SAPIENZA
UNIVERSITÀ DI ROMA

Environmental geophysics

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1. Seismic methods

Instruments

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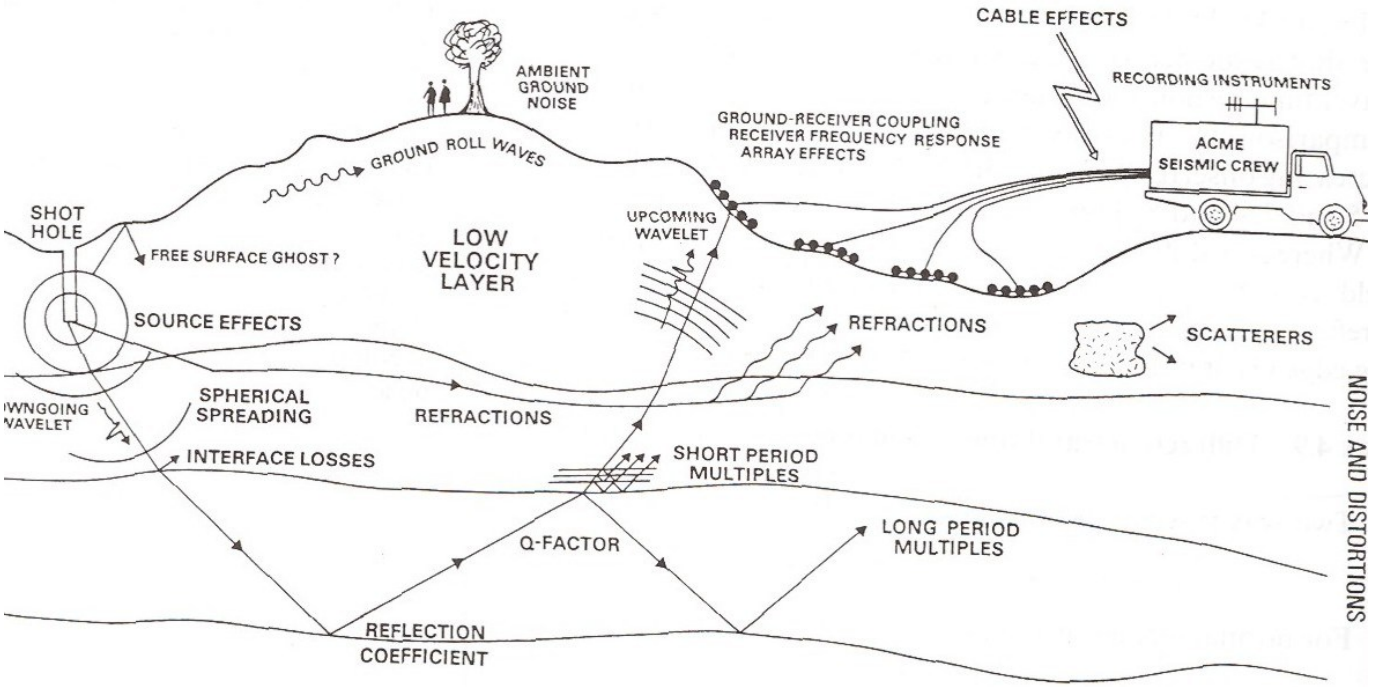
Seismic instruments

Seismic equipment for wave generation and signal recording

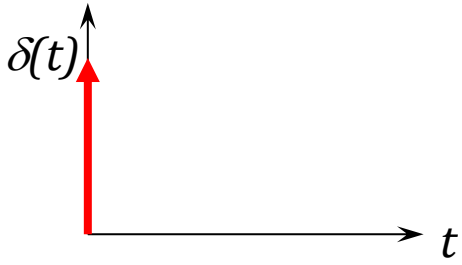
- SOURCE (different types)
- RECEIVER(S) (different types)
- TRASMISSION CABLES
- SEISMOGRAPH (A/D conversion and signal recording)



Seismic sources

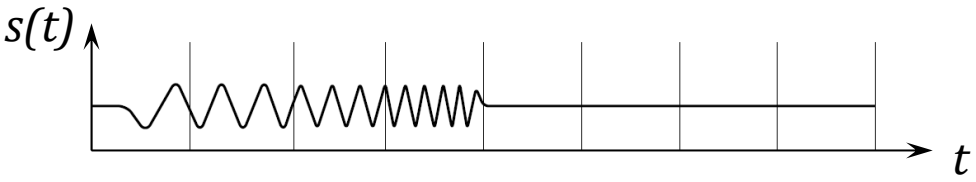
Seismic sources can be divided into two main classes, depending on the woking principle:

- **Pulse**
  - ✓ Hammer
  - ✓ Weight drop
  - ✓ Explosives
  - ✓ Shotgun
  - ✓ Sparker



Sending an unknown signal, approximating an instantaneous impulse (Dirac delta)

- **Vibrating**
  - ✓ Vibroseis
  - ✓ Chirp (marine survey)



Sending a known signal: I must correlate the receiver response with the source signal (cross-correlation) to extract seismic information

Seismic sources – P-wave

Sledge-hammer + plate

- ✓Most popular
- ✓Economic
- ✓Low energy
- ✓Low repeatability

Light-hammer + plate

- ✓Only feasible option for archaeological purposes
- ✓Economic
- ✓Low energy
- ✓Low repeatability

Examples of weight drop

Seismic sources – P-wave

Shotgun

- ✓ Slightly expensive (bullets)
- ✓ Moderate energy
- ✓ Good repeatability

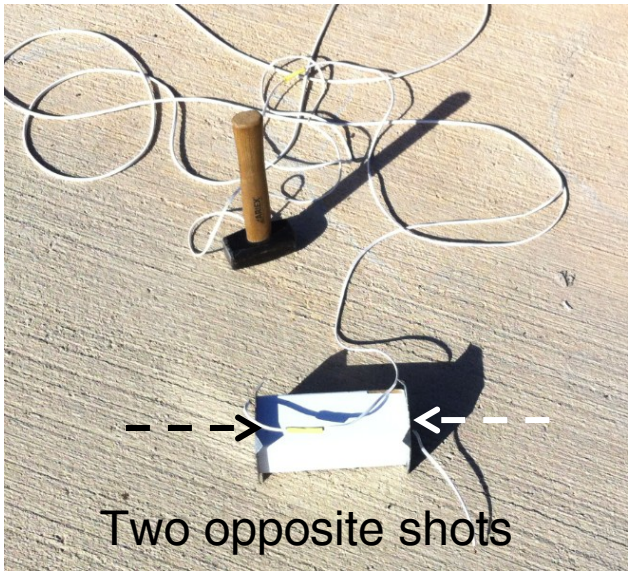
Blast (explosion)

- ✓ Very expensive
- ✓ Good only for large areas without anthropic features
- ✓ High energy
- ✓ Good repeatability

