Sonic or Acoustic Log

DEFINITION

- The sonic log is a porosity log that measures interval transit time (**Δt**) of compressional sound wave traveling through one foot of formation.

UNITS

- The units are micro seconds/ft, which is the inverse of velocity.

THE SONIC TRANSIT TIME(T)

It depends on the lithology, porosity and fluids in the pore spaces. It also assumes a homogeneous distribution of porosity. Vuggy and fracture porosity give spurious results.

PRINCIPLES 0F MEASUREMENTS

The tool measures the time it takes for a pulse of "sound" (i.e., and elastic wave) to travel from a transmitter to a receiver, which are both mounted on the tool. The transmitted pulse is very short and of high amplitude vice versa.

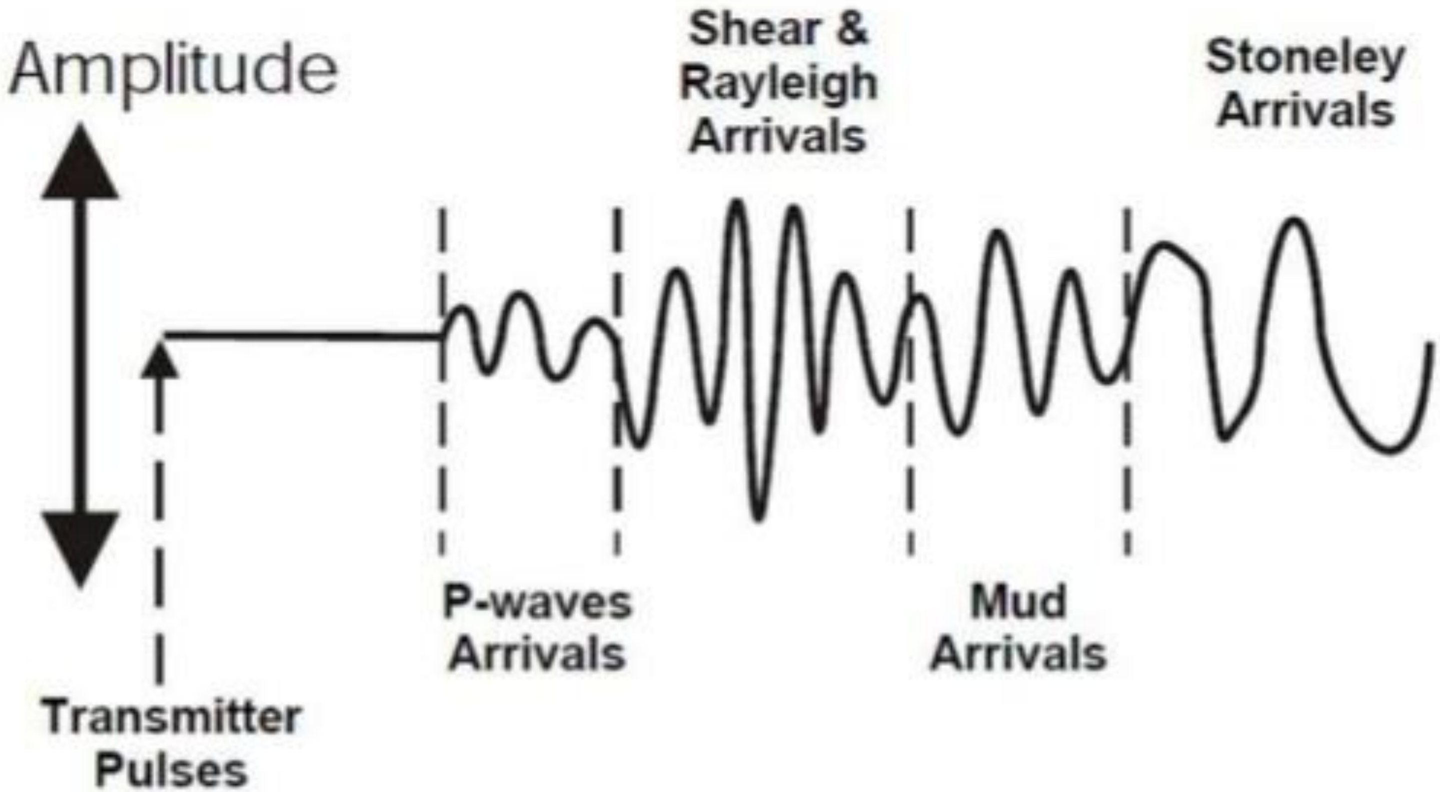
There are Four types of measuring waves

- 1. Compressional or Pressure wave (P wave).

  It is usually the fastest wave, and has a small amplitude.(Fig.1.0)
- 2.The transverse or shear wave (S wave).

  This is slower than the P-wave, but usually has a higher amplitude. So shear wave can't propagate through the fluids.
- 3. Stoneley waves.
- 4. Mud waves

THE GEOPHYSICAL WAVETRAIN RECEIVED BY A SONIC LOG.(FIG.1)



