Sonic

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# Sonic Waves

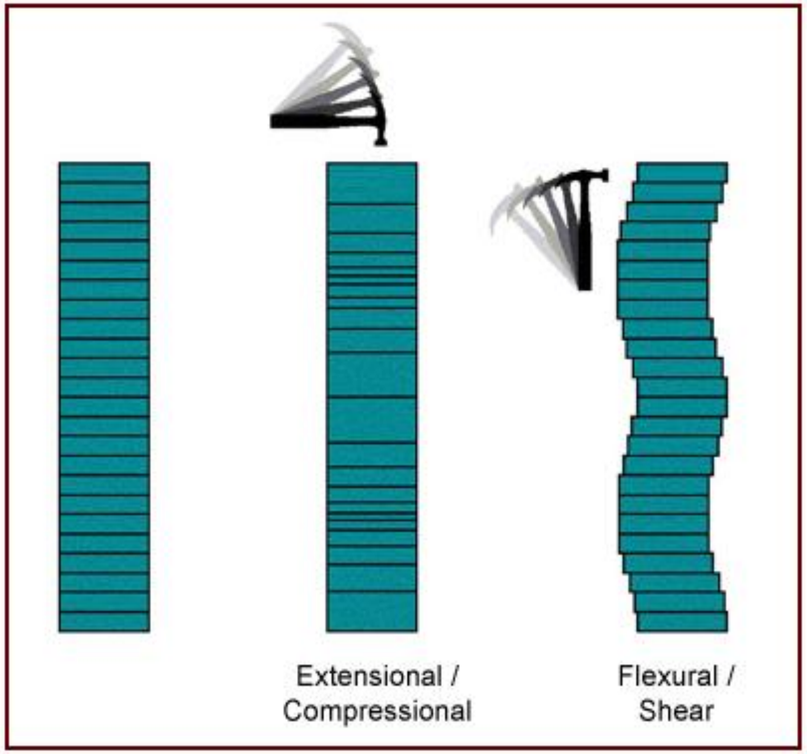
- A wave is a **disturbance** or **variation** which travels through a medium.
- The medium through which the wave travels may experience some local oscillations as the wave passes, but the particles in the medium do **not** travel with the wave.

# Types of sound waves

- Body Waves – Compressional and Shear
- Surface Waves – Pseudo-Rayleigh; Flexural, Leaky-P and the Stoneley

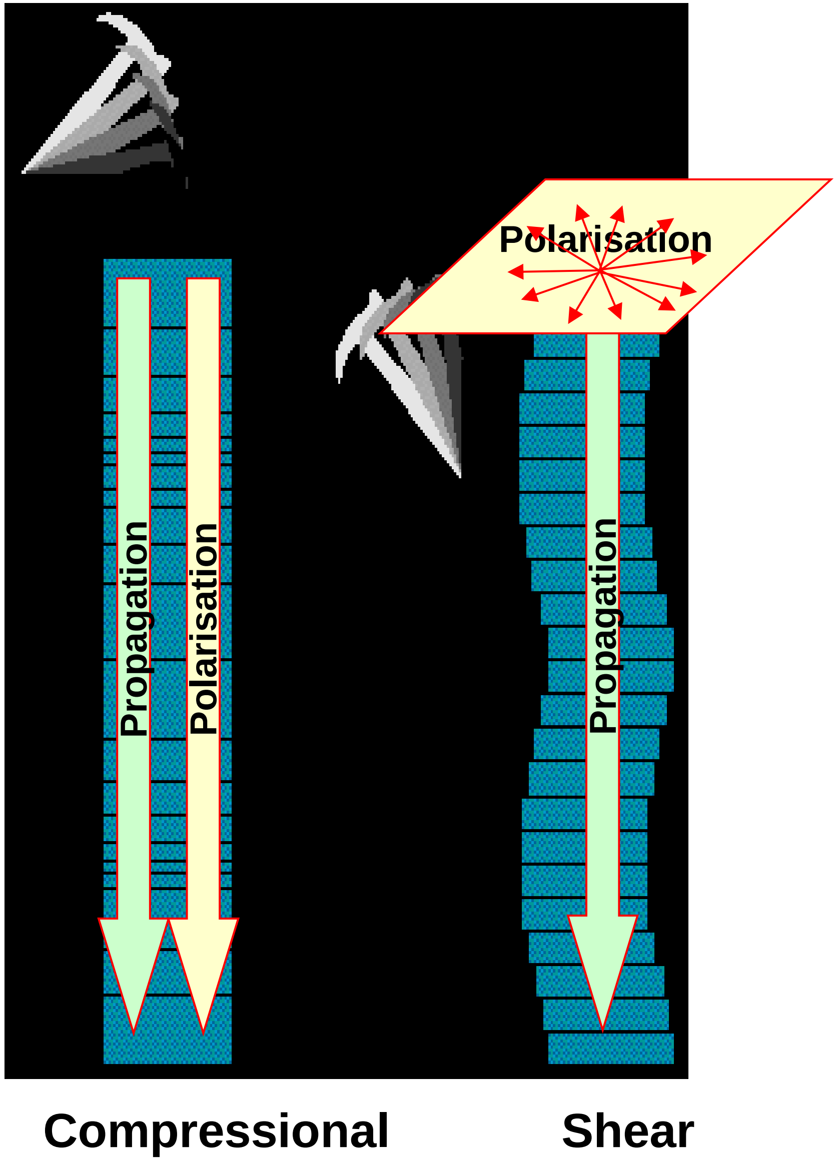
# Body Waves

- A vibration may propagate vertically as a succession of compressions and extensions – **Compressional wave**. Here, the particle moves parallel to the direction of vibration in this case
- If one hits on a pole laterally, the vibration propagates vertically as a flexion of the pile – **Shear Wave**. Here, the particle motion is perpendicular to the vibration propagation direction
- Compressional (Primary wave) wave is faster than the Shear wave (Secondary Wave



# Particles movement

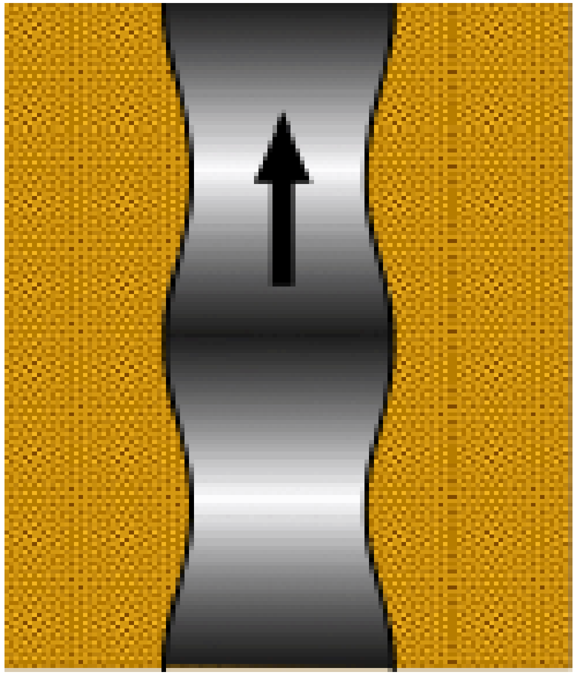
- Polarization: the direction of particle oscillation
- Propagation: direction of wave
- In compressional wave the particle vibrate with the direction of propagation
- In Shear wave the particle propagate perpendicular on wave of propagation



