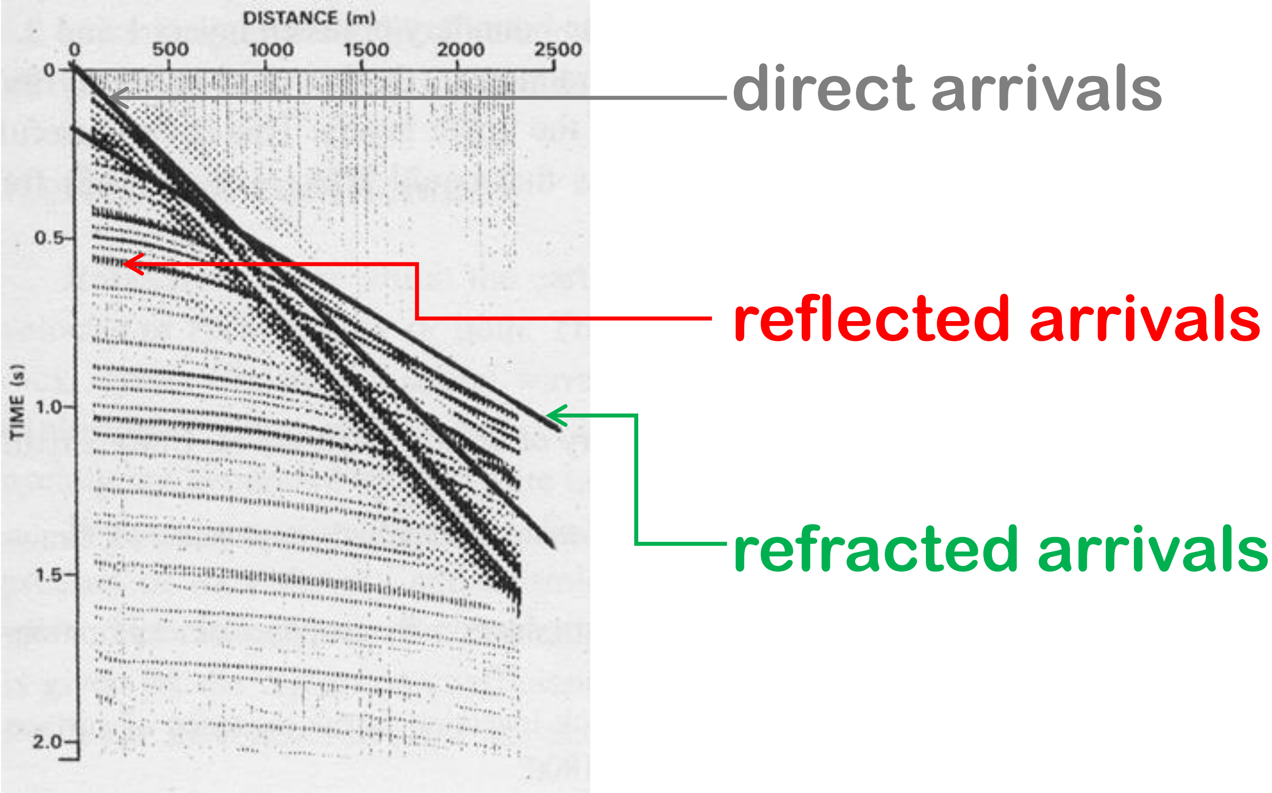
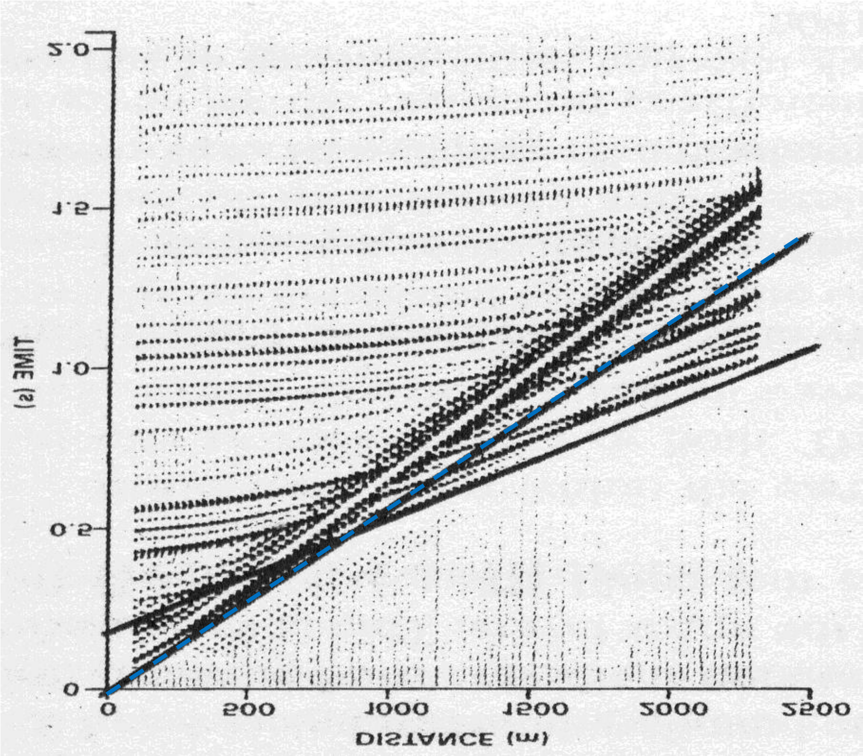
Basic Geophysical Assumptioni



