Rock Physics

From mm. to Km. scale

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9. Seismic exploration and survey

Contents :

I. Introduction

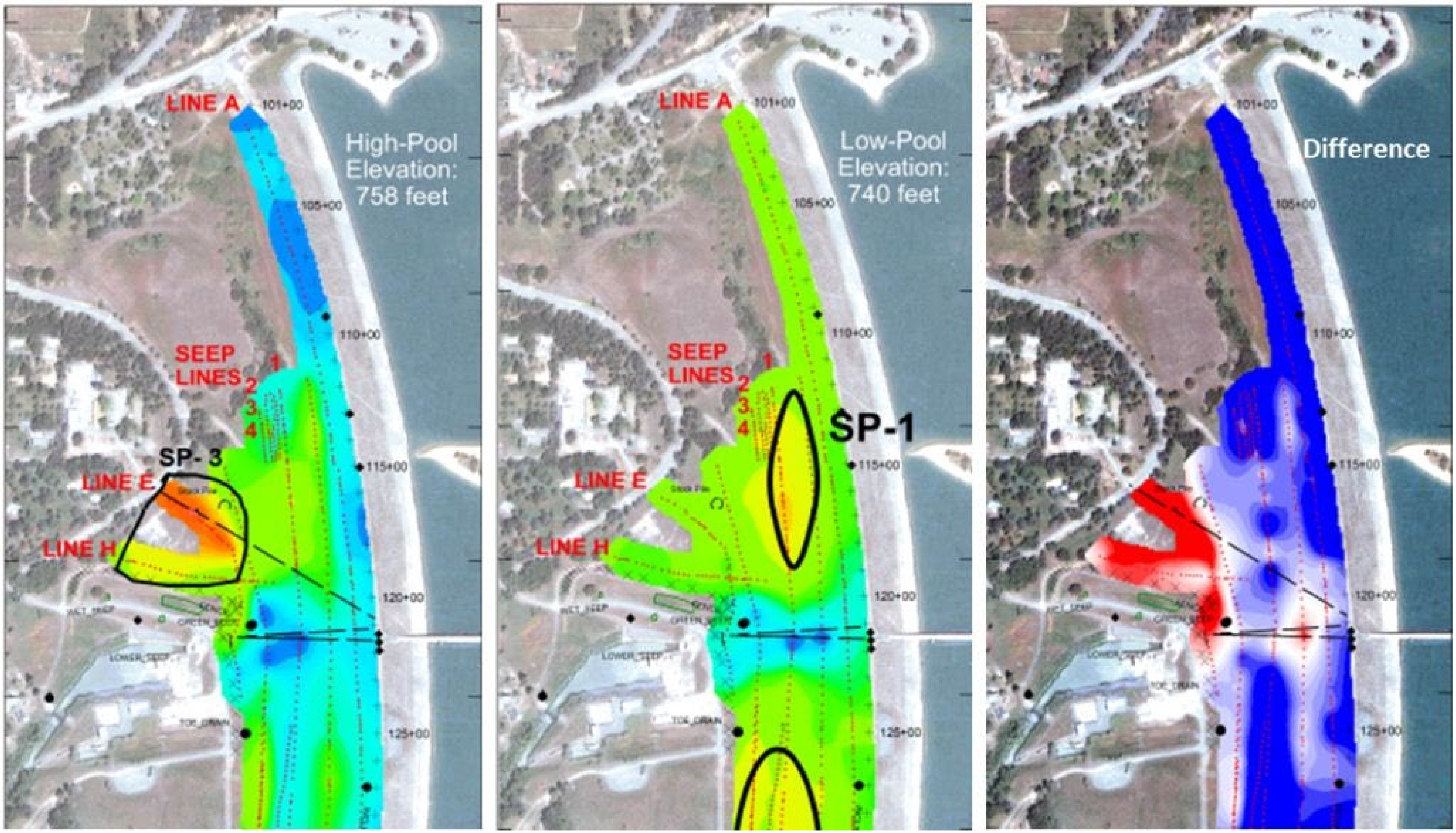
➢ Why?

- Determine historical ground movement for infrastructure planning
- Determine historical ground movement for pipeline routing
- Monitoring ground movement along pipelines
- Geological and terrain base maps for development of environmental baseline
- Geohazard exposure analysis
- Identify the cause of geological movement
- Obtaining detailed terrain mapping for construction
- Forecasting landslide locations

- Identifying seasonal terrain changes e.g. for access
- Identify geological structure through landform
- Identify geohazards and landscape change rates
- Identification of slope instability
- Terrain stability for route planning
- Oil and gaz prospection
- Geothermal prospection
- Reservoir Monitoring
- Groundwater exploration

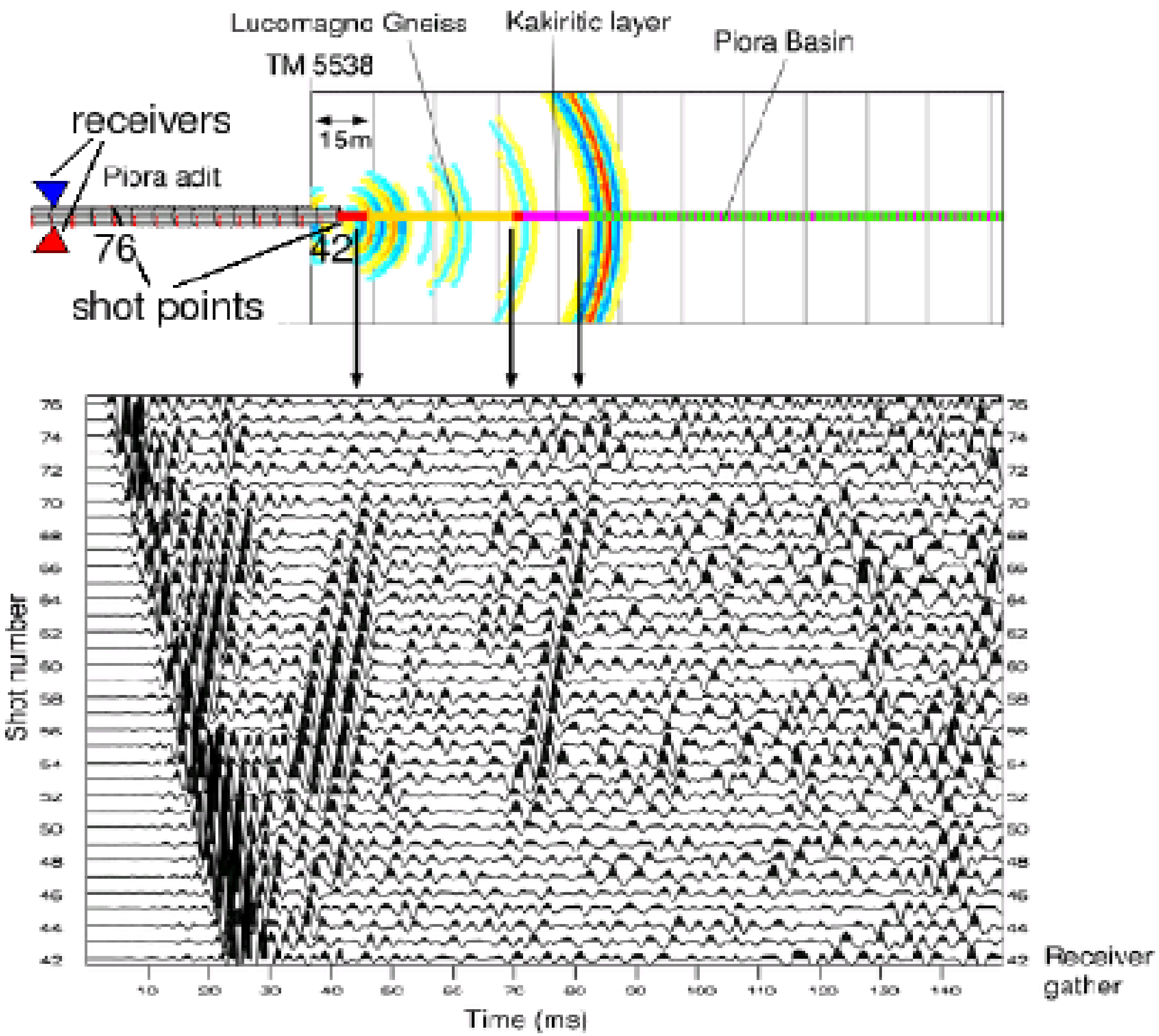
I. Introduction

➢ Dam monitoring



I. Introduction

➢ Detailed terrain mapping for Tunelling



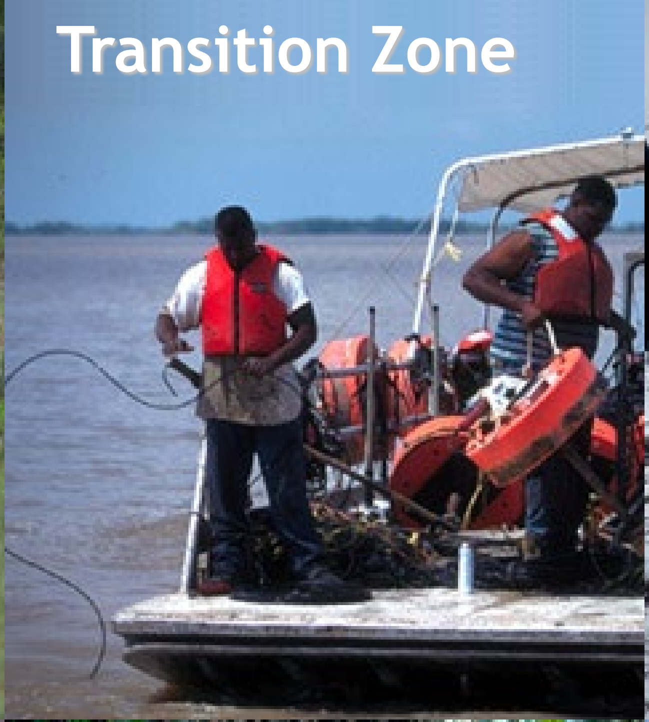
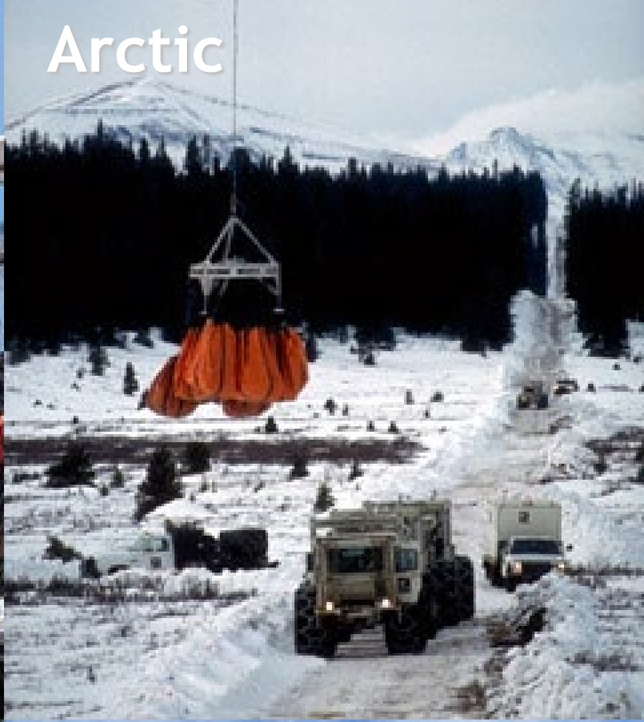
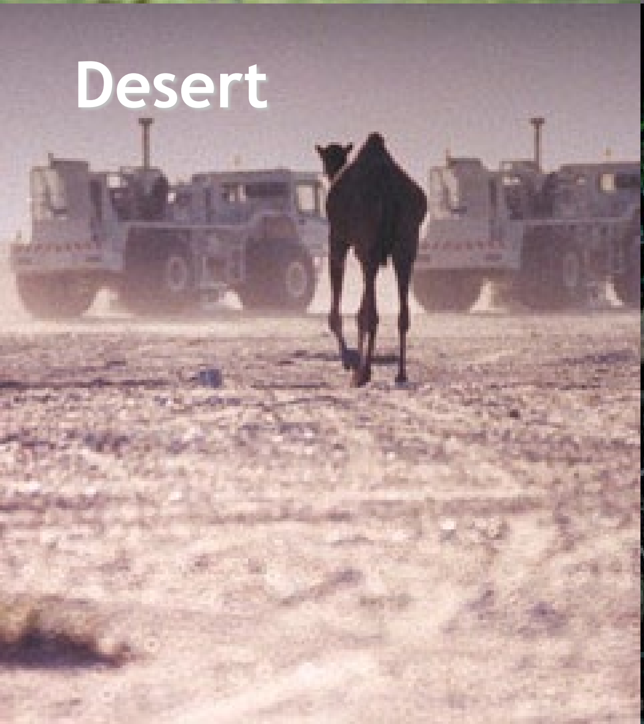
I. Introduction

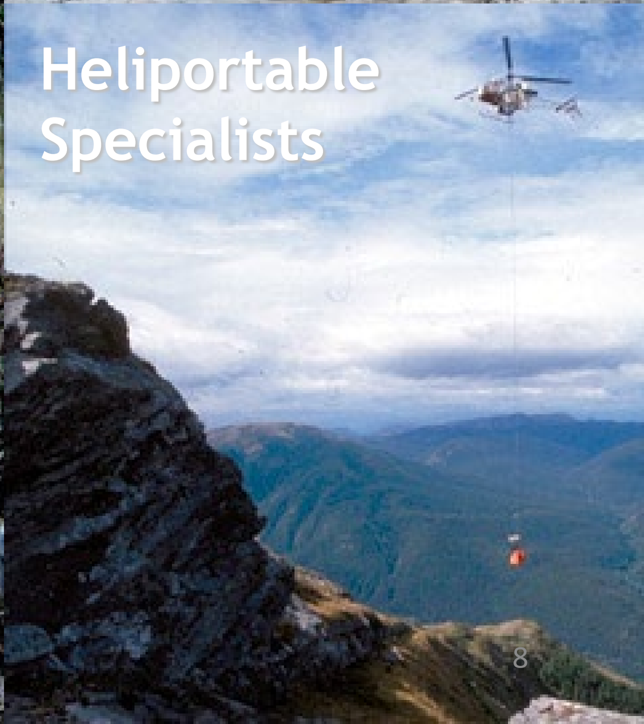
- Detailed terrain mapping for construction

I. **Introduction**

➢ Where ?

- On shore
- Off shore


Highlands

Transition Zone

Arctic

Desert

Jungle

Heliportable
Specialists

Geophone Team

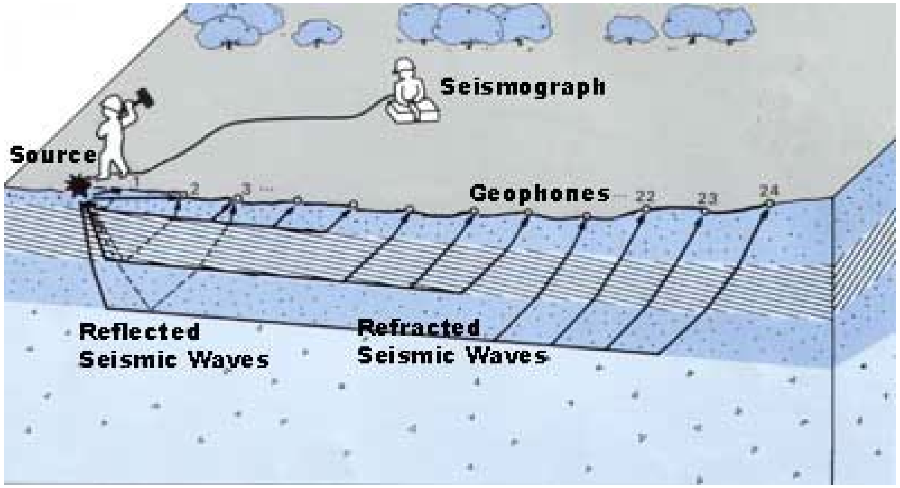
Marine Seismic Acquisition

Marine Seismic Acquisition

II. Waves

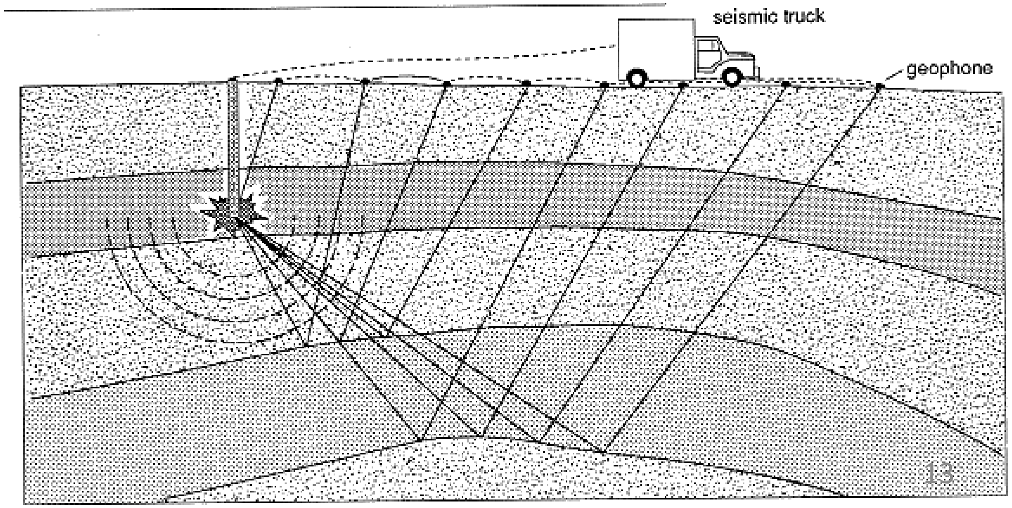
➢ Seismic prospection

Elastic waves ➔ geologic strata



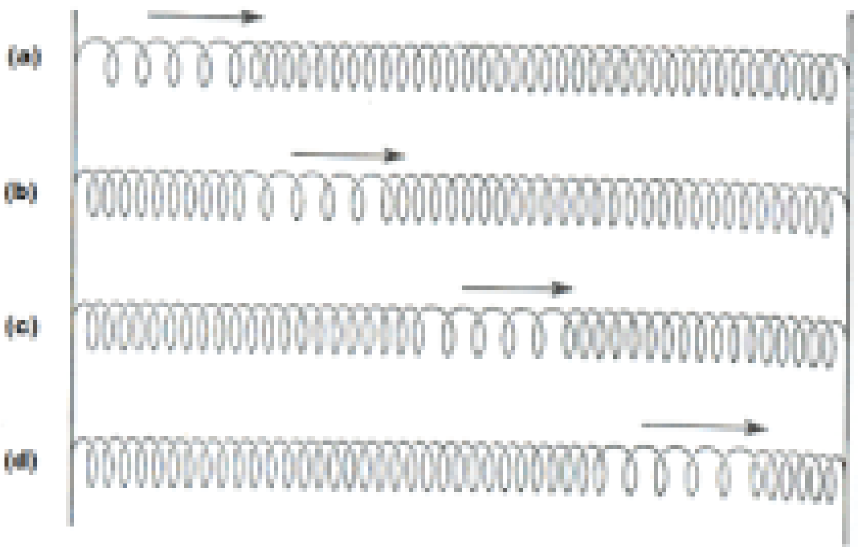
- Active source
- Wave propagation
- Waves is reflected or refracted
- Signal acquisition
- Signal treatment
- Interpretations

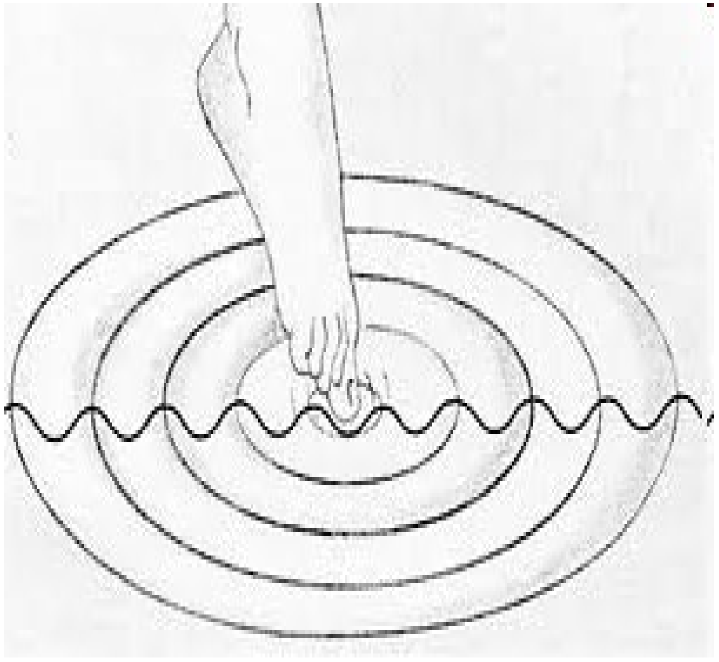
Detection of interfaces with different physical properties!



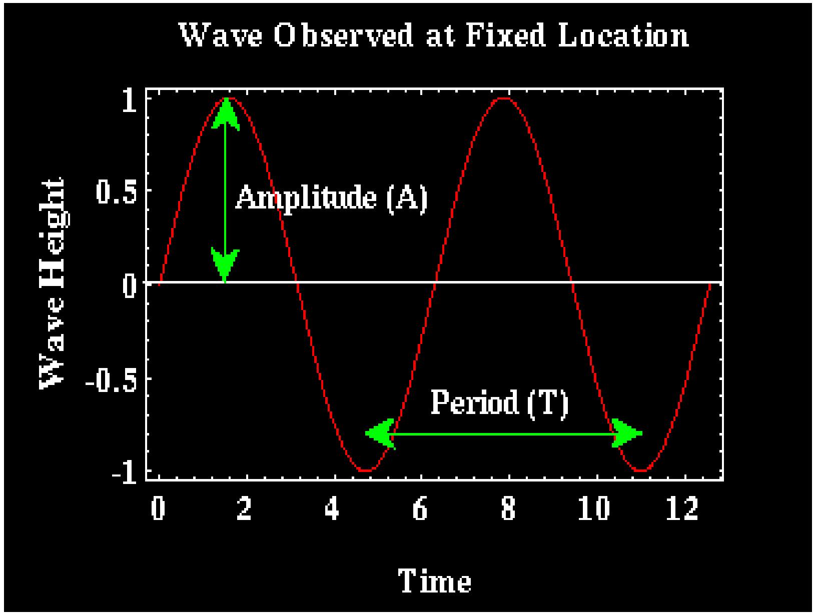
II. **Waves**

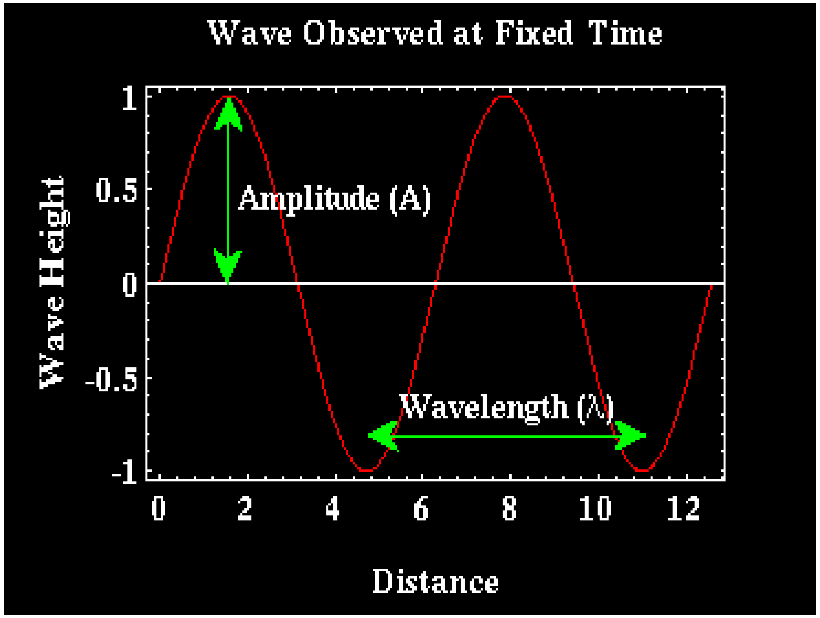
- **Elastic wave,** motion in a medium in which, when particles are displaced, a force proportional to the displacement acts on the particles to restore them to their original position.





II. Waves





$f(t) = \boxed{A \sin(\omega t - \phi)}$

Speed V [m/s]

Wave length $\lambda = V\,T = V / f$ [m]

Time t [s]

Phase ϕ [rad]

Amplitude A [ ]

Périod T [s]

Fréquency f [Hz]

Pulsation $\omega = 2\pi f = 2\pi / T$ [rad/s]

II. Waves

➢ Seismic waves

$$\boxed{V_P = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}}}$$

$$\boxed{V_s = \sqrt{\frac{\mu}{\rho}}}$$

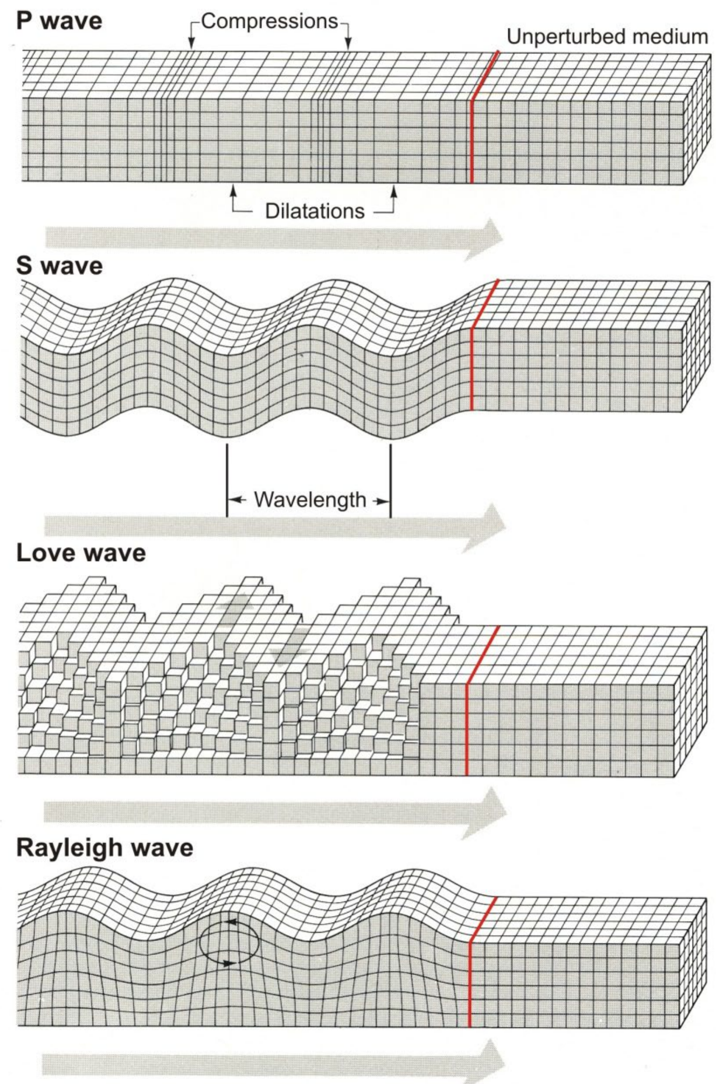
$$\boxed{\upsilon = \frac{3K - 2\mu}{2(3K + \mu)} = \frac{1}{2}\frac{V_p^2 - 2V_s^2}{V_p^2 - V_s^2}}$$

K bulk modulus, μ shear modulus

- *Vs* < *Vp*
- *Vs* = 0 if μ = 0 (fluids)

Interference between S_h and S_H waves

Interference between P and S waves



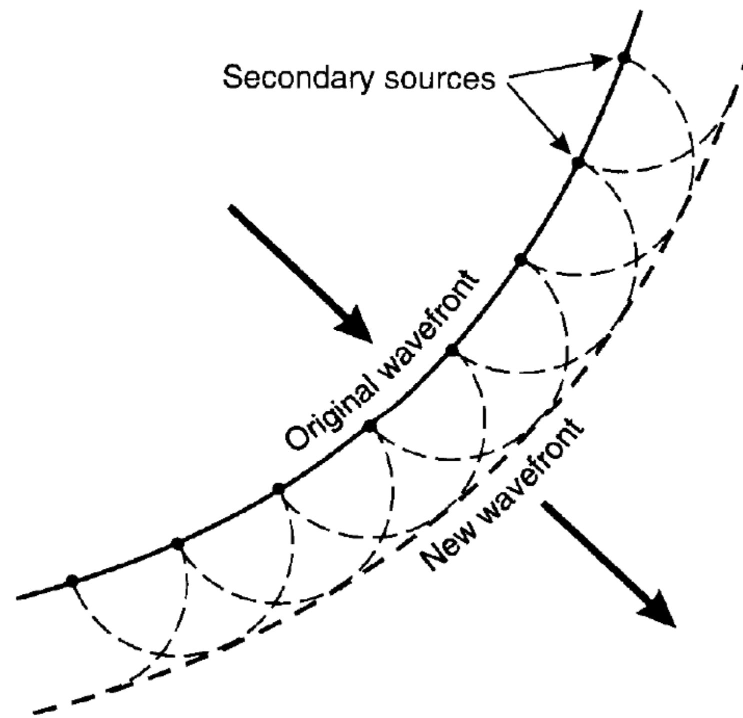
II. Waves

Huygens's principle: every point on a wavefront can be considered to be a secondary source of waves.

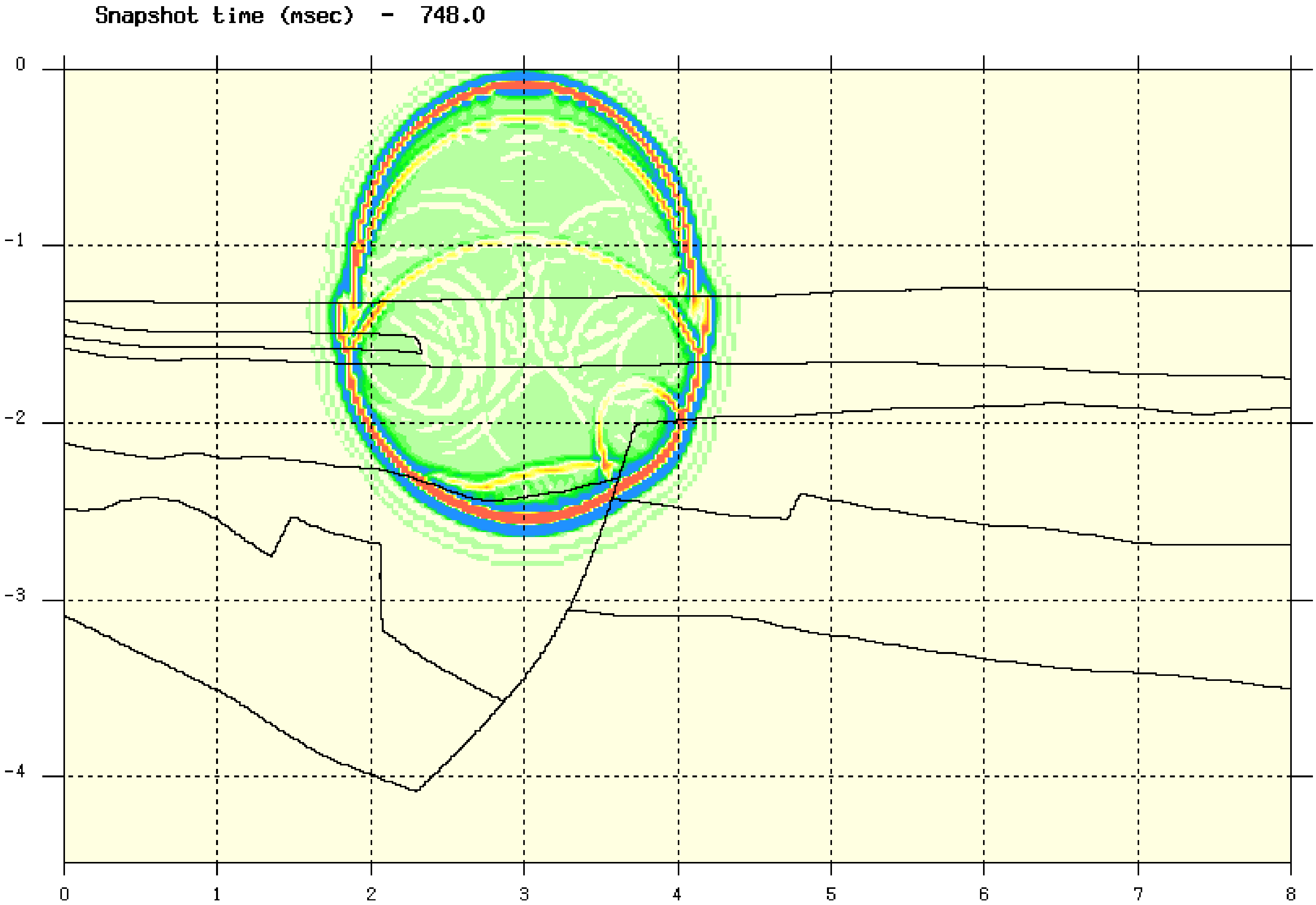
-Wavefront: surface connecting all points of equal travel time from the source (particles that vibrate in phase)

-Ray paths : Direction perpendicular to the wavefront.

