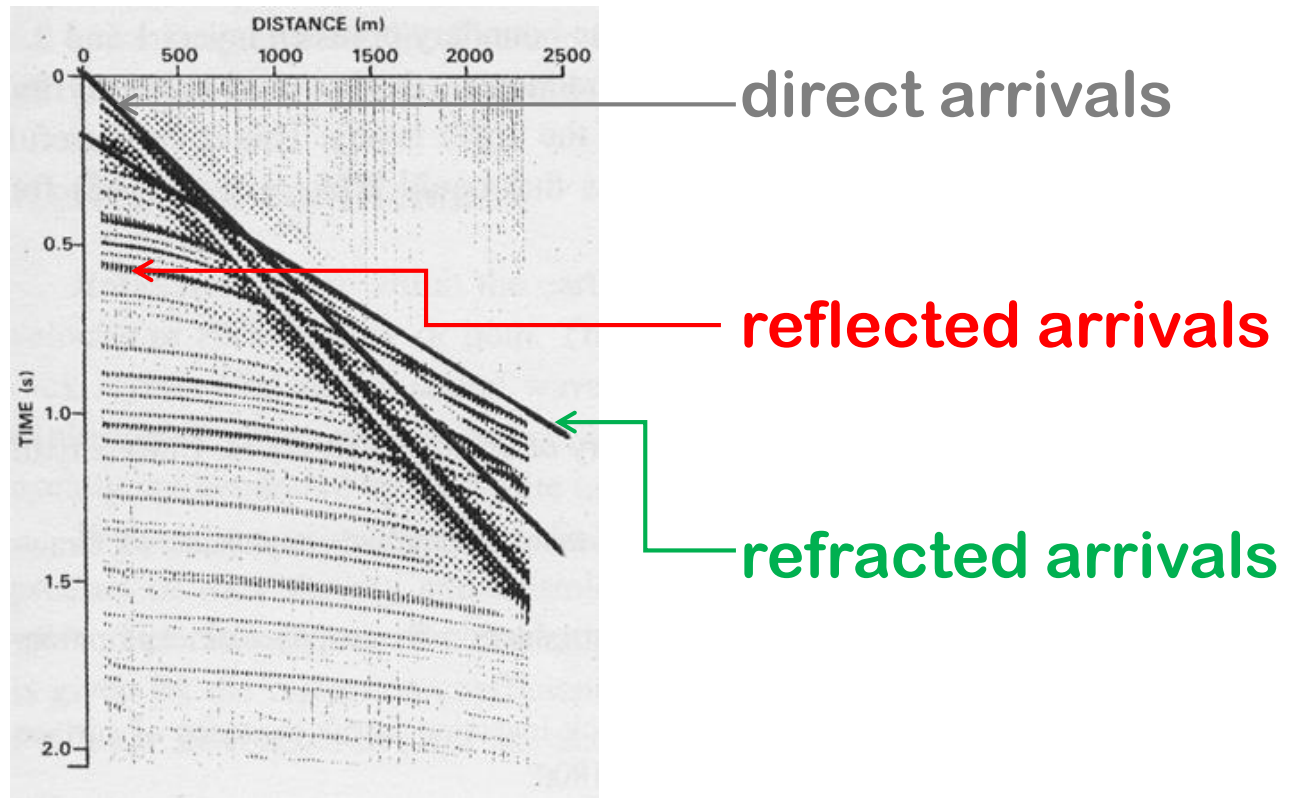
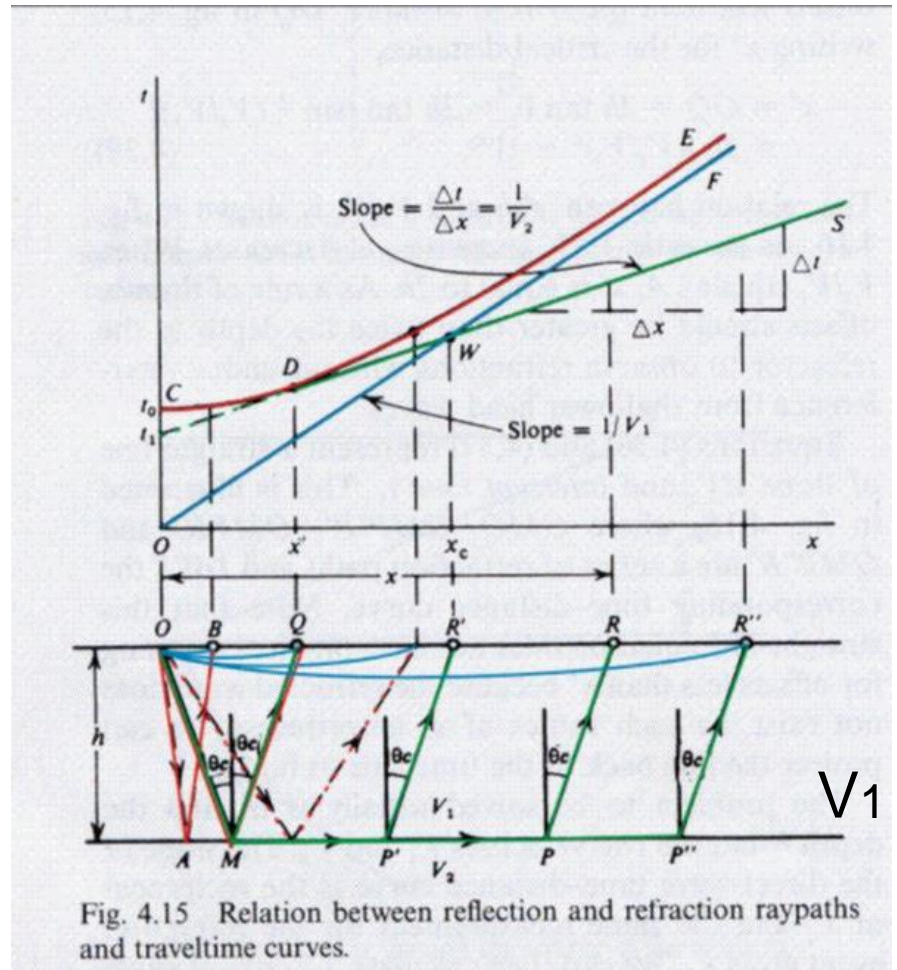
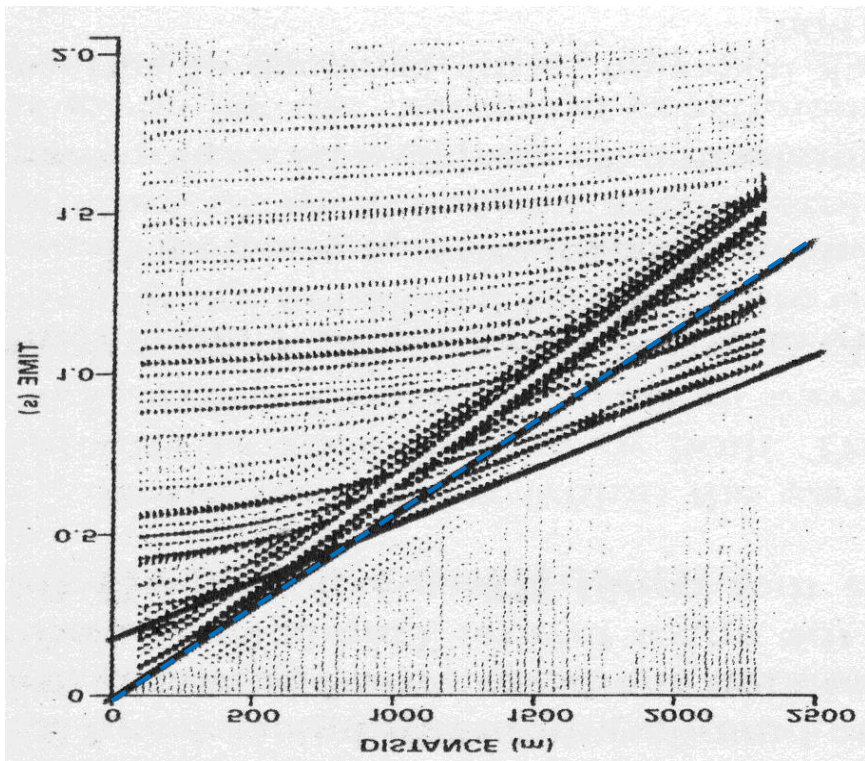


