SAPIENZA
UNIVERSITÀ DI ROMA

# Environmental geophysics

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## *1. Seismic methods*

*Instruments*

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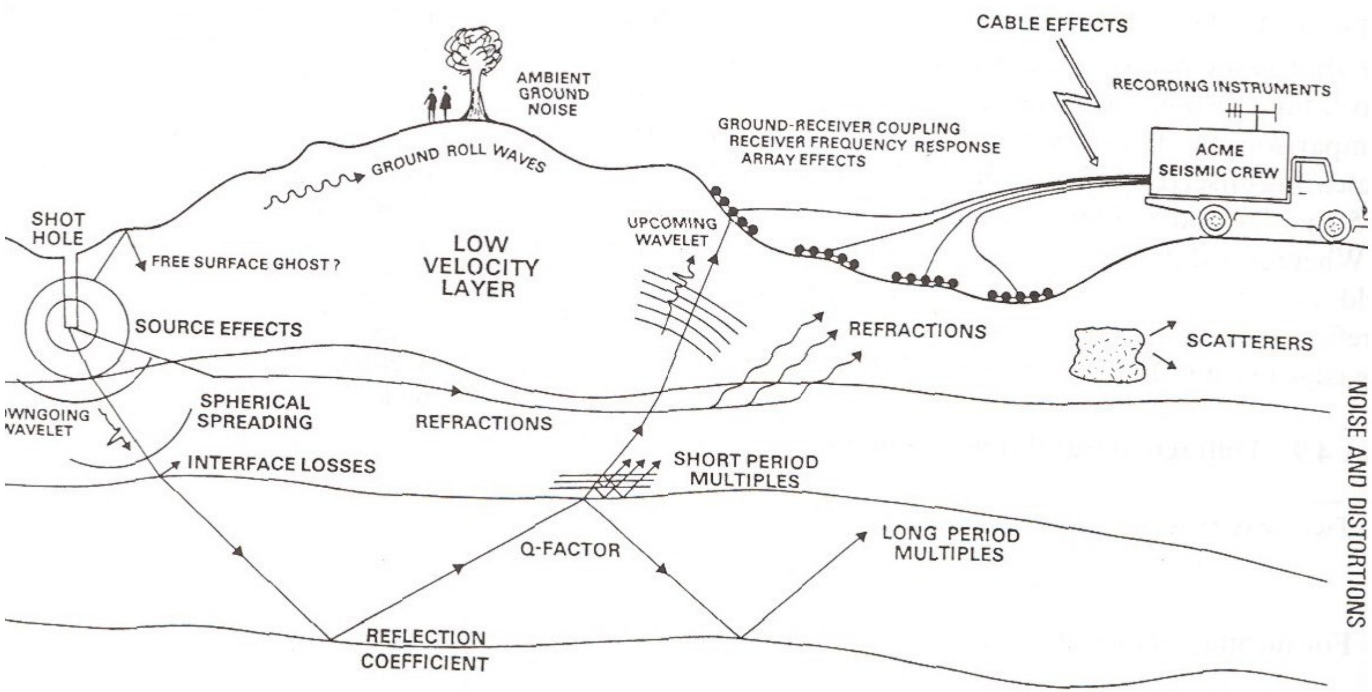
# Seismic instruments

**Seismic equipment for wave generation and signal recording**

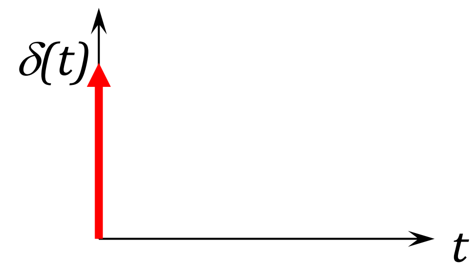
- SOURCE (different types)
- RECEIVER(S) (different types)
- TRASMISSION CABLES
- SEISMOGRAPH (A/D conversion and signal recording)