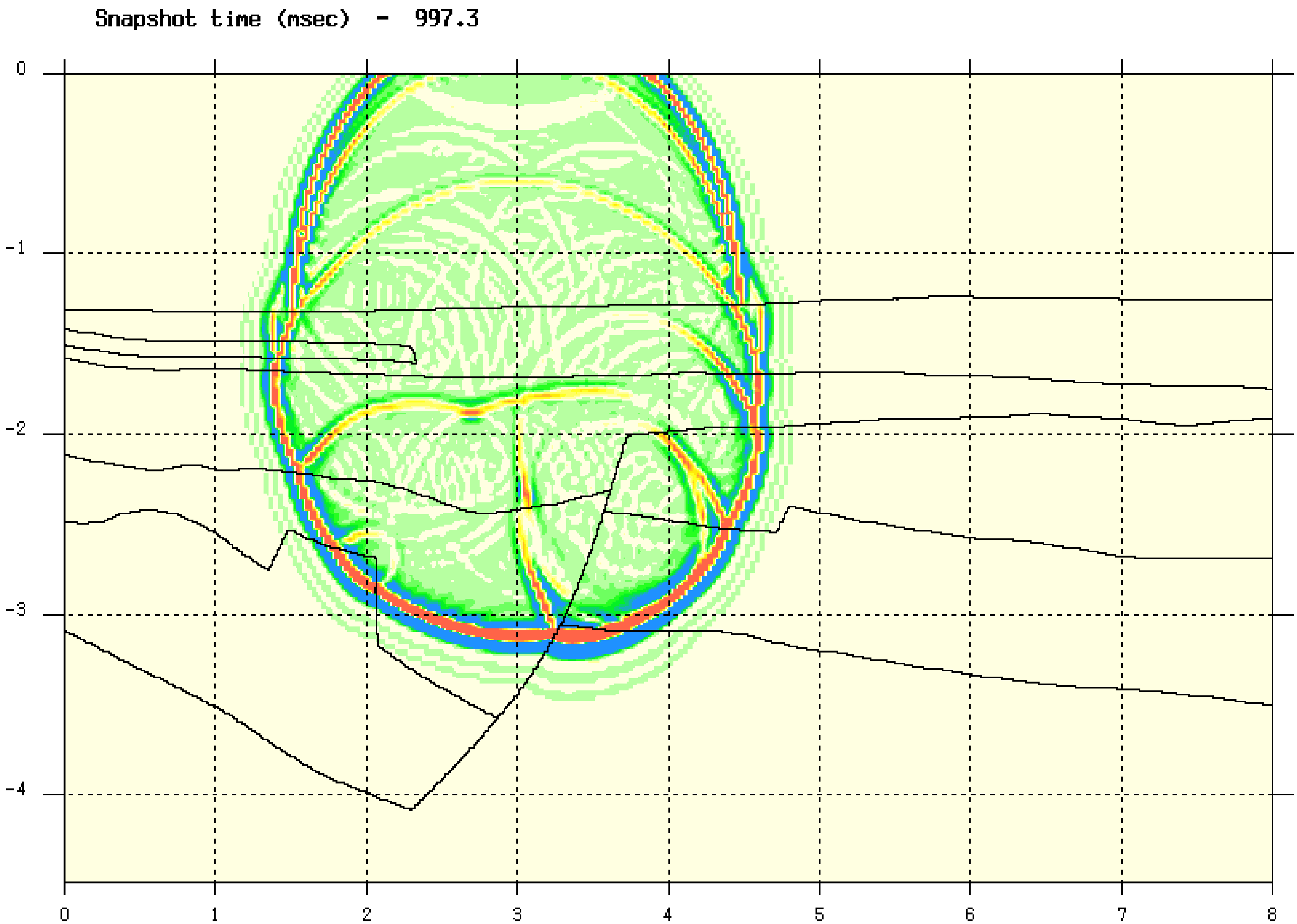
Travel time ➔ wave speed



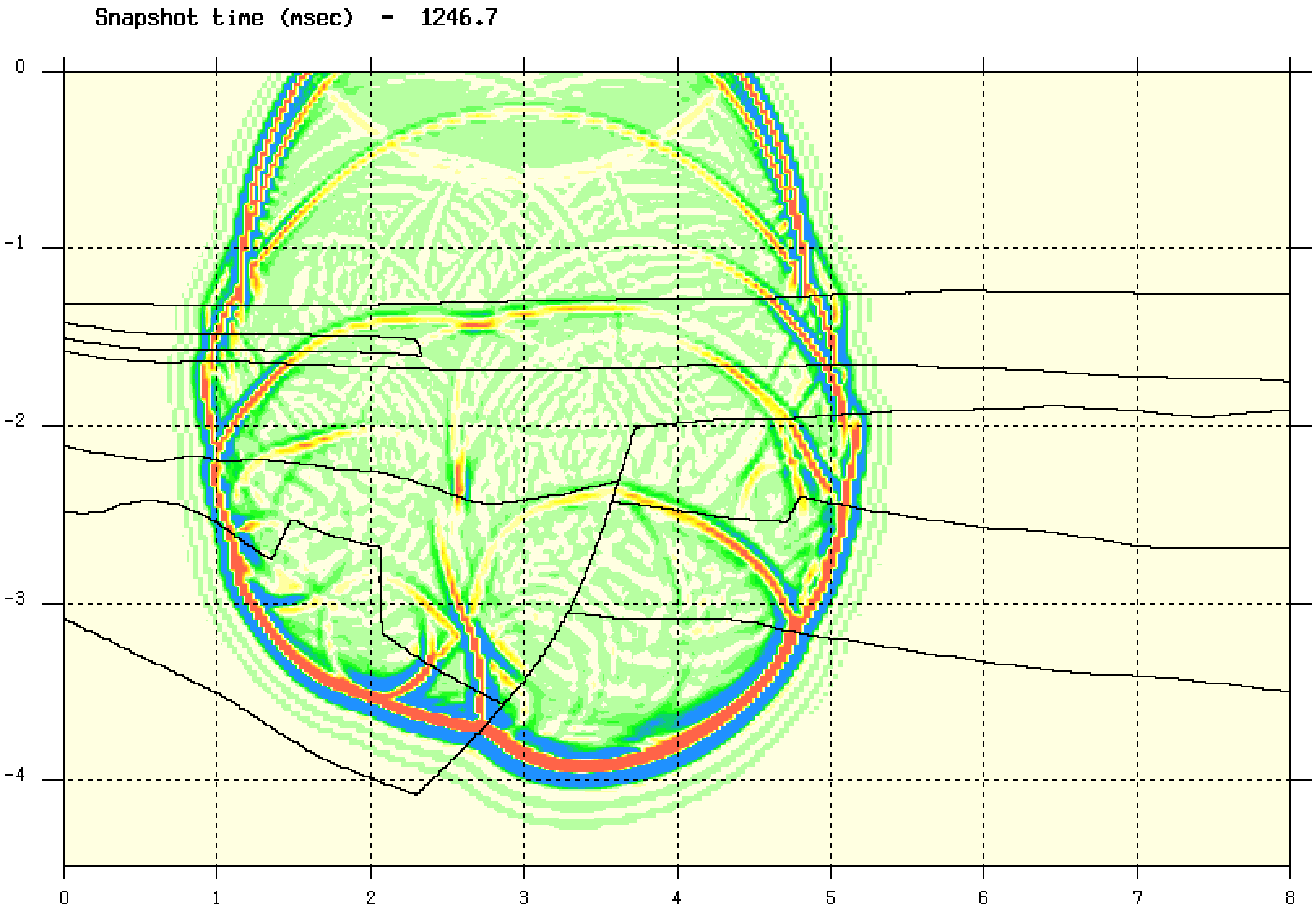
II. **Waves**



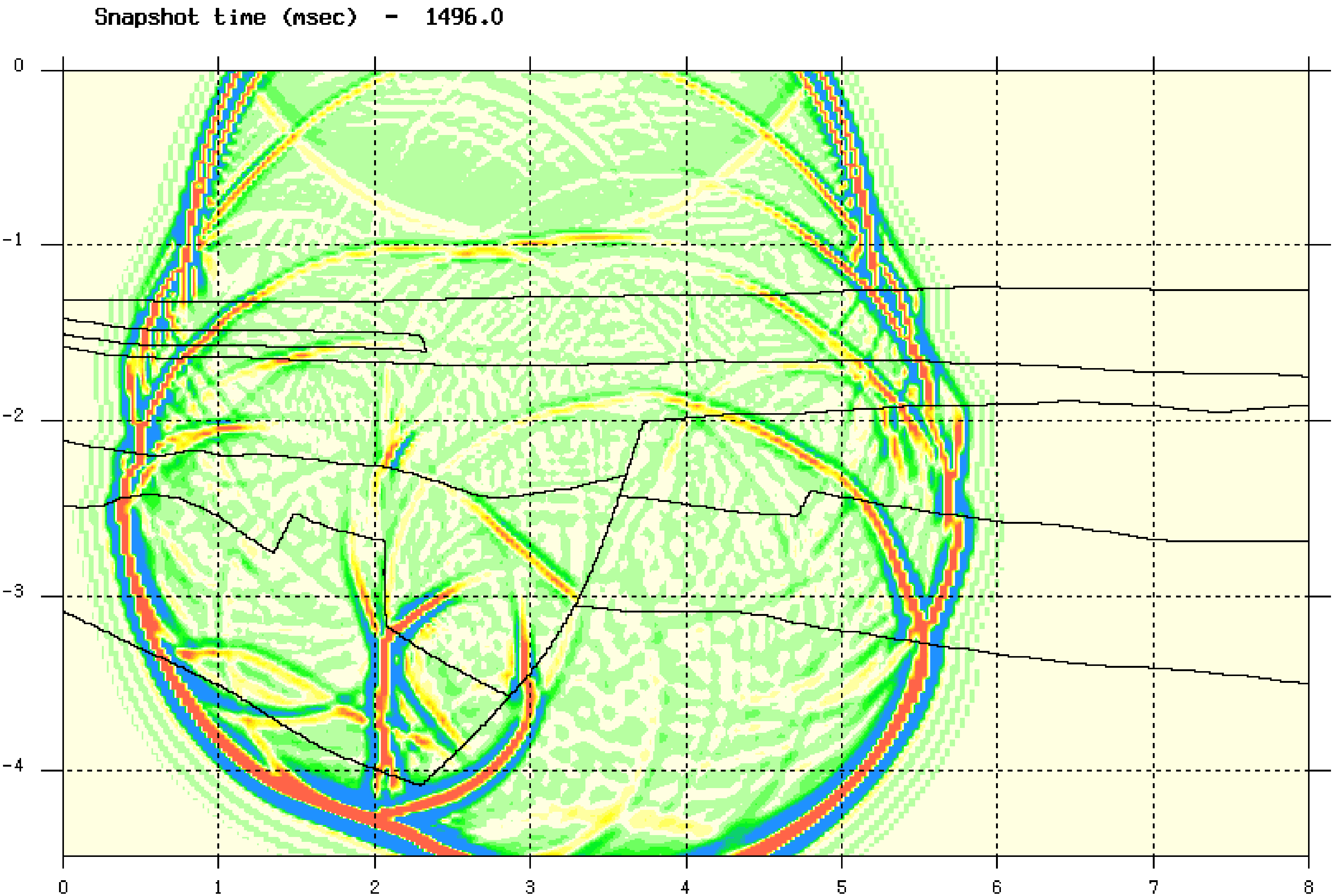
II. Waves



II. Waves

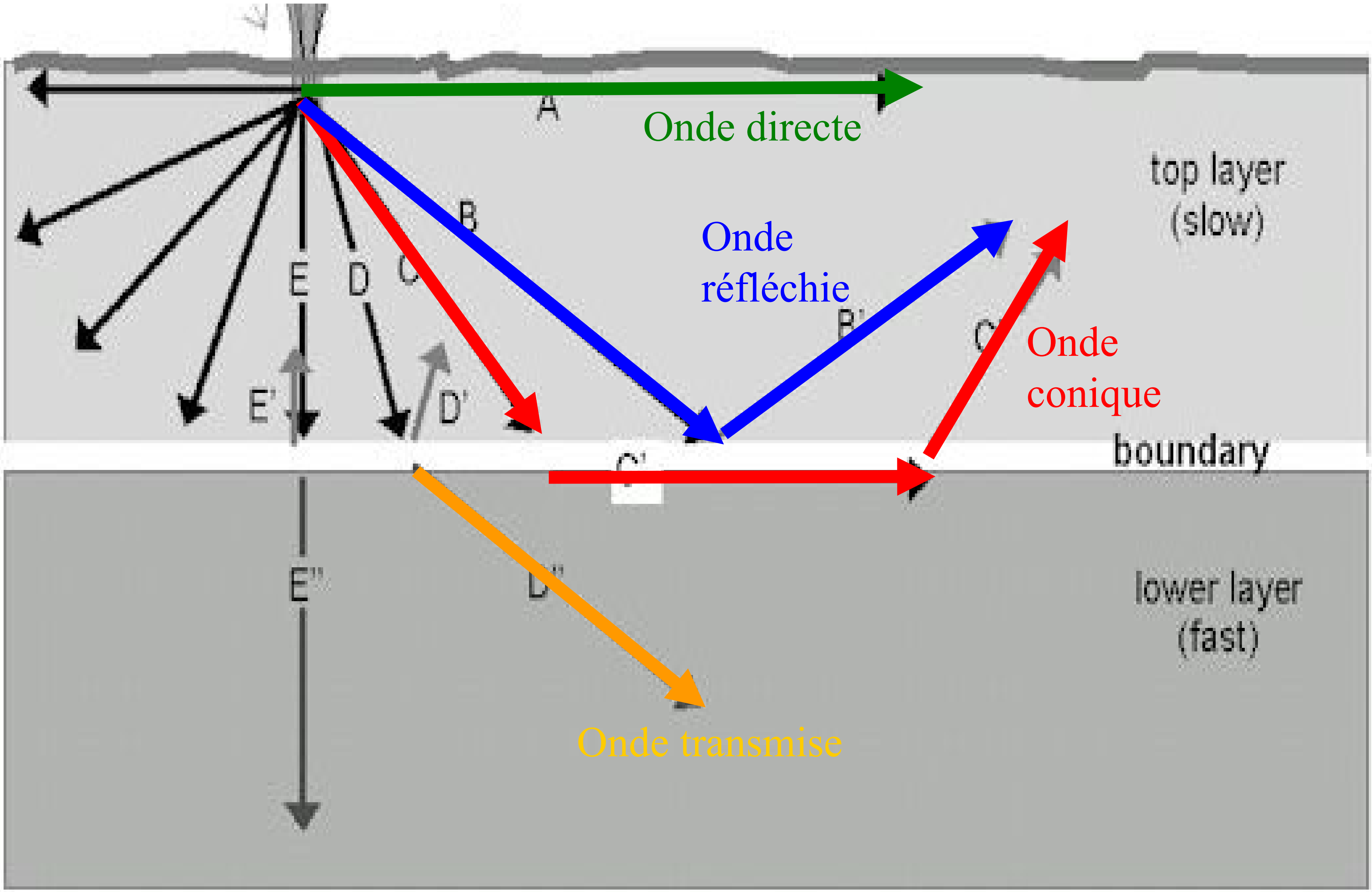


II. Waves



II. **Waves**

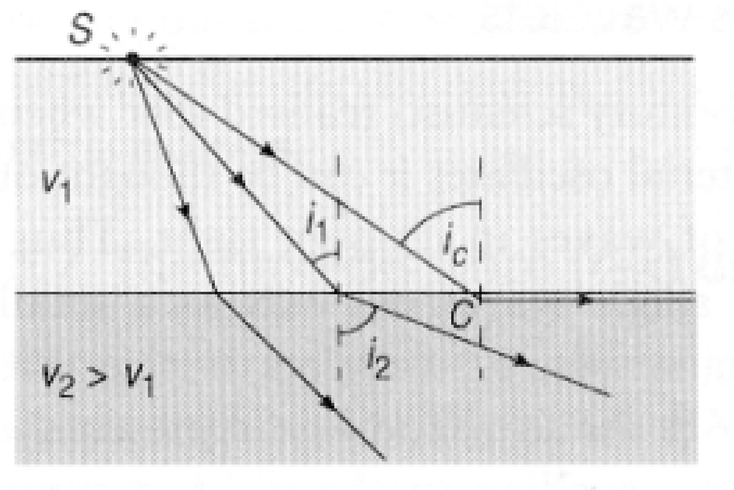
- Reflection and Refraction

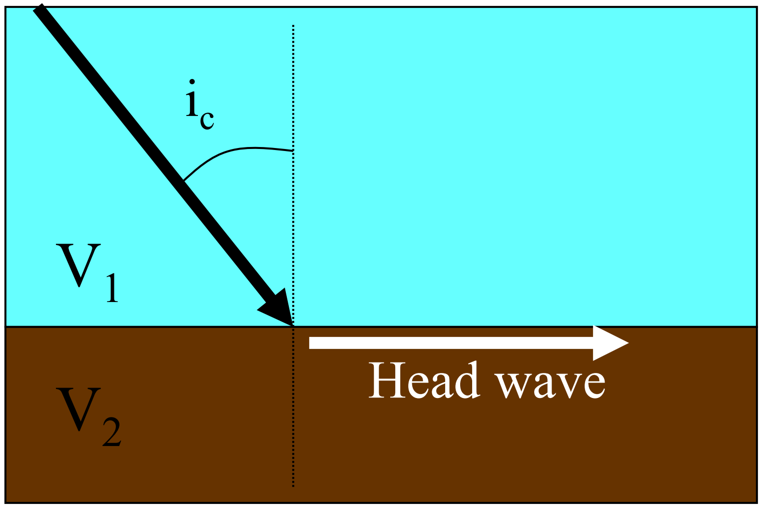


II. **Waves**

➢ Head waves

Si **V2>V1**,





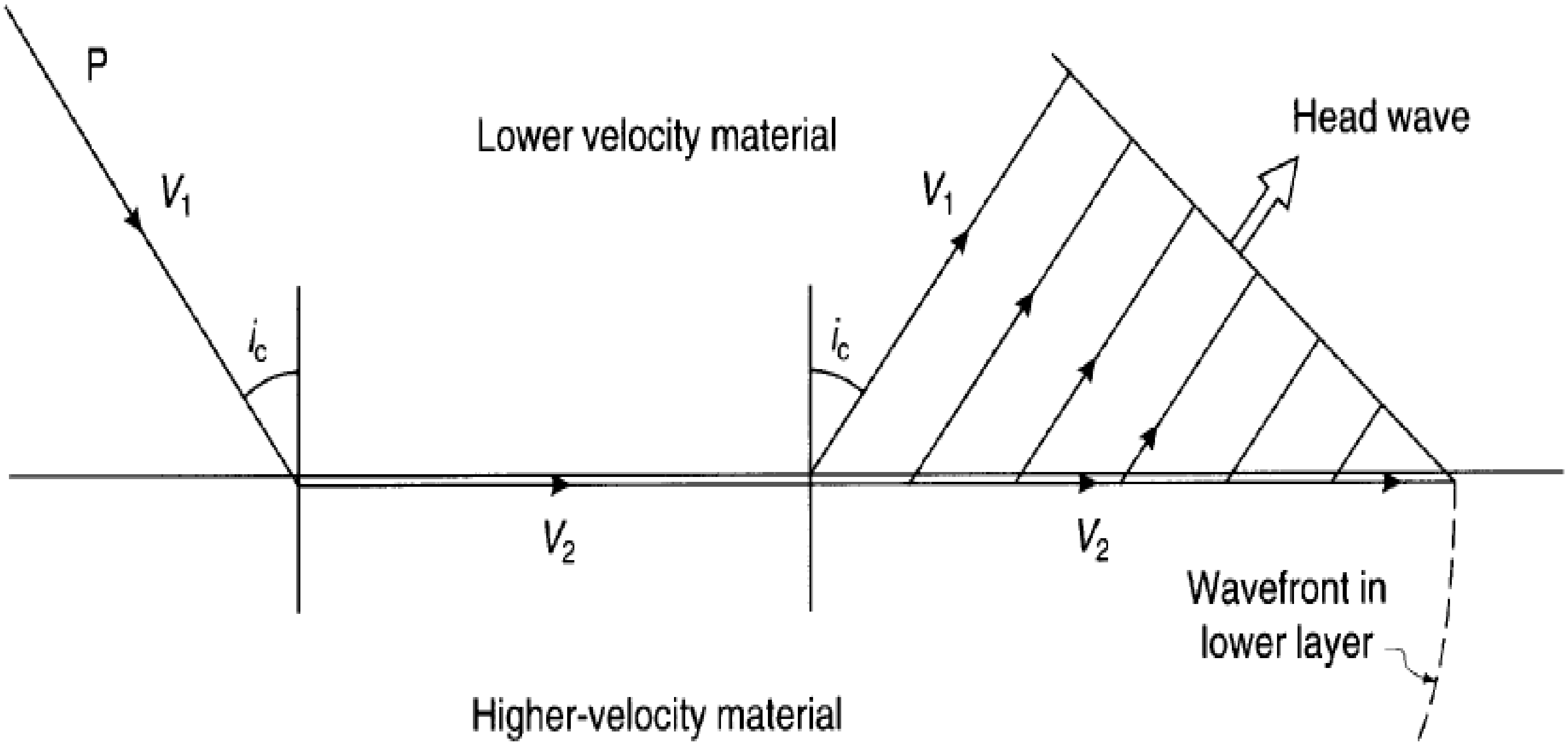
$$\boxed{\frac{\sin i_c}{V_1} = \frac{\sin 90°}{V_2}}$$

$$\boxed{\sin i_c = \frac{V_1}{V_2}}$$

If i1=Ic= No transmitted waves ➔ conic wave ➔ refracted waves

II. **Waves**

- Critical refraction angle



➢ Seismic methods

- **Seismic reflexion**
- **Seismic refraction**

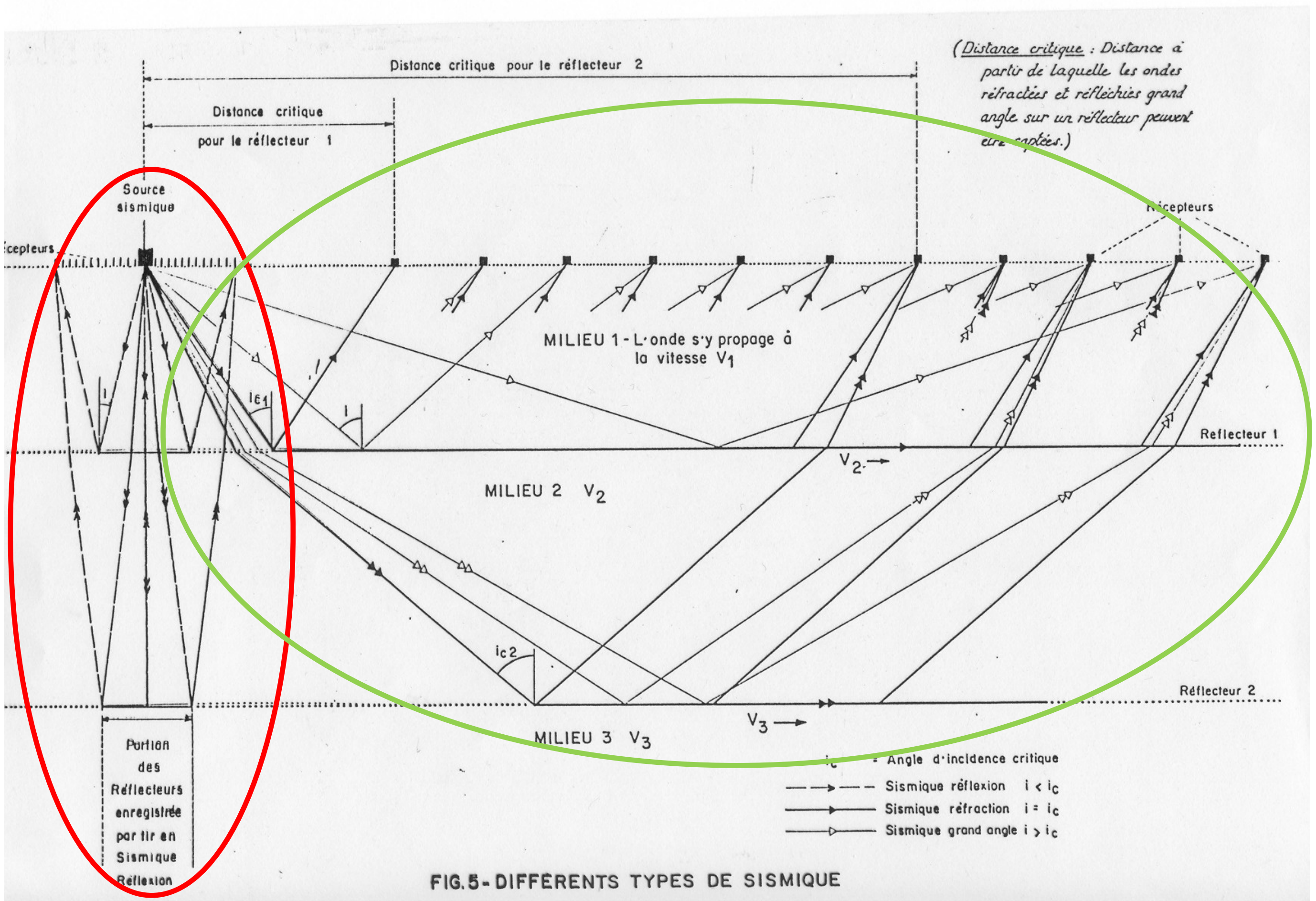


FIG.5 - DIFFÉRENTS TYPES DE SISMIQUE

II. **Waves**

➢ Seismic methods

- **Refraction**
  - Wave speed
  - Image of geological limits with different wave velocities
  - Depth of geological structure << distance source – receptor

- **Reflexion**
  - Wave speed
  - Image of geological limits with different impedance
  - Depth Geological structure >> distance source – receptor

II. **Waves**

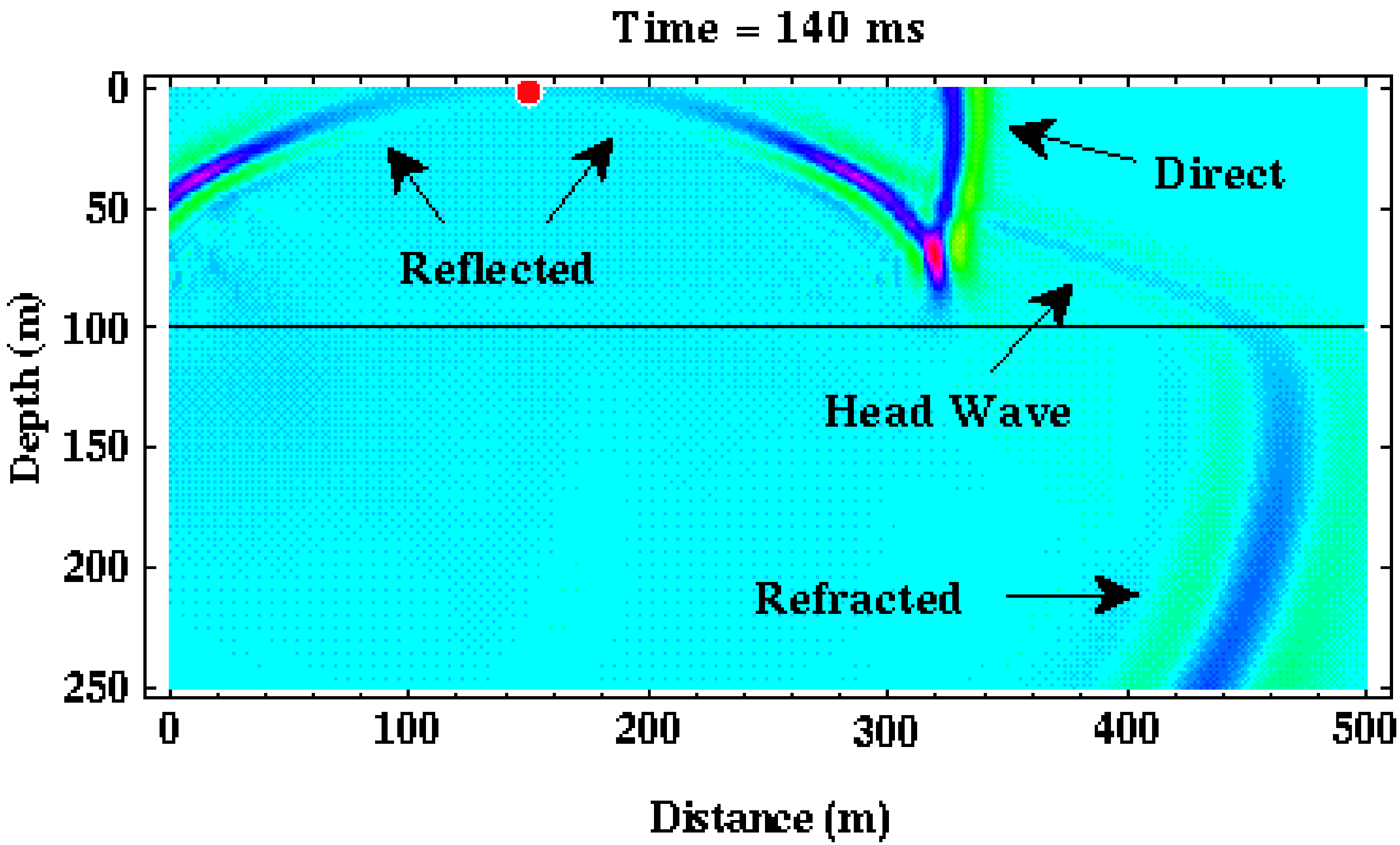
➢ Refraction vs. Reflection

- So, what are the main take-home differences between these two seismic techniques?