# Basic Geophysical Assumptions





Onda diretta  $T = \frac{x}{V_1}$

T = arrival time

x = source-receiver distance (offset)

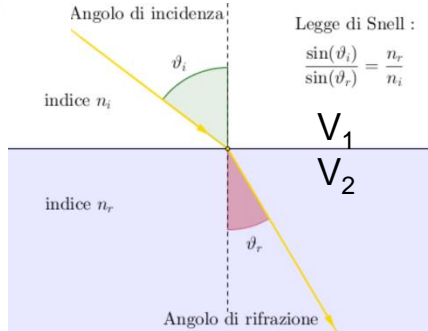
V<sub>1</sub> = velocity of P wave in the top layer

Onda rifratta

$$T = \frac{x}{v_2} + \frac{2h \cos i_c}{v_1}$$

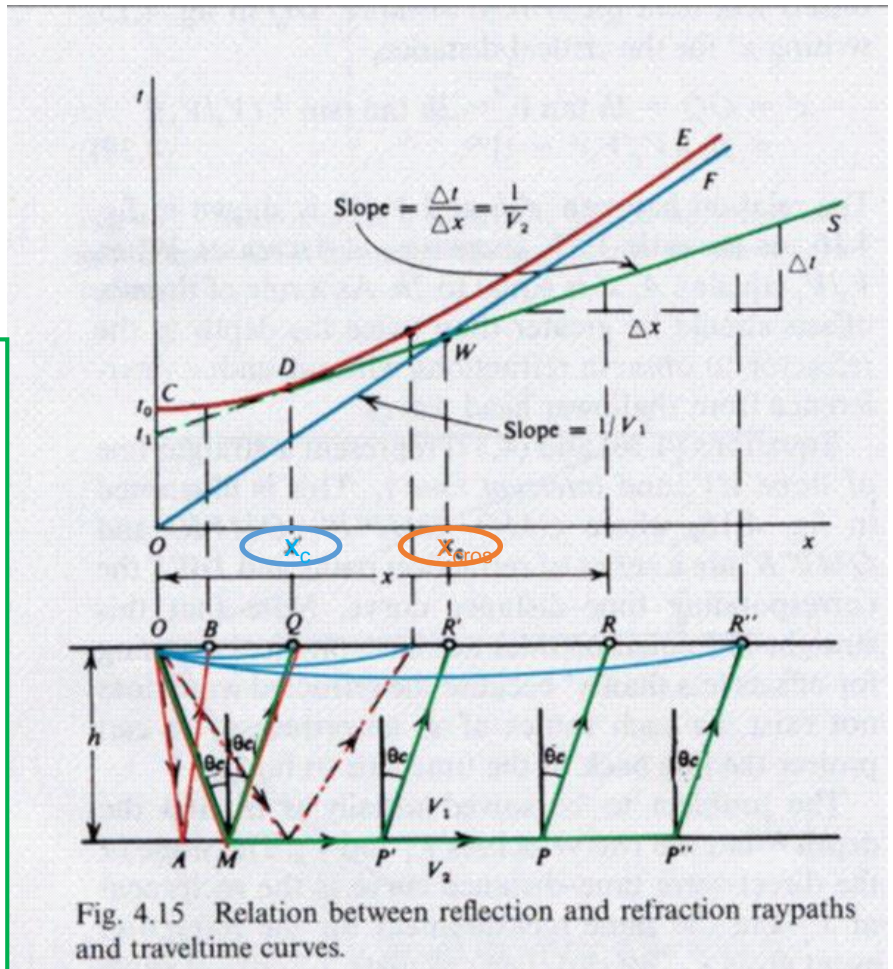
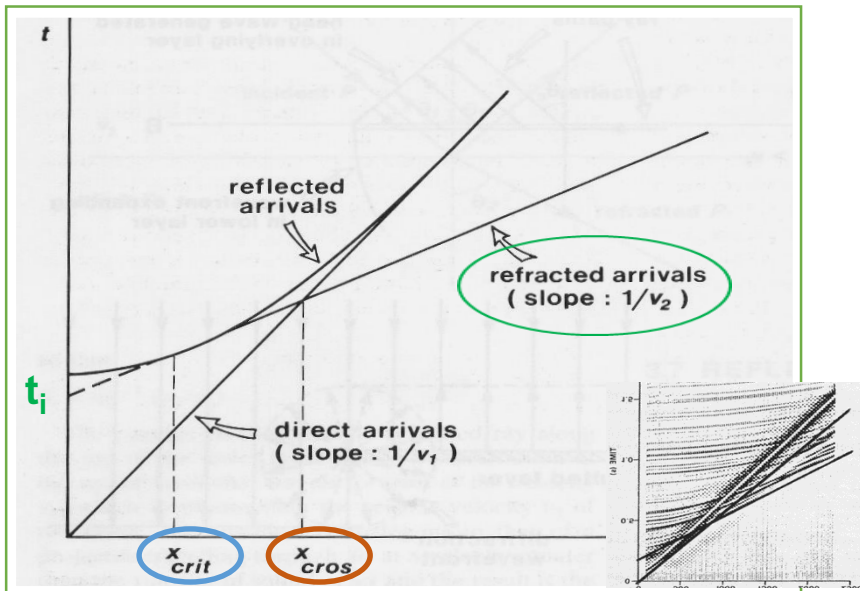
$$\frac{\sin \theta_1}{v_1} = \frac{\sin \theta_2}{v_2} = p.$$