Seismic sources – S-wave

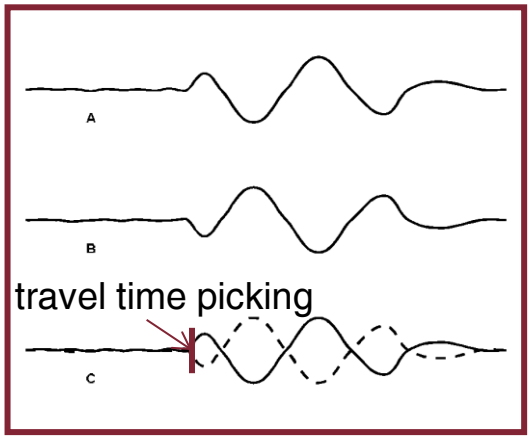
Sledge-hammer + plate

Light-hammer + plate



Q. Why we do perform two opposite shots?

A. Because the **S-wave is never the first arrival**. Therefore, we can easily understand the travel time **picking** as **the instant where the two traces diverge.**



Seismic sources – S-wave

Sledge-hammer + plate

Seismic sources – Borehole

Sparker

✓Slightly expensive
✓Only for borehole seismics
✓High energy
✓ Good repeatability

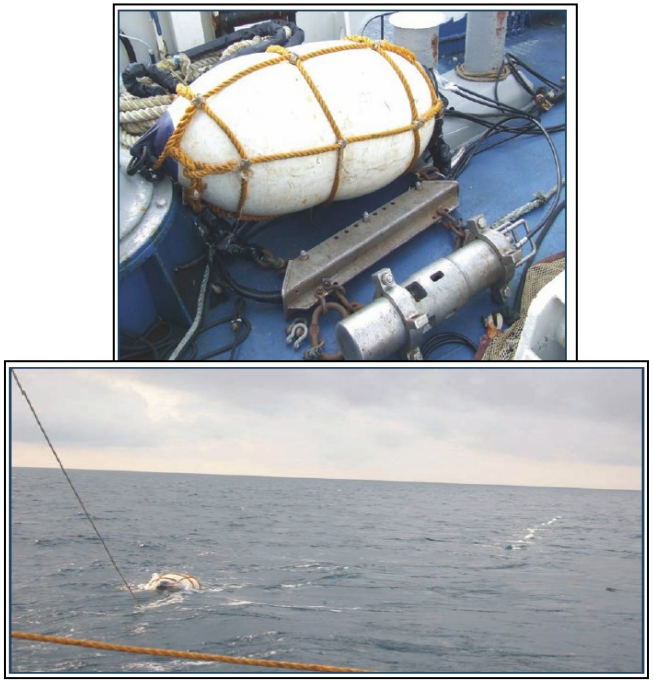
Vibroseis

✓Signal needs to be correlated
✓Very slow
✓Moderate energy
✓Good repeatability

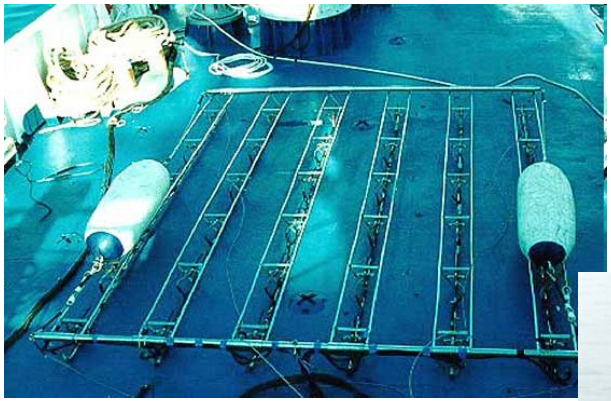
Seismic sources – Marine

Marine surveys are carried out with pulse or vibrating sources using the same principles as for land sources but with different features

Airgun (pulse)



Sparker (pulse)

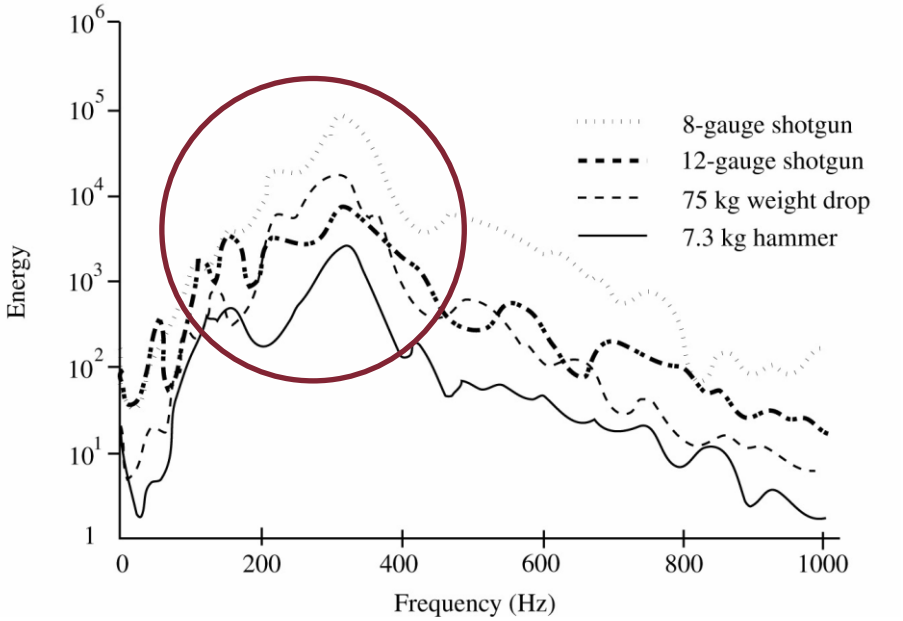


Chirp (vibrating)