Refraction	Reflection
Resolves gross crustal velocities	Resolves fine subsurface details
critical refraction requires large v gradient	requires a change in v or density
X=5-10x the depth of interest	X=1x the depth of interest
Processing is relatively easy	Processing can be very time consuming

III. **Seismic refraction**

Waves passing from slow to fast medium



III. **Seismic refraction**

- Methods

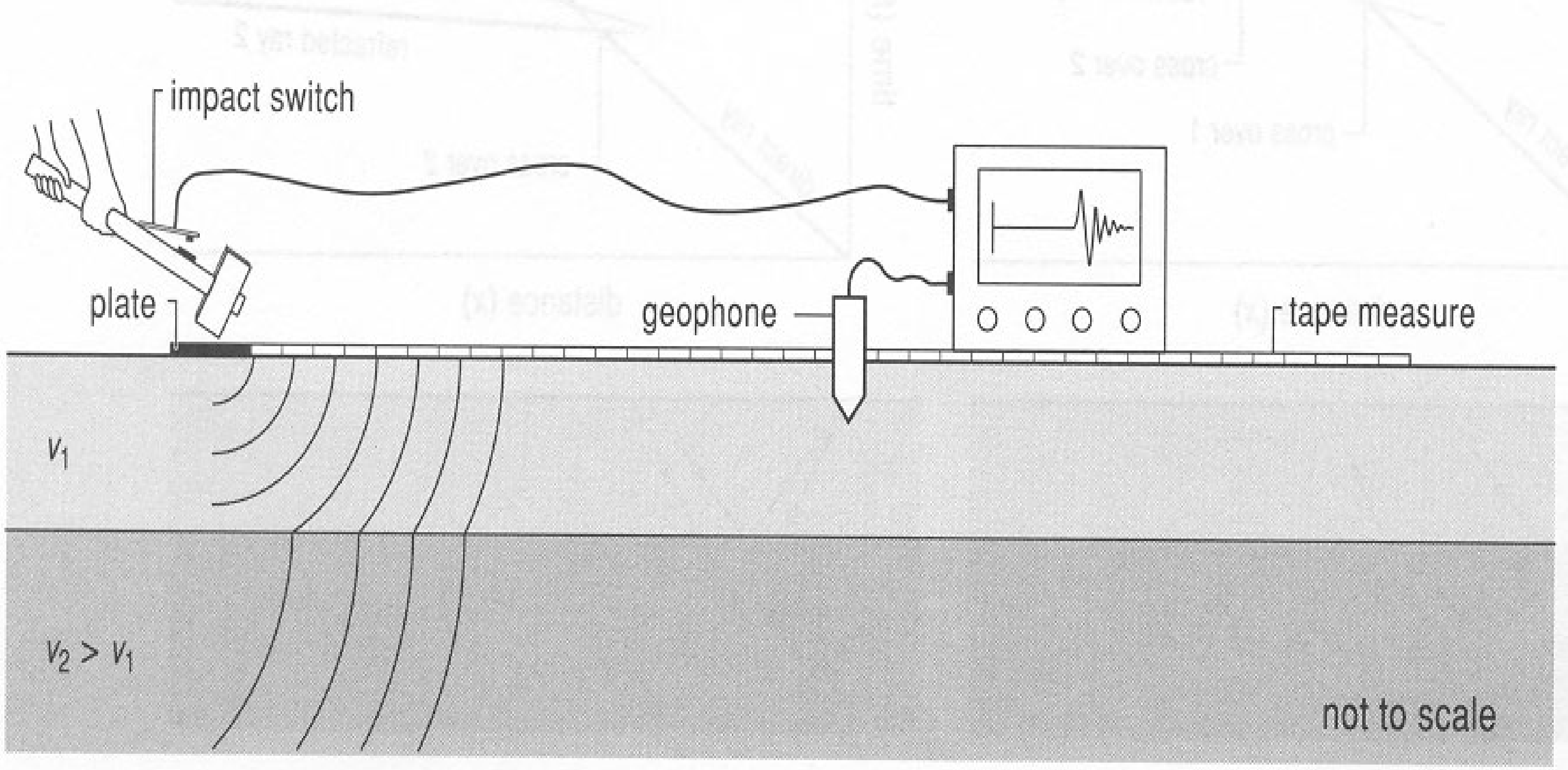


Figure 6.13 Hammer system.

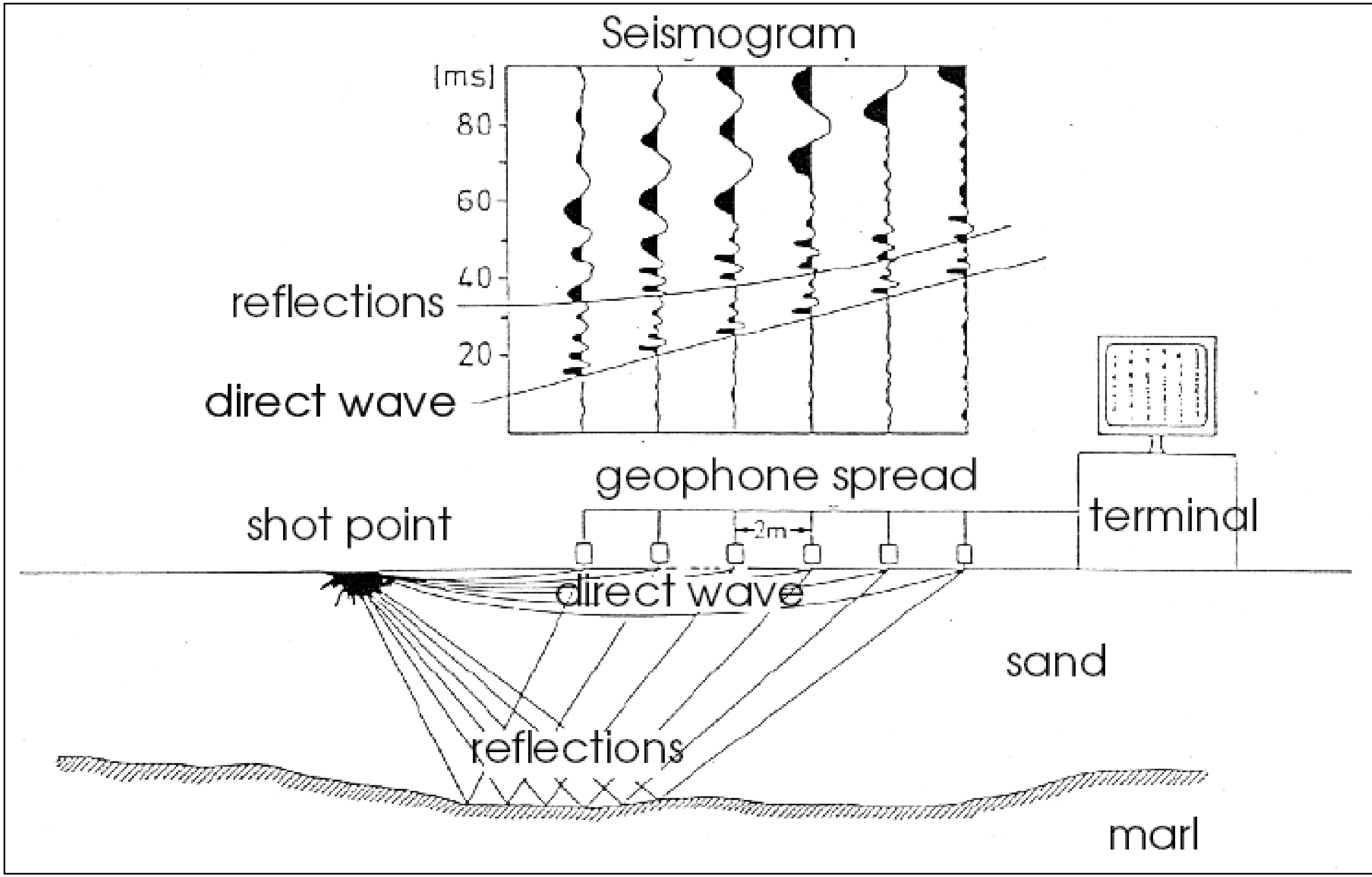
III. **Seismic refraction**

➢ Seismic Source

	On land	On water	
Impact:	Sledge hammer Drop-weight Accelerated weight		
Impulsive:	Dynamite Detonating cord Airgun Shotgun Borehole sparker	Airgun Gas gun Sleeve gun Water gun Steam gun	Pinger Boomer Sparker
Vibrator:	Vibroseis Vibrator plate Rayleigh wave generator	Multipulse GeoChirp	

III. **Seismic refraction**

- Seismic trace

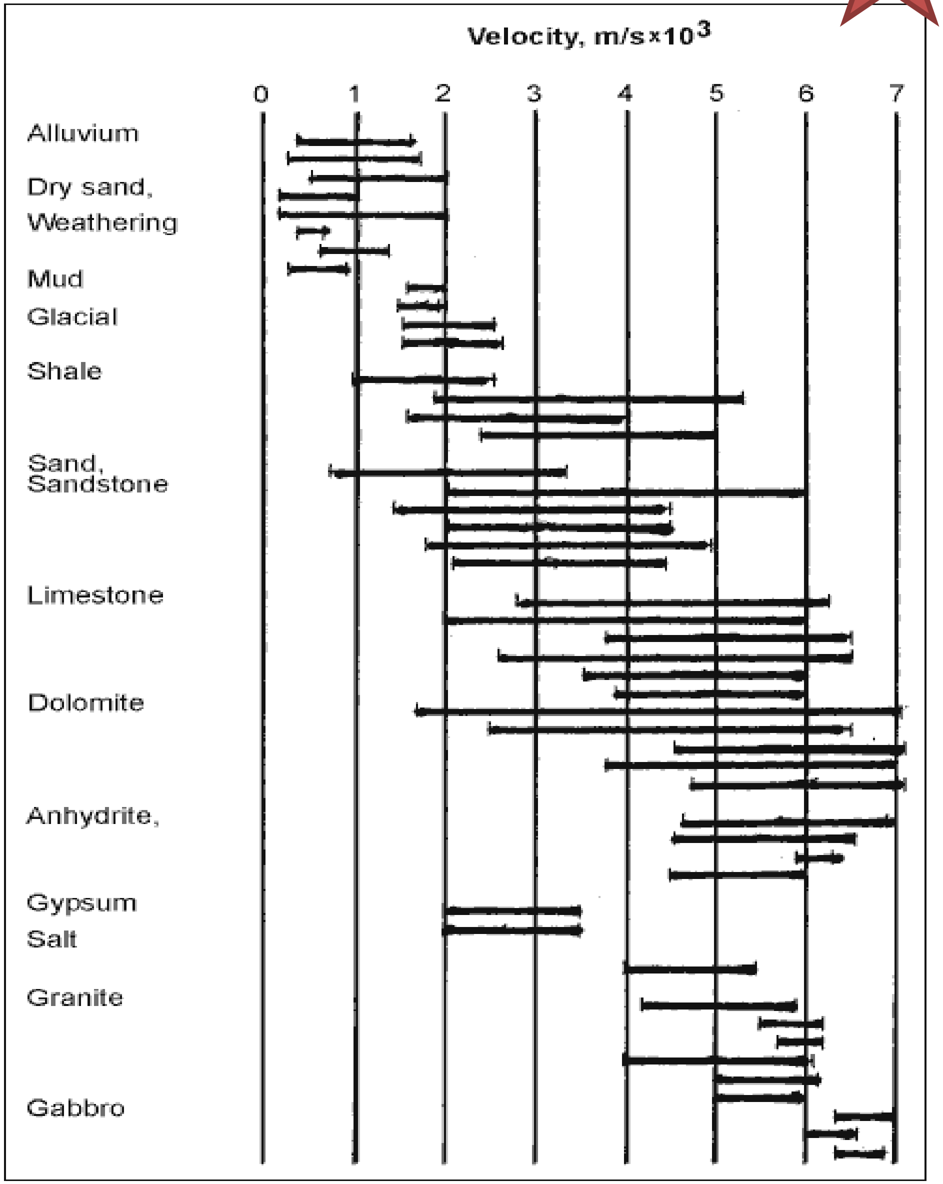


III. Seismic refraction

➢ Seismic waves

$$V_p = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}}$$

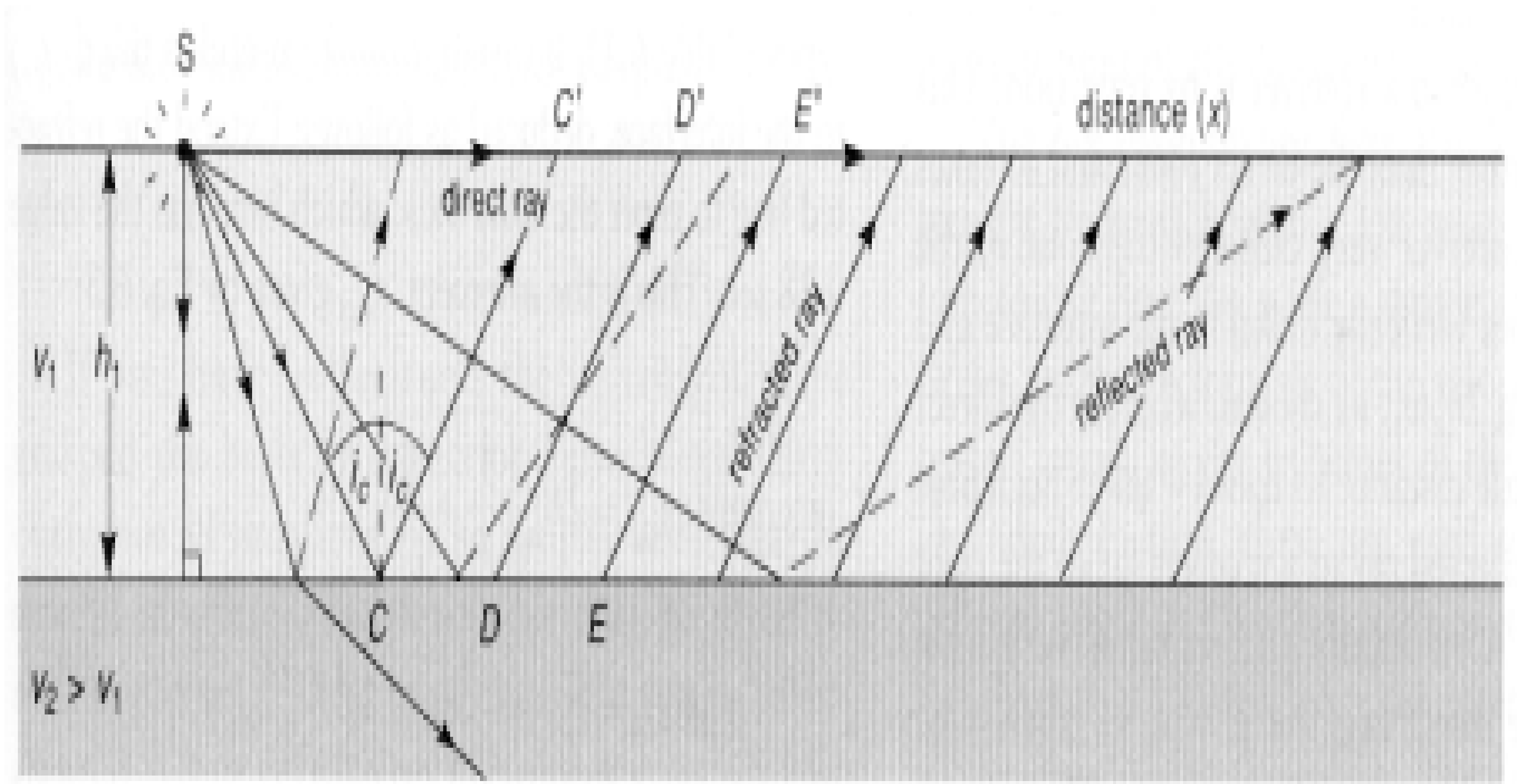
Seismic waves ➡ **Geology**



III. **Seismic refraction**

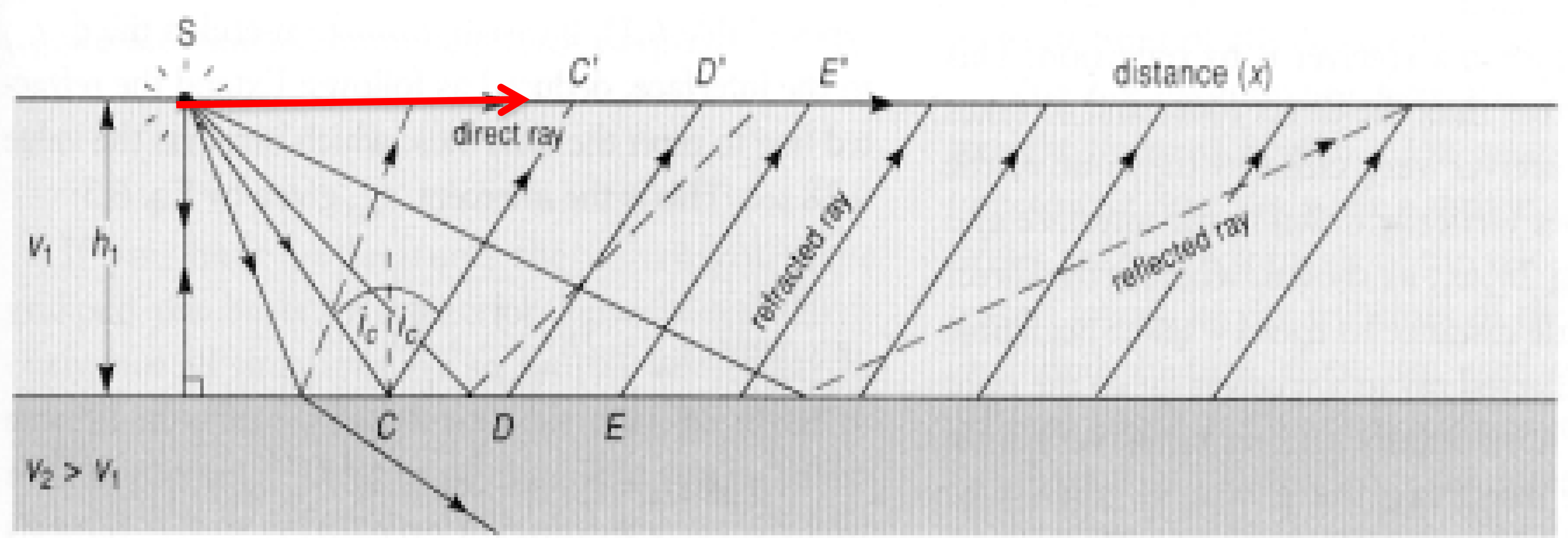
- Interpretations

1 single horizontal plane



III. **Seismic refraction**

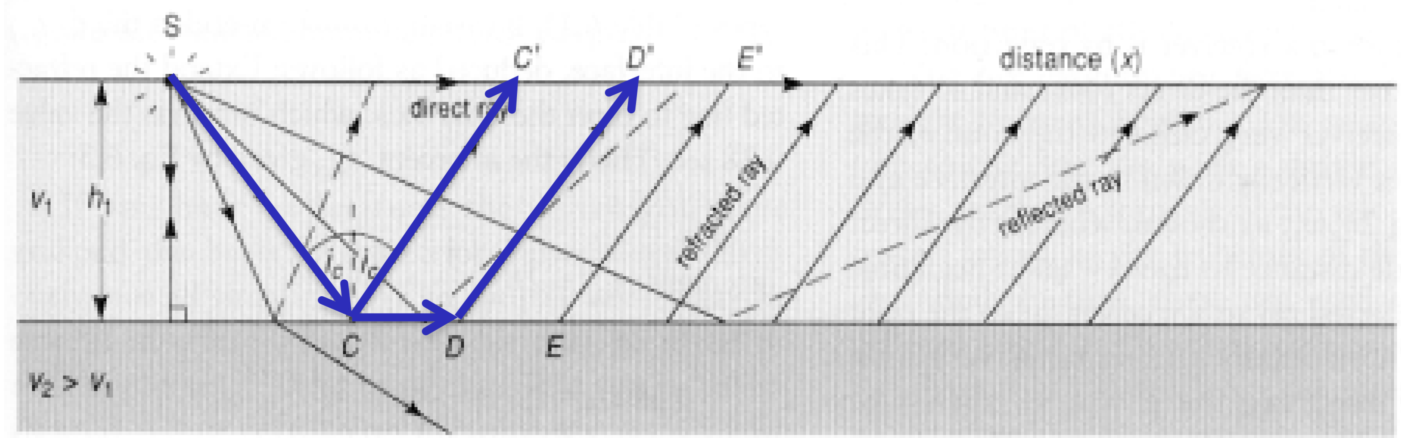
➢ Interpretations



Direct wave : $$\boxed{t = \frac{x}{V_1}}$$

III. **Seismic refraction**

➢ Interpretations



Head waves: Critical distance

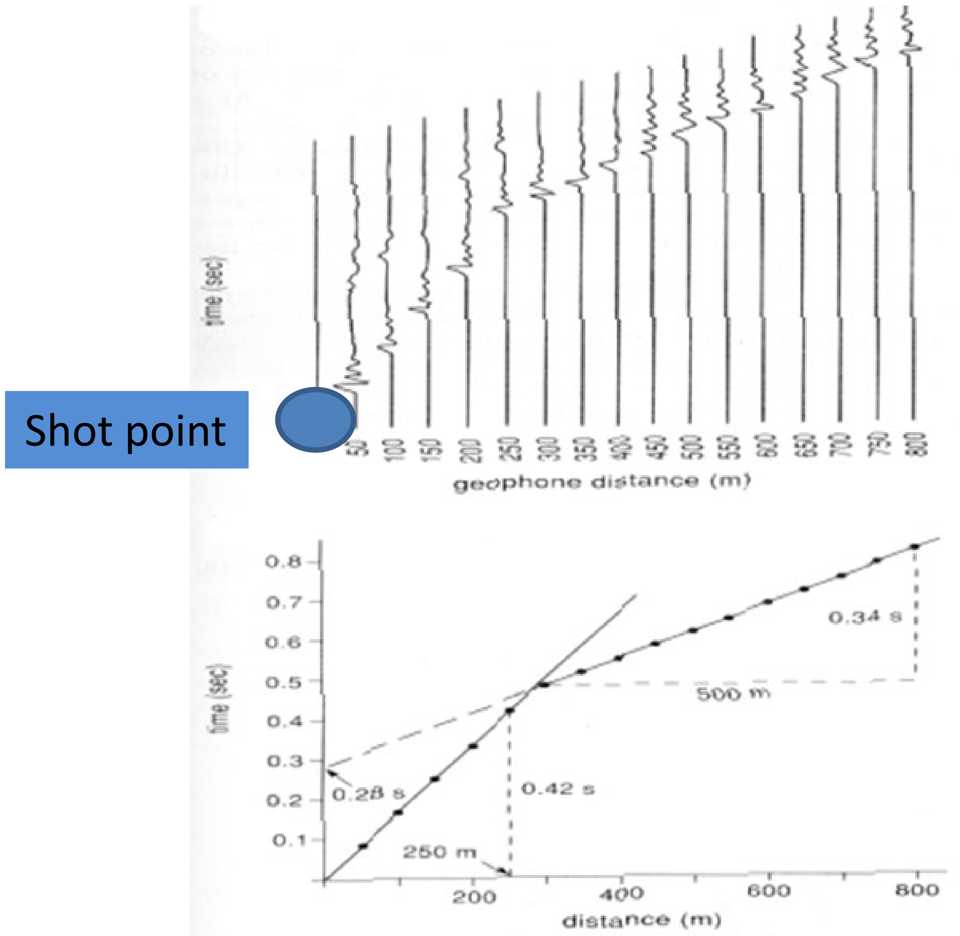
t= (x/V2) +2h/Cos(ic)*v1

Equation of a straight line whose slope is equal to 1/V, and the intercept is a function of the layer thickness and the velocities above and below the interface.

III. **Seismic refraction**

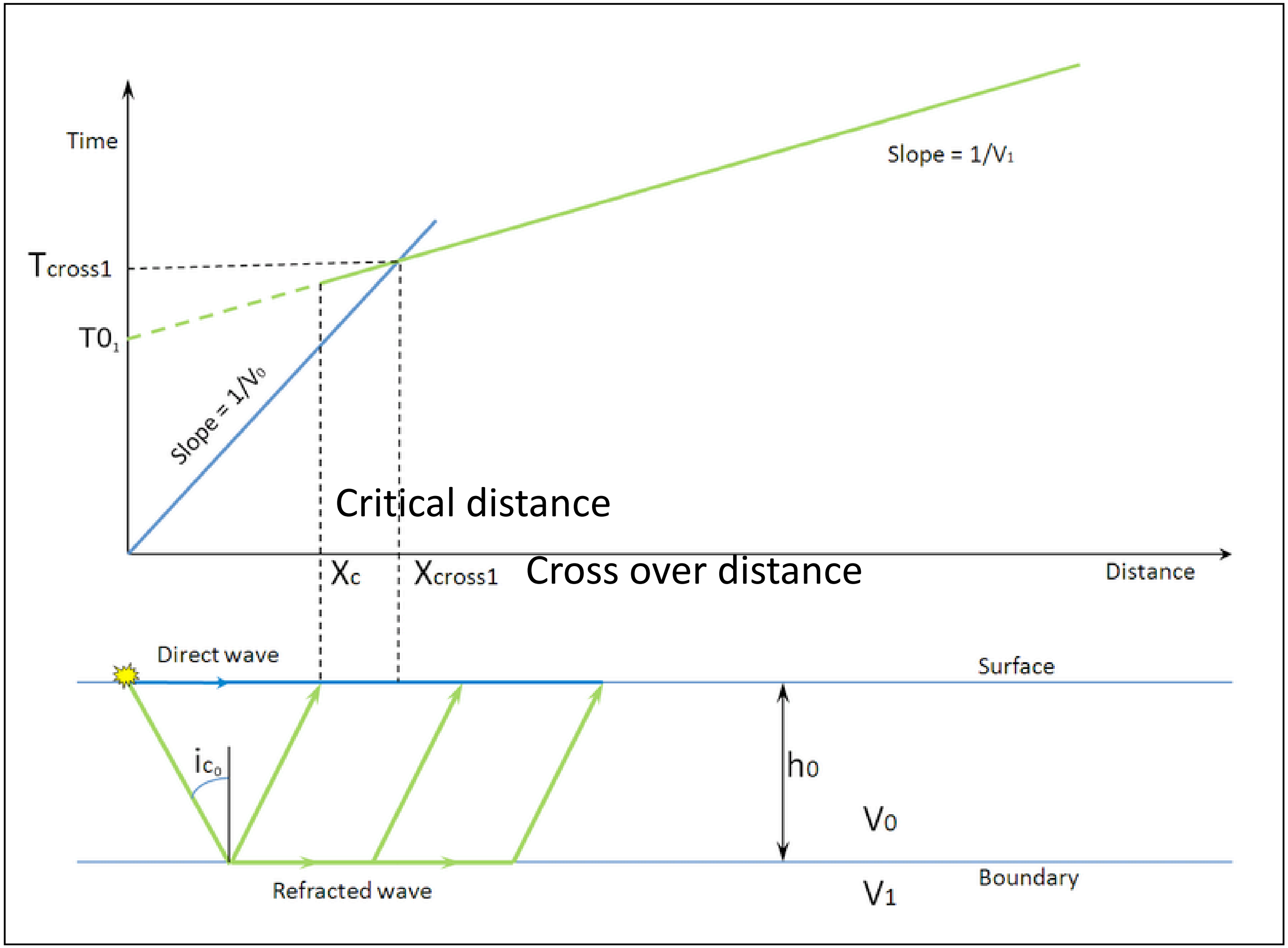
Interpretations

1 single horizontal plane



III. **Seismic refraction**

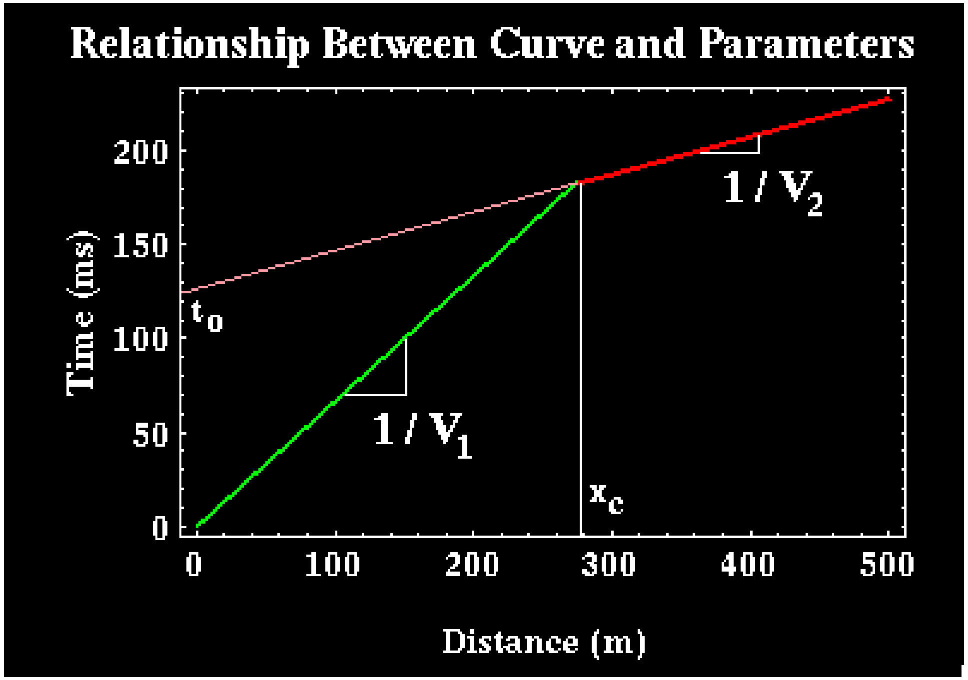
Interpretations



III. **Seismic refraction**

Interpretation

- Determine V1
- Determine V2
- Deduce Ic
- Deduce h



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

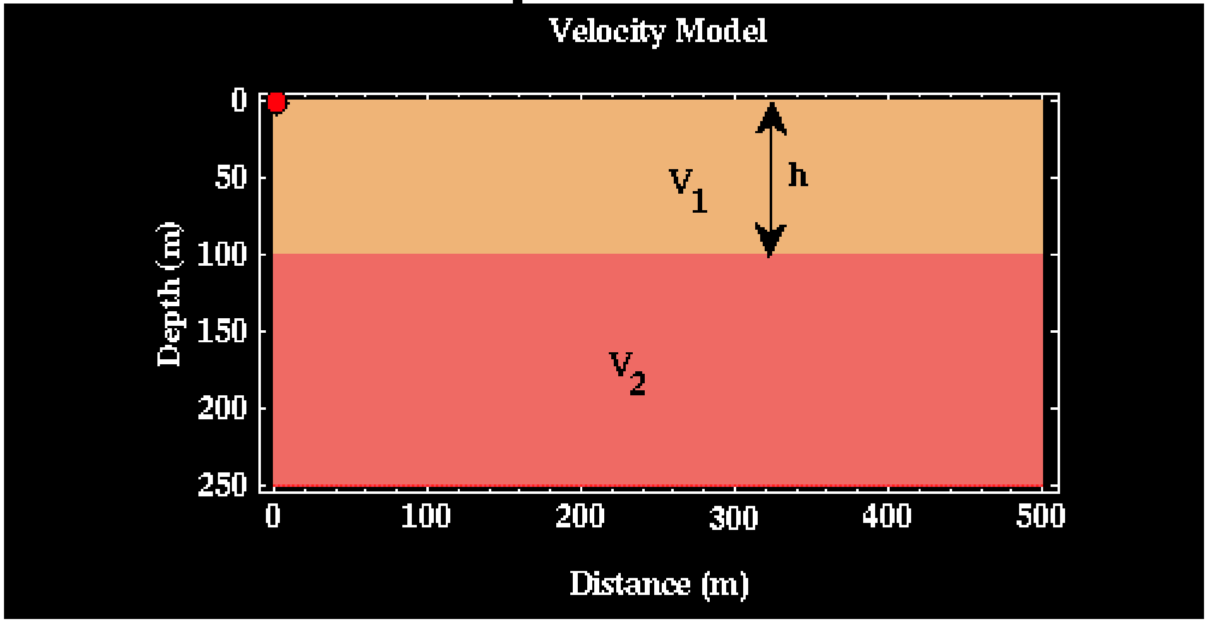
$$h = \frac{t_o V_2 V_1}{2(V_2^2 - V_1^2)^{1/2}}$$