direct arrivals

reflected arrivals

refracted arrivals



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

T = arrival time

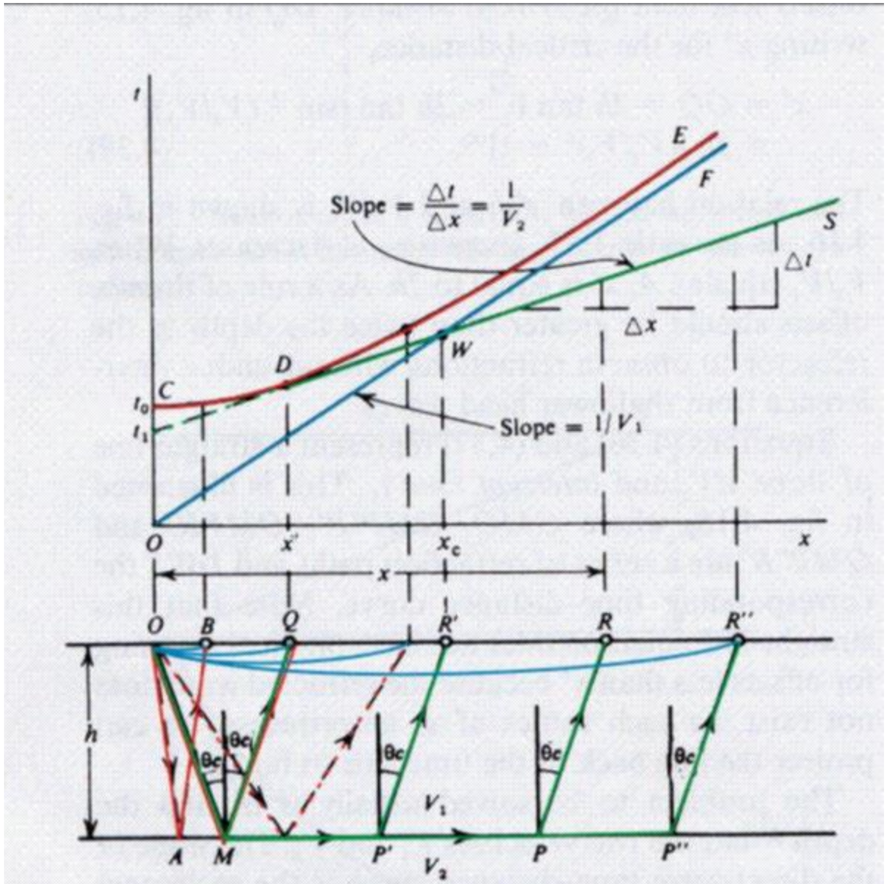


Fig. 4.15 Relation between reflection and refraction raypaths and traveltime curves.

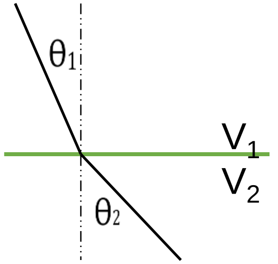
x = source-receiver distance ***(offset)***

V_1 = velocity of P wave in the top layer

Onda rifratta $T = \frac{x}{V_2} + \frac{2h \cos i_c}{V_1}$

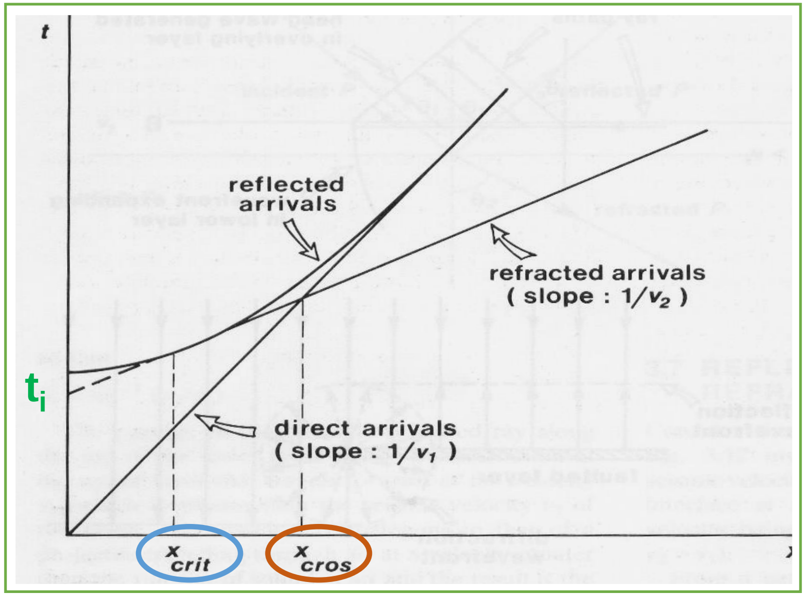
Snell law

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



Seismic Refraction

$\theta_2 = 90°$ → θ_1 = critical angle



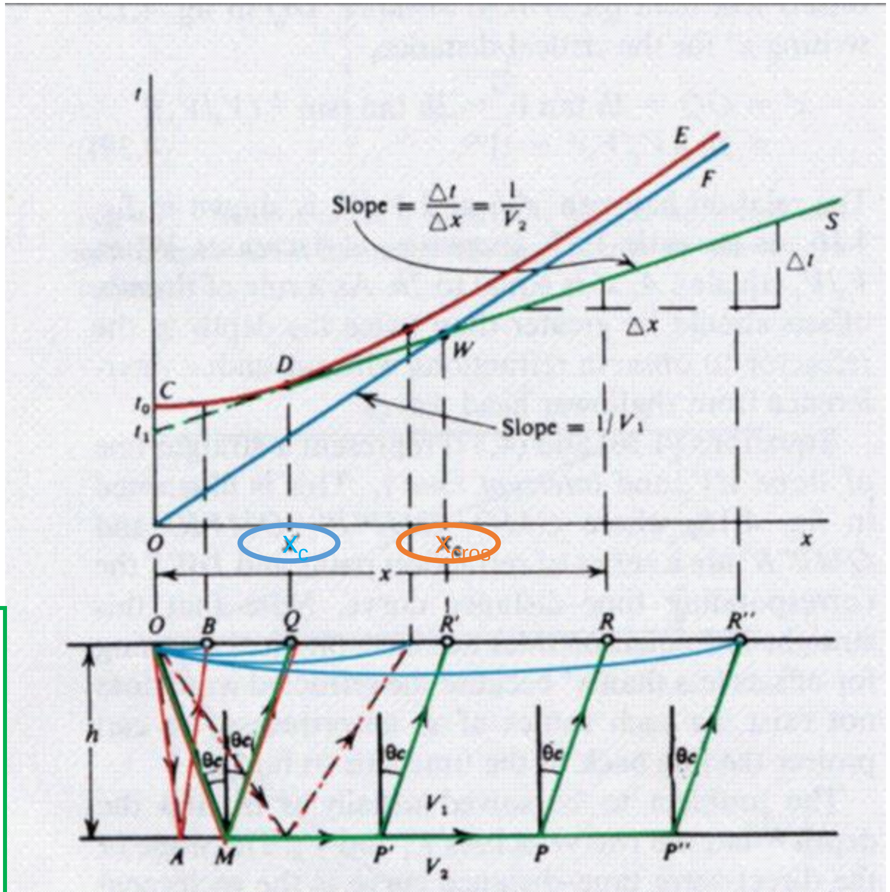


Fig. 4.15 Relation between reflection and refraction raypaths and traveltime curves.