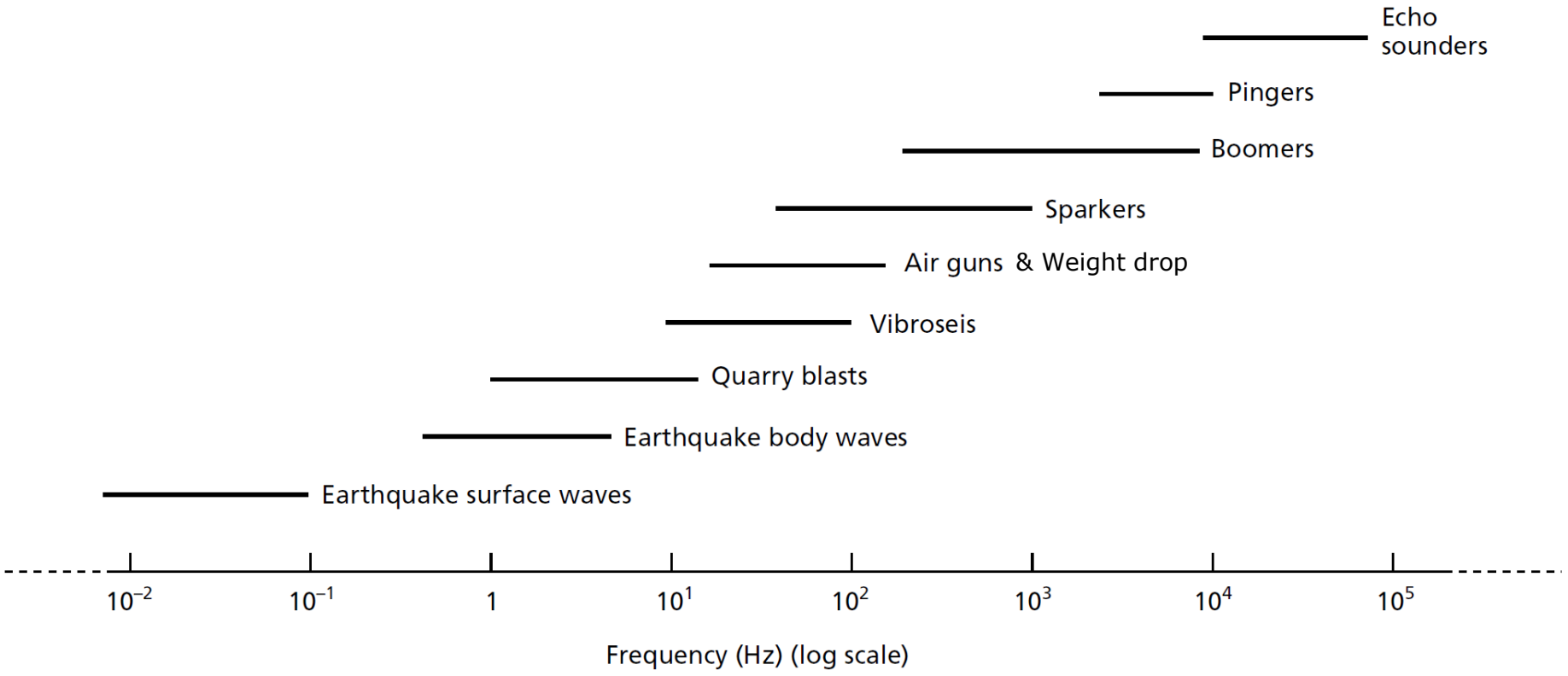
Seismic sources

Source	Repeatability	Frequency (Hz)	Cost
Hammer	Low	50-400	€
Weight drop	Good	50-400	€€
Shotgun	Good	50-400	€€
Blast	Good	1-20	€€€
Vibroseis	Good	10-100	€€
Chirp (marine)	Good	2000-20000	€€€
Sparker (borehole & marine)	Good	200-2000	€€€

Sledge-hammer
vs.
Shotgun

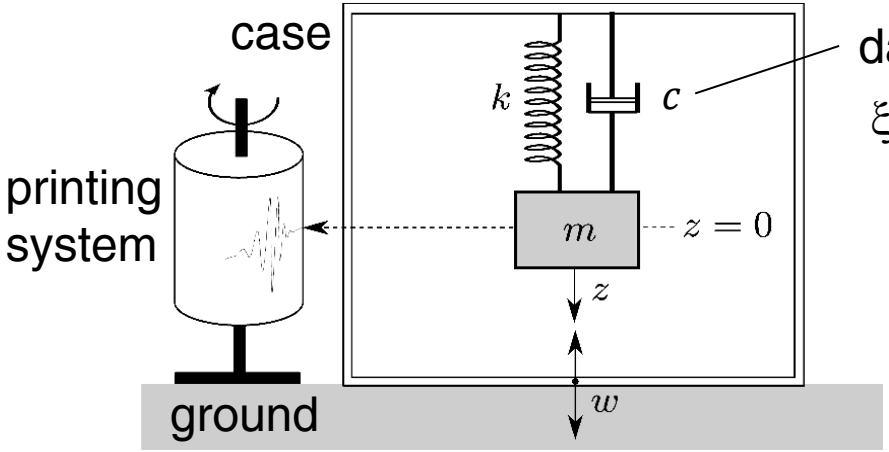


Frequency range



Seismic receivers

Devices able to record ground motion



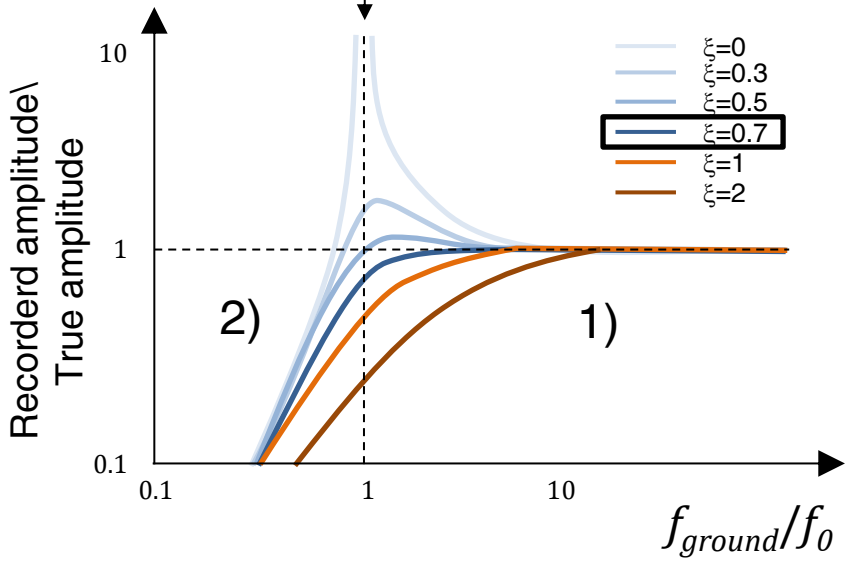
Without any damping ξ=0 (harmonic oscillator)

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Resonant frequency amplitude → ∞

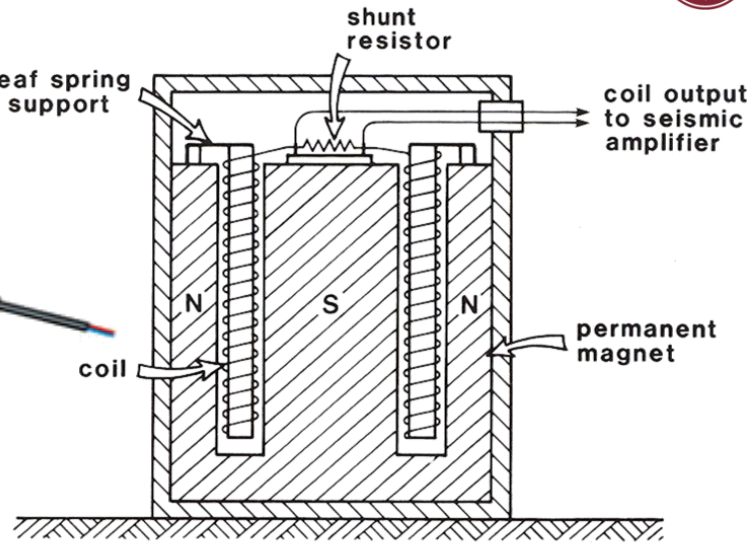
1) If $f_{ground} >> f_0$ the mass moves at the same amplitude of the ground

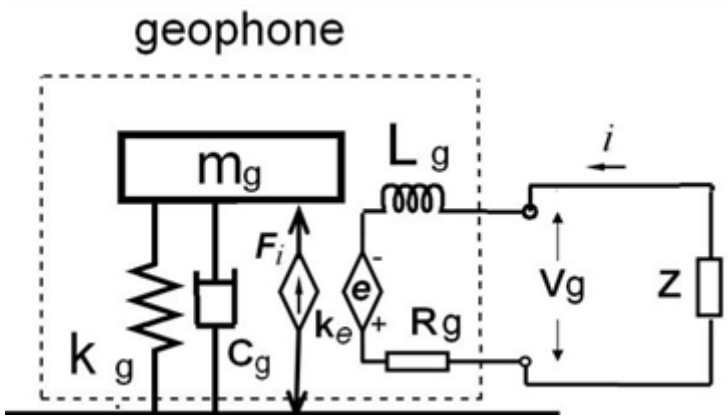
2) If $f_{ground} << f_0$ the mass does not move relatively to the ground