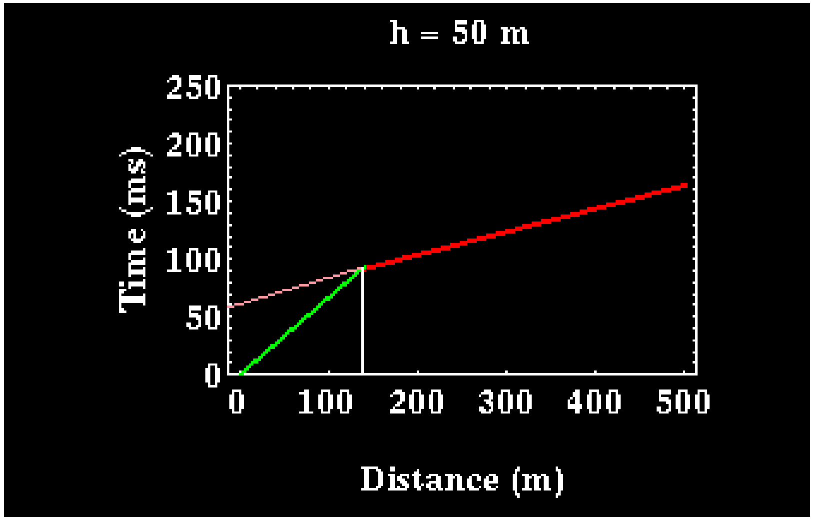
or

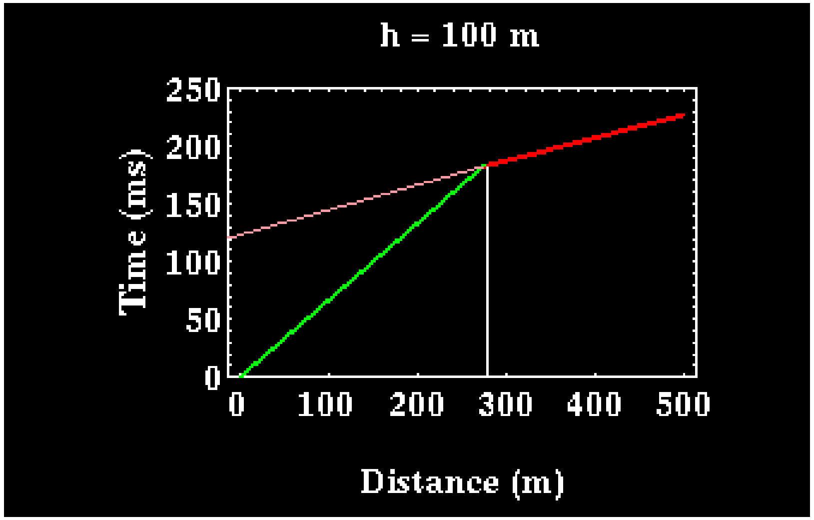
$$h = \frac{x_c}{2}\left(\frac{V_2 - V_1}{V_2 + V_1}\right)^{1/2}$$

III. **Seismic refraction**

Interpretation







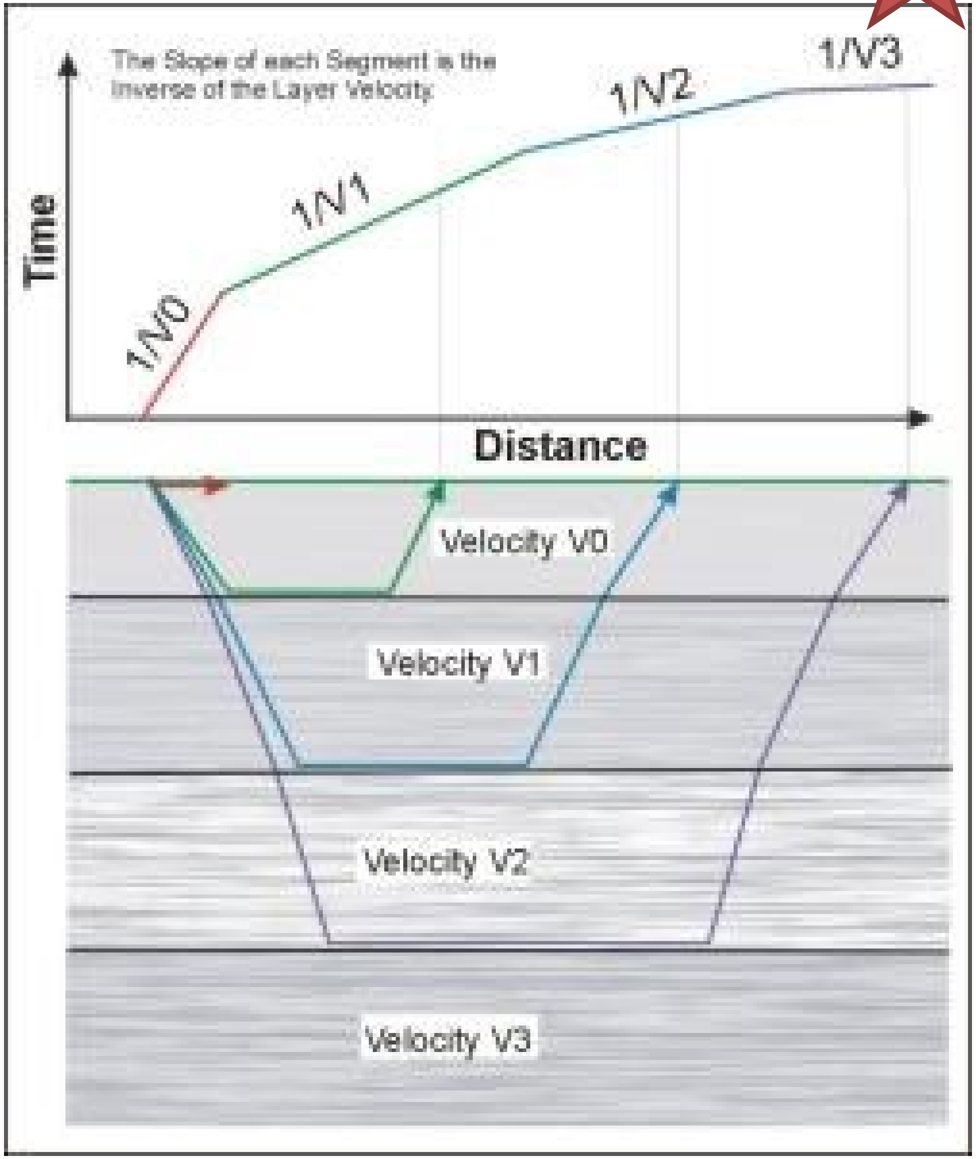
III. **Seismic refraction**

- Interpretations

- Multiple horizontal planes

$$\boxed{t = \frac{x}{V_n} + \sum_{k=1}^{n-1} \frac{2h_k \cos i_k}{V_k}}$$

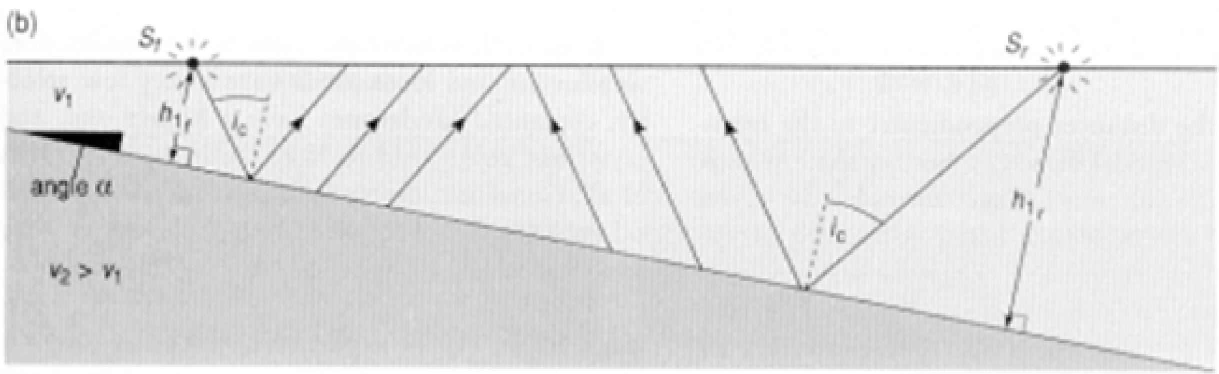
$$\boxed{\sin i_k = \frac{V_k}{V_n}}$$

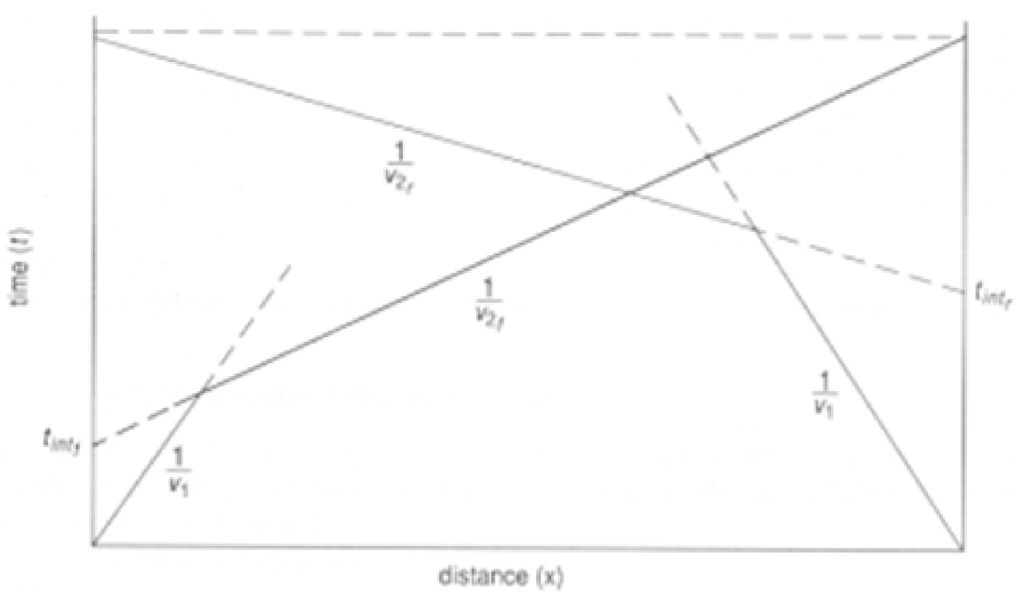


III. **Seismic refraction**

➢ Problem 1

Dipping plane: acquisition in two directions!



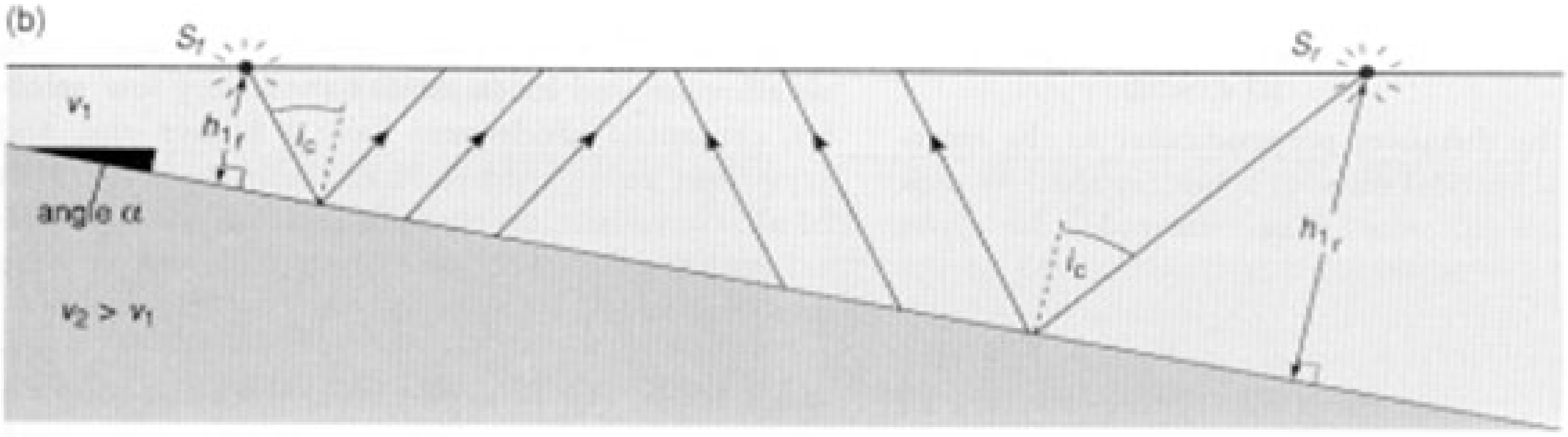


Velocities are called "apparent velocities"

III. **Seismic refraction**

- Problem 1

Dipping plane: acquisition in two directions!



$$\boxed{t^- = \frac{x}{V_1}\sin(i_c + \alpha) + \frac{2h\cos\alpha\cos i_c}{V_1}}$$

$$\boxed{t^+ = \frac{x}{V_1}\sin(i_c - \alpha) + \frac{2H\cos\alpha\cos i_c}{V_1}}$$

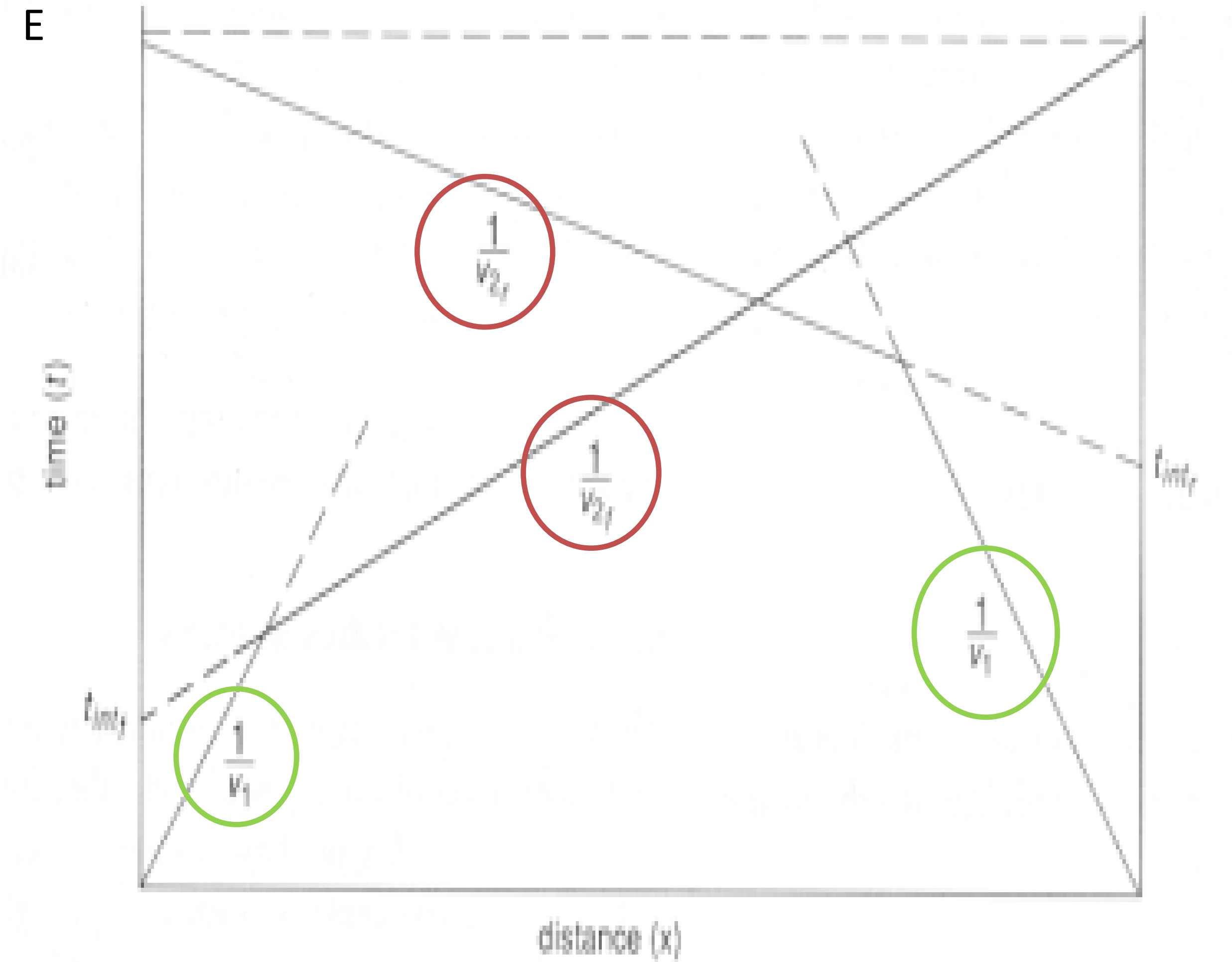
III. Seismic refraction

- Problem 1

Dipping plane: acquisition in two directions!

Shoot in E

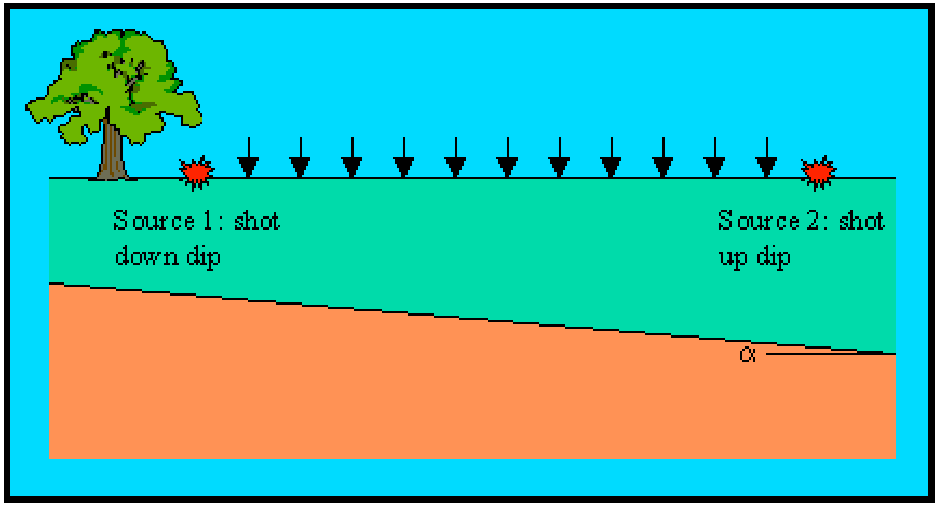
shoot in R

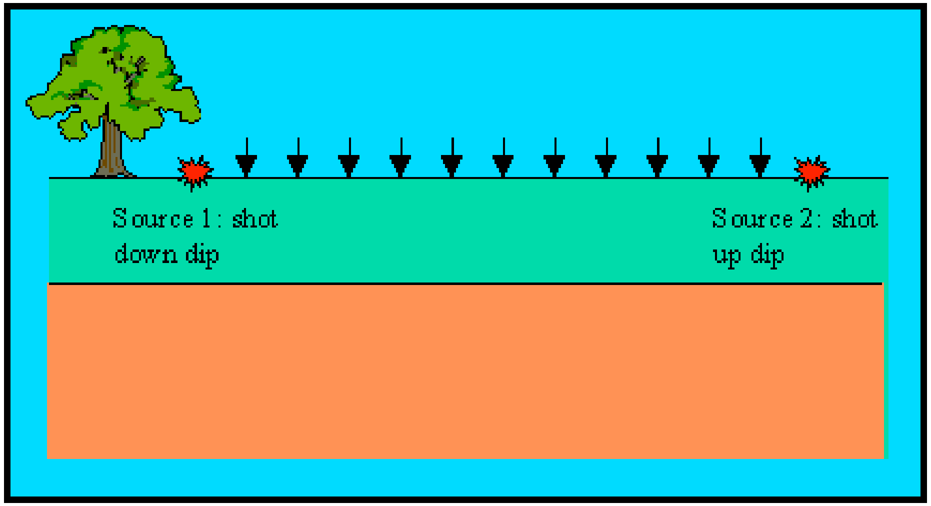


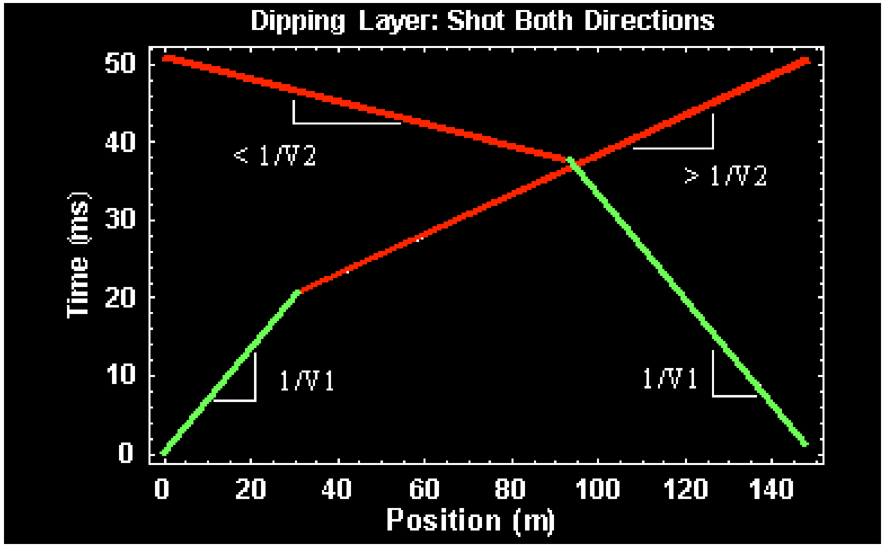
1. Determine V_1
2. Determine apparent velocities v2 in R and E
3. Deduce i_c et α
4. Deduce V_2
5. Deduce h et H

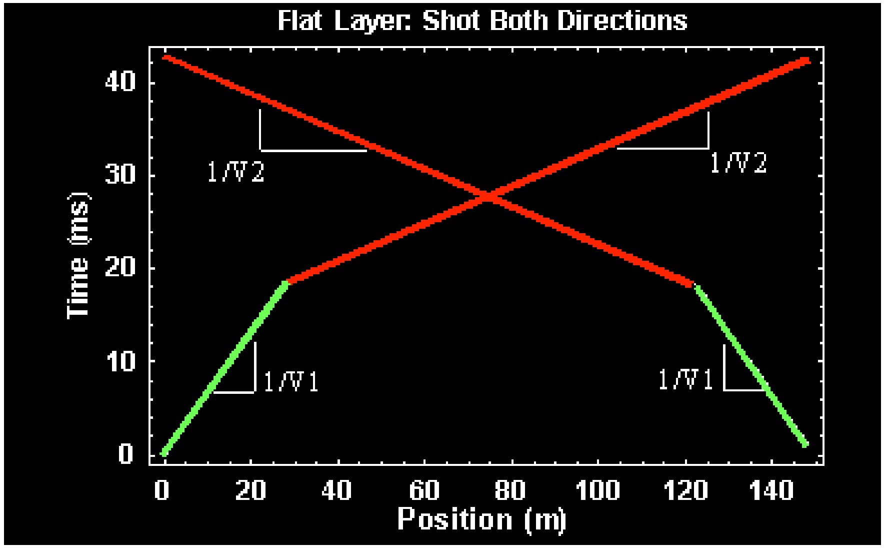
III. Seismic refraction

➢ Problem 1









III. Seismic refraction

➢ Problem 2

Hidden layer

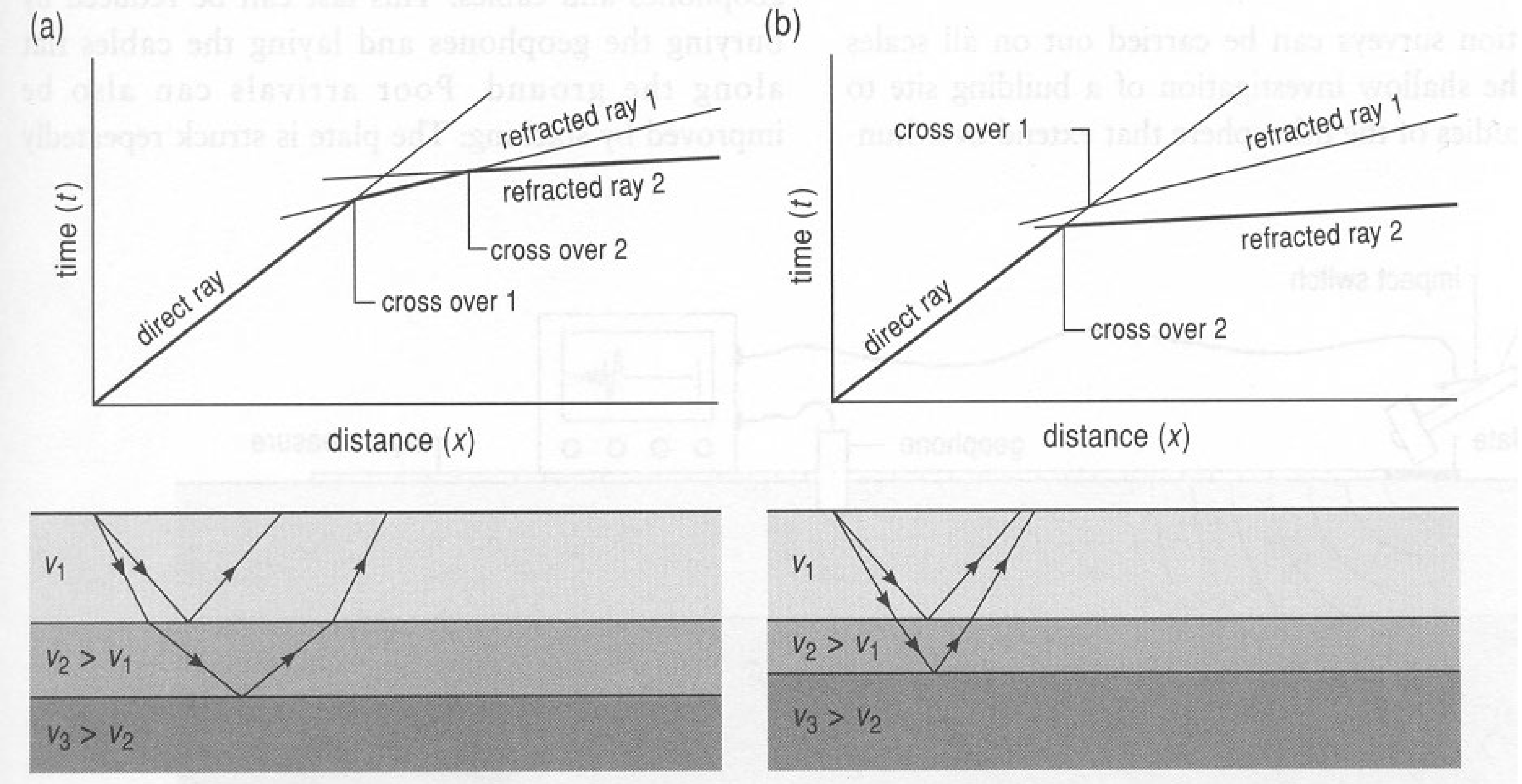
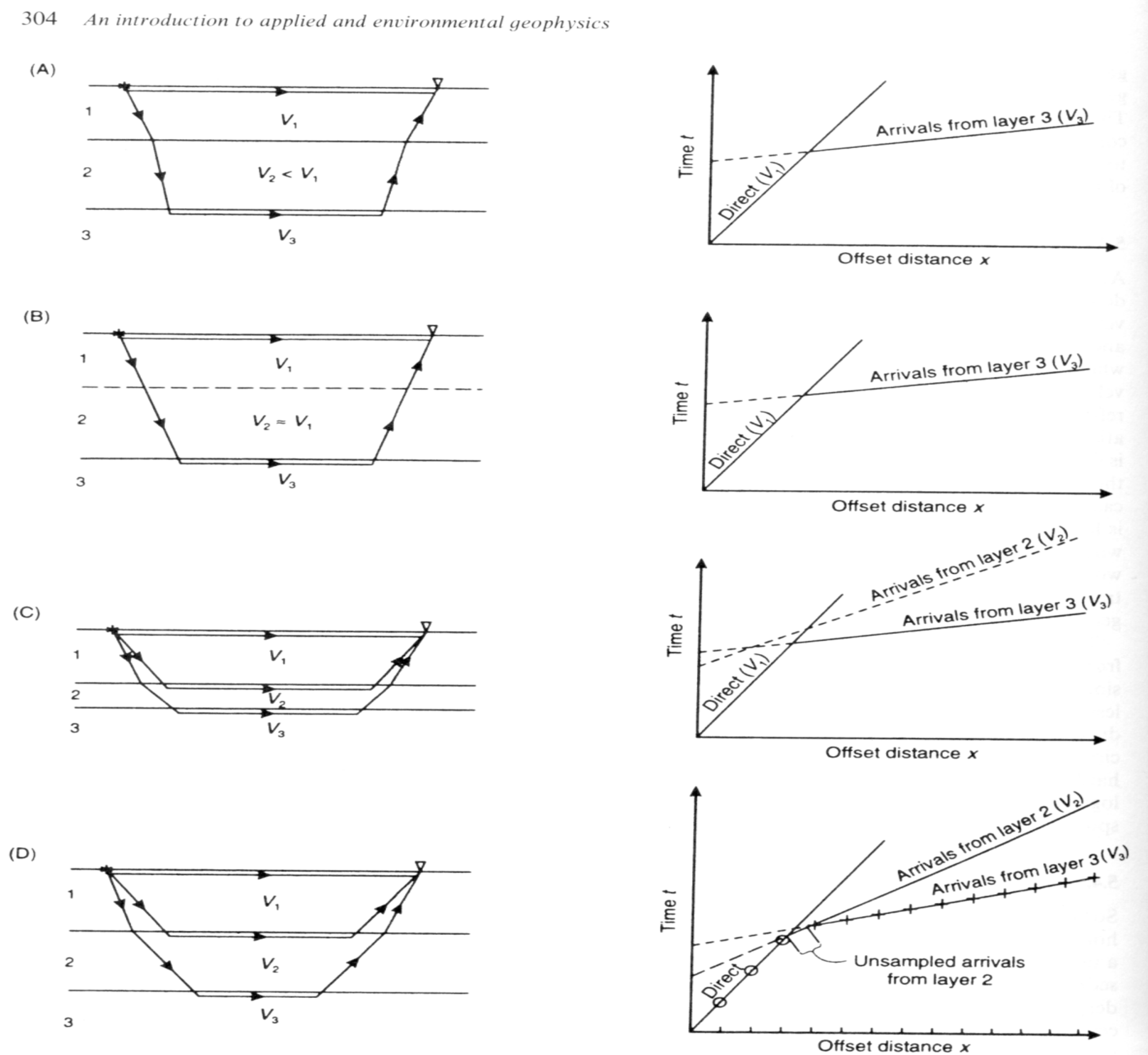


Figure 6.11 Hidden layer.