# Surface Waves

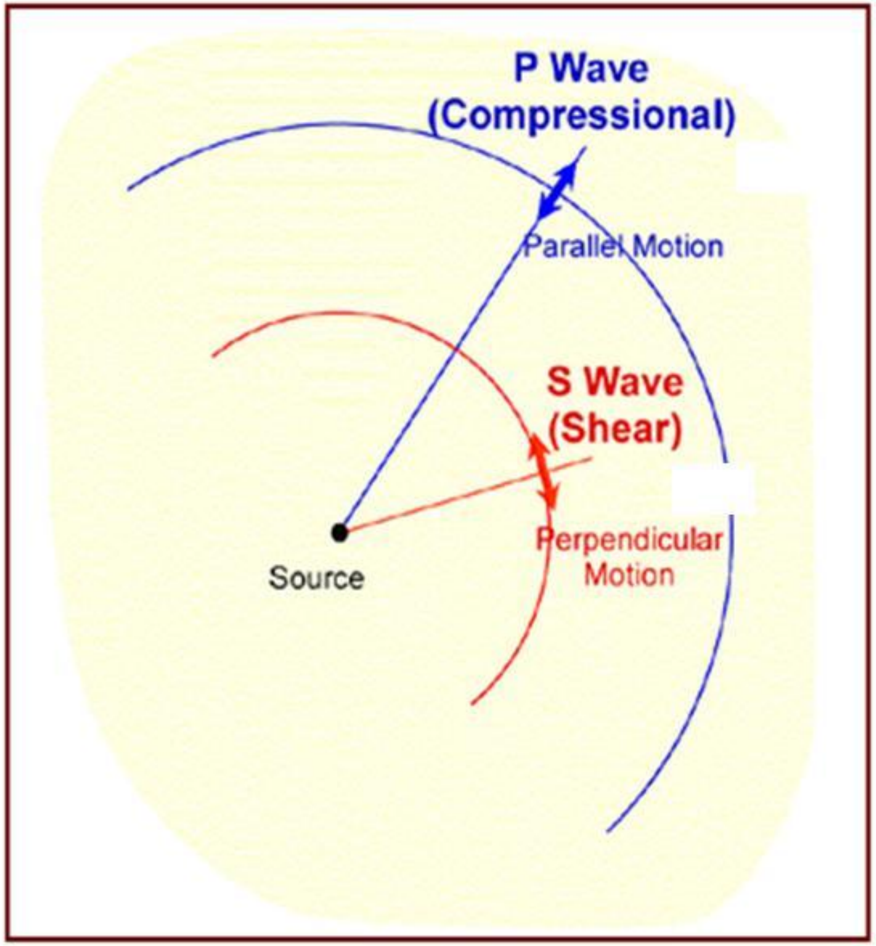
- Coming after the shear head wave is the **pseudo-Rayleigh** - with elliptical particle motion that forms the late part of the shear packet in the waveform
- Stoneley is another surface wave, always slower than the mud
- At low frequency (below 1KHz), the Stoneley becomes a Tube wave – a compression of the BH fluid constrained within the BH by shear rigidity of the formation