WORKING TOOLS

1. Early Tool
2. Dual Receiver Tool
3. Borehole Compensated Sonic(BHC) Tool
4. Long Spacing Sonic (LSS) Tool

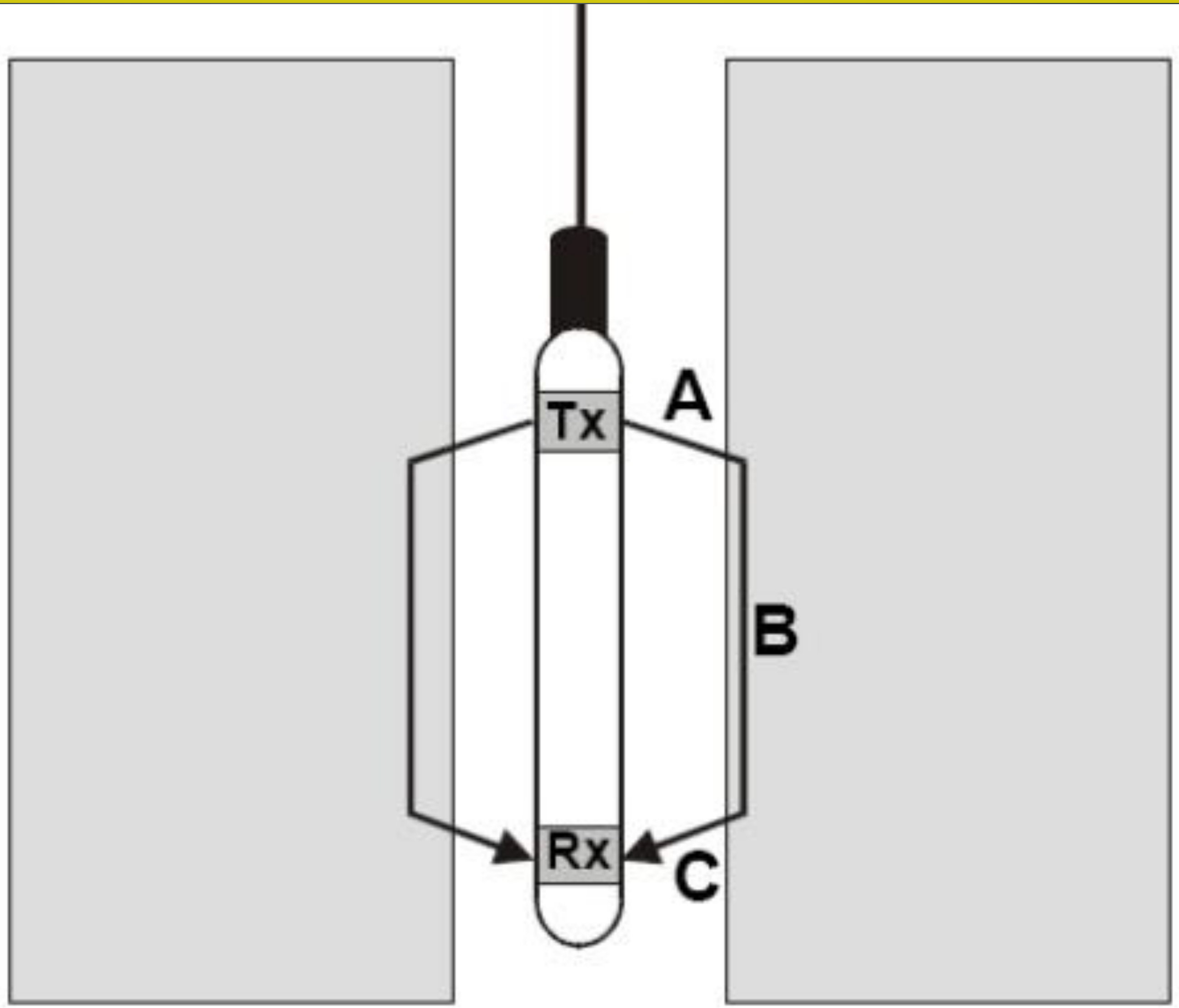
1.Early Tool

Early tools had one (distance from transmitter)Tx and one Rx(distance from receiver) (Fig 1.1). The body of the tool was made from rubber (low velocity and high attenuation material) to stop waves travelling preferentially down the tool to the Rx.

PROBLEM WITH EARLY TOOL

There were two main problems with this tool.

1. The measured travel time was always too long.
2. The length of the formation through which the elastic wave traveled was not constant.



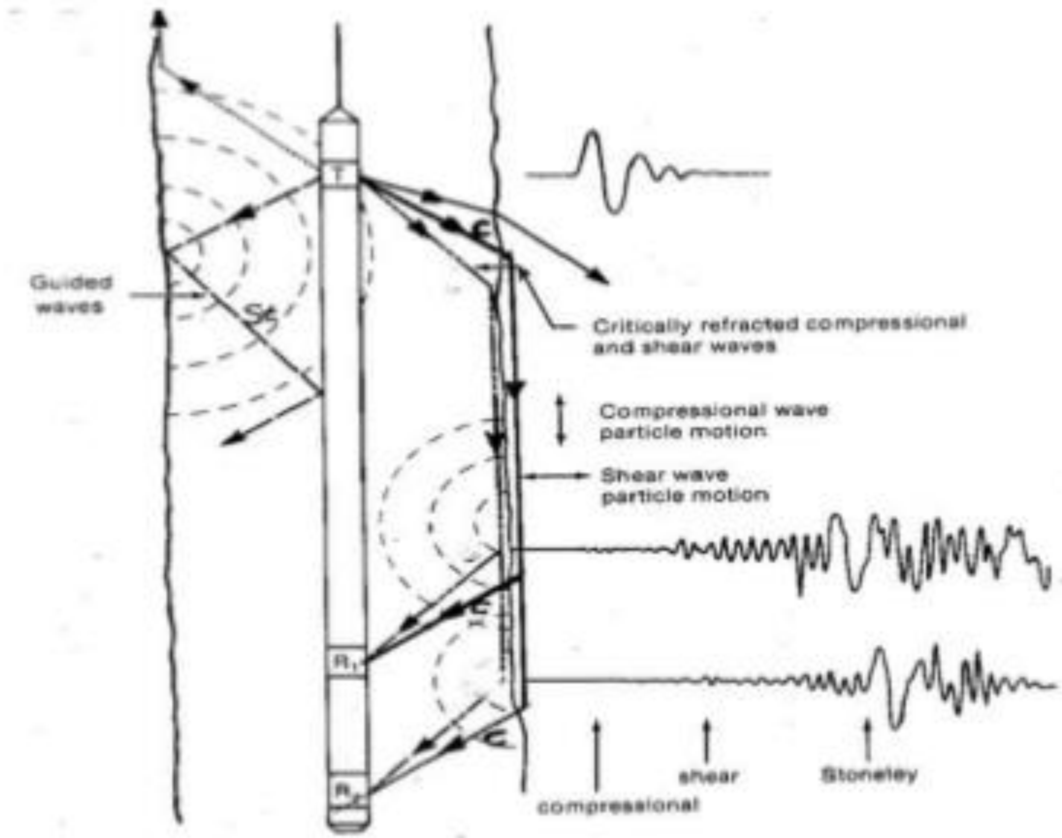
(Fig 1.1). Early tool

2.Dual Receiver Tools

These tools were designed to overcome the problems in the early tools.

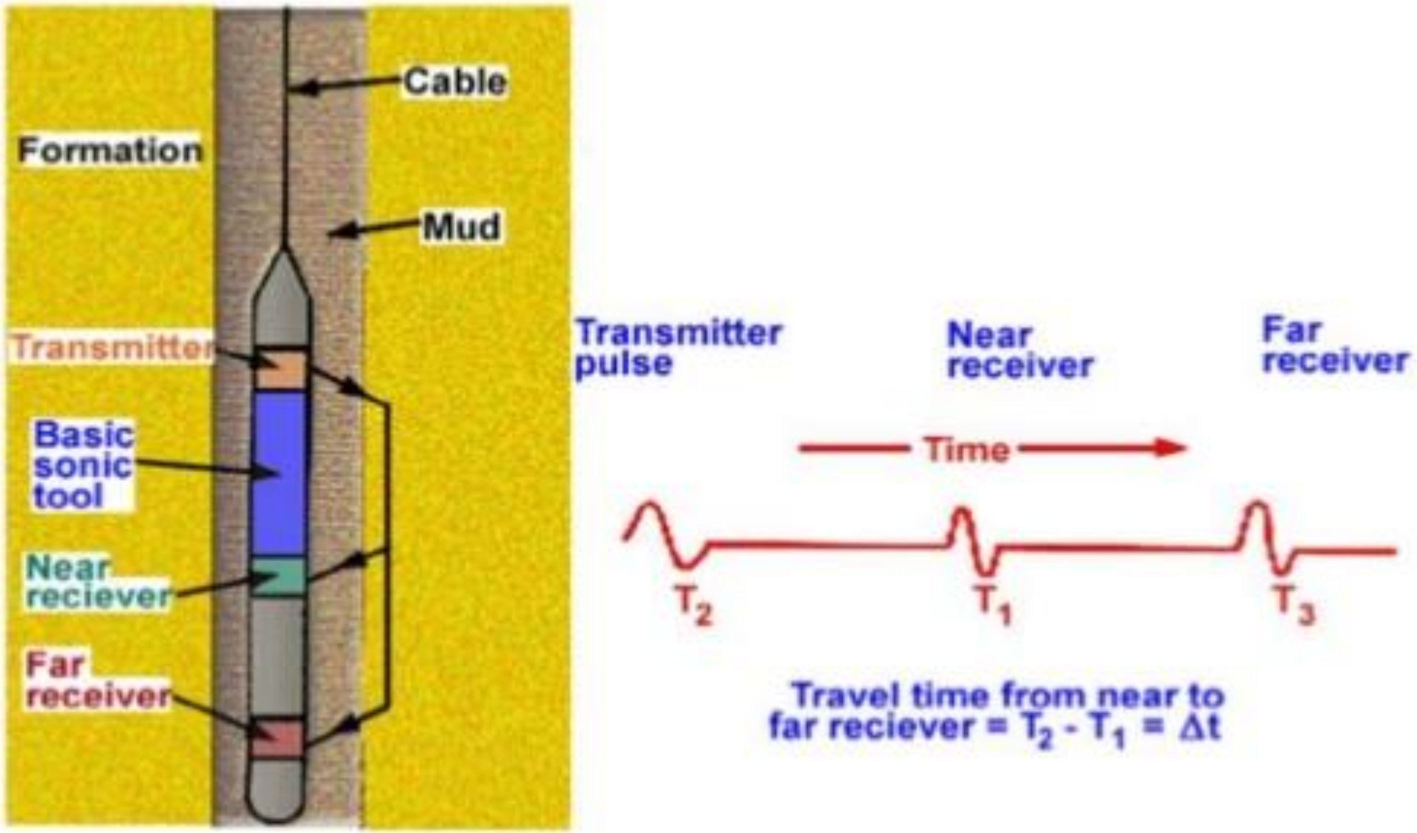
They use two receivers a few feet apart, and measure the difference in times of arrival of elastic waves at each Receiver from a given pulse from the Transmitter (Fig. 1.2,3). This time is called the sonic interval transit time (Δt).