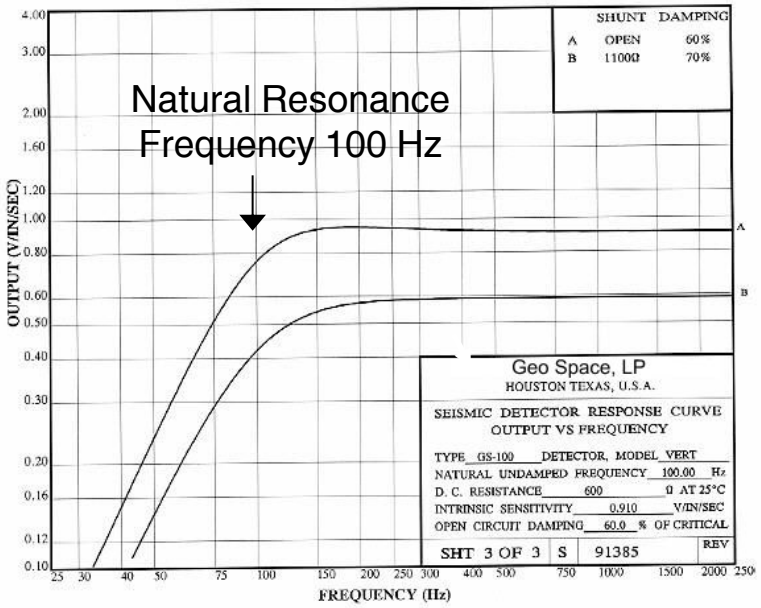
Geophones (vertical or horizontal)

Convert ground motion into electricity

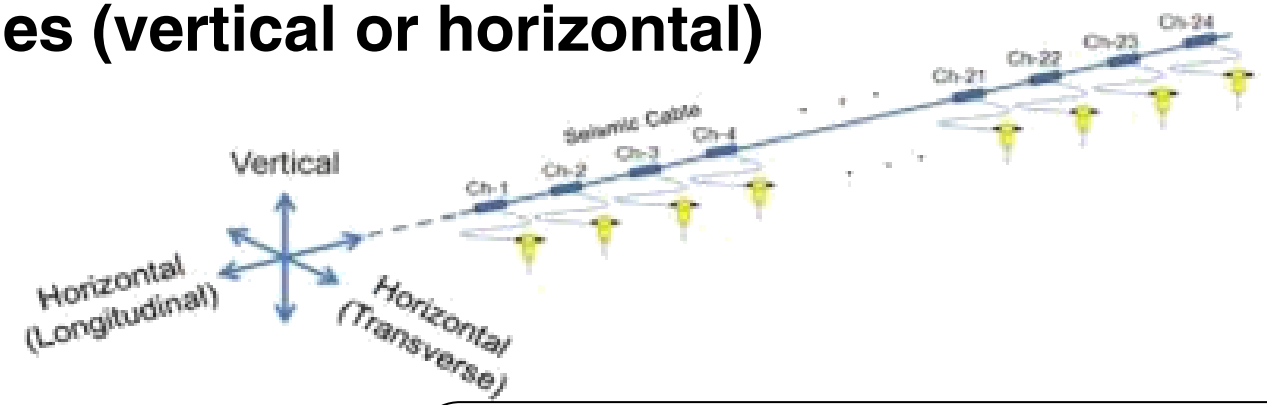




The ground motion produces a variation of the electromagnetic flux inducing electric current in the recording circuit



Geophones (vertical or horizontal)



Vertical geophones record the vertical component of the motion generated by a P-wave source

Horizontal geophones record the horizontal component of the motion generated by a S-wave source in the longitudinal or transverse directions (depends on the orientation of the geophones)

vertical

The arrows indicate the direction of the coil movement

longitudinal

transverse

Seismic receivers – P- and S-wave geophones

soft soils

Vertical 10 Hz-geophone with cable connections

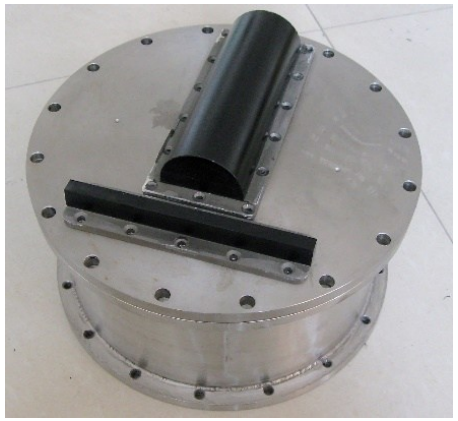
Horizontal 50 Hz-geophone

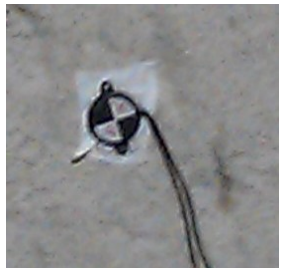
hard soils, rocks and pavements

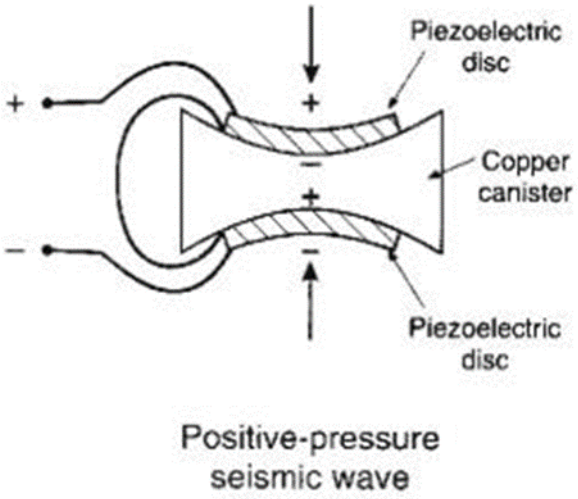
geophones mounted on land streamers

Transducer

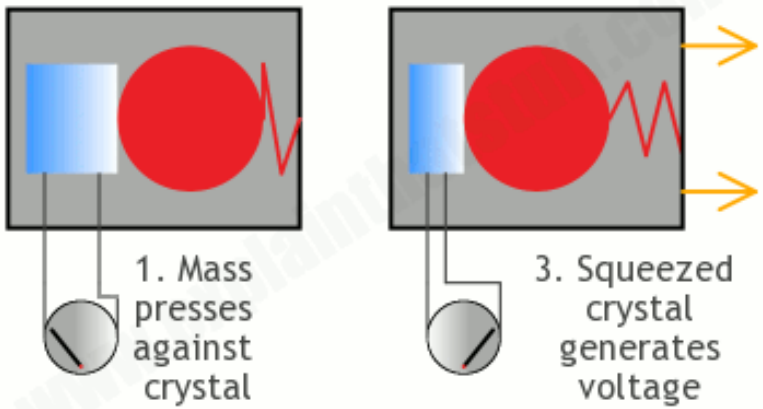
Device converting an electrical signal into an acoustic wave in water and vice versa