t_i = intercept time

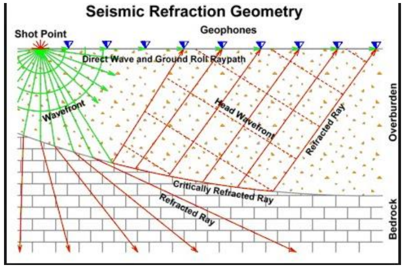
x_c o x_{crit} = critical distance

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°

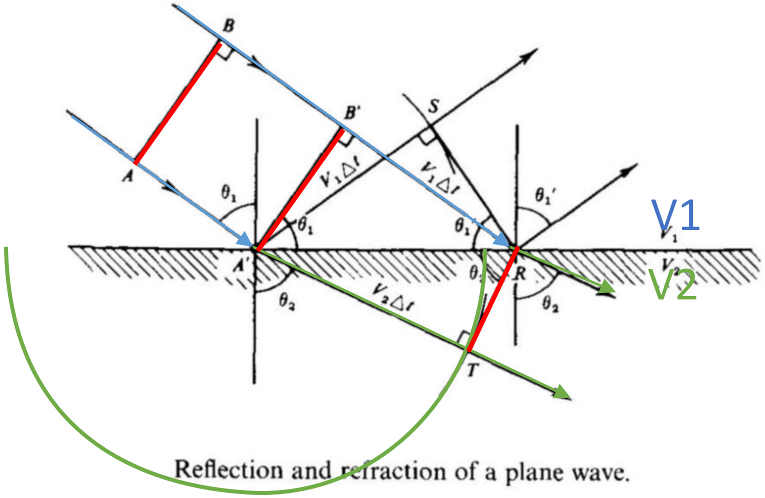


$$\frac{\sin \theta_1}{V_1} = \frac{\sin \theta_2}{V_2} = p.$$

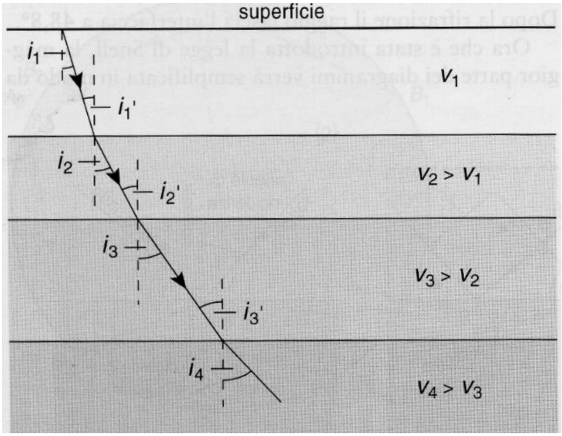
The P waves with an incidence angle smaller than the critical angle, represent the part of energy that will be transmitted (refracted) to the depth, and it will cross the geological discontinuities. This is the energy that could be reflected by the deeper discontinuities.

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.

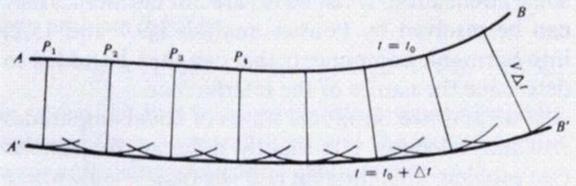


Fig. 2.8 Using Huygens' principle to locate new wavefronts.

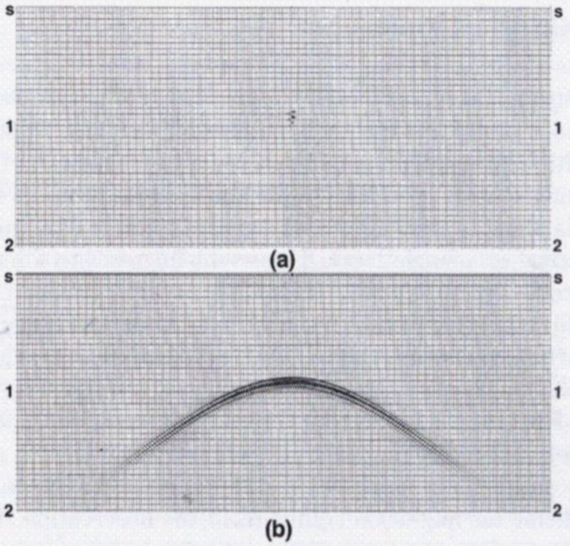


FIG. 4.1-11. A point that represents a Huygens' secondary source (a) produces a diffraction hyperbola on the zero-offset time section (b). The vertical axis in this section is two-way time

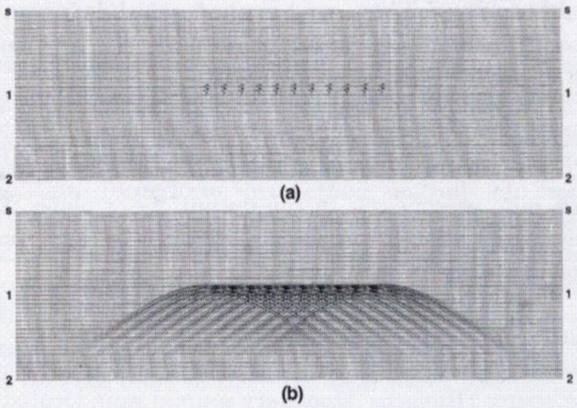


FIG. 4.1-12. Superposition of the zero-offset responses (b) of a discrete number of Huygens' secondary sources as in (a).

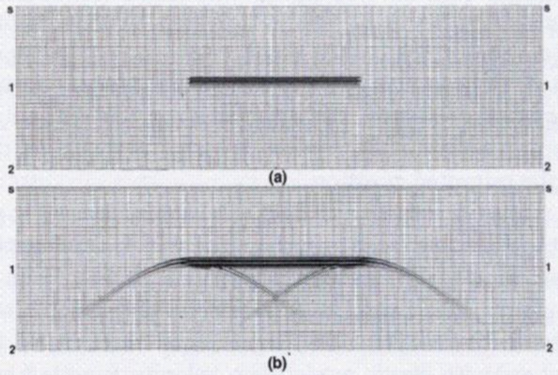


FIG. 4.1-13. Superposition of the zero-offset responses (b) of a continuum of Huygens' secondary sources as in (a).

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

Onda riflessa $T^2 = \left(\frac{x}{V_1}\right)^2 + \left(\frac{2h}{V_1}\right)^2$