DUAL RECEIVER TOOLS



(Fig. 1.2).

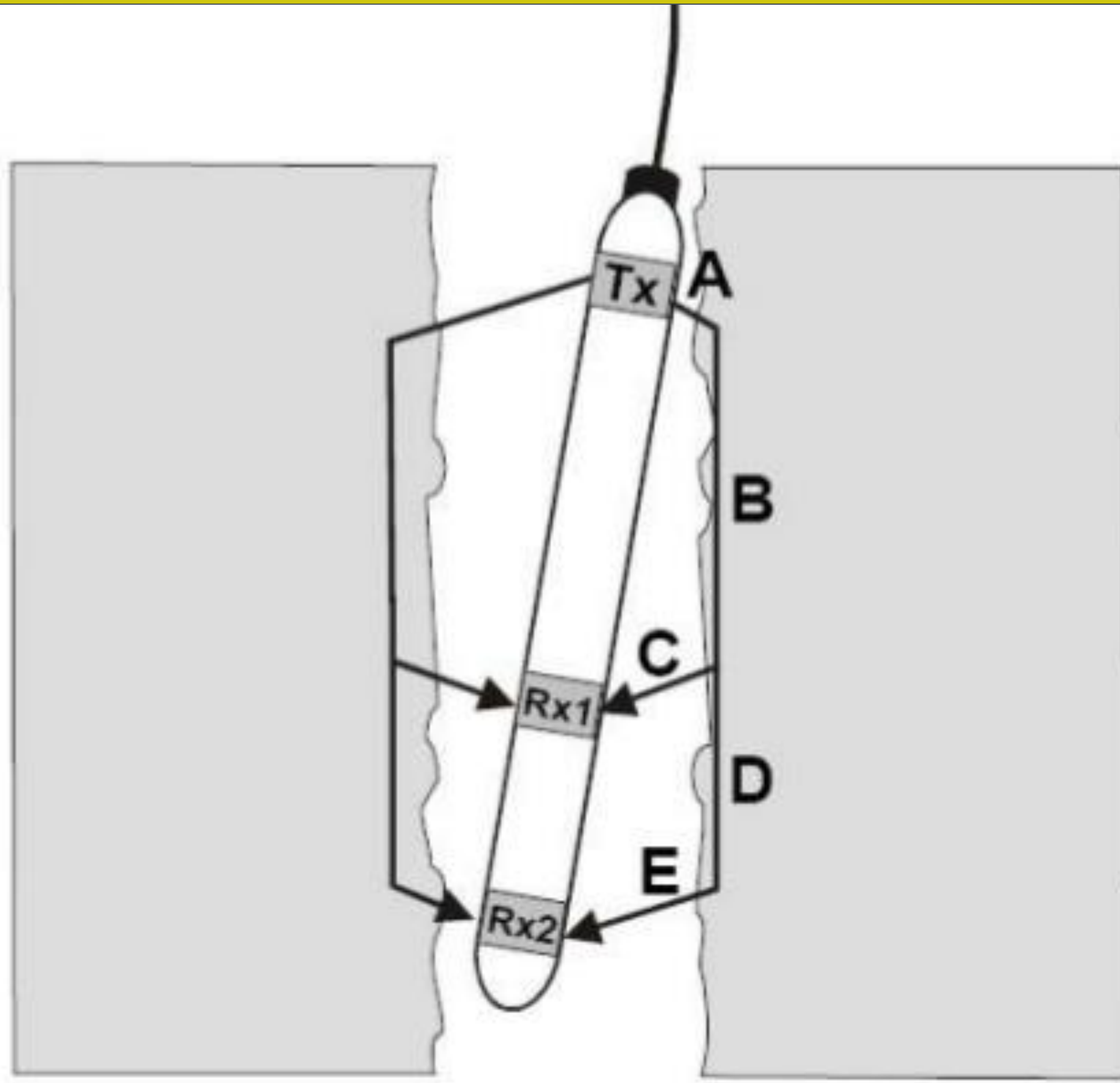
DUAL RECEIVER TOOLS



(Fig. 1.3).

PROBLEM WITH DUAL ARRANGEMENT

The problem with this arrangement is that if the tool is tilted in the hole, or the hole size changes,here the two Rx system fails to work.(Fig.1.4)



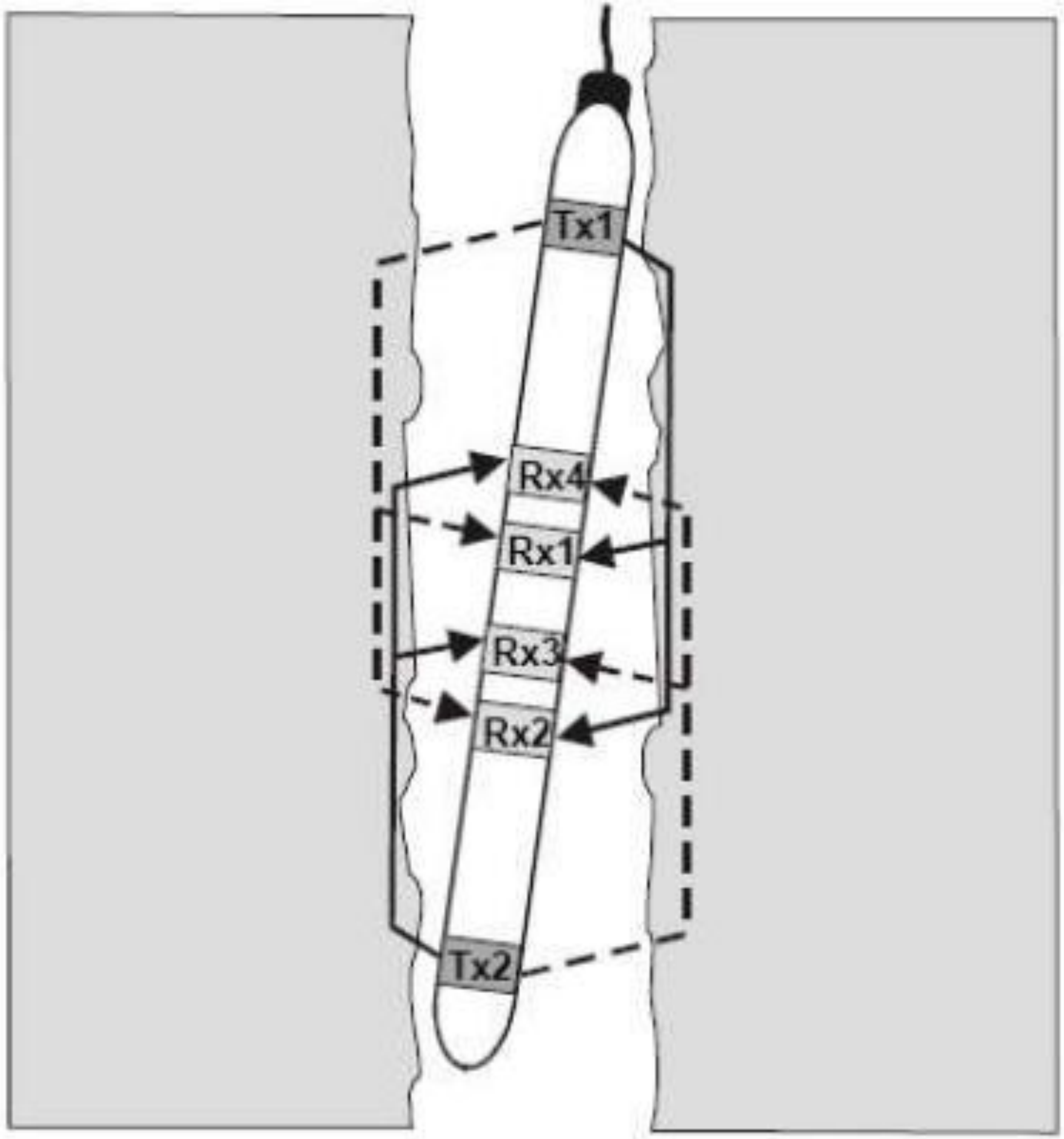
(Fig. 1.4).