Snell law



Seismic Refraction

$$\theta_2 = 90^\circ \rightarrow \theta_1 = \text{critical angle}$$



$t_i$  = intercept time

$x_c$  o  $x_{crit}$  = critical distance

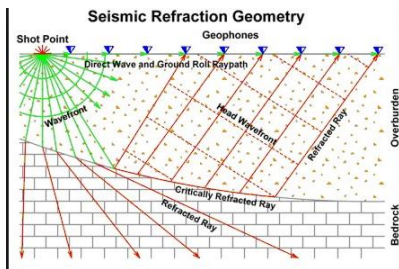
$x_{cros}$  = crossover distance

# Refracted waves

The refraction seismic uses the refracted waves originated by incident waves with incidence angle equal to the

critical angle  $i_c$

→ refraction angle is  $90^\circ$

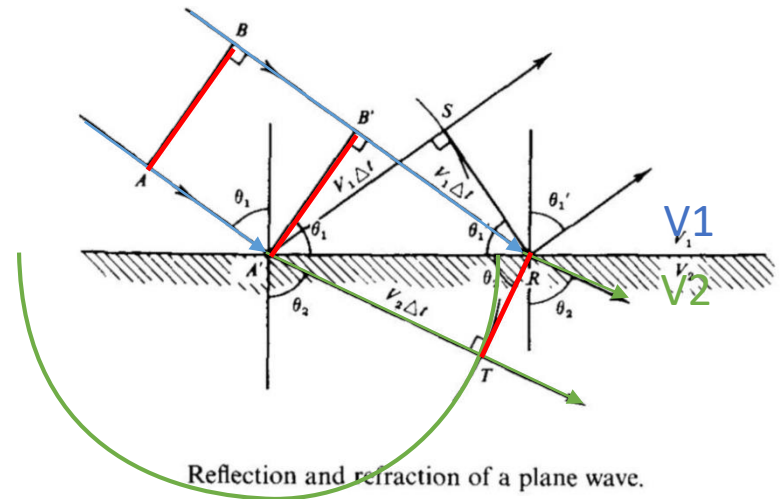


$$\frac{\sin \theta_1}{V_1} = \frac{\sin \theta_2}{V_2} = p.$$

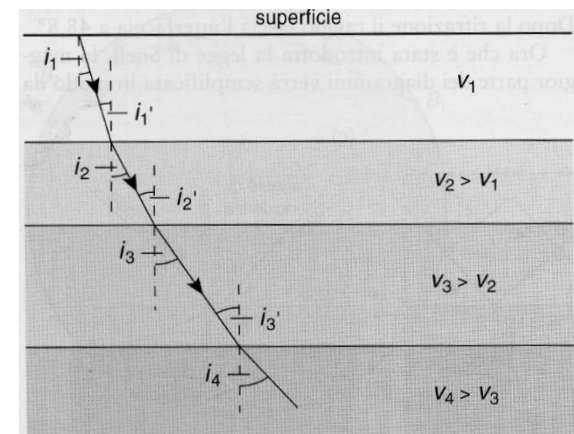
The P waves with an incidence angle smaller than the critical angle, represent the part of energy that will be transmitted (refracted) to the depth, and it will cross the geological discontinuities. This is the energy that could be reflected by the deeper discontinuities.

# Huygens principle

Each point of a wave front can be thought as a point source of waves with the same phase.



Reflection and refraction of a plane wave.



# Huygens Principle Effects

The interference figure (envelope) obtained from the spherical waves generated in point sources, constitutes the new front of the advancing wave.

Each spherical wave front is recorded, in terms of arrival time, as a hyperbola.

The several hyperbolas, generated from a series of aligned and spaced points, interfere negatively.

If the points are aligned and continuous, the hyperbolas add up and cancel each other out.

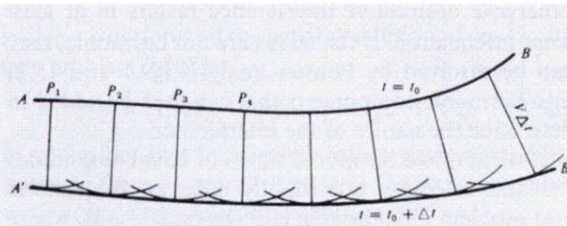


Fig. 2.8 Using Huygens' principle to locate new wavefronts.

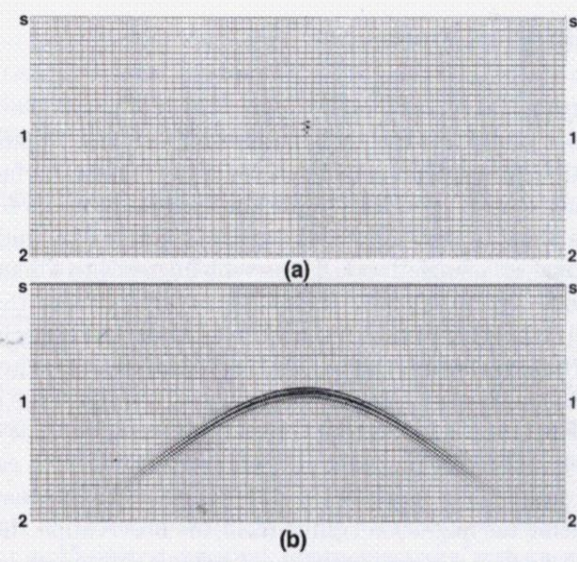


FIG. 4.1-11. A point that represents a Huygens' secondary source (a) produces a diffraction hyperbola on the zero-offset time section (b). The vertical axis in this section is two-way time

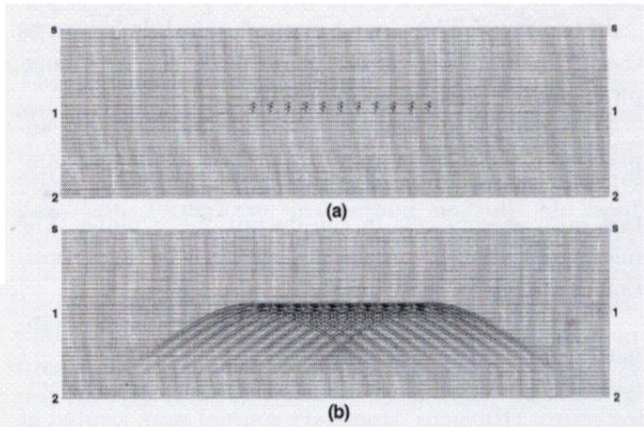


FIG. 4.1-12. Superposition of the zero-offset responses (b) of a discrete number of Huygens' secondary sources as in (a).

