Waves and Rays

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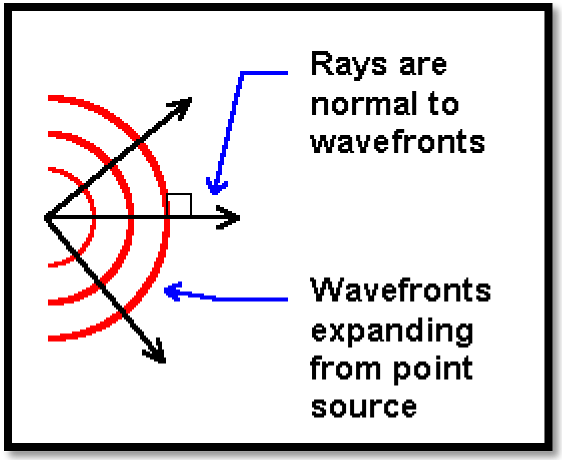
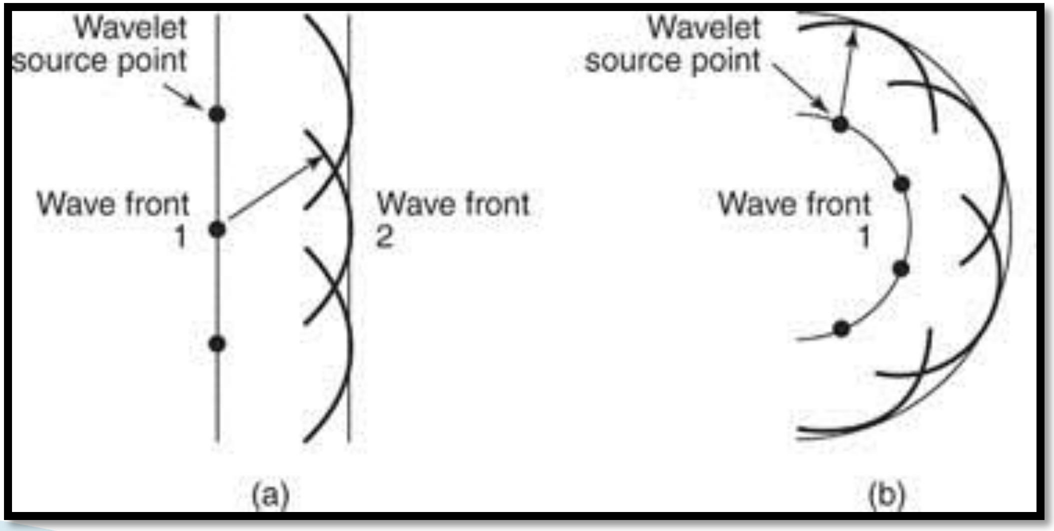
Waves and Rays

- In a homogeneous, isotropic medium, a seismic wave propagates away from its source at the same speed in every direction.
- **The wavefront is the leading edge of the disturbance.**
- **The ray is the normal to the wavefront.**