3.Borehole Compensated Sonic (BHC) Tool

This tool compensates automatically for problems with tool misalignment and the varying size of the hole (to some extent) that were encountered with the dual receiver tools. It has two transmitters and four receivers, arranged in two dual receiver sets, but with one set inverted (i.e., in the opposite direction). Each of the transmitters is pulsed alternately, and Δt values are measured from alternate pairs of receivers (Fig.1.5). These two values of Δt are then averaged to compensate for tool misalignment, at to some extent for changes in the borehole size.

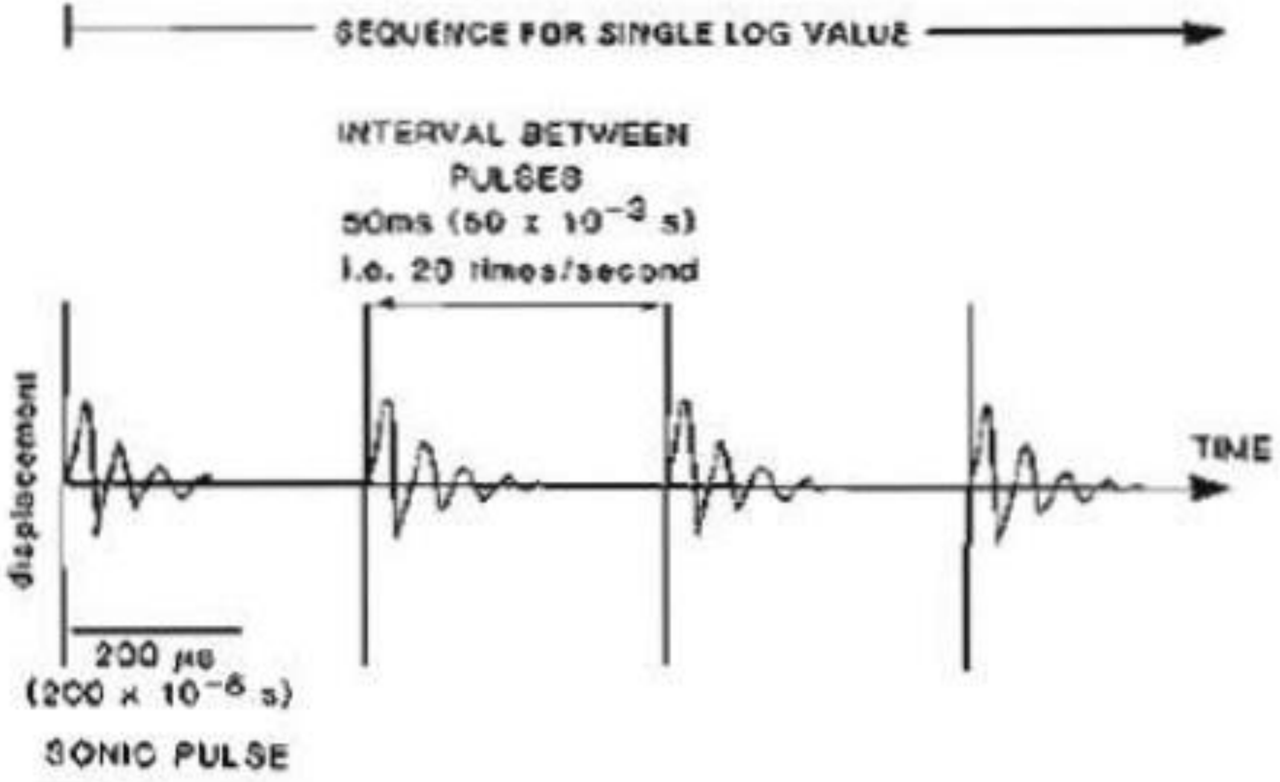
Borehole Compensated Sonic (BHC) Tool

- Automatically compensates for borehole effects and sonde tilt.
- System of upper and lower transmitters bounding two sets of receivers.



(Fig. 1.5).

Four pulses are needed for a complete (BHC) log measurement.



(Fig. 1.6).

Log Presentation

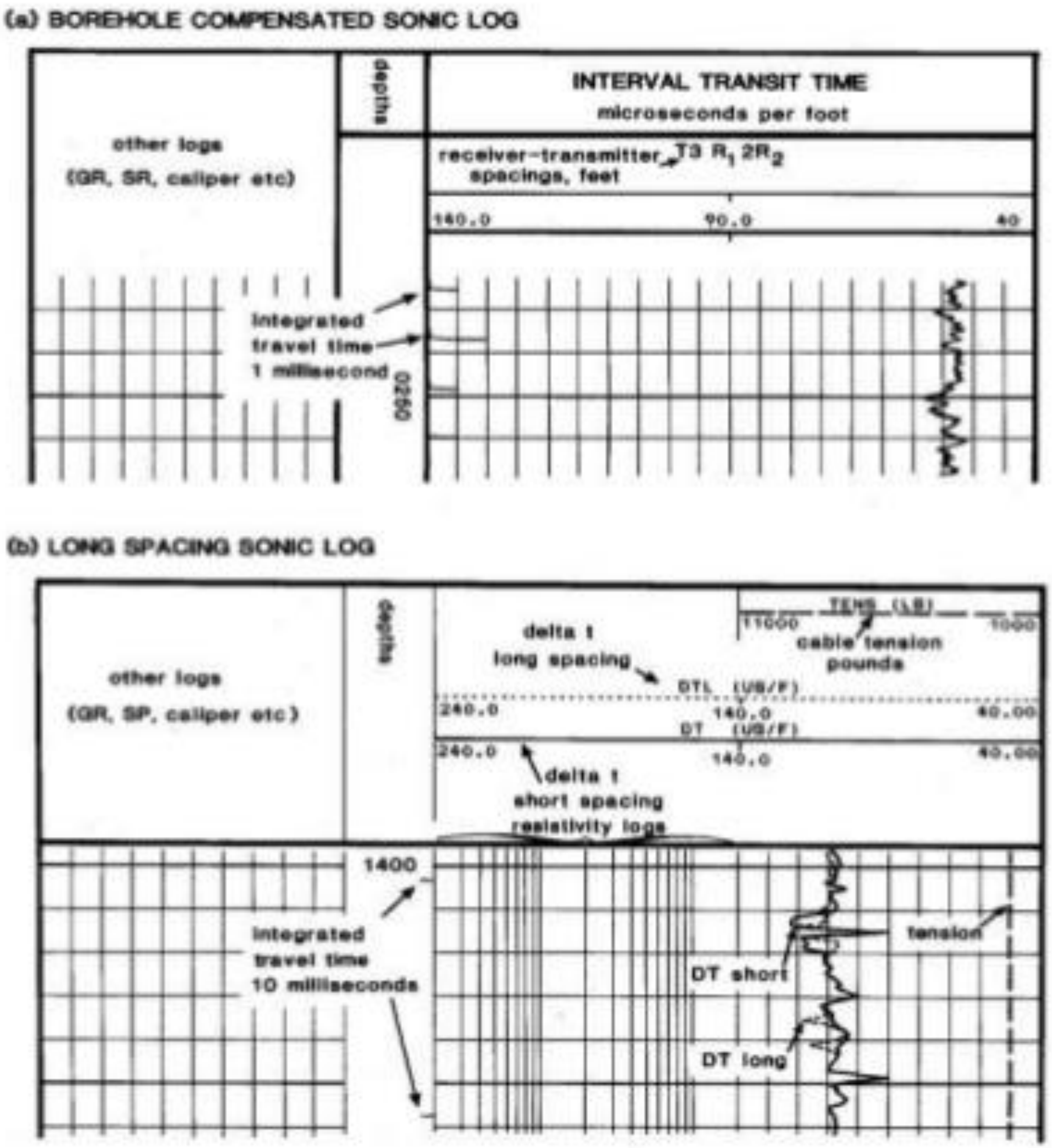
- 1.The Time: The interval transit time t is recorded on the log in microseconds per foot (µs/ft=1.10^{-6} seconds/ft)