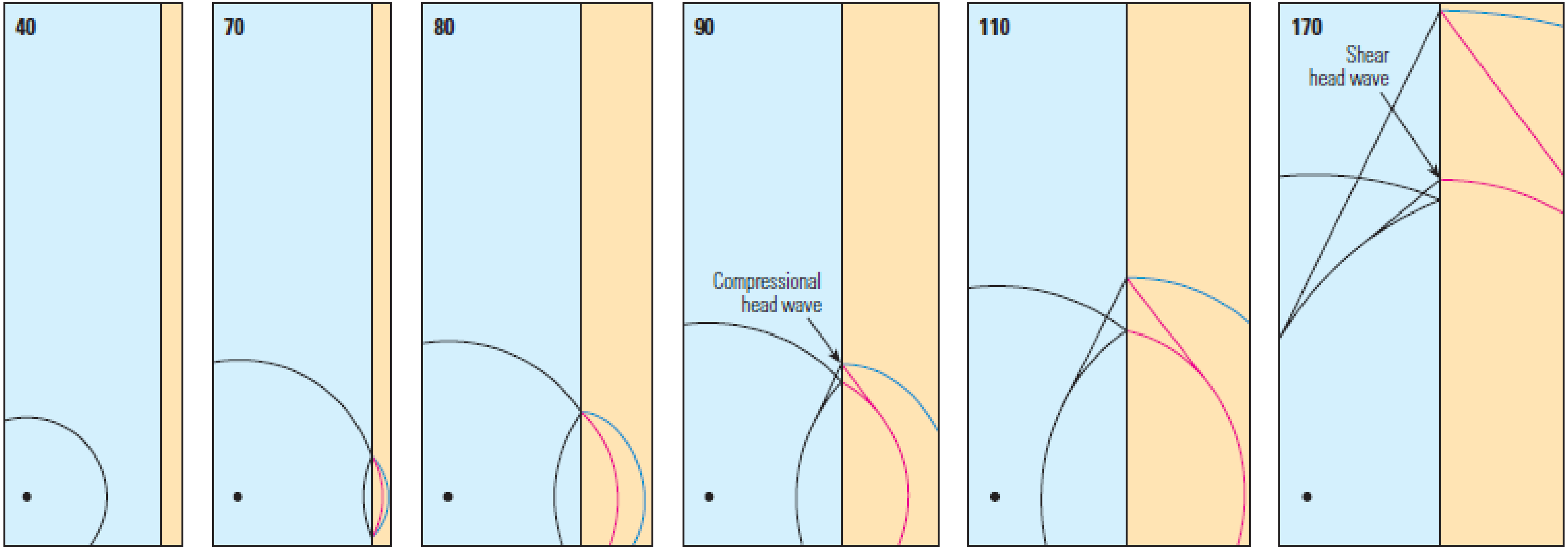
Stoneley
Borehole mode



# Body Waves in Homogeneous, Isotropic medium

- Acoustic waves propagate in all direction

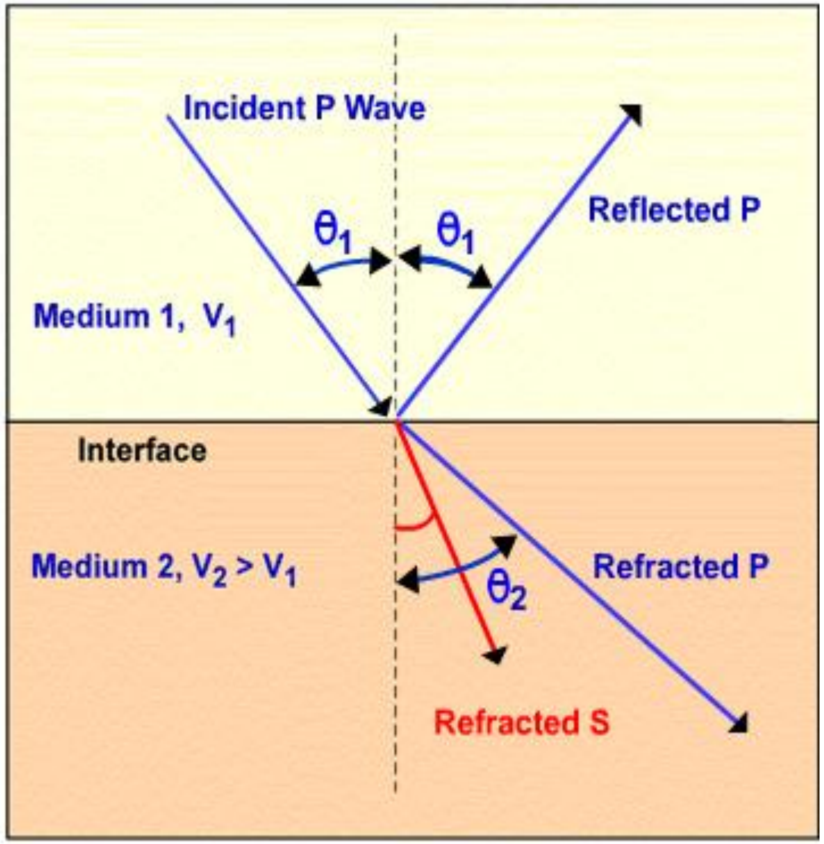





^ The first few moments of simplified wavefront propagation from a monopole transmitter in a fluid-filled borehole (blue) and a fast formation (tan). Both media are assumed homogeneous and isotropic. Tool effects are neglected. Time progression is to the right. Numbers in the upper left corner correspond to time in μs after the source has fired. Wavefronts in the mud are black, compressional wavefronts in the formation are blue, and shear wavefronts in the formation are red. The compressional head wave can be seen at 90 μs, and the shear head wave can be seen at 170 μs.

# At the Interfaces

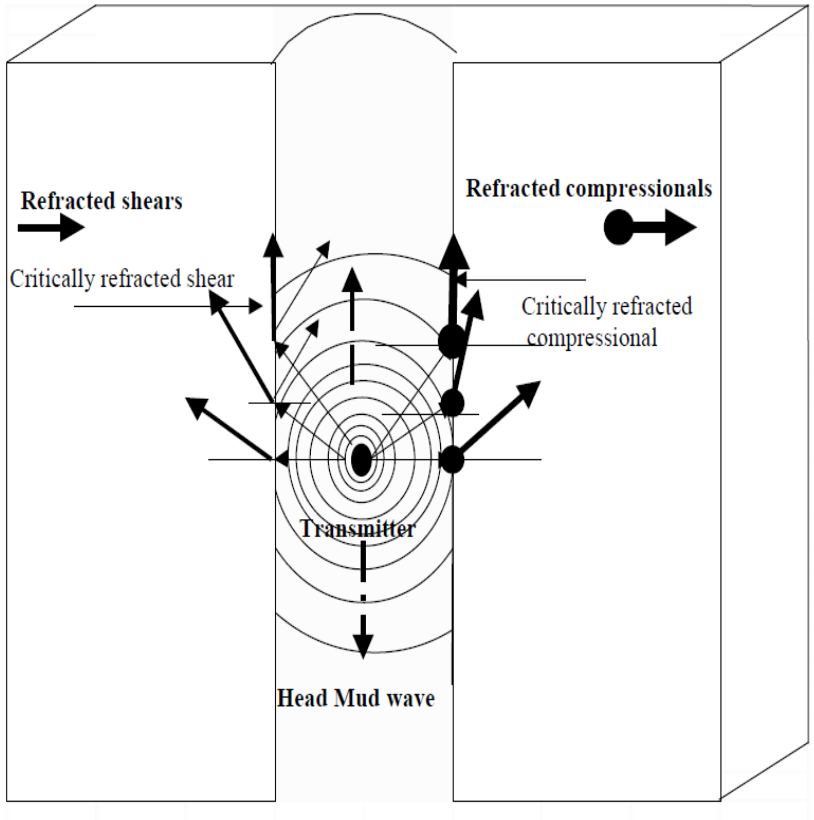
- When an acoustic wave comes to interface such as boundary between two formation or fracture
- Part of energy is transmitted by **refraction** and the other part is **reflected**
- The direction of propagation of the refracted waves obeys Snell's law
- Transmitted energy causes a P wave and a S wave and the refracted angle depends on the angle of incidence and velocity contrast between the two media as per Snell's Law
- The critical angle is the value of the incidence angle $\Theta_1$ such that $\Theta_2 = 90º$.
- Sin Ɵ critical = ΔT2 / ΔT21




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

# Wave Propagation in the Well

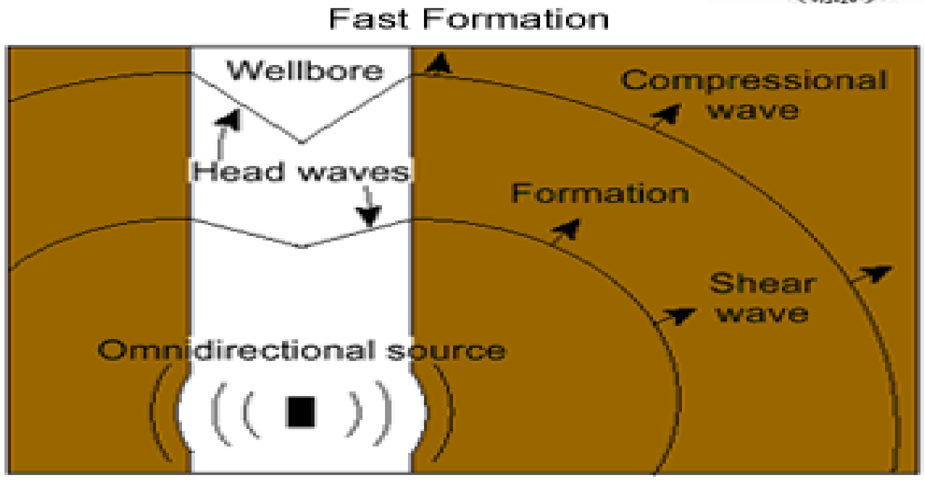
- TR generates the wave which radiates radially from the source and hits the wall of the well-bore
- At this point, it undergoes both reflection and refraction at different Ɵi.
- At Ɵi_**crit**, the refracted wave undergoes internal refraction and travels along the well-bore: Prefr.; Srefr.
- As the wave travels along the well-bore in the formation, it is continuously reflected back to the formation, and refracted into the mud at the formation-mud interface
- Head waves of both the Compressional, and shear are propagated
- At some point where a receiver is located, the receiver picks up a wave train