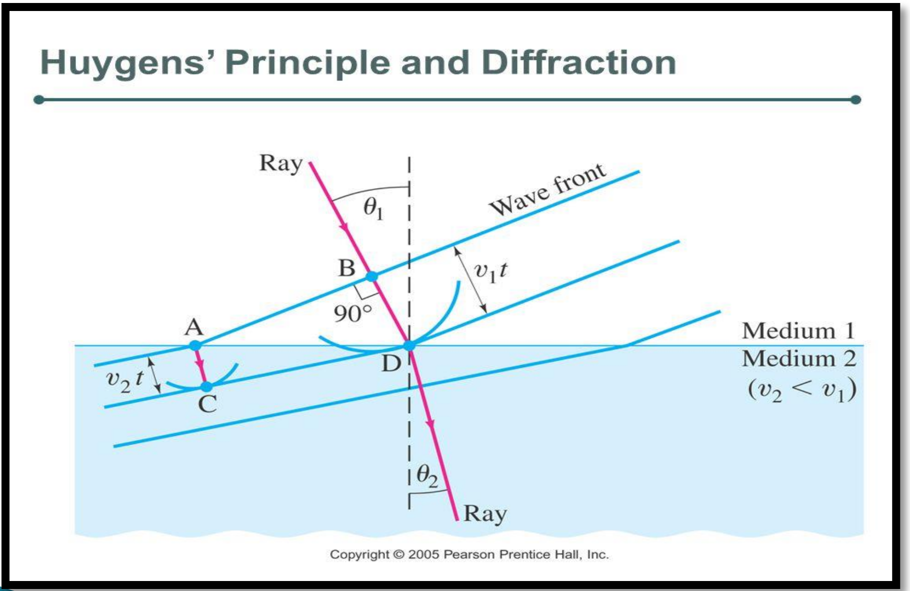
Huygen’s Principle

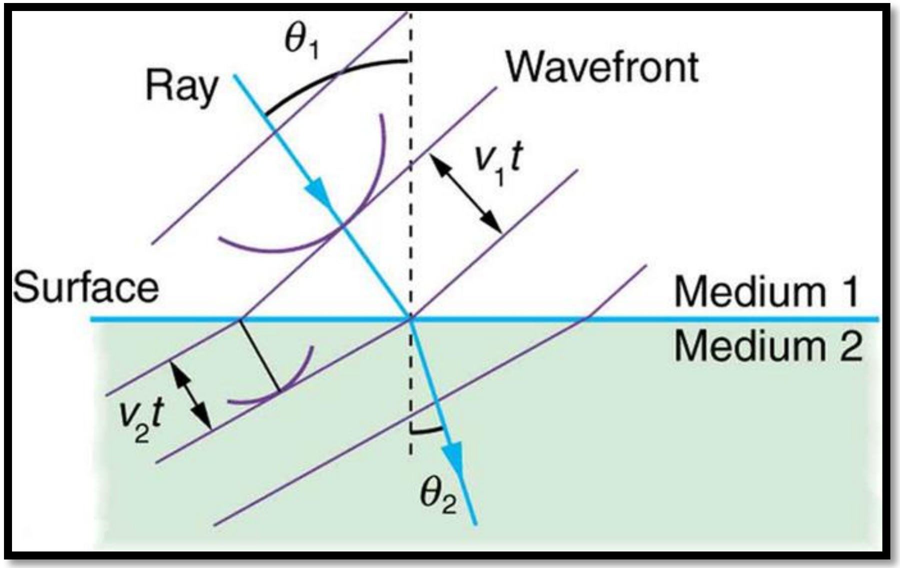
- Every point on a wavefront can be considered a secondary source of spherical waves, and the position of the wavefront after a given time is the envelope of these secondary wavefronts.



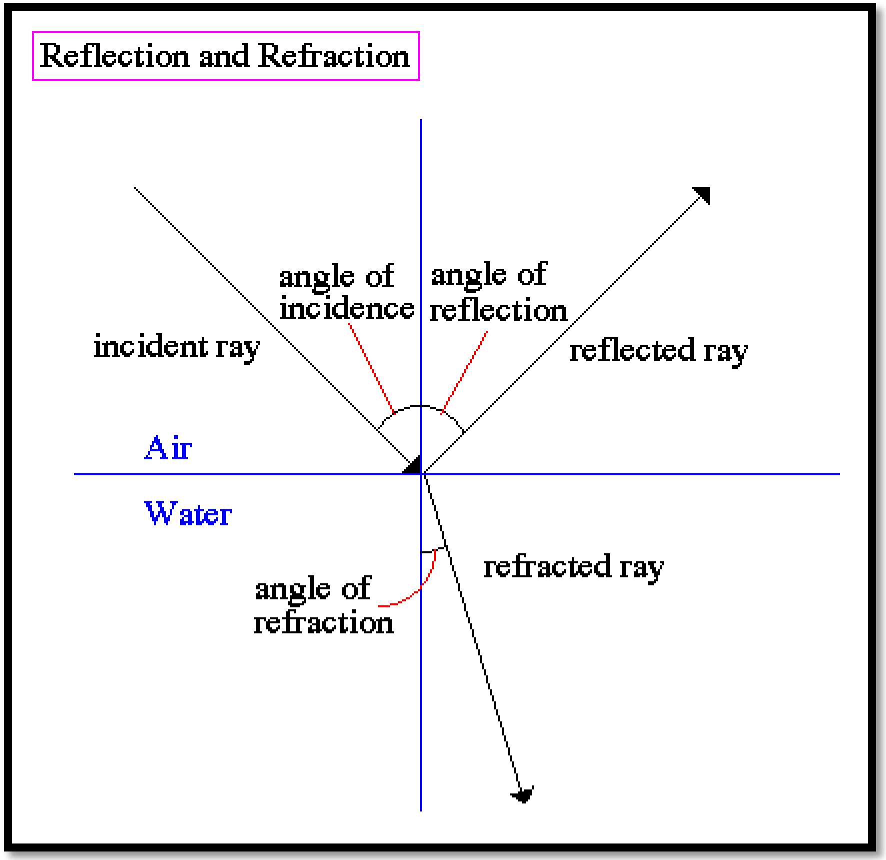
Huygen's Principle

- Huygen's construction can be used to explain reflection, refraction and diffraction of waves, Figure 1.