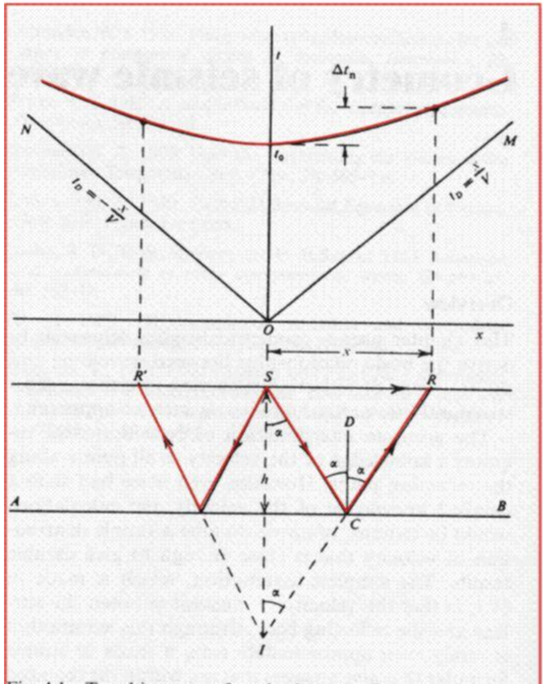
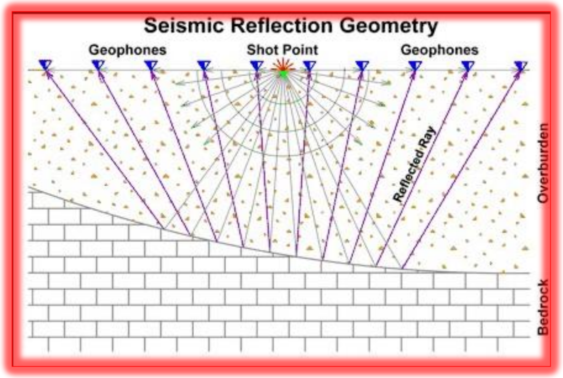
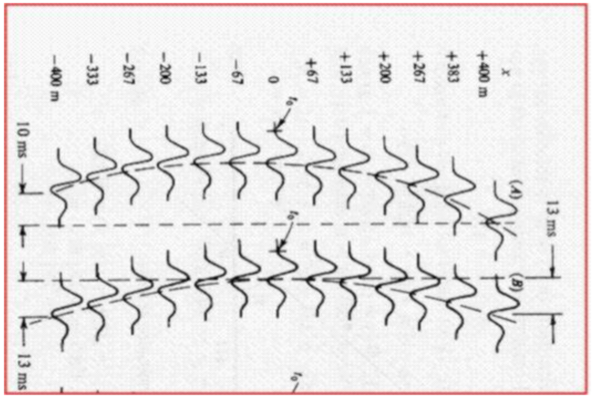


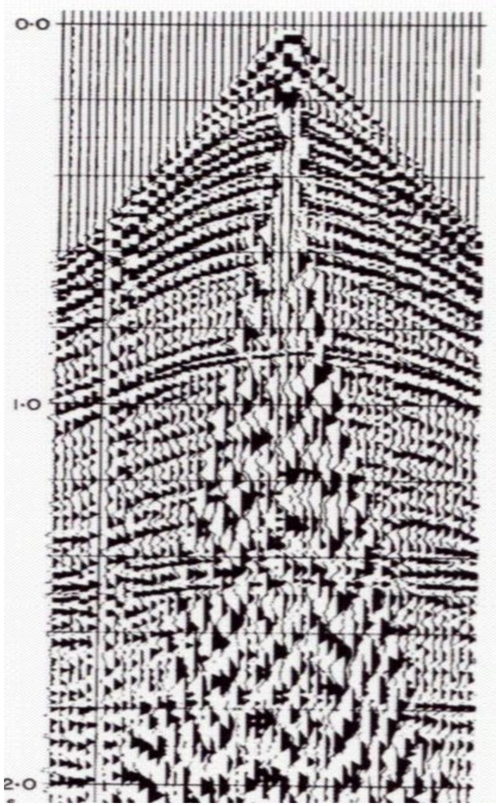
Fig. 4.1 Traveltime curve for a horizontal reflector.

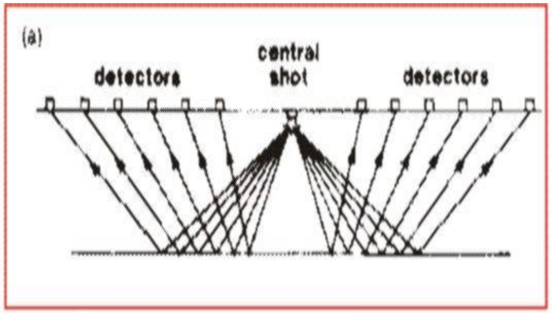


Reflection angle = incidence angle

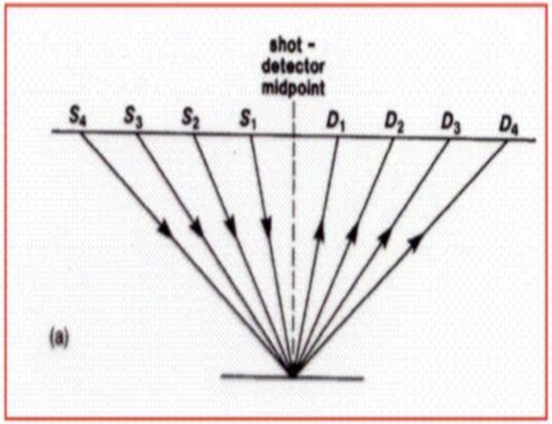
The reflected wave equation is represented by a hyperbole. It tends asymptotically to the direct wave line.





