ISTerre
Institut des Sciences de la Terre

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Part I: Seismic Refraction

Streaming training

http://www.geomatrix.co.uk/training-videos-seismic.php

Other references …

Overview

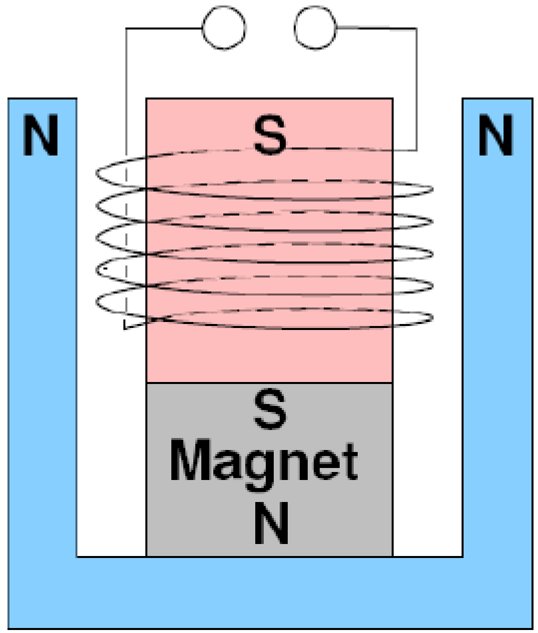
- Introduction

- Chapter 1: Fundamental concepts
- Chapter 2: Material and data acquisition
- Chapter 3: Data interpretation

Material

- Geophones
- Recording device (Computer, Seismograph)
- Source (hammer, explosives)
- Battery
- Cables
- (Geode)

Material: Geophones



Geophones need a good connection to the ground to decrease the S/N ratio (can be buried)

Geophones could record also horizontal motion and should be oriented for radial or transverse motion.

Geophones could be passive or active: method of zero-technology.

Material: Cable, Geode

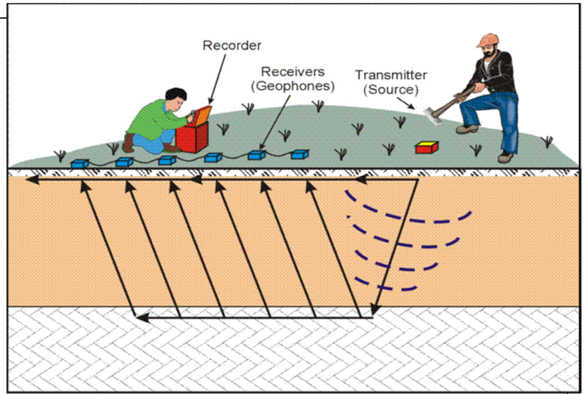
Material: Energy Source

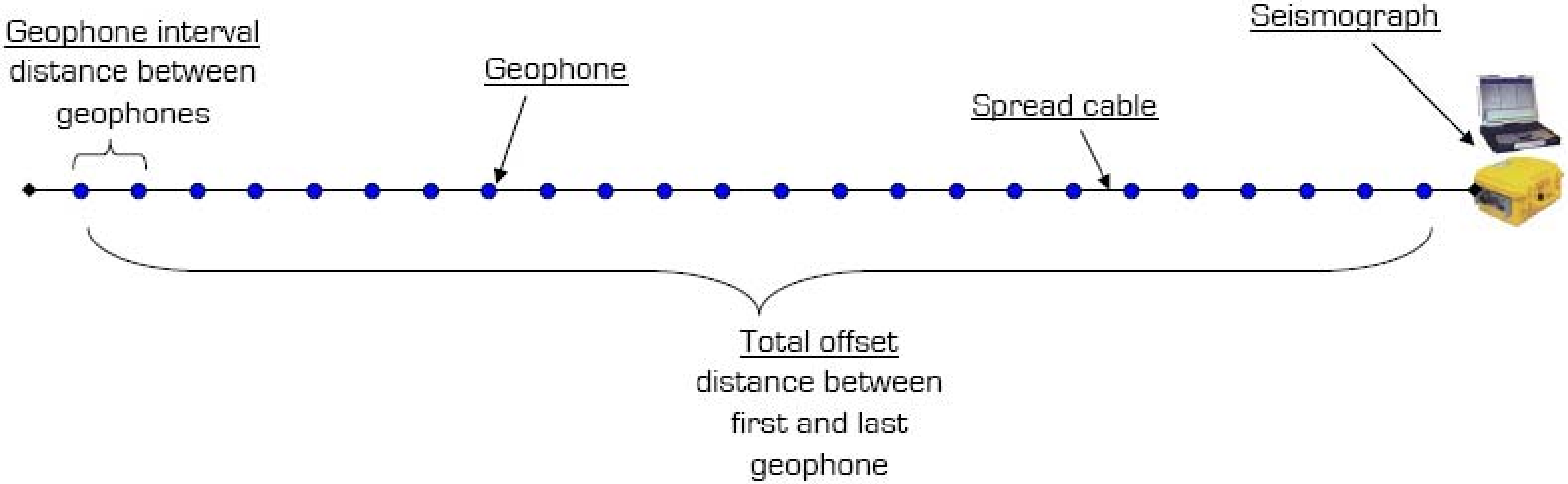
- Sledge hammer (Easy to use, cheap)
- Buffalo gun (More energy)
- Explosives (Much more energy, licence required)
- Drop weight (Need a flat area)
- Vibrator (Uncommun use for refraction … but sometimes)
- Air gun (For lake / marine prospection)

Goal: Produce a good energy with high frequencies, Possible investigation depth 10-50 m

You can add (stack) few shots to improve signal/noise ratio

Data acquisition





Number of receivers and spacing between them

=> will define length of the profile and resolution

Number of shots to stack (signal to noise ratio)

Position of shots

Geophone Spacing / Resolution

- Often near surface layers have very low velocities
  - E.g. soil, subsoil, weathered top layers of rock
  - These layers are likely of little interest, but due to low velocities, time spent in them may be significant

To correctly interpret data these layers must be detected

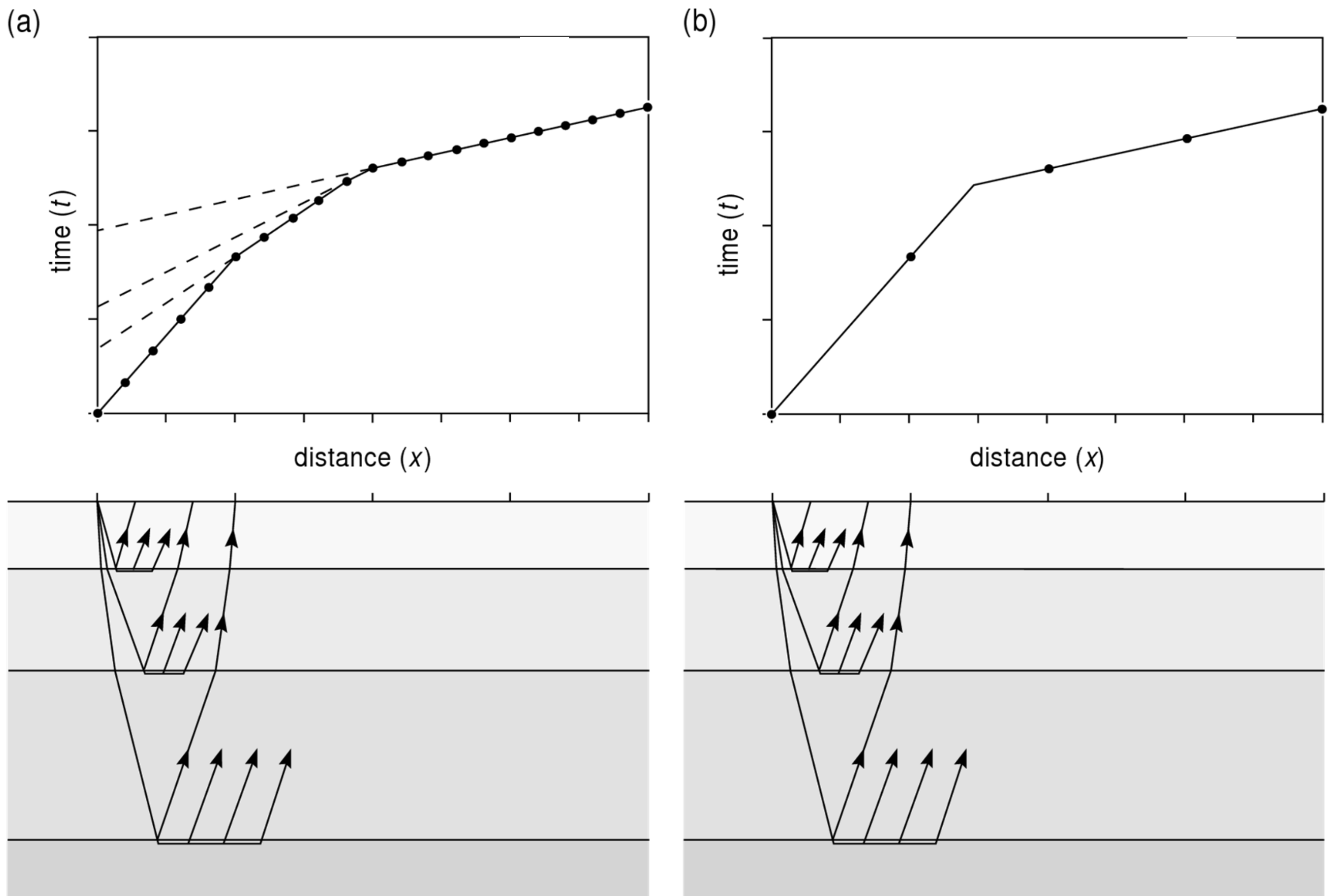
<u>Find compromise between</u>:

Geophone array length needs to be 4-5 times longer than investigation depth

Geophone distance cannot be too large, as thin layer won't be detected

Geophone Spacing / Resolution

- This problem is an example of…?



Overview

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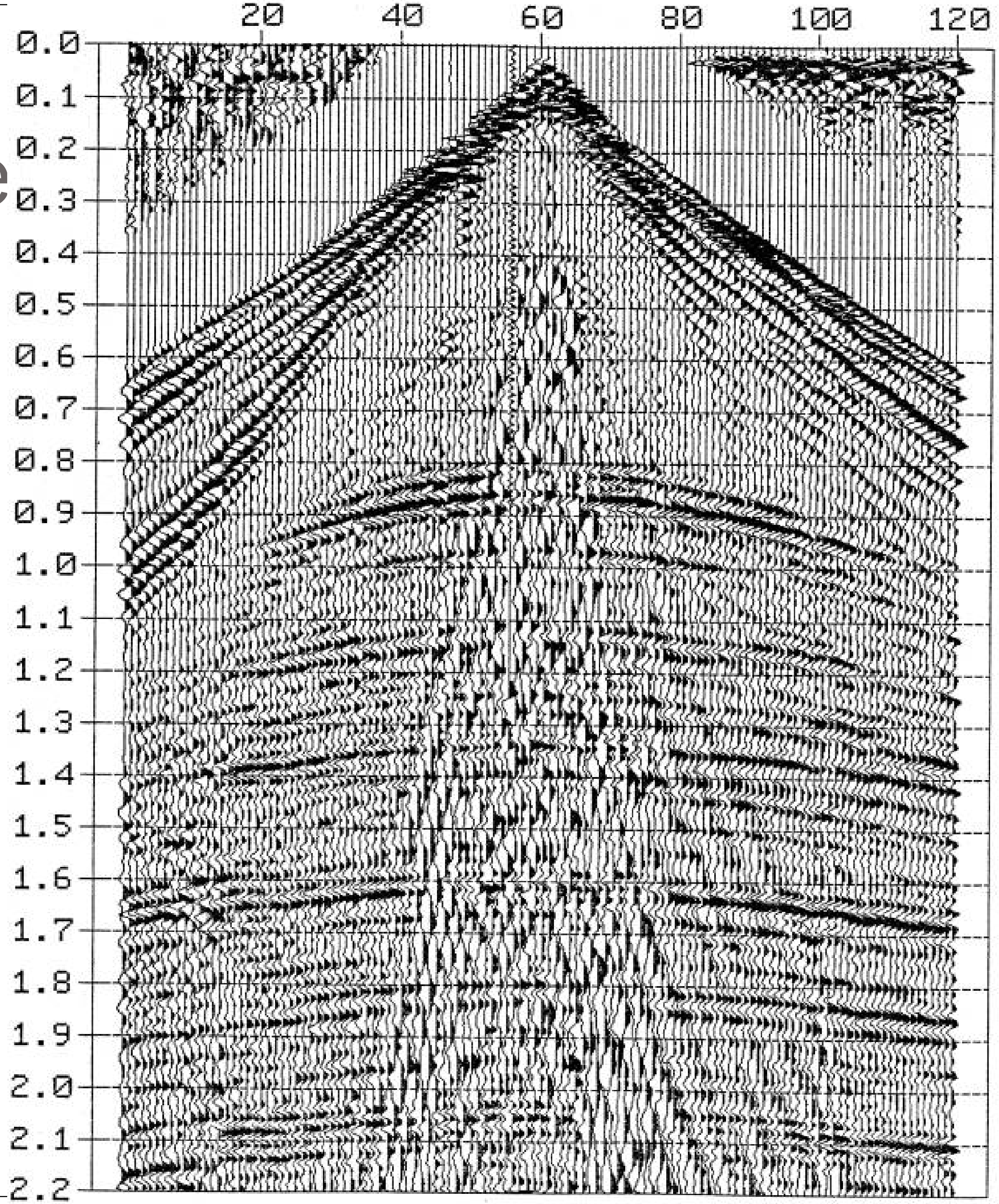
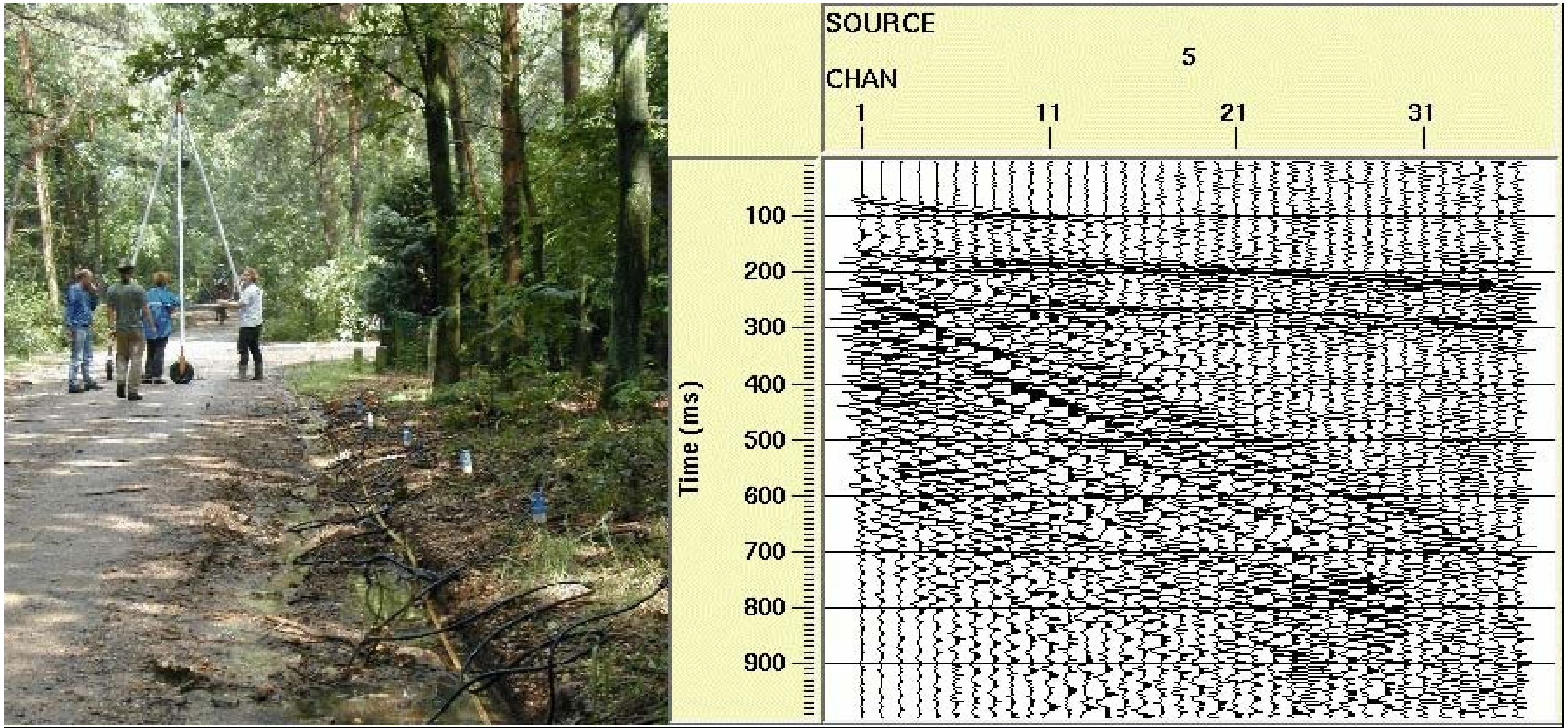
- Chapter 2: Data acquisition and material
- Chapter 3: Data processing and interpretation

Record example

Dynamite shot recorded using a 120-channel recording spread

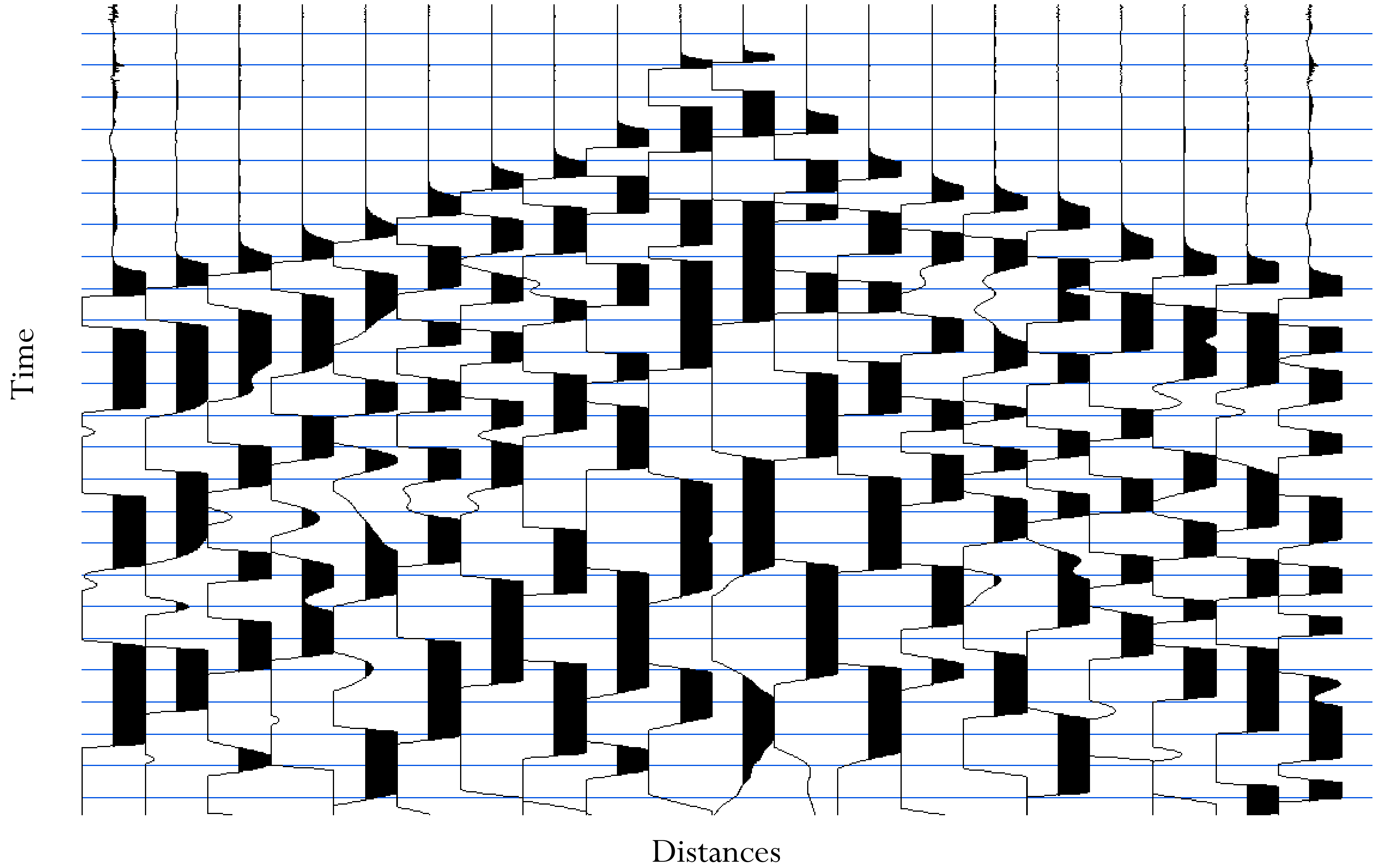


Record example



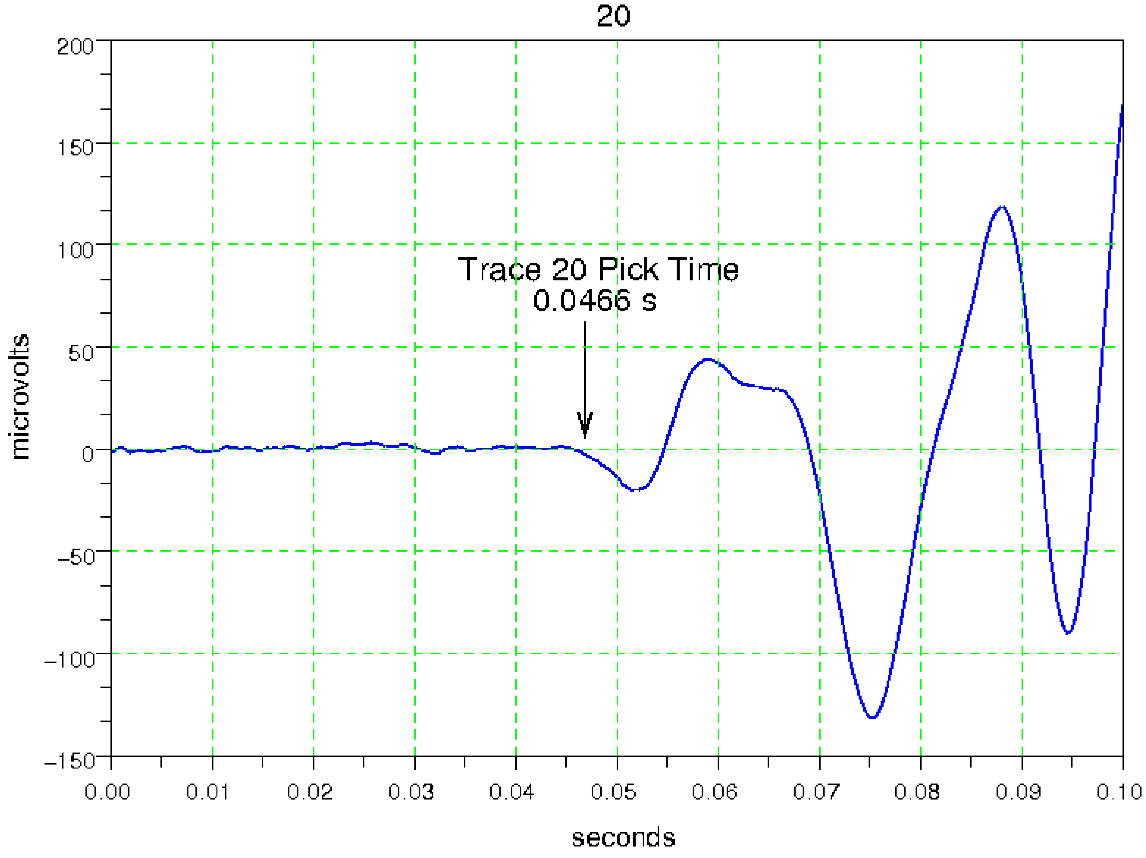
Example of seismic refraction data acquisition where students are using a 'weight-drop' - a 37 kg ball dropped on hard ground from a height of 3 meter - to image the ground to a depth of 1 km

Record example

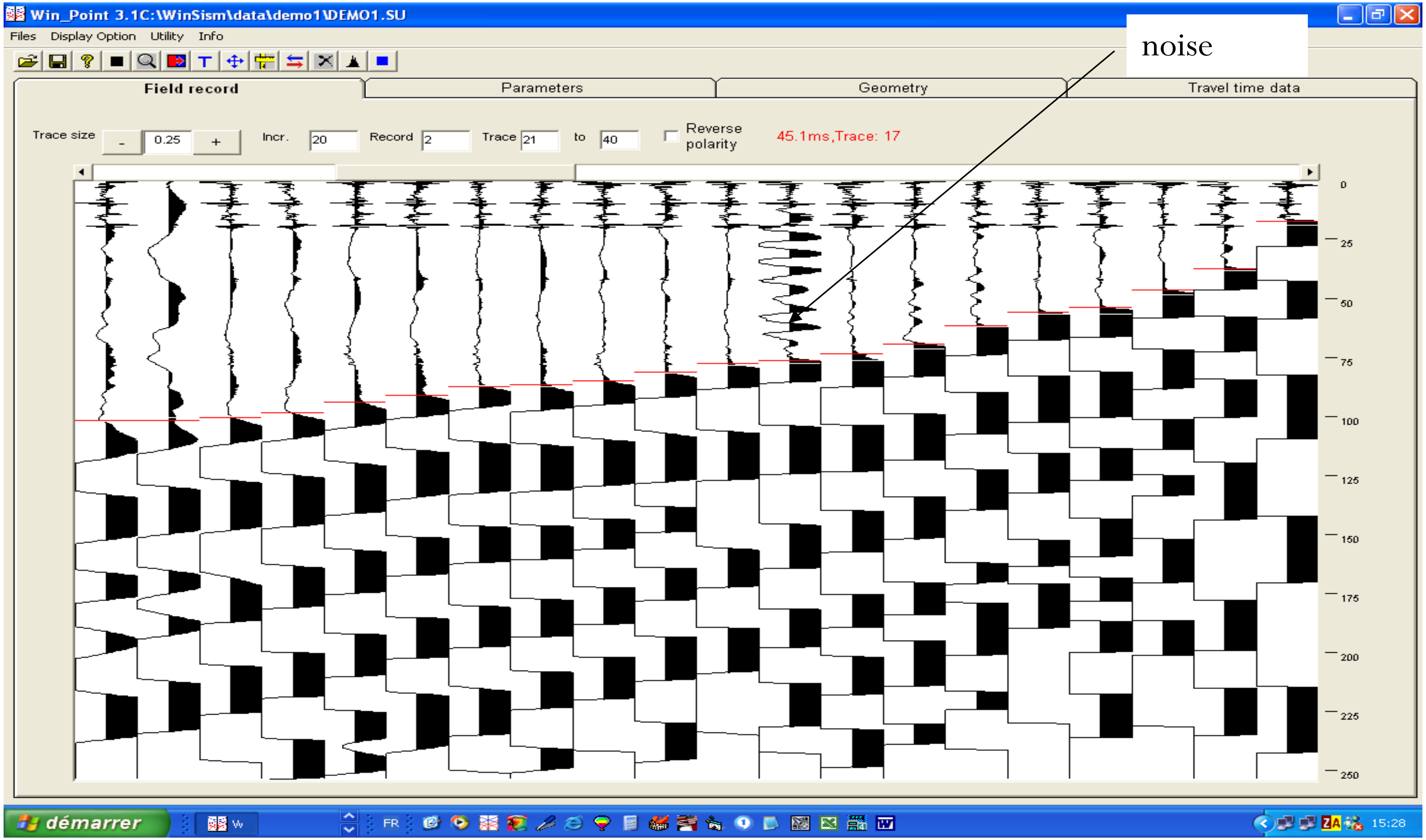


First Break Picking

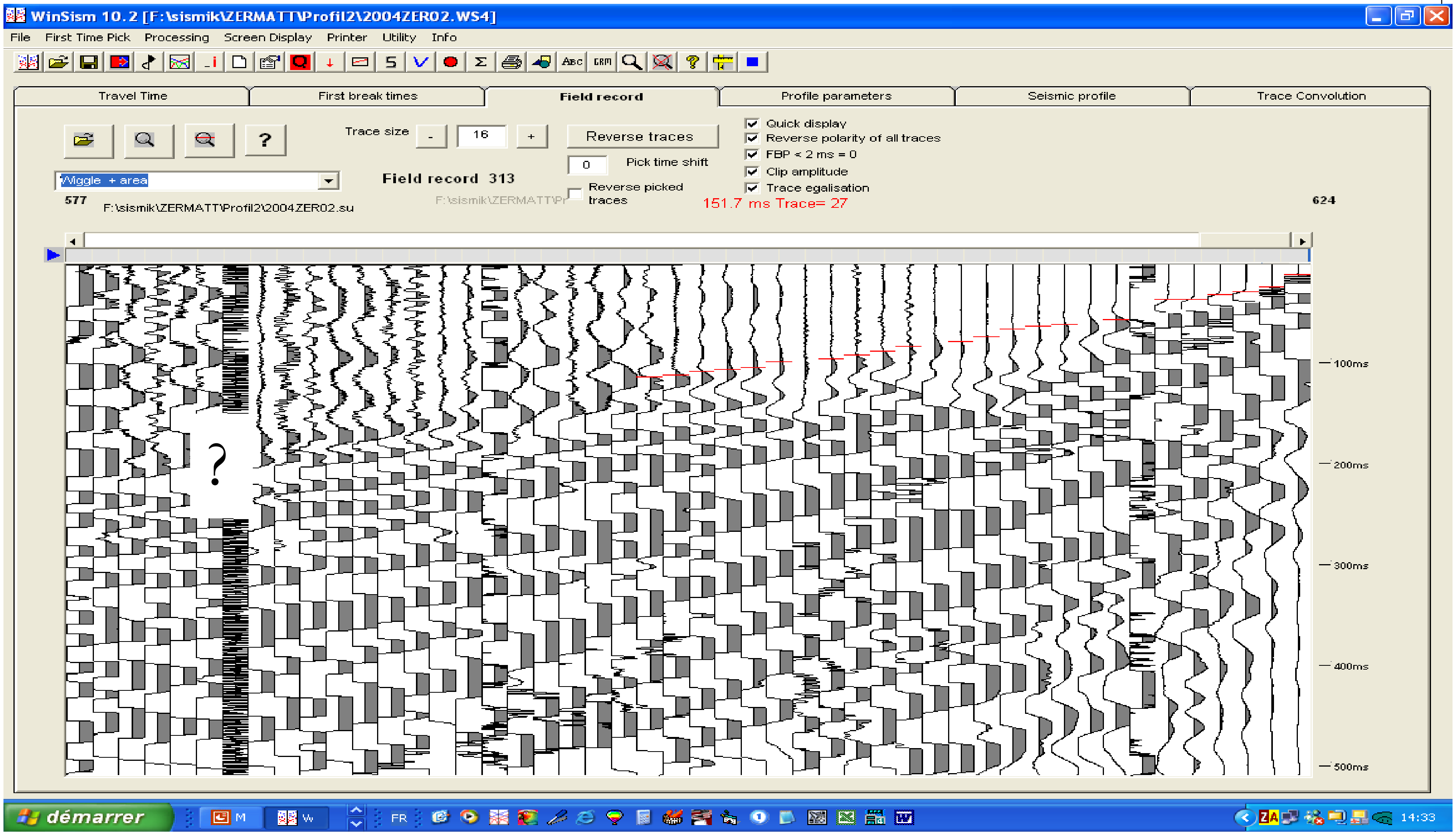
- This is the most important operation, good picking on **good data** !!!!
- A commun problem is the **lack of energy, for far offset geophones**



