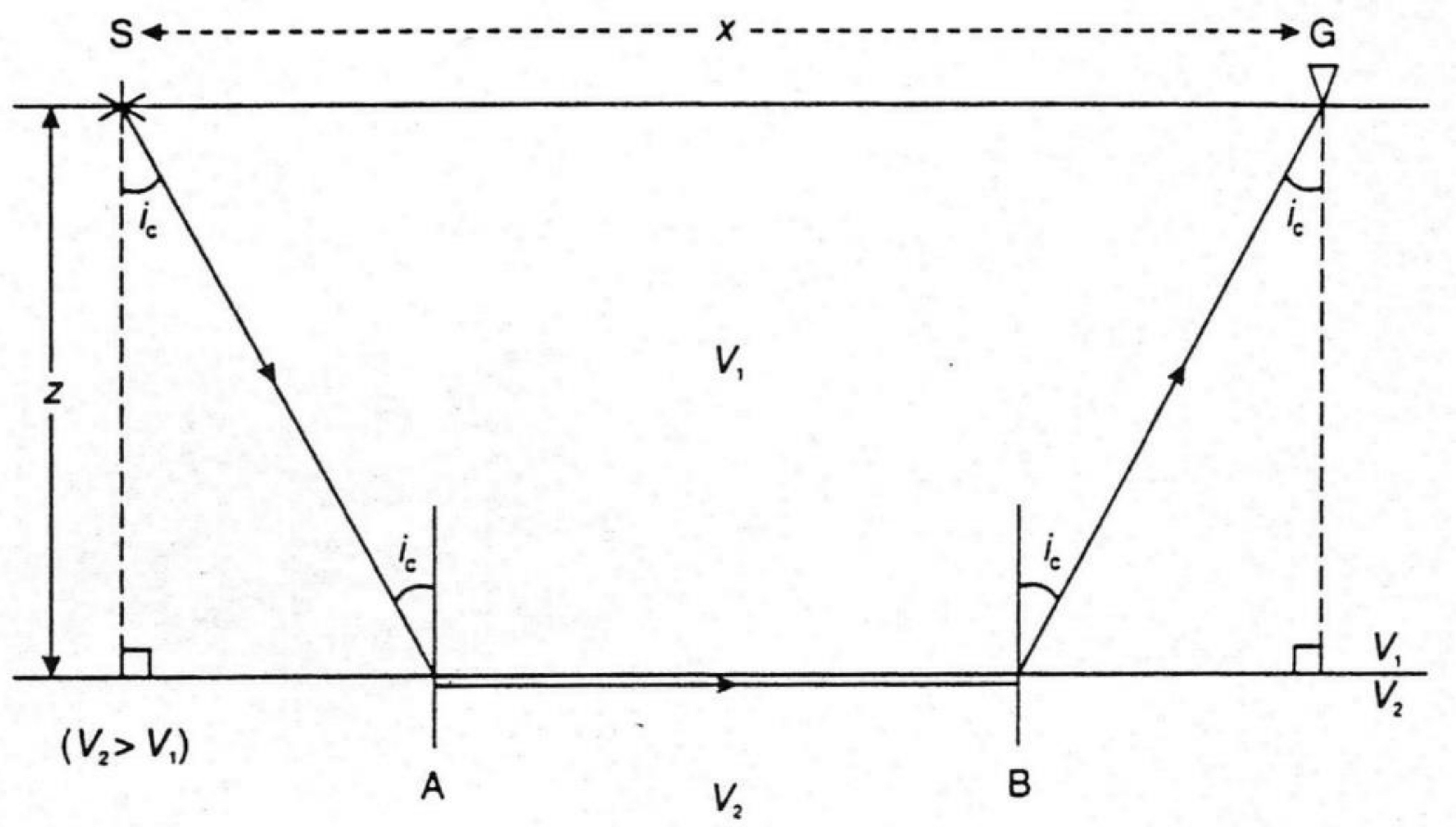
$$t_i = \frac{2z.\cos i_c}{V_1}$$

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

$$t_i = \frac{2z}{V_1 V_2}\sqrt{V_2^2 - V_1^2}$$

and

$$z = \frac{t_i . V_1 V_2}{2\sqrt{V_2^2 - V_1^2}}$$



$$t_i = \frac{2z.\cos i_c}{V_1}$$

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REFRACTION SEISMIC SURVEYING