# Seismic sources

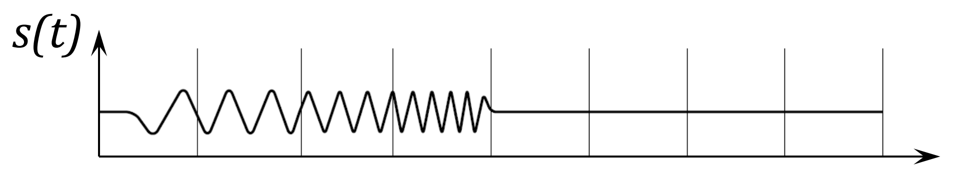
Seismic sources can be divided into two main classes, depending on the woking principle:

- **Pulse**
  - ✓ Hammer
  - ✓ Weigth 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

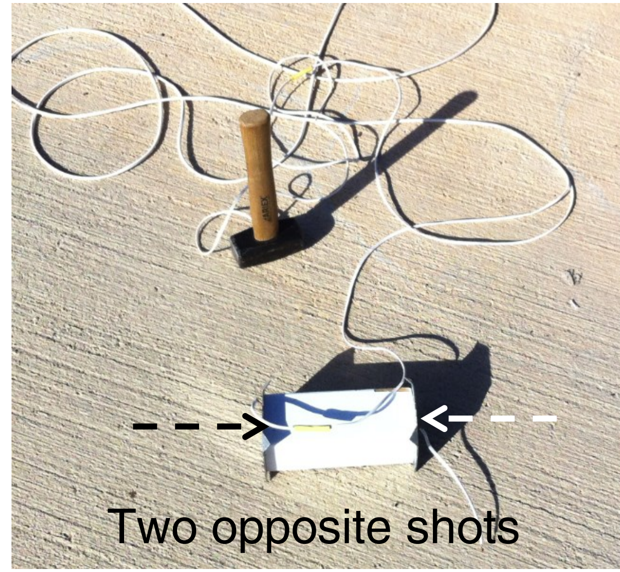
## Blast (explosion)