- 2. Track: If the log is run on its own, the log takes up the whole of Track 2 and 3, if combined with other logs, it is usually put in Track 3 (Fig.1.7).
- 3.Scale: Most formations give transit times between 40 µs/ft. and 140 µs/ft., so these values are usually used as the scale.

Depth of Investigation

The refracted wave travels along the borehole wall, and its depth of penetration is small (2.5 to 25 cm). It is independent of Tx-Rx spacing, but depends upon the wavelength of the elastic wave.

As wavelength $\lambda = V/f$ (i.e., velocity divided by frequency), for any given tool higher the frequency, higher the velocity the formation has, the larger the wavelength and the deeper the Penetration.



(a) BOREHOLE COMPENSATED SONIC LOG
other logs
(GR, SR, caliper etc)
depths
INTERVAL TRANSIT TIME
microseconds per foot
receiver-transmitter spacings, feet
140.0
90.0
40
integrated
travel time
1 millisecond
0260
(b) LONG SPACING SONIC LOG
other logs
(GR, SP, caliper etc)
depths
delta t
long spacing
TENS (LB)
cable tension
pounds
DTL (US/F)
240.0
140.0
40.00
DT (US/F)
240.0
140.0
40.00
delta t
short spacing
resistivity logs
1400
integrated
travel time
10 milliseconds
DT short
tension
DT long

(Fig. 1.7).

APPLICATION IN GEOLOGY

Quantities Uses

Determination of Porosity

The sonic log can be used to calculate porosities.

To use the log it is necessary to propose that a formation has, on average, a uniform distribution of small pores and is subjected to a heavy confining pressure, there is a simple relationship between velocity and porosity.

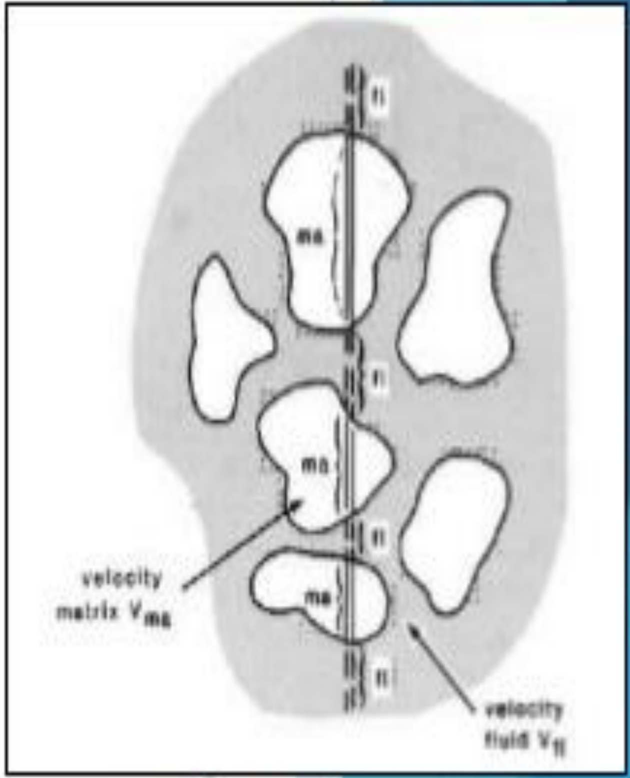
The Wyllie Time Average Equation

- The velocity of elastic waves through a given lithology is a function of porosity

$$\frac{1}{V} = \frac{\phi}{V_p} + \frac{(1-\phi)}{V_{ma}}$$

$$\Delta t = \phi \, \Delta t_p + (1-\phi) \Delta t_{ma}$$

$$\phi_s = \frac{\Delta t - \Delta t_{ma}}{\Delta t_p - \Delta t_{ma}}$$



$Ø_{sonic}$ = sonic derived porosity in clean formation
Δt = interval transit time of formation
$Δt_{ma}$ = interval transit time of the matrix
(sandstone=55.5,limestone=47.6,dolomite=43.5,anhydrite=50)
$Δt_p$ = interval transit time of the pore fluid in the well bore
(fresh mud = 189; salt mud = 185)
Unit=microsecond per feet

Fig 1.6 The wave path through porous fluid saturated rocks

The Wyllie Time Average Equation

- Wyllie Time Average Equation is valid only for
  - For clean and consolidated sandstones
  - Uniformly distributed small pores

- **Correction:** Observed transit times are greater in uncompacted sands; thus apply empirical correction factor, Cp
  - $\Phi_c = \Phi/Cp$
  - $Cp = c * \Delta t_{sh}/100$ (Δt_{sh} = Interval transit time for the adjacent shale)
  - C=shale compaction coefficient (ranges from $0.8 < c < 1.3$)

- Fluid Effect in high porosity formations with high HC saturation.
  - Correct by
  - *OIL:* $\Phi_{corr} = \Phi_c * 0.9$
  - *GAS:* $\Phi_{corr} = \Phi_c * 0.7$

Material	Δt (µs/ft.)	V (ft./s)	V (m/s)
Compact sandstone	55.6 – 51.3	18000 – 19500	5490 – 5950
Limestone	47.6 – 43.5	21000 – 23000	6400 – 7010
Dolomite	43.5 – 38.5	23000 – 26000	7010 – 7920
Anhydrite	50.0	20000	6096
Halite	66.7	15000	4572
Shale	170 – 60	5880 – 16660	1790 – 5805
Bituminous coal	140 – 100	7140 – 10000	2180 – 3050
Lignite	180 – 140	5560 – 7140	1690 – 2180

Table.1. Values of Δt and V in different rocks

Overpressure

- An increase in pore pressures is shown on the sonic log by a drop in sonic velocity or an increase in sonic travel time

Break in the compaction trend with depth to higher transit times with no change in lithology

Indicates the top of an overpressured zone.