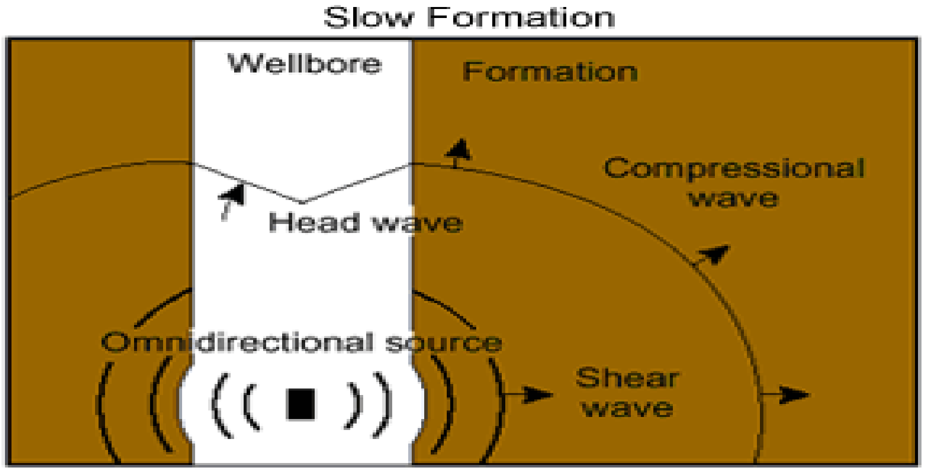


# HW's in FAST / SLOW Formations

- In a fast formation, shear is faster than the compressional in the mud. Both **P** and **S** HW's are present in the BH. Monopole Sonic tools can measure shear slowness

- In slow formation the **S** is slower than the **P** wave in the mud. There is no **S** HW in this case and the monopole sonic tools cannot measure shear



# Sonic logs

## ΔT = Slowness

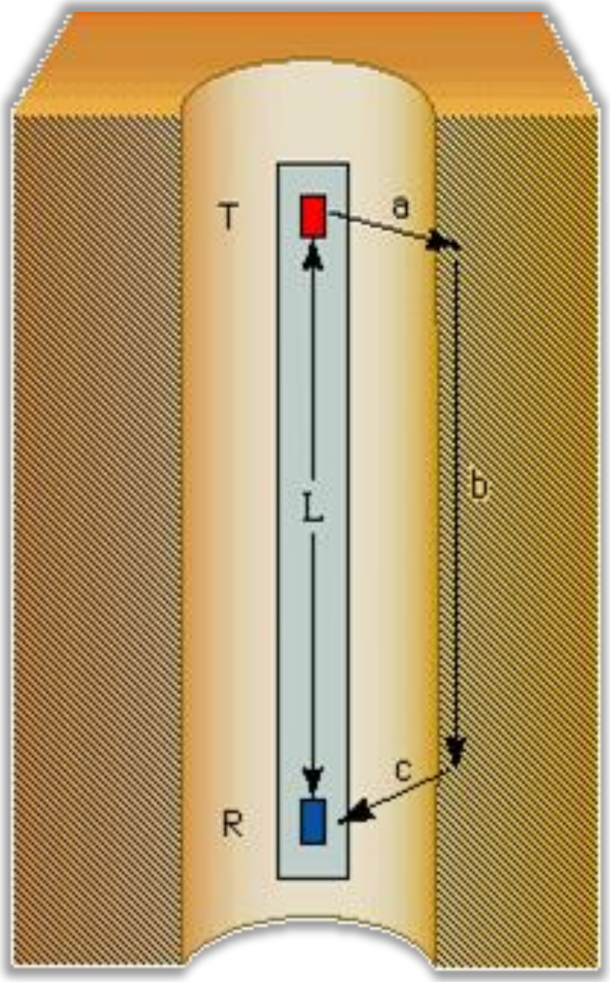
Unit: us/ft or us/m

- 5300 m/s – 57 us/ft (casing)
- 1500 m/s – 200 us/ft (water)

Inverse of velocity V [m/s or ft/s]

**ΔT = 1 / Velocity**

The goal of sonic logging is to measure the effects of the formation on the velocity of the waveform




**In a single TR configuration, the time to traverse rays a, b and c is measured. The effect of mud in rays a and c is "unknown" Hence we do not know the formation velocity**

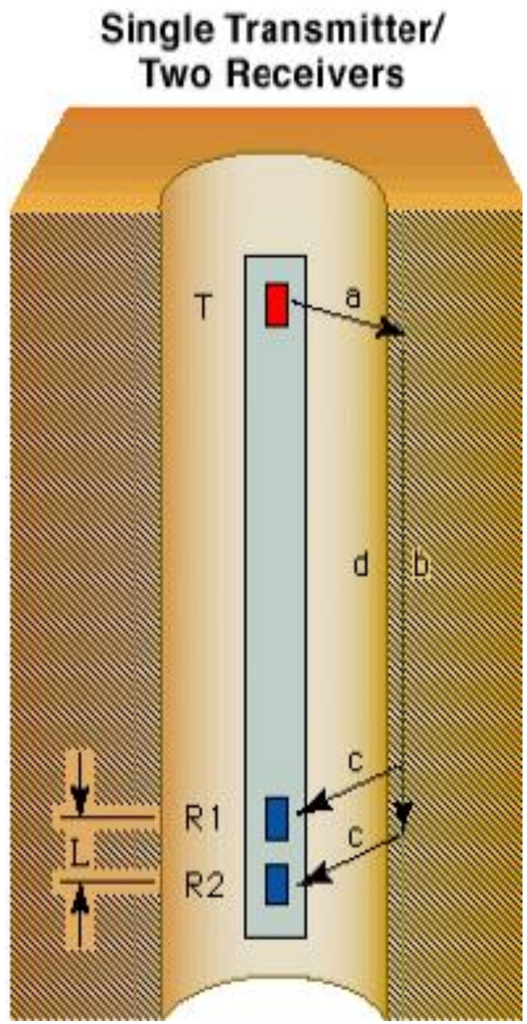
**Slowness = Δt = 1/V = (a+b+c)/L**

# 2 Receivers

- 1 T & 2 R
- With this configuration, travel time in mud can be negated by subtracting the transit time of R1 from R 2

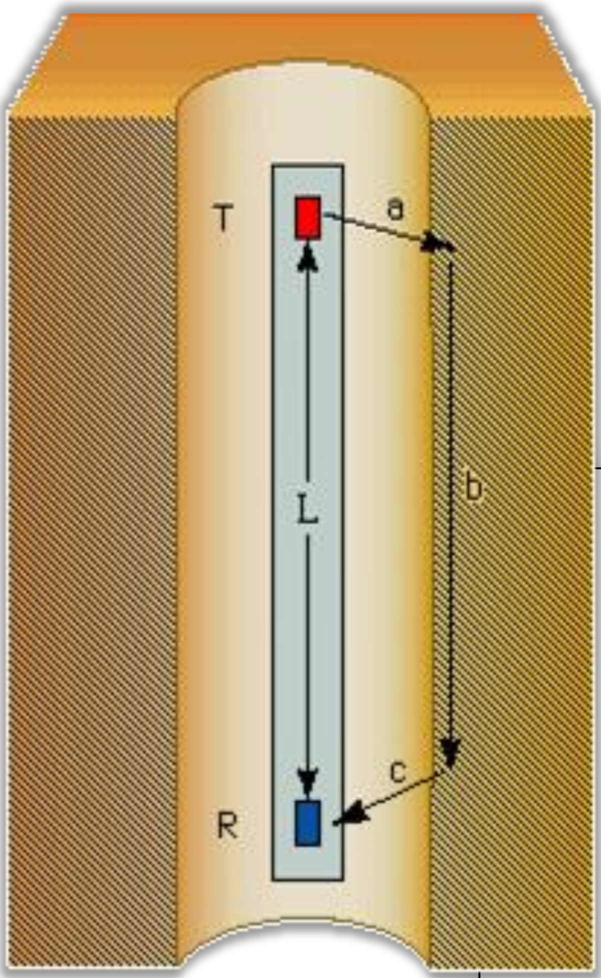
**Slowness = [ (a+b+c) - (a+d+c)]/L= (b-d)/L**