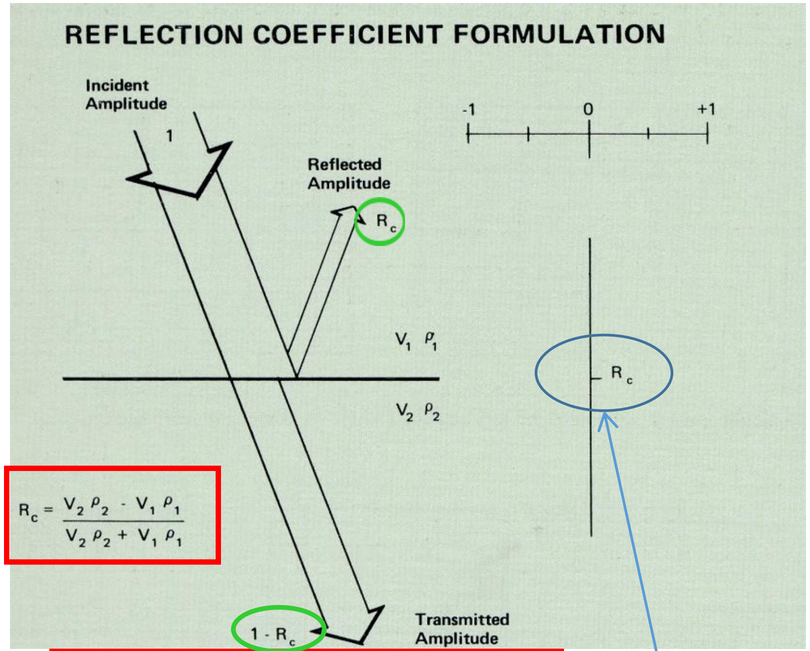


Common Shot Gather



Common Midpoint Gather

Acoustic Impedance ρv
Reflection Coefficient Rc

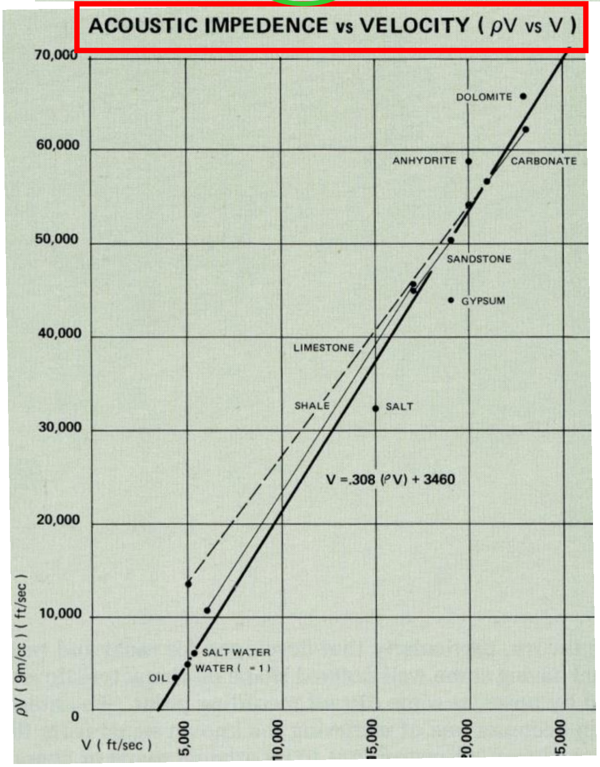


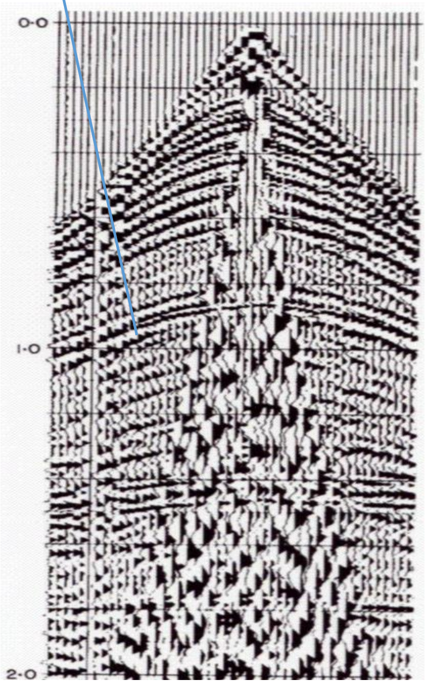
The sedimntary rocks are less dense (~ 2.1 ± 0.3 gr/cm^3 l) than other rocks.The density contrast between adjacent sedimentary rocks is rarely plus than 0.25 g/cm^3

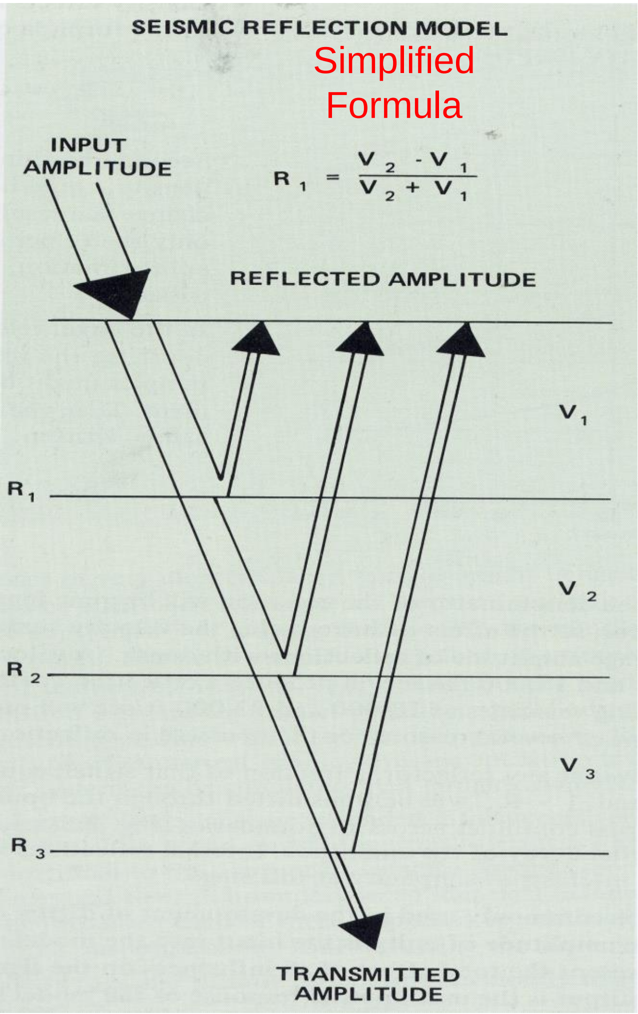
$$Rc_1 = \frac{V_2 - V_1}{V_2 + V_1}$$ Basic approximation

$$Rc_1 = \frac{\rho_2 V_2 - \rho_1 V_1}{\rho_2 V_2 + \rho_1 V_1}$$ Better approximation

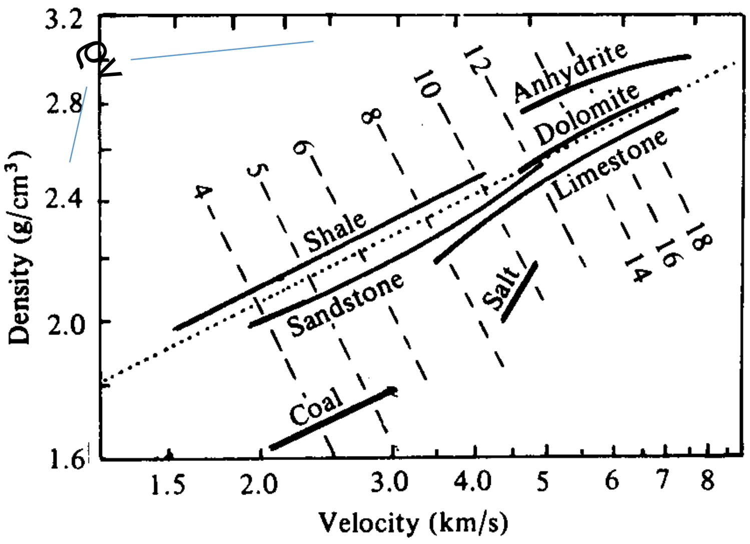
ρ = Density





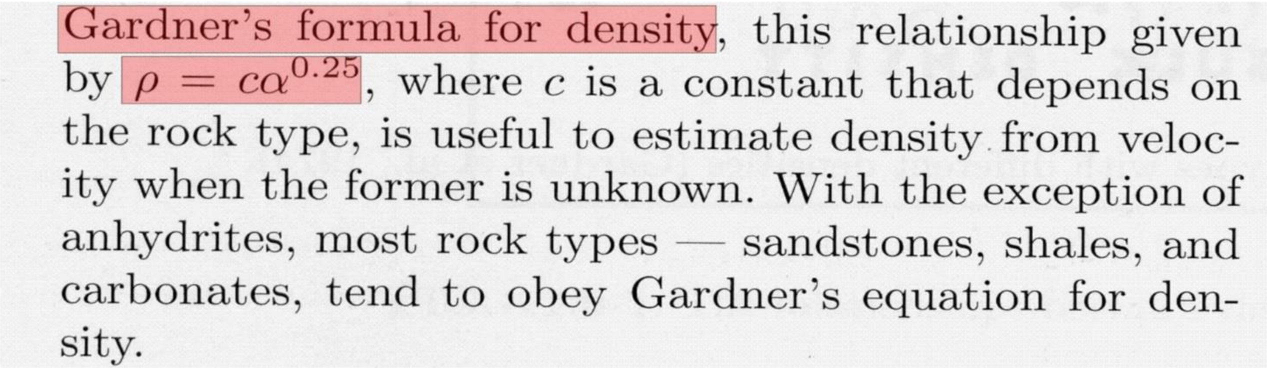


RELATION between DENSITY and VELOCITY



The linear function between acoustic impedance and velocity delle onde P (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 = α)*