III. Seismic refraction

Hidden layer



III. Seismic refraction

- Problem 3

Low velocity layer

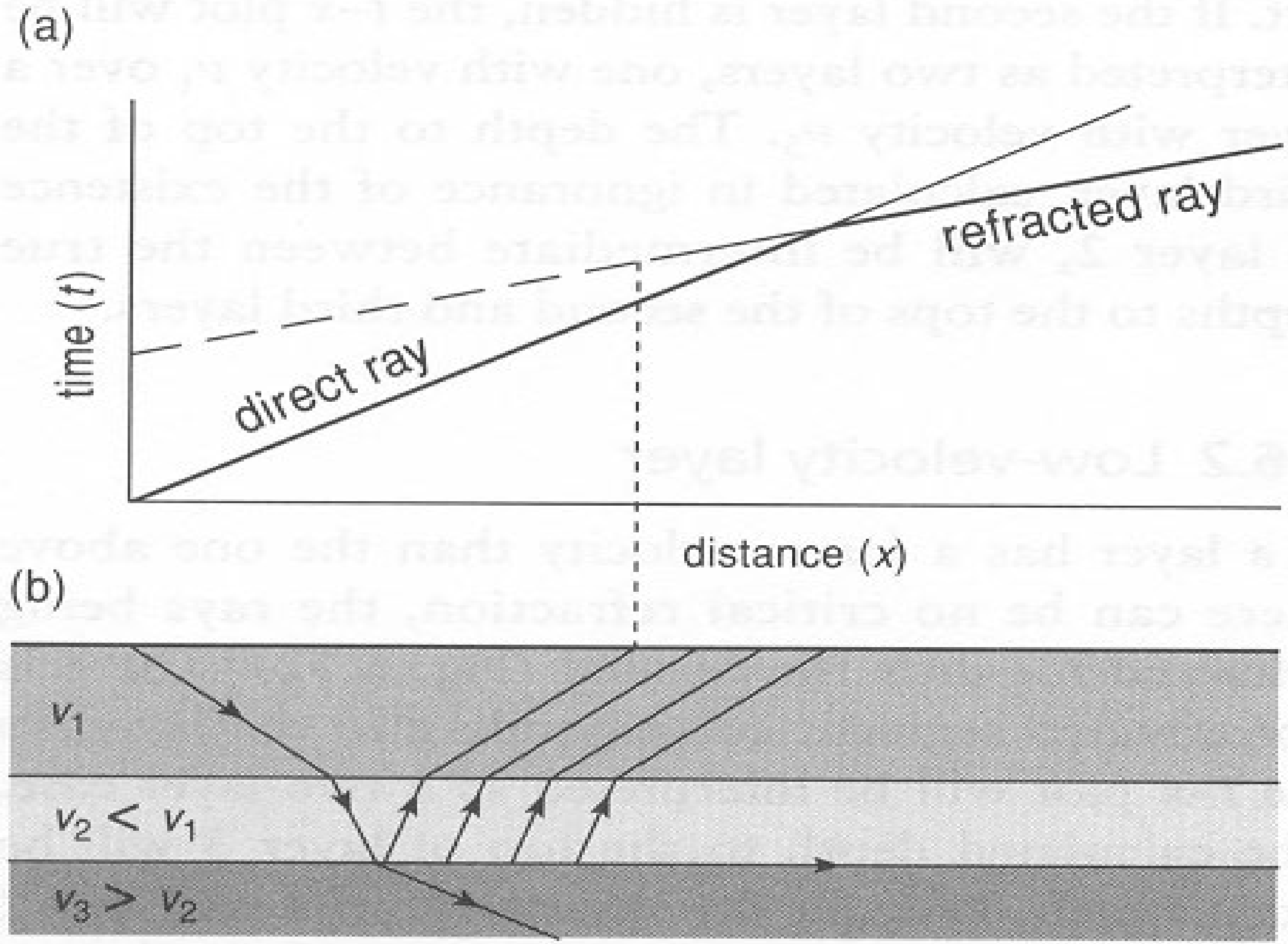
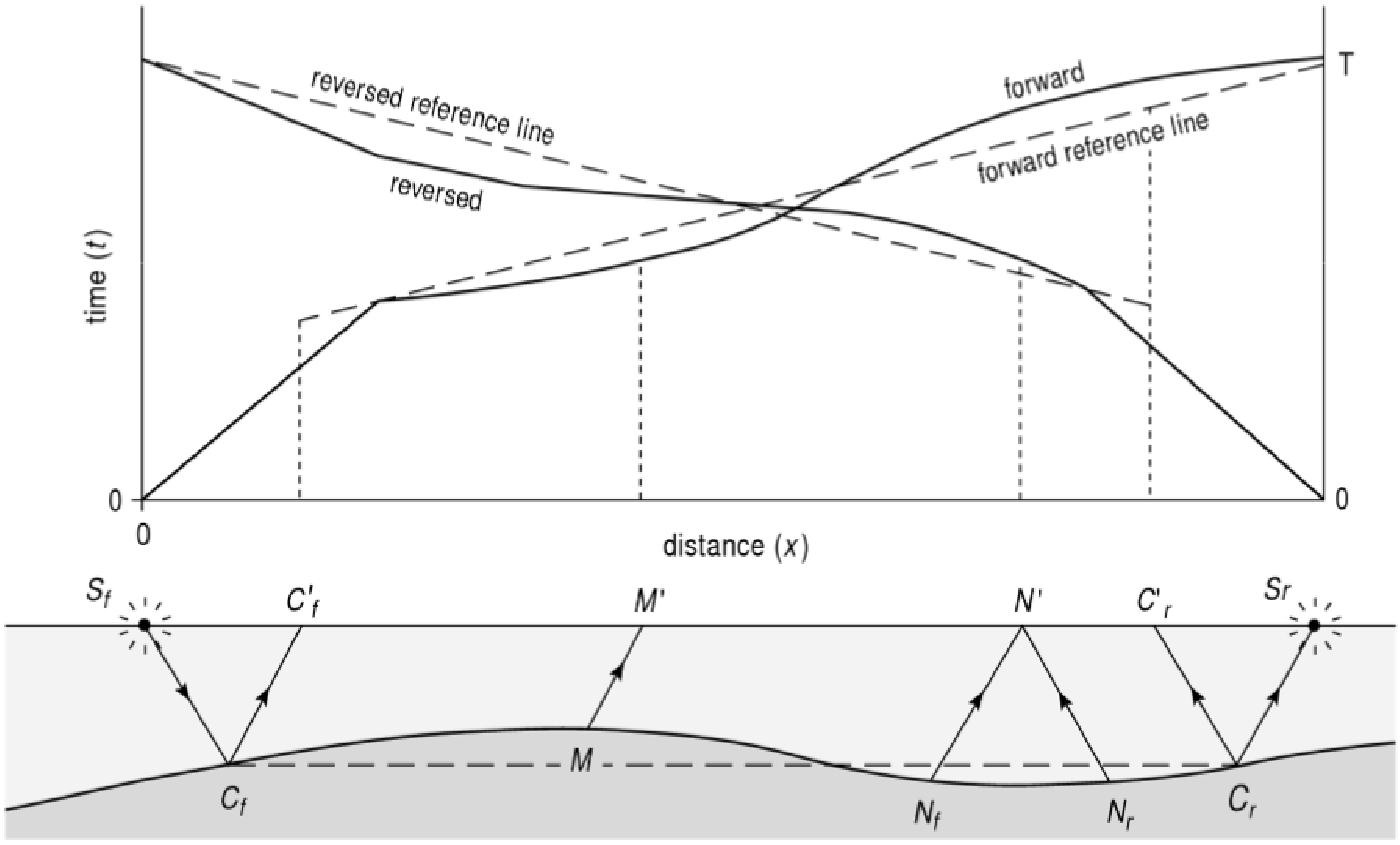


Figure 6.12 Low-velocity layer.

III. **Seismic refraction**

➢ Problem 4

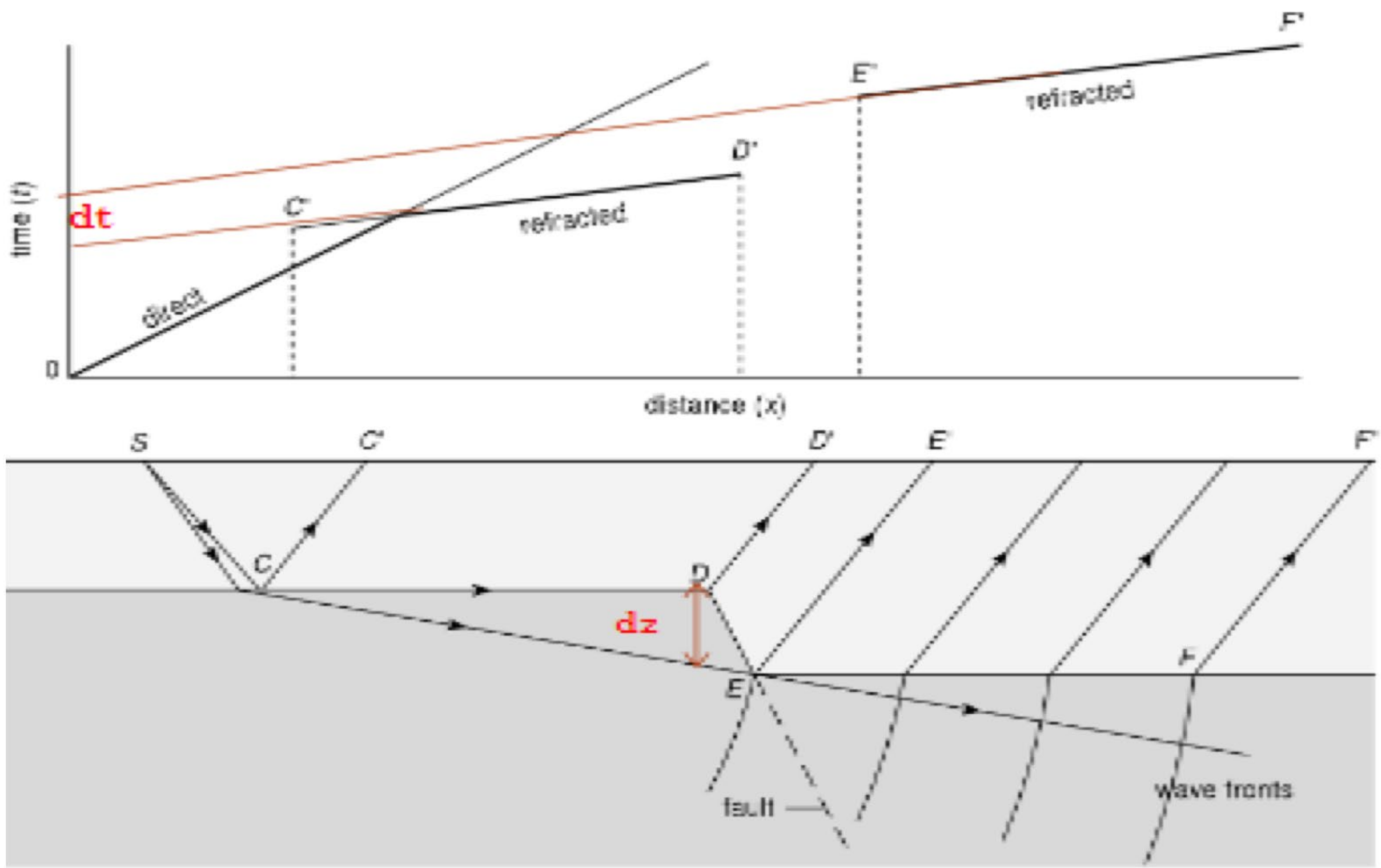
Undulating interface



III. Seismic refraction

➢ Problem 5

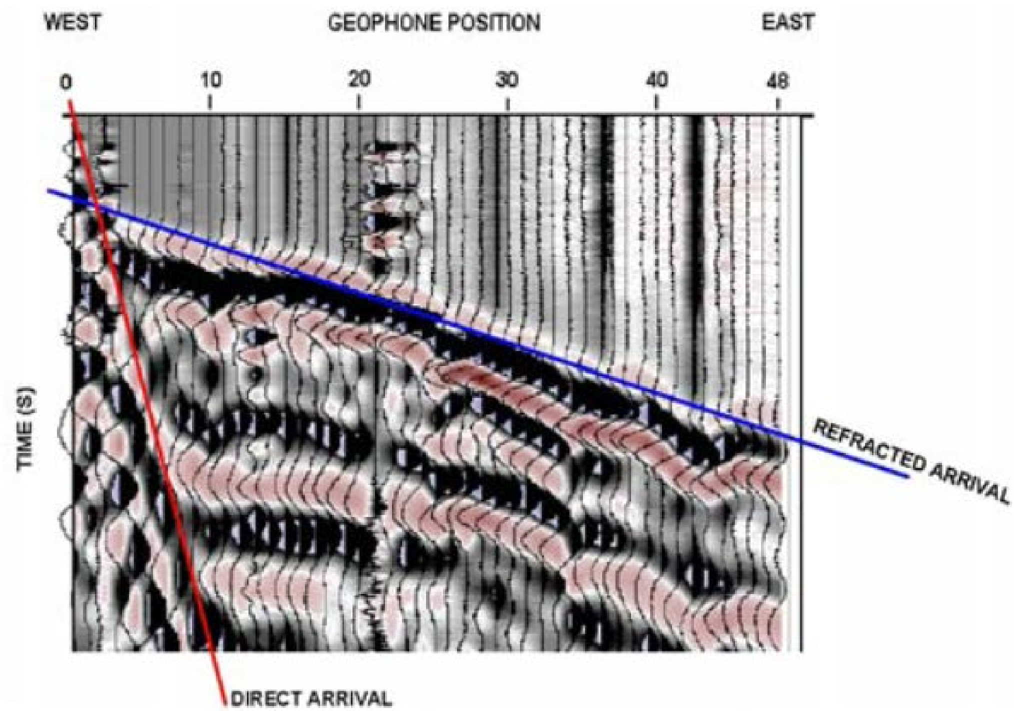
Step discontinuties



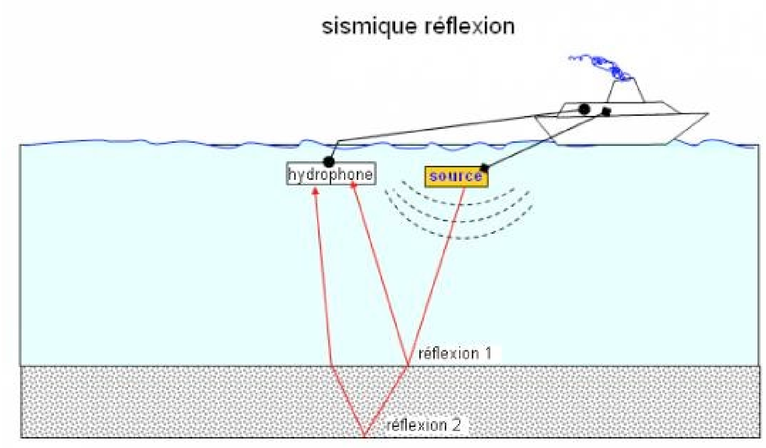
III. **Seismic refraction**

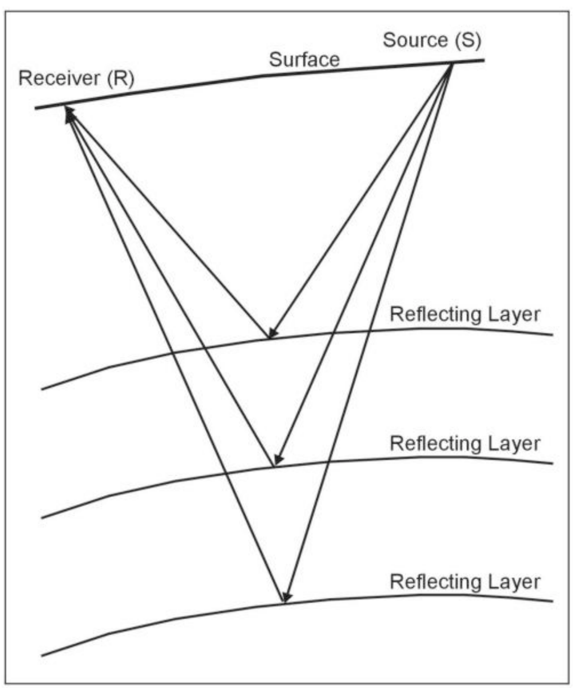
➢ Applications

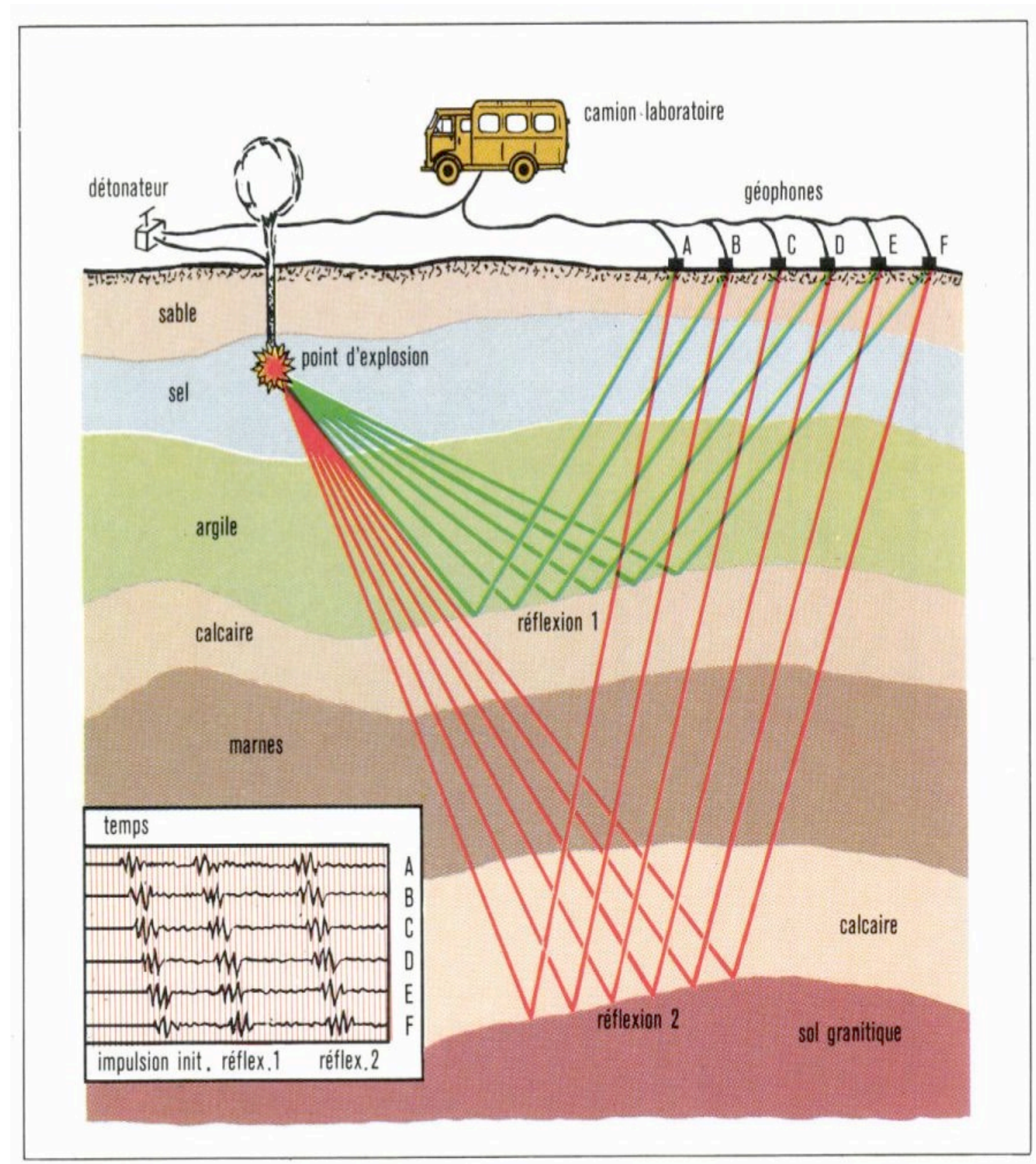
- Depth to bedrock (example from Northern Alberta)



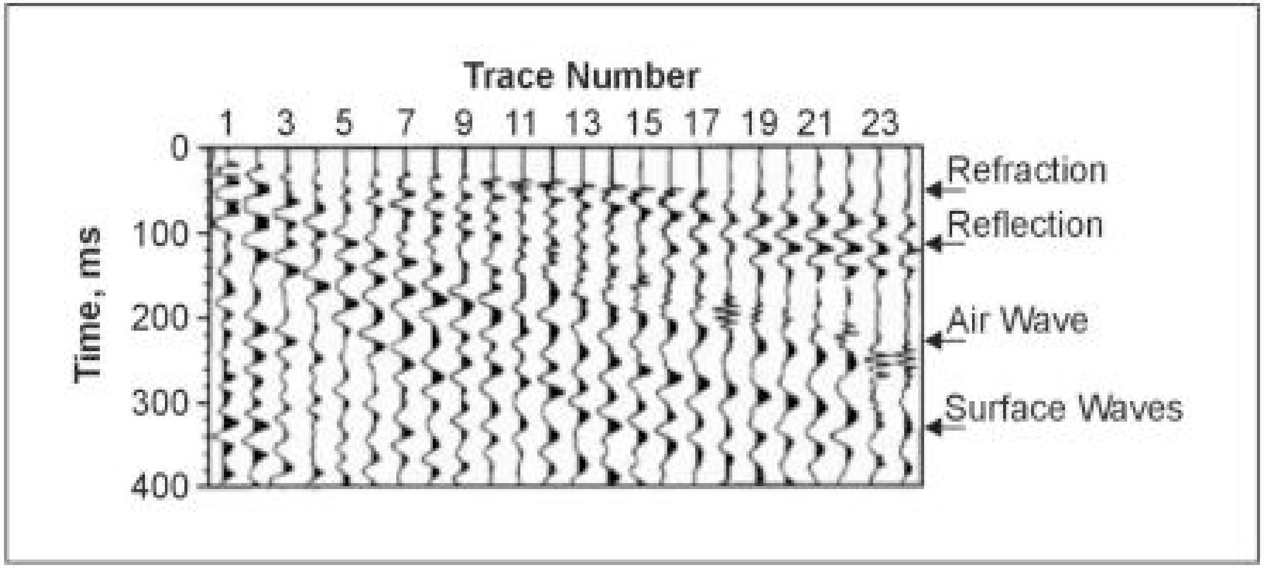
IV. **Seismic reflexion**

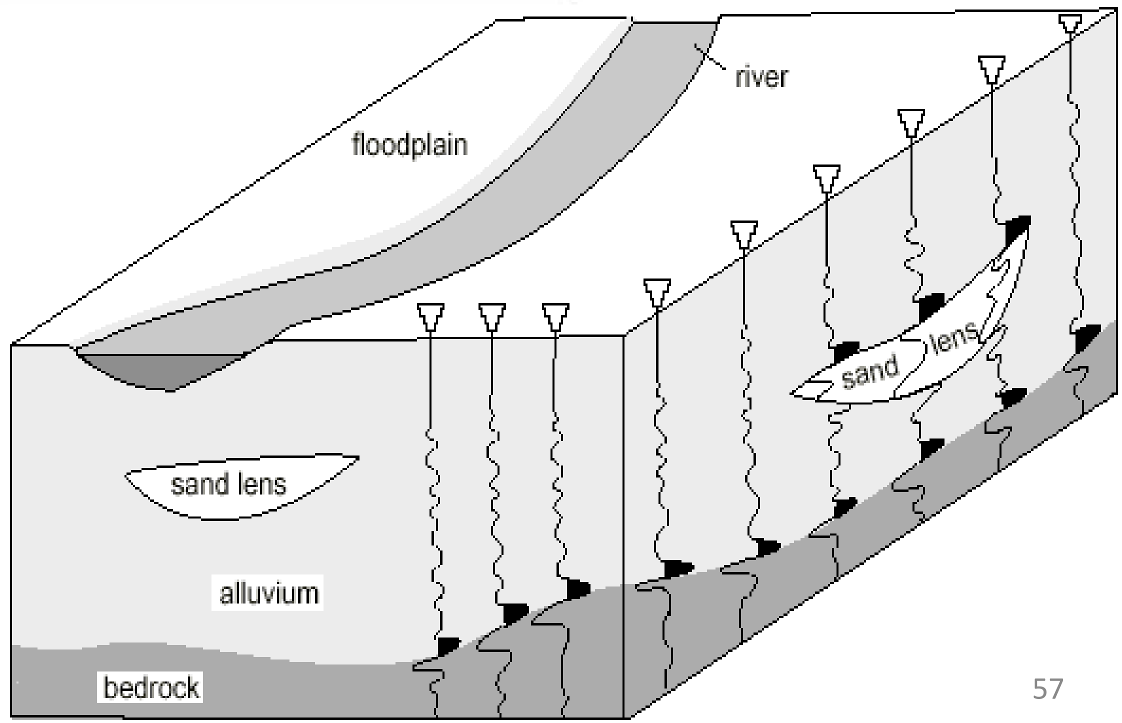




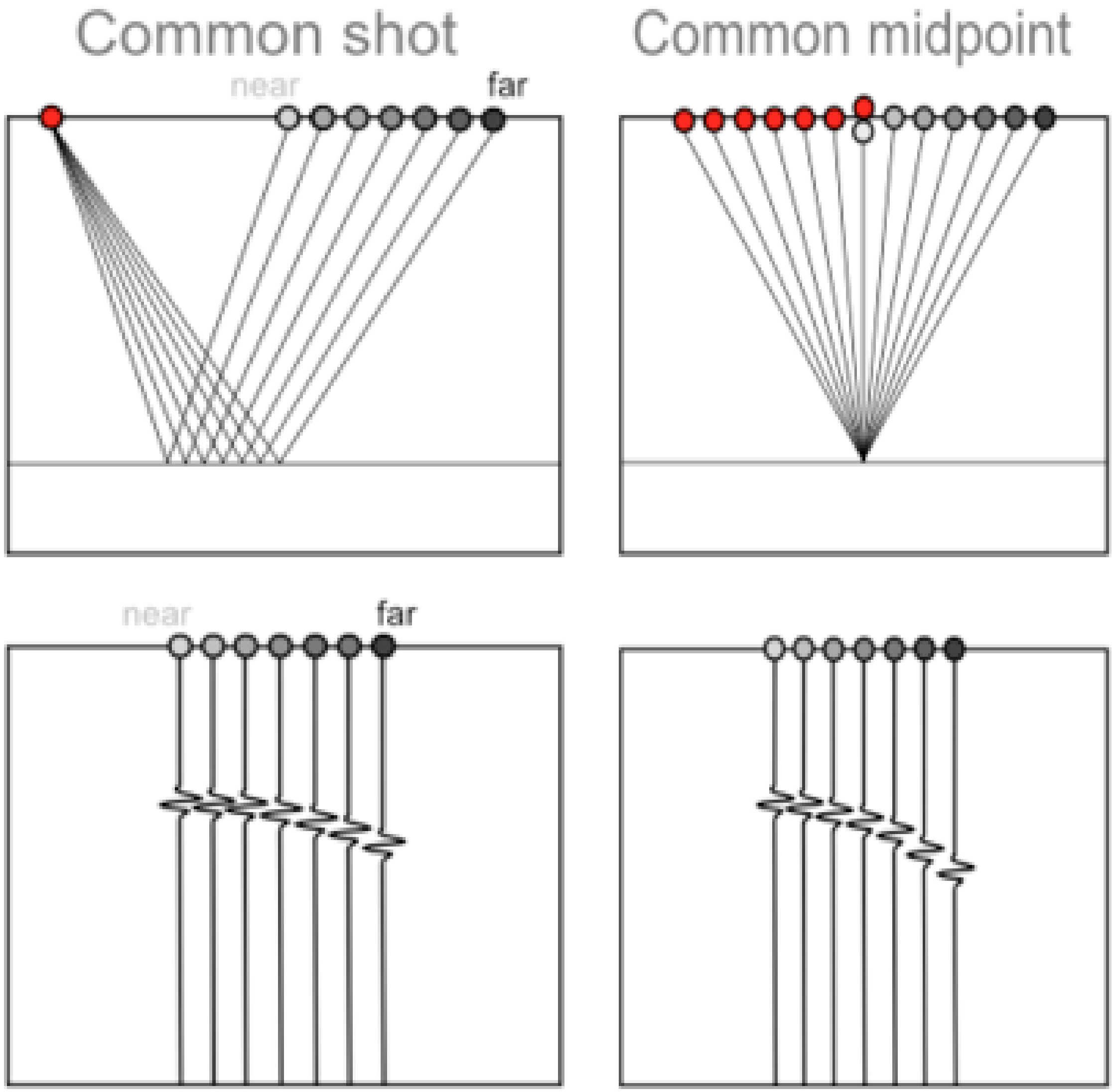


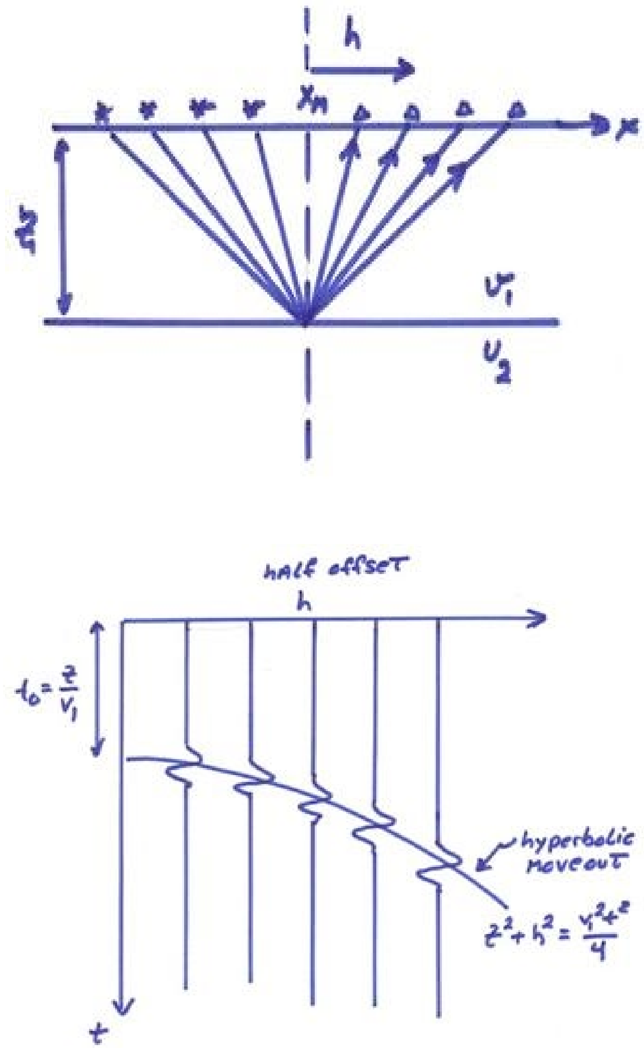
IV. Seismic reflexion





IV. Seismic reflexion





IV. **Seismic reflexion**

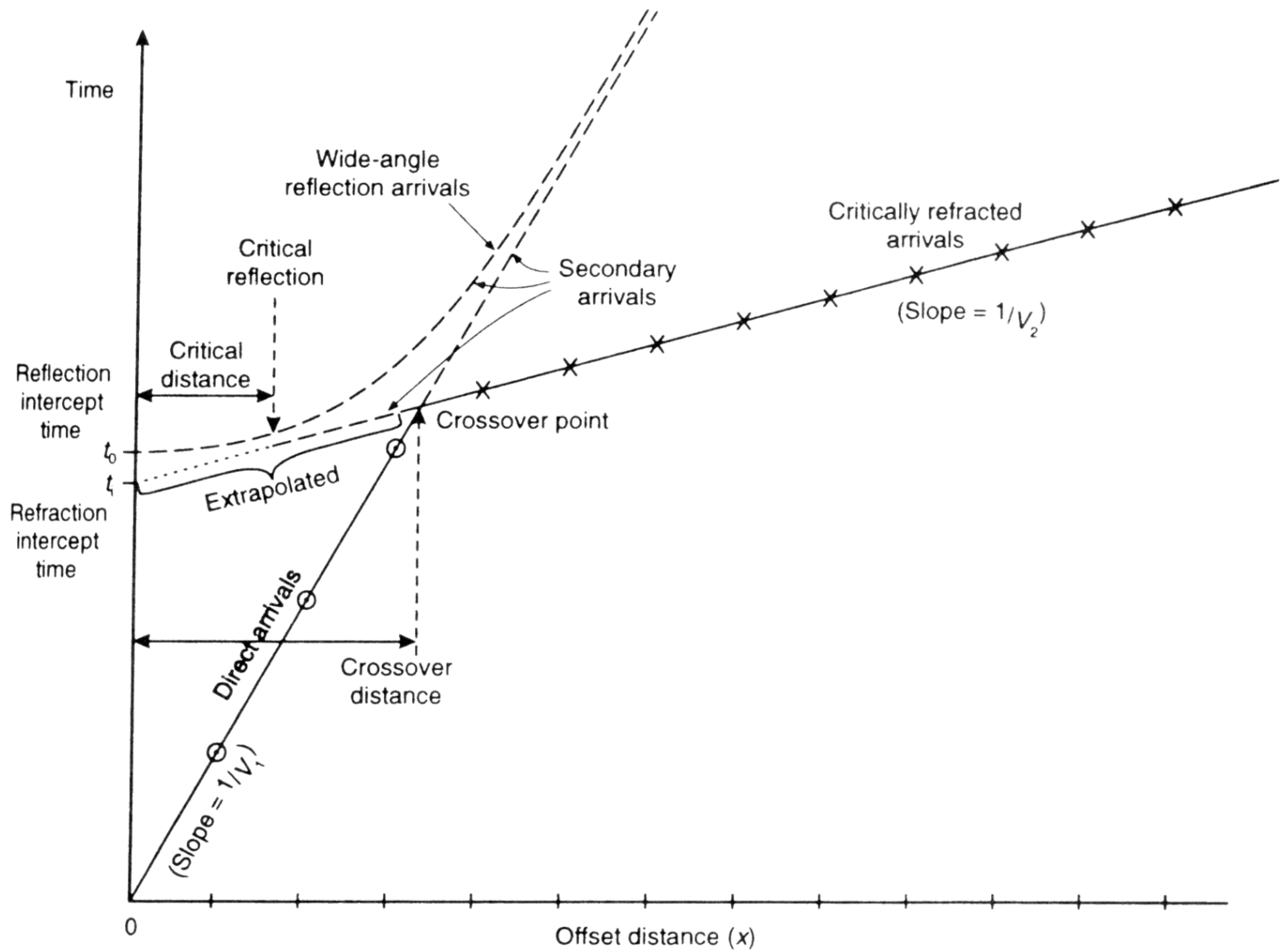
➢ Travel time for reflected waves

The travel time of the reflected wave is given by:

$$\boxed{t = \frac{2}{V_0}\sqrt{h_0^2 + \left(\frac{X}{2}\right)^2} \Longrightarrow t^2 = \left(\frac{2h_0}{V_0}\right)^2 + \left(\frac{X}{V_0}\right)^2}$$