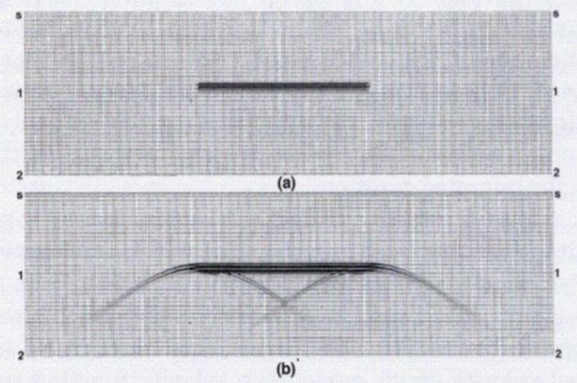


FIG. 4.1-13. Superposition of the zero-offset responses (b) of a continuum of Huygens' secondary sources as in (a).

The reflections can therefore have seen as a consequence of the Huygens Principle.

Onda riflessa 
$$T^2 = \left(\frac{x}{v_1}\right)^2 + \left(\frac{2h}{v_1}\right)^2$$

The reflected wave equation is represented by a hyperbole. It tends asymptotically to the direct wave line.

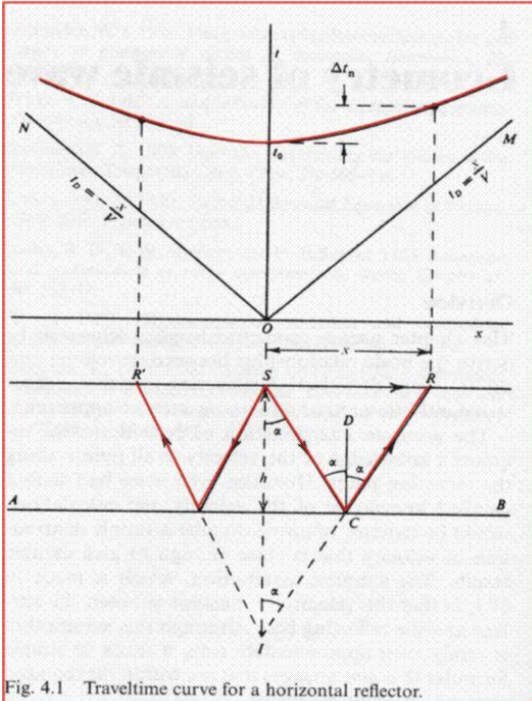
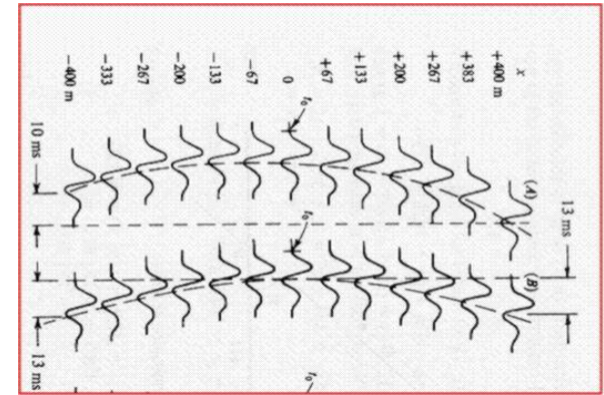
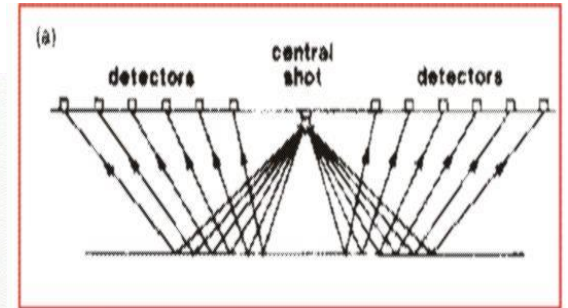
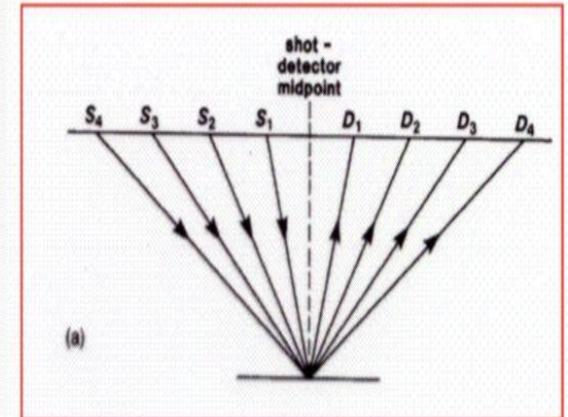


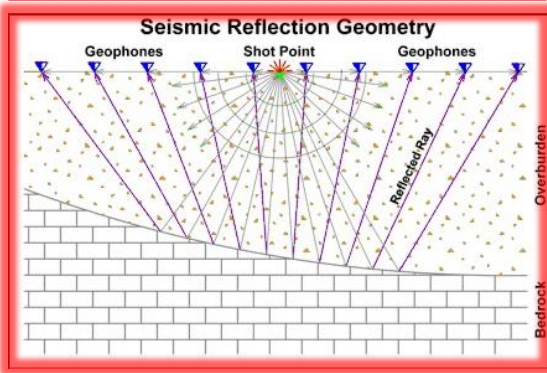
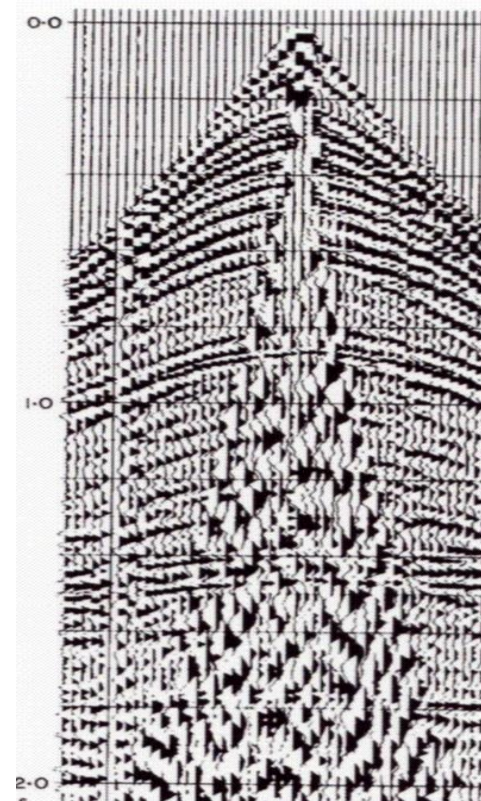
Fig. 4.1 Traveltime curve for a horizontal reflector.