Travel time equations: a single horizontal layer

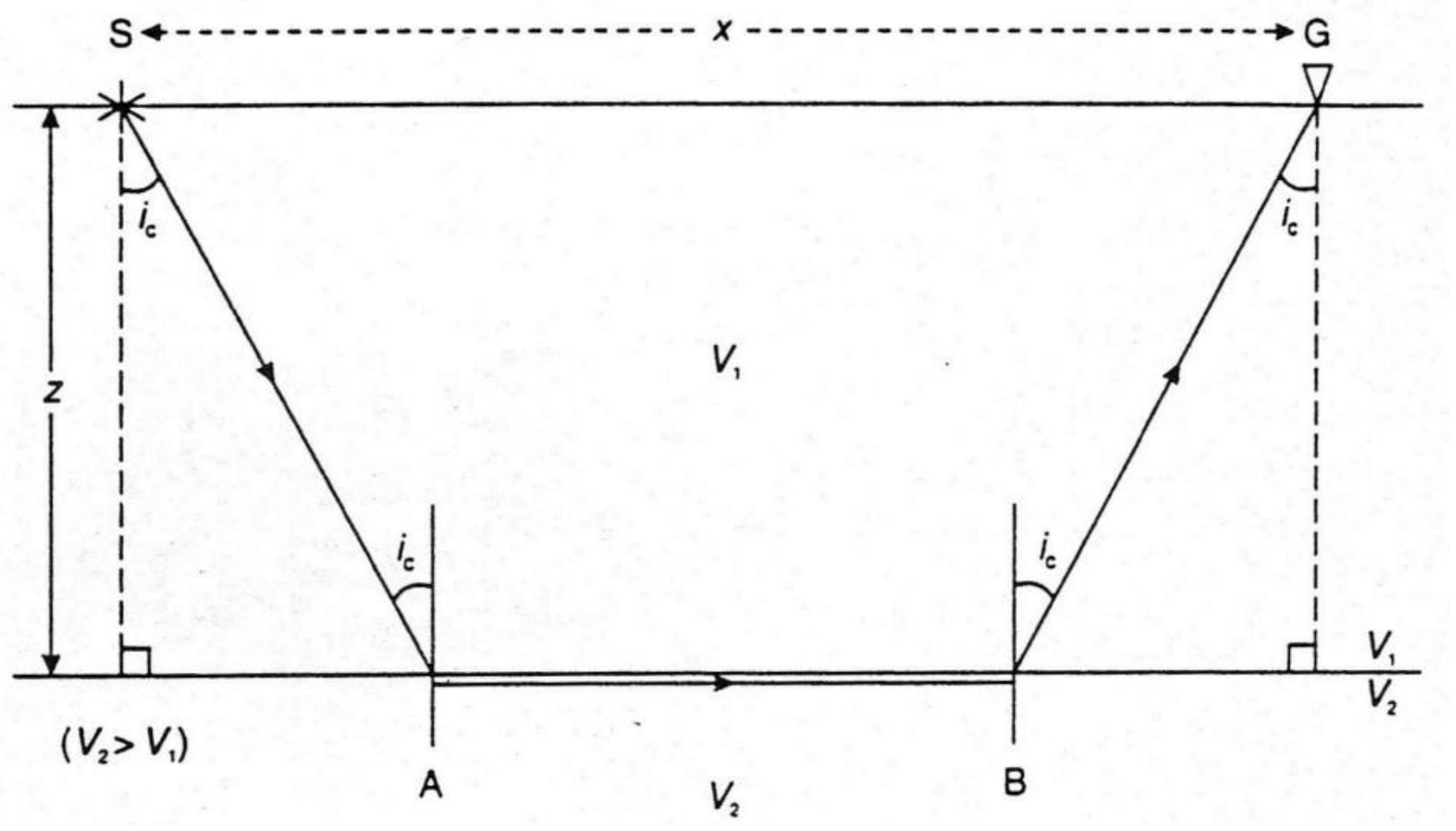
Calculation of the crossover distance x_{cross}

$$Travel\ time\ direct\ ray\ @\ x_{cross}$$

$$t = \frac{x_{cross}}{V_1}$$

$$Travel\ time\ refracted\ ray\ @\ x_{cross}$$

$$T_{SG} = \frac{x}{V_2} + t_i$$



$$T_{SG} = \frac{x}{V_2} + \frac{2z.\cos i_c}{V_1}$$

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REFRACTION SEISMIC SURVEYING

Travel time equations: a single horizontal layer

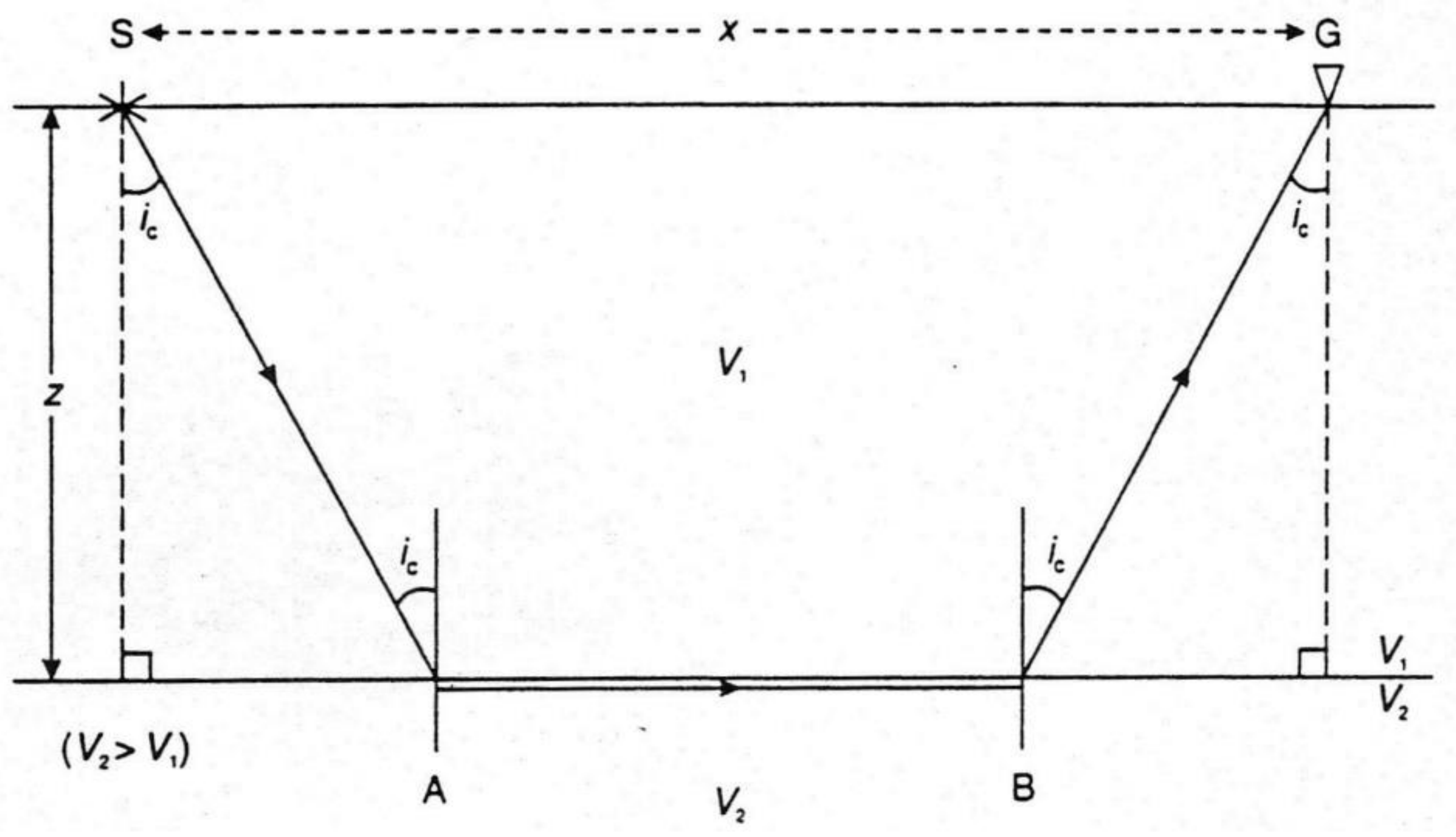
$$\frac{x_{cross}}{V_1} = \frac{x_{cross}}{V_2} + 2z\frac{\sqrt{V_2^2 - V_1^2}}{V_1.V_2}$$