First Break Picking –on good data

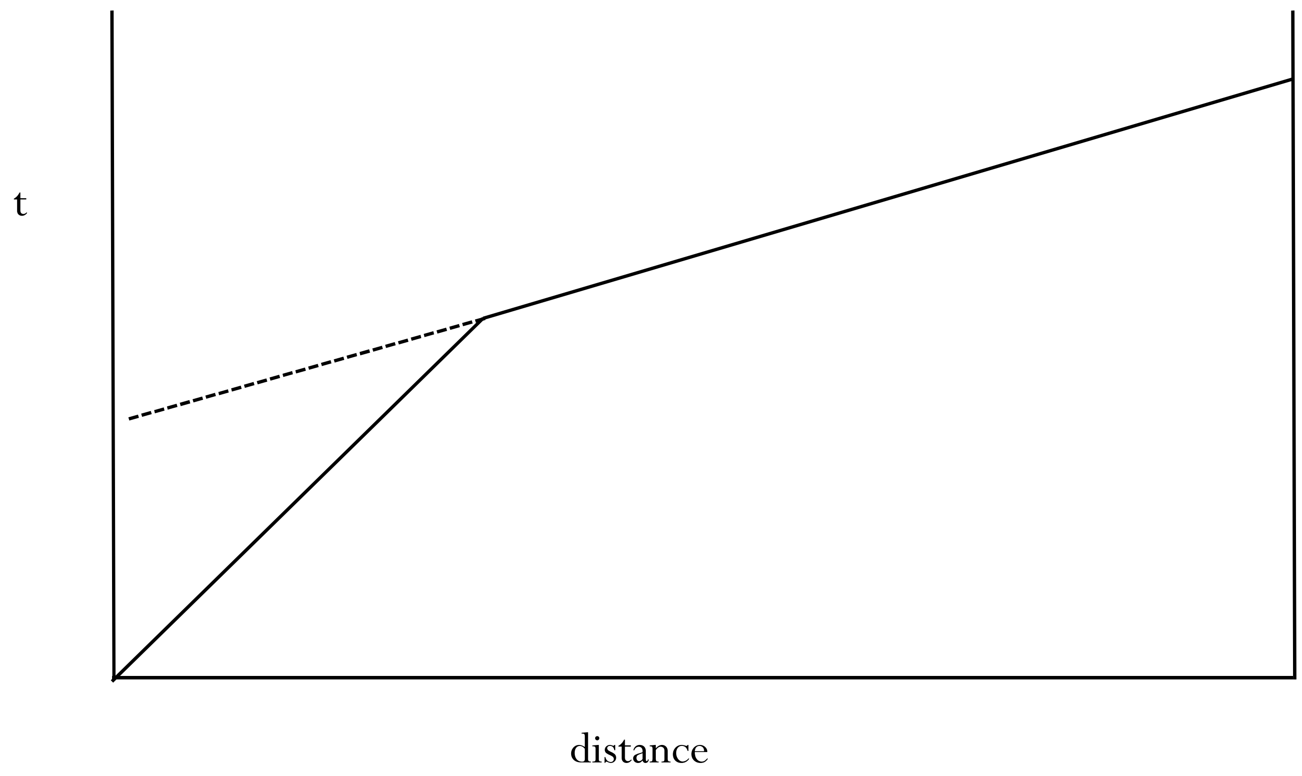


First Break Picking –on poor data



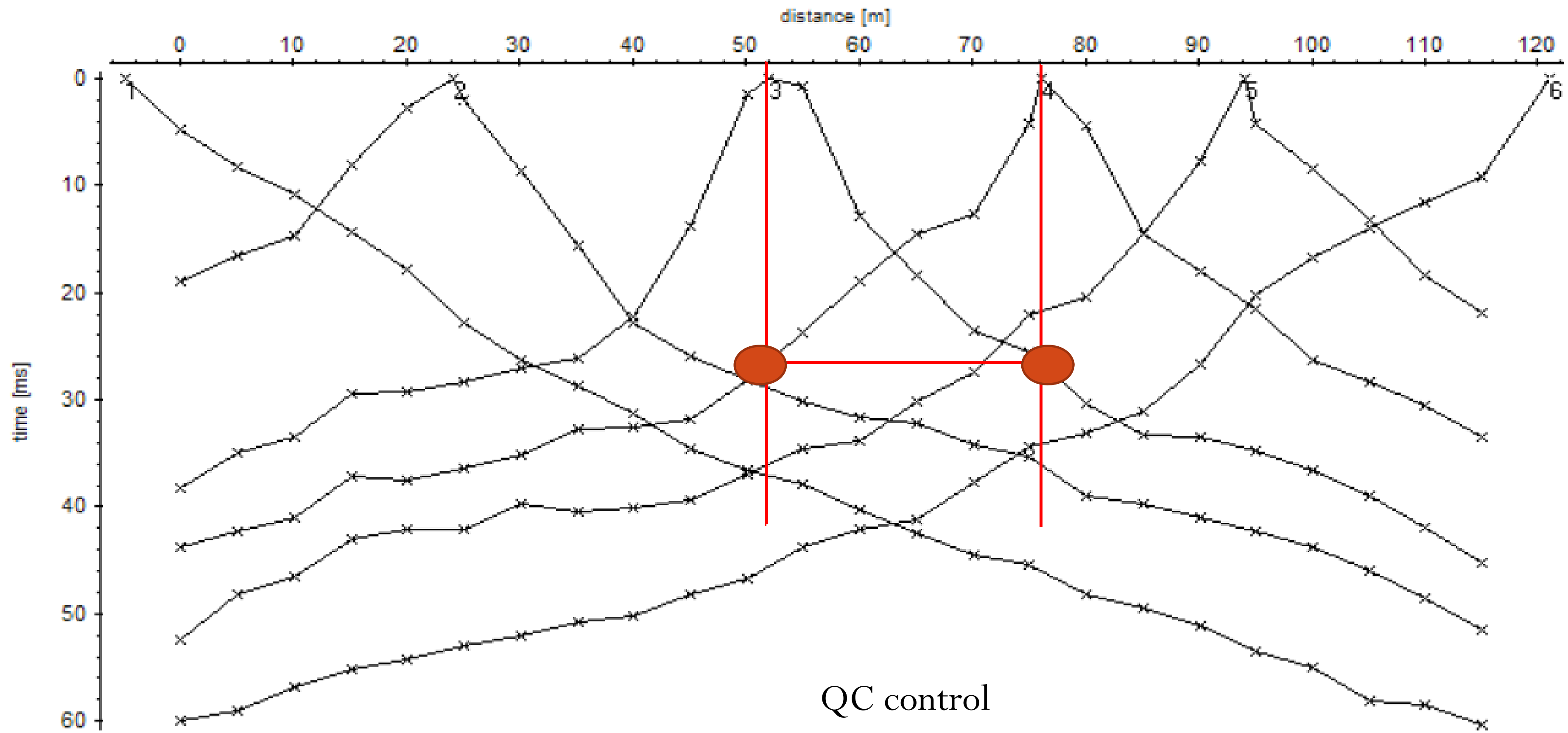
Travel-time curve

How does the inverse shot look like in an planar layered medium?



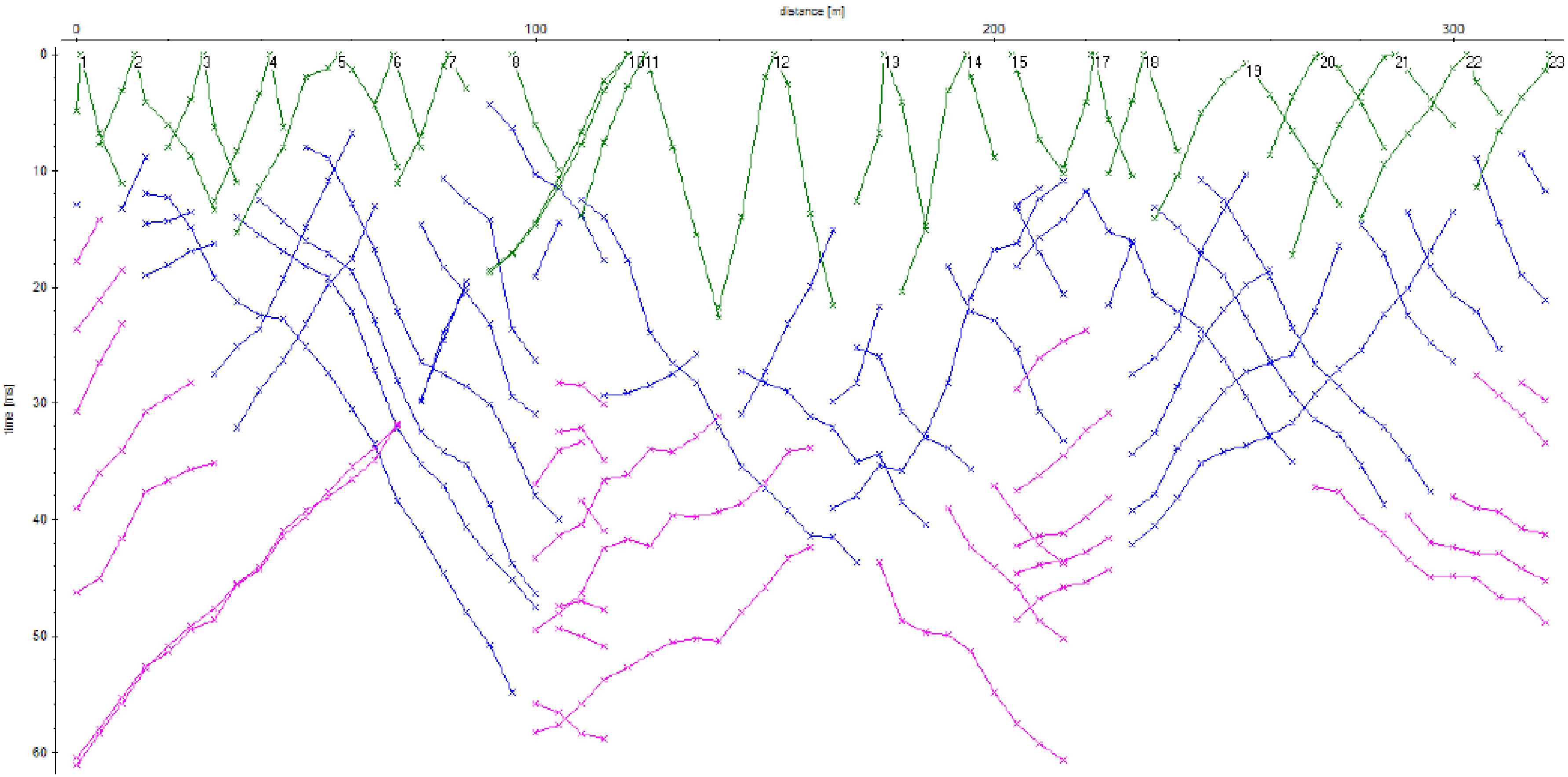
Reciprocity of travel-times

$$t_{AB} = t_{BA}$$



QC control

Assigning different layers



Planar & horizontal interfaces

$$t_n = \frac{x}{v_n} + \sum_{i=1}^{n-1} \frac{2z_i \cos\theta_{in}}{v_i}$$

where

$$\theta_{in} = \sin^{-1}(v_i/v_n)$$

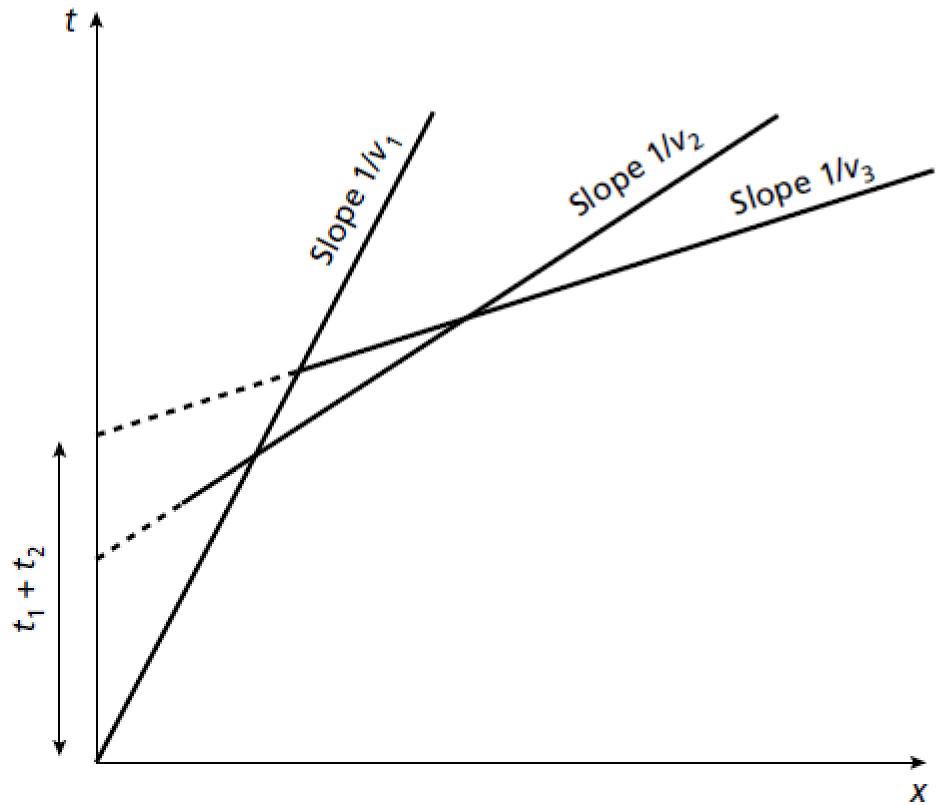
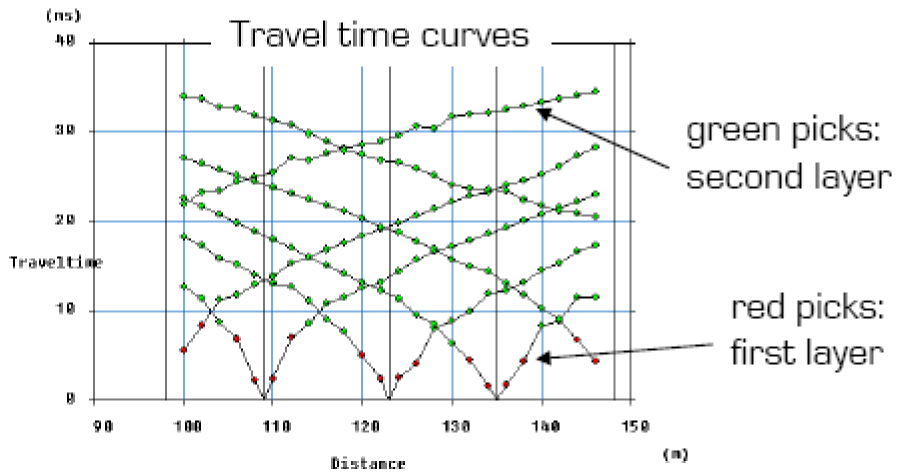
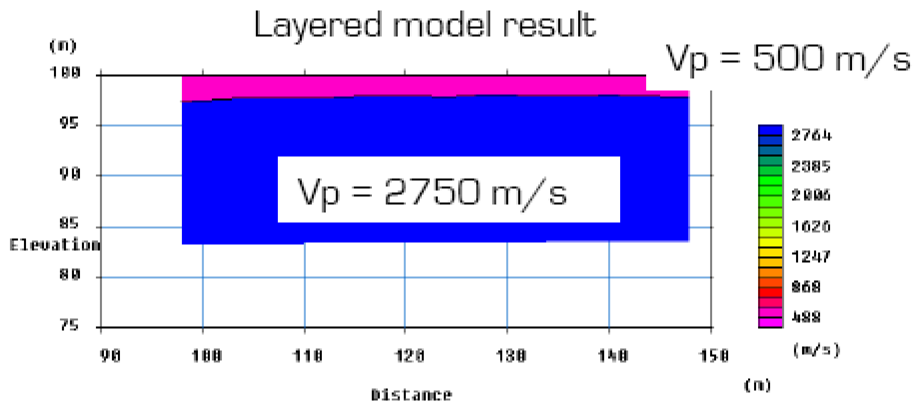


Fig. 5.4 Travel-time curves for the direct wave and the head waves from two horizontal refractors.

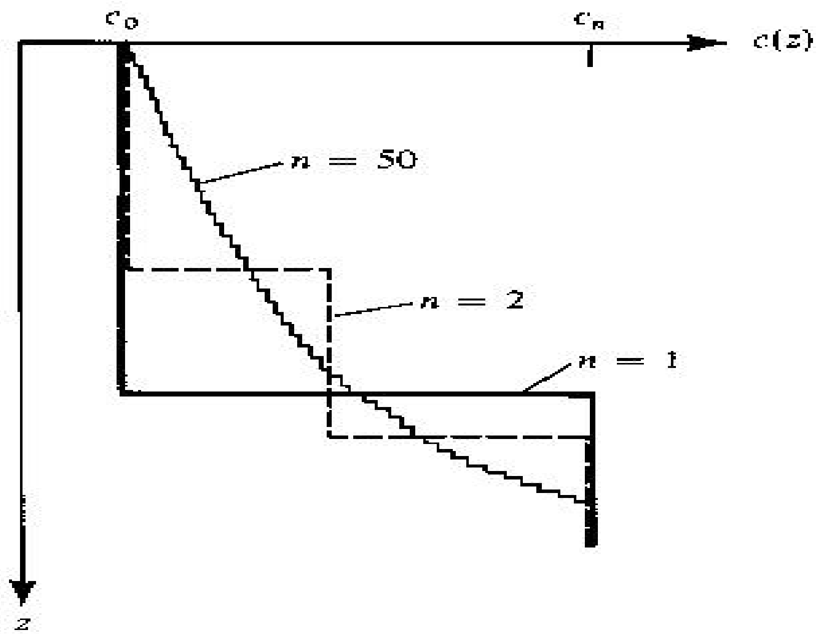
Complete analysis process

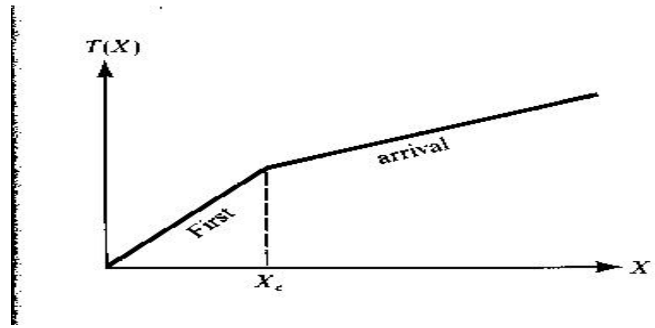
- Pick first breaks
- Select analysis method
  - Time-term inversion gives a quick solution for 2 to 3-layer cases with evident breaks in slope
- Assign layers
- Input elevations (if applicable)
- Run inversion
- Compare calculated to observed data
- Final layered model result





First-arrival time ambiguity





Non-unicity of the medium Converted phases : reflection tomography

Few problems you may think about

Some difficulties

Dipping interfaces

Undulating interfaces

There are two cases where a seismic interface will not be revealed by a refraction survey.

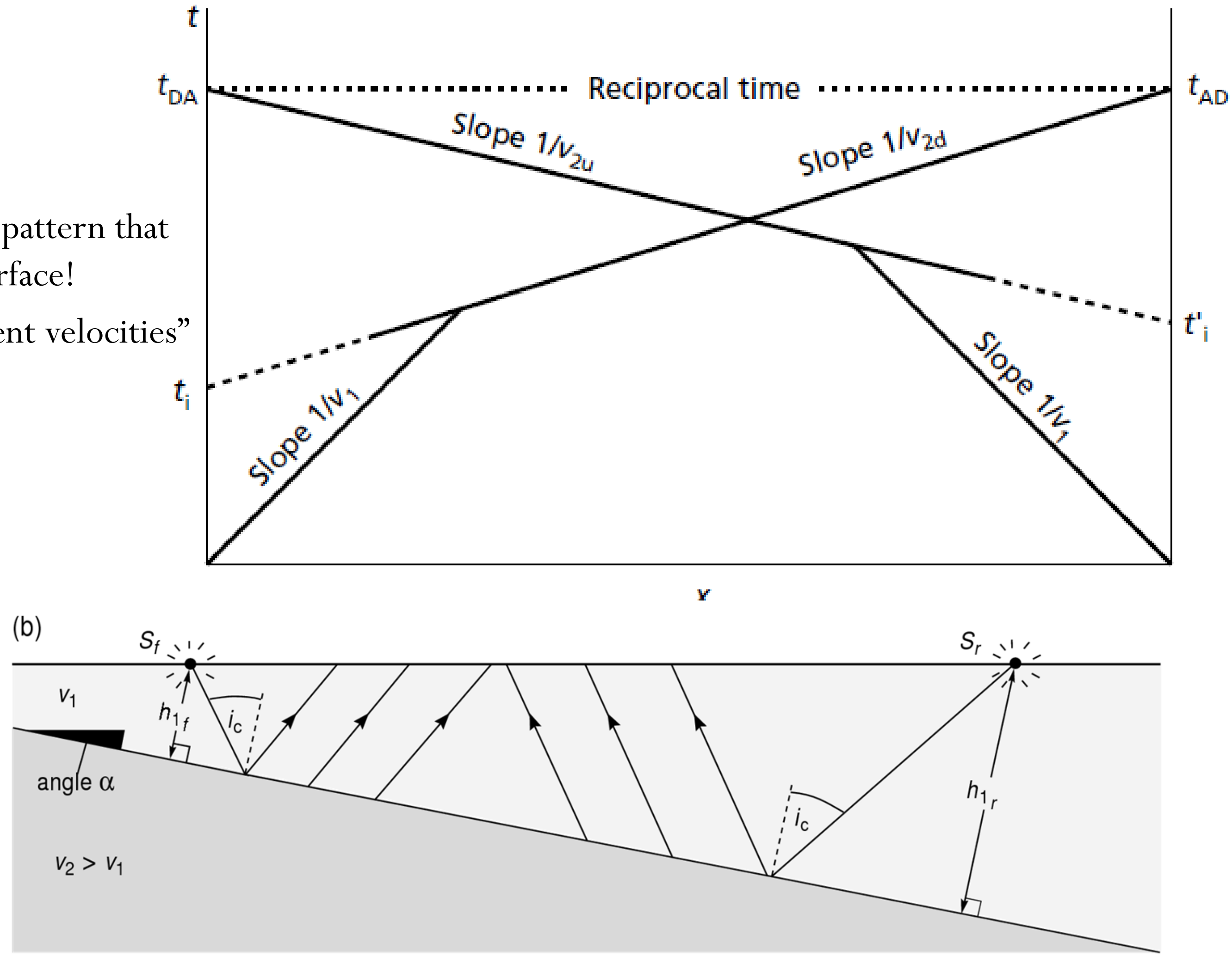
The low velocity layer

The hidden layer

Other features difficult to detect and quantify?

Dipping Interfaces

- What if the critically refracted interface is not horizontal?



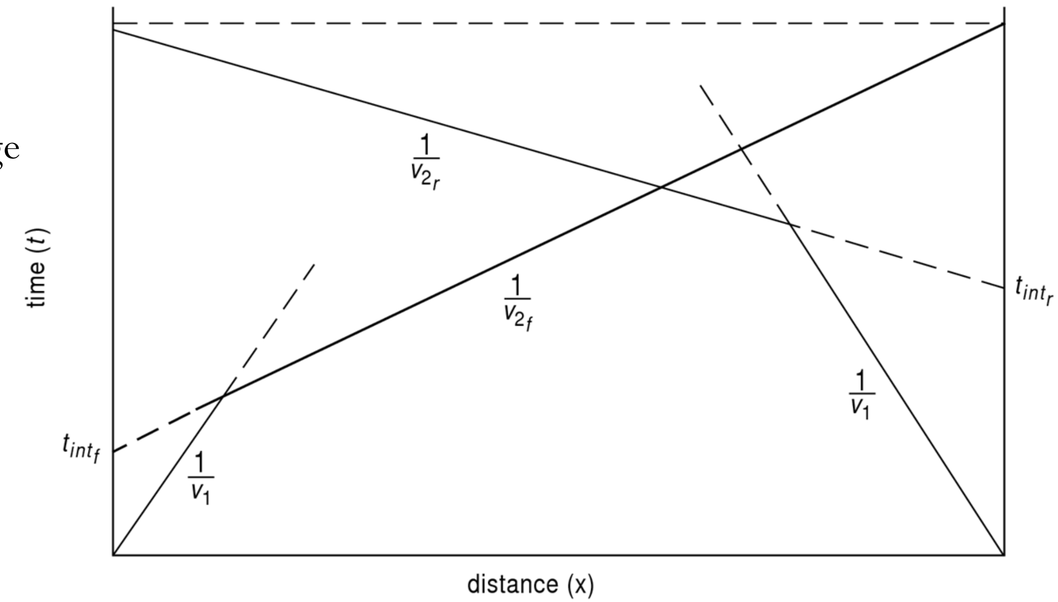
- A dipping interface produces a pattern that looks just like a horizontal interface!
  - Velocities are called "apparent velocities"
- What do we do?