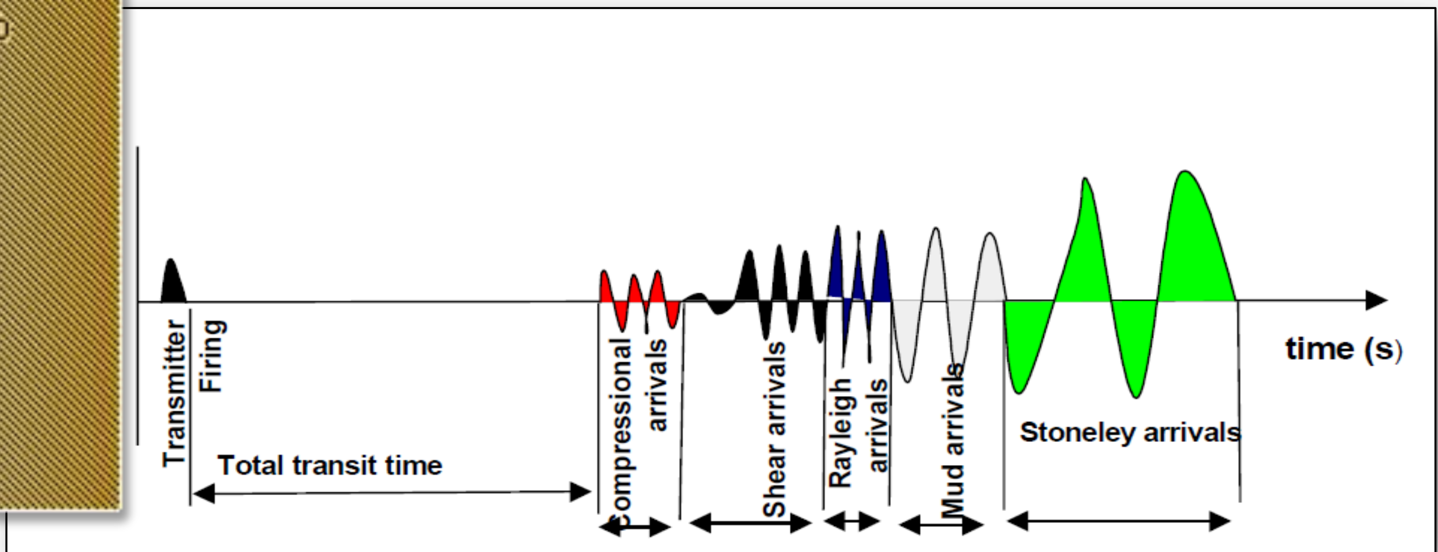
- Tool tilt causes a problem as then mud travel time in R1 is not the same as R2 and is not negated as a result



# What does the receiver record?

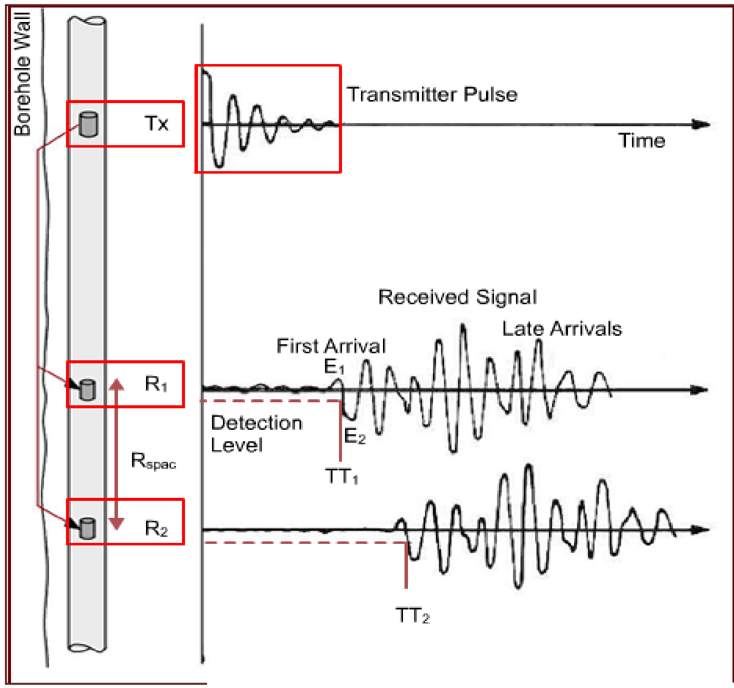
- The receiver record wave train, first arrival is P-wave then shear wave (which are body waves)then mud arrival, then stonely( which is surface wave)



# Recording with 2 receiver and FMD approach

- Recording with 2 receiver will make the receiver 1 record p-wave before receiver 2. so there will be time delay inside the formation. By subtracting these 2 first arrivals we will cancel the travel time in the mud and the time difference is only represented by the time traveled inside the formation

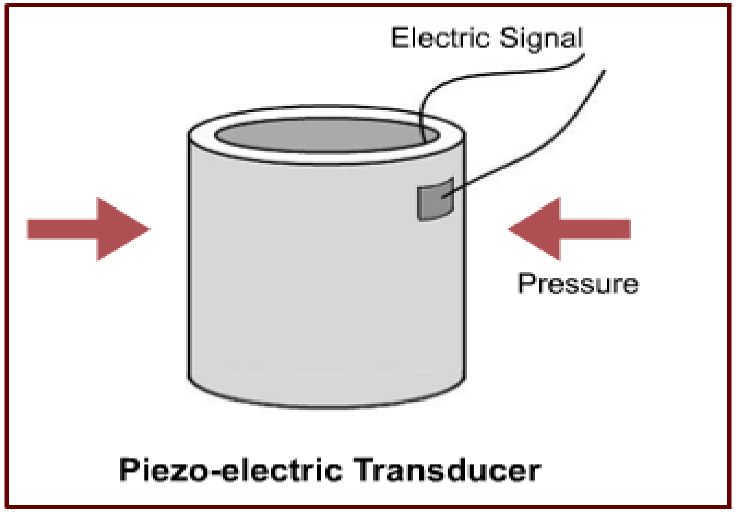



- This approach called First Motion Detection FMD.
- The tool is programed for a threshold for the amplitude. When there will be amplitude higher than threshold the receiver will recorded as TT1 and TT2. to avoid recording noise