$$x_{cross}.\frac{V_2 - V_1}{V_1.V_2} = 2z\frac{\sqrt{V_2^2 - V_1^2}}{V_1.V_2}$$

$$x_{cross} = 2z\frac{\sqrt{V_2^2 - V_1^2}}{V_2 - V_1}$$

$$x_{cross} = 2z\frac{\sqrt{(V_2 - V_1)(V_2 + V_1)}}{\sqrt{(V_2 - V_1)(V_2 - V_1)}}$$

$$x_{cross} = 2z\sqrt{\frac{(V_2 + V_1)}{(V_2 - V_1)}}$$



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REFRACTION SEISMIC SURVEYING

Travel time equations: two horizontal layers

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

$$T_{SA} = T_{DG} = \frac{z_1}{V_1 \cos\theta_1}$$

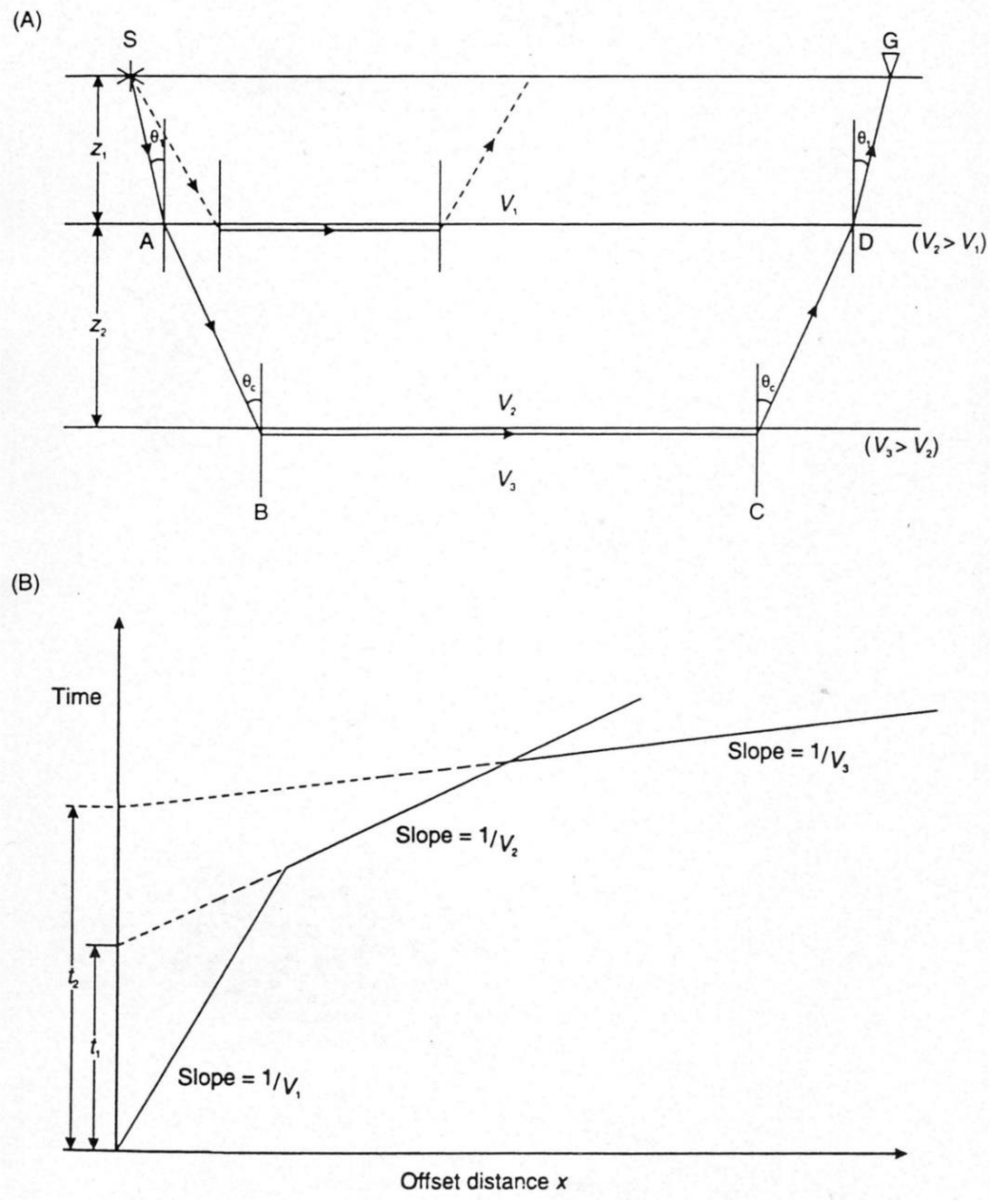
$$T_{AB} = T_{CD} = \frac{z_2}{V_2 \cos\theta_c}$$