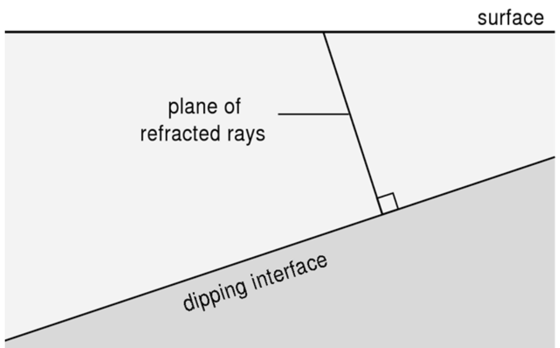
In this case, velocity of lower layer is underestimated

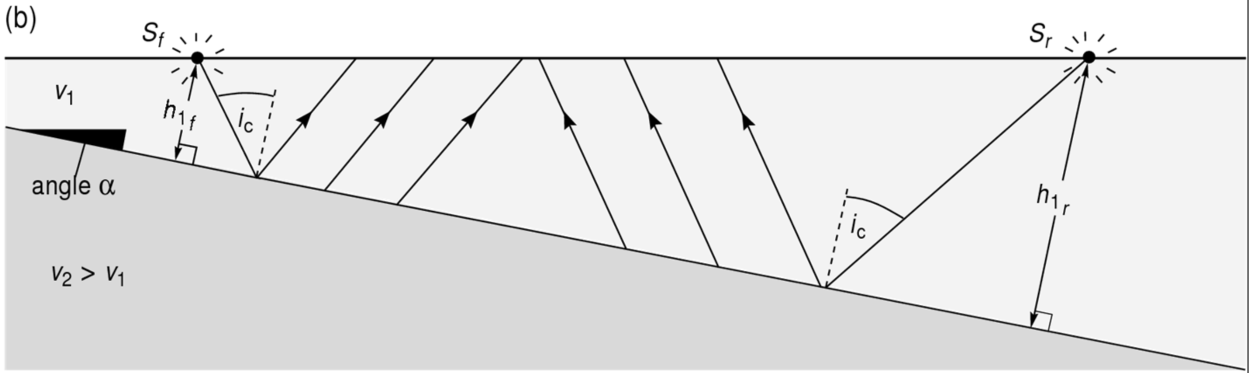
Dipping Interfaces

- To determine if interfaces are dipping…

- Shoot lines forward and reversed
- If dip is small (< 5°) you can take average slope (formulation ?)
- The intercepts will be different at both ends
  - Implies different thickness



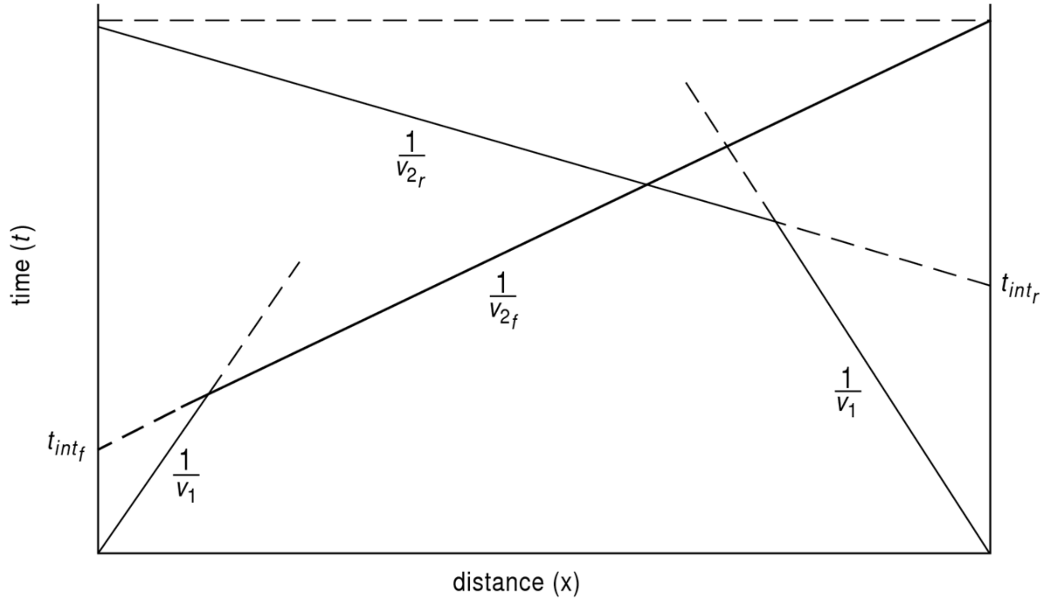


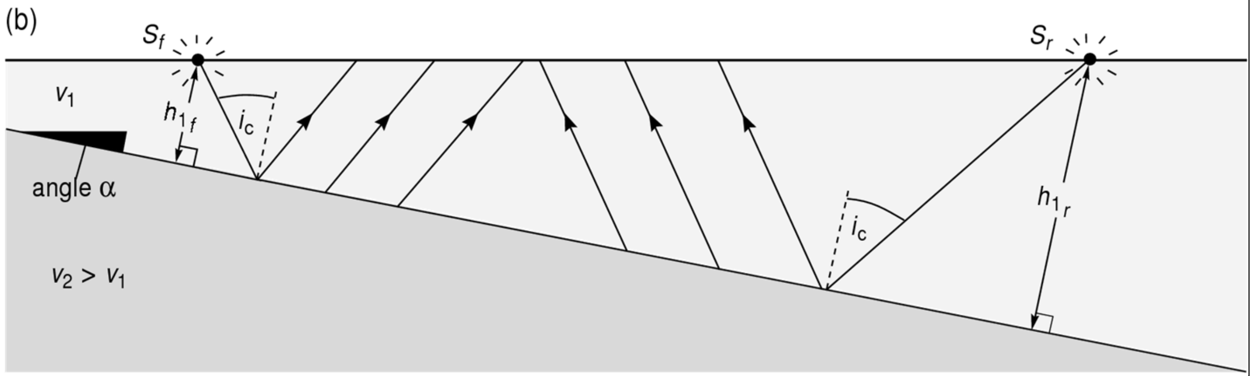


Beware: the calculated thicknesses will be perpendicular to the interface, not vertical

Dipping Interfaces

- If you shoot down-dip
  - Slopes on t-x diagram are too steep
    - Underestimates velocity
  - May underestimate layer thickness
- Converse is true if you shoot up-dip
- In both cases the calculated direct ray velocity is the same.





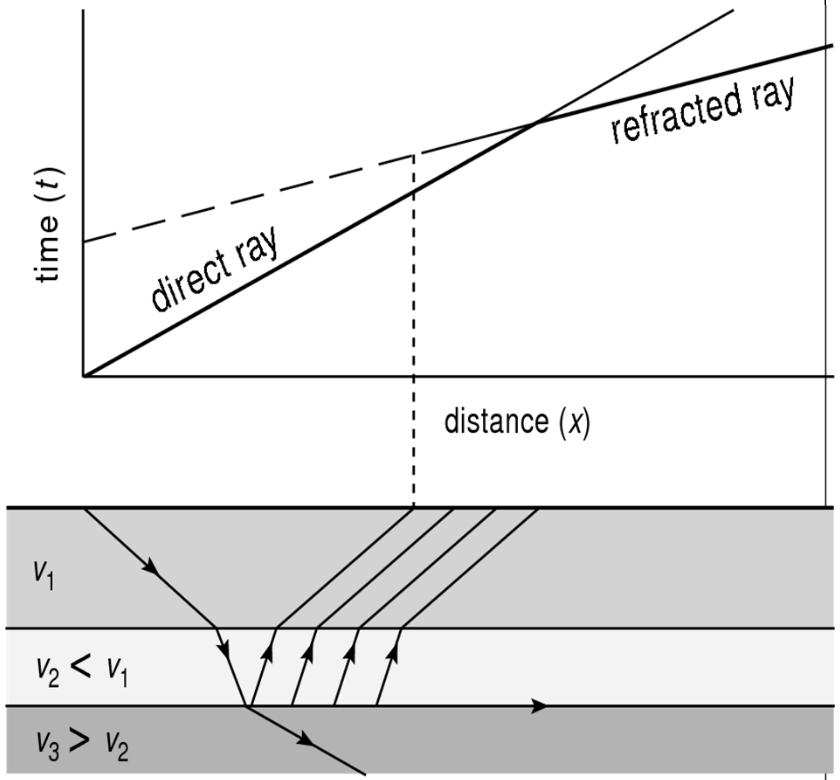
- The intercepts t_{int} will also be different at both ends of survey

Problem 1: Low velocity layer

If a layer has a lower velocity than the one above…

- There can be no critical refraction - The refracted rays are bent towards the normal
- There will be no refracted segment on the t-x diagram for the second layer
- The t-x diagram to the right will be interpreted as - Two layers

  - Depth to layer 3 and thickness of layer1 will be exaggerated



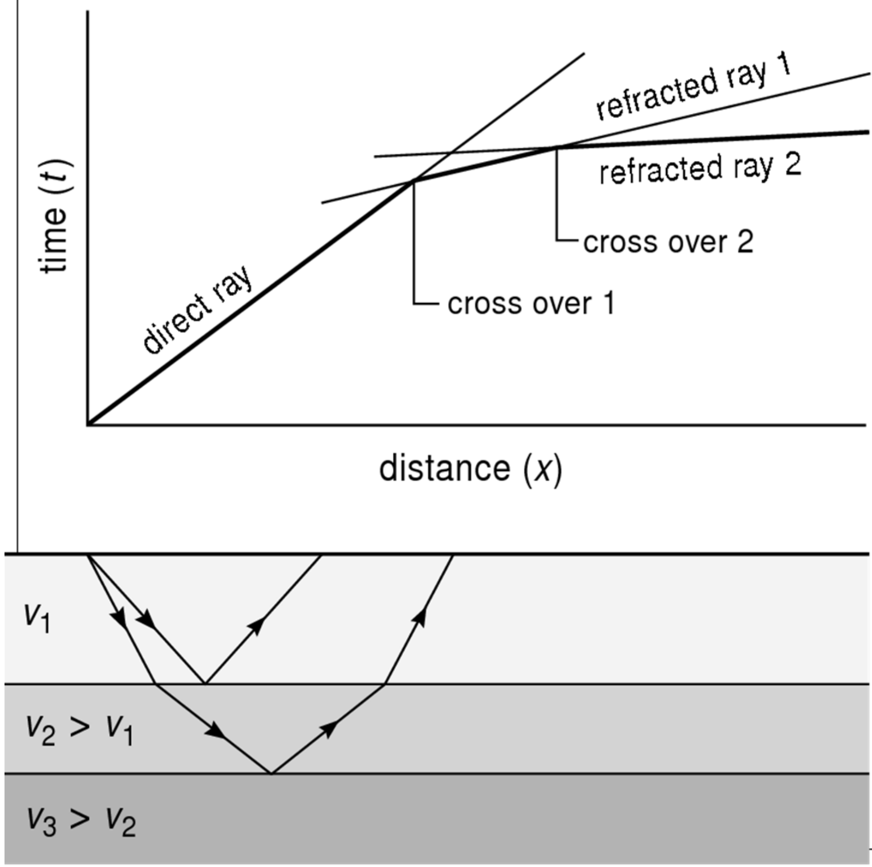
<u>Causes:</u>

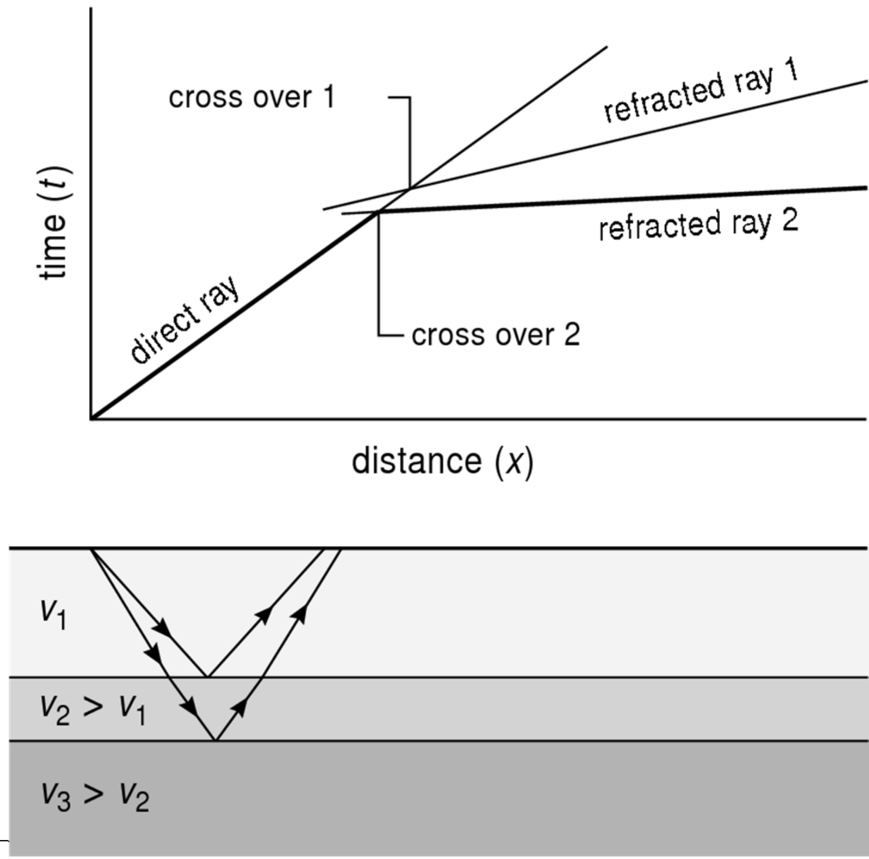
- Sand below clay
- Sedimentary rock below igneous rock
- (sometimes) sandstone below limestone

<u>How Can you Know?</u>

Problem 2: Hidden layer

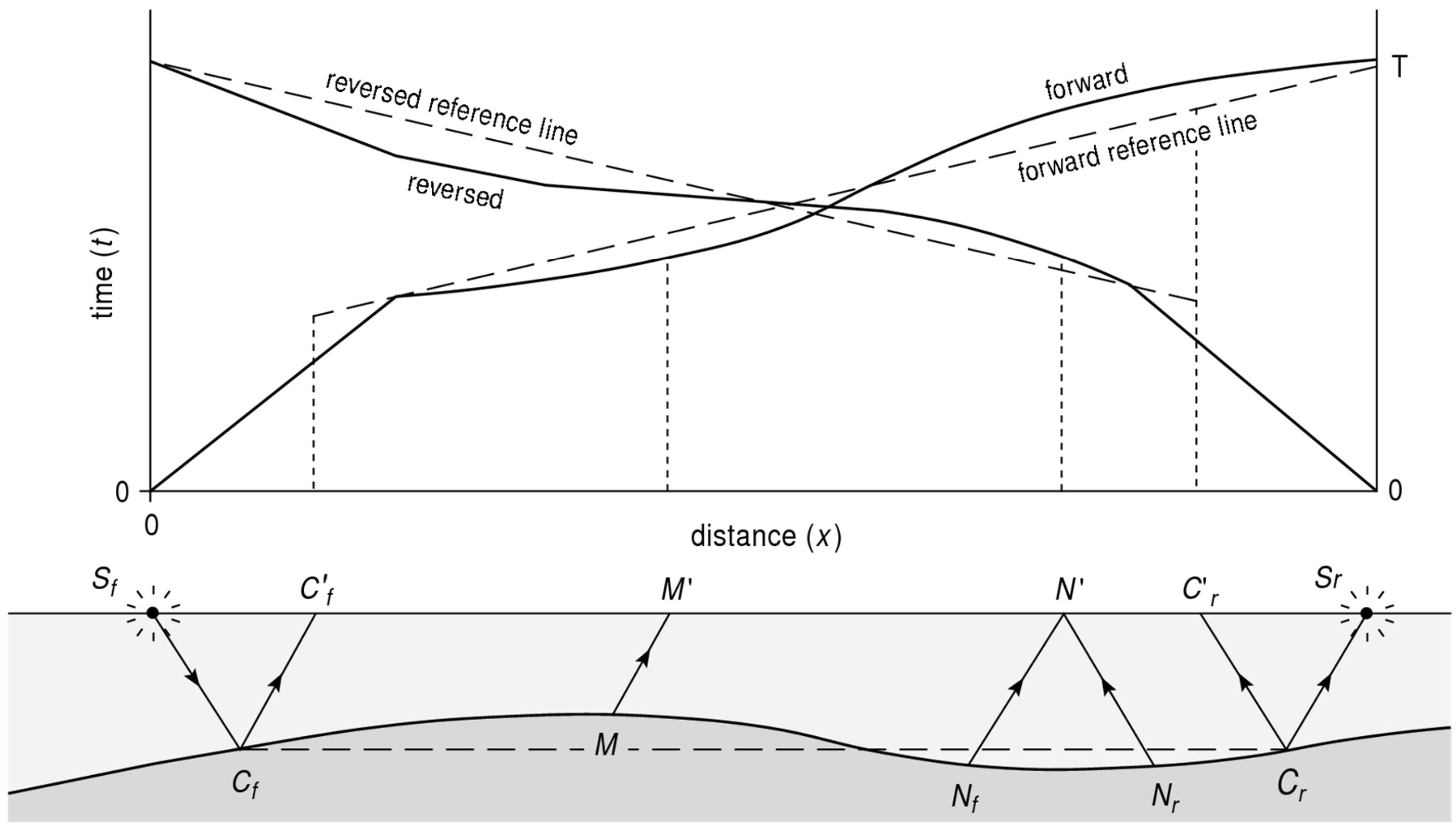
- Recall that the refracted ray eventually overtakes the direct ray (cross over distance).
- The second refracted ray may overtake the direct ray first if:
  - The second layer is thin
  - The third layer has a much faster velocity





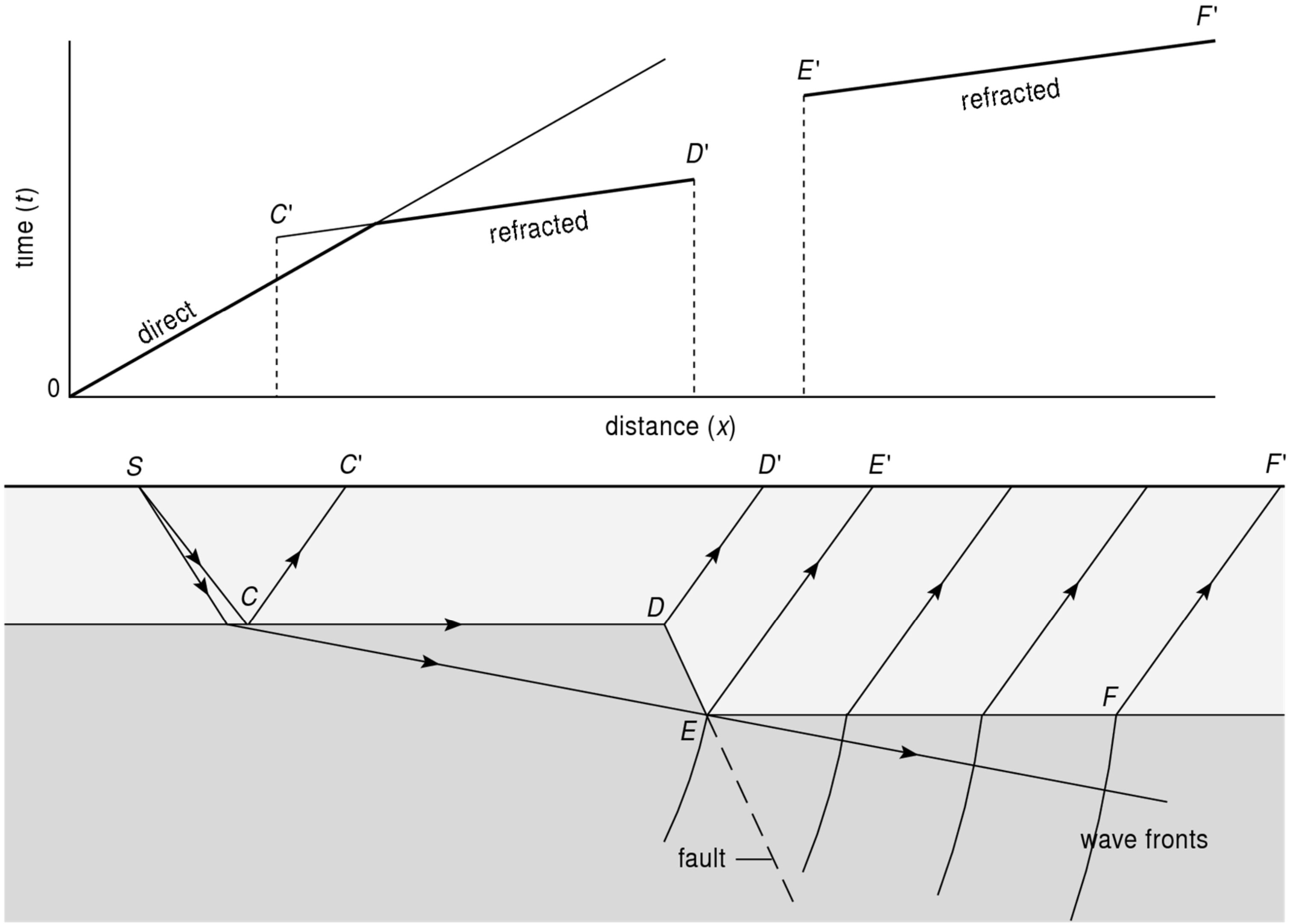
Undulating Interfaces

- Undulating interfaces produce non-linear t-x diagrams
- There are techniques that can deal with this
  - delay times & plus minus method
  - We will see them later…

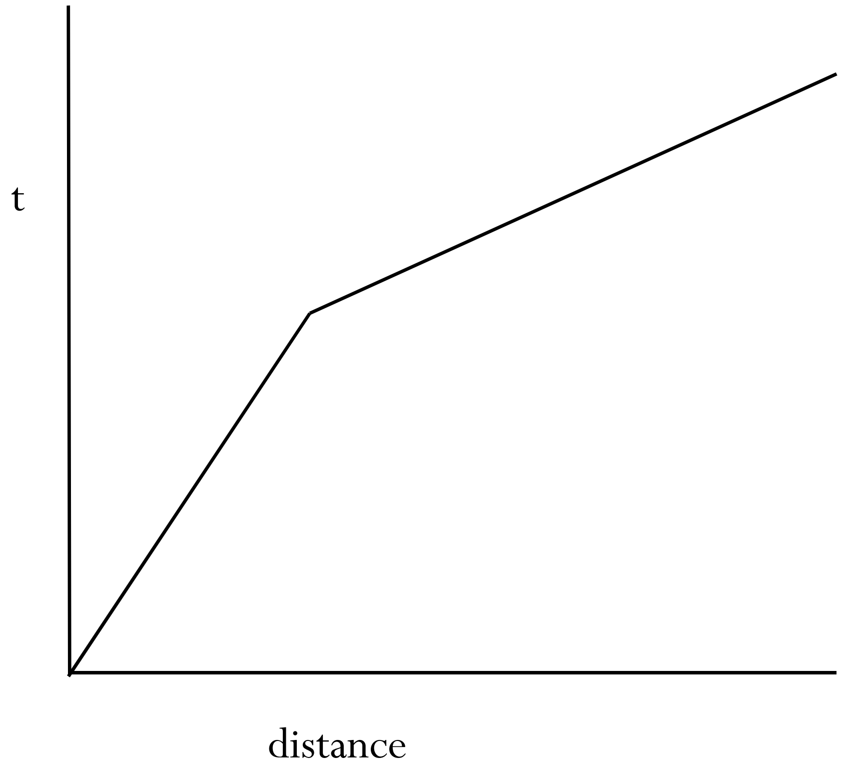


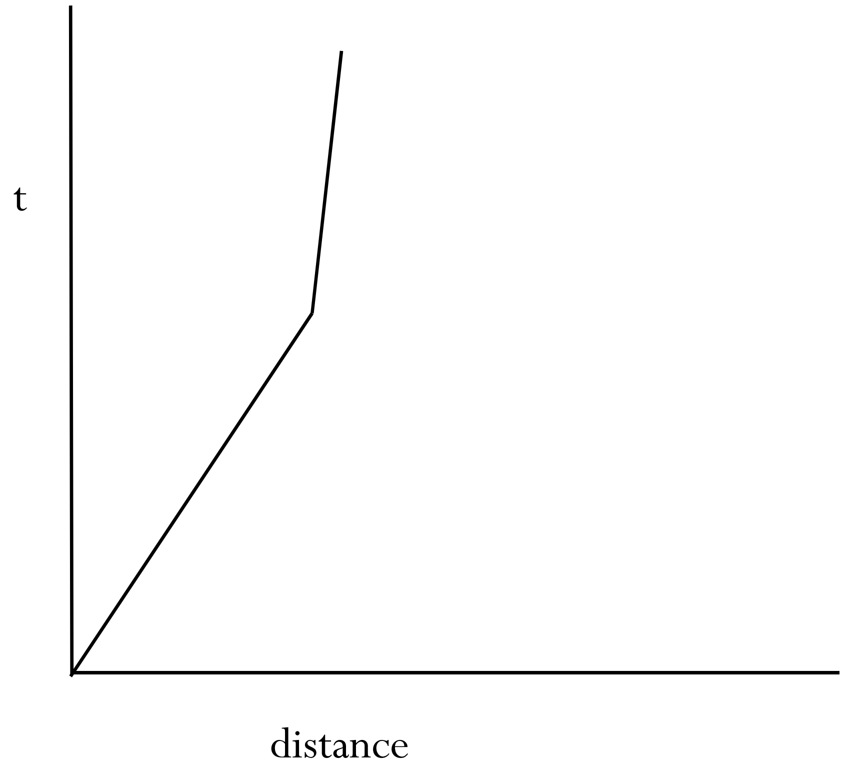
Detecting Offsets

- Offsets are detected as discontinuities in the t-x diagram
  - Offset because the interface is deeper and D'E' receives no refracted rays.



Question: To which type of underground model correspond the following travel-time curves?





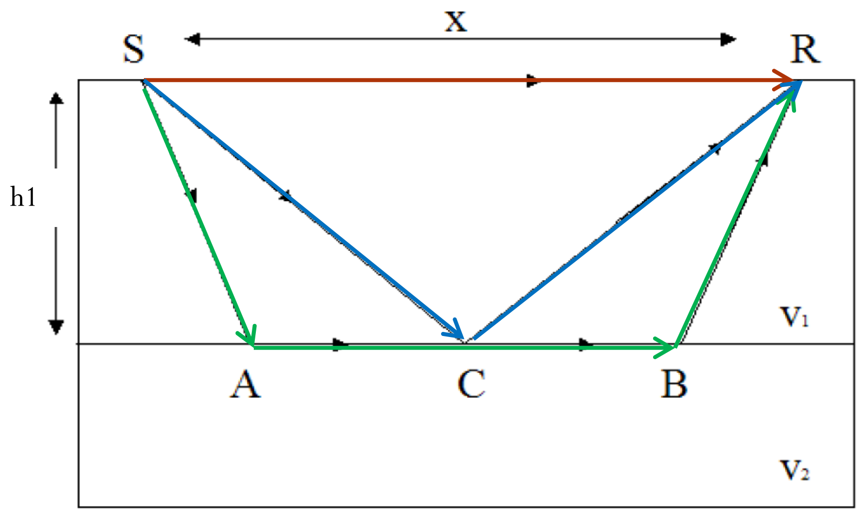
Overview

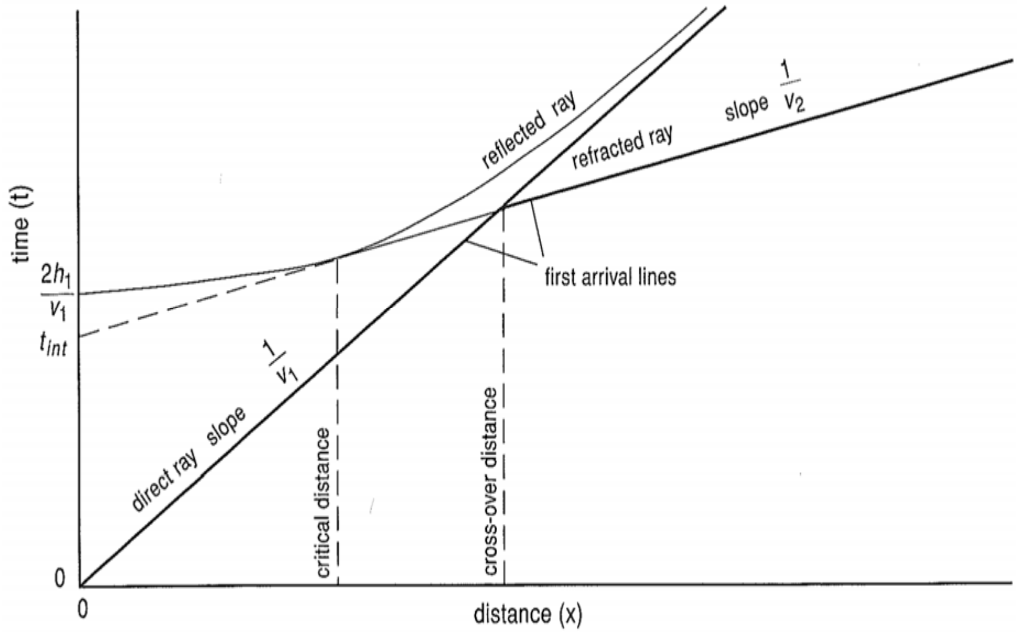
- Introduction – historical outline

- Chapter 1: Fundamental concepts
- Chapter 2: Data acquisition and material
- Chapter 3: Data processing and interpretation

Simple case

- v1 determined from the slope of the direct arrival (straight line passing through the origin)
- v2 determined from the slope of the head wave (straight line first arrival beyond the critical distance)
- Layer thickness h1 determined from the intercept time of the head wave (already knowing v1 and v2)

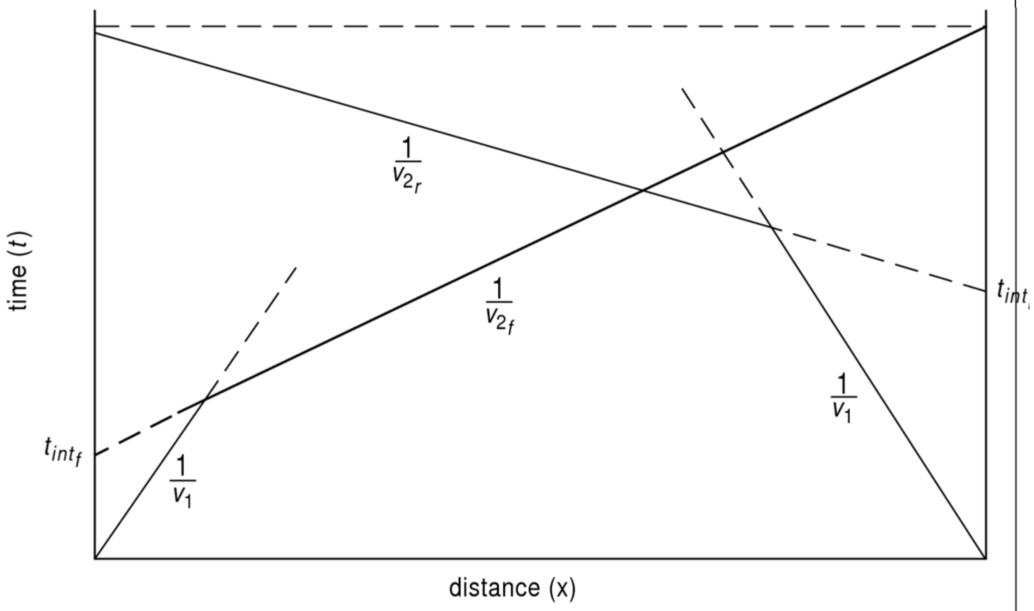




Complex geometries

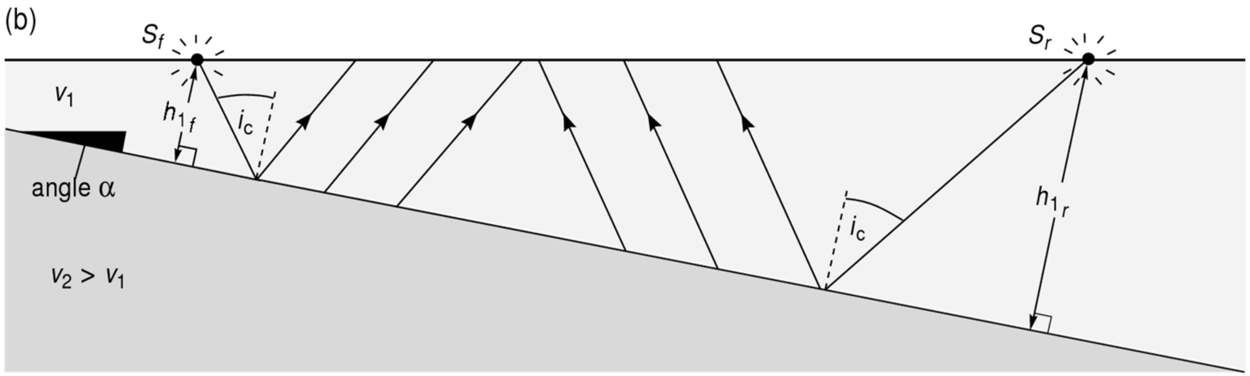
Dipping Interfaces

- What if the critically refracted interface is not horizontal?