$$\Delta t = \frac{TT_2 - TT_1}{Rspac}$$

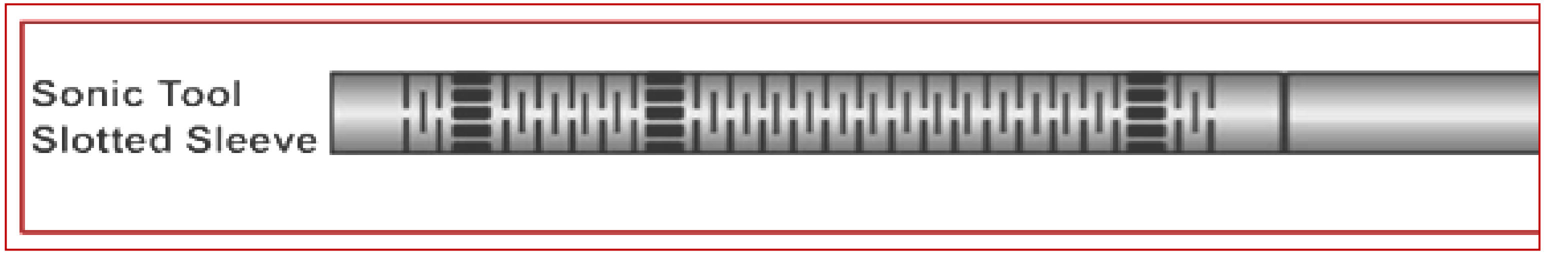
# Receiver and transmitter design

- Sonic transmitter – Piezoelectric material
- Electric pulse is applied to the transmitter – changes volume and generates pressure wave




- Sonic receivers – Piezoelectric ceramic
- This receiver material generates electric voltages when pressure varies

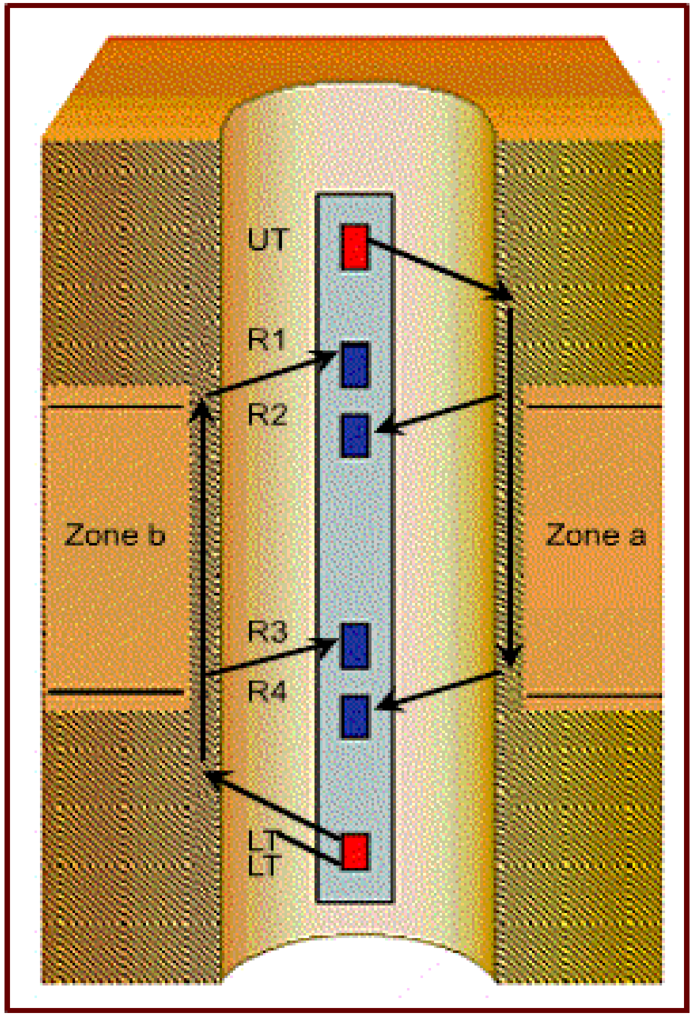
- First motion tools only measure the first arrival – the compressional dt



# BHC Tool

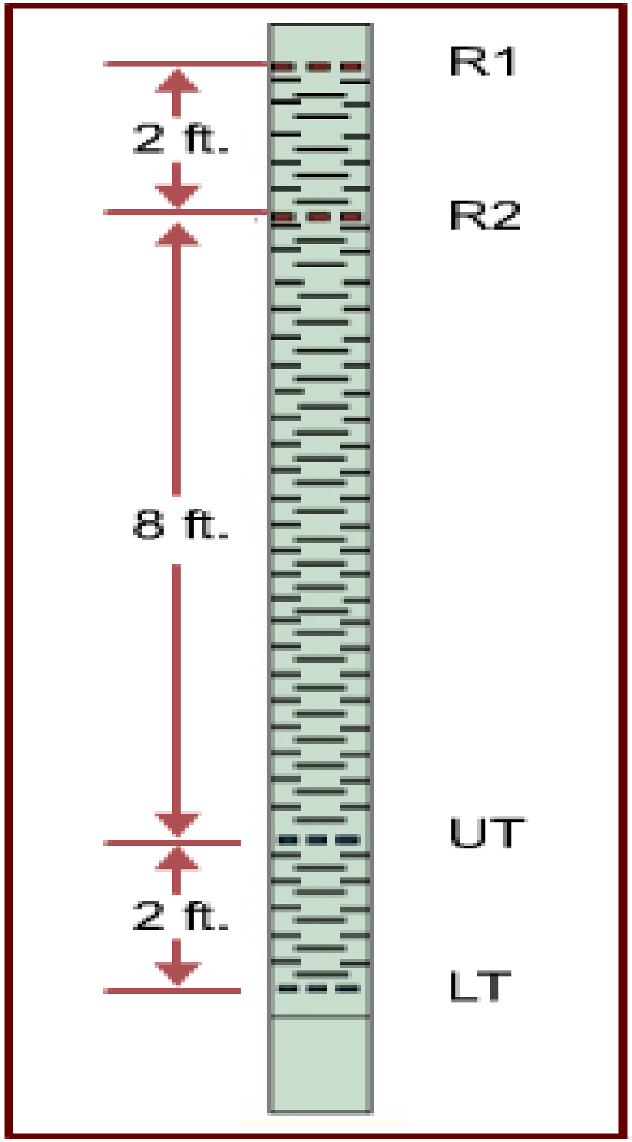
- The tool T-R configuration on the left
- The T-R spacing is 3ft and 5ft
- Dt_BHC is average of Dt_u and Dt_L