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

# Seismic sources – S-wave

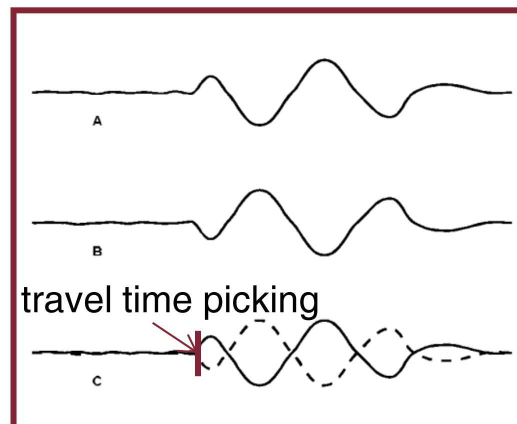
## Sledge-hammer + plate


## 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.**



# Sledge-hammer + plate

# Seismic sources – Borehole

## Sparker

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

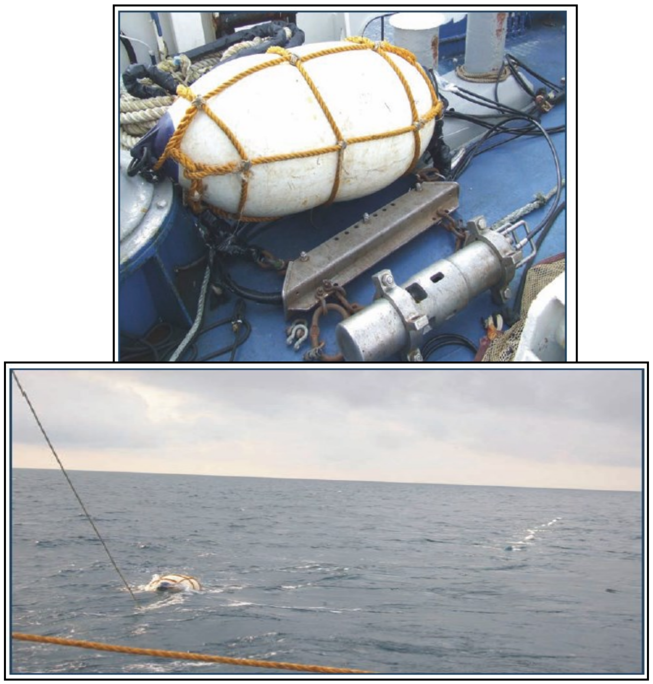
## Vibroseis

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

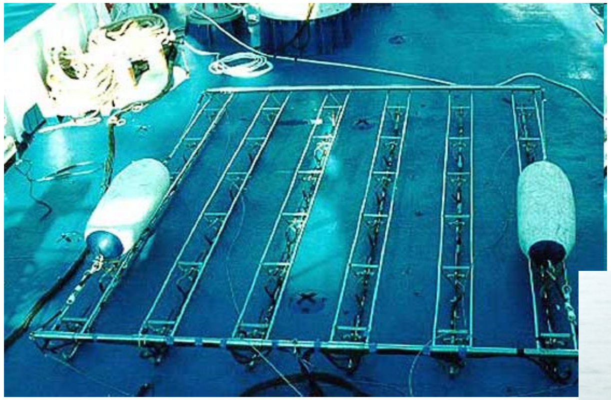
# Seismic sources – Marine

**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)

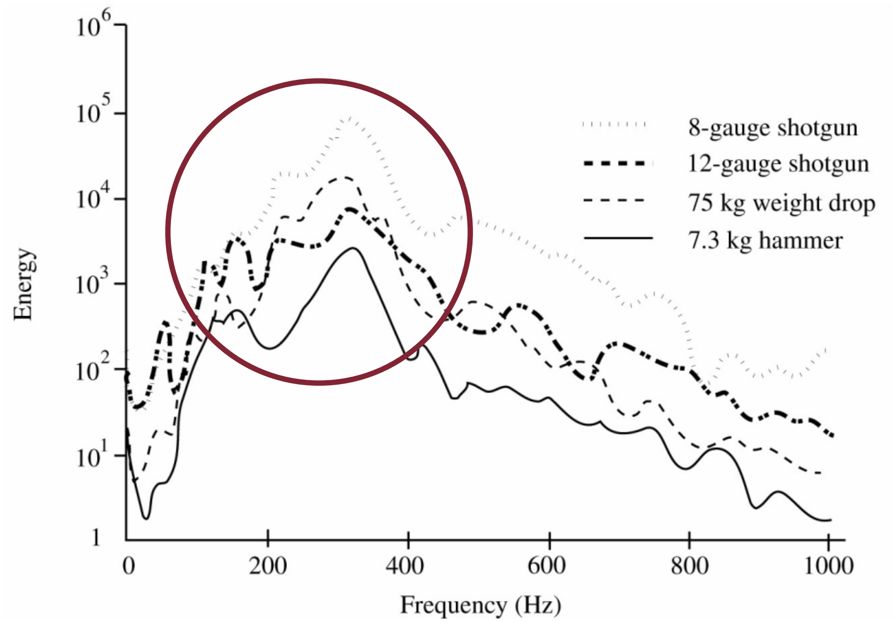


Chirp (vibrating)