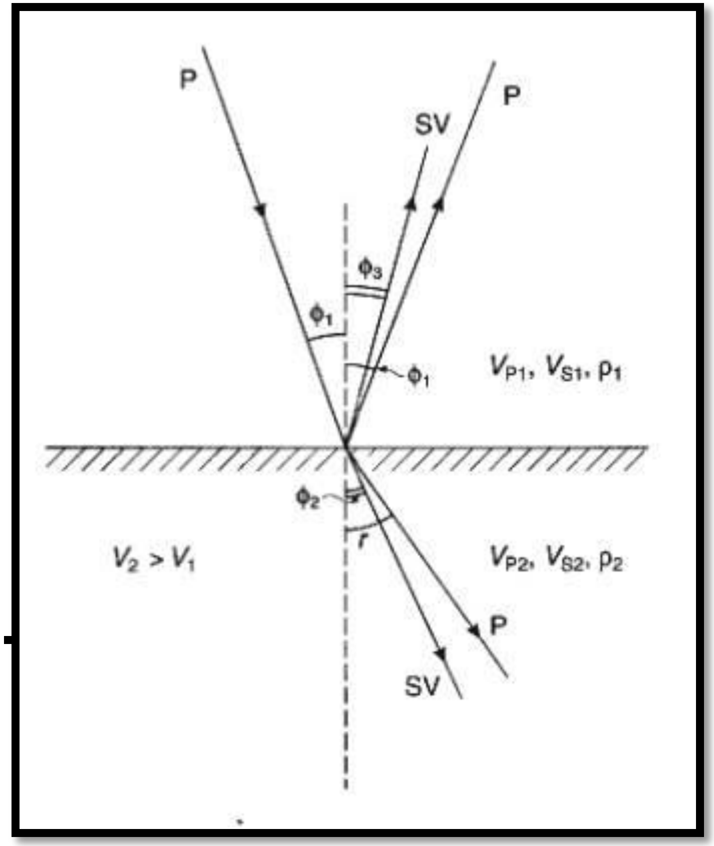


- However, it is often simpler to consider wave propagation in terms of rays, though they cannot explain some effects such as diffraction into shadow zones.



Reflection and Refraction at Oblique Incidence

- When a P wave is incident on a boundary, at which elastic properties change, two reflected waves (one P, one S) and two transmitted waves (one P, one S) are generated.
- Angles of transmission and reflection of the S waves are less than the P waves.



Attenuation of Waves

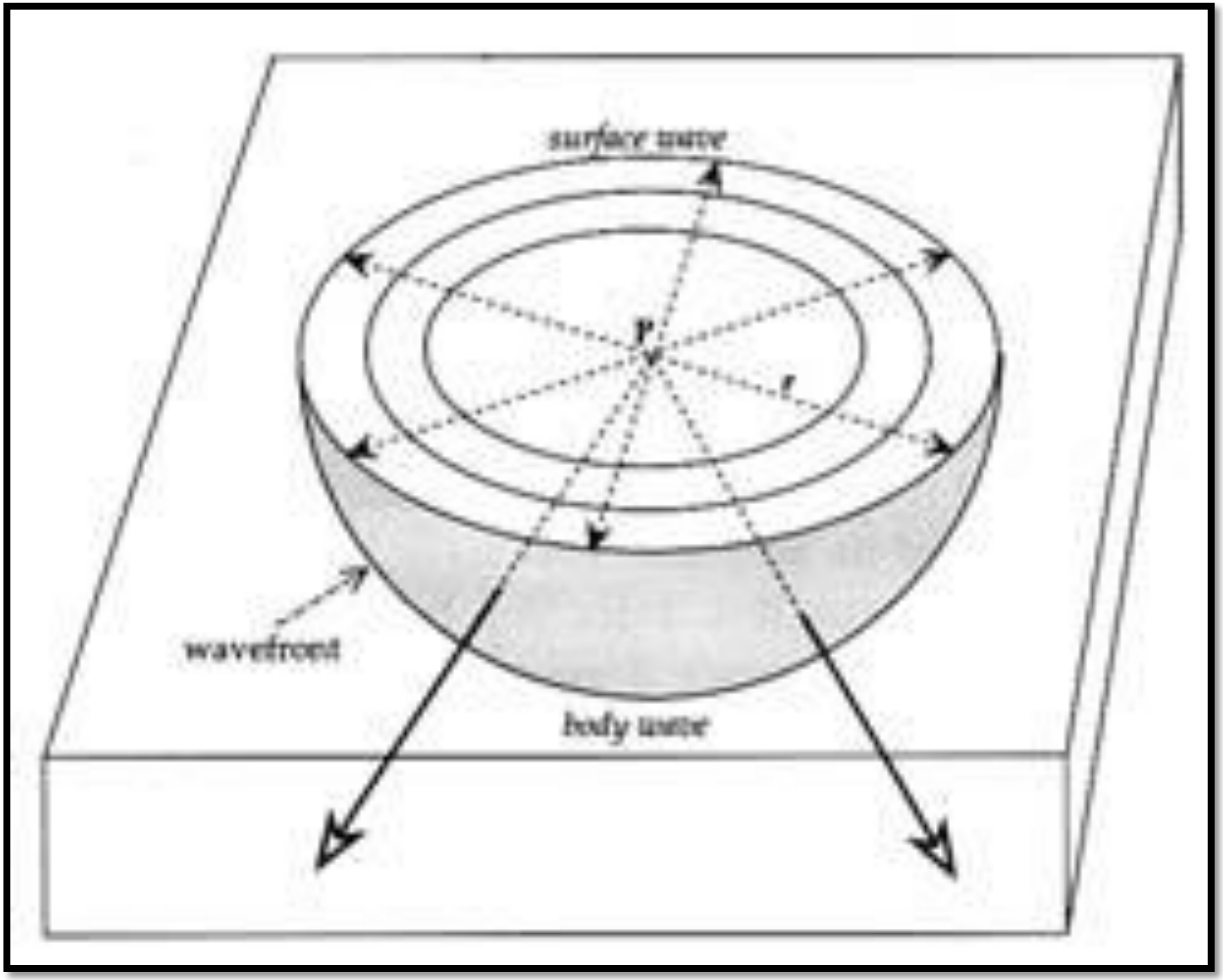
- **Attenuation**

  The amplitude of an arrival decreases with distance from the source.