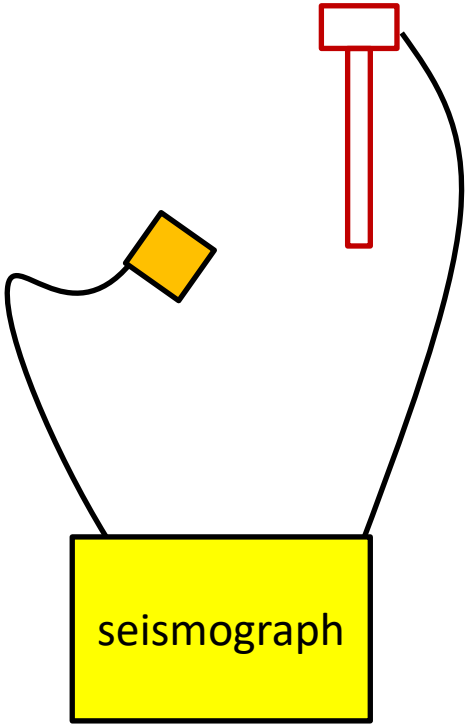
Piezoelectric effect: shifting of the positive and negative charge centres in the material as an effect of an applied load result in a recorded voltage difference



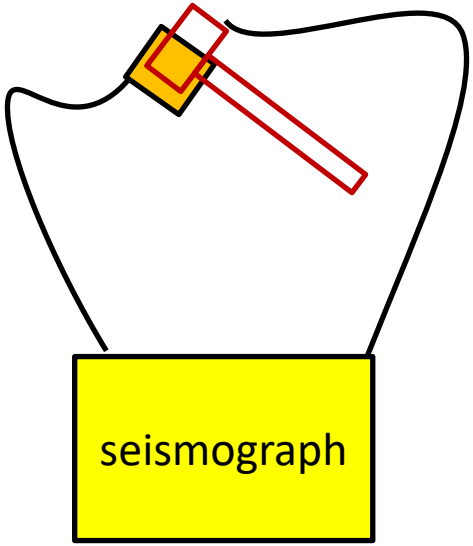
Seismic instruments – Trigger

The trigger is a device that can measure the shot instant (**zero-time**). It is extremely important because the travel times are all referred to this instant. Generally it operates by opening or closing of an electric circuit.

Before shot (open circuit)



After shot (closed circuit)



Seismic instruments – Seismograph

The seismograph is basically an A/D converter. It records the shot instant and all the geophone signals with a given sampling rate
(e.g. 1 sample each 10 ms = sampling frequency: 100 Hz).

2 seismographs

Acquisition settings

Sampling rate: it depends on the signal frequency. Should be at least higher than the inverse of the Nyquist frequency: $f_{Nyq} = 2\max(f_S)$

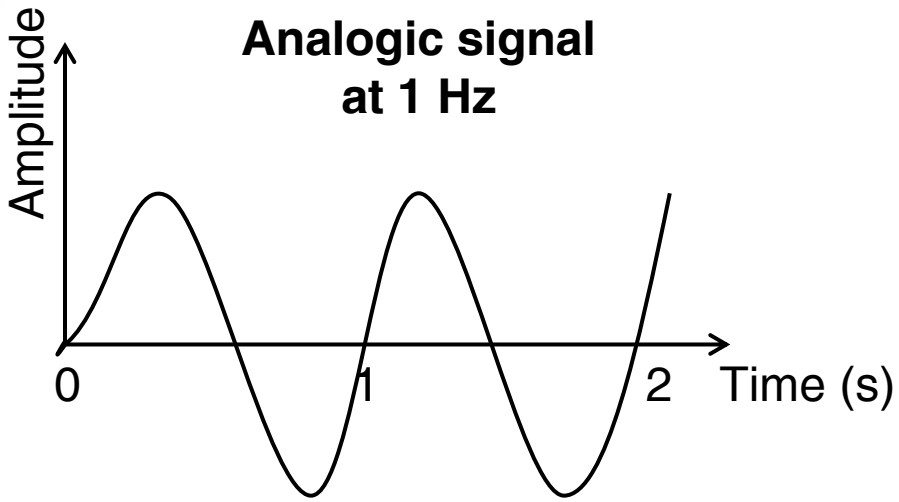
Trace length: it depends on the survey geometry and expected velocities.
Not too short: *I would take in all the seismic waves*
Not too long: *too much allocated memory*

Temporal aliasing and sampling rate

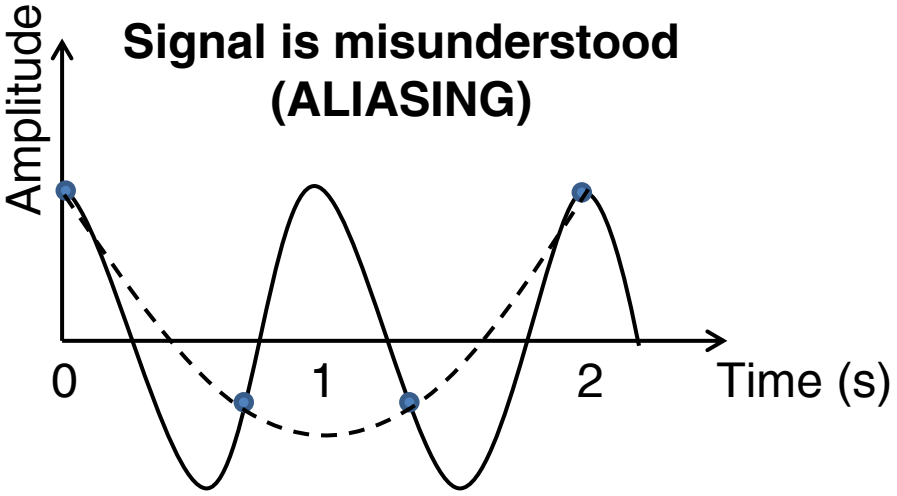
Sampling rate Δt: it depends on the signal frequency. Should be at least higher than the Nyquist frequency:

$$f_{Nyq} = 2\max(f_S)$$

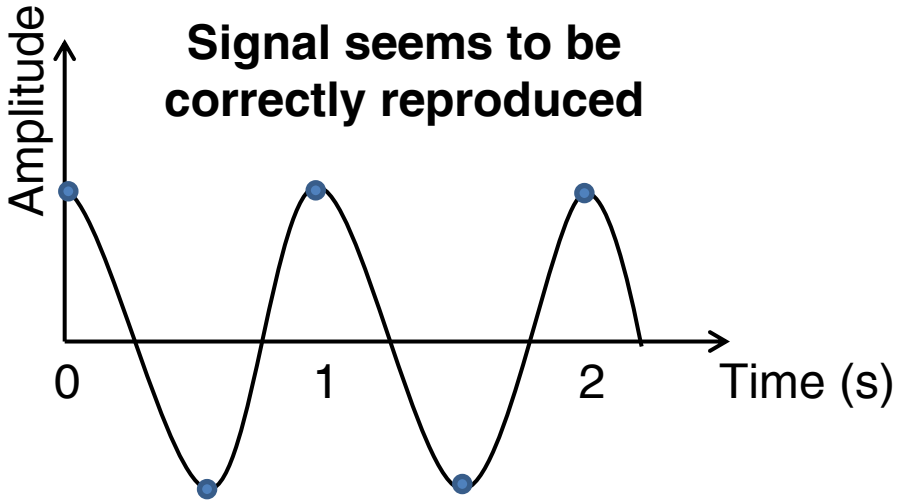
$$\Delta t \leq \frac{1}{f_{Nyq}} \leq \frac{1}{2\max(f_S)}$$