$$T_{BC} = \frac{1}{V_3}\left(x - 2z_1 \tan\theta_1 - 2z_2 \tan\theta_c\right)$$

$$\sin\theta_1 = \frac{V_1}{V_2}$$

$$\sin\theta_c = \frac{V_2}{V_3}$$

$$\frac{\sin\theta_1}{V_1} = \frac{\sin\theta_c}{V_2} = \frac{1}{V_3}$$



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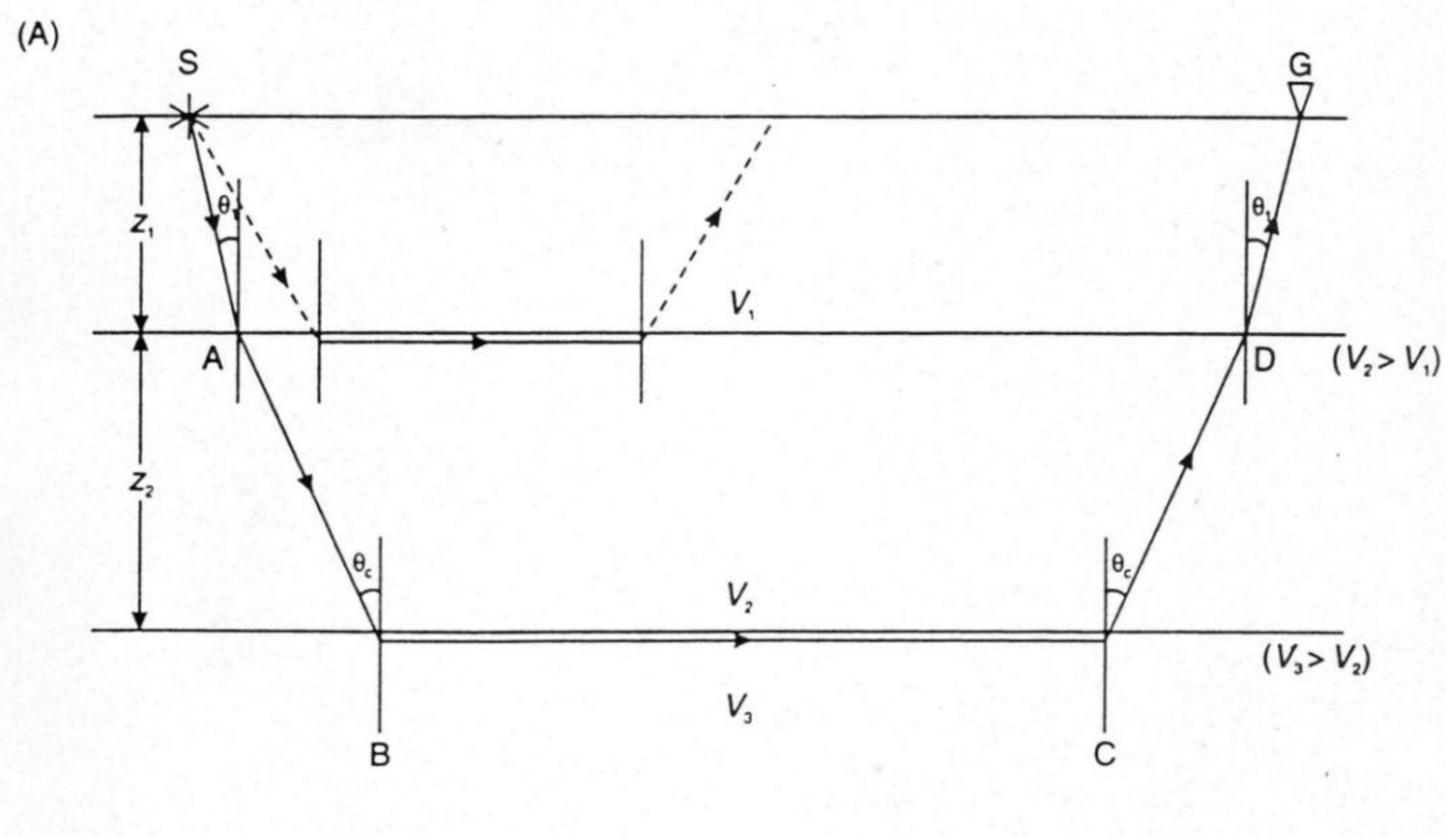
REFRACTION SEISMIC SURVEYING

Travel time equations: two horizontal layers

$$T_{SG} = \frac{x}{V_3} - \frac{2z_1 \tan\theta_1}{V_3} - \frac{2z_2 \tan\theta_c}{V_3} + \frac{2z_1}{V_1 \cos\theta_1} + \frac{2z_2}{V_2 \cos\theta_c}$$

$$T_{SG} = \frac{x}{V_3} + \frac{2z_1 \cos\theta_1}{V_1} - \frac{2z_2 \cos\theta_c}{V_2}$$

$$T_{SG} = \frac{x}{V_3} + t_2$$



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REFRACTION SEISMIC SURVEYING