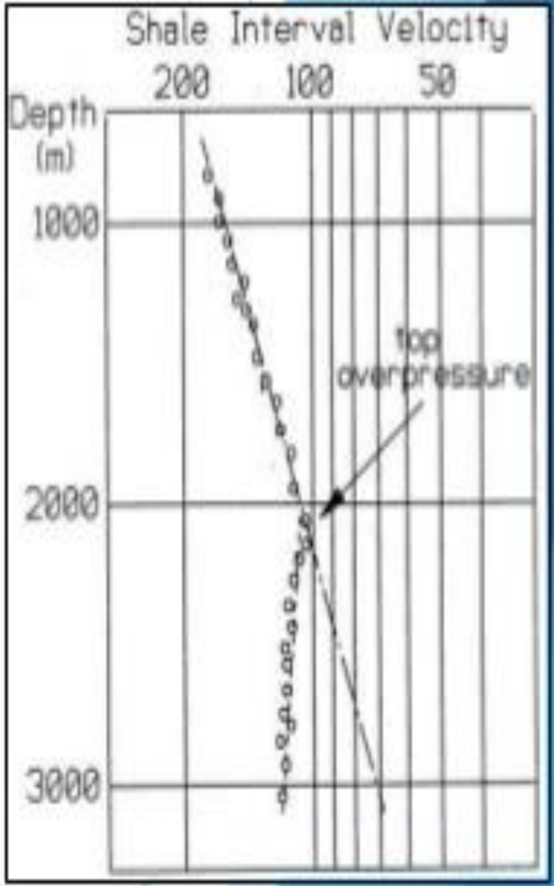


Fig 1.9 An overpressured zone distinguished from sonic log data.

Vertical and Bed Resolution

The vertical resolution is equal to the Rx-Rx spacing, and hence is 2 ft. Beds less than this thickness can be observed, but will not have the signal fully developed.

Logging Speed

The typical logging speed for the tool is 5000 ft/hr (1500 m/hr), although it is occasionally run at lower speeds to increase the vertical resolution.

THE EFFECT OF GAS ON THE SONIC DERIVED POROSITY

Gas has a low density, This causes an increase in the sonic transit time, and hence an increase in porosity that is overestimated.

However, the sonic tool penetrates to shallow levels, and senses the flushed zone. Most gas, even in high porosity gas-bearing formations will be replaced by mud filtrate.

The remaining 15% or so will still have an effect upon the measure sonic transit time and the sonic porosity.

Qualitative Uses

Lithology identification

The velocity or interval travel time is rarely diagnostic of a particular rock type.