Sampling at 1.5 Hz
1 sample each 0.67 s



Sampling at 2 Hz
1 sample each 0.5 s



Temporal aliasing and sampling rate

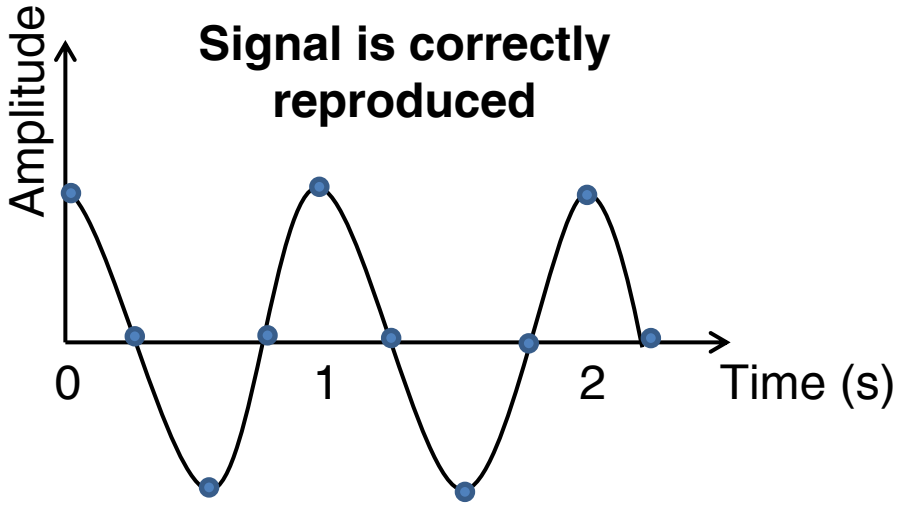
Sampling rate Δt: it depends on the signal frequency. Should be at least higher than the Nyquist frequency:

$$f_{Nyq} = 2\max(f_S)$$

$$\Delta t \leq \frac{1}{f_{Nyq}} \leq \frac{1}{2\max(f_S)}$$

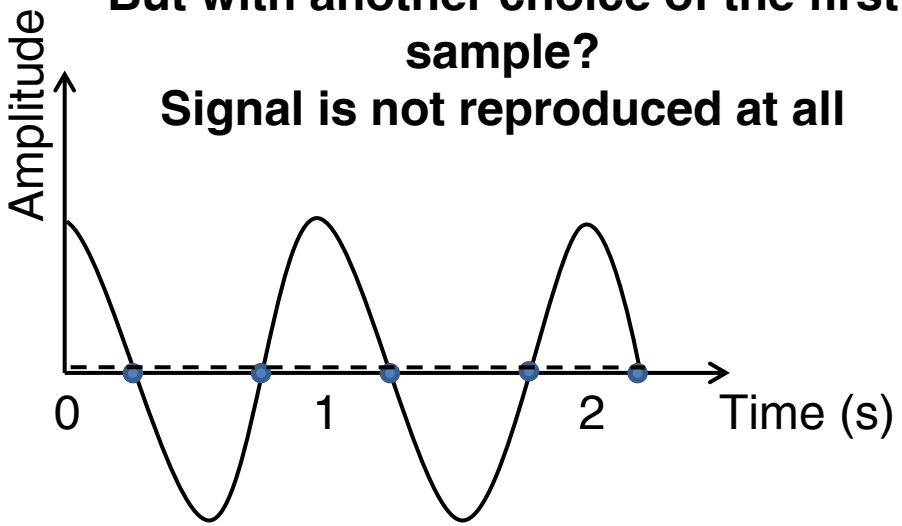
Sampling at 4 Hz
1 sample each 0.25 s

Signal is correctly reproduced



Sampling at 2 Hz
1 sample each 0.5 s (other choice)

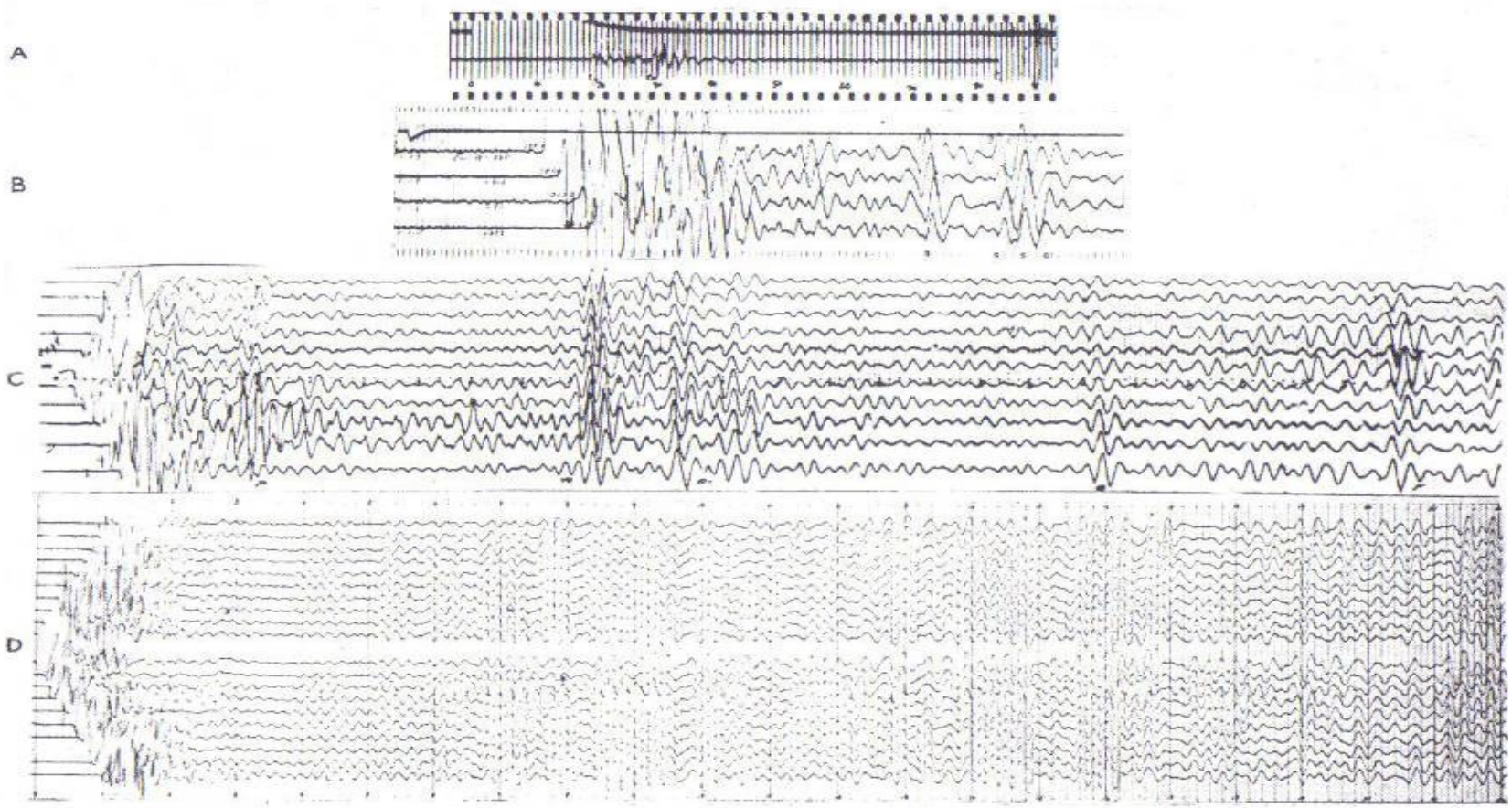
But with another choice of the first sample?
Signal is not reproduced at all