Common Shot Gather

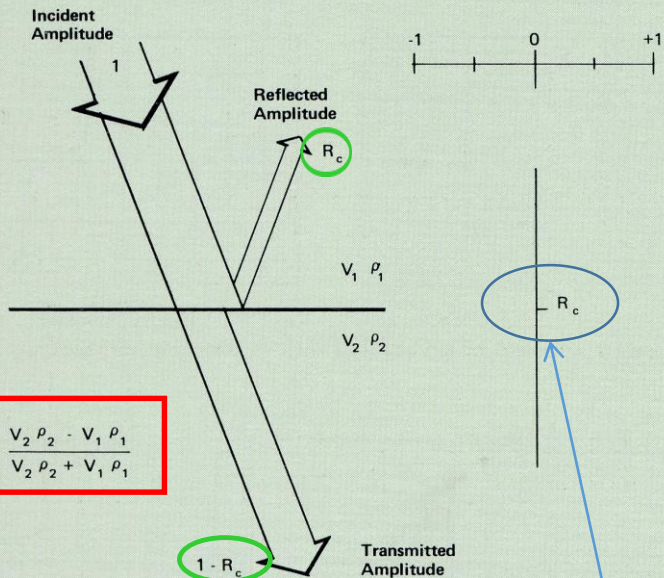


Common Midpoint Gather



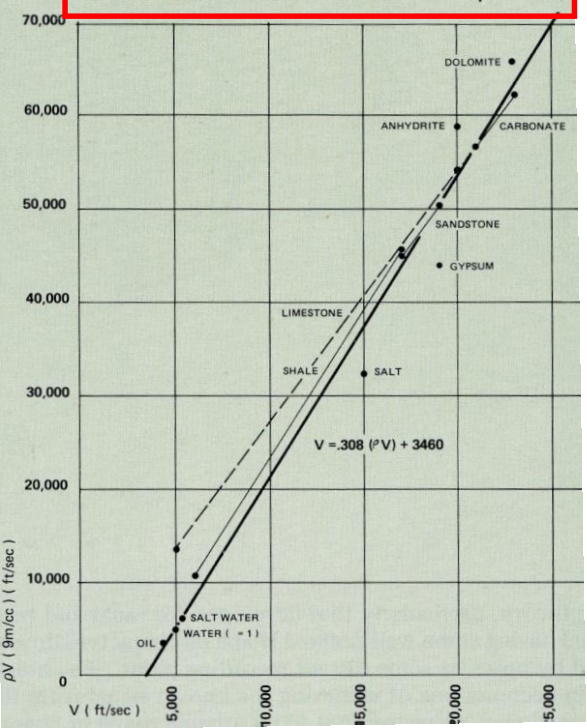
Reflection angle = incidence angle

## REFLECTION COEFFICIENT FORMULATION



$$R_c = \frac{V_2 \rho_2 - V_1 \rho_1}{V_2 \rho_2 + V_1 \rho_1}$$

## ACOUSTIC IMPEDENCE vs VELOCITY ( $\rho V$ vs $V$ )



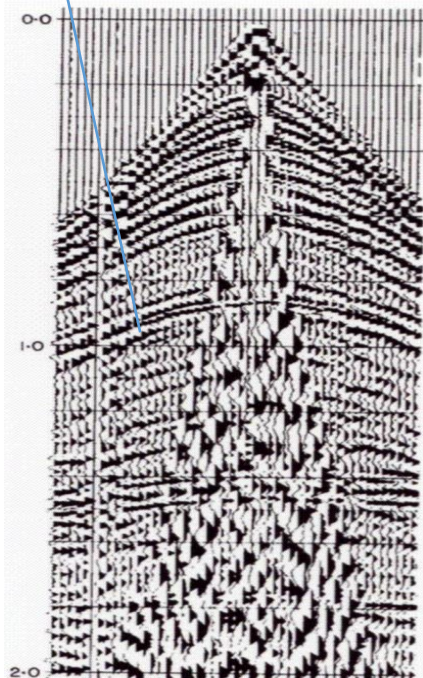
## Acoustic Impedance $\rho v$ Reflection Coefficient $R_c$

The sedimentary rocks are less dense ( $\sim 2.1 \pm 0.3 \text{ gr/cm}^3$ ) than other rocks. The density contrast between adjacent sedimentary rocks is rarely plus than  $0.25 \text{ g/cm}^3$

$$R_{c1} = \frac{V_2 - V_1}{V_2 + V_1} \quad \text{Basic approximation}$$

$$R_{c1} = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1} \quad \text{Better approximation}$$

$\rho = \text{Density}$

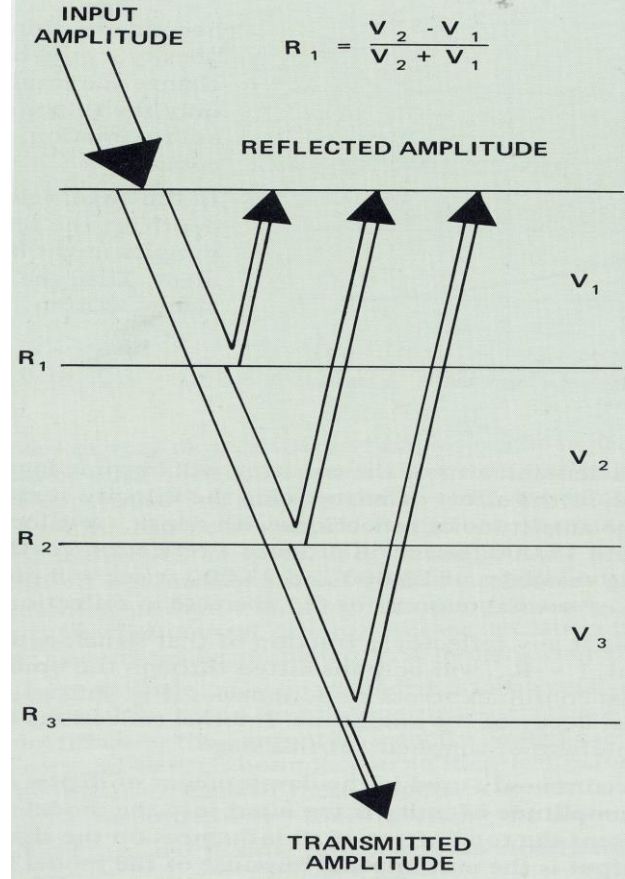


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## SEISMIC REFLECTION MODEL

### Simplified Formula

$$R_1 = \frac{V_2 - V_1}{V_2 + V_1}$$



## RELATION between DENSITY and VELOCITY

The linear function between acoustic impedance and velocity of the P waves (previous slide) tells about an approximately constant density.