- Types of attenuation

  I. Geometric spreading

  Energy spread over a sphere: $4\mu r^2$. Amplitude $\propto 1/r$.



Geometrical Spreading

Attenuation of Waves

II. Intrinsic attenuation

Rocks are not perfectly elastic. Some energy is lost as heat due to frictional dissipation.

$$\text{Amplitude} \propto e^{-\alpha r}$$

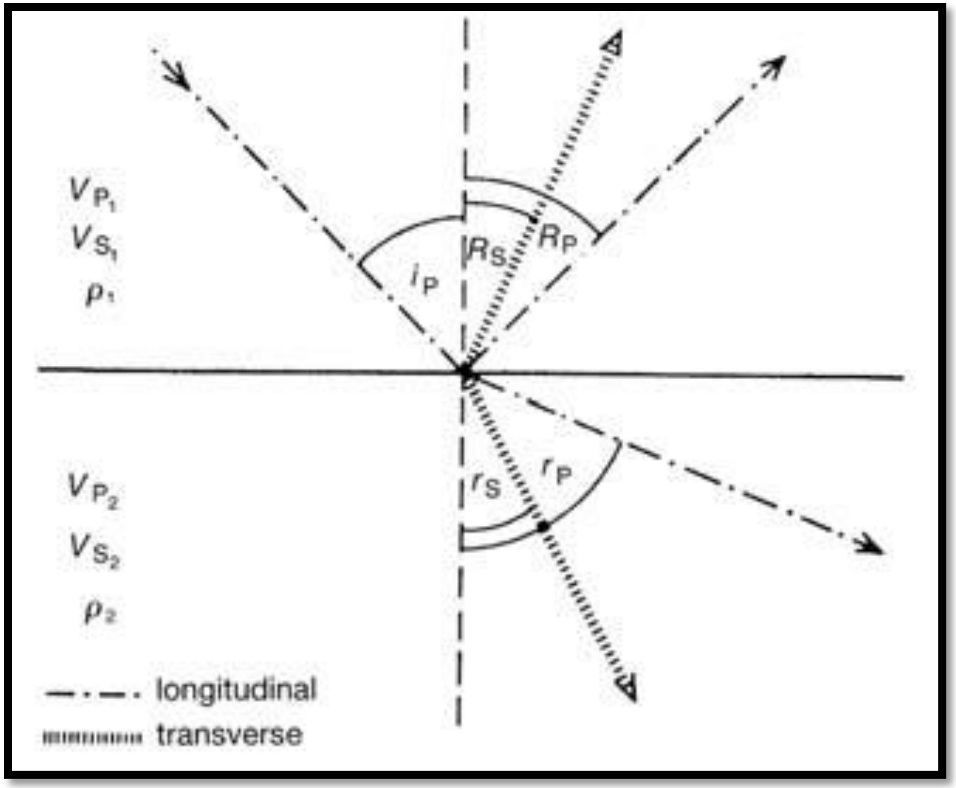
- Total attenuation

$$A = (A_0\, e^{-\alpha r})$$

- Higher frequencies attenuate over shorter distances due to their shorter wavelengths.
- Therefore, high frequencies decay first leaving a low frequency signal remaining.

Reflection and transmission

- Seismic rays obey Snell's Law (just like in optics).



Reflection and transmission

- The angle of incidence equals the angle of reflection, and the angle of transmission is related to the angle of incidence through the velocity ratio.