- A dipping interface produces a pattern that looks just like a horizontal interface!
  - Velocities are called "apparent velocities"
- What do we do?

Shoot lines forward and reversed



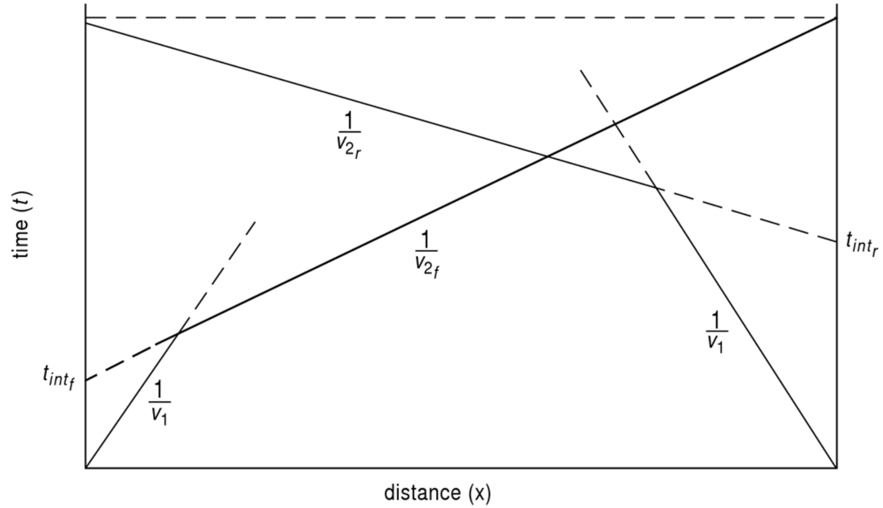
Beware: the calculated thicknesses will be perpendicular to the interface, not vertical

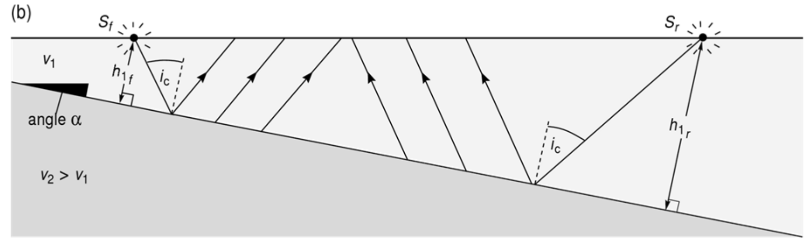
In this case, velocity of lower layer is underestimated

Dipping Interfaces

So : $V_r > V_f$

Vf: apparent velocity for all trajectories "downwards"
Vr: apparent velocity for all trajectories upwards





These apparent velocities are given by:

$$\sin(\lambda + \alpha) = \frac{V1}{V_f} \quad \Rightarrow \quad \lambda + \alpha = \arcsin\frac{V1}{Vf}$$

$$\sin(\lambda - \alpha) = \frac{V1}{V_r} \quad \Rightarrow \quad \lambda - \alpha = \arcsin\frac{V1}{Vr}$$

$$\alpha = \frac{1}{2}\left(\arcsin\frac{V1}{Vf} - \arcsin\frac{V1}{Vr}\right)$$

Real velocity of the second layer:

$$\frac{1}{V2} = \frac{1}{2}\left(\frac{1}{V_f} + \frac{1}{V_r}\right)\frac{1}{cos\alpha}$$

Dipping Interfaces

You can also write:

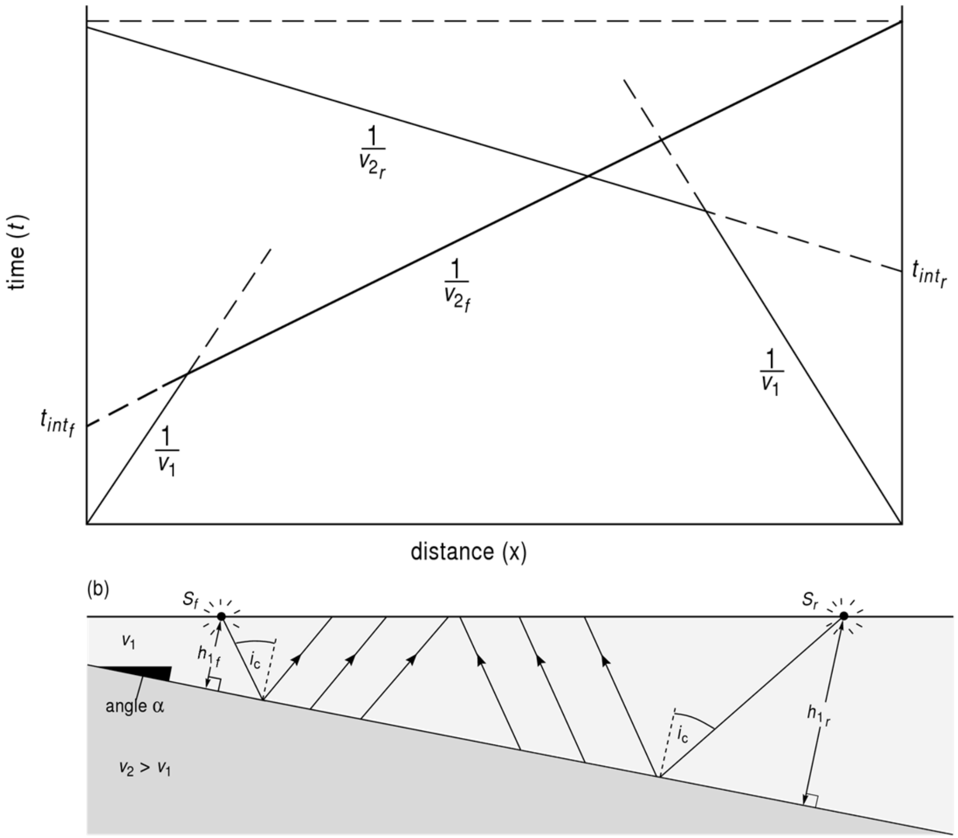
$$V2 = \frac{2V_f V_r}{V_f + V_r} cos\alpha$$

If the dip is small (<<5%), you can take the average slope, as   is close to 1

$$V2 = \frac{2V_f V_r}{V_f + V_r}\ cos\alpha$$

The perpendicular distances to the interface are calculated from the intercept times.

$$h_r = \frac{V_2 t_{int\_r}}{2cos\lambda} \qquad h_f = \frac{V_2 t_{int\_f}}{2cos\lambda}$$



Dipping Interfaces

Example, V1=2500 m/s, V2=4500 m/s

Pendage Angle α	Vitesse apparente Amont	Vitesse apparente Aval	Moyenne Harmonique exacte(x cosα	Moyenne Harmonique approchée	Ecart %
0	4500	4500	4500	4500	0.00
5	5198	3994	4500	4517	0.38
10	6208	3615	4500	4569	1.54
15	7778	3325	4500	4659	3.53
20	10519	3100	4500	4789	6.42
25	16436	2924	4500	4965	10.34
30	38235	2787	4500	5196	15.47
35	-114511	2682	4500	5493	22.08
40	-22960	2604	4500	5874	30.54
45	-12813	2549	4500	6364	41.42
50	-8934	2515	4500	7001	55.57

limite de validité
de la formule approchée

A very small inclination of the interface is enough to cause a large difference between apparent and real velocity!!!

Step discontinuity

Offsets are detected as discontinuities in the t-x diagram

-Offset because the interface is deeper and D'E' receives no refracted rays.

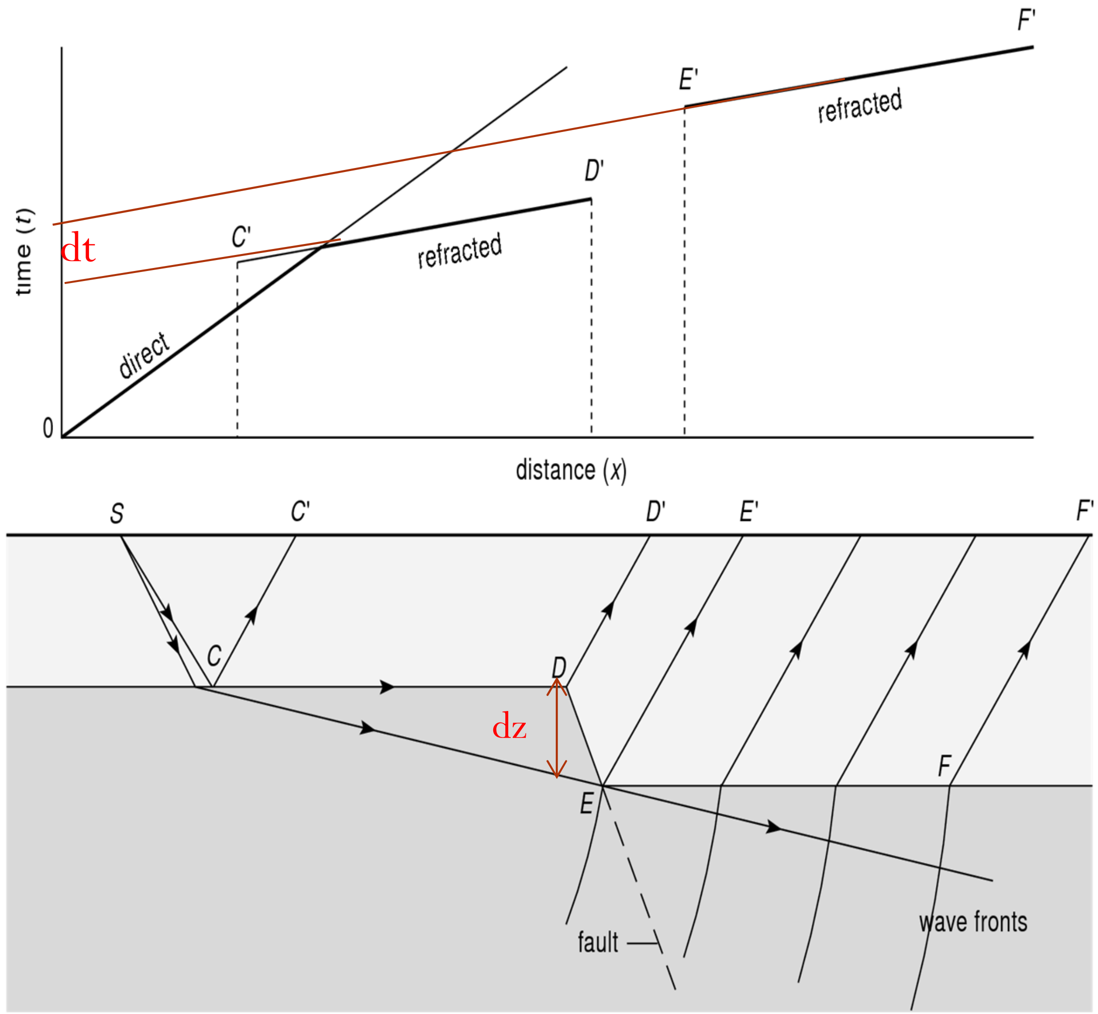
<u>Geological example:</u>

-backfilled quarry

-normal fault

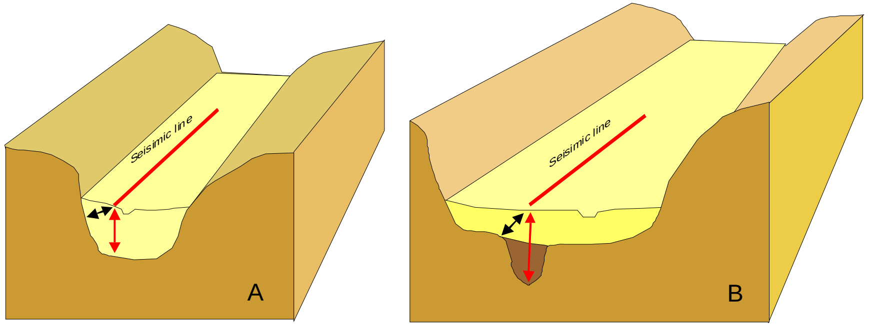
When the size of the step discontinuity is small with respect to the depth of the refractor, the following equation can be used:

$$\delta z = \frac{\delta t V1V2}{\sqrt{V2^2 - V1^2}}$$

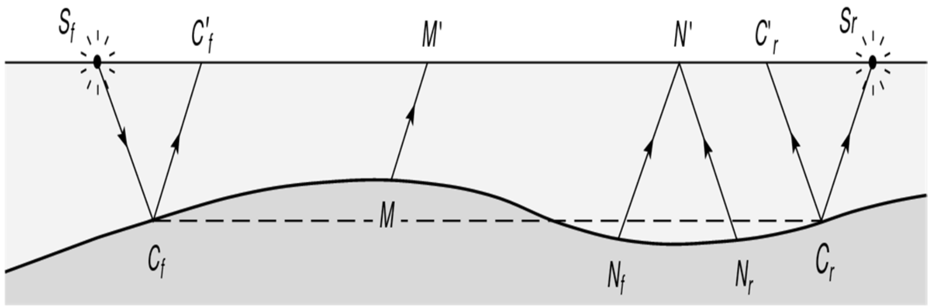


Unfavourable geological settings with refraction seismics

Different interpretation methods are available



Red ray pathes are always hidden by shorter black rays



Before starting the interpretation, inspect the traveltime-distance graphs

- As a check on quality of data being acquired
- In order to decide which interpretational method to use:

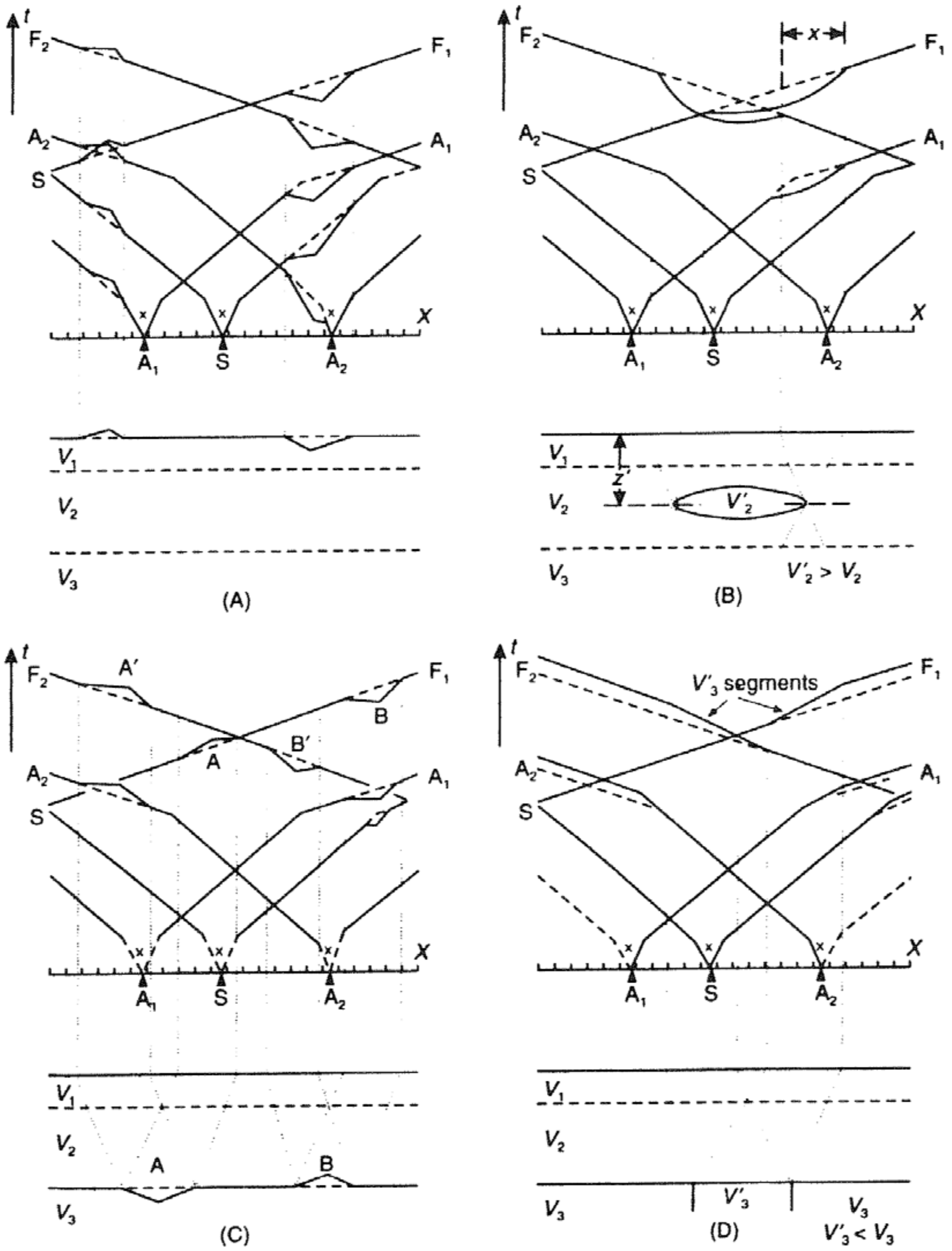
  - simple solutions for planar layers and for a dipping refractor

  - more sophisticated analysis for the case of an irregular interface

	Travel time anomalies
i)	Isolated spurious travel time of a first arrival, due to a mispick of the first arrival or a mis-plot of the correct travel time value
ii)	Changes in velocity or thickness in the near-surface region
iii)	Changes in surface topography
iv)	Zones of different velocity within the intermediate depth range
v)	Localised topographic features on an otherwise planar refractor
vi)	Lateral changes in refractor velocity

Travel time anomalies and their respective causes

A) Bump and cusp in layer 1
B) Lens with anomalous velocity in layer 2
C) Cusp and bump at the interface between layers 2 and 3
D) Vertical, but narrow zone with anomalous velocity within layer 3



Interpretation methods

Several different interpretational methods have been published, falling into two approaches:

- Delay time
- Wavefront construction

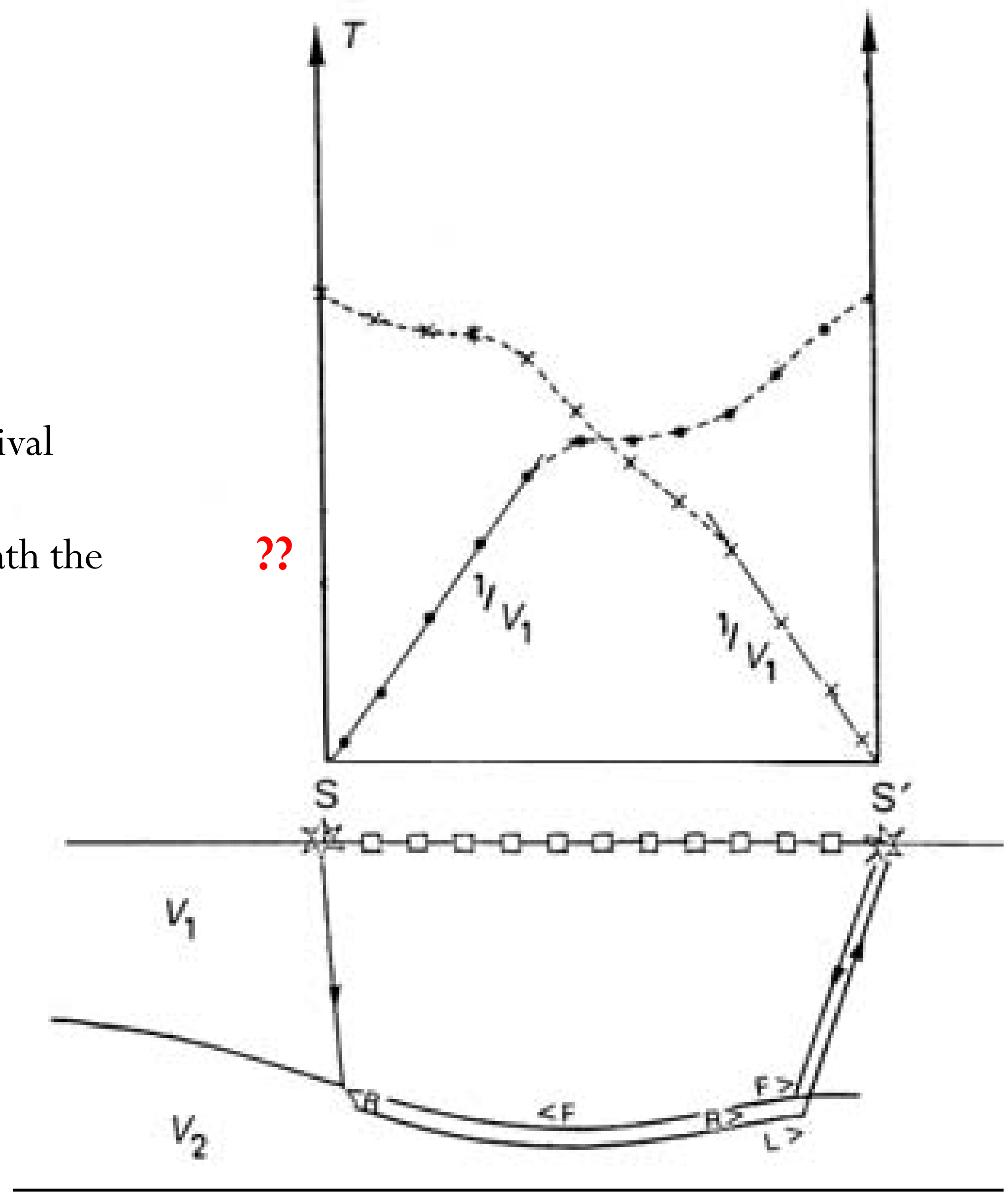
Two methods emerge as most commonly used:

- Plus-minus method (Hagedoorn, 1959)
- Generalised Reciprocal method – GRM (Palmer, 1980)

Phantom arrivals

Undulating interfaces

- Impossible to extrapolate the head wave arrival time curve back to the intercept
- How do we determine layer thickness beneath the shot, S?



Phantom arrivals

1. Shoot a long-offset shot, SL

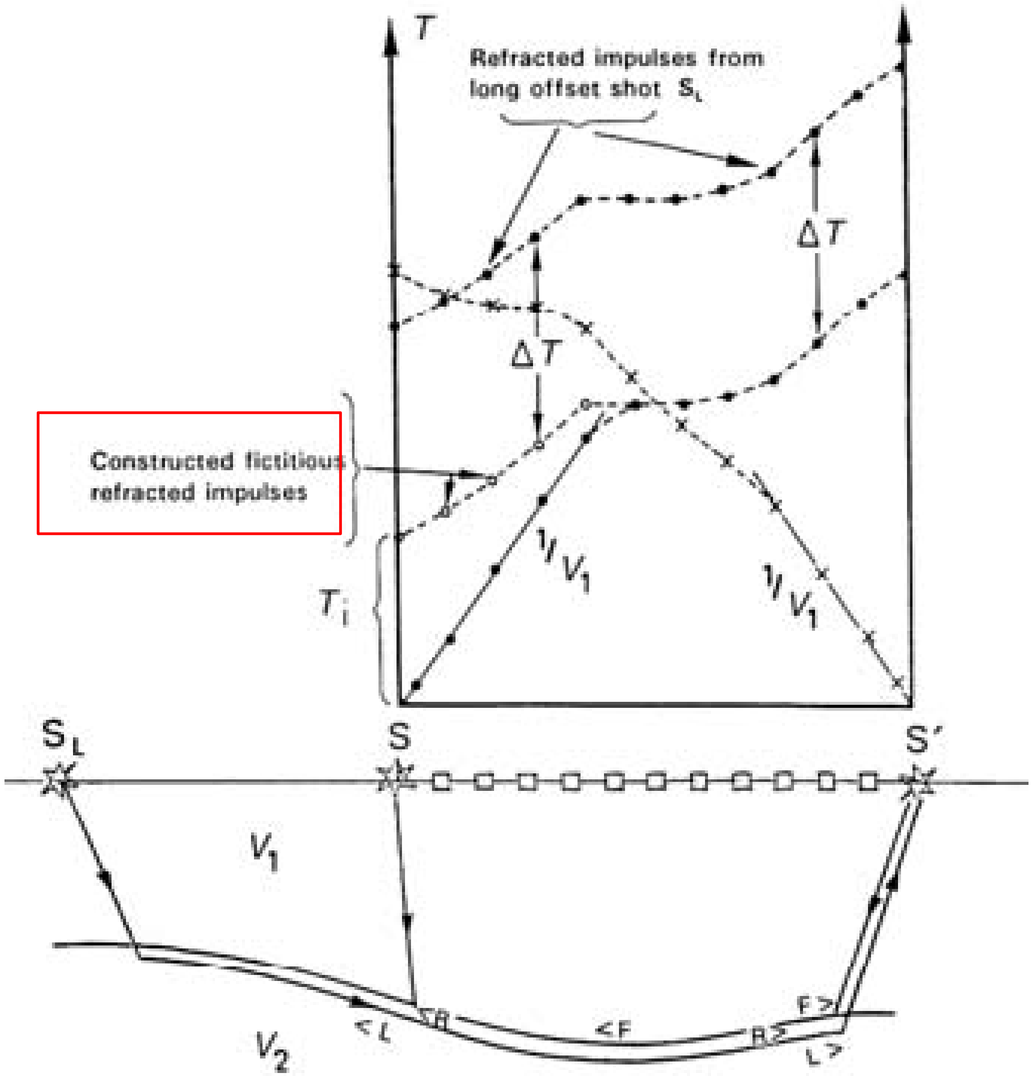
2. The head wave traveltime curves for both shots will be parallel, offset by time ΔT