$$\Delta t_{BHC} = \frac{\Delta t_U + \Delta t_L}{2}$$



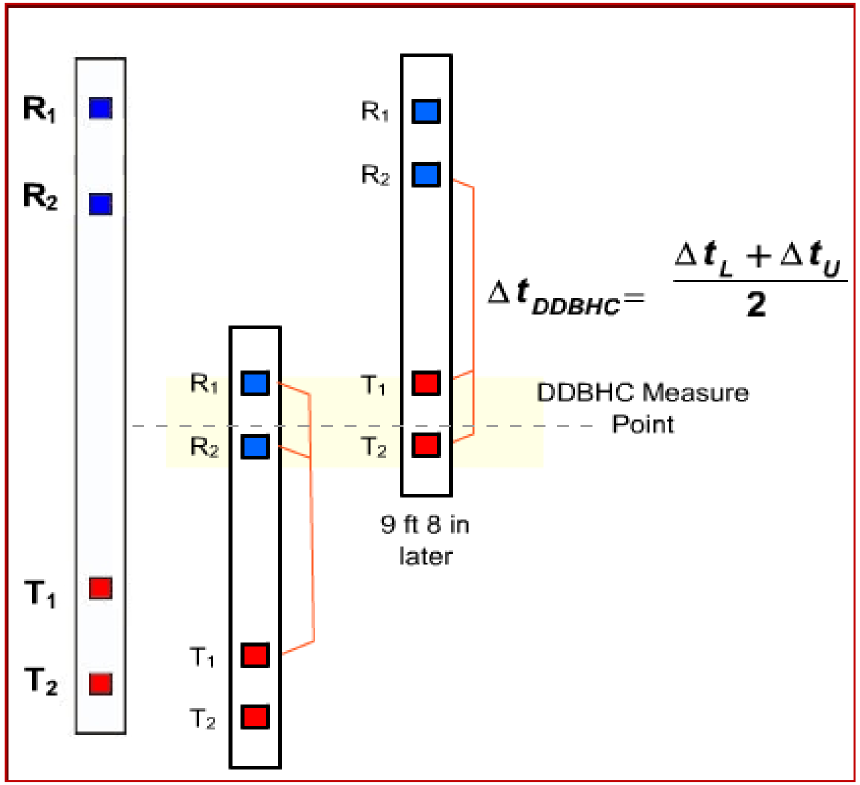
# Long Spaced Sonic Tool (LSS)

- Targeted at altered formation and large boreholes
- The altered zone is slower than the original formation
- This affects Dt from shallow BHC tools (3-5ft)
- LSS tools counter this problem by having a higher T-R spacing>7ft
- LSS → 8-10 ft & 10-12 ft Dt measurements



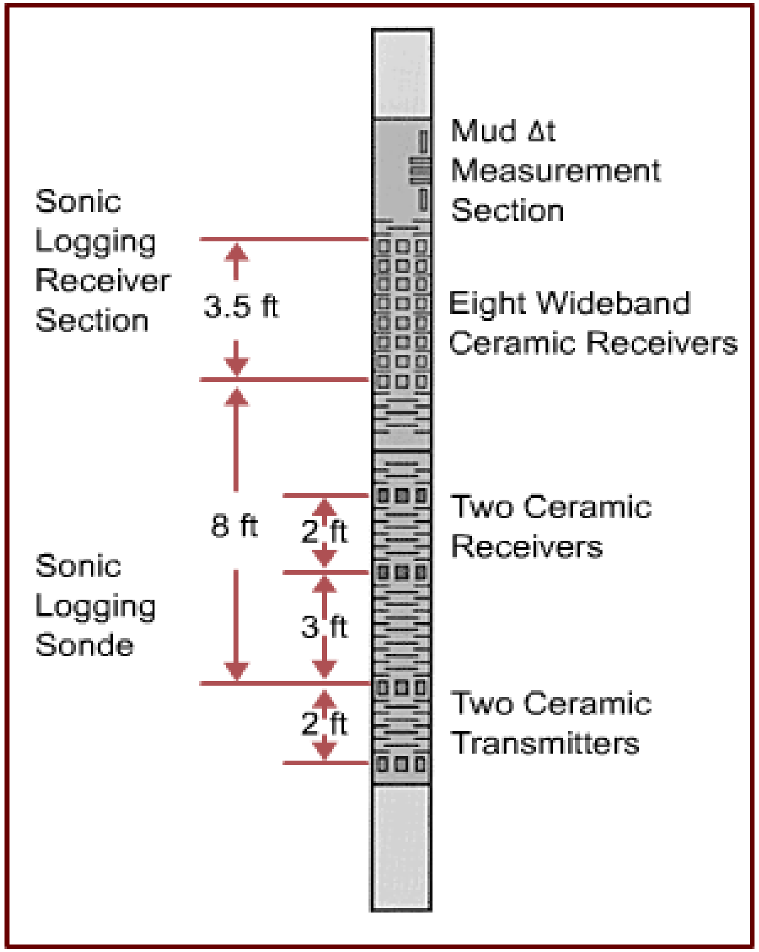
# BH Compensation with LSS

- First Dt is measured between a transmitter and 2 receivers
- Value is memorized
- After the transmitter section has moved up to the interval to be measured, Dt is measured between both transmitters and a common receiver. The average of the two measurements yields DDBHC