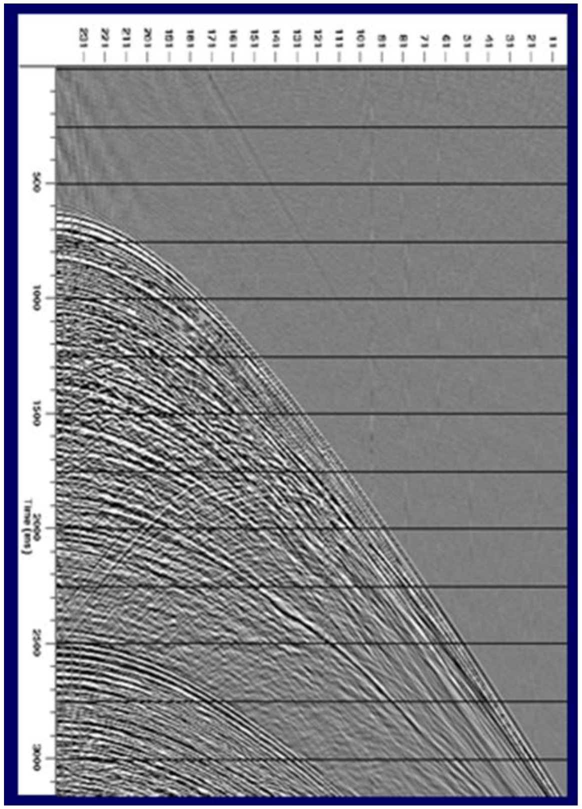
So the travel time curve of this ray is a hyperbola!

IV. **Seismic reflexion**



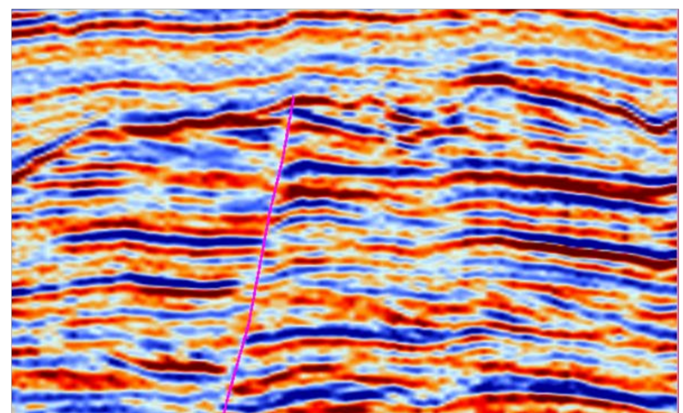
IV. **Seismic reflexion**

➢ Seismic processing



Field Record (marine)

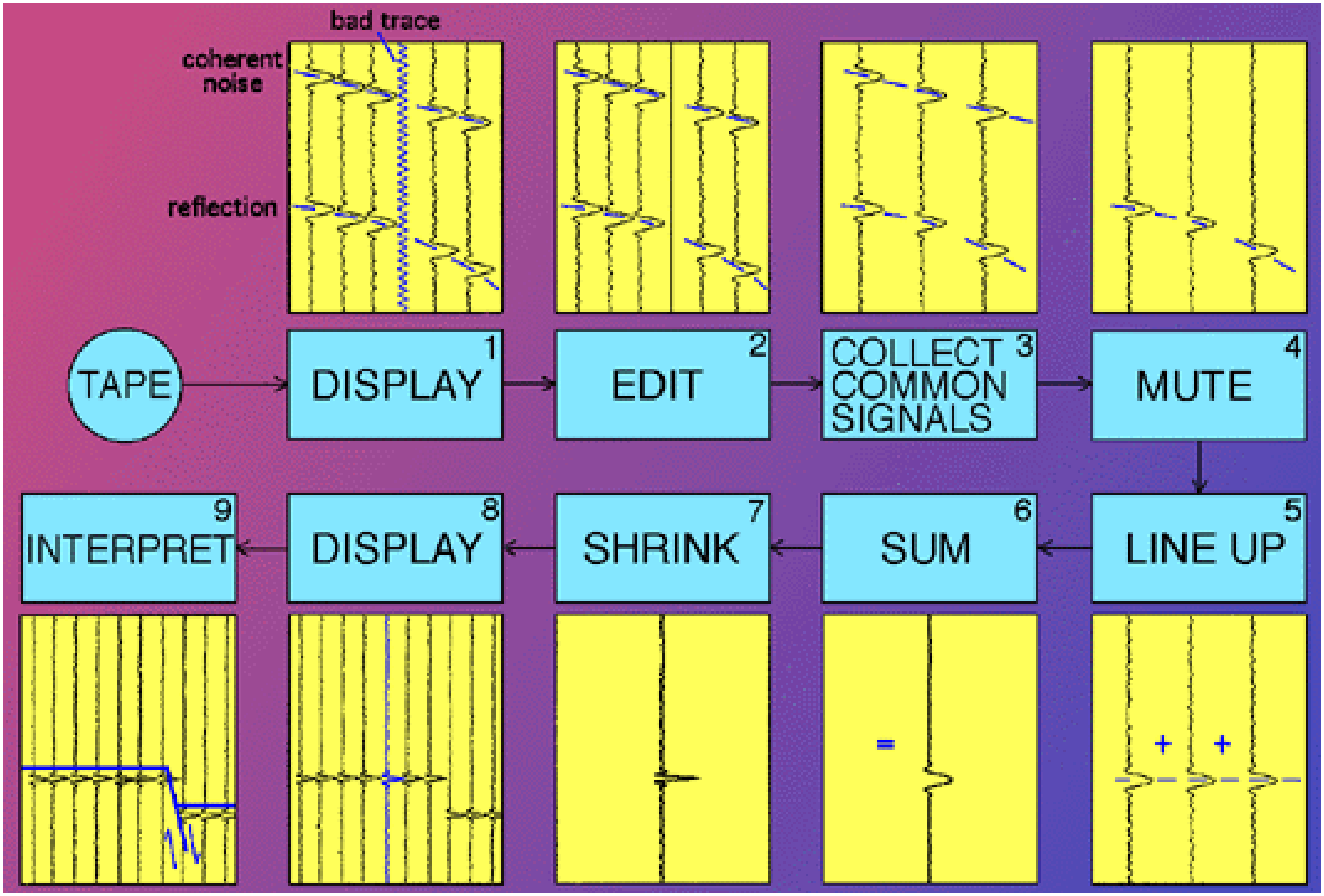
Data Processing Stream



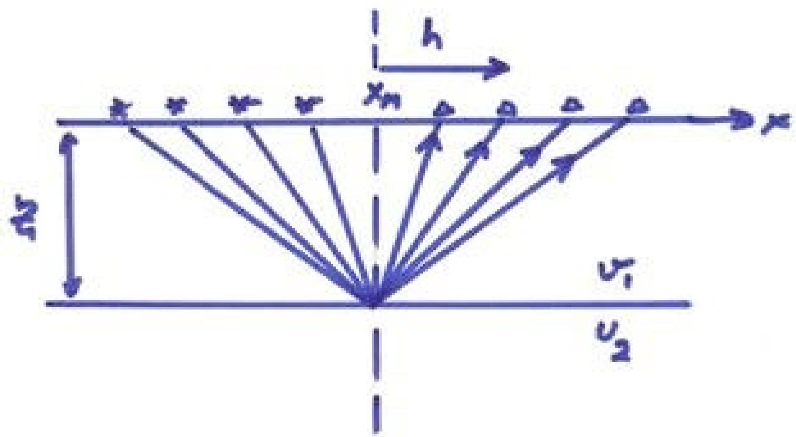
Subsurface 'Image'

IV. **Seismic reflexion**

➢ Acquisition

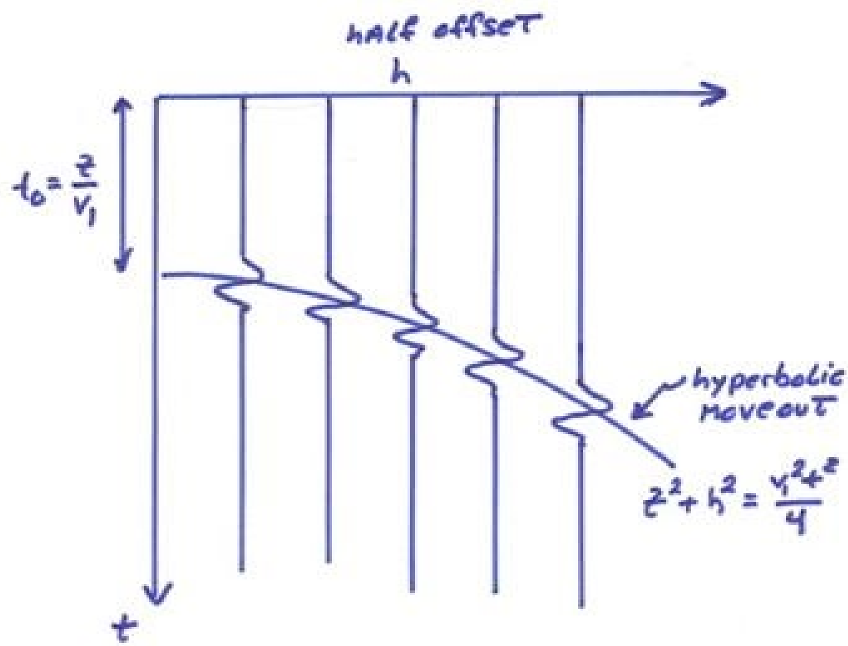


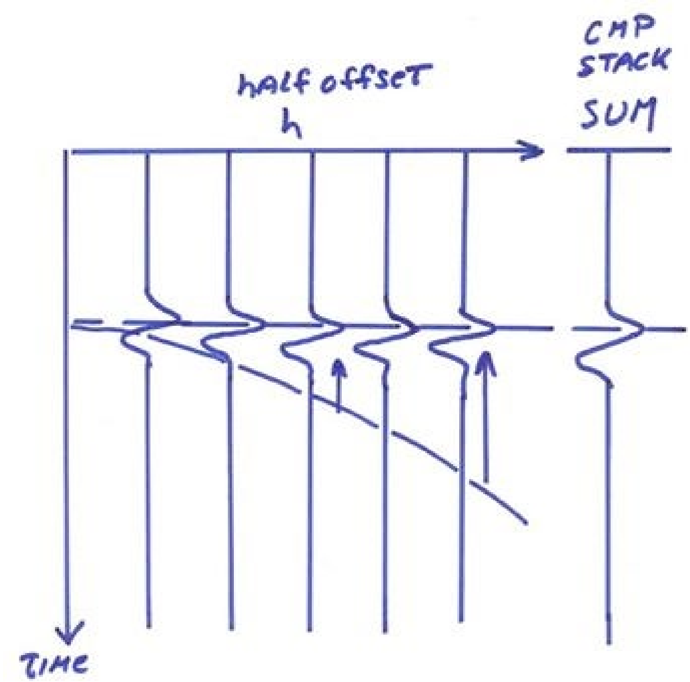
IV. **Seismic reflexion**



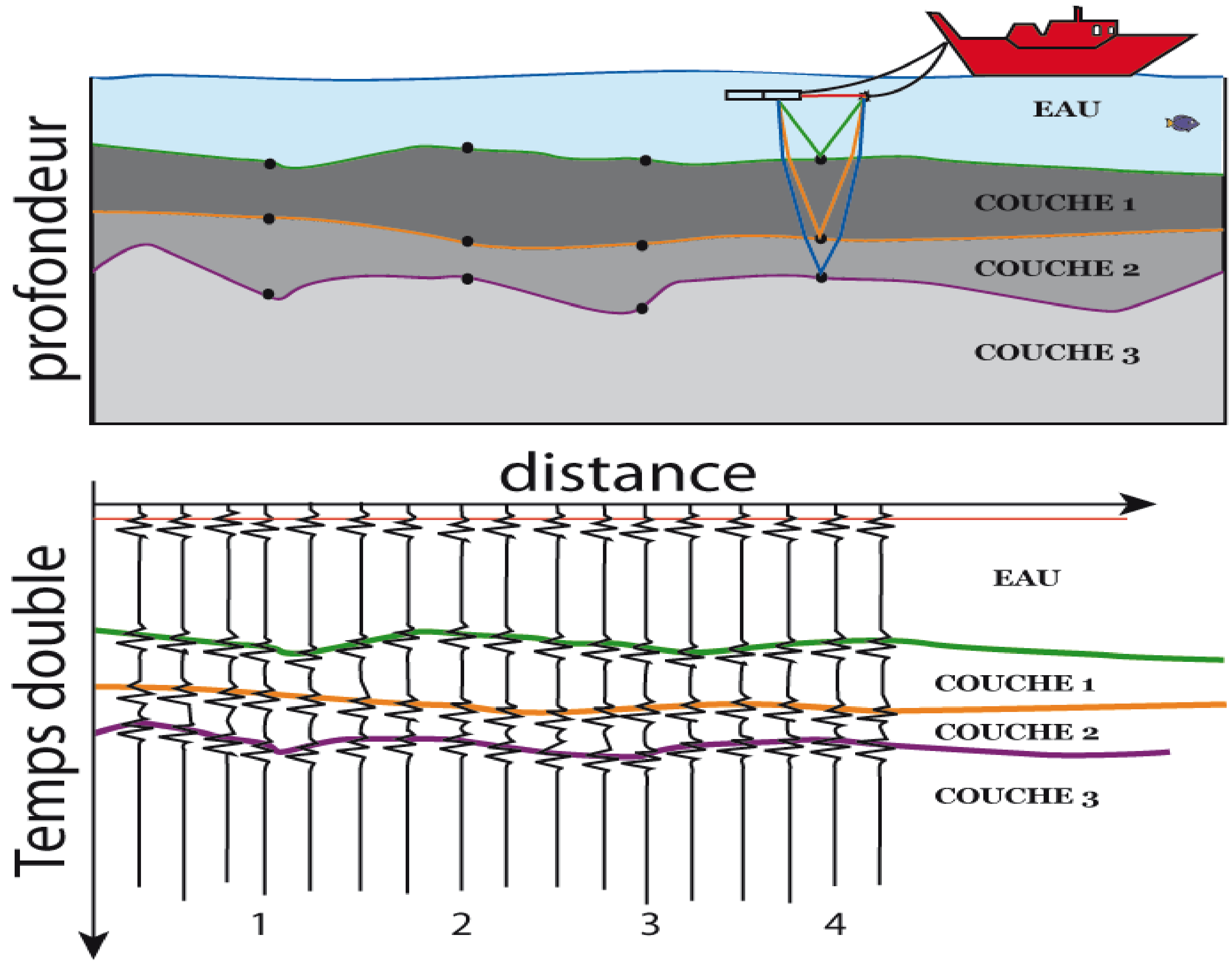
Normal Move Out: NMO

→ Analyse de vitesses

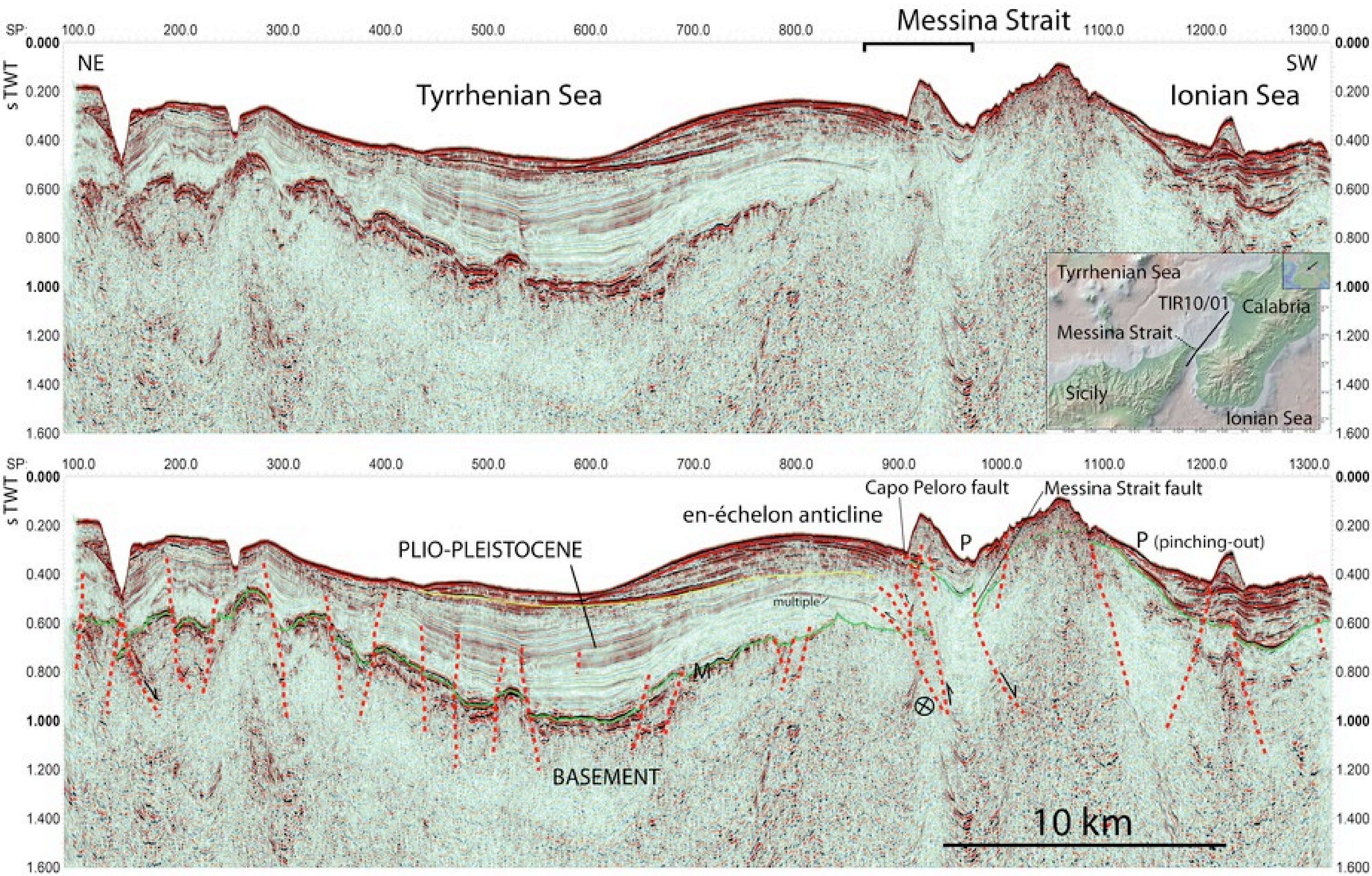




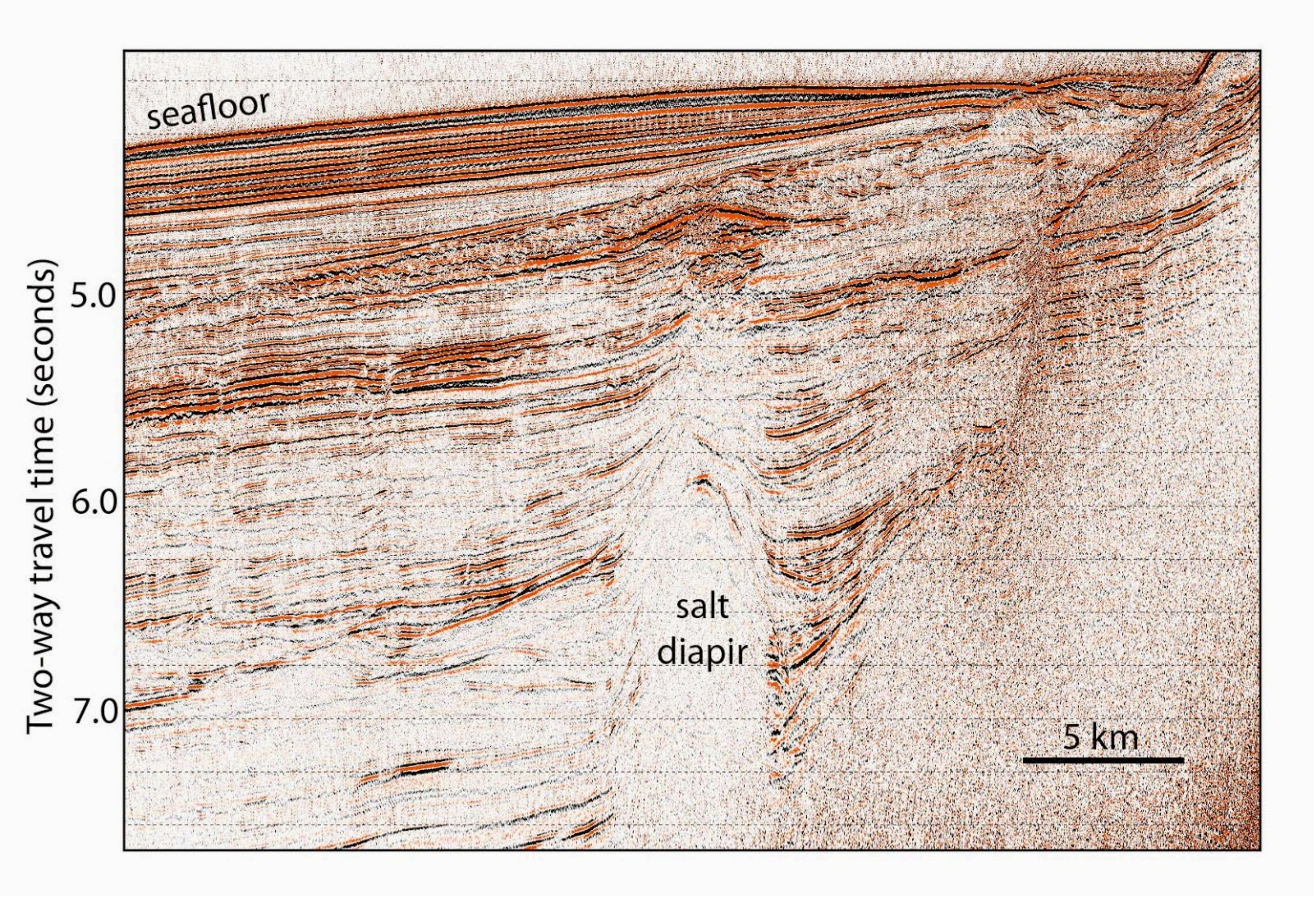
IV. **Seismic reflexion**



IV. **Seismic reflexion**

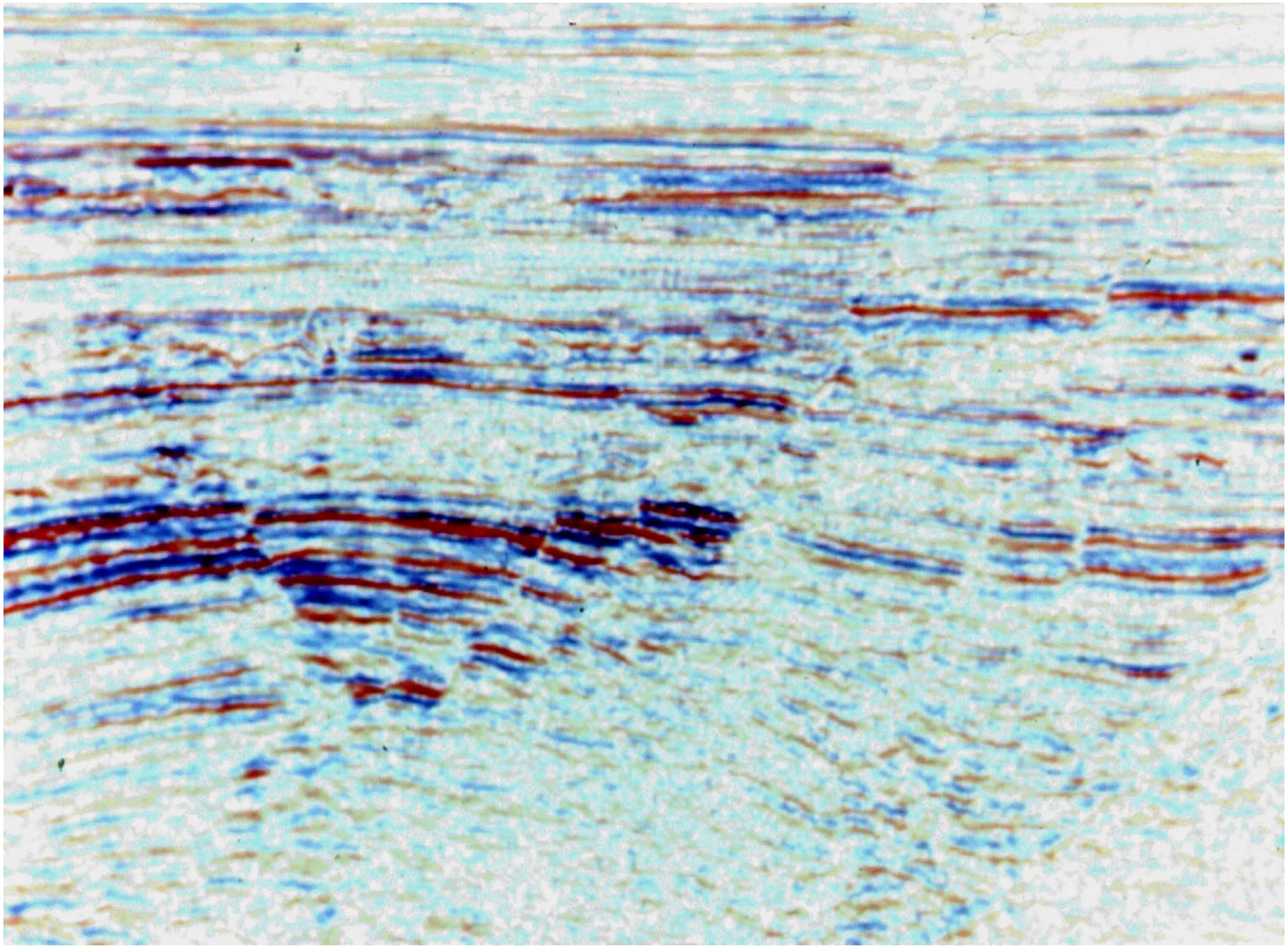


IV. **Seismic reflexion**



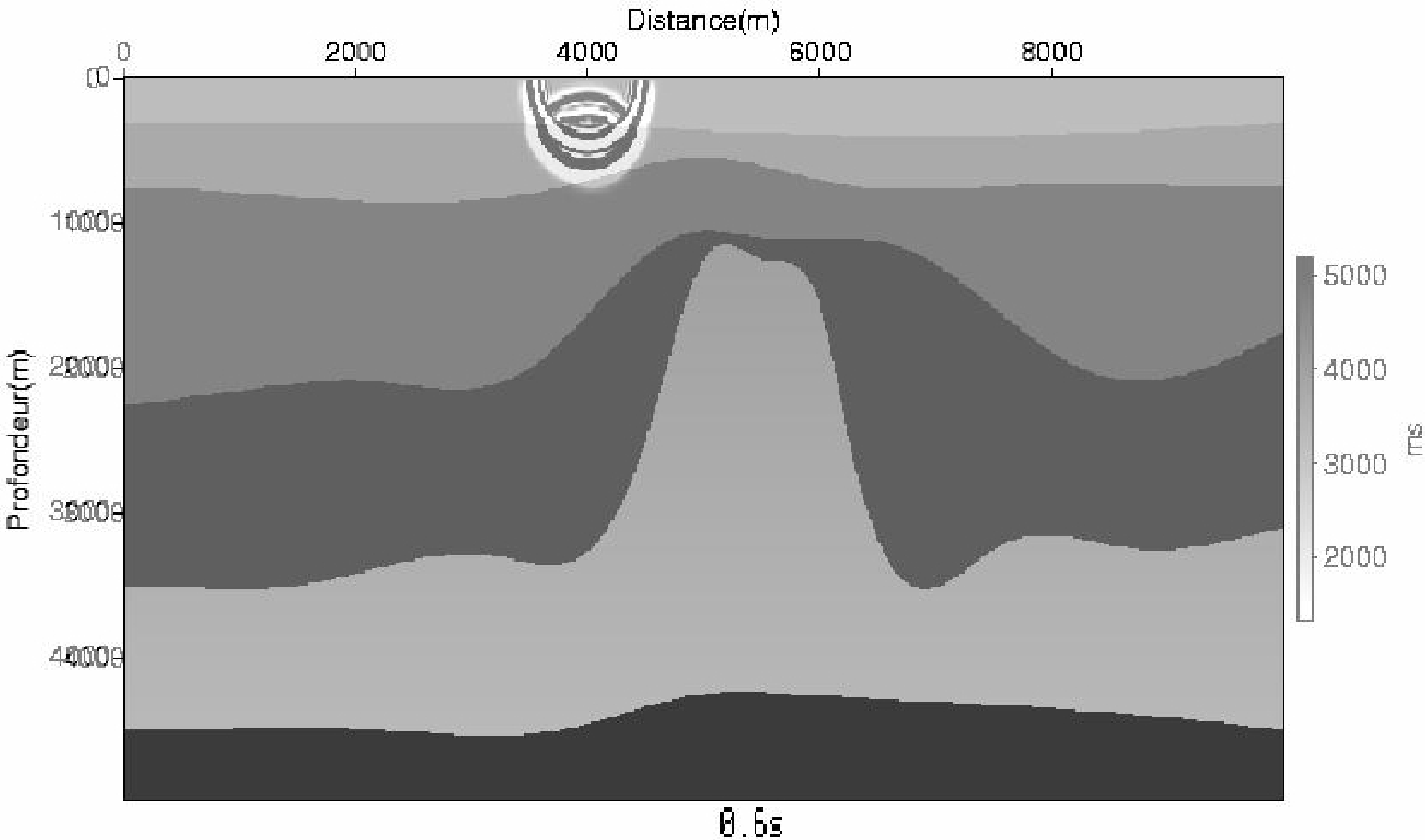
IV. **Seismic reflexion**

- Where are faults?