3. Subtract ΔT from the SL arrivals to generate fictitious 2nd layer arrivals close to S – the phantom arrivals

4. The intercept point at S can then be determined: Ti

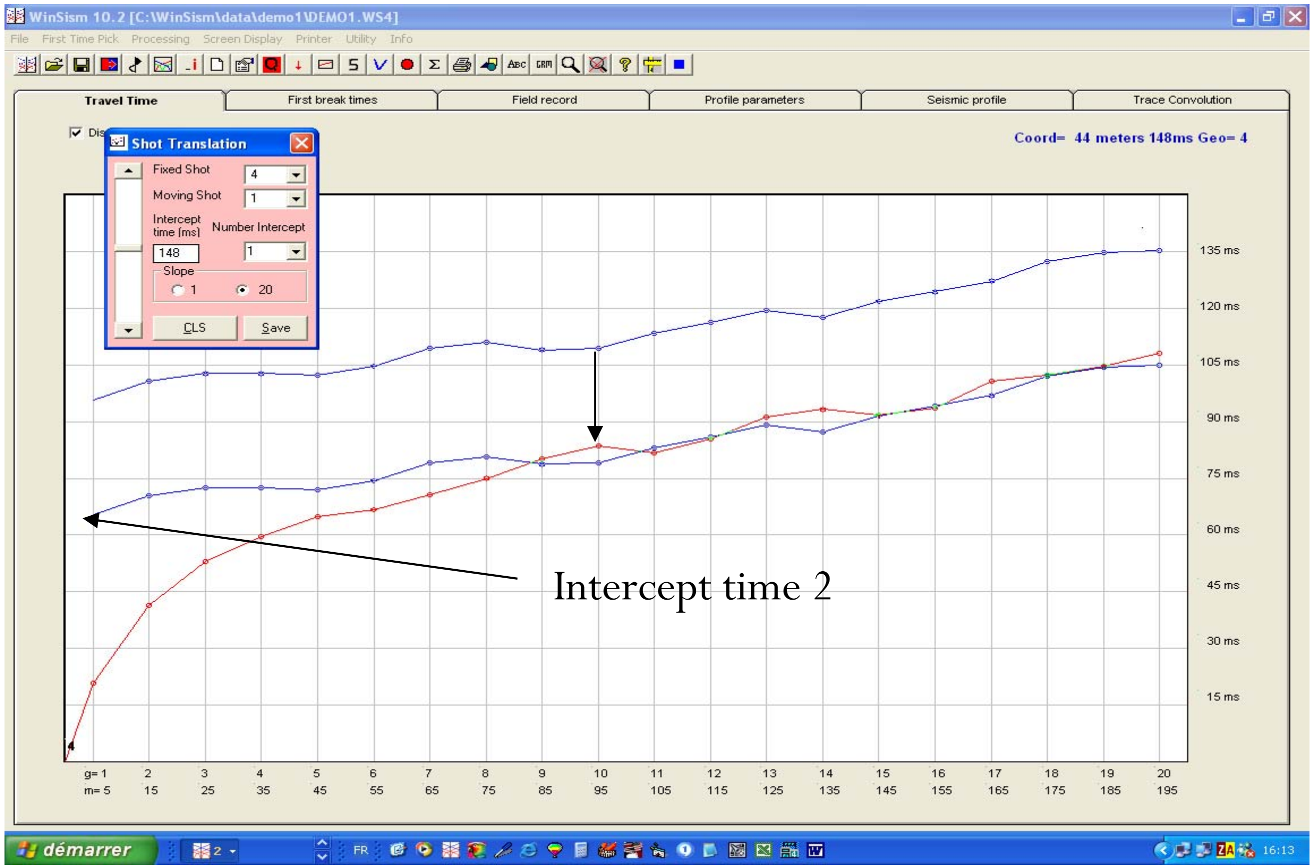
5. Use the usual formula to determine perpendicular layer thickness beneath S

$$T_i = \frac{2h_s\sqrt{V_2^2 - V_1^2}}{V_2 V_1}$$



Phantom arrivals

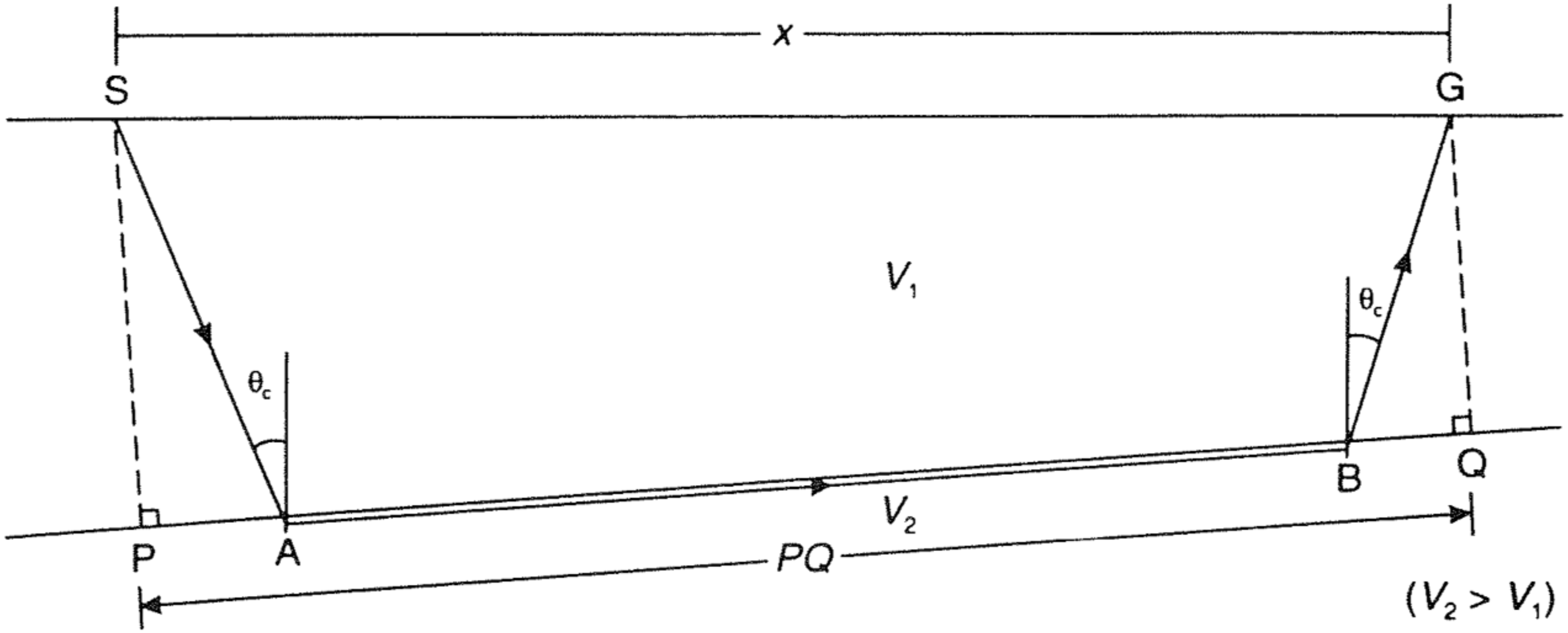
Move offset shot to end shot to determine which part corresponds to bedrock arrivals



<u>Advantage</u>: remove the necessity to extrapolate the travel time graph from beyond the crossover point back to the zero-offset point.

Plus minus-method

The method uses intercept times and delay times in the calculation of the depth to the refractor below any geophone location.

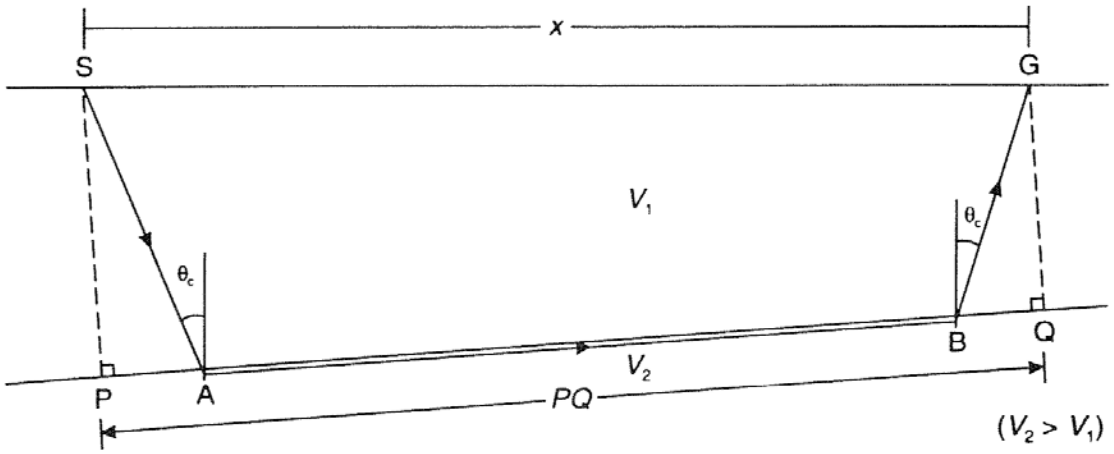


The delay time (δt) is the difference in time between:

1) T(SG) along SABG
2) T(PQ)

The total delay time is effectively the sum of the "shot-point delay time" δt_s and the "geophone delay time" δt_g

Plus minus-method



The total delay time is given by:

$$\delta t = T_{SG} - T_{PQ}$$

and

$$T_{SG} = (SA + BG)/V_1 + AB/V_2 \quad \text{and} \quad T_{PQ} = PQ/V_2 .$$

Thus:

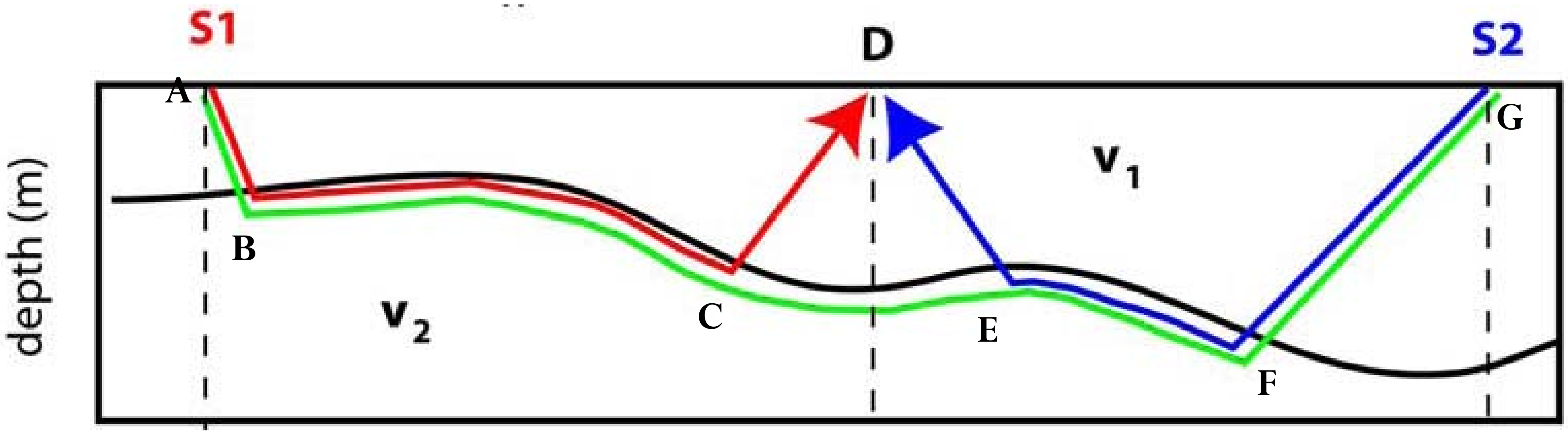
$$\begin{aligned}\delta t &= (SA + BG)/V_1 - (PA + BQ)/V_2 \\ &= (SA/V_1 - PA/V_2) + (BG/V_1 - BQ/V_2) \\ &= \delta t_s + \delta t_g \approx T_{SG} - x/V_2 .\end{aligned}$$

Reciproqual time TSG

Alternatively:

$$T_{SG} = x/V_2 + \delta t_s + \delta t_g$$

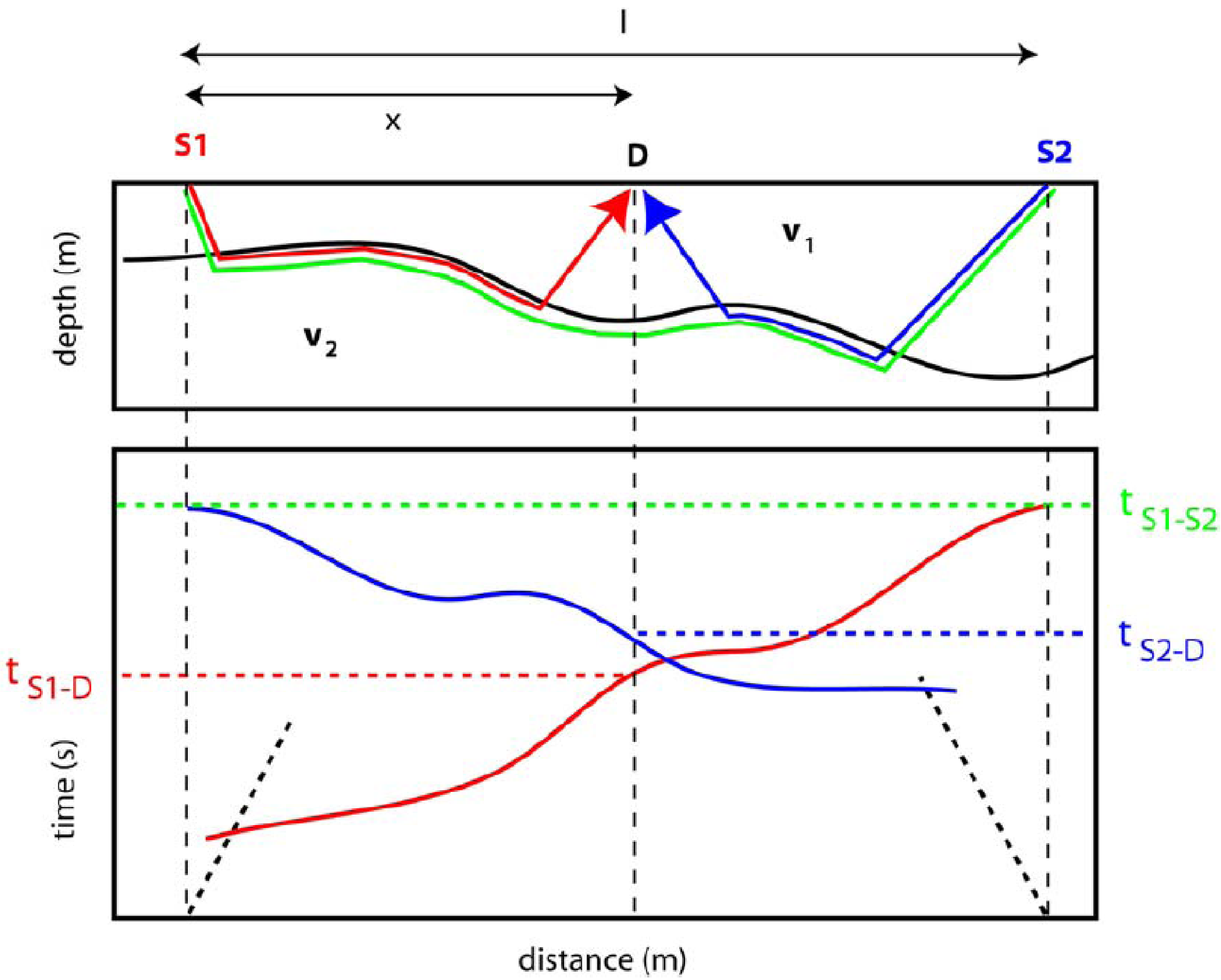
Plus minus Method Principle



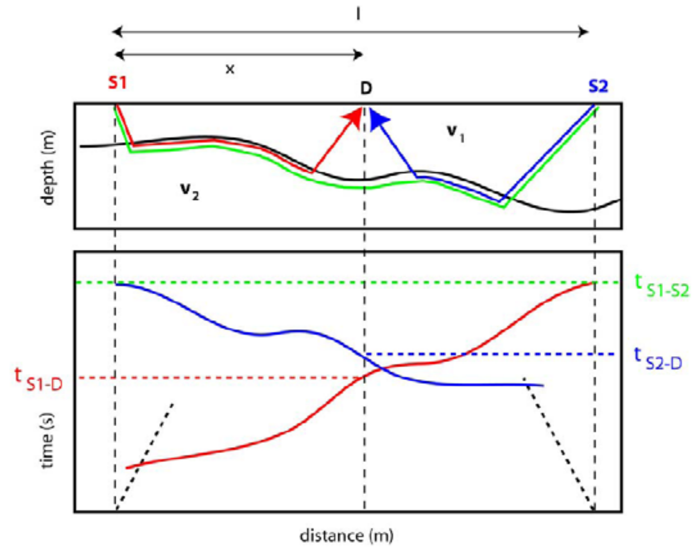
Time CDE = Time ABCD + Time DEFG – Time ABCEFG

Total time

Plus minus method



Plus minus method



Consider the model with two layers and an undulating interface. The refraction profile is reversed with two shots (S^1 and S^2) fired into each detector (D).

Consider the following three travel times:

(a) The reciprocal time is the time from *S^1 to S^2*

$$t_{S_1S_2} = \frac{l}{v_2} + \delta_{S_1} + \delta_{S_2} = t_{S_2S_1}$$

(b) Forward shot into the detector

$$t_{S_1D} = \frac{x}{v_2} + \delta_{S_1} + \delta_D$$

(c) Reverse shot into the detector

$$t_{S_2D} = \frac{(l-x)}{v_2} + \delta_{S_2} + \delta_D$$

Our goal is to find lower layer velocity v2 and the delay time at the receiver, δ^D. From the delay time, δ^D, we can find the depth of the interface below the receiver.

Plus minus method

(a) The reciprocal time is the time from S^1 *to* S^2

$$t_{S_1S_2} = \frac{l}{v_2} + \delta_{S_1} + \delta_{S_2} = t_{S_2S_1}$$

(b) Forward shot into the detector

$$t_{S_1D} = \frac{x}{v_2} + \delta_{S_1} + \delta_D$$

(c) Reverse shot into the detector

$$t_{S_2D} = \frac{(l-x)}{v_2} + \delta_{S_2} + \delta_D$$

Minus term to estimate velocity (v_2)

(b)-(c) will eliminate δ_D

$$t_{S_1D} - t_{S_2D} = \frac{(2x-l)}{v_2} + \delta_{S_1} - \delta_{S_2}$$

$$t_{S_1D} - t_{S_2D} = \frac{2x}{v_2} + C$$

where C is a constant. A plot of $t_{S_1D} - t_{S_2D}$ versus $2x$ will give a line with slope = $1/v_2$

Plus minus method

(a) The reciprocal time is the time from S^1 *to* S^2

$$t_{S_1S_2} = \frac{l}{v_2} + \delta_{S_1} + \delta_{S_2} = t_{S_2S_1}$$

(b) Forward shot into the detector

$$t_{S_1D} = \frac{x}{v_2} + \delta_{S_1} + \delta_D$$

(c) Reverse shot into the detector

$$t_{S_2D} = \frac{(l-x)}{v_2} + \delta_{S_2} + \delta_D$$

Plus term to estimate delay time at the detector

(b)+(c) gives

$$t_{S_1D} + t_{S_2D} = \frac{l}{v_2} + \delta_{S_1} + \delta_{S_2} + 2\delta_D$$

Using the result (a) we get

$$t_{S_1D} + t_{S_2D} = t_{S_1S_2} + 2\delta_D$$

Re-arranging to get an equation for δ_D

$$\delta_D = \frac{1}{2}(t_{S_1D} + t_{S_2D} - t_{S_1S_2})$$

This process is then repeated for all detectors in the profile

Plus minus method

Calculate the **depth to the refractor beneath any geophone** (z) from the delay time

$$T^+ = t_{S1D} + t_{S2D} - t_{DS1S2} = 2\delta t_D$$

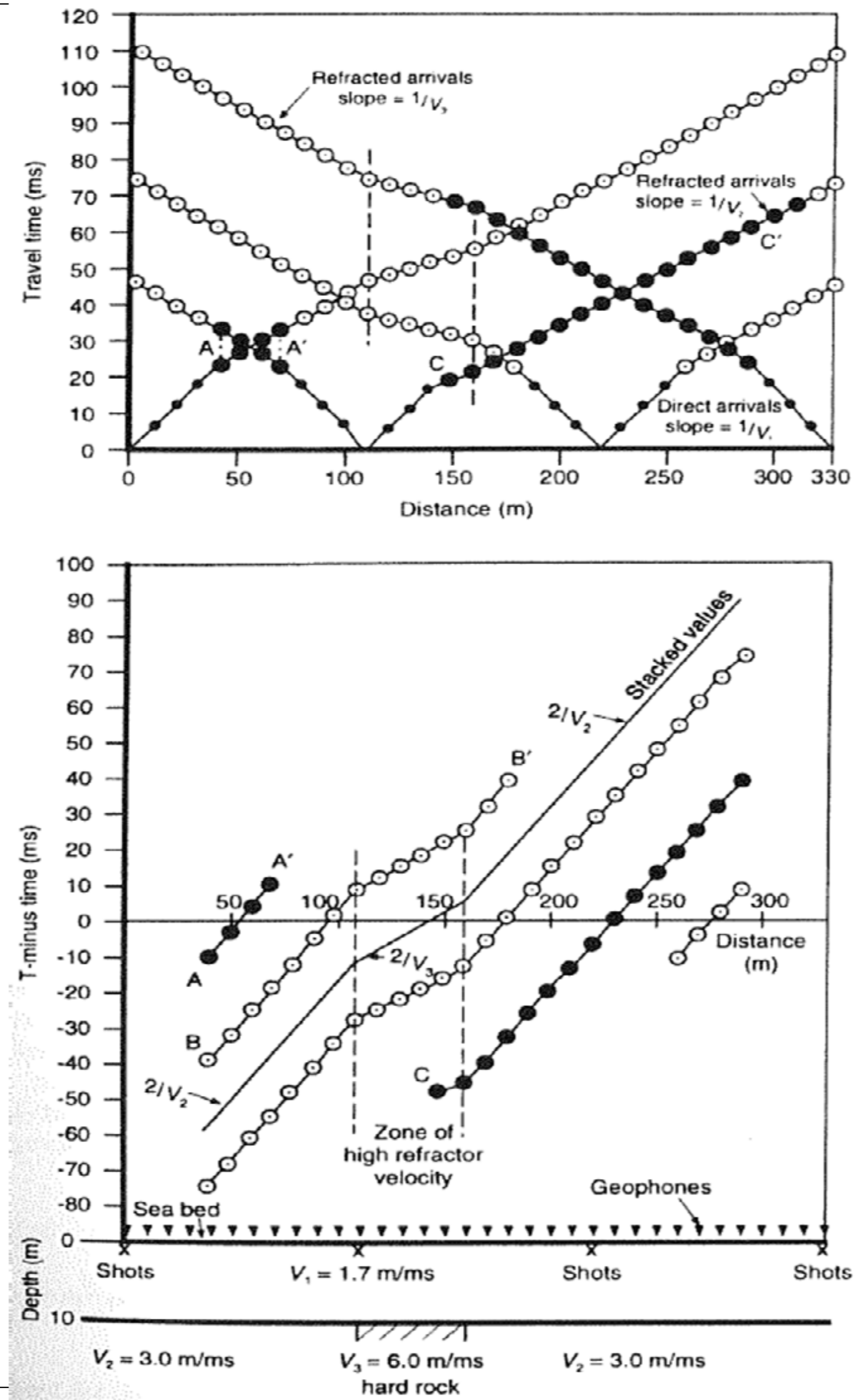
$$2\delta t_D = \frac{2\, z\, cos(i)}{V1}$$

i being the critical angle

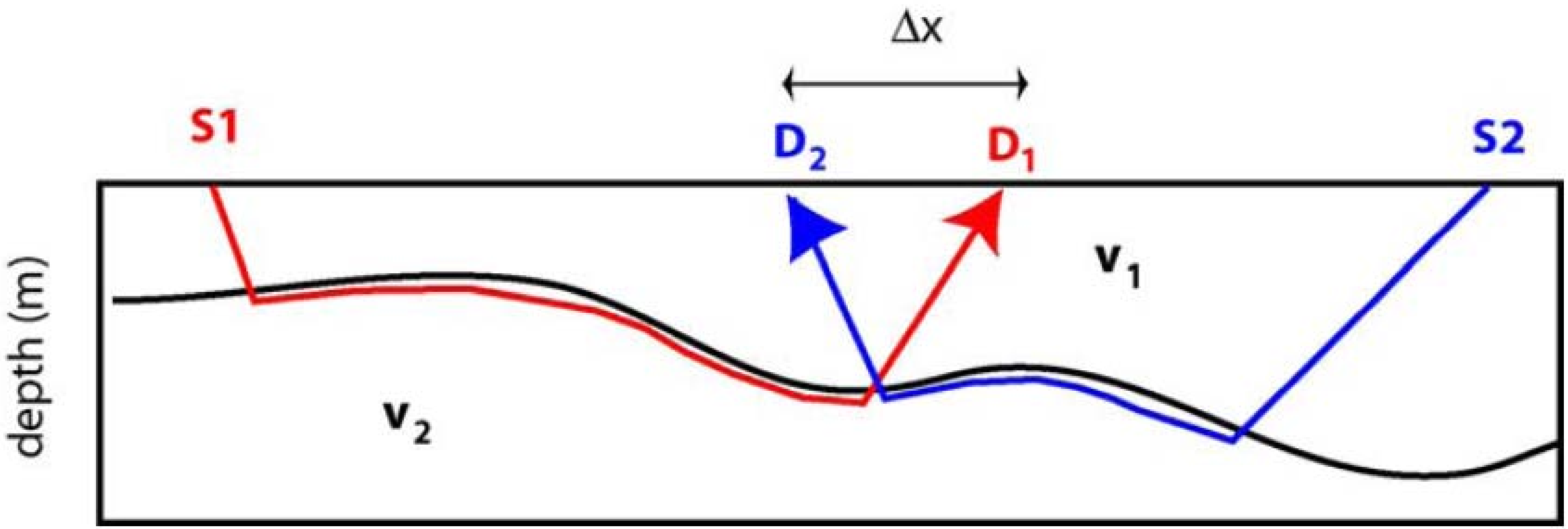
$$z = \frac{T^+ V1}{2\cos(i)} = \frac{T^+ V1V2}{2\sqrt{(V_2^2 - V_1^2)}}$$

a) Composite travel-time distance graph
b) T^- graph
c) Calculated depth to a refractor

T^- Provides a possibility to examine lateral velocity variations (lateral resolution equal to the geophone separation)



Generalized reciprocal method (1979)



The plus-minus method assumes a linear interface between points where the ray leaves the interface. A more powerful technique is the **Generalized reciprocal method in which pairs of rays are chosen that leave the interface at the same location.**

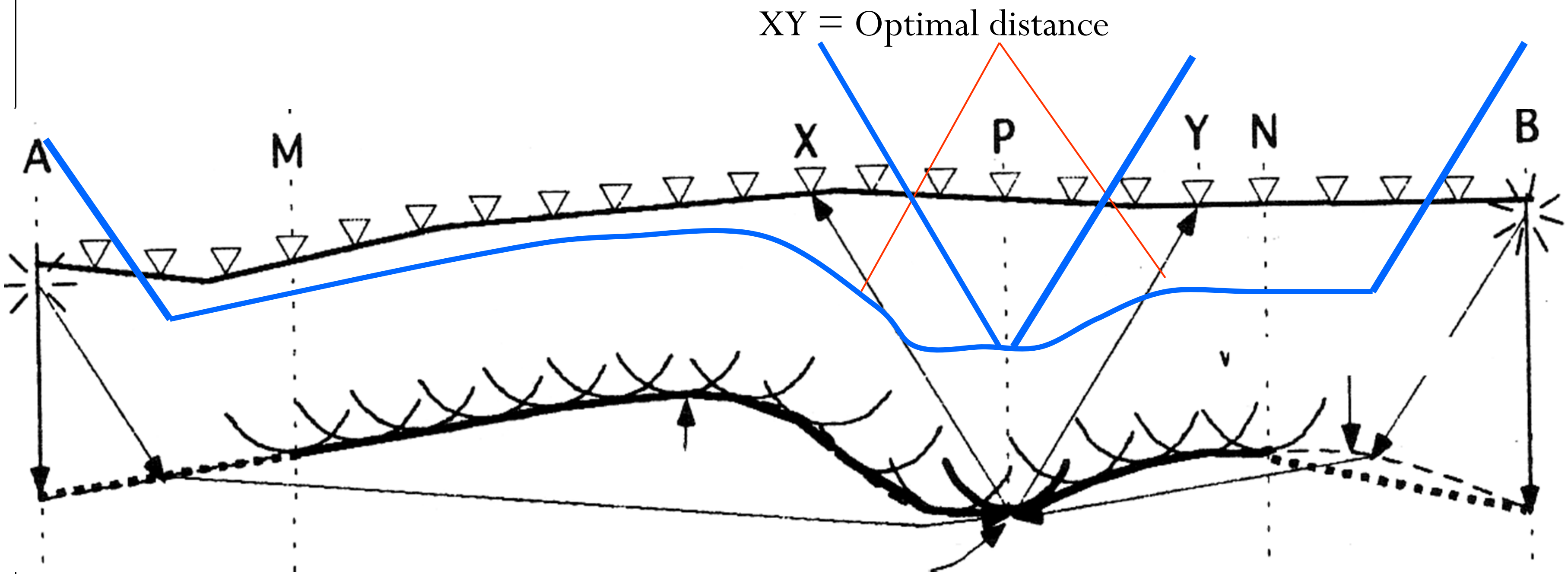
-> further development of the plus minus method

Generalized Reciprocal Method

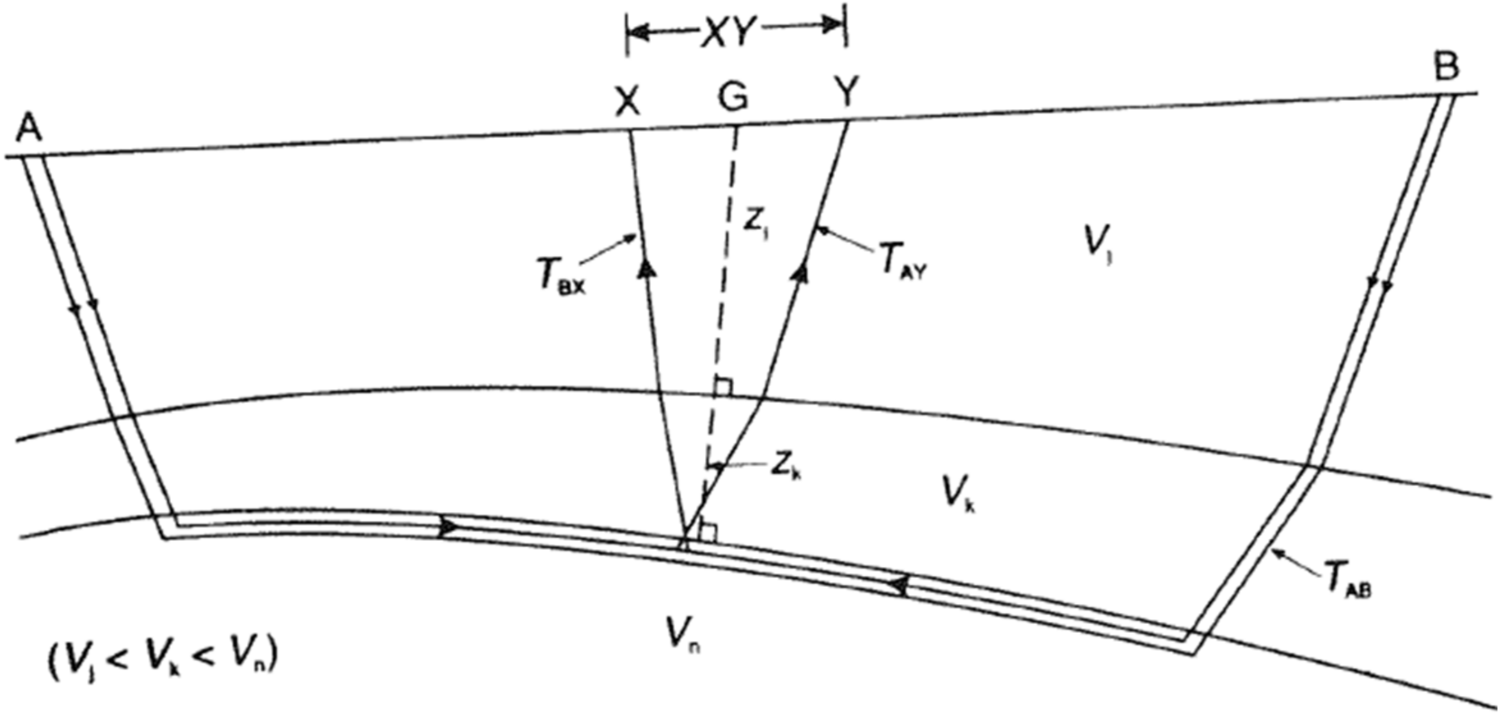
-GRM requires more receivers than Plus-Minus

-multiple estimates of the depth are made below each point, using different separations between X and Y.