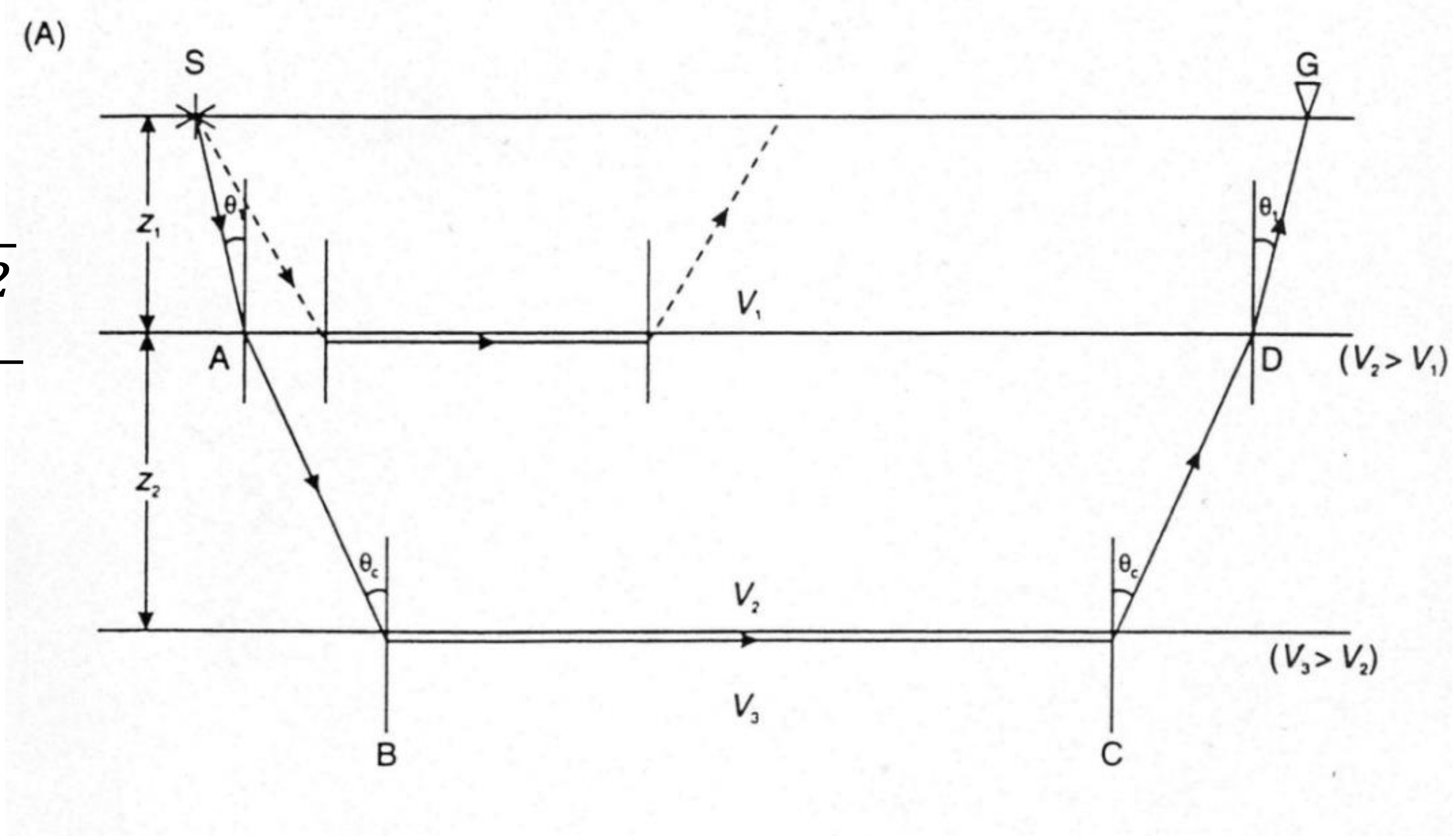
Travel time equations: two horizontal layers

$$t_2 = \frac{2z_1 \cos\theta_1}{V_1} - \frac{2z_2 \cos\theta_c}{V_2}$$

Whereas $z_1 = D_1 = \dfrac{t_1 V_1 V_2}{2\sqrt{V_2^2 - V_1^2}}$

Thus, in replacing $\cos\theta_1$ *and* $\cos\theta_c$

$$t_2 = \frac{t_2 V_2 V_3}{2\sqrt{V_3^2 - V_2^2}} - \frac{z_1 V_2 \sqrt{V_3^2 - V_1^2}}{V_1 \sqrt{V_3^2 - V_2^2}}$$



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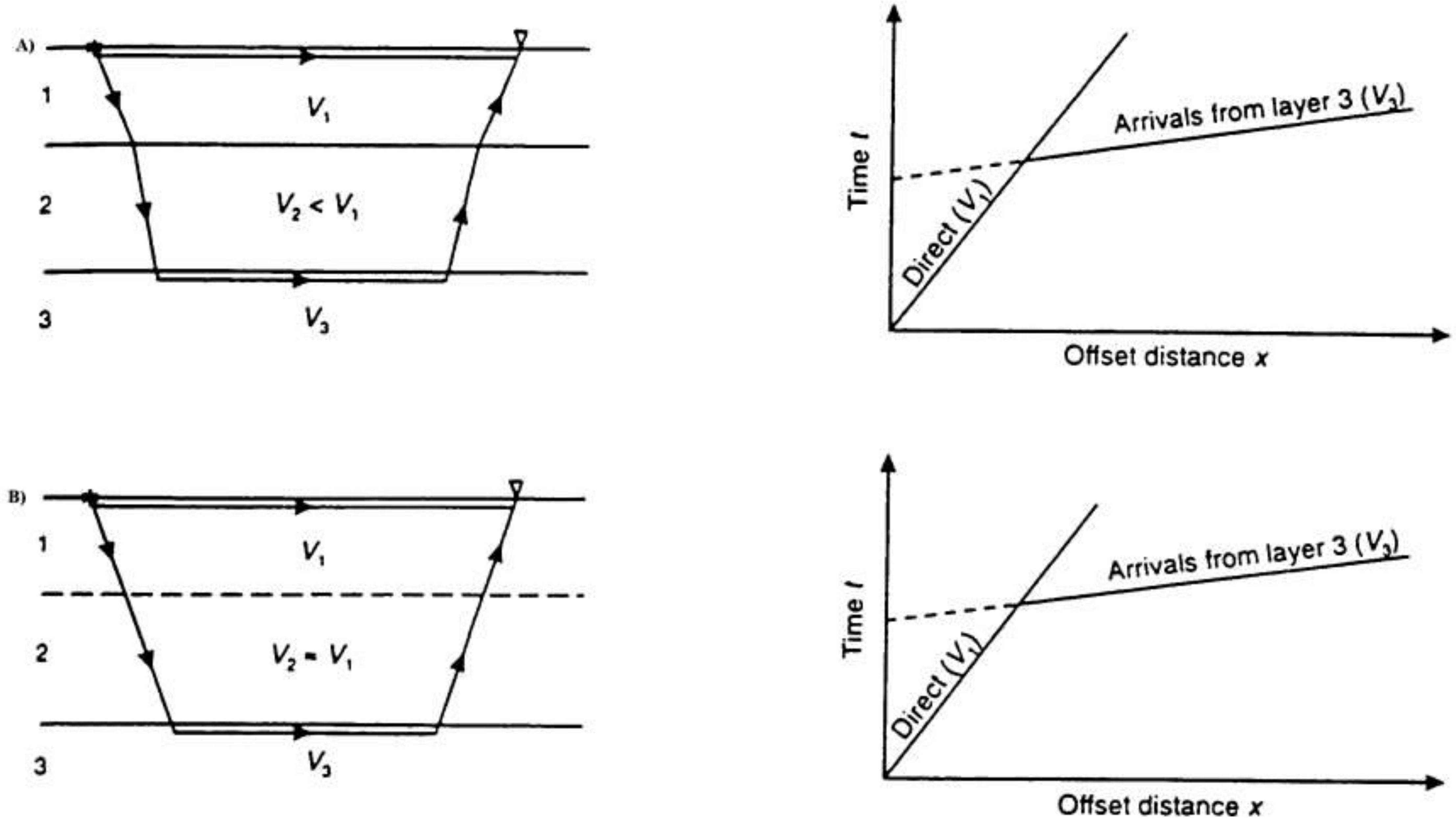
REFRACTION SEISMIC SURVEYING