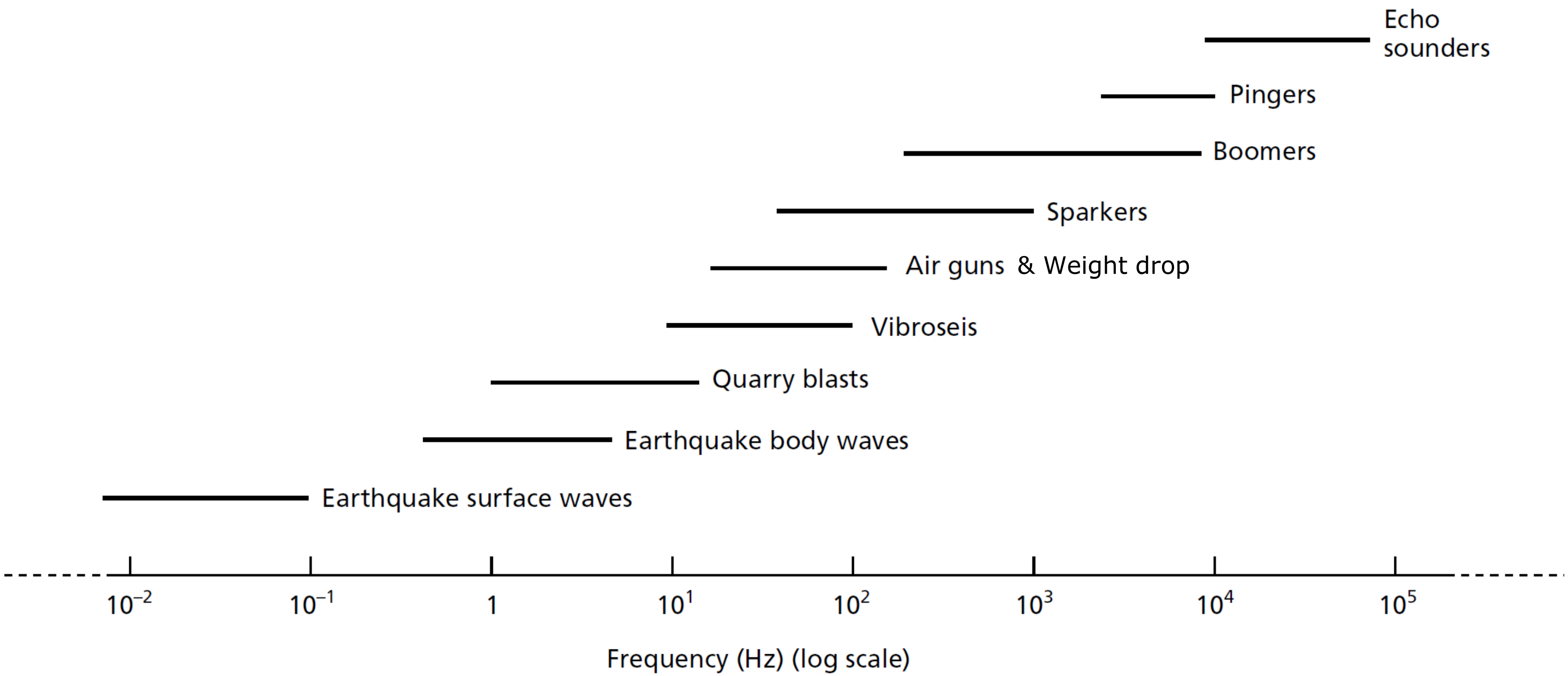
# Seismic sources

| 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 | €€€ |

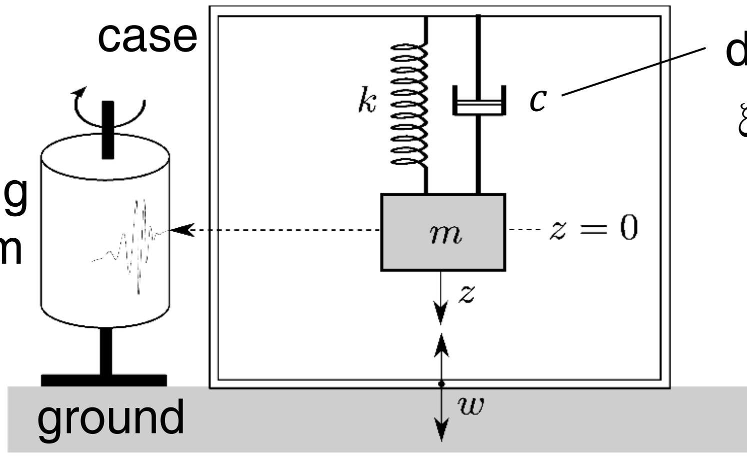
Sledge-hammer
vs.
Shotgun



# Frequency range



# Devices able to record ground motion




$\xi = \frac{c}{2\sqrt{mk}}$