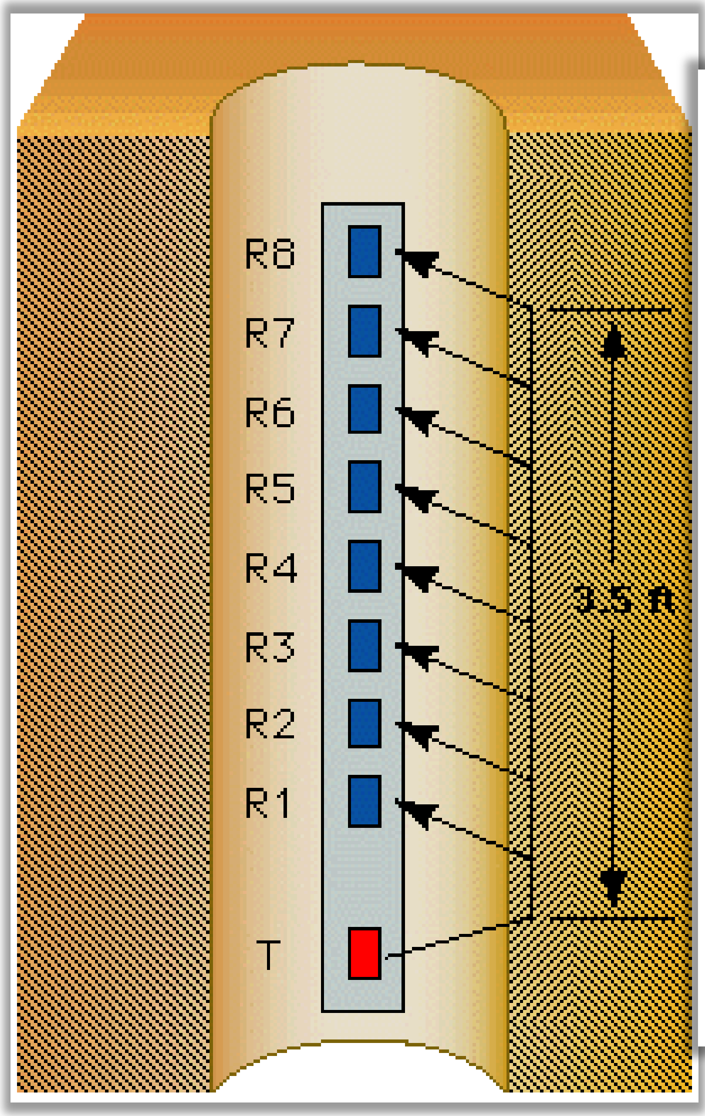


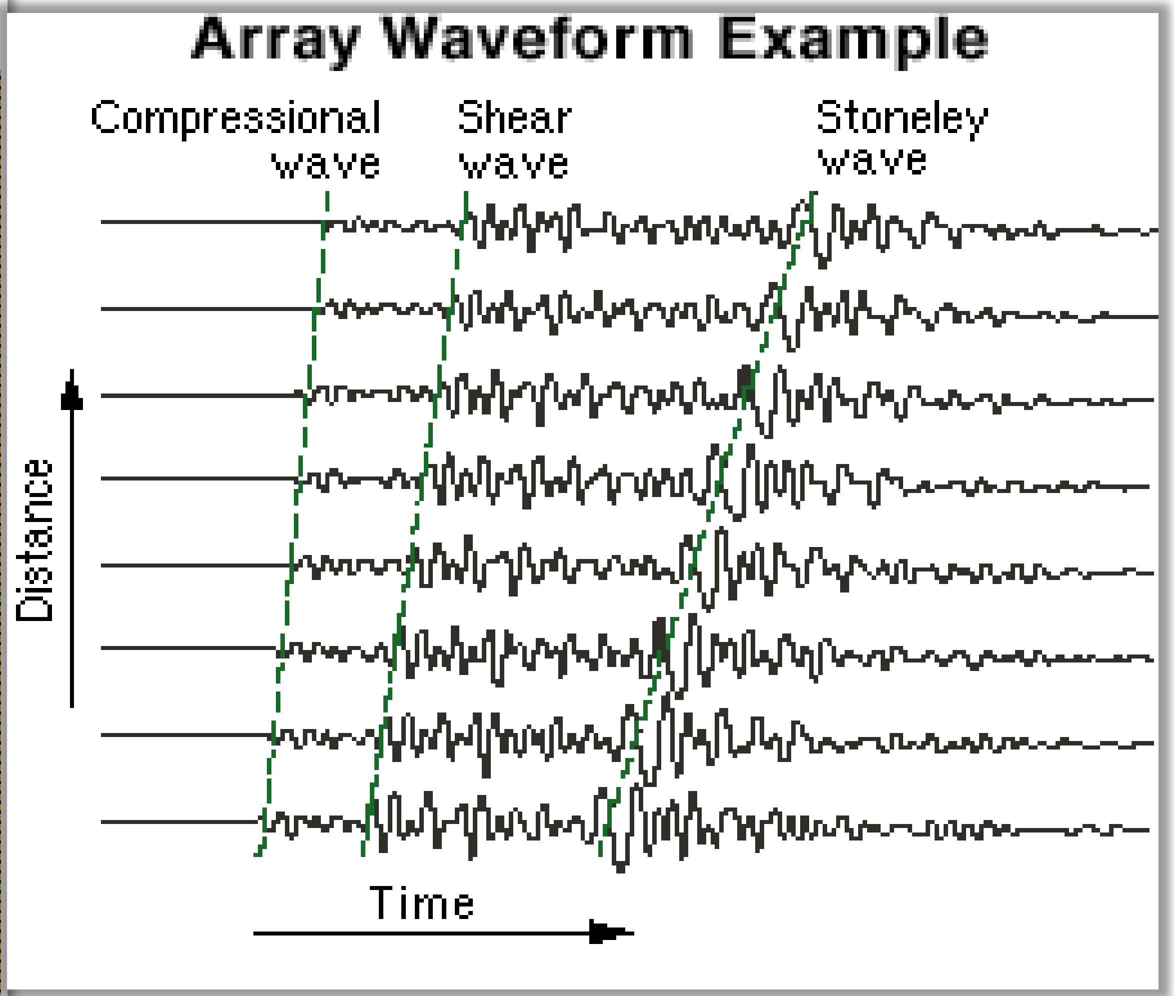
# Array Sonic Tool (SDT)

- First tool that acquires waveforms from an array of receivers
- This allows the evaluation of waveform components in addition to compressional – Shear & Stoneley
- Replaces LSS & BHC
- 8 R – 6 inches apart
- 1st and 5th receiver data used for FMD and Dtc



# Sonic Array


R8
R7
R6
R5
R4
R3
R2
R1
T
3.5 ft


Array Waveform Example
Compressional wave
Shear wave
Stoneley wave
Distance
Time

## Porosity

$\phi_S$ = sonic-derived porosity

$\Delta t_{ma}$ = interval transit time in the matrix (Table 4.1)

$\Delta t_{log}$ = interval transit time in the formation

$\Delta t_{fl}$ = interval transit time in the fluid in the formation (freshwater mud = 189 μsec/ft; saltwater mud = 185 μsec/ft)

$$\phi_S = \frac{\Delta t_{\log} - \Delta t_{ma}}{\Delta t_{fl} - \Delta t_{ma}}$$

Where a sonic log is used to determine porosity in unconsolidated sands, an empirical compaction factor ($C_p$) should be added to the Wyllie et al. (1958) equation:

$$\phi_S = \left(\frac{\Delta t_{\log} - \Delta t_{ma}}{\Delta t_{fl} - \Delta t_{ma}}\right) \times \frac{1}{C_p} \qquad 4.3$$

where:

$C_p$ = compaction factor

The compaction factor is obtained from the following formula:

$$C_p = \frac{\Delta t_{sh} \times C}{100} \qquad 4.4$$

where:

$t_{sh}$ = interval transit time in a shale adjacent to the formation of interest.

$C$ = a constant which is normally 1.0 (Hilchie, 1978).

Interval transit time values from selected depths on

Table 4.1. Sonic Velocities and Interval Transit Times for Different Matrixes. These constants are used in the sonic porosity formulas above (after Schlumberger, 1972).

| Lithology/ Fluid | Matrix velocity ft/sec | $\Delta t_{matrix}$ or $\Delta t_{fluid}$ (Wyllie) µsec/ft [µsec/m] | $\Delta t_{matrix}$ (RHG) µsec/ft [µsec/m] |
|---|---|---|---|
| Sandstone | 18,000 to 19,500 | 55.5 to 51.0 [182 to 168] | 56 [184] |
| Limestone | 21,000 to 23,000 | 47.6 [156] | 49 [161] |
| Dolomite | 23,000 to 26,000 | 43.5 [143] | 44 [144] |
| Anhydrite | 20,000 | 50.0 [164] | |
| Salt | 15,000 | 66.7 [219] | |
| Casing (iron) | 17,500 | 57.0 [187] | |
| Freshwater mud filtrate | 5,280 | 189 [620] | |
| Saltwater mud filtrate | 5,980 | 185 [607] | |