Hidden layers: velocity-related effects



- Located in between 2 higher velocity layers: no display on t(x) diagram
- Wrong depth calculations: interception time / crossover distance

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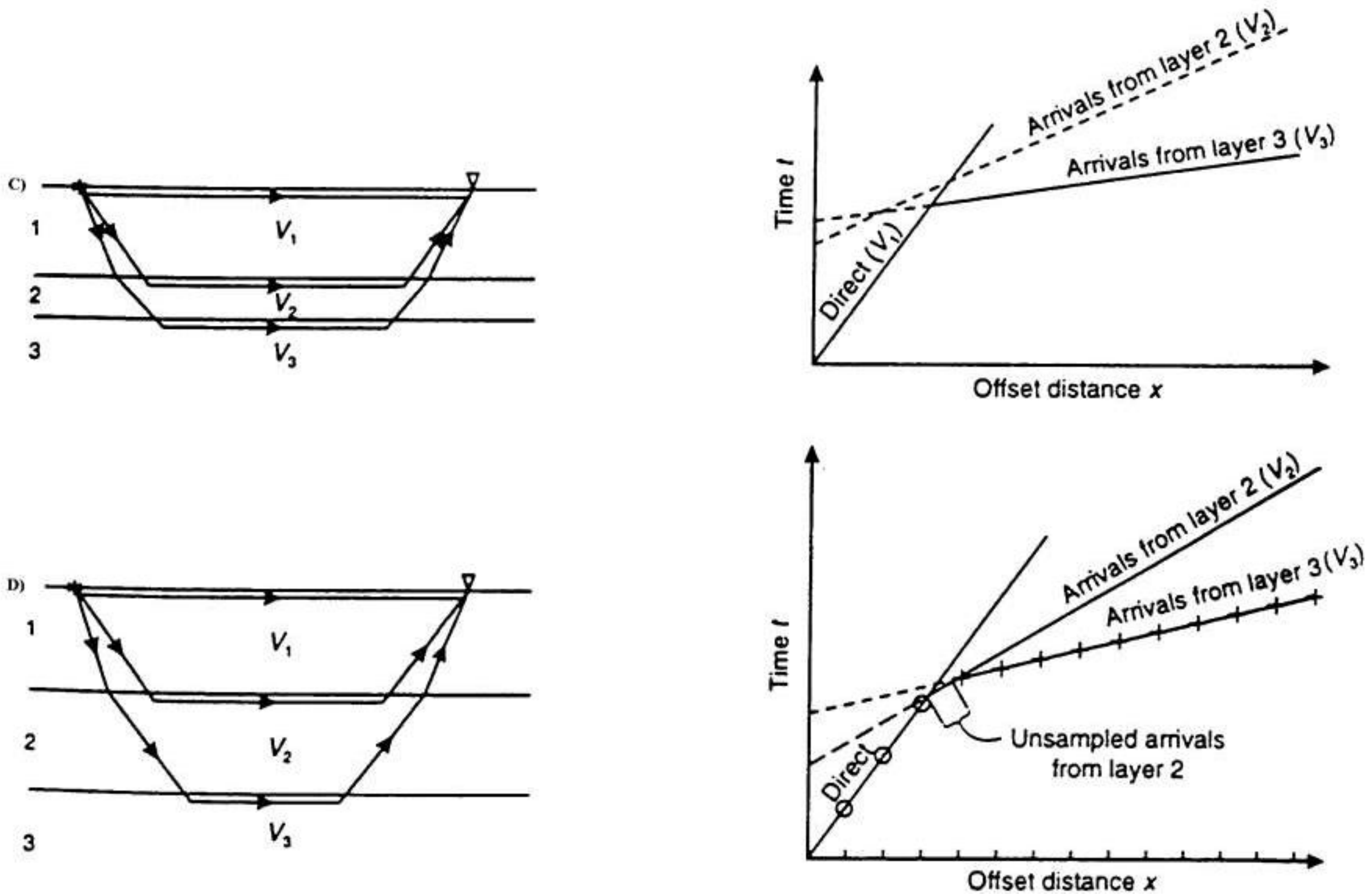
REFRACTION SEISMIC SURVEYING