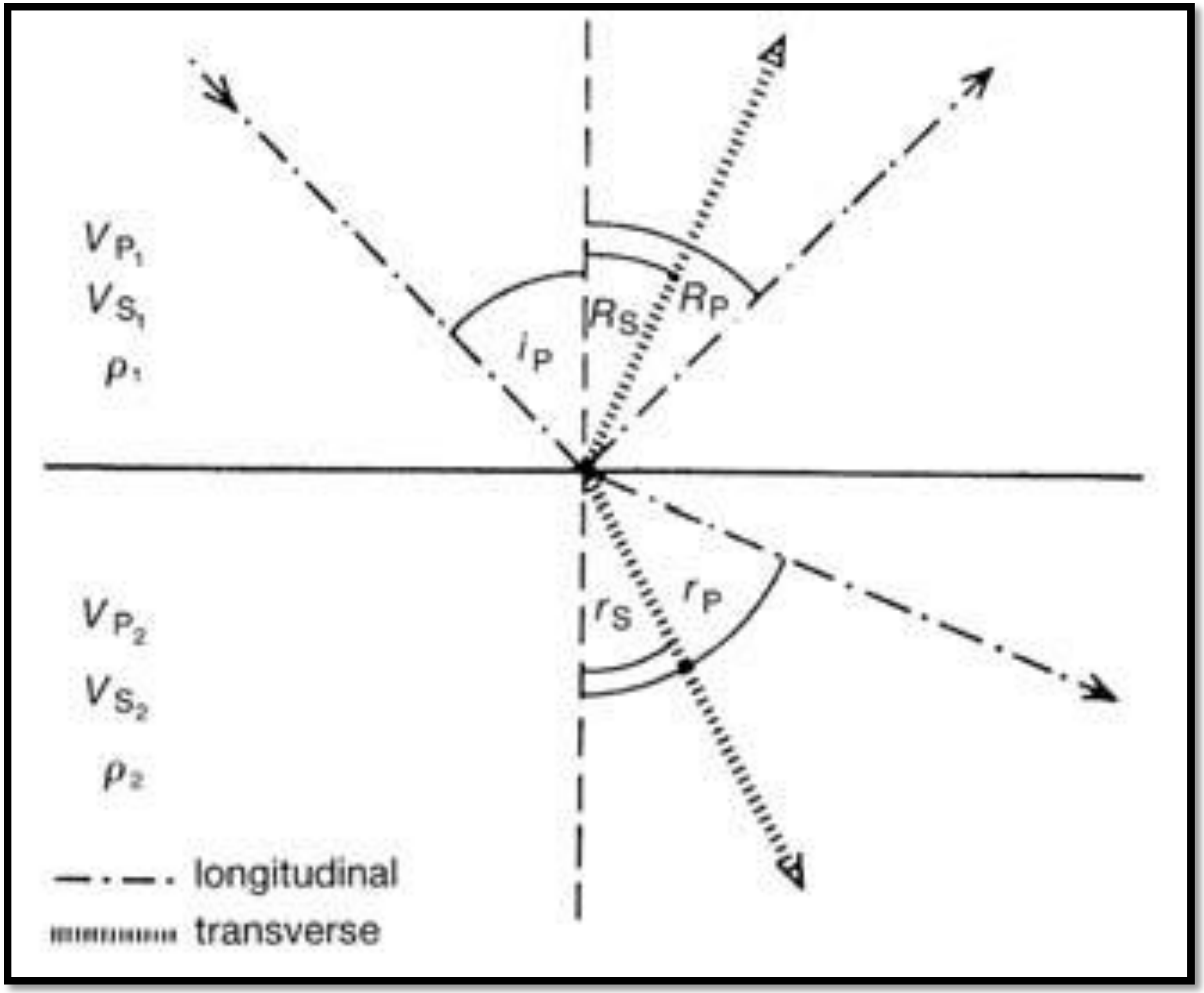
$$\sin i_p / V_{P1} = \sin R_p / V_{P1} = \sin r_p / V_{P2}$$

Conversion

- A conversion from P to S or vice versa can also occur at the interface between the media of different acoustic impedances.
- The angles are determined by the velocity ratios.

$\sin i_p / V_{P1} = \sin R_p / V_{P1} = \sin r_p / V_{P2} = \sin R_S / V_{S1} = \sin r_S / V_{S2} = P$