This is not really true: generally, there is a relation between density and velocity values.

A more realistic relation was developed by Gardner, with an empiric formula (*where velocity =  $\alpha$* )

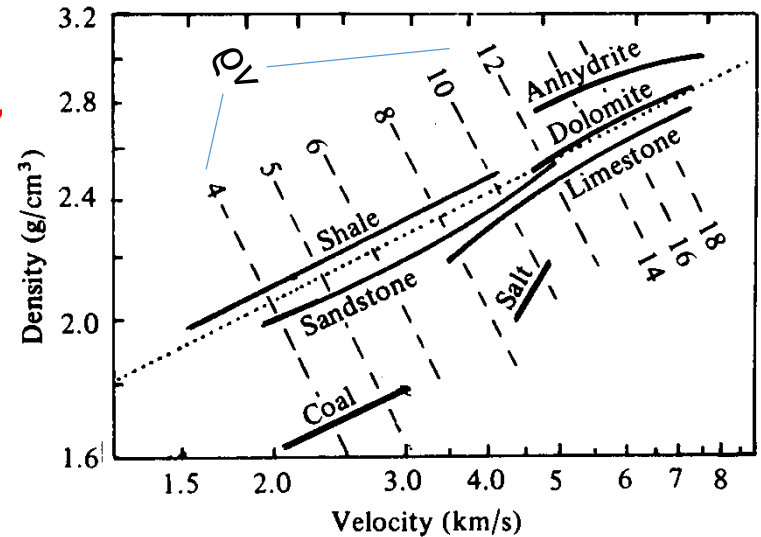
**Gardner's formula for density**, this relationship given by  $\rho = c\alpha^{0.25}$ , where  $c$  is a constant that depends on the rock type, is useful to estimate density from velocity when the former is unknown. With the exception of anhydrites, most rock types — sandstones, shales, and carbonates, tend to obey Gardner's equation for density.

$c$  depends by the rocks type and by the unit of measure of  $v$ .

Often, we can use the values:

-  $c = 0.23 \rightarrow$  if  $V_p$  is in m/sec

-  $c = 0.31 \rightarrow$  if  $V_p$  is in feet/sec





# Some values of

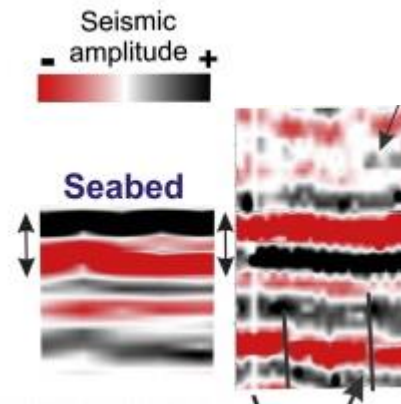
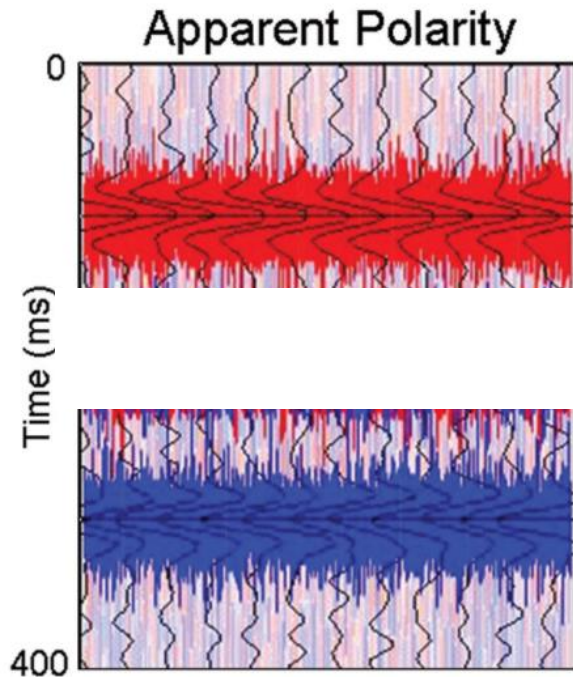
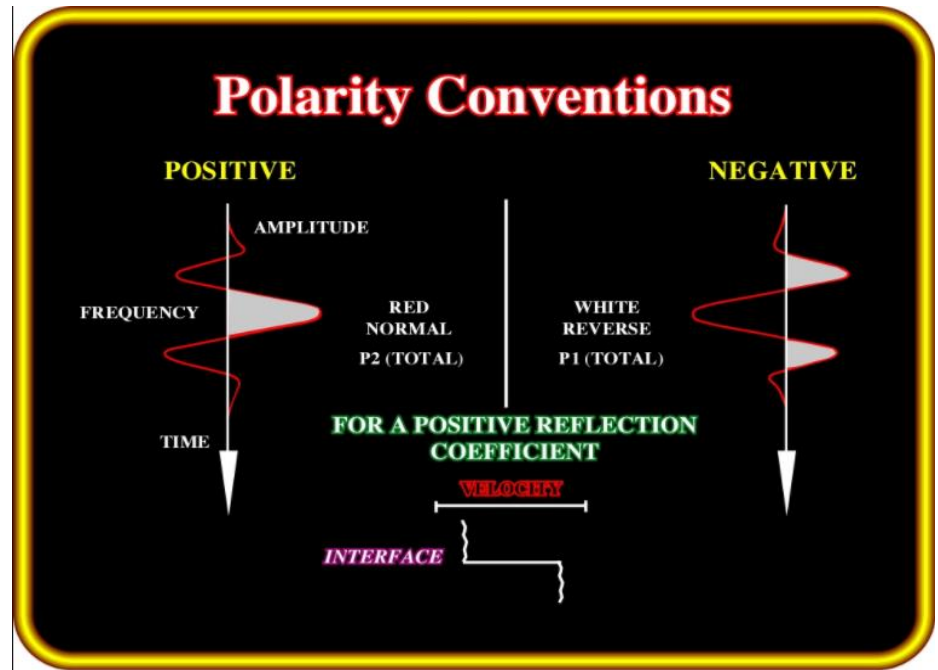
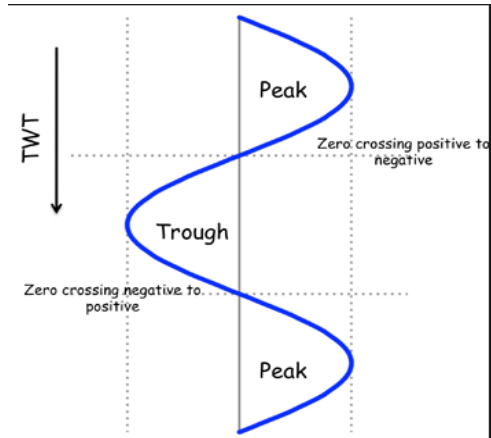
velocity  $v_p$     density  $\rho$     reflection coefficients  $R_c$   
in standard lithological conditions