Hidden layers: thickness-related effects



– There will always be the formation of a head wave

– But the head wave of layer 2 will be passed by a deeper one

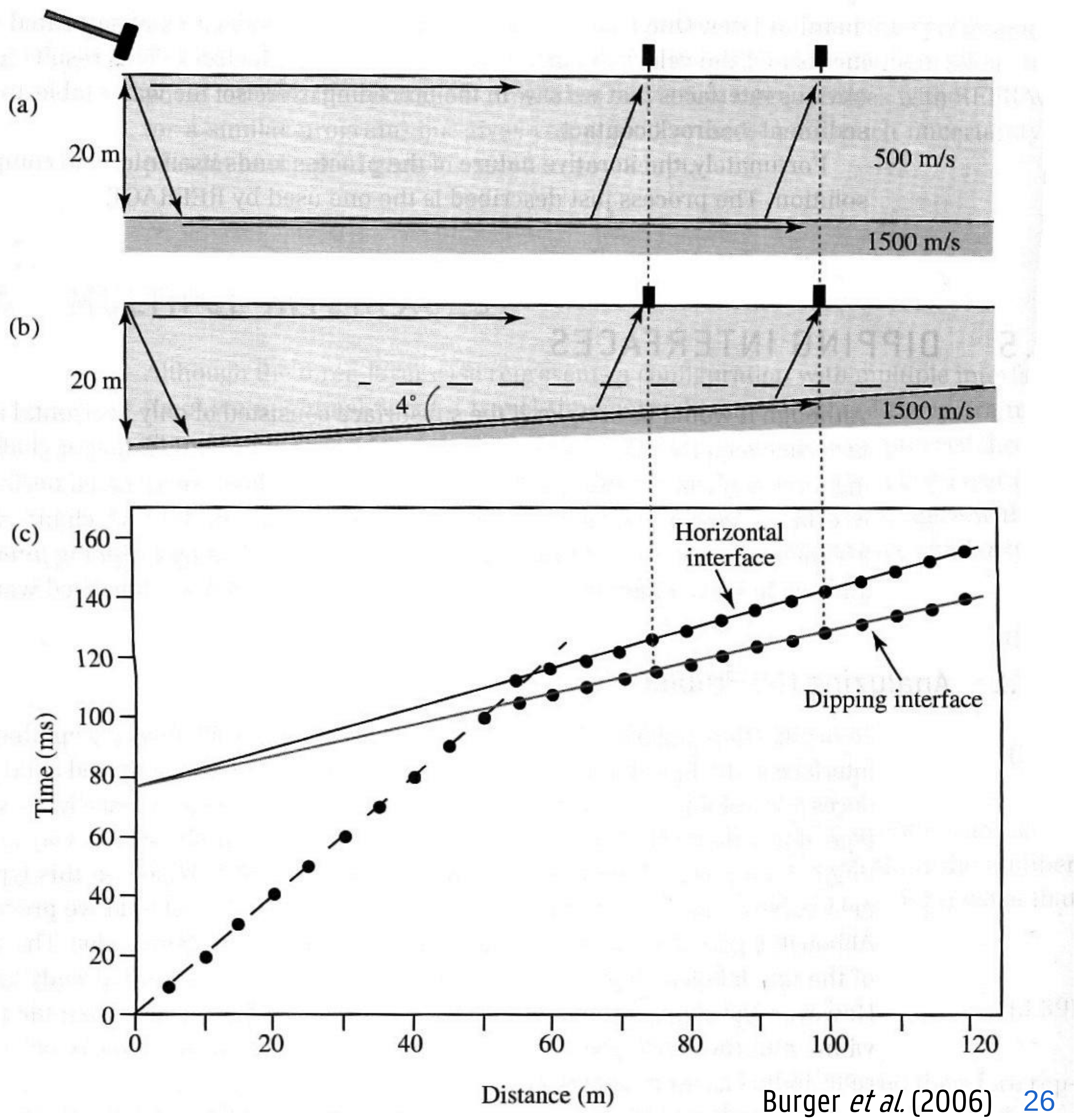
REFRACTION SEISMIC SURVEYING

The problem of sloping layers

a) Horizontal interface at a depth of 20 m with velocities above and below the interface of 500 m/s and 1500 m/s

b) Dipping interface with identical depth to that in (a) at the site of the hammer impact and identical velocities

c) Travel time plot



Burger *et al.* (2006)

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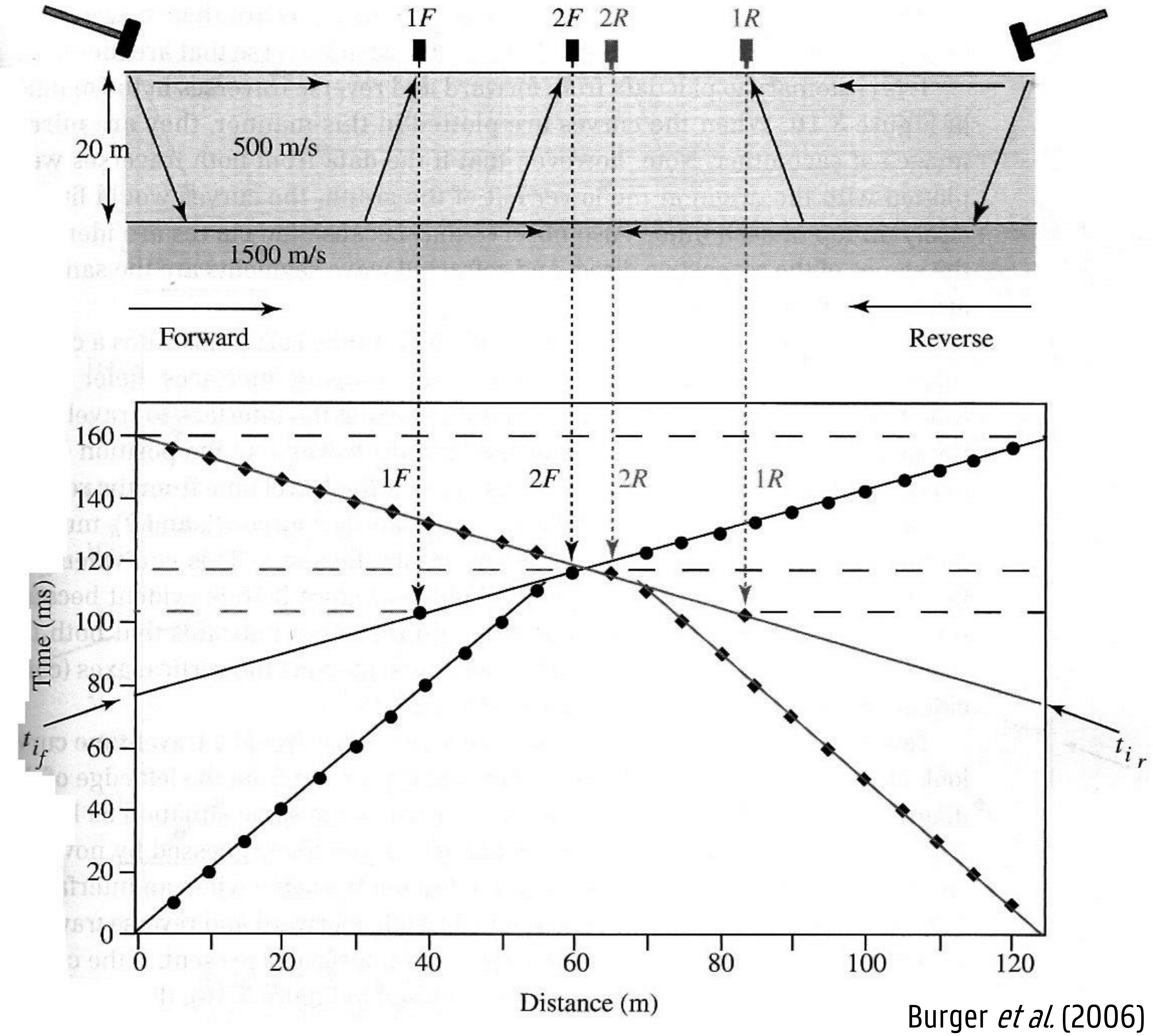
REFRACTION SEISMIC SURVEYING