-geophysicist must select the optimal distance (XY) (most linear T- and the most detail in a T+ profile)



Generalized reciprocal method



Generalized reciprocal method

The **refractor velocity analysis function** (t_v) is given by:

$$t_v = (T_{AY} - T_{BX} + T_{AB})/2 \qquad (1)$$

where the distances AY and BX can be defined in terms of the

XY and AG, such that:

$$AY = AG + XY/2 \qquad \text{and} \qquad BX = AB - AG + XY/2.$$

A graph of t_v plotted as a function of distance x has a slope $= 1/V_n$, where V_n is the seismic velocity in the refractor (which is the nth layer).

The **time–depth function** (t_G) is given by:

$$t_G = [T_{AY} + T_{BX} - (T_{AB} + XY/V_n)]/2. \qquad (2)$$

The time–depth function, plotted with respect to position G, is related to the thicknesses (z_{jG}) of the overlying layers, such that:

$$t_G = \sum_{j=1}^{n-1} z_{jG}(V_n^2 - V_j^2)^{1/2}/V_n V_j \qquad (3)$$

where z_{jG} and V_j are the perpendicular thickness below G and velocity of the jth layer, respectively.

"An Introduction to Applied and Environmental Geophysics" by John M. Reynolds

Generalized reciprocal method

The optimum distance XY (XY_{opt}) is related to layer thickness z_{jG} and seismic velocities V_j and V_n by:

$$XY_{\mathrm{opt}} = 2 \sum_{j=1}^{n-1} z_{jG} \tan \theta_{jn} \tag{4}$$

where $\sin \theta_{jn} = V_j / V_n$.

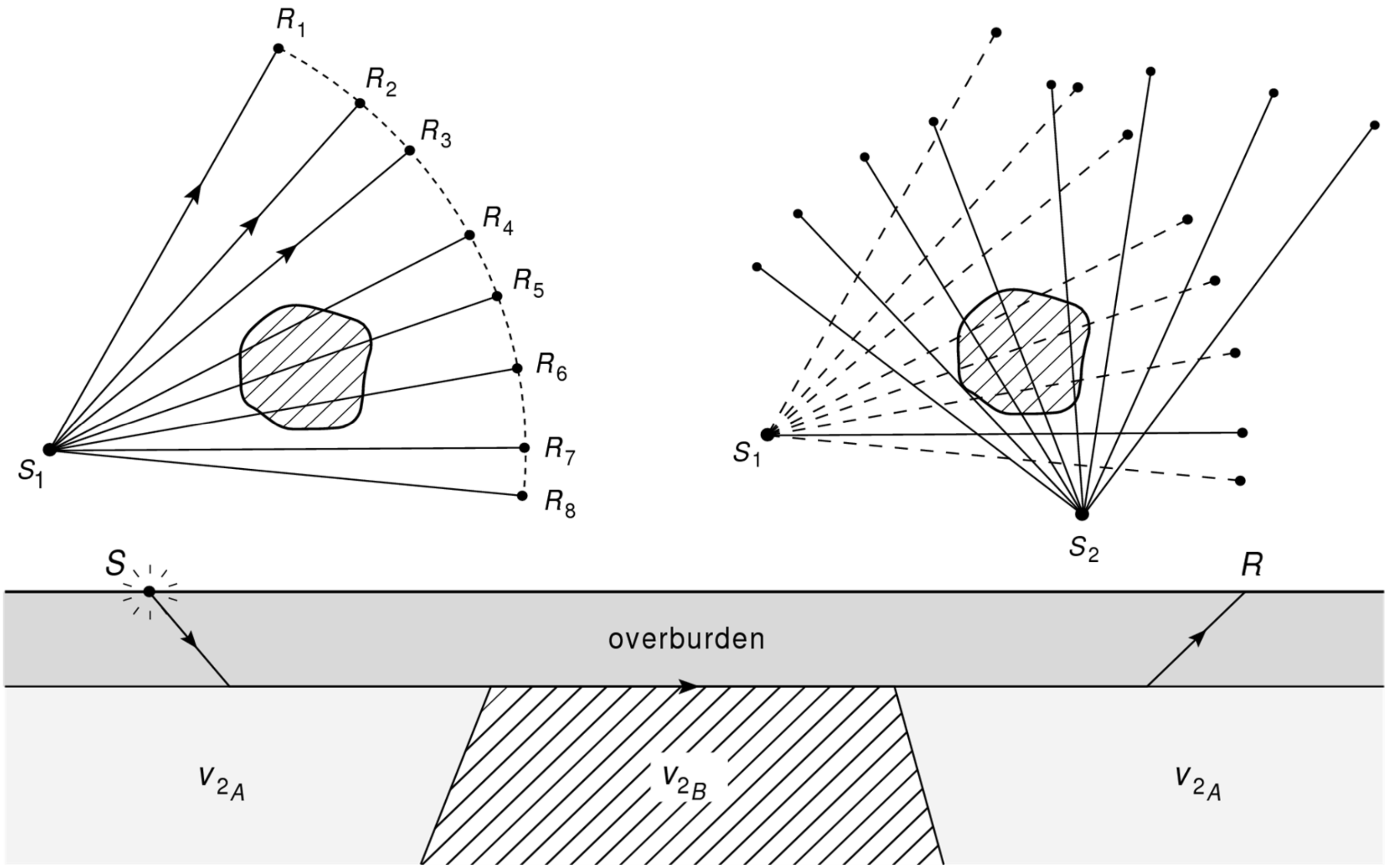
Given a value of XY_{opt}, an average velocity (V') of all the layers above the refractor (layer n) is given by:

$$V' = [V_n^2 \, XY_{\mathrm{opt}} / (XY_{\mathrm{opt}} + 2t_{\mathrm{G}} V_n)]^{1/2}. \tag{5}$$

Fan Shooting

Discontinuous targets can be mapped using radial transects: called "Fan Shooting"

A form of seismic tomography



Fan Shooting

Technique first used in the 1920's in the search for salt domes. The higher velocity of the salt causes earlier arrivals for signals that travel though the salt.

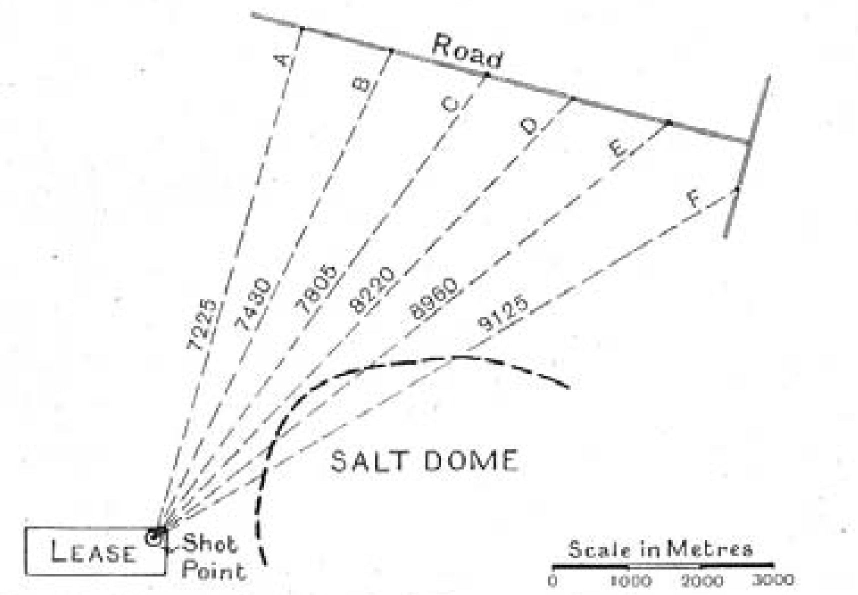


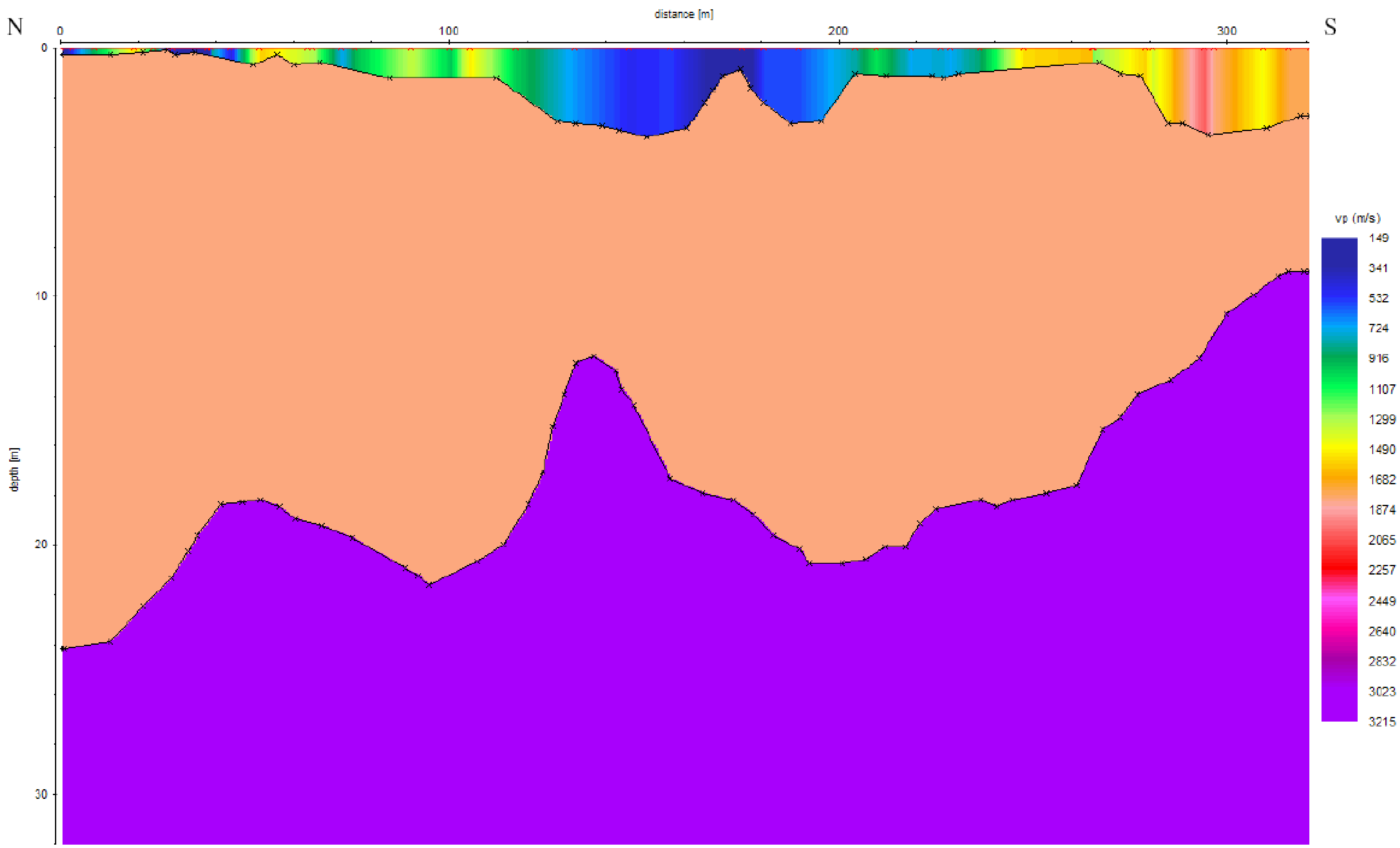
Fig. 80. Diagram showing the "shot-point" and positions of six recording seismographs.

Eve and Keys, *Applied Geophysics, 1928*

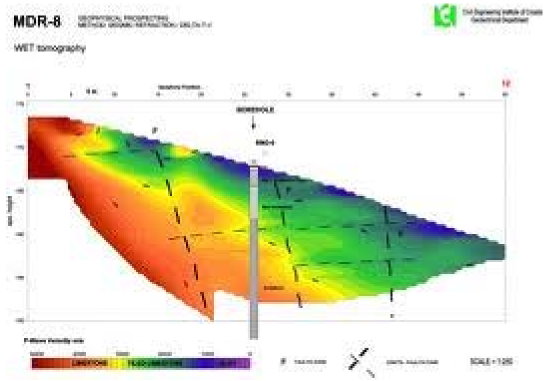
Refraction Analysis Comparison

ORIGINAL METHODS	REFRACTION TOMOGRAPHY
EXAMPLES	
•Generalized reciprocal method (GRM) •Delay-time method •Slope-Intercept method •Plus-minus method	•Raytracing algorithms •Numerical eikonal solvers •Wavepath eikonal traveltime (WET) •Generalized simulated annealing
VELOCITY MODELS	
•Layers defined by interfaces –Can be dipping •All layers have constant velocities –May define lateral velocity variations by dividing layer into finite "blocks" •Limited number of layers •Layers only increase in velocity with depth •Typically requires more subjective input –Assignment of traces to refractors	•Not interface-based •Smoothly varying lateral & vertical vels. –Can be difficult to image distinct, or abrupt, interfaces •Unlimited "layers" •Imaging of discontinuous velocity inversions possible •Typically requires less user input

Travel time inversion to find best matching underground model



Travel time Tomography

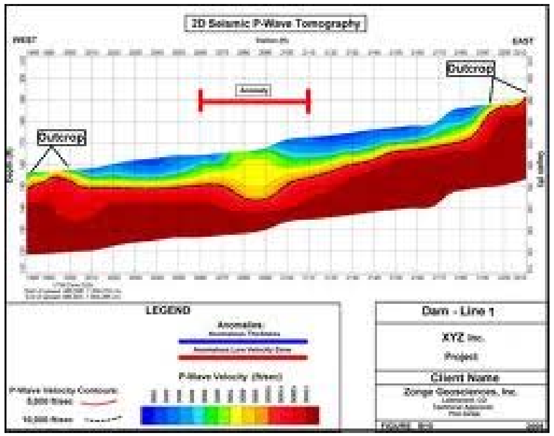


Seismic tomography (tomo=slice+graph=picture) refers to the derivation of the velocity structure of earth from seismic waves.

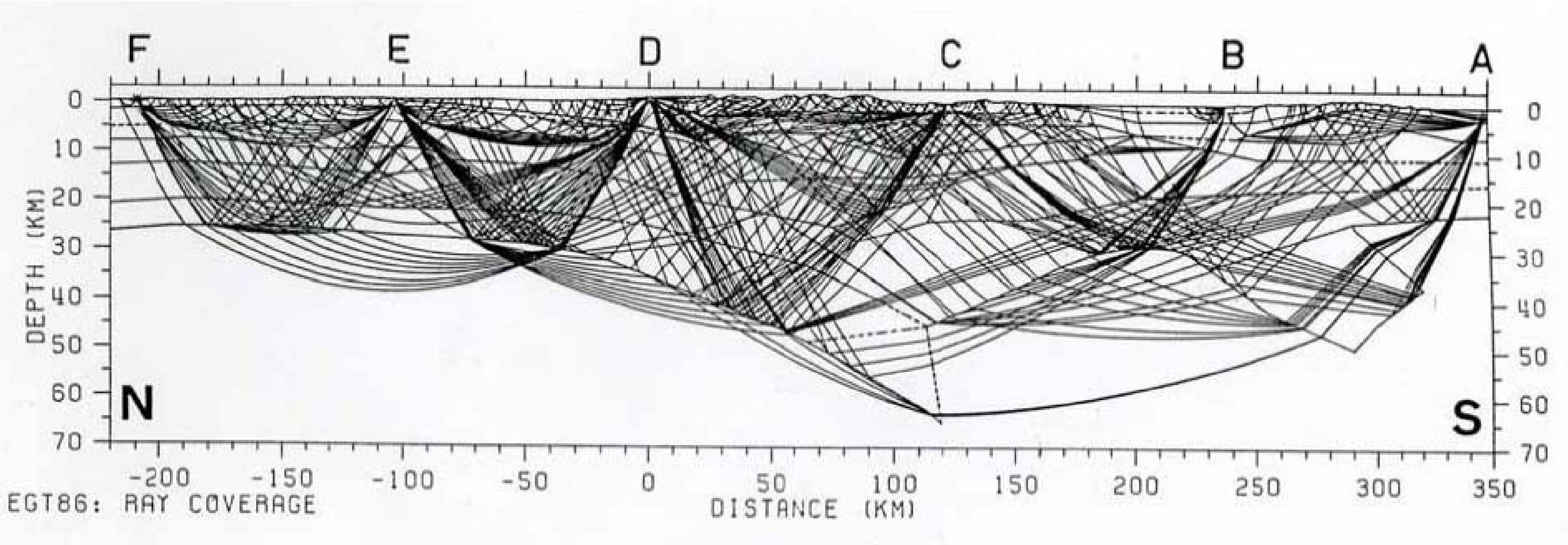
There are at two main types of seismic data to be inverted: traveltime data and waveform data.

Traveltime tomography reconstructs earth velocity models with several times lower resolution compared to waveform tomograms.

But on the other hand traveltime tomography is typically much more robust, easier to implement, and computationally much cheaper



Travel time Tomography



Ray tracing

Delayed travel-time tomography

$$t(source, receiver) = \int_{source}^{receiver} u(x,y,z)dl$$

Finding the slowness u(x) from t(s,r) is a difficult problem: only techniques for one variable !

Consider small perturbations $\delta u(x,y,z)$ from a slowness field $u_0(x,y,z)$

$$t(src, rec) = \int_{src}^{rec} u_0(x,y,z)dl + \int_{src}^{rec} \delta u(x,y,z)dl$$

$$t(src, rec) \approx \int_{src_0}^{rec_0} u_0(x,y,z)dl + \int_{src_0}^{rec_0} \delta u(x,y,z)dl$$

$$t(src, rec) - t_0(src, rec) \approx \int_{src_0}^{rec_0} \delta u(x,y,z)dl$$

$$\boxed{\delta t(src, rec) \approx \int_{src_0}^{rec_0} \delta u(x,y,z)dl}$$

This a LINEAR PROBLEM

$$\delta t(s,r) = A(u_0)\,\delta u(x,y,z)$$

Model description

- The model of velocity perturbation (or slowness $\delta u(x, y, z)$) could be described in a regular mesh with values at each node $\delta u_{i,j,k}$. We may define the interpolation function (shape function) for the estimation of slowness perturbation everywhere.
- A simple shape function $h_{i,j,k}$ could be 1 in a box and and 0 everywhere else.

$$\delta u(x, y, z) = \sum_{cube} \delta u_{i,j,k} \, h_{i,j,k}$$

Linear system

$$\delta u(x,y,z) = \sum_{cube} \delta u_{i,j,k}\, h_{i,j,k}$$

Slowness perturbation description

$$\delta t(src,rec) = \int_{src_0}^{rec_0} dl \sum_{cube} \delta u_{i,j,k}\, h_{i,j,k}$$

Discretisation of the medium fats the ray

$$\delta t(src,rec) = \sum_{cube} \delta u_{i,j,k} \int_{src_0}^{rec_0} dl\, h_{i,j,k}$$

Sensitivity matrice is a sparse matrice

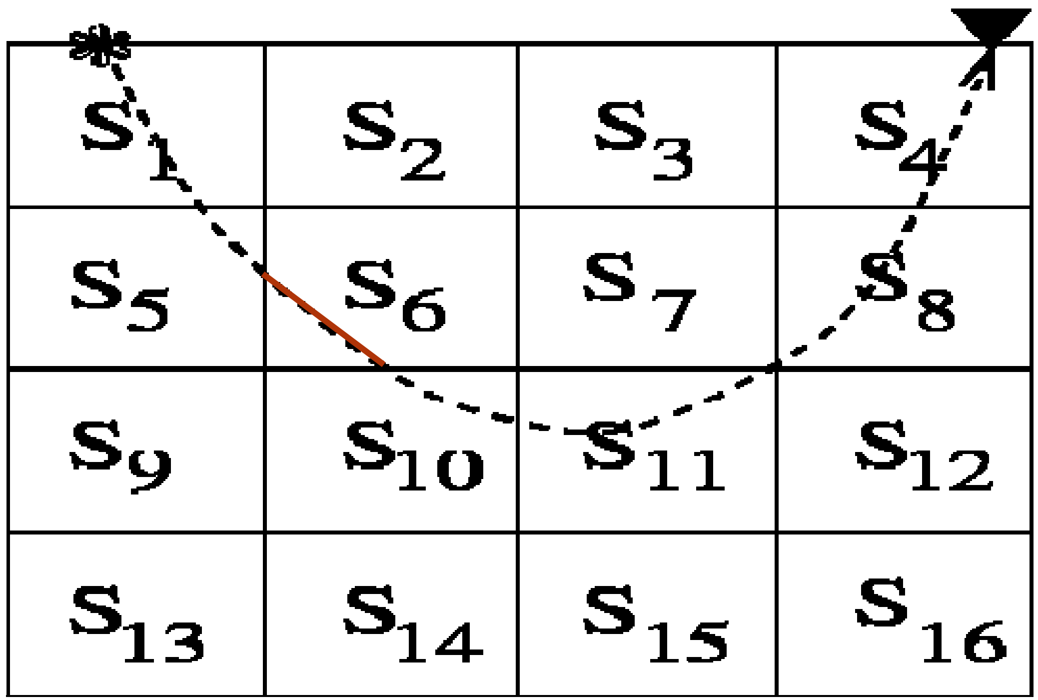
$$\delta t(src,rec) = \sum_{cube} \delta u_{i,j,k} \frac{\partial t}{\partial u}$$

$$\Delta t = A_0 \Delta u$$

Matrice of sensitivity or of partial derivatives

Travel time Tomography

Interpretation of the derivative



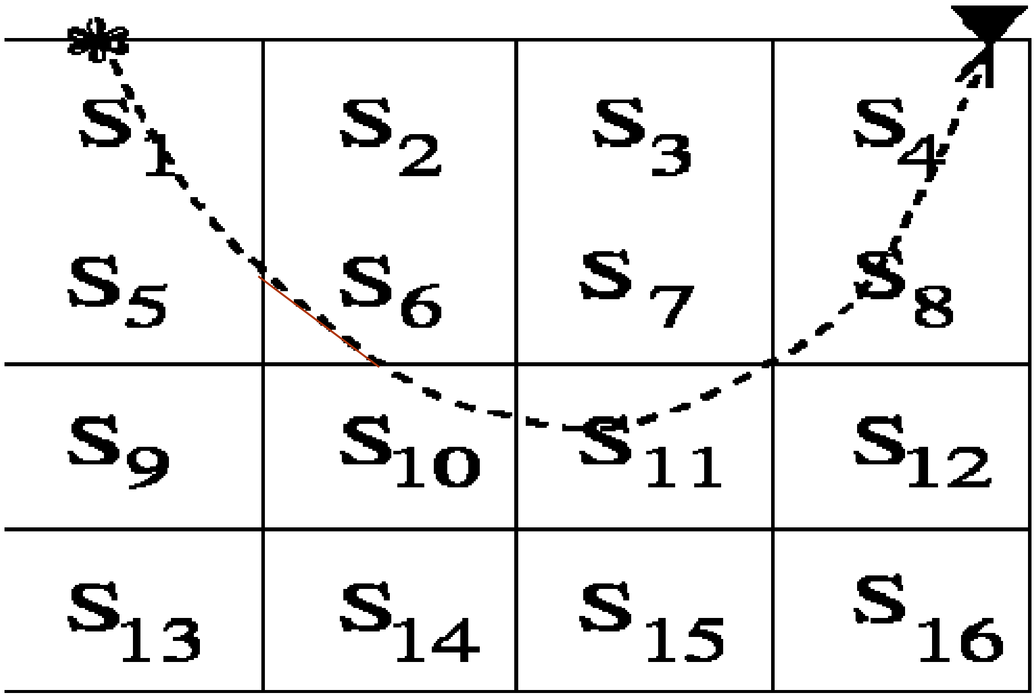
Travel time Tomography

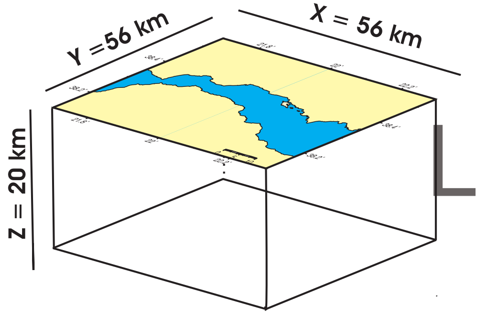
Traveltime tomography is the procedure for reconstructing the earth's velocity model from picked traveltimes.

This is an **inverse problem** : convert observed measurements into a model that is capable of explaining them.

$$\Delta t = A_0 \Delta u$$

d= Gm ➡ $m=G^{-1}d$



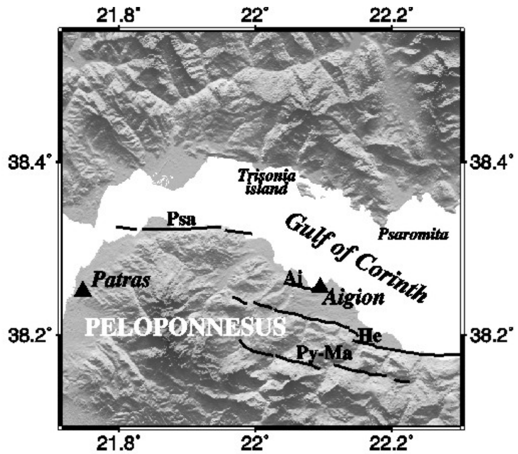


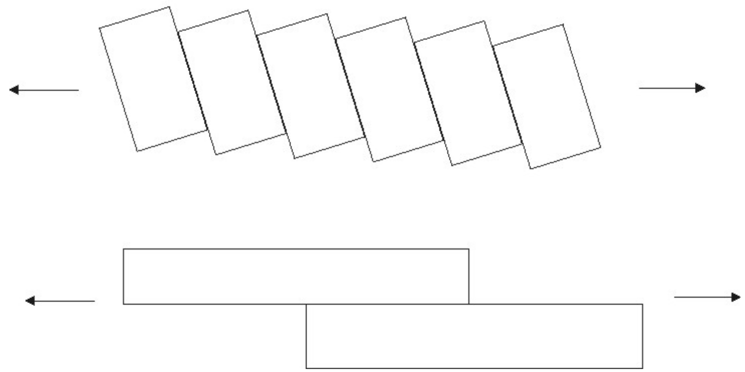
LE RIFT DE CORINTHE

Une zone en extension où projet de forage profond

Comment s'ouvre le rift corinthien ?