$$\Delta t \leq \frac{1}{4\max(f_S)}$$

Shot gather – Time-lapse progress

Analog recordings (paper)



Analog recordings (photographic film) – 1960-70

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Università di Roma

Rilievo sismico nº _____

Località NIBBI

Data 12/10/64 Scoppio nº 2

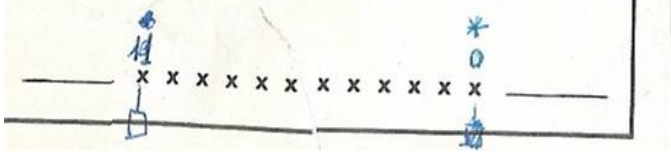
Profilo K Base _____

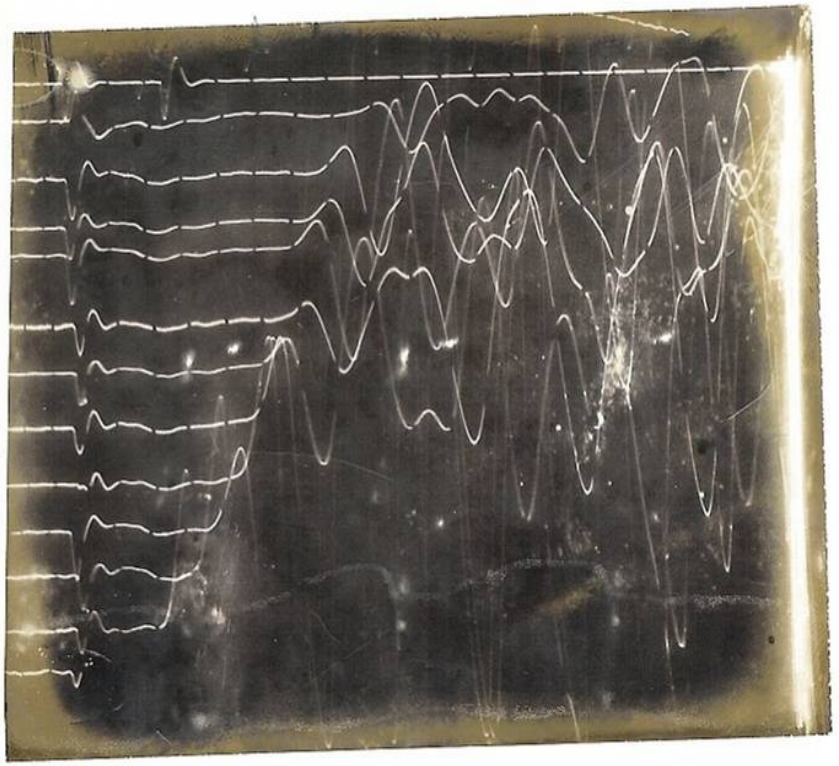
Ampl. ____ Carica ____ Prof.Scoppio ____

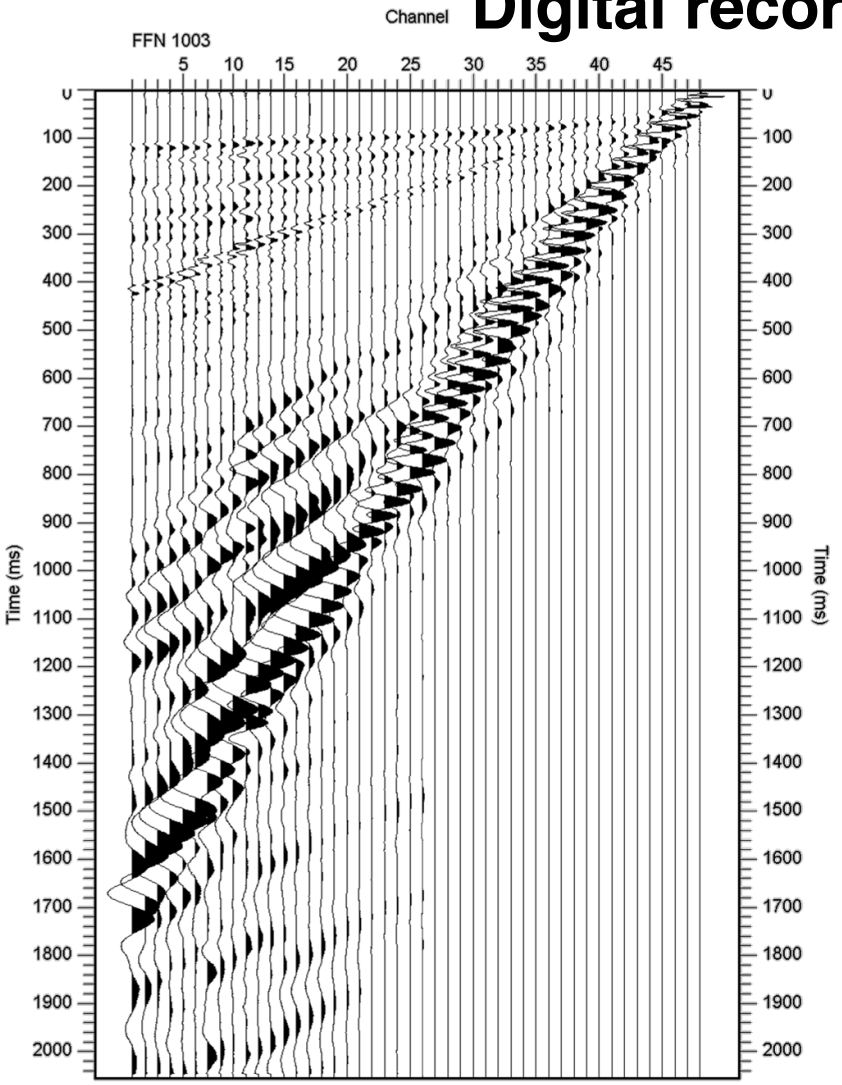
Gain ____ Scostamento in linea ____

Filter ____ laterale 3m

Note







Digital recordings (from 1980/90-present)