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:
-if Vp is in m/sec → c = 0.23

-if Vp is in feet/sec → c = 0.31

Some values of

velocity v_P density ρ reflection coefficients R_c

in standard lithological conditions

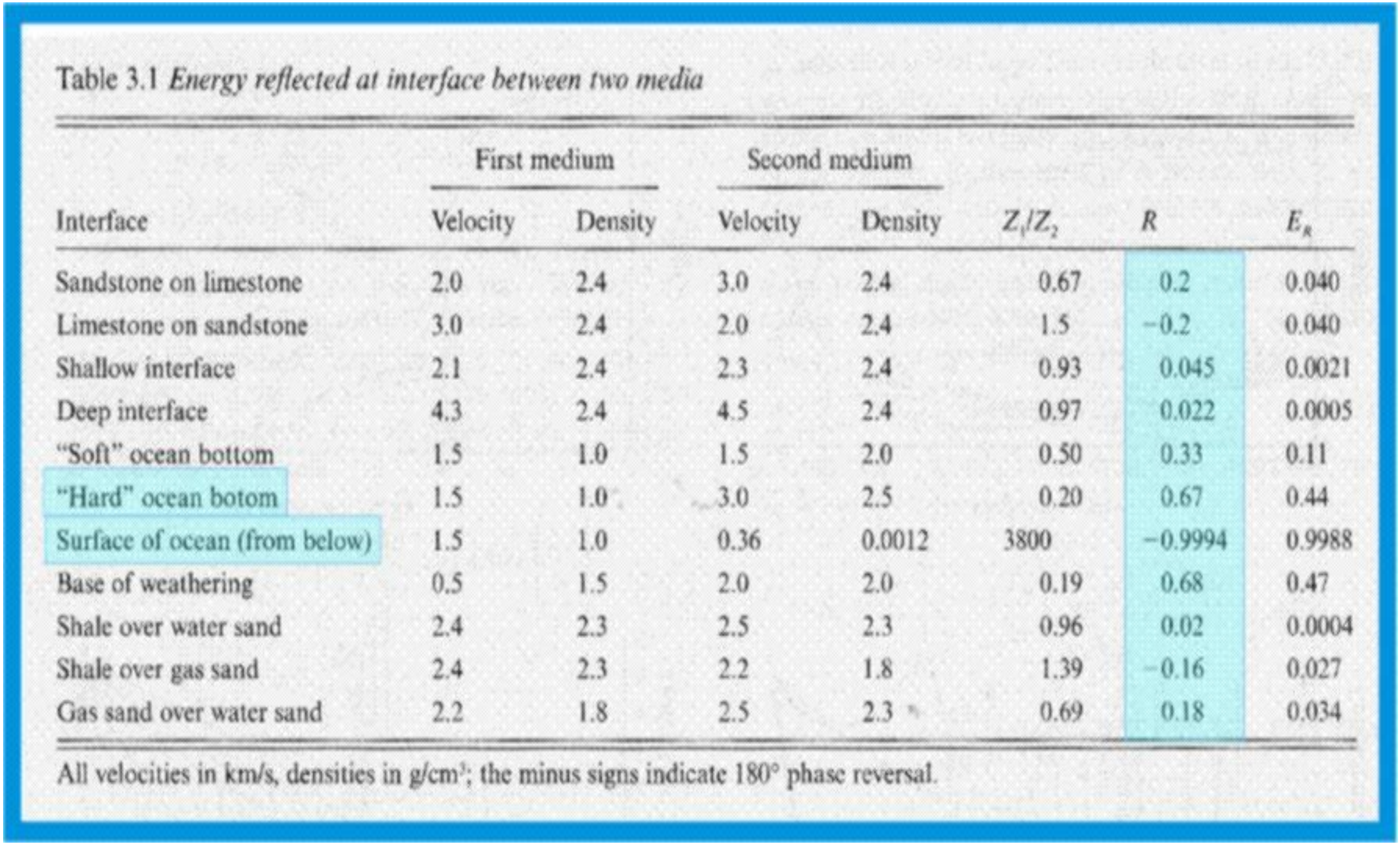
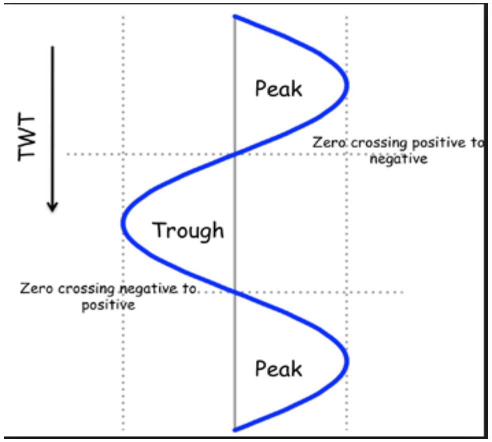


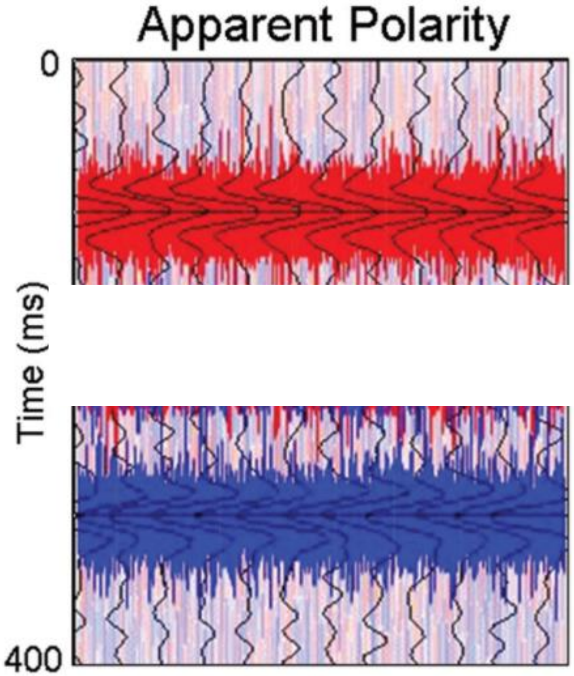
Table 3.1 *Energy reflected at interface between two media*