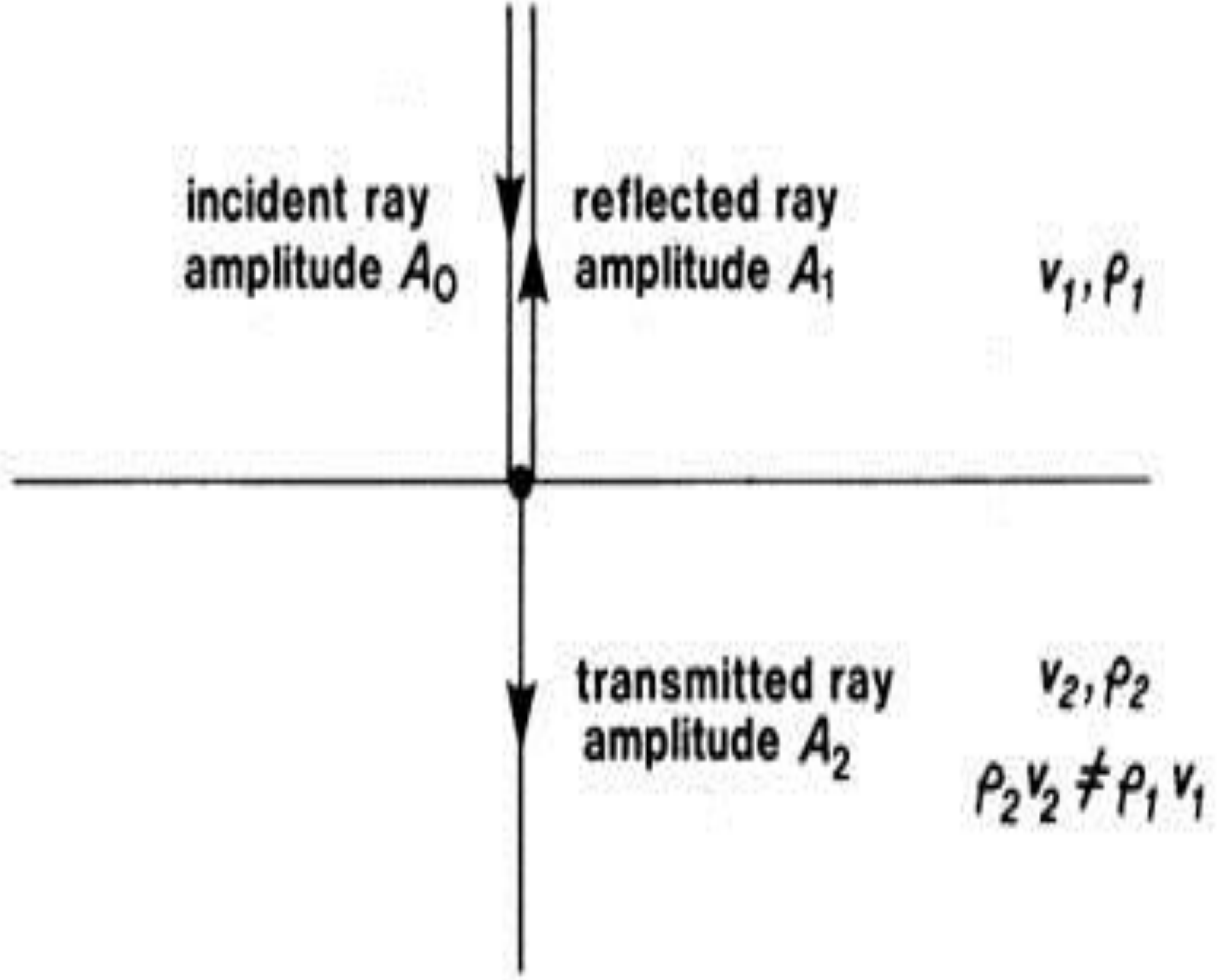
- where p is the **ray parameter** and is constant along each ray.



Conversion of Seismic Waves

Amplitudes reflected and transmitted

- The amplitude of the reflected, transmitted and converted phases can be calculated as a function of the incidence angle using **Zoeppritz’s equations.**
- Simple case: **Normal incidence**


incident ray
amplitude A_0
reflected ray
amplitude A_1
v_1, ρ_1
transmitted ray
amplitude A_2
v_2, ρ_2
$\rho_2 v_2 \neq \rho_1 v_1$

Amplitudes reflected and transmitted

Reflection coefficient (R_C)

$$\text{Reflection Coefficient} = \frac{\text{Amplitude reflected}}{\text{Amplitude incident}} = \frac{V_1\rho_1 - V_2\rho_2}{V_1\rho_1 + V_2\rho_2}$$

where $V_1\rho_1$ acoustic impedance of layer 1

and $V_2\rho_2$ acoustic impedance of layer 2

Amplitudes reflected and transmitted

Transmission coefficient (T_C)

Transmission coefficient = $\frac{Amplitude\ transmitted}{Amplitude\ incident}$

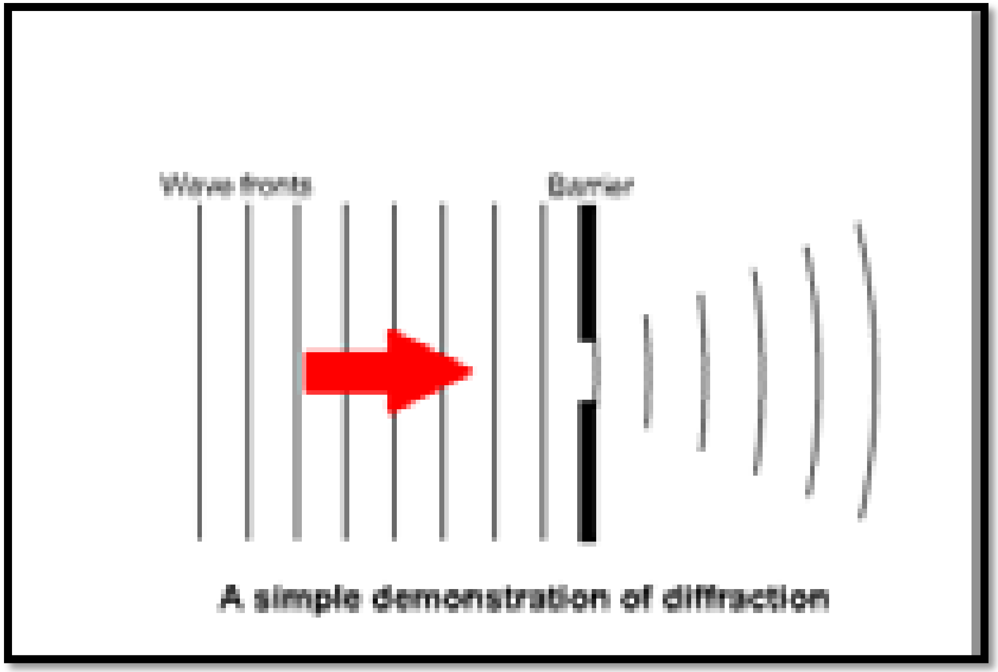
$$= \frac{2\rho 1V1}{\rho 2V2 + \rho 1V1}$$

$T_C = 1 - R_C$

R_C usually small – typically 1% of energy is reflected.