Table 3.1 *Energy reflected at interface between two media*

Interface	First medium		Second medium		$Z_1/Z_2$	$R$	$E_R$
	Velocity	Density	Velocity	Density			
Sandstone on limestone	2.0	2.4	3.0	2.4	0.67	0.2	0.040
Limestone on sandstone	3.0	2.4	2.0	2.4	1.5	-0.2	0.040
Shallow interface	2.1	2.4	2.3	2.4	0.93	0.045	0.0021
Deep interface	4.3	2.4	4.5	2.4	0.97	0.022	0.0005
"Soft" ocean bottom	1.5	1.0	1.5	2.0	0.50	0.33	0.11
"Hard" ocean bottom	1.5	1.0	3.0	2.5	0.20	0.67	0.44
Surface of ocean (from below)	1.5	1.0	0.36	0.0012	3800	-0.9994	0.9988
Base of weathering	0.5	1.5	2.0	2.0	0.19	0.68	0.47
Shale over water sand	2.4	2.3	2.5	2.3	0.96	0.02	0.0004
Shale over gas sand	2.4	2.3	2.2	1.8	1.39	-0.16	0.027
Gas sand over water sand	2.2	1.8	2.5	2.3	0.69	0.18	0.034

All velocities in km/s, densities in  $g/cm^3$ ; the minus signs indicate  $180^\circ$  phase reversal.

# What does **negative reflection coefficient $R_c$** mean?



Type of formation	P wave velocity (m/s)	S wave velocity (m/s)	Density (g/cm <sup>3</sup> )	Density of constituent crystal (g/cm <sup>3</sup> )
Scree, vegetal soil	300-700	100-300	1.7-2.4	-
Dry sands	400-1200	100-500	1.5-1.7	2.65 quartz
Wet sands	1500-2000	400-600	1.9-2.1	2.65 quartz
Saturated shales and clays	1100-2500	200-800	2.0-2.4	-
Marls	2000-3000	750-1500	2.1-2.6	-
Saturated shale and sand sections	1500-2200	500-750	2.1-2.4	-
Porous and saturated sandstones	2000-3500	800-1800	2.1-2.4	2.65 quartz
Limestones	3500-6000	2000-3300	2.4-2.7	2.71 calcite
Chalk	2300-2600	1100-1300	1.8-3.1	2.71 calcite
Salt	4500-5500	2500-3100	2.1-2.3	2.1 halite
Anhydrite	4000-5500	2200-3100	2.9-3.0	-
Dolomite	3500-6500	1900-3600	2.5-2.9	(Ca, Mg) CO <sub>3</sub> 2.8-2.9
Granite	4500-6000	2500-3300	2.5-2.7	-
Basalt	5000-6000	2800-3400	2.7-3.1	-
Gneiss	4400-5200	2700-3200	2.5-2.7	-
Coal	2200-2700	1000-1400	1.3-1.8	-
Water	1450-1500	-	1.0	-
Ice	3400-3800	1700-1900	0.9	-
Oil	1200-1250	-	0.6-0.9	-

Typical rock velocities, from Bourbie, Coussy, and Zinszner, Acoustics of Porous Media, Gulf Publishing

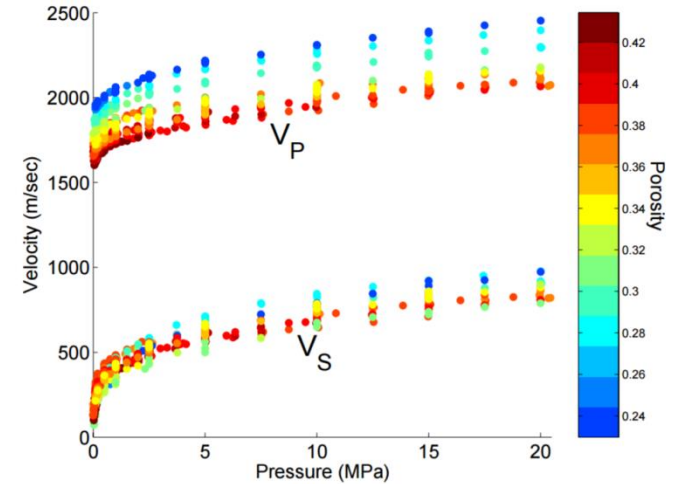


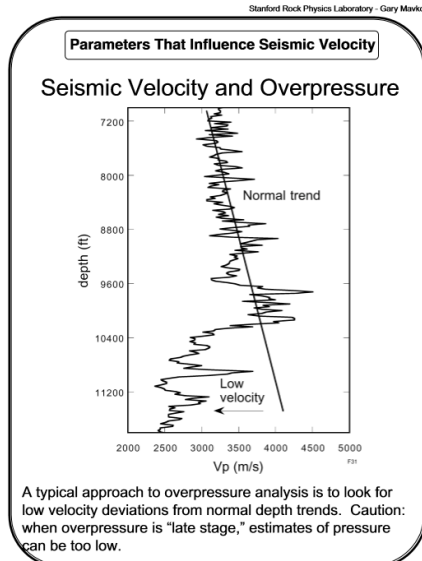
Figure 4.4: Gassmann fluid-substituted velocity data plotted against pressure, color-coded by porosity. The systematic porosity dependence of the compressional-wave velocities is easily visible.