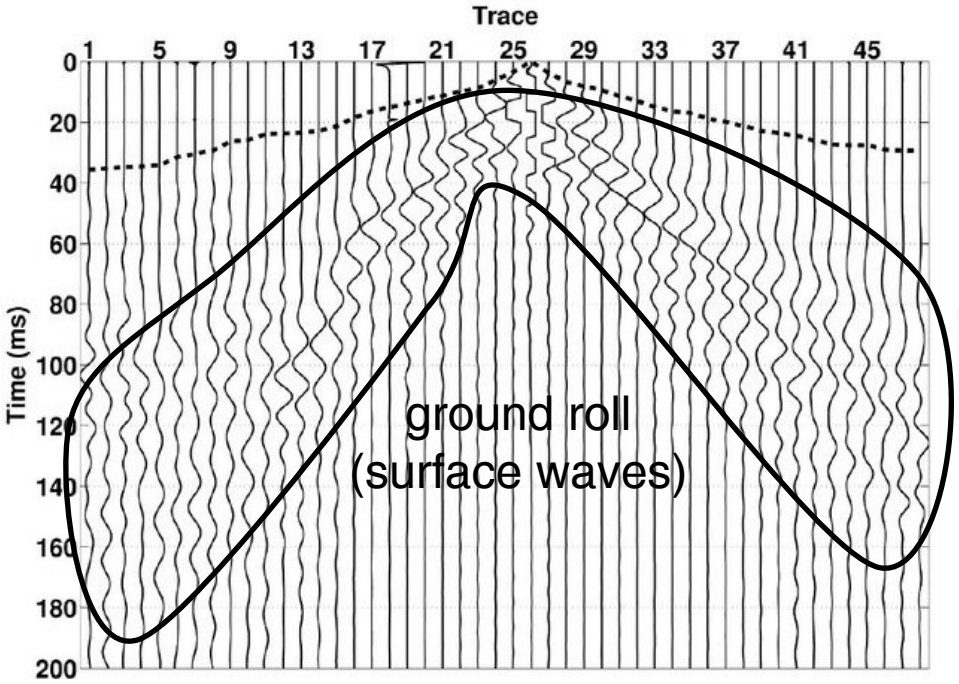
The SEG (Society of Exploration Geophysicists) has defined two main standards for seismic file structures: SEG2 (for 2D surveys) and SEGY (for reflection and more complex surveys). In both cases, the file is a binary file featuring a header section that contains the acquisition parameters, such as:

- *dt*: sample interval
- *ns*: number of samples
- *gx,gy,gev*: receiver(s) coordinates
- *sx,sy,sev*: source(s) coordinates
- *dx*: trace spacing (constant for 2D)
- *offset*: shot-receiver distance
- *ntr*: number of traces
- *channel*: number of channels
- *FFN* : field file number

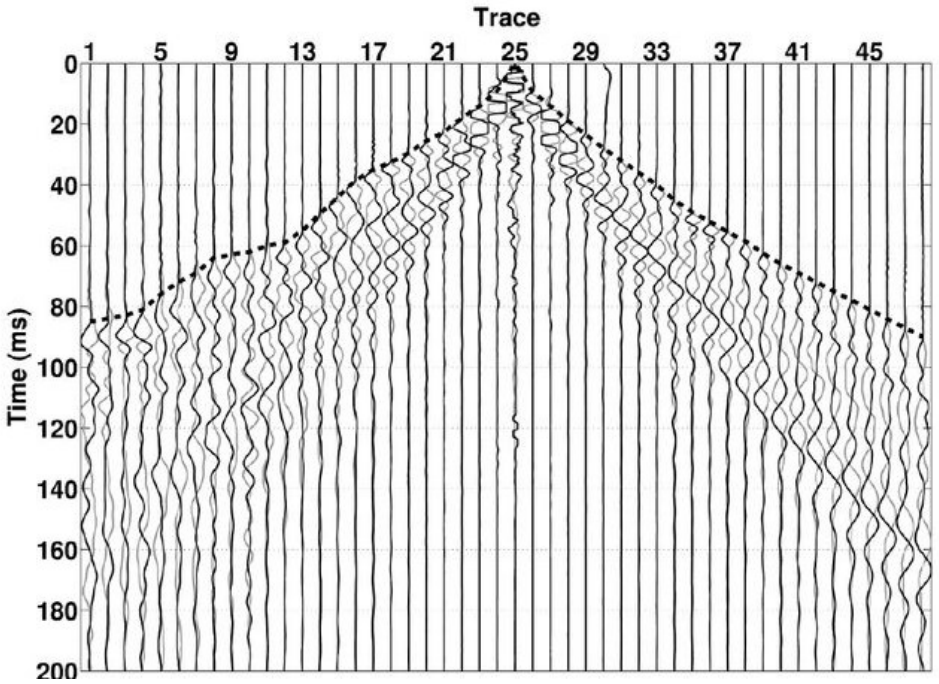
Seismic instruments – P- and S-wave shot gather

In a **shot gather** all traces related to a single shot are plotted as a function of time (zero-time is shot instant). We can pick first arrivals for P-wave and S-wave (dashed lines) and investigate ground roll (surface waves)

P-wave source shot at G26 (48 receivers)



S-wave source shot at G25 (48 receivers)



Seismic acquisition, processing and inversion

Seismic sources for P- and S-wave generation

P-wave source | S-wave source

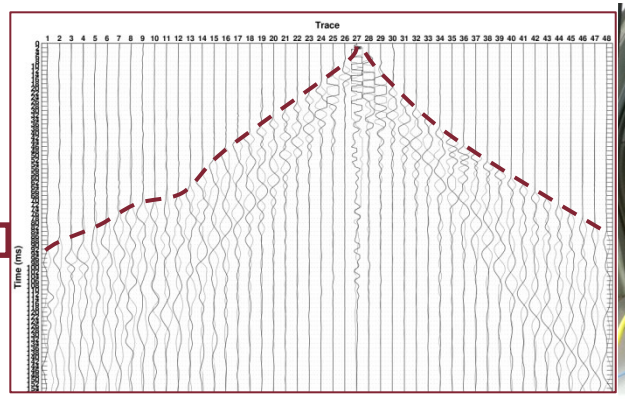
Wave propagation

Geophones/transducers (P- and S-wave receivers)

P-wave geophones | S-wave geophones

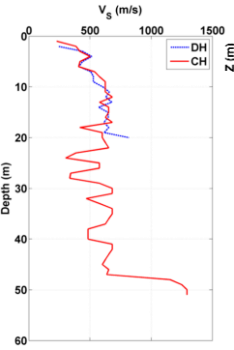
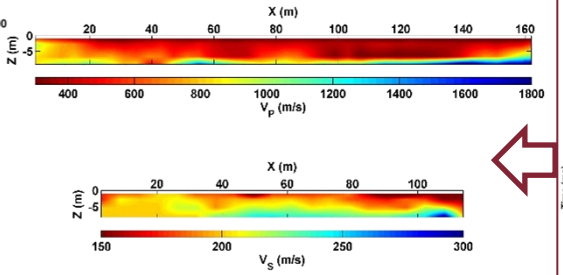
Recording - A/D converting Seismograph

Shot gathers Picking of travel-times



Processing and/or inversion Velocity model

1-D model



2-D models