Diffraction

- A sharp break in a reflector acts as a secondary source of a spherical wavefront.



A simple demonstration of diffraction

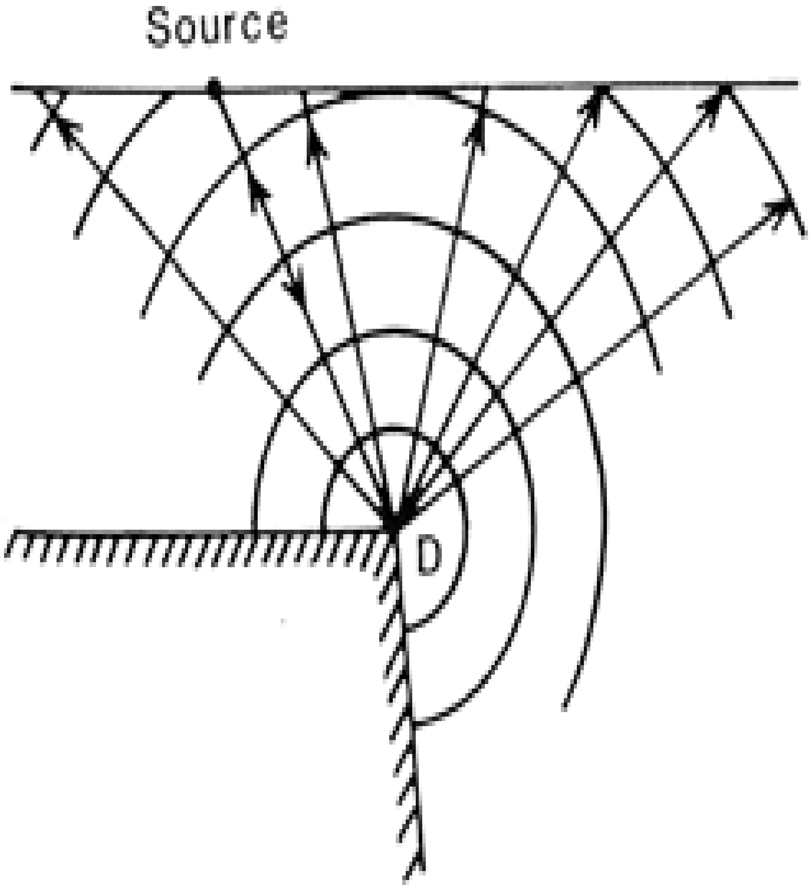
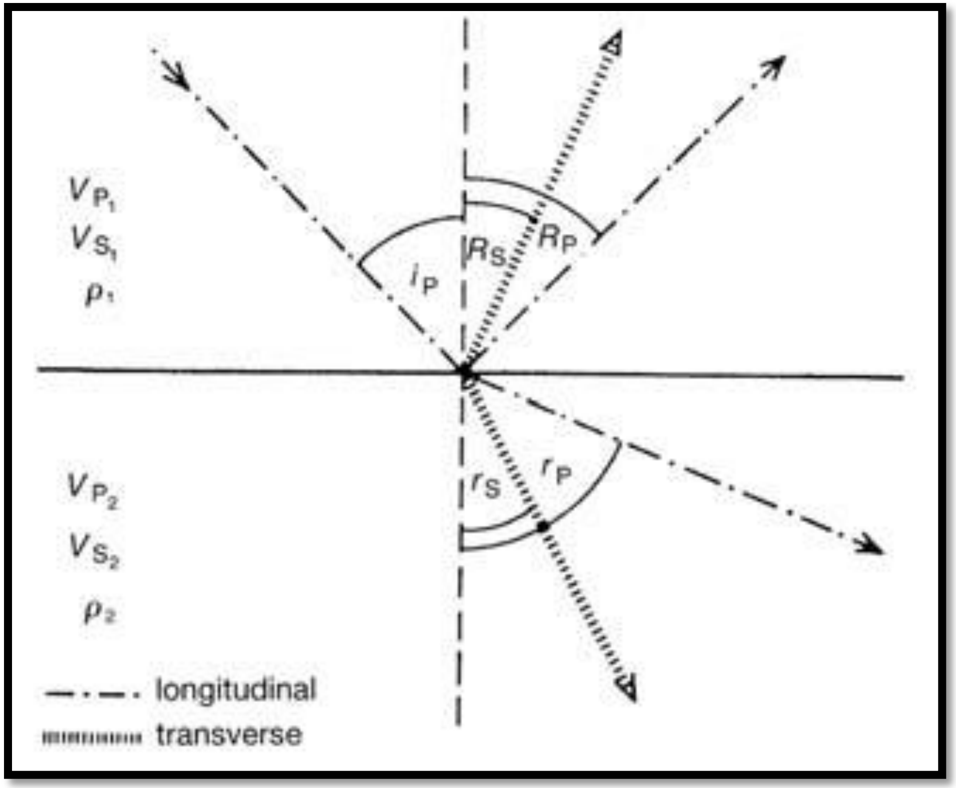


Fig. 4.5 Diffracted wavefronts from a sharp edge, D, which has been set into oscillation by waves coming from a seismic source.