Zimmer, 2004

## The $V_P$ velocity of a rock depends on:

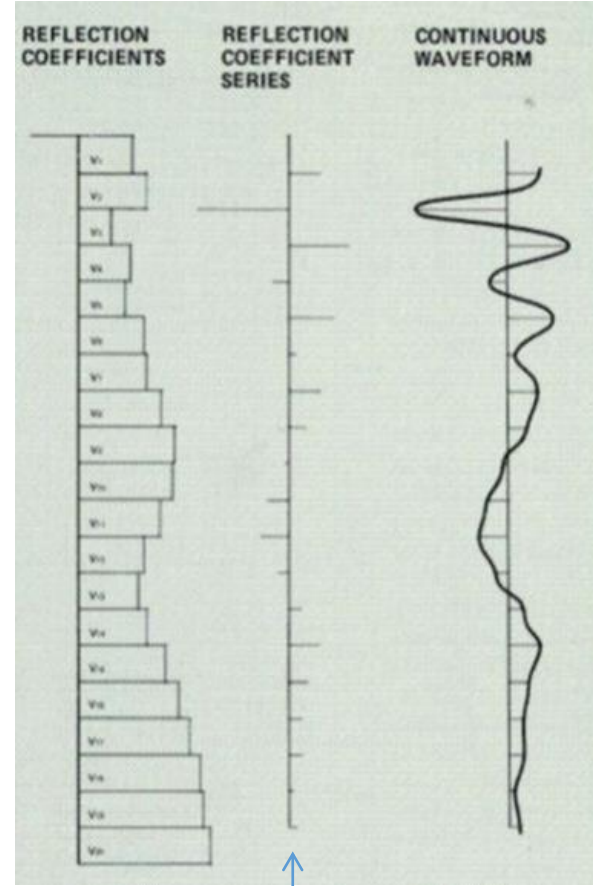
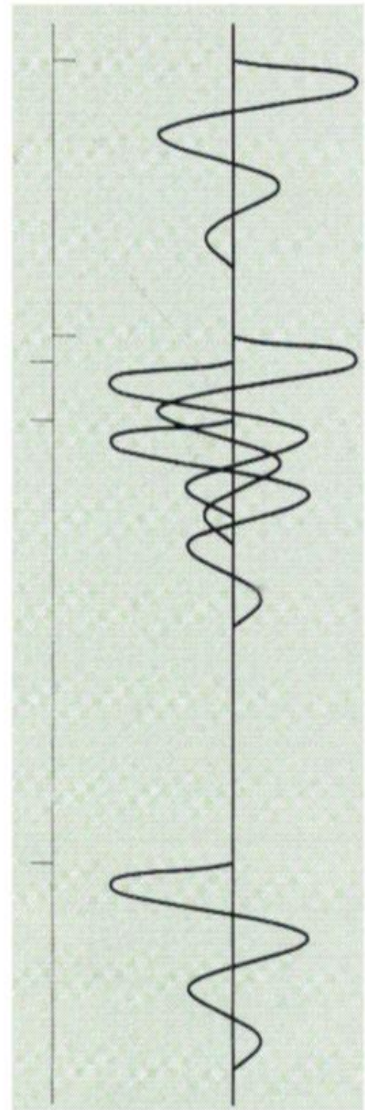
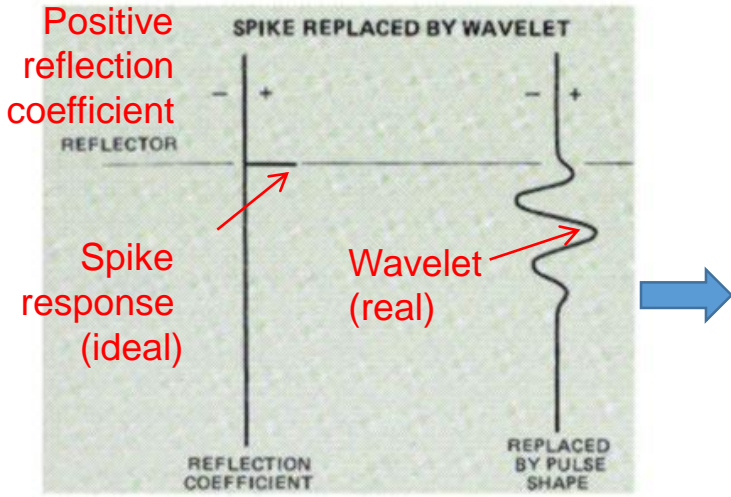
- type of rock: important, in particular, for fine sediments/clay, specially for low pressure (reduced depth)
  - porosity (decreases with the depth)
  - fluids saturation
  - lithostatic pressure
  - pore pressure (it often acts in opposite direction to lithostatic pressure)
  - microfractures presence (...both -P & S-seismic wave velocities decrease with increasing crack density. By O'Connell and Budiansky, 1974)
- } **Effective pressure**

High pore pressure for long time can inhibit the diagenetic processes and maintain the porosity: this allows to maintain low velocity  $V_p$

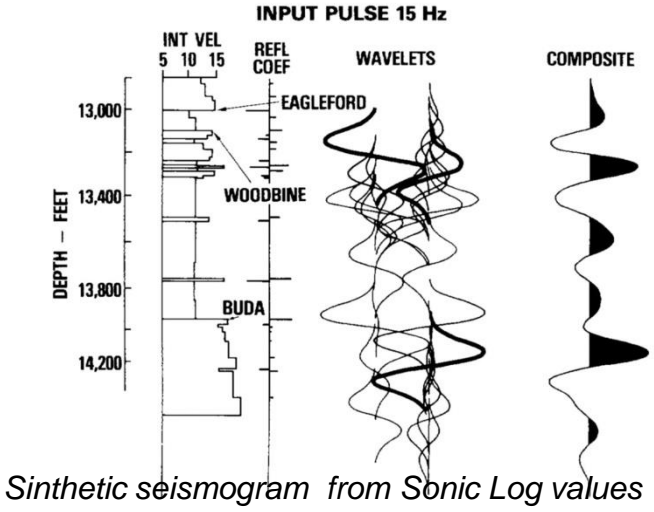


The simplest reflection model considers two superimposed omogeneous strata characterized by different elastic properties (->  $V_p$  and  $\rho$ )

# What is a Seismogram?



Note the decreasing reflection coefficients with the increasing depth .....



Synthetic seismogram from Sonic Log values

FIG. 14—Synthetic seismogram, Shell 1 Southland Paper Mills, Polk County, Texas. Interval velocity in thousands of feet per second.

# Sea profile (offshore)

997.0.30	AGIP	PROIEZIONE CARTOGRAFICA	FOGLIO NUMERO
OFFSHORE ITALIA ZONA F	SECT. PROCESSING P5	1. AREA: 4800 S. 2. MET. LINEA: 1000 M. 3. MET. LINEA: 1000 M. 4. MET. LINEA: 1000 M. 5. MET. LINEA: 1000 M. 6. MET. LINEA: 1000 M.	Stop: 10/07/1995 Data: 10/07/1995 Time: 10:00 Scale: 1:1000 Author: [illegible] Date: 10/07/1995
S/N 2218	LINEA F.75.87	3792	