V. Example of waves propagations

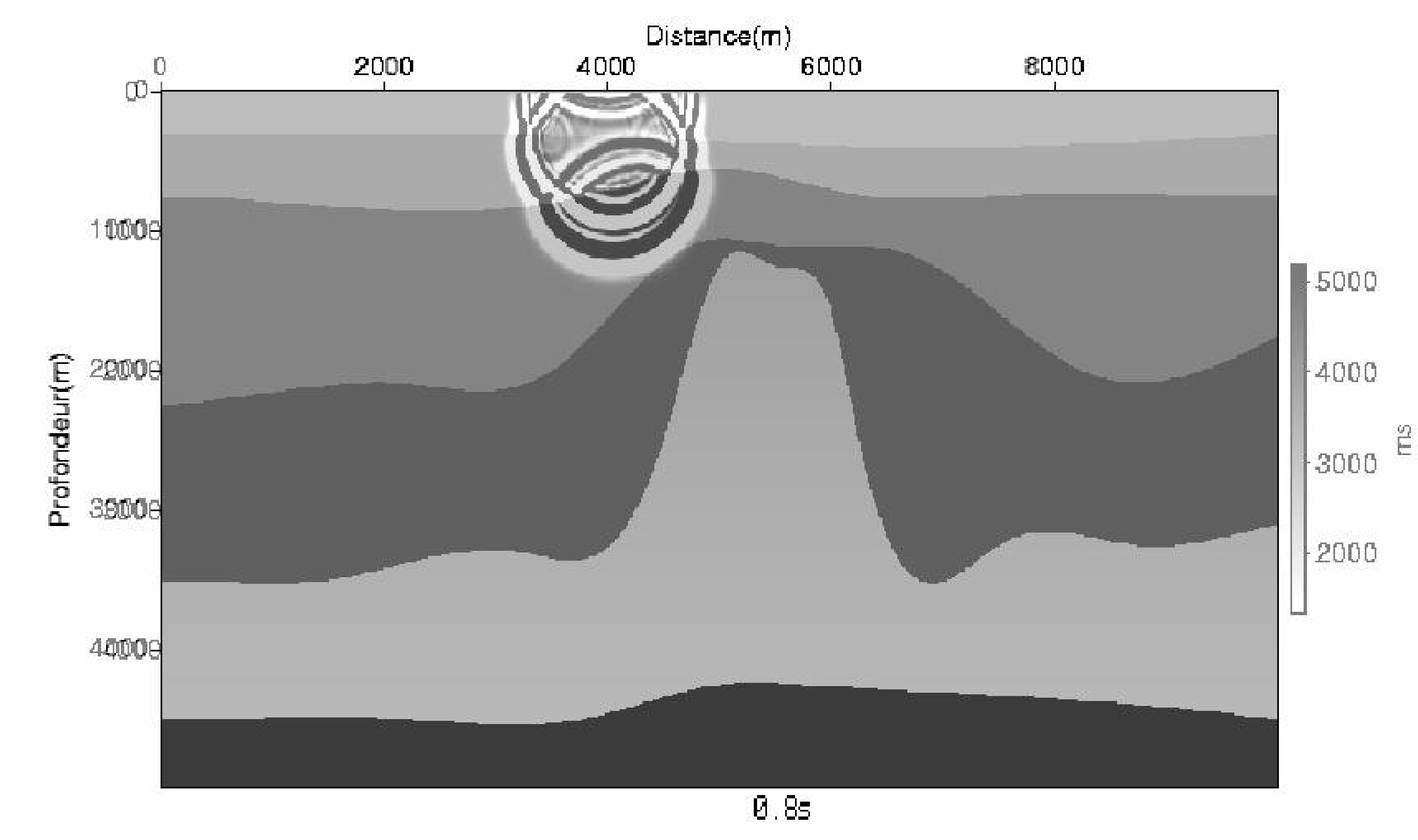
Simulation de la propagation d'onde dans un modèle



ENSPM

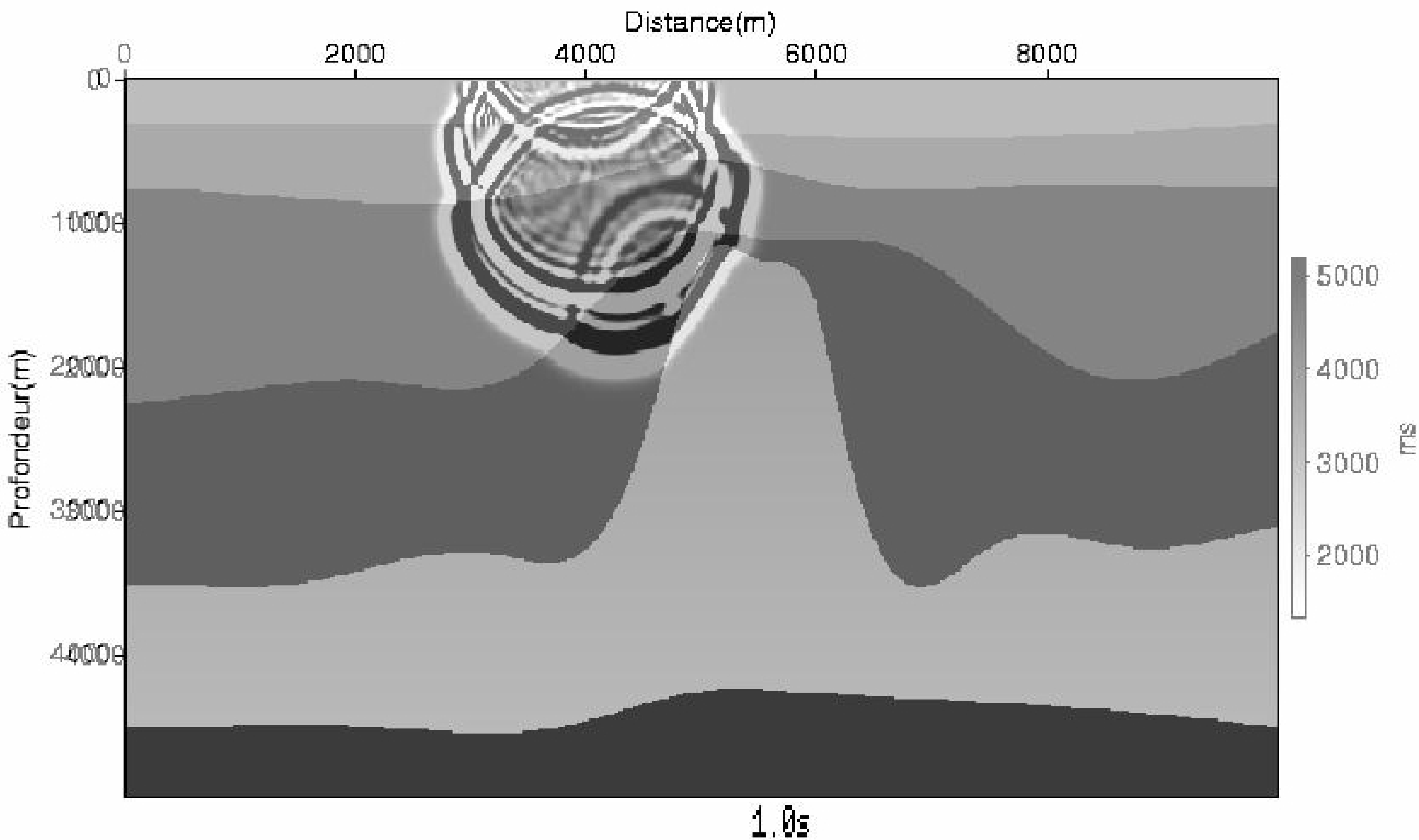
V. Example of waves propagations

Simulation de la propagation d'onde dans un modèle



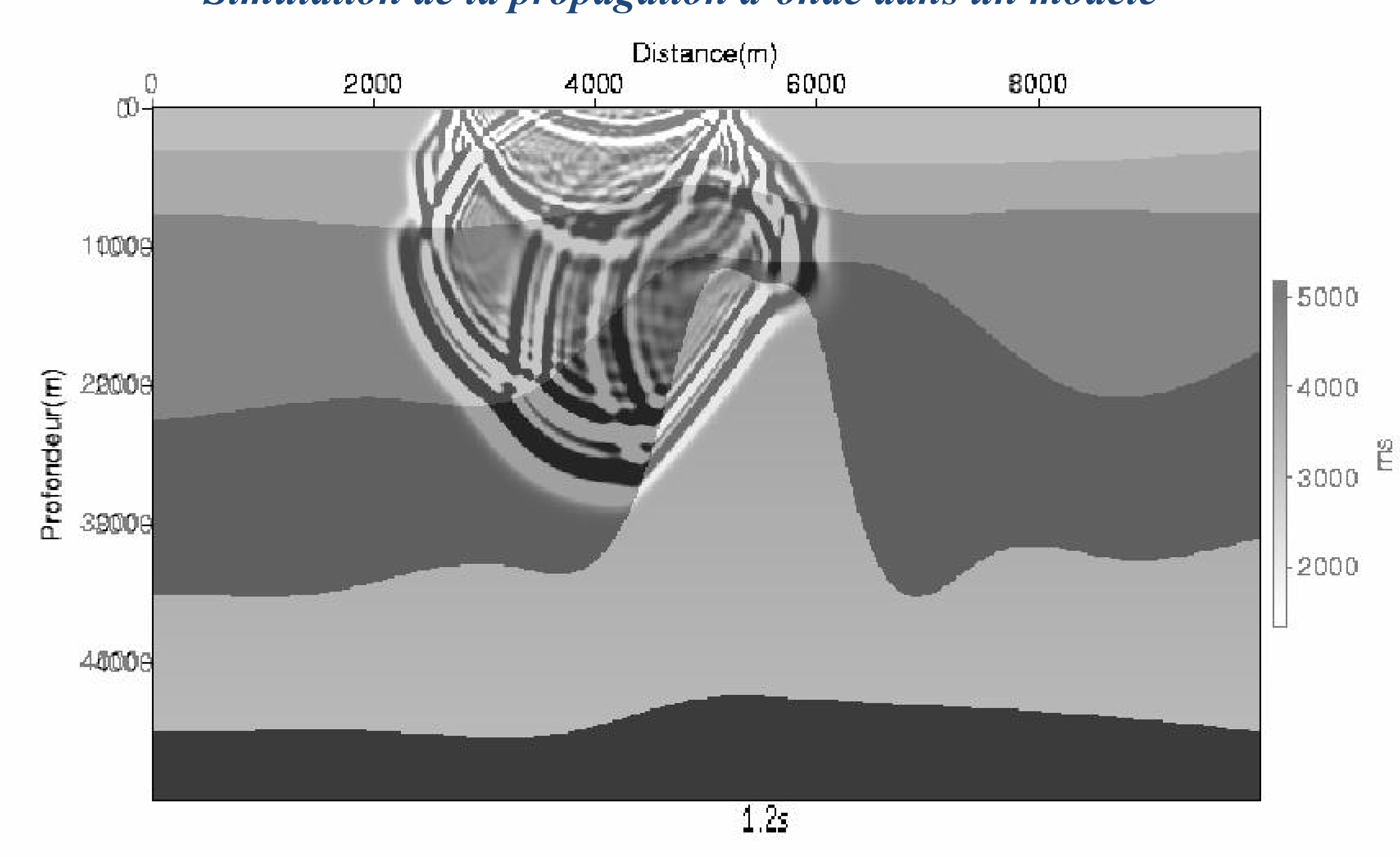
V. **Example of waves propagations**

Simulation de la propagation d'onde dans un modèle



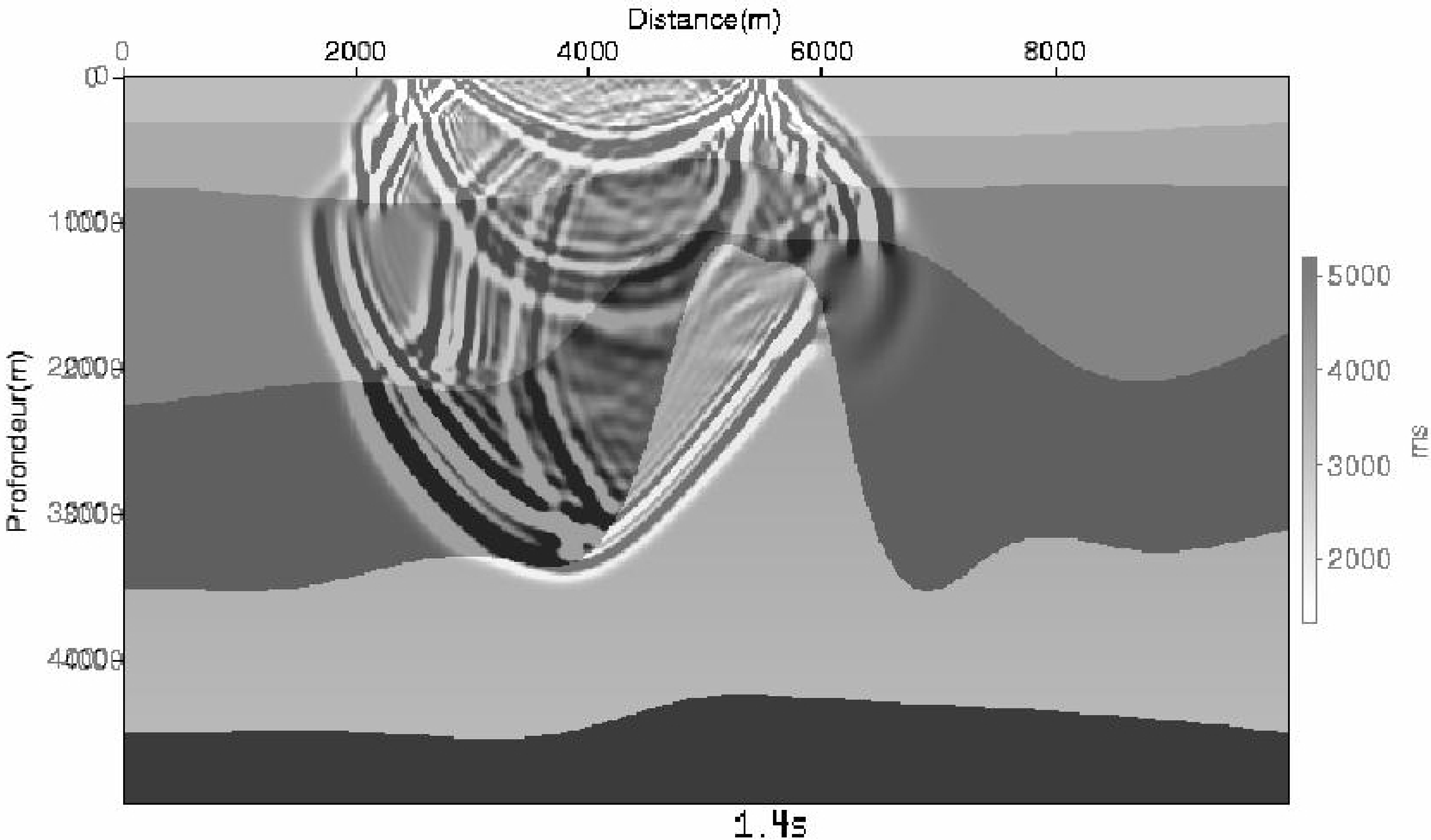
V. Example of waves propagations

Simulation de la propagation d'onde dans un modèle



V. **Example of waves propagations**

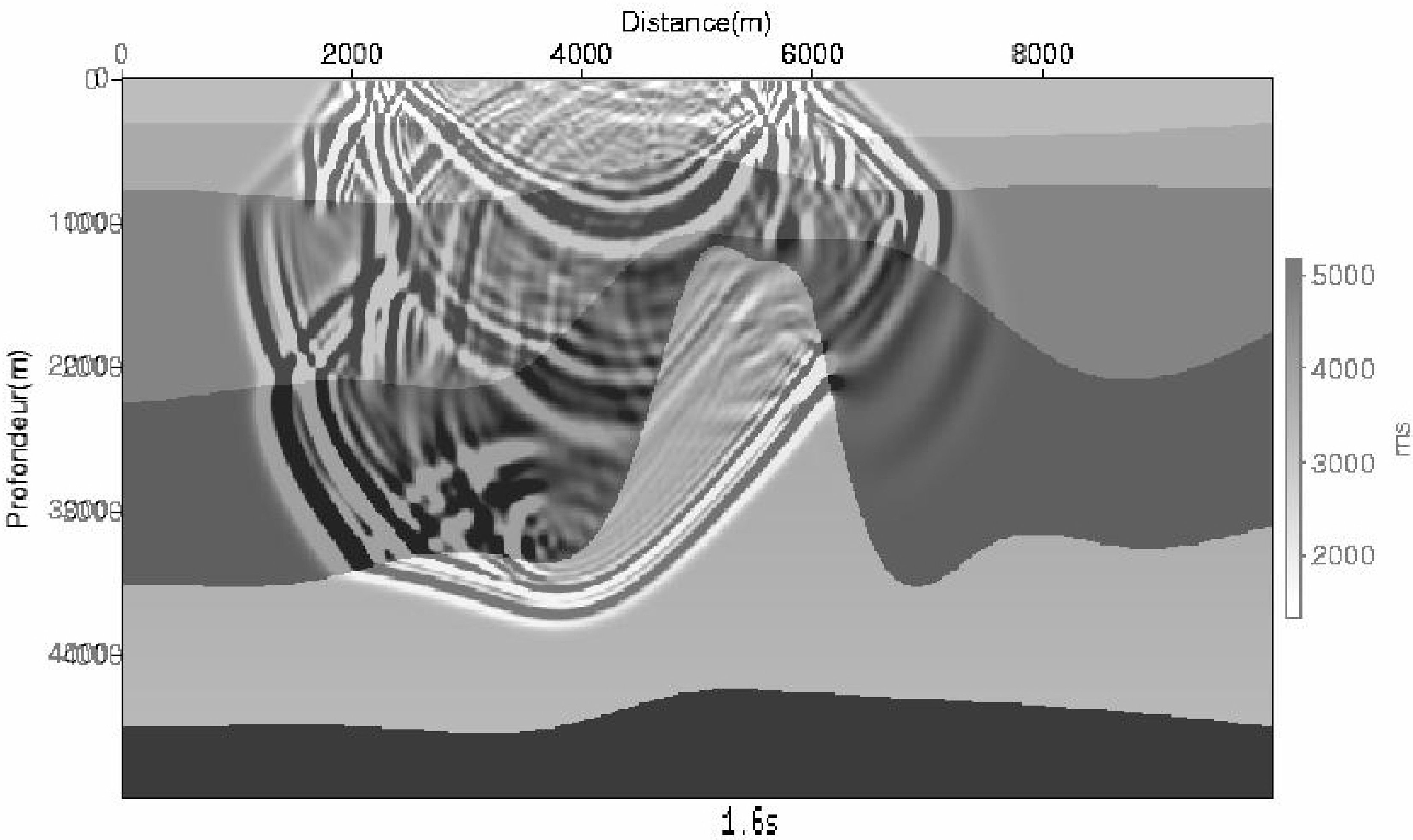
Simulation de la propagation d'onde dans un modèle



ENSPM

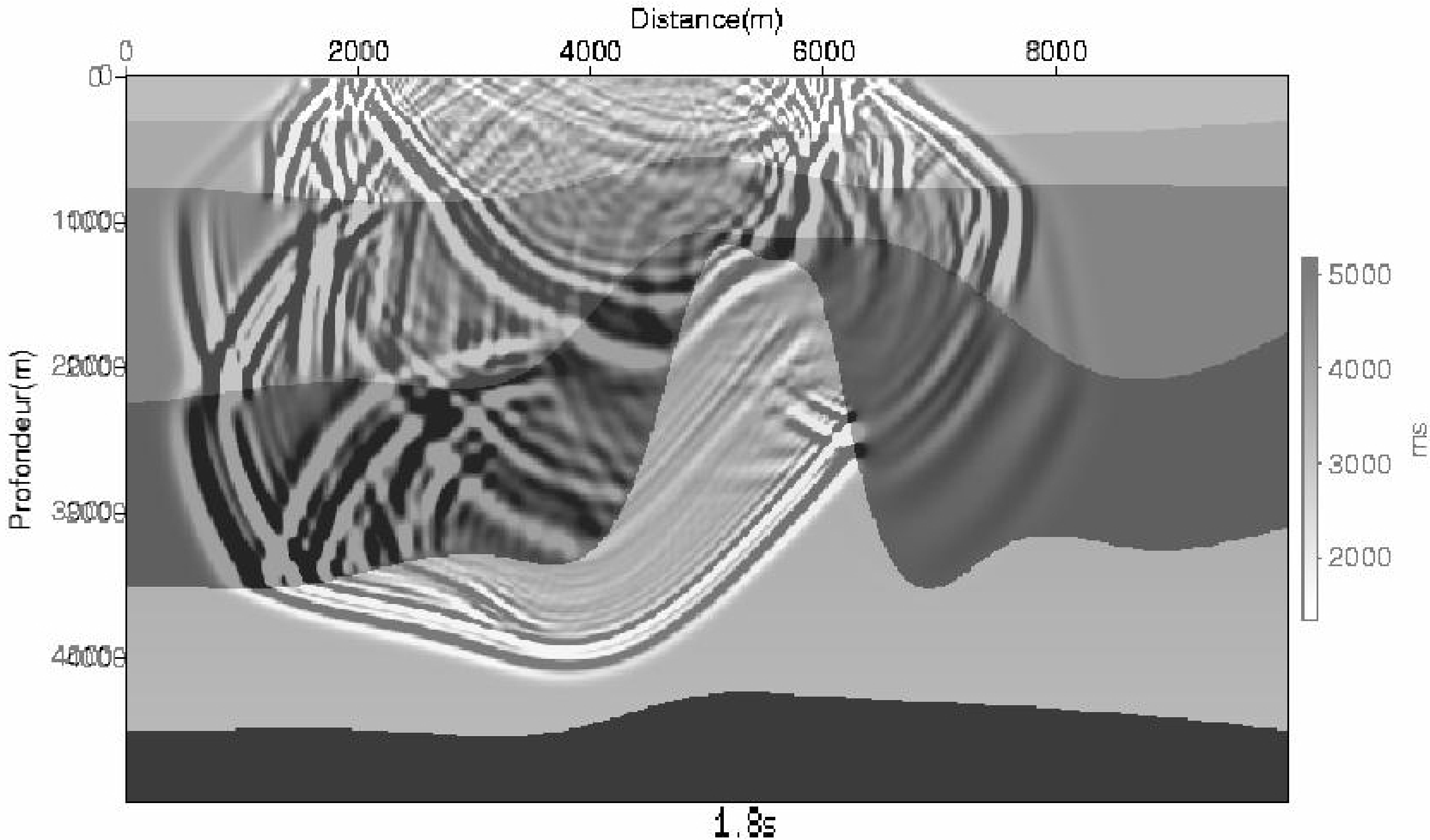
V. **Example of waves propagations**

Simulation de la propagation d'onde dans un modèle



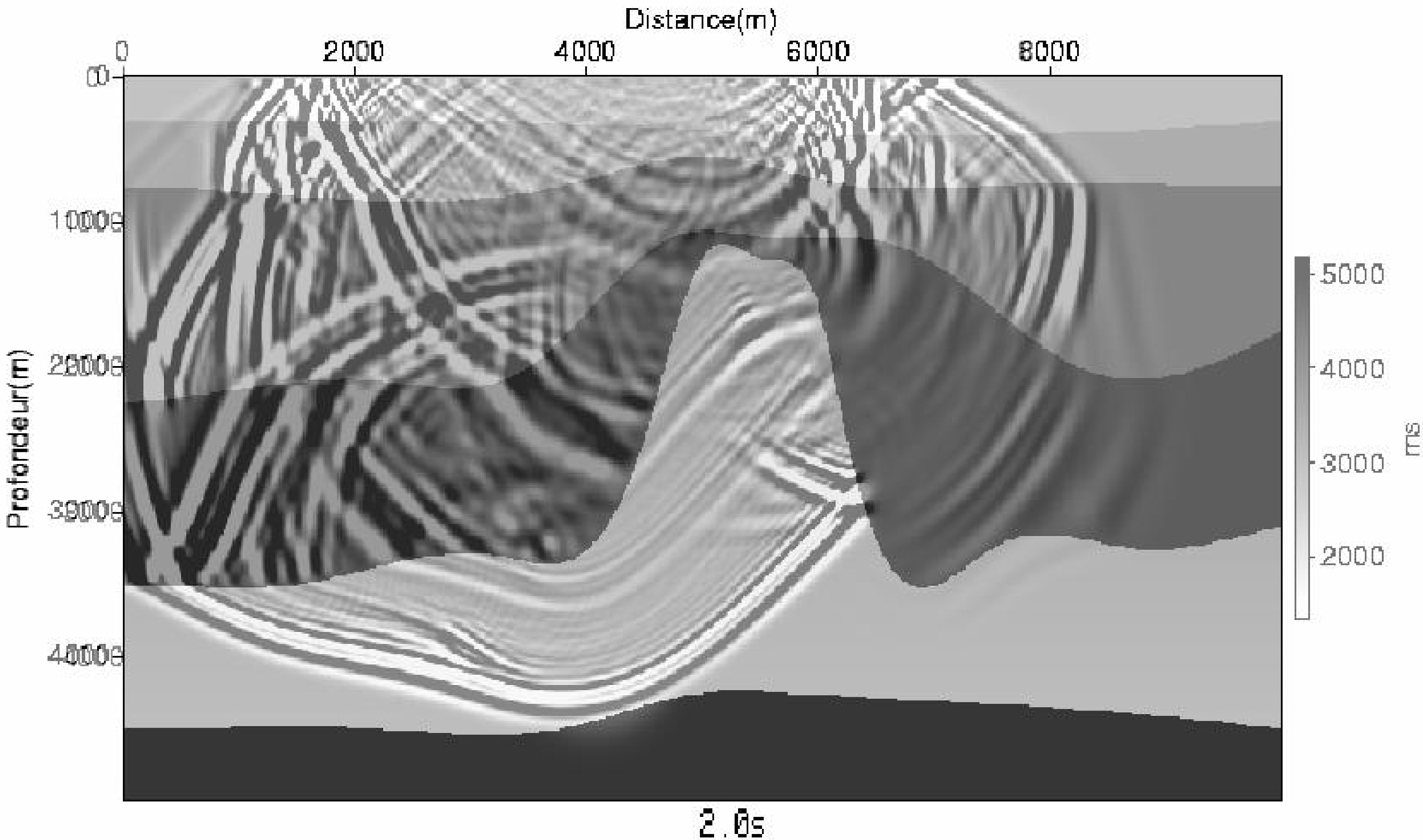
V. Example of waves propagations

Simulation de la propagation d'onde dans un modèle



V. Example of waves propagations

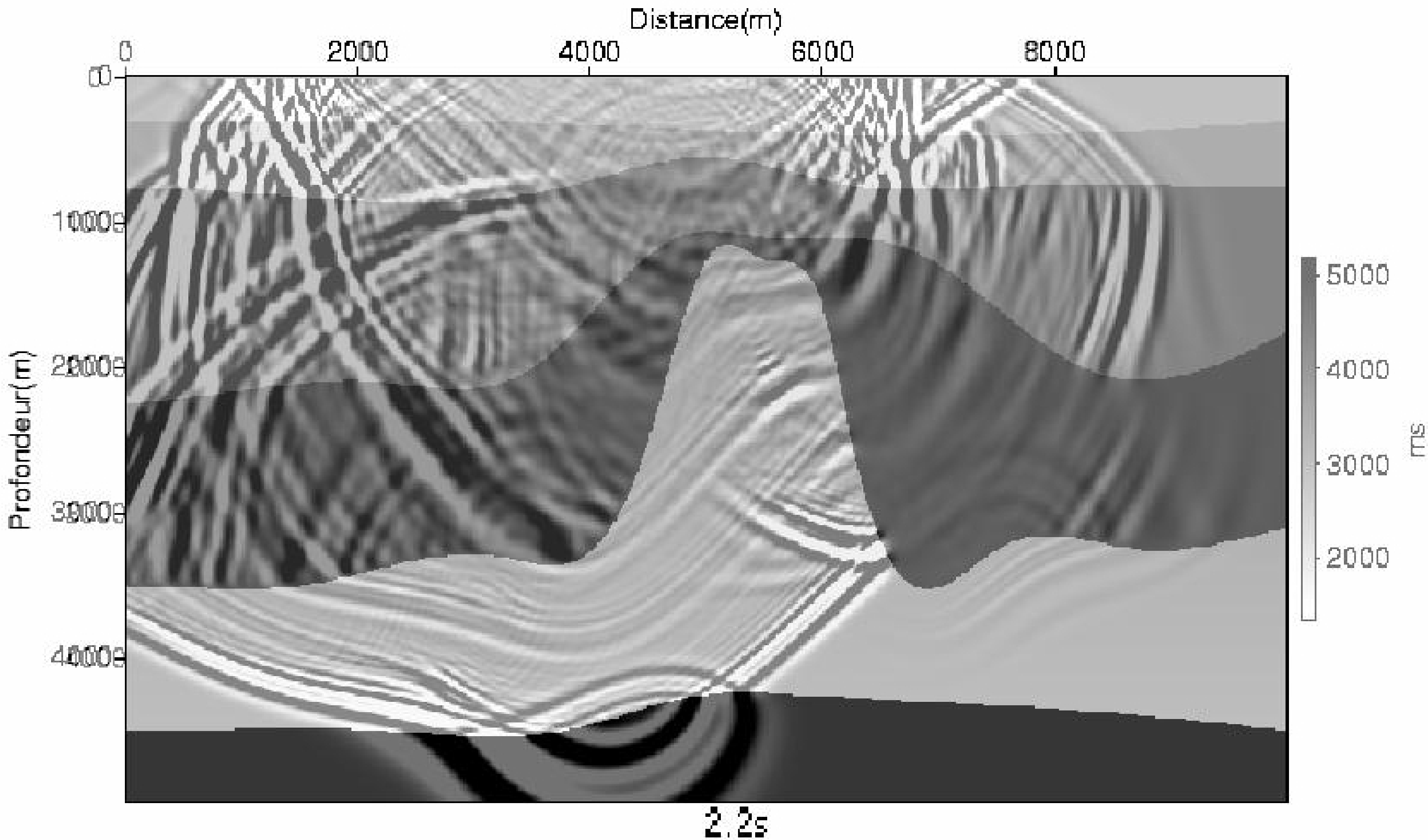
Simulation de la propagation d'onde dans un modèle