Quels sont les mécanismes physiques (fractures, fluides, équilibre isostatique ???)





CAMPAGNE 1991

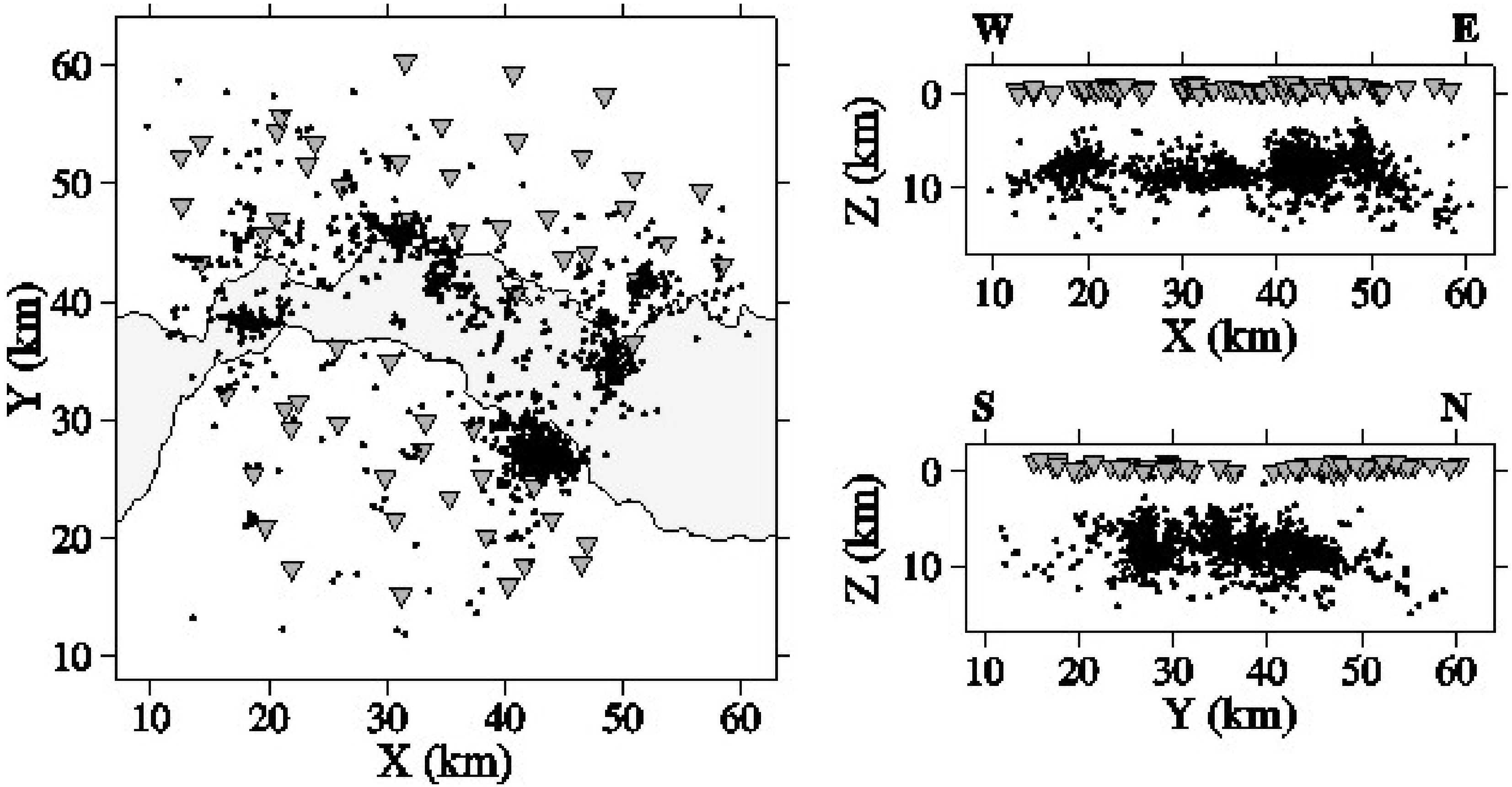


IMAGE VITESSE

Coupes horizontales

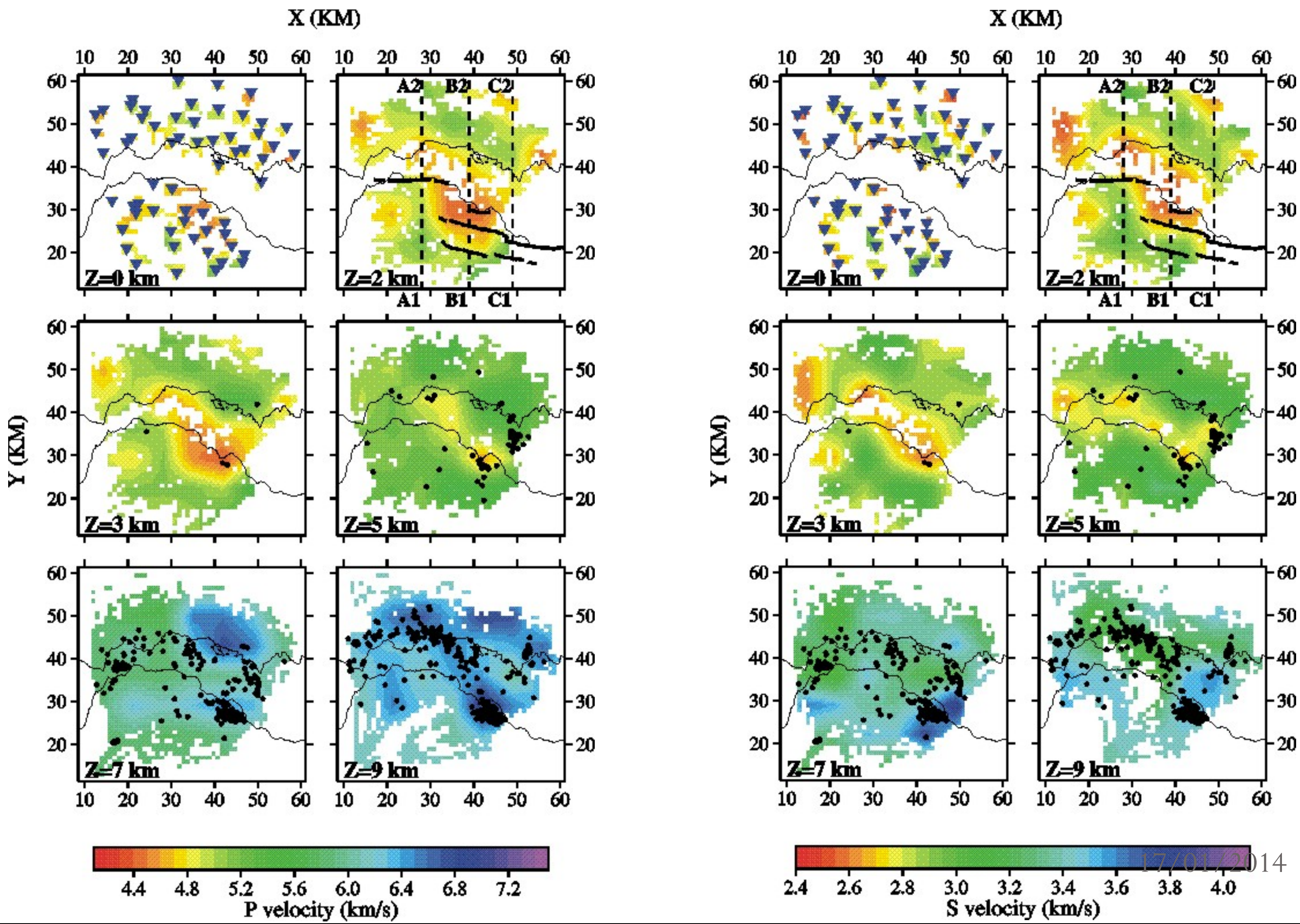
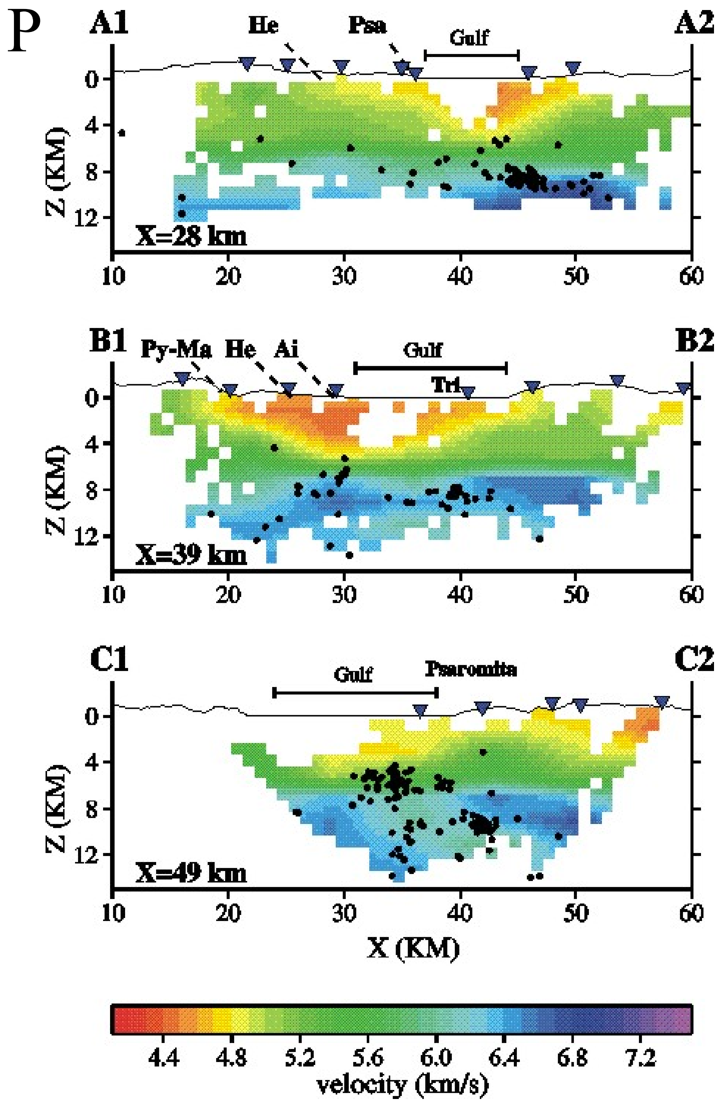
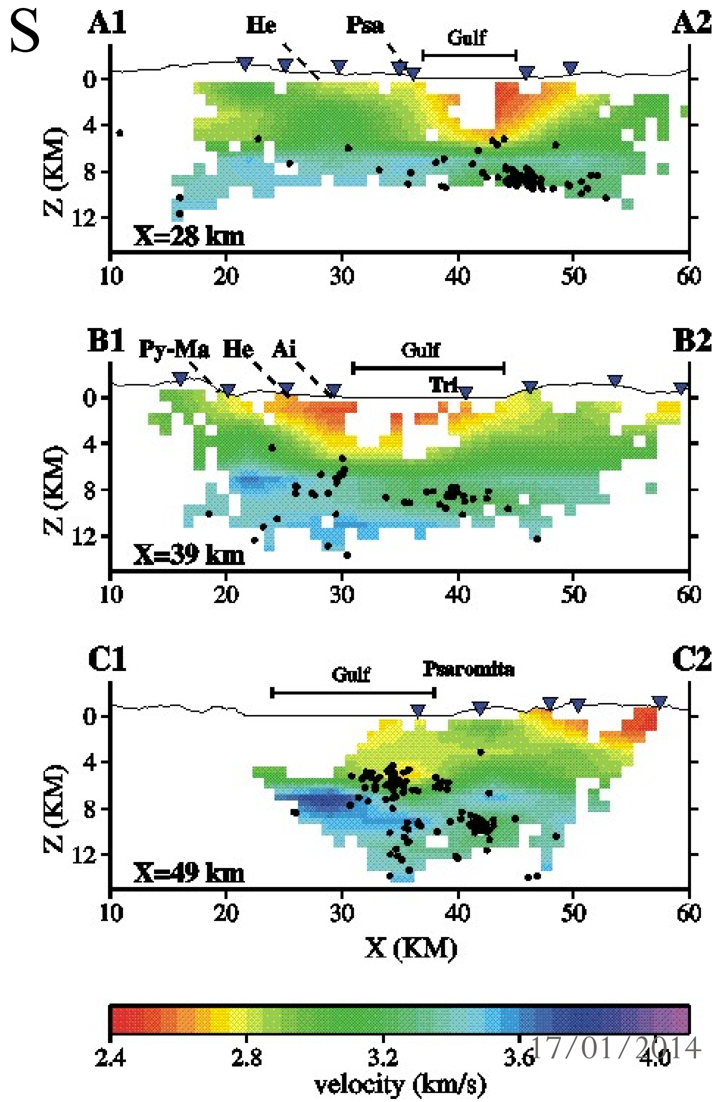


IMAGE VITESSE

Coupes verticales

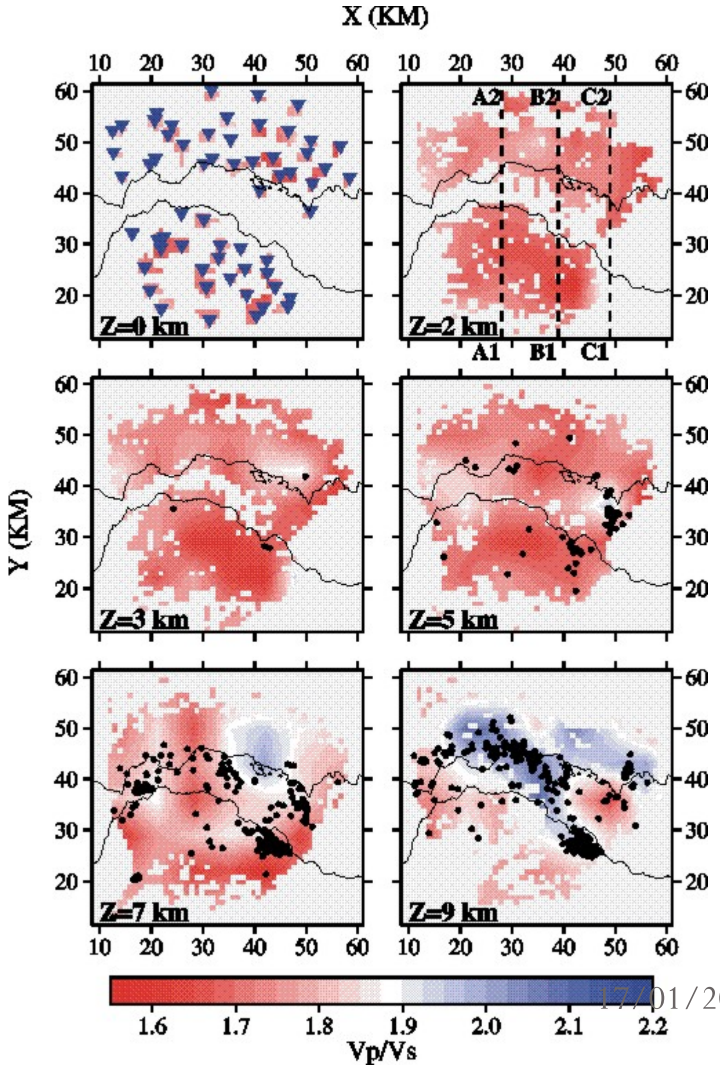




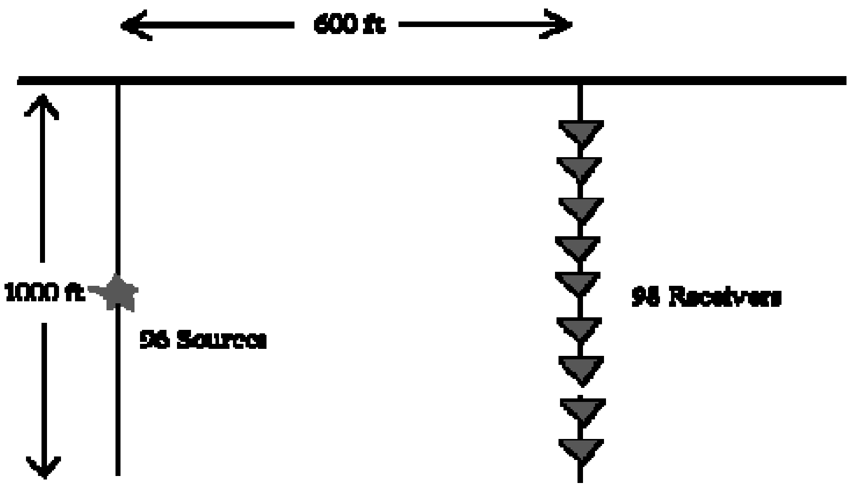
Le rapport Vp/Vs :
présence de fluides ?

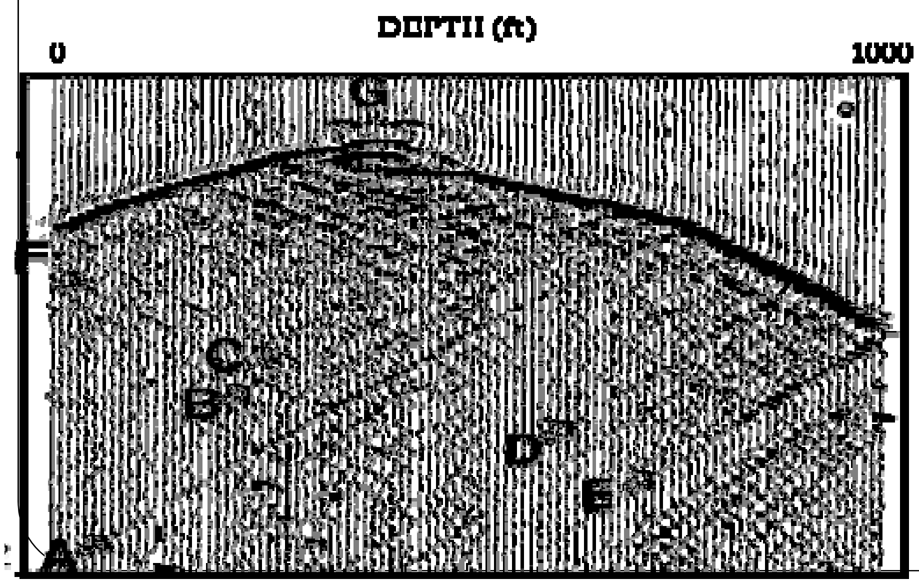
Certains paramètres déduits portent des interprétations plus faciles comme le rapport Vp/Vs en relation avec la présence de fluides ou le produit Vp*Vs en relation avec la porosité

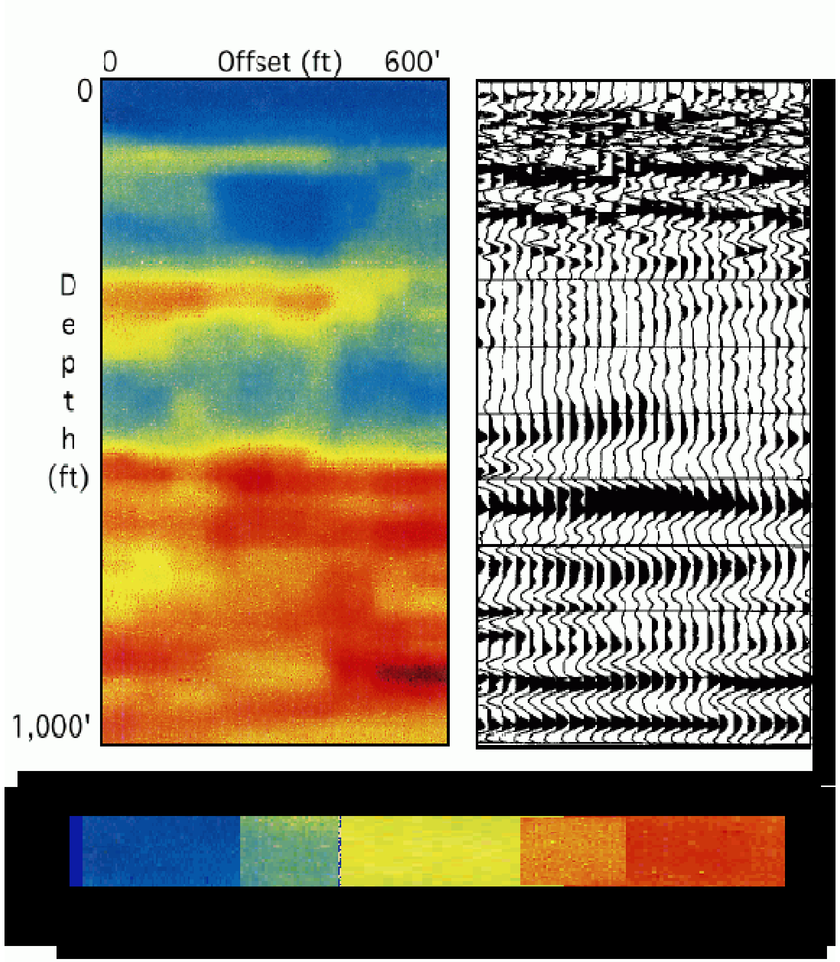
Faveur pour le 2ème mécanisme ????



Example





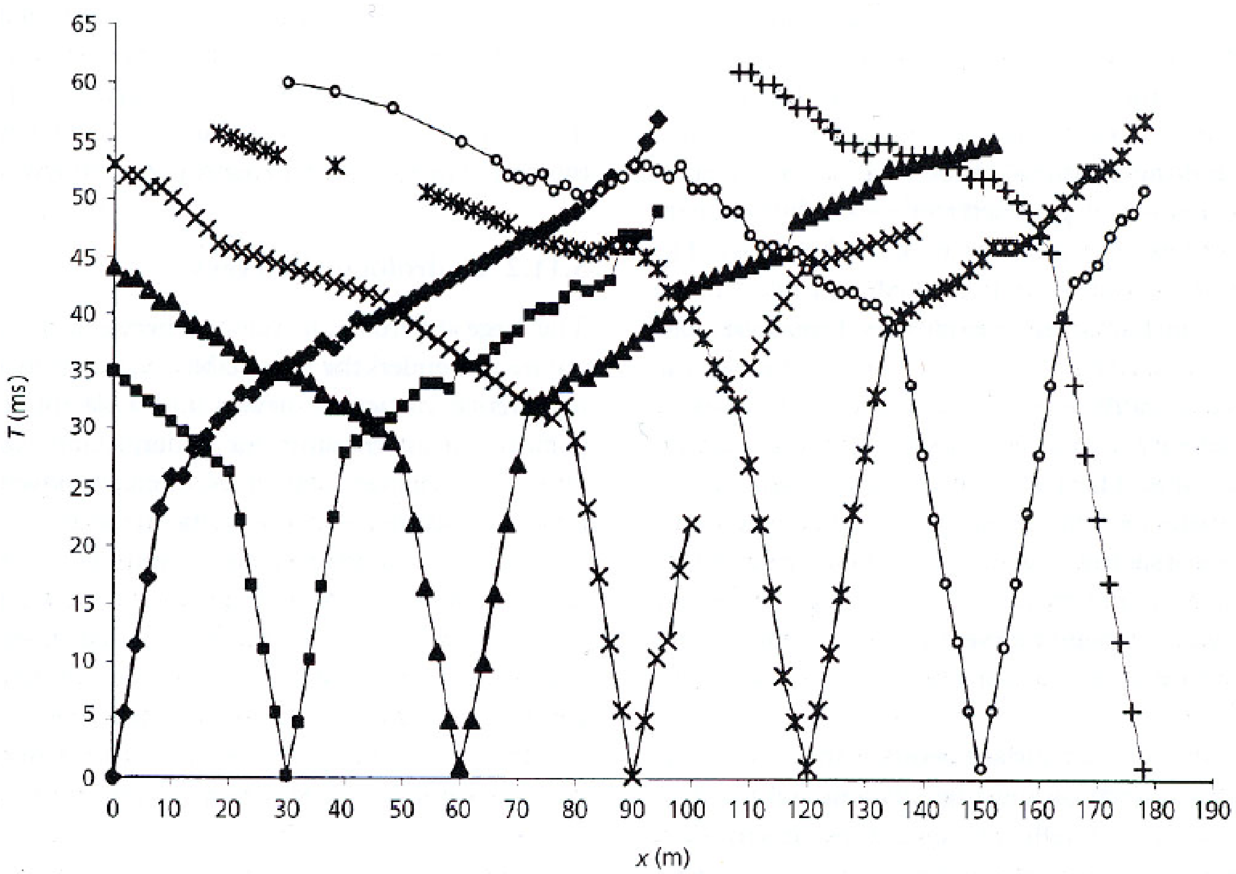


Velocity tomogram on left and reflection image obtained from CDP data on right

Applications

Shallow applications of seismic refraction

1. Depth to bedrock

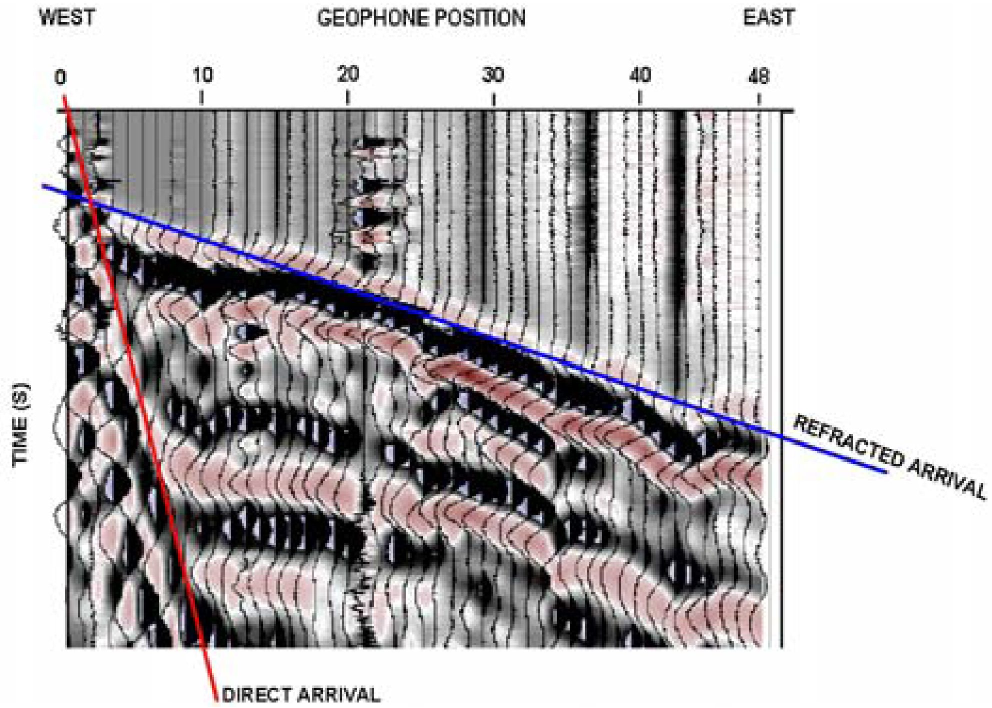


- velocity of bedrock greater than unconsolidated layer
- in this example, a shot point was located every 30 m
- depth to bedrock increases with *x*

Shallow applications of seismic refraction

1. Depth to bedrock (example from Northern Alberta)

Seismic refraction was used to determine depth to bedrock at the location where a pipeline was planned to cross a creek.

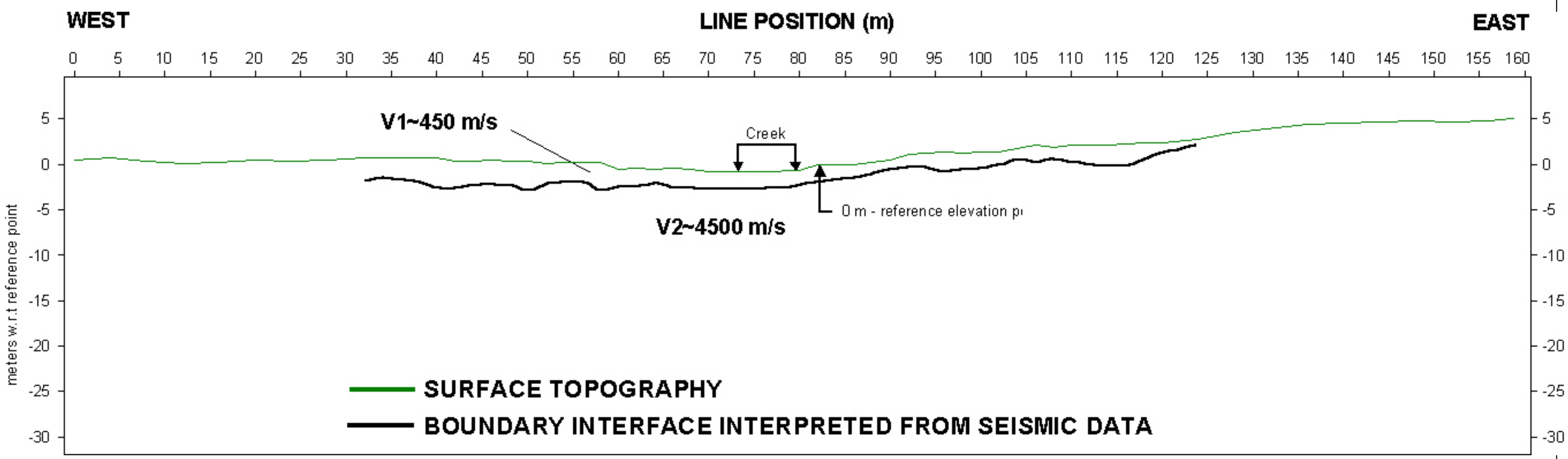


Note that the direct wave is only the first arrival at the first 2 geophones. This is because of a very high velocity contrast between the upper and lower layers.