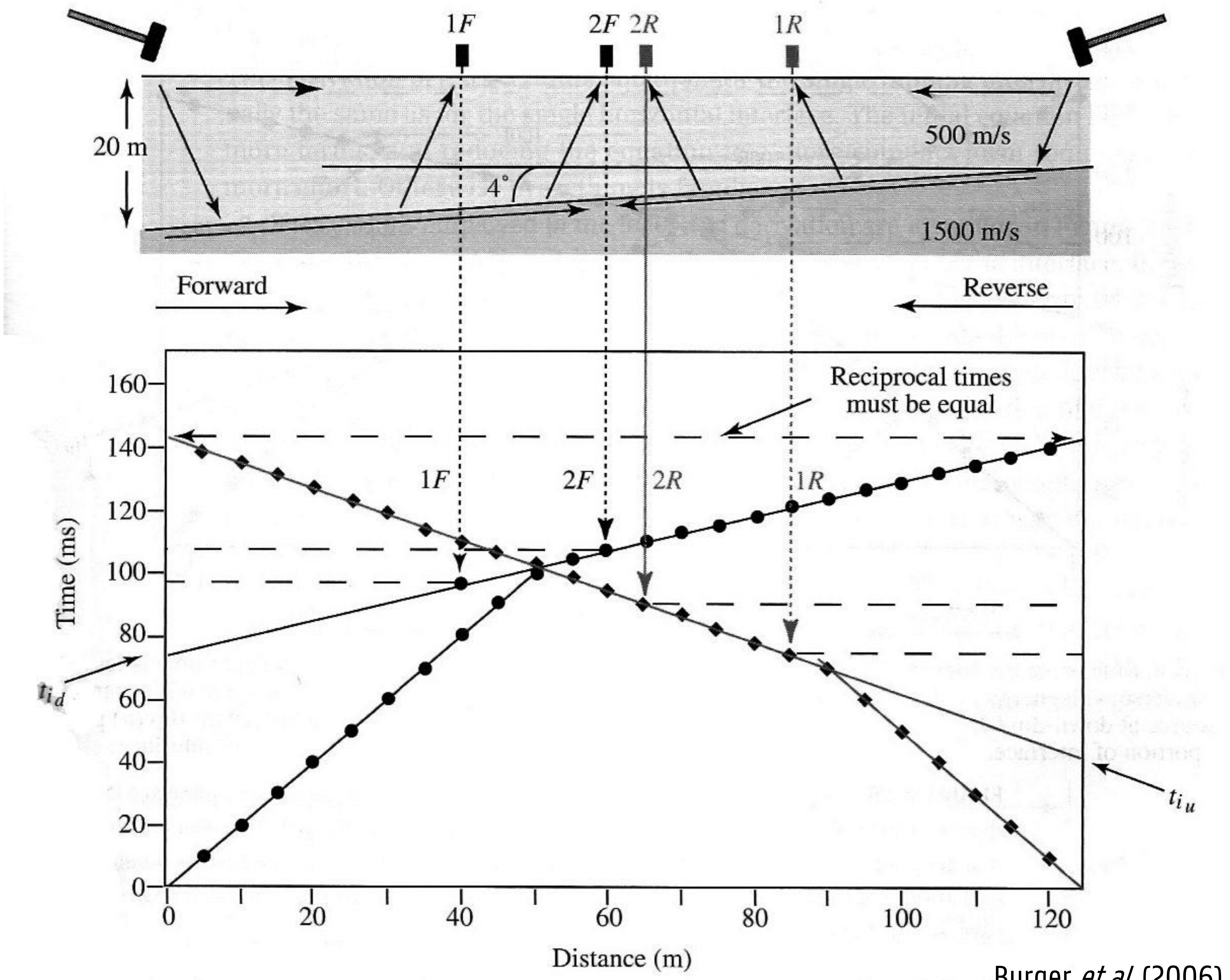
The problem of sloping layers: forward & reverse traverses



Burger *et al.* (2006)

REFRACTION SEISMIC SURVEYING

The problem of sloping layers: forward & reverse traverses



Burger *et al.* (2006)