High velocities

Usually indicate carbonates

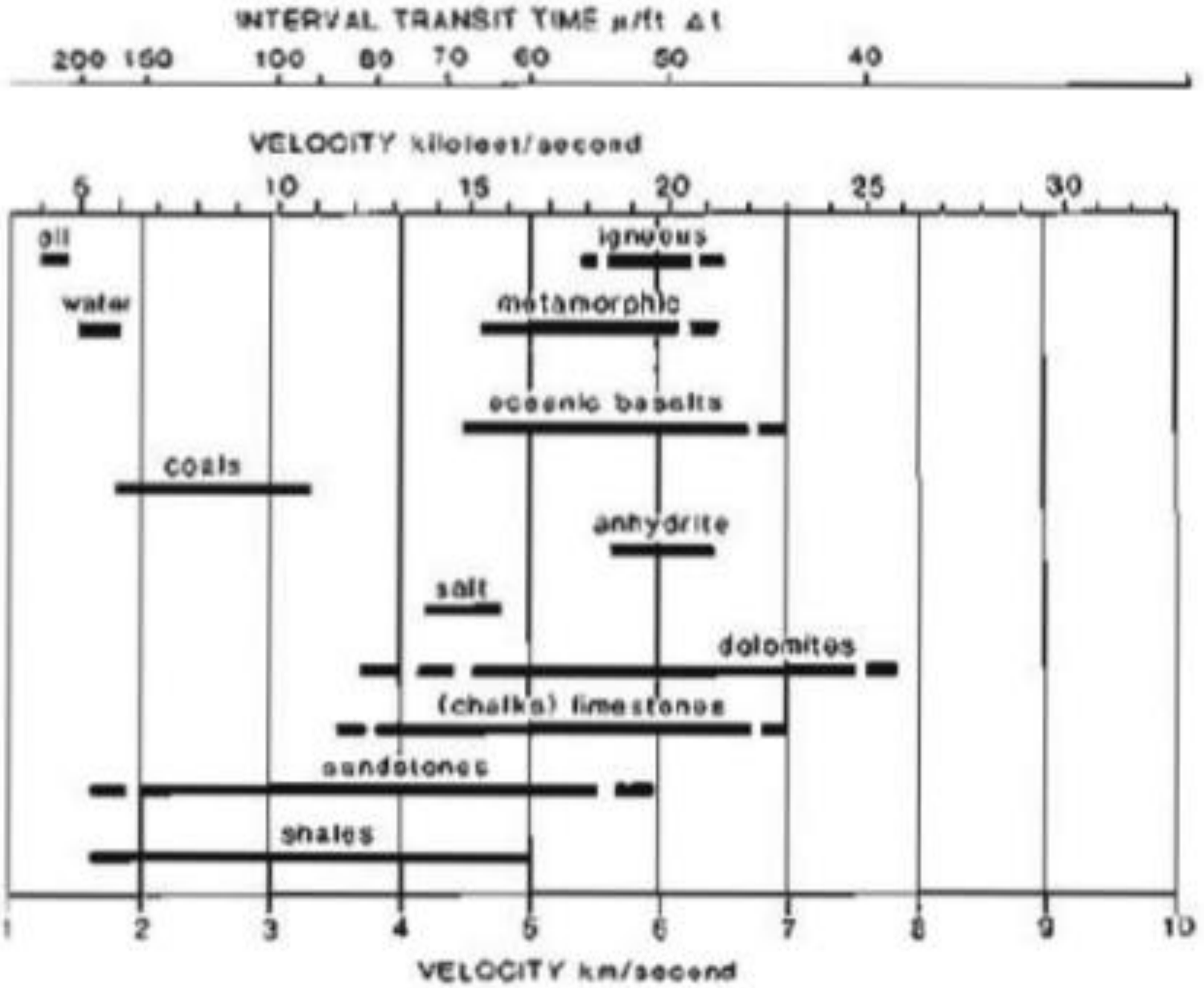
Middle velocities

Indicate sands

Low velocities

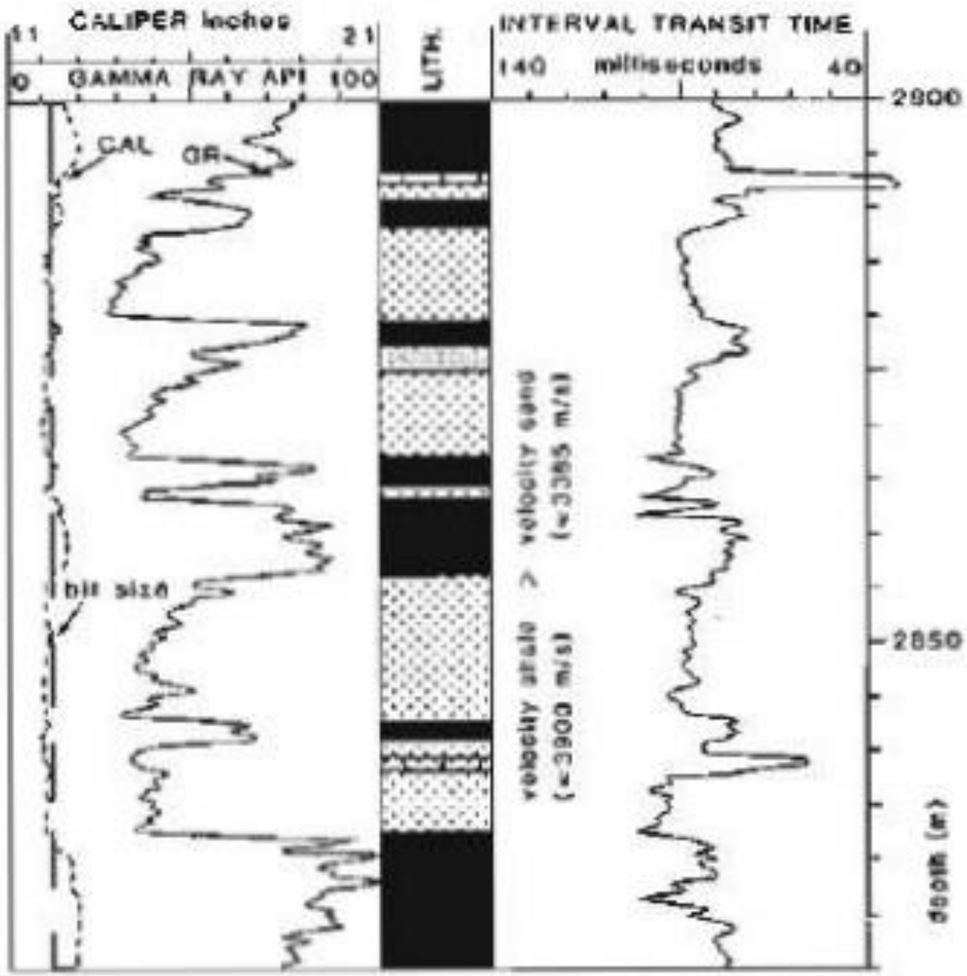
Indicate shale

RANGES OF VELOCITIES IN COMMON LITHOLOGIES



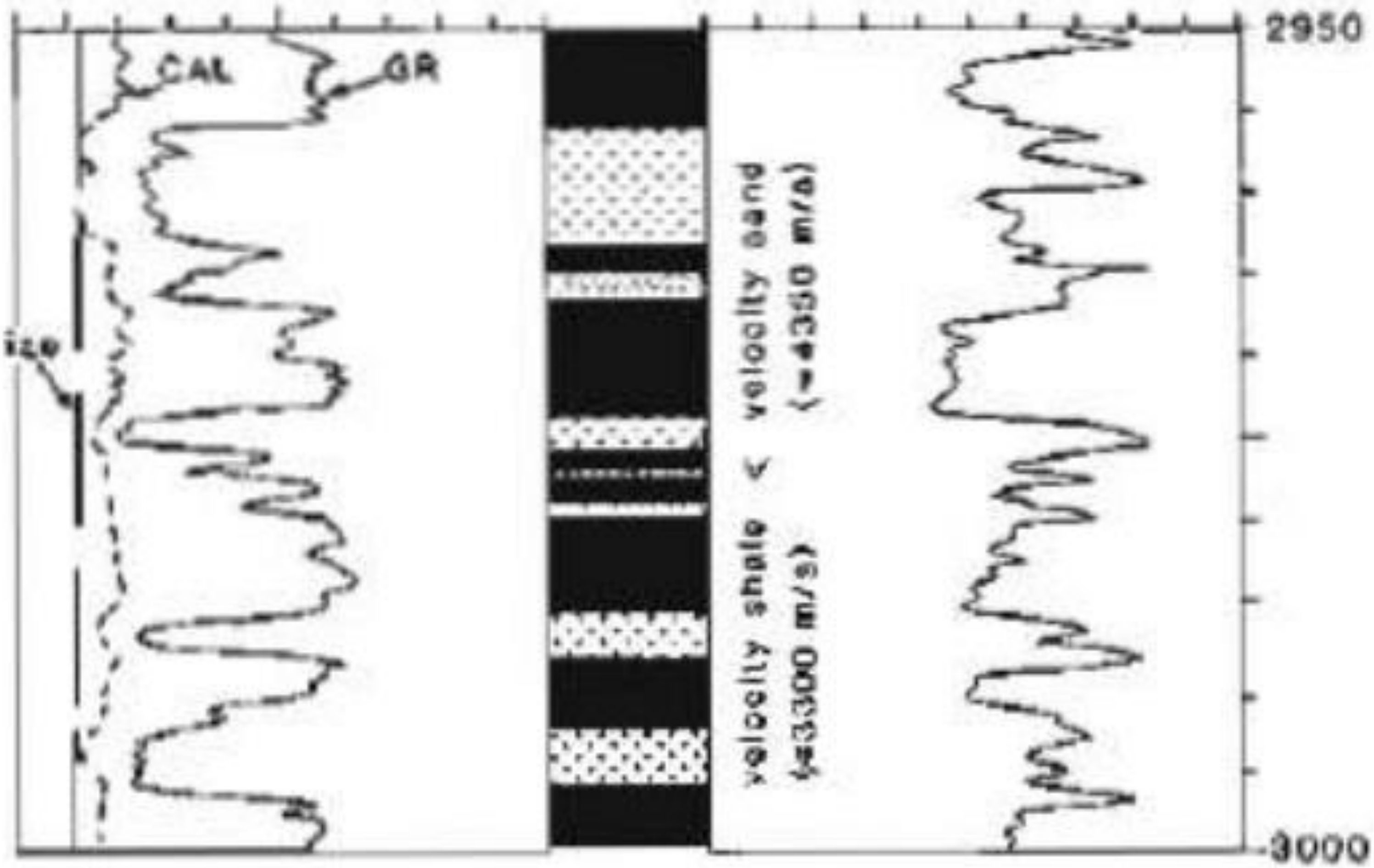
(Fig. 1.9).

LOG ILLUSTRATION



(Fig. 1.10).

LOG ILLUSTRATION



(Fig. 1.11).