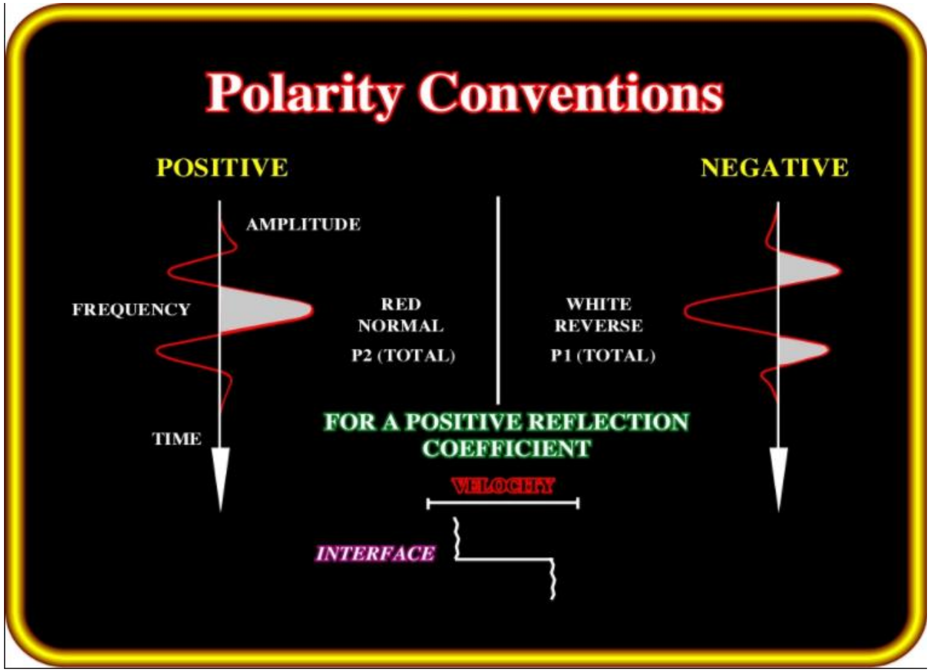
	First medium		Second medium				
Interface	Velocity	Density	Velocity	Density	Z_1/Z_2	R	E_R
Sandstone on limestone	2.0	2.4	3.0	2.4	0.67	0.2	0.040
Limestone on sandstone	3.0	2.4	2.0	2.4	1.5	−0.2	0.040
Shallow interface	2.1	2.4	2.3	2.4	0.93	0.045	0.0021
Deep interface	4.3	2.4	4.5	2.4	0.97	0.022	0.0005
"Soft" ocean bottom	1.5	1.0	1.5	2.0	0.50	0.33	0.11
"Hard" ocean botom	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

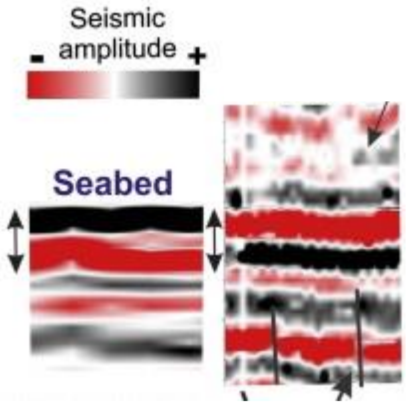
All velocities in km/s, densities in g/cm³; the minus signs indicate 180° phase reversal.

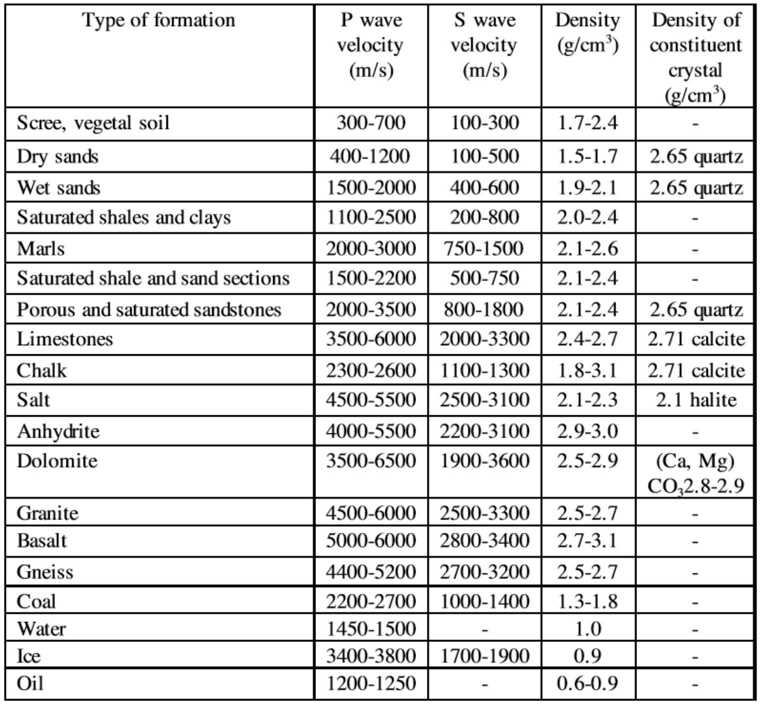
What does negative reflection coefficient Rc mean?





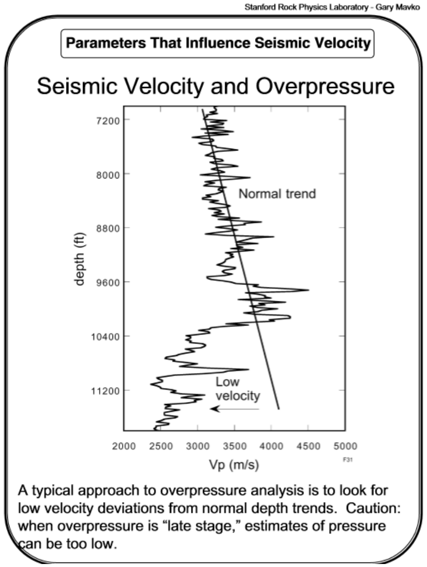






Type of formation	P wave velocity (m/s)	S wave velocity (m/s)	Density (g/cm^3)	Density of constituent crystal (g/cm^3)
Scree, vegetal soil	300-700	100-300	1.7-2.4	-
Dry sands	400-1200	100-500	1.5-1.7	2.65 quartz
Wet sands	1500-2000	400-600	1.9-2.1	2.65 quartz
Saturated shales and clays	1100-2500	200-800	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$_3$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



Stanford Rock Physics Laboratory - Gary Mavko

Parameters That Influence Seismic Velocity

Seismic Velocity and Overpressure

A typical approach to overpressure analysis is to look for low velocity deviations from normal depth trends. Caution: when overpressure is "late stage," estimates of pressure can be too low.