ENSPM

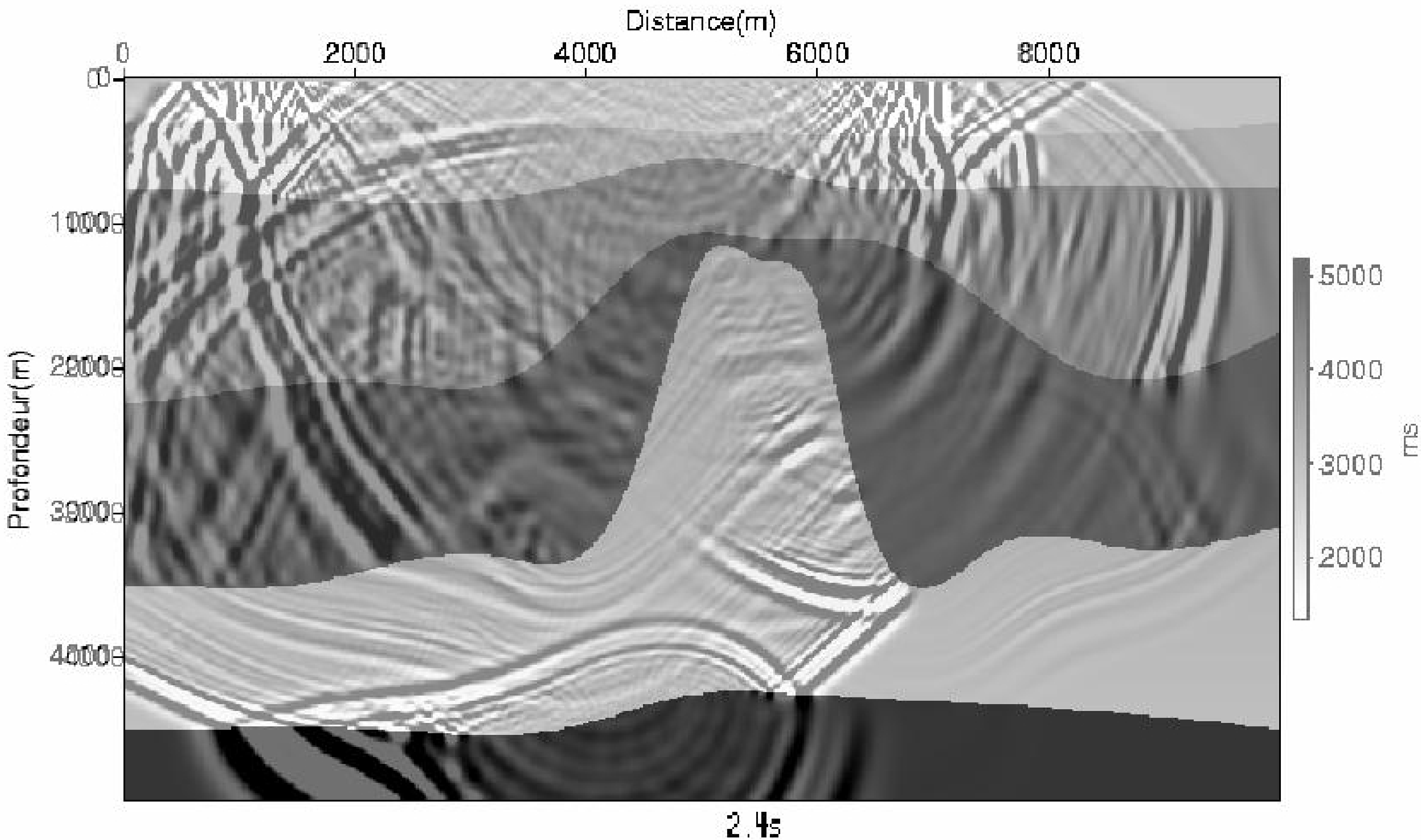
V. **Example of waves propagations**

Simulation de la propagation d'onde dans un modèle



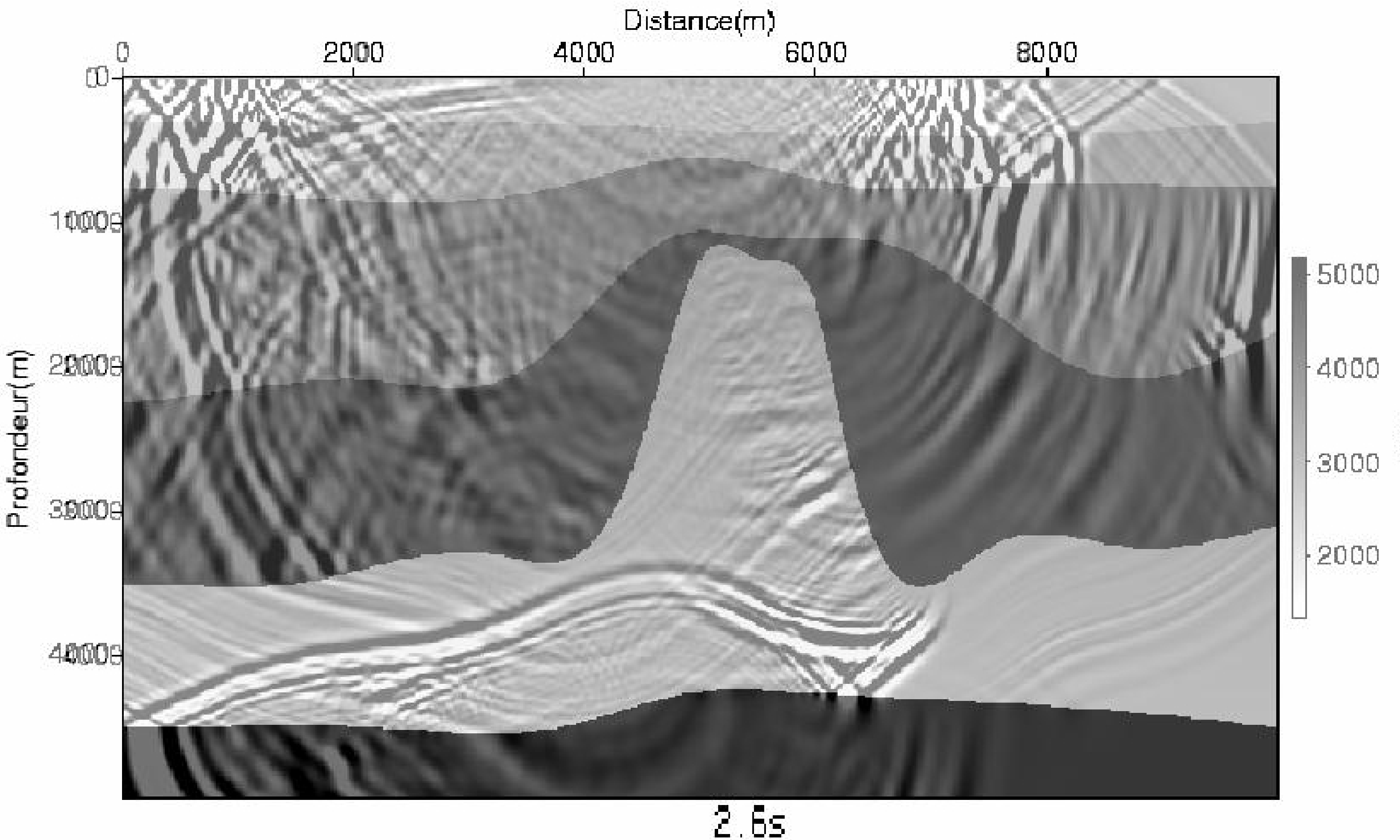
V. **<u>Example of waves propagations</u>**

Simulation de la propagation d'onde dans un modèle



V. Example of waves propagations

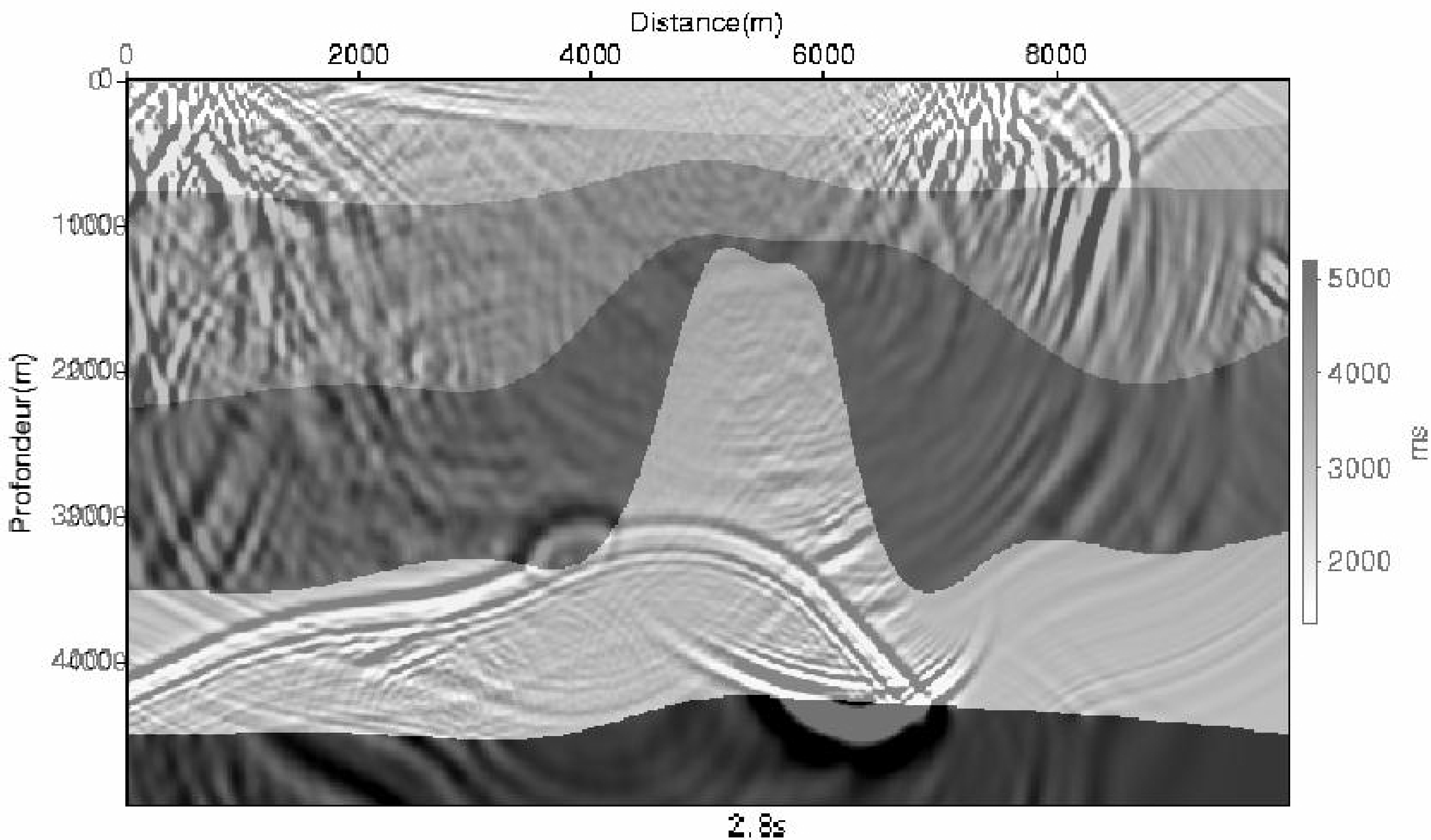
Simulation de la propagation d'onde dans un modèle



ENSPM

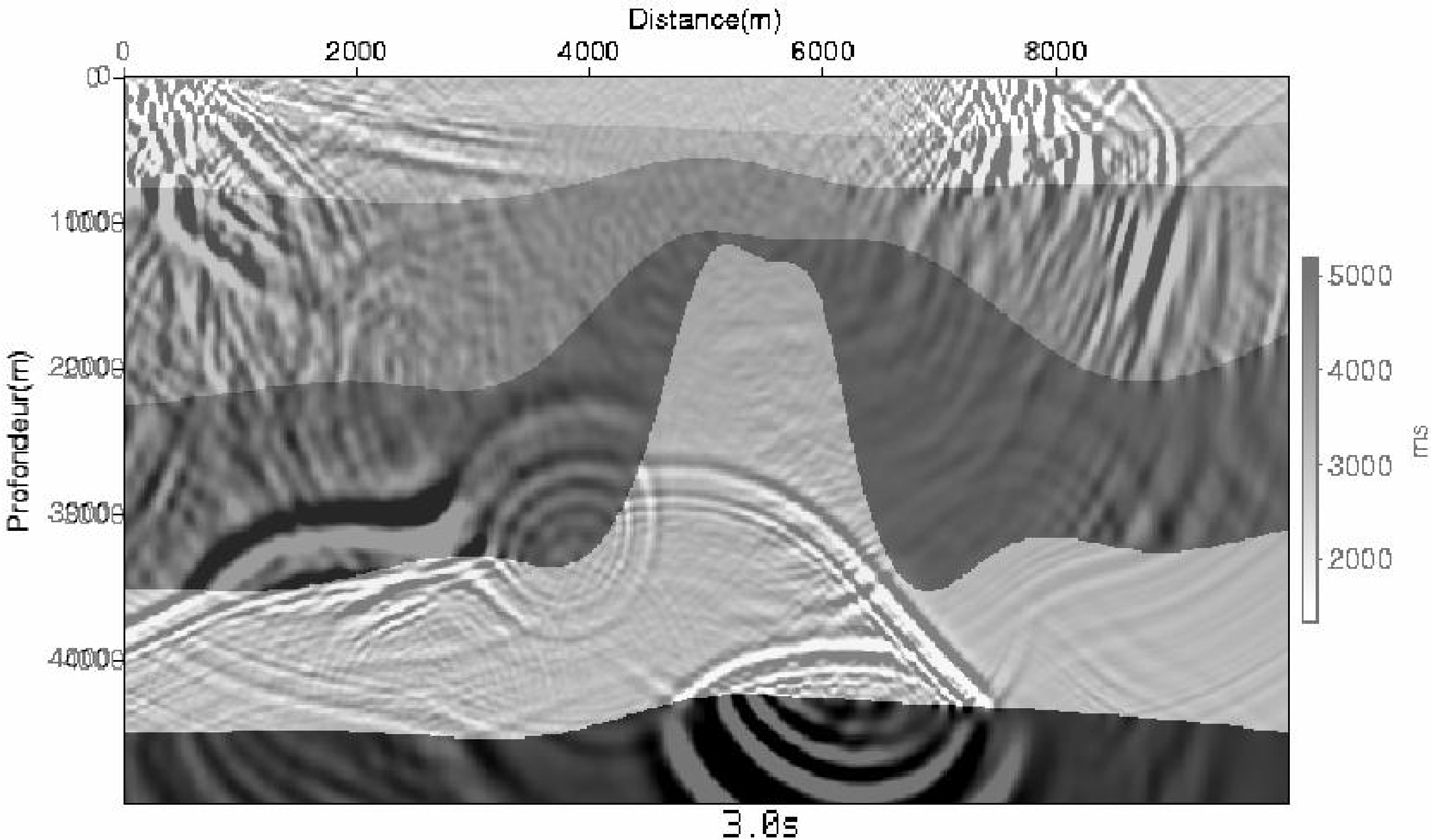
V. Example of waves propagations

Simulation de la propagation d'onde dans un modèle



V. **Example of waves propagations**

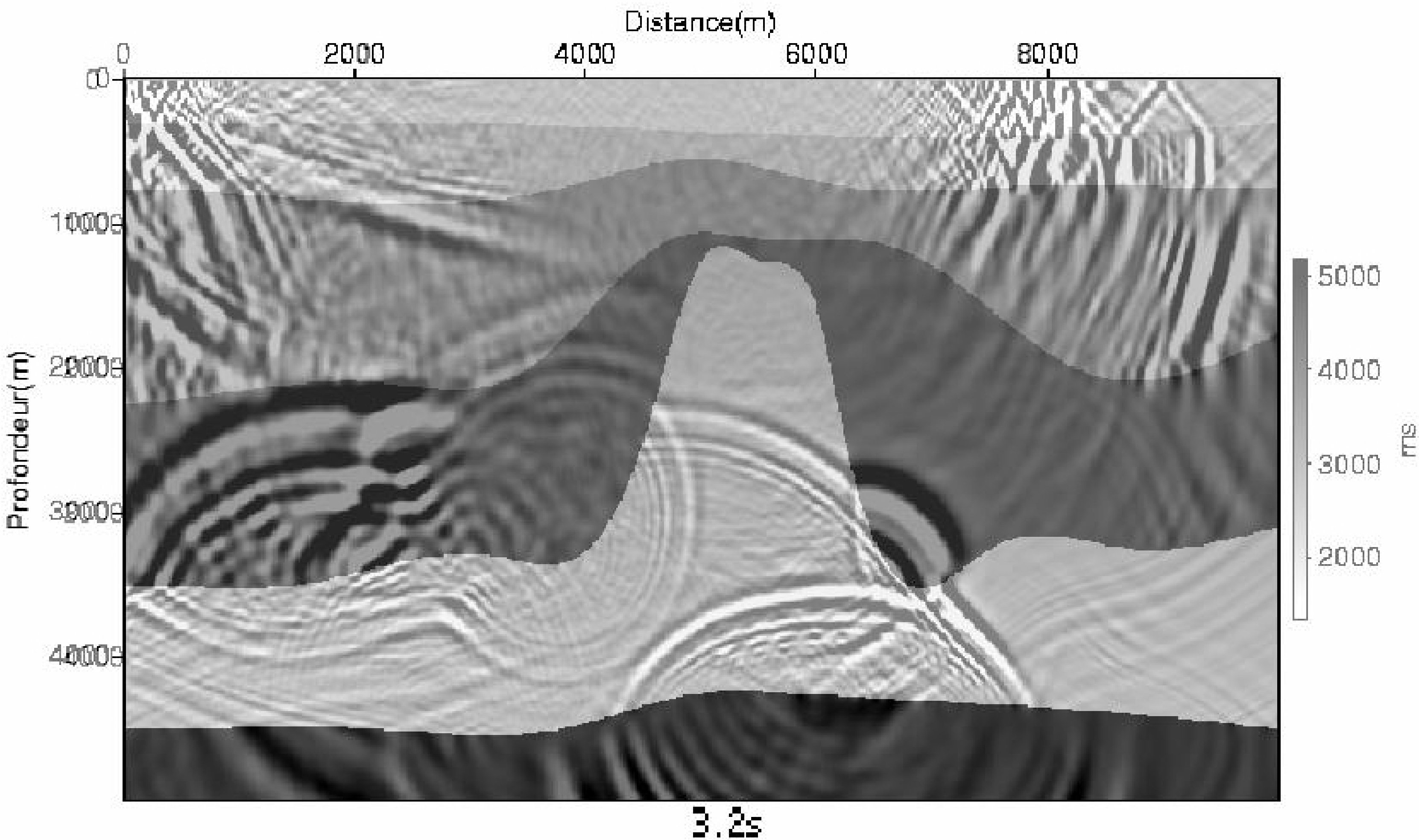
Simulation de la propagation d'onde dans un modèle



ENSPM

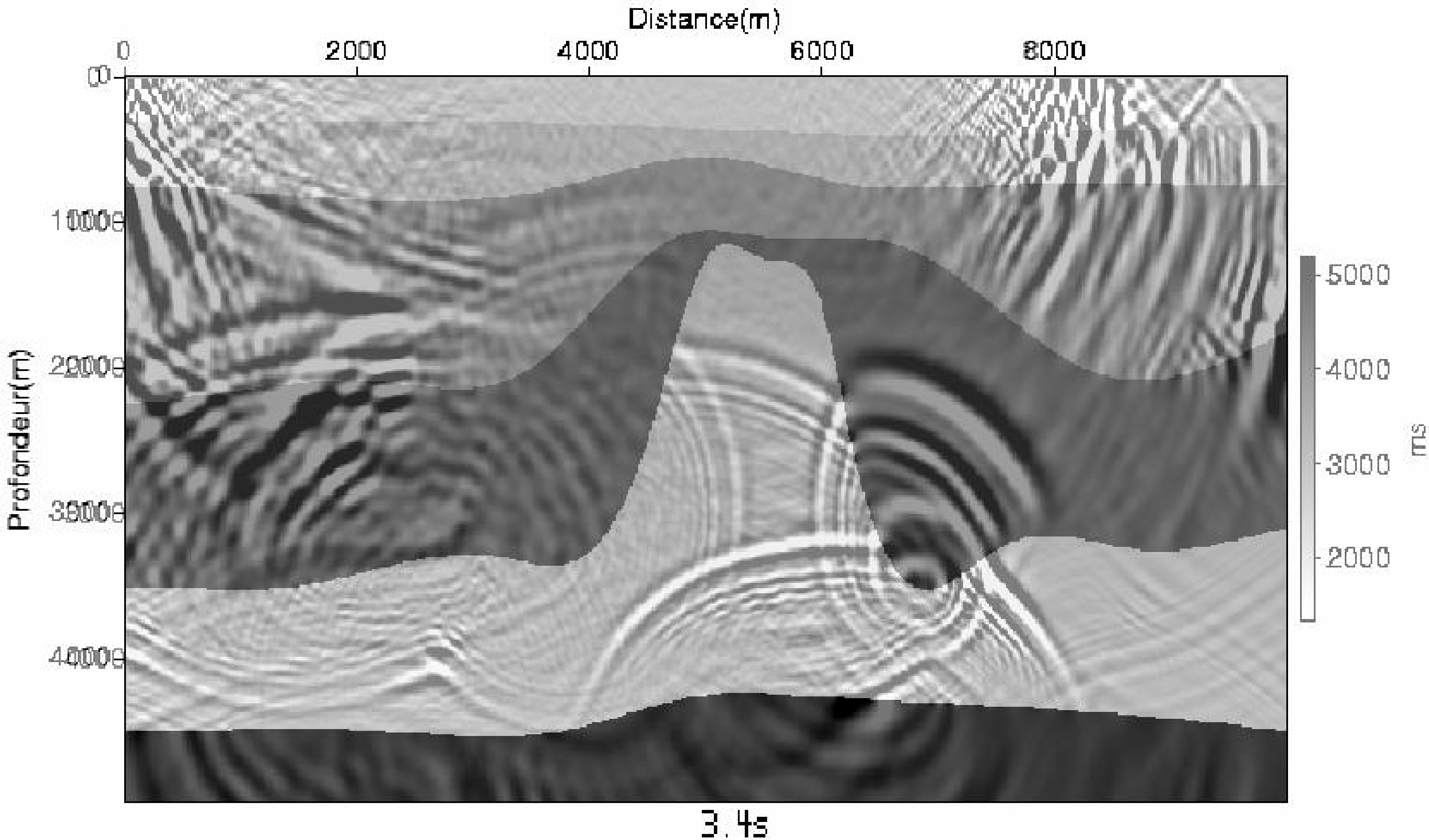
V. Example of waves propagations

Simulation de la propagation d'onde dans un modèle



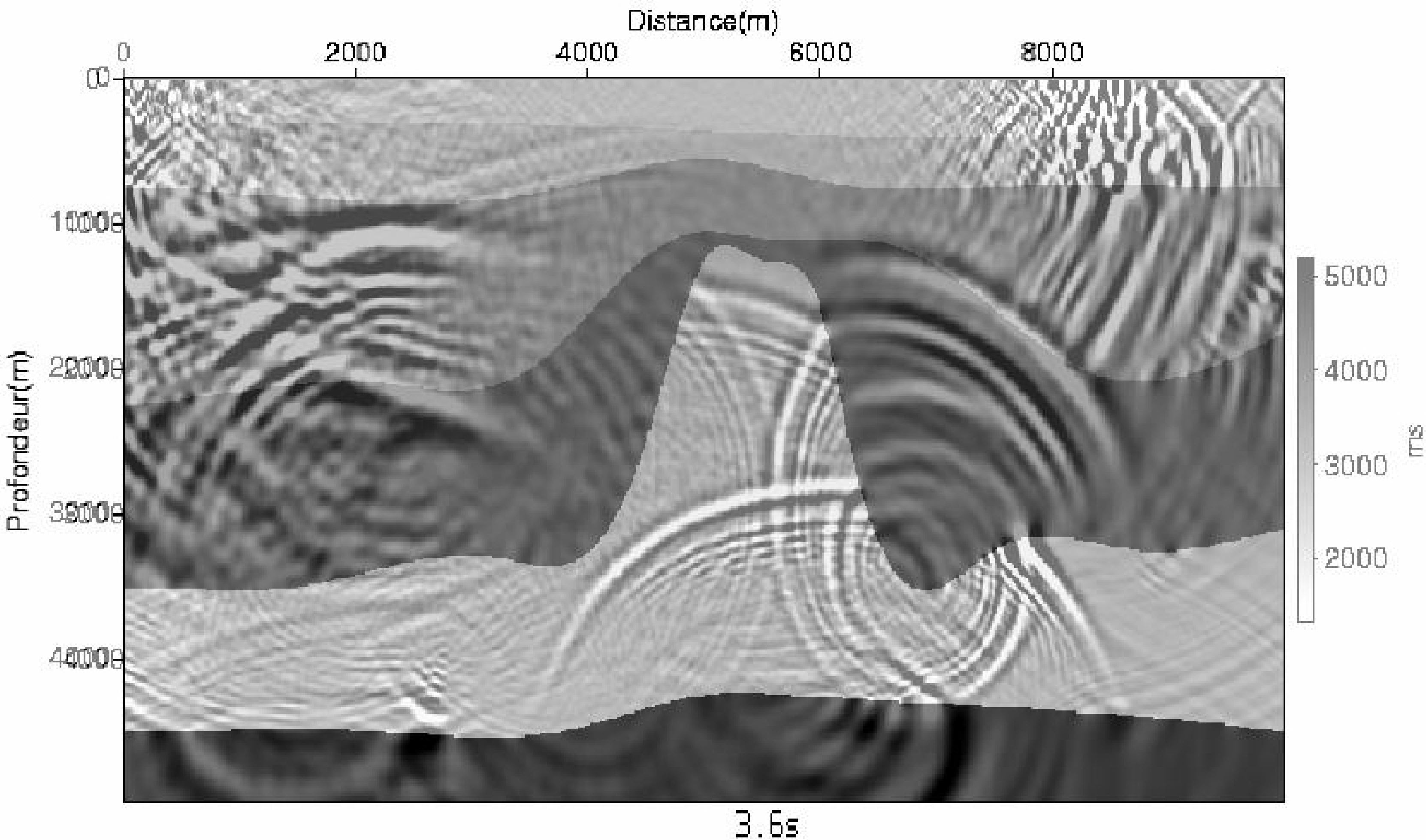
V. Example of waves propagations

Simulation de la propagation d'onde dans un modèle



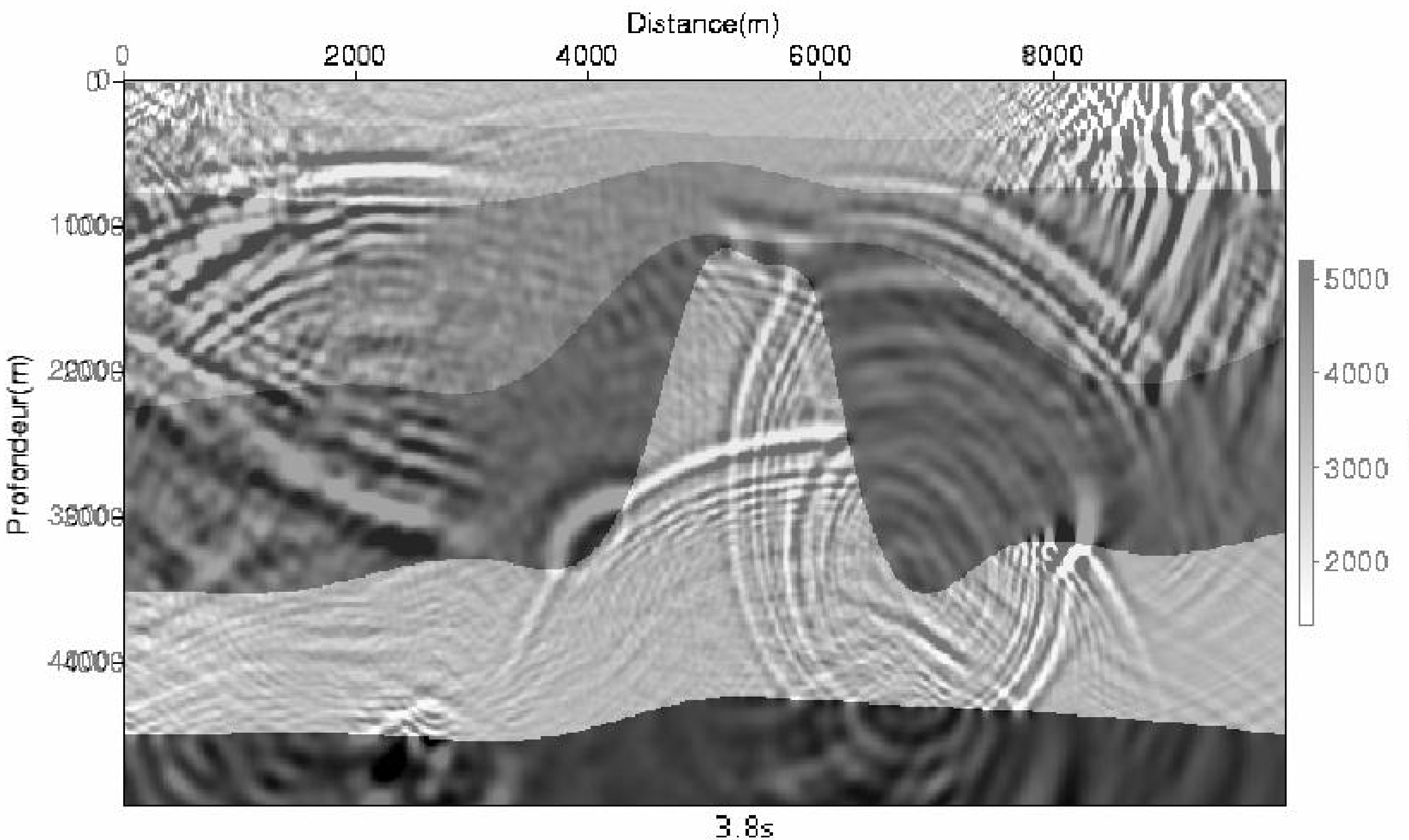
V. Example of waves propagations

Simulation de la propagation d'onde dans un modèle



V. Example of waves propagations

Simulation de la propagation d'onde dans un modèle



V. **Example of waves propagations**

Simulation de la propagation d'onde dans un modèle