Critical incidence

$$\frac{\sin ip}{Vp1} = \frac{\sin rp}{Vp2}$$



When $V_2 > V_1$, $r_p > i_{p,}$ therefore, we can increase iP until $r_P = 90°$.

Critical incidence

- When $r_P = 90°$ $i_P = i_C$ the critical angle.

$$\sin i_C = \frac{Vp1}{Vp2}$$

- The critically refracted energy travels along the velocity interface at V_2 continually refracting energy back into the upper medium at an angle i_C → a **head wave.**

Head wave

- Occurs due to a low to high velocity interface
- Energy travels along the boundary at the higher velocity
- Energy is continually refracted back into the upper medium at an angle i_C
- Provides constraints on the boundary depth e.g. Moho depth

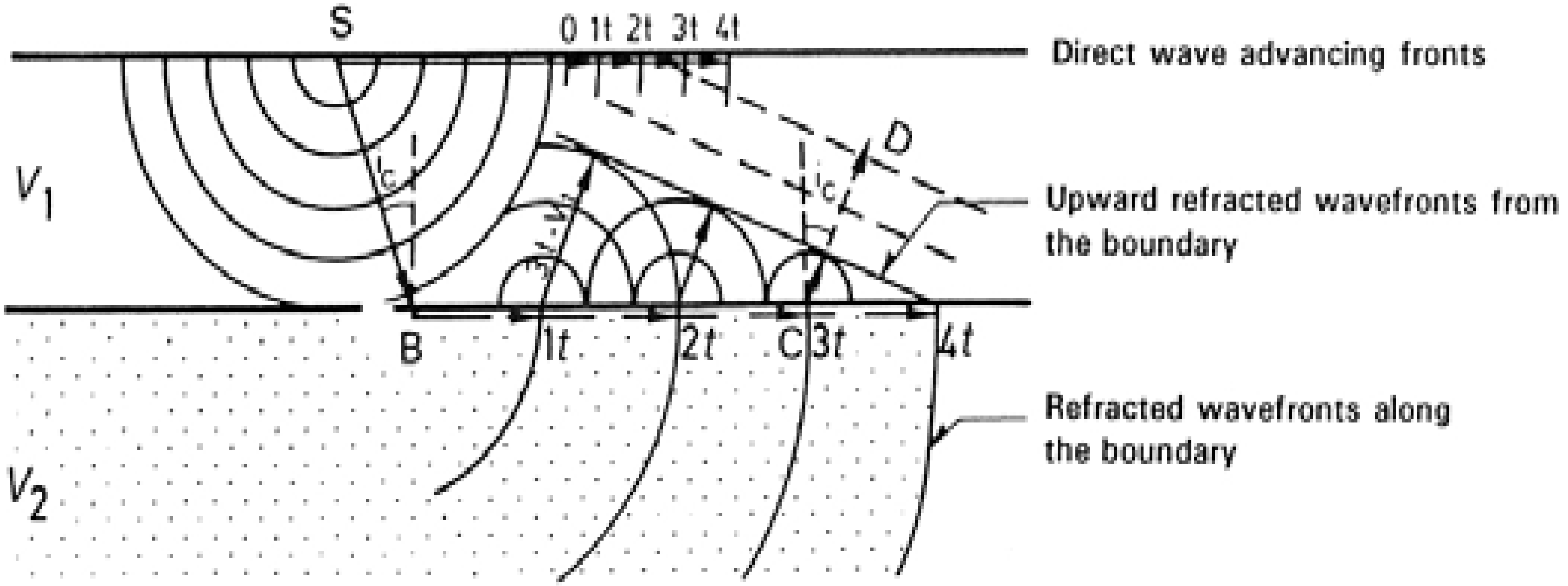


Fig. 4.6 Schematic illustration showing the ray paths of the incident wave (SB) striking the boundary at critical angle (i_c), and the refracted wave (BC) traveling along the boundary with velocity V_2 ($>V_1$). The latter is refracted back to the first medium (V_1) at the same angle (i_c) and re-emerges with a ray path such as CD. Advancement of the wavefronts is shown from the instant ($t=0$) when the incident ray strikes the boundary at B. (Modified from Klitten, 1987.)

Textbook

Alsadi, H.N. (1980) Seismic Exploration: Technique and Processing. Springer Basel AG, 194p.