TEXTURE DETERMINATION

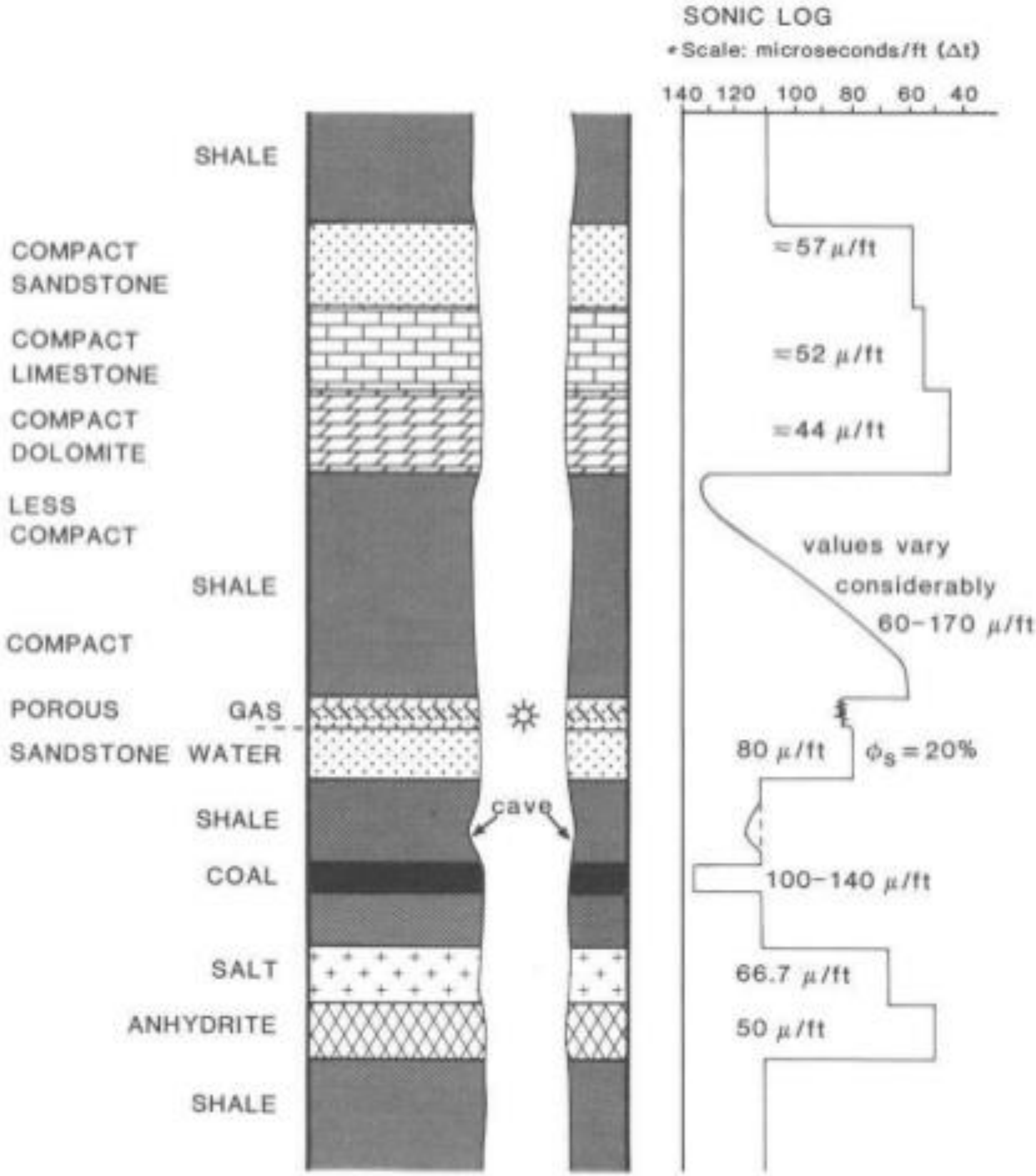
Sonic response may not be diagnostic in terms of lithology, it is very sensitive to rock texture, even subtle changes.

The way in which sound travels through a formation is intimately associated with

- Matrix
- Matrix materials
- Grain size distribution
- Shape, and cementation in other words texture.

Compaction

As a sediment becomes compacted, the velocity of elastic waves through it increases. If one plots the interval transit time on a logarithmic scale against depth on a linear scale, a straight line relationship emerges. This is a compaction trend.


SONIC LOG
* Scale: microseconds/ft (Δt)
140 120 100 80 60 40
SHALE
COMPACT
SANDSTONE
COMPACT
LIMESTONE
COMPACT
DOLOMITE
LESS
COMPACT
SHALE
COMPACT
POROUS
GAS
SANDSTONE
WATER
SHALE
COAL
SALT
ANHYDRITE
SHALE
cave
≈57 μ/ft
≈52 μ/ft
≈44 μ/ft
values vary
considerably
60-170 μ/ft
80 μ/ft
φs = 20%
100-140 μ/ft
66.7 μ/ft
50 μ/ft

(Fig. 1.12).

Fracture Identification

- The sonic log porosity is probably only that due to the matrix, and does not include fracture porosity. this is because the sonic pulse will follow the fastest path to the receiver and this will avoid fractures. Comparing sonic porosity to a global porosity (density log)should indicate zone of fracture.

Seismic Data Calibration

The presence of a sonic log in a well that occurs on a seismic line or in a 3D survey enables the log data to be used to calibrate and check the seismic data. As the resolution of the sonic log is about 61cm and that of the seismic technique is 100cm to 500cm, the sonic data must be averaged for the comparison to be made.

So It must be remembered that the sonic log gives a one-way travel time, and the seismic technique gives a two-way travel time.

Synthetic Seismograms

- Represents the seismic trace that should be observed with the seismic method at the well location
- Improve the picking of seismic horizons
- Improve the accuracy and resolution of formations of interest

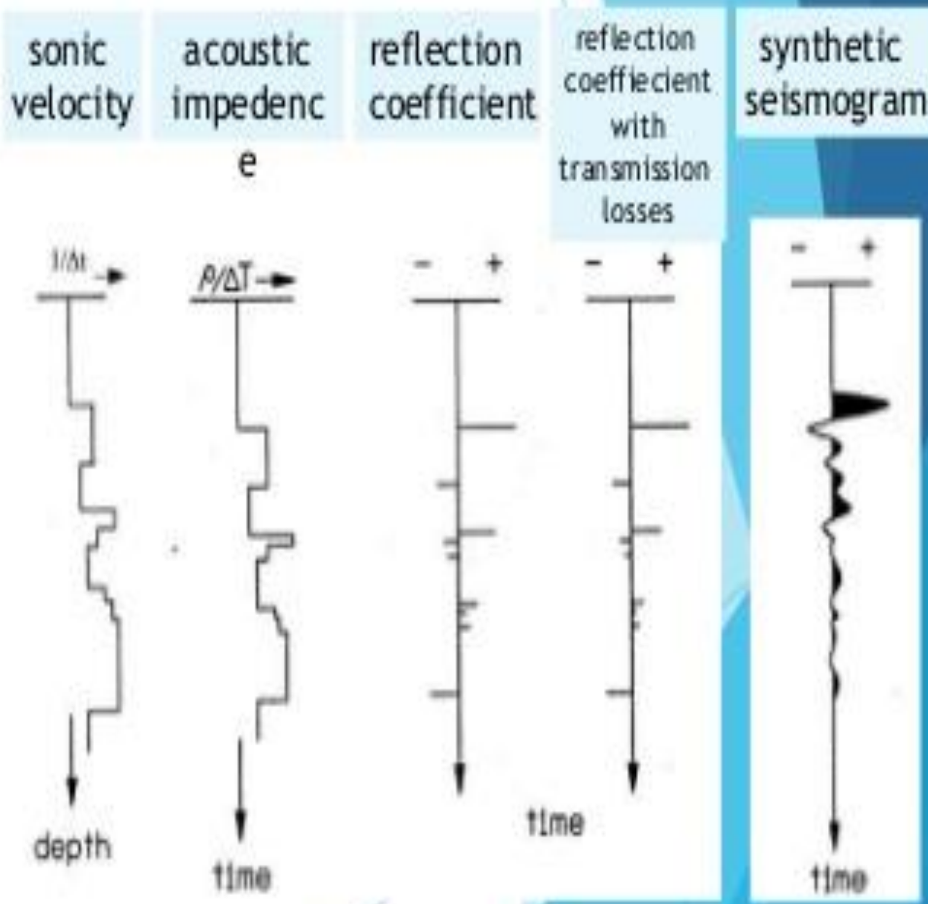


Fig 1.10 The construction of a synthetic seismogram.

REFERENCES

1. Serra, O. (1988) Fundamentals of well-log interpretation. 3rd ed. New York: Elselvier science publishers B.V..p.261-262.
2. Rider, M. (2002) The geological interpretation of well logs. 2nd ed. Scotland: Rider French consulting Ltd..p.26-32.
3. http://www.dot.ca.gov/hq/esc/geotech/gg/Sonic_log.htm
4. Neuendorf, et al. (2005) Glossary of Geology. 5th ed. Virginia: American geological institute.p.90, 379, 742.