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

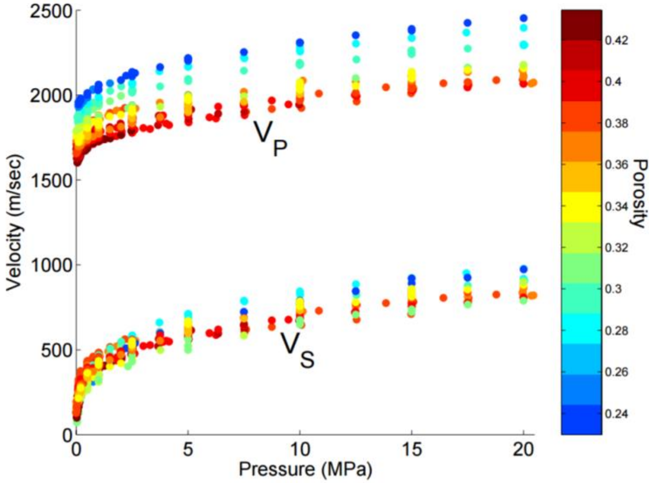


Figure 4.4: Gassmann fluid-substituted velocity data plotted against pressure, color-coded by porosity. The systematic porosity dependence of the compressional-wave velocities is easily visible.

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

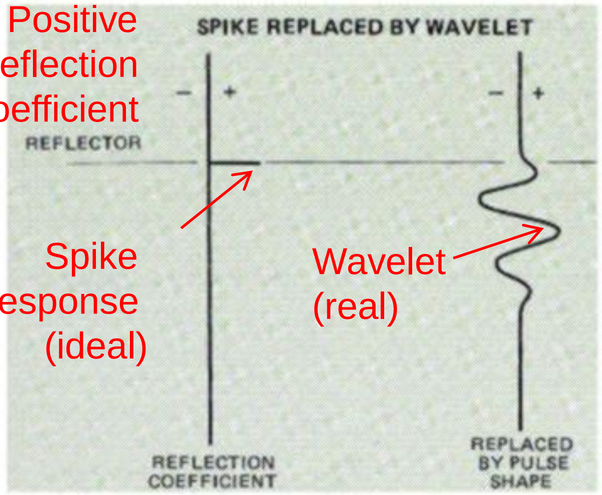
-lithostatic pressure } Effective pressure

-pore pressure (it often acts in opposte direction to lithostatic pressure)

-microfractures presence (…both -P & S- seismic wave velocities decrease with increasing crack density. By O'Connel and Budiansky, 1974)

What is a Seismogram?

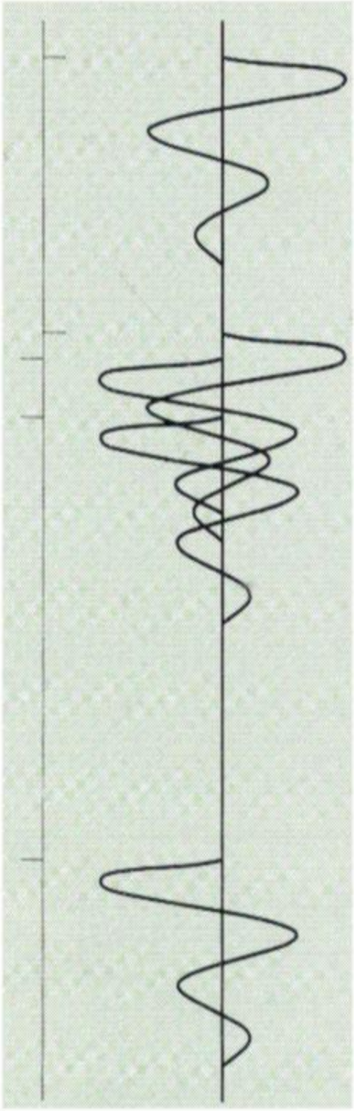
The simplest reflection model considers two superimposed omogeneous strata characterized by different elastic properties (-> Vp and ϱ)

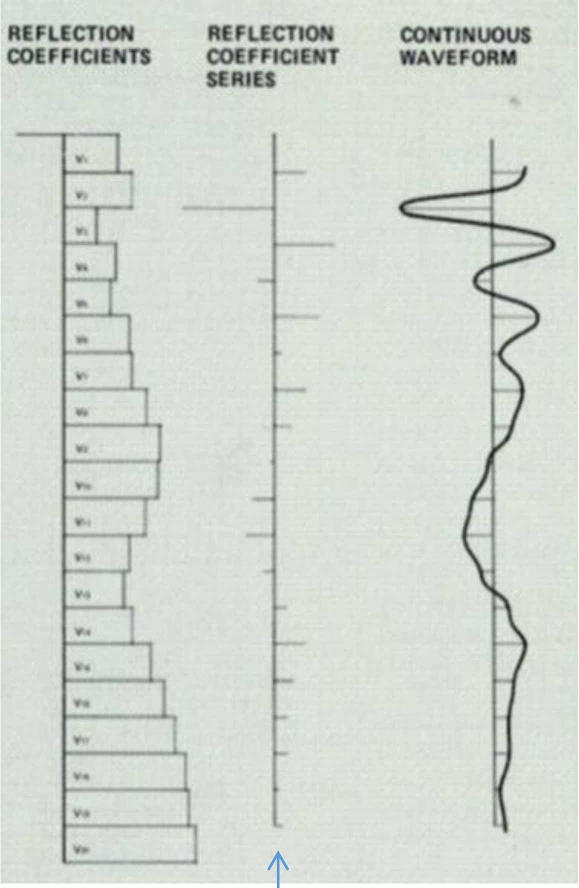


Positive reflection coefficient

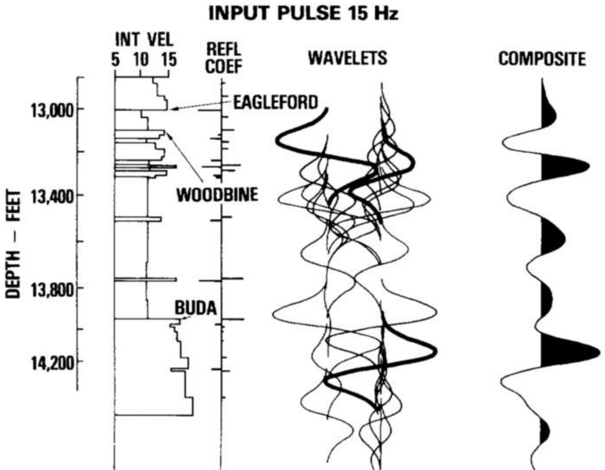
Spike response (ideal)

Wavelet (real)





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



Sinthetic 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.