Shallow applications of seismic refraction

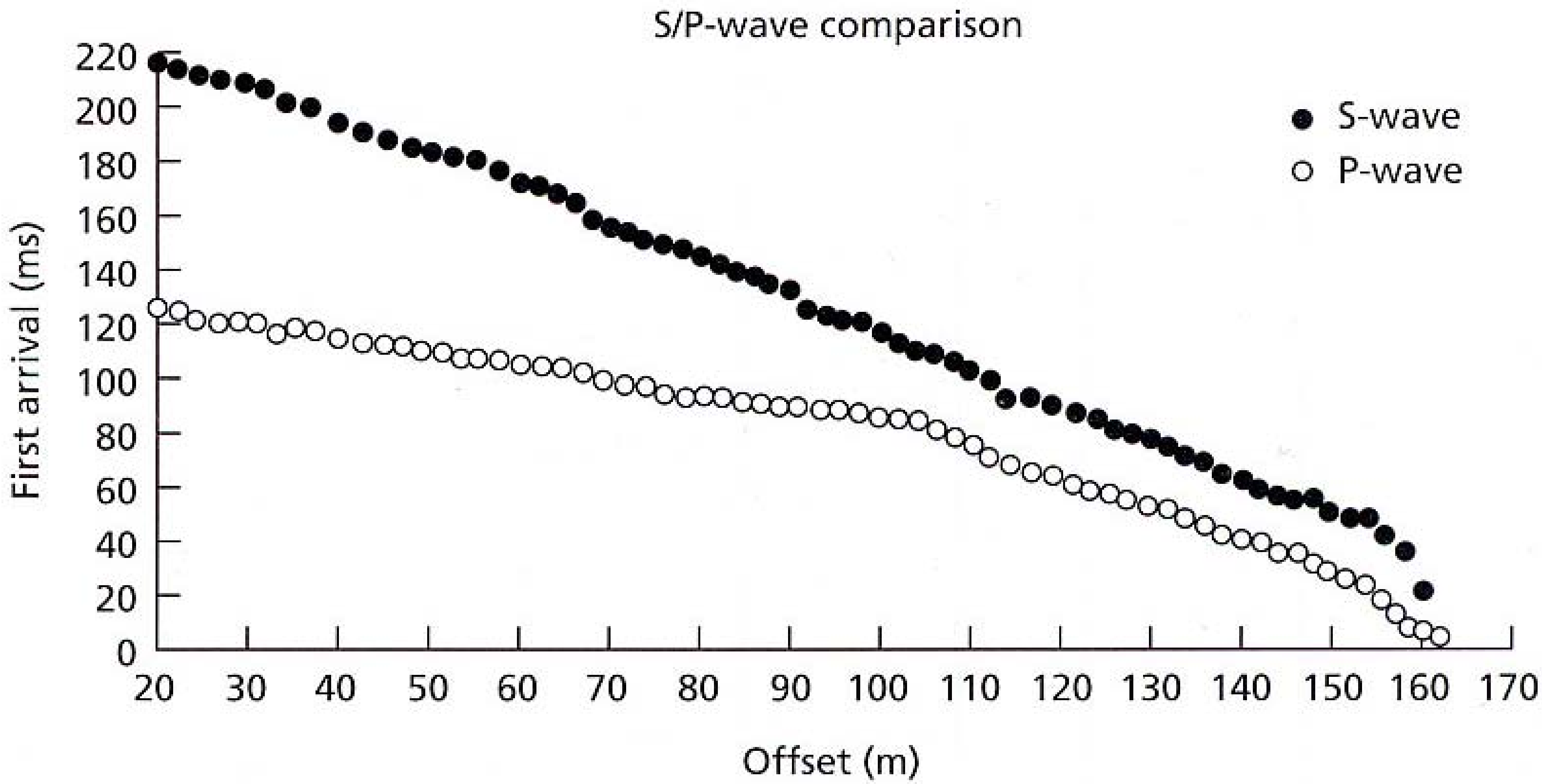
1. Depth to bedrock (example from Northern Alberta)

The model below was derived from the seismic data using the general reciprocal method.



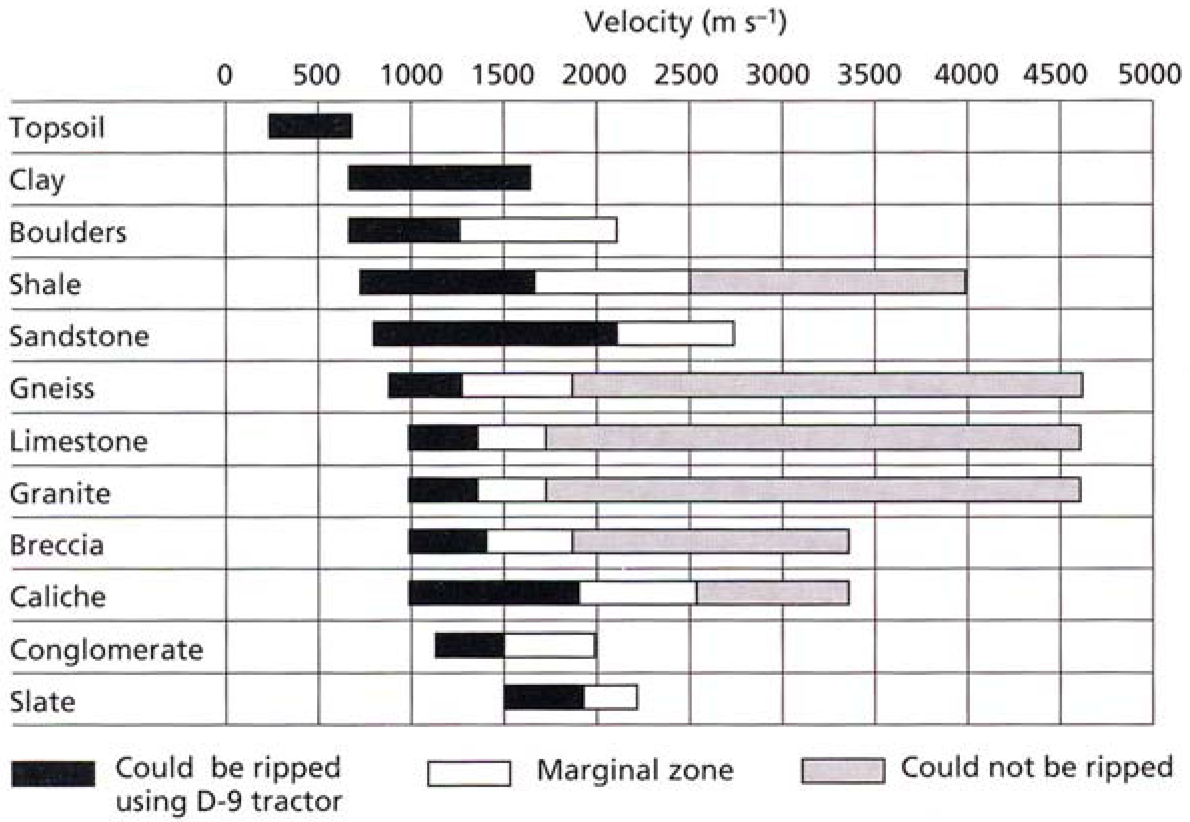
Shallow applications of seismic refraction

2. Locating a water table

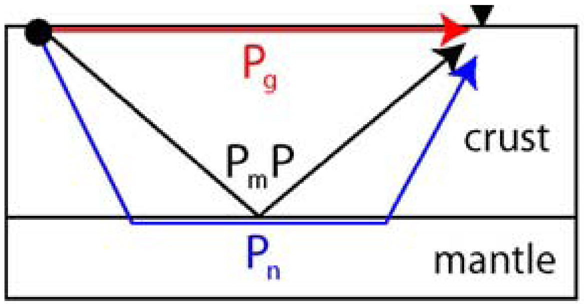


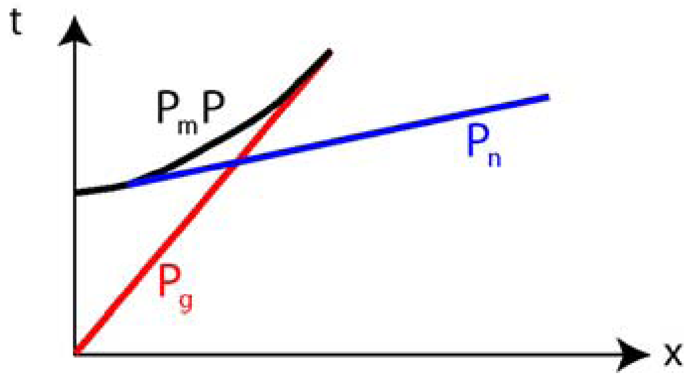
Shallow applications of seismic refraction

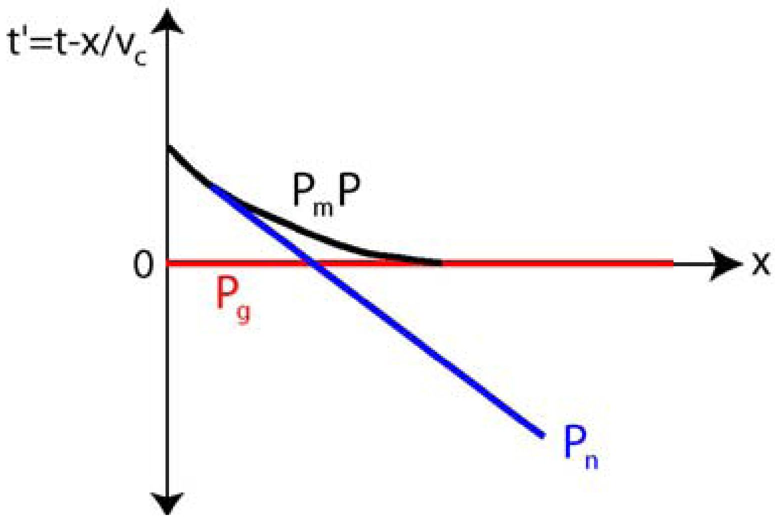
3. Determine rippability



Depth of Moho from seismic refraction







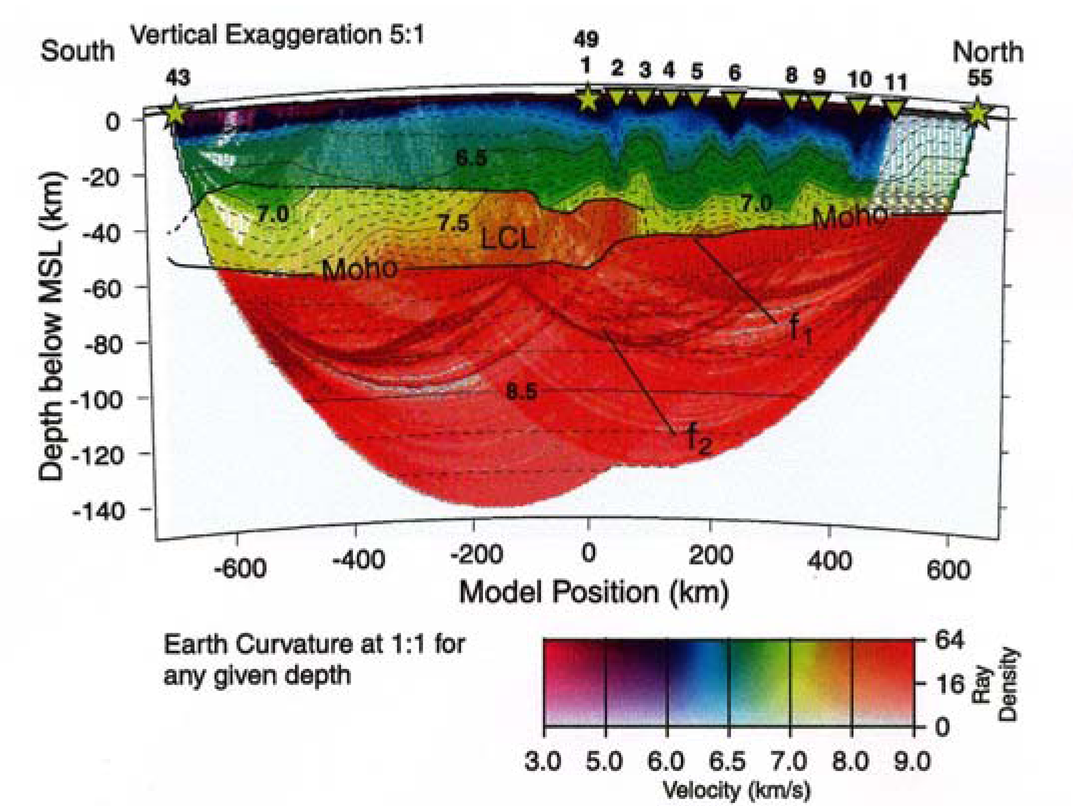
• the head wave that travels in the upper mantle is called P^n

● reflection from the Moho is called P^mP

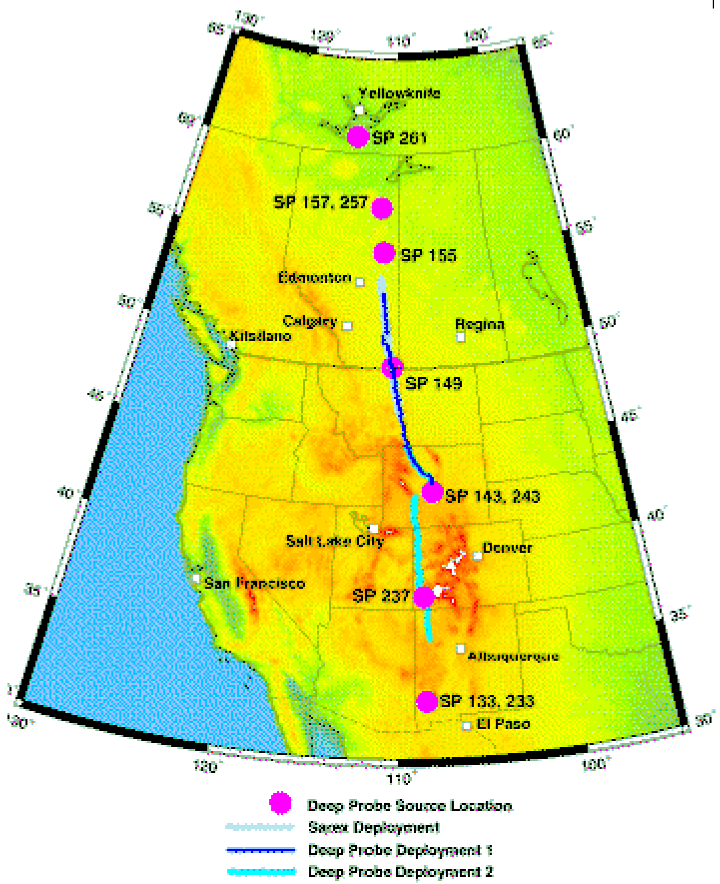
● reduced travel time is sometimes plotted on the vertical axis.
$t' = t – x/v^{red}$
where v^{red} is the reduction velocity. This has the effect of making arrivals with $v=v^{red}$ plot horizontally on a t-x plot.

● in the figure on the left, the crustal P-wave velocity was used as the reduction velocity.

Tectonic studies of the continental lithosphere with seismic refraction

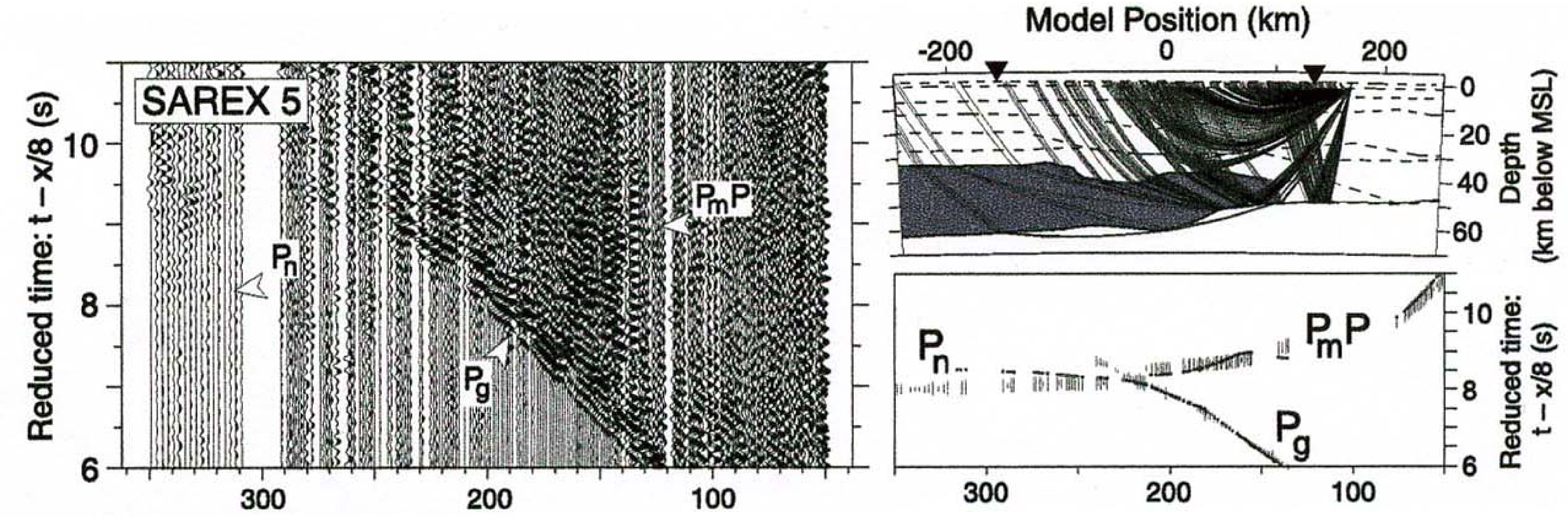


Gorman, A.R. *et al, Deep probe: imaging the roots of western North America, Canadian Journal of Earth Sciences, 39, 375-398, 2002.*



Explosive shots up to 2400 kg with seismic recorders deployed on a profile from 60°N to 43°N

Tectonic studies of the continental lithosphere with seismic refraction

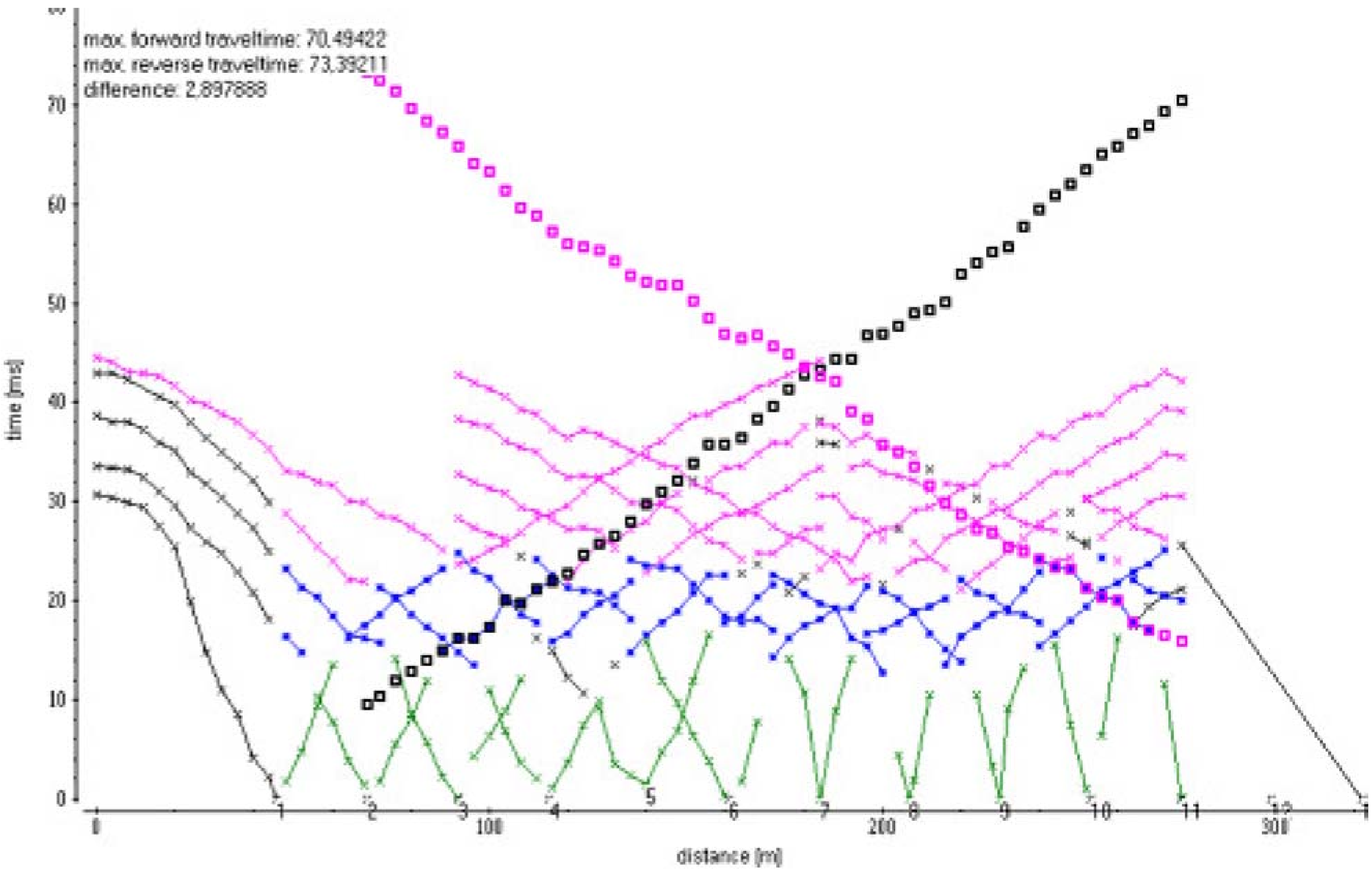


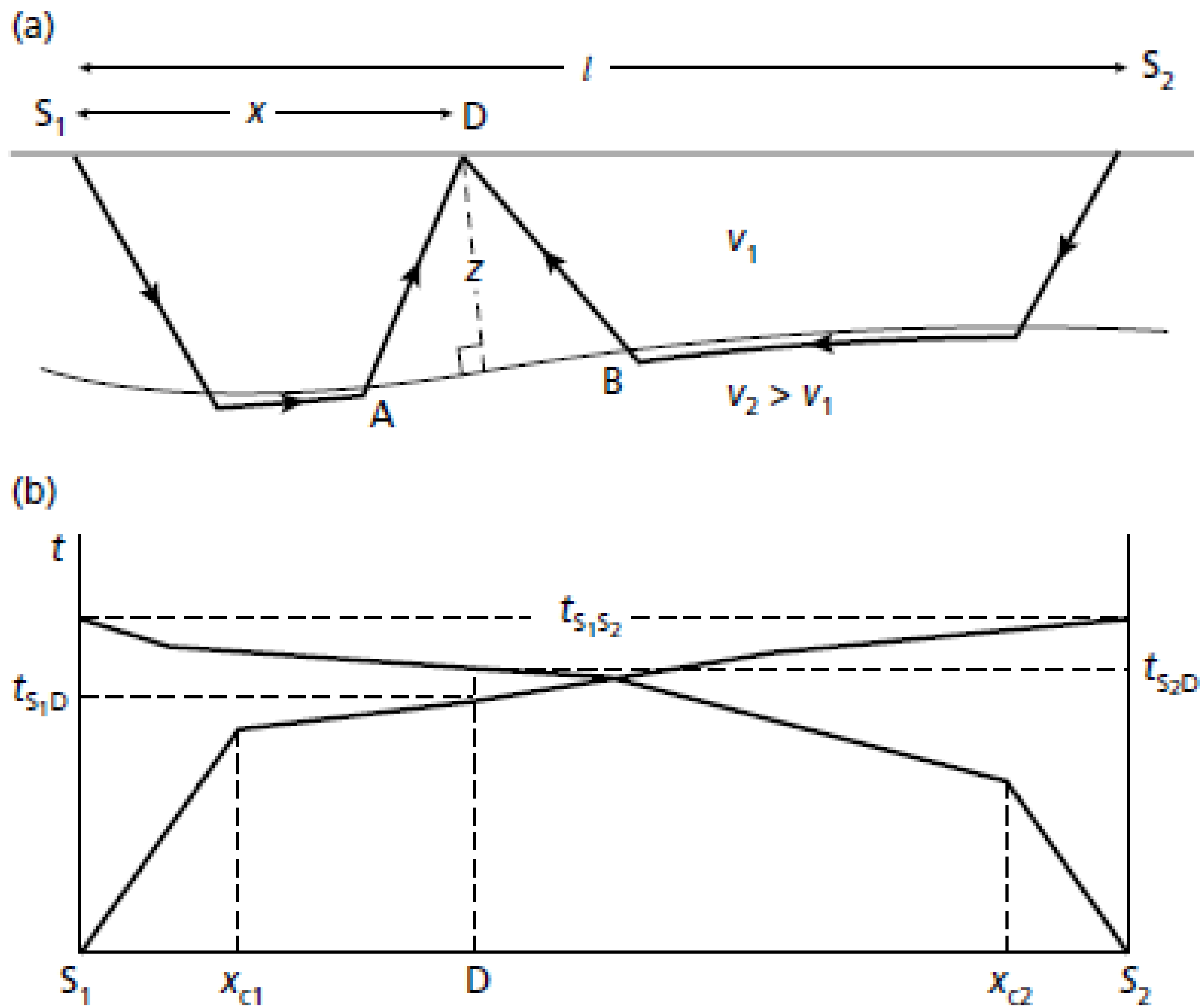
The figure above shows ray tracing used to model the data. Measures the variation in Moho depth and crustal structure. Note that with a reduction velocity of 8 km/s, P^n plots as a horizontal line, while the slower P^g has a positive slope.

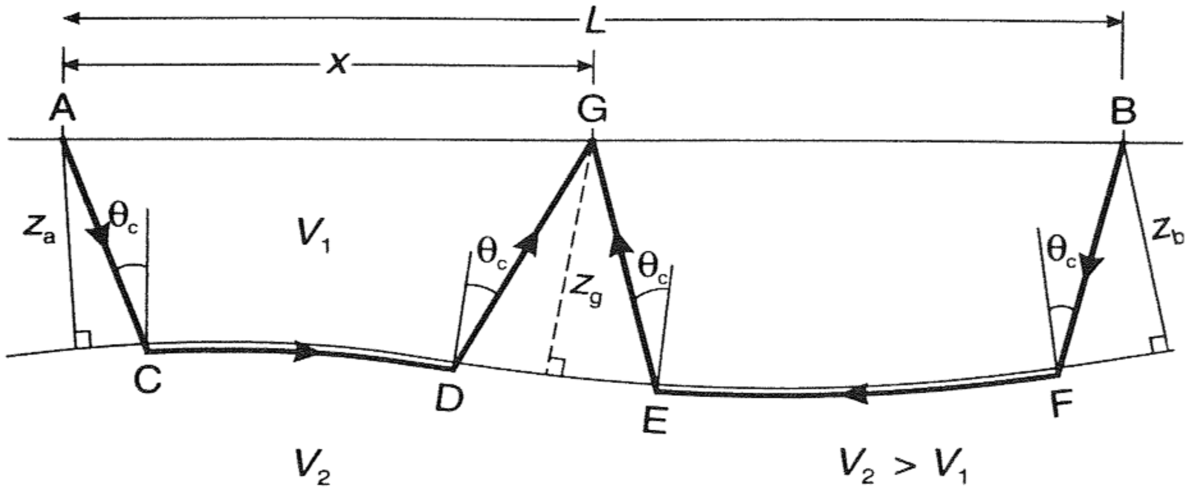
END !

Thank you for your attention

Control of travel-times




(a)
l
S1
S2
x
D
z
v1
A
B
v2 > v1
(b)
t
tS1S2
tS1D
tS2D
S1
xc1
D
xc2
S2



Assumptions to use the method:

-Present layers are homogeneous

-Large velocity contrast between the layers

-Angle of dip of the refractor is less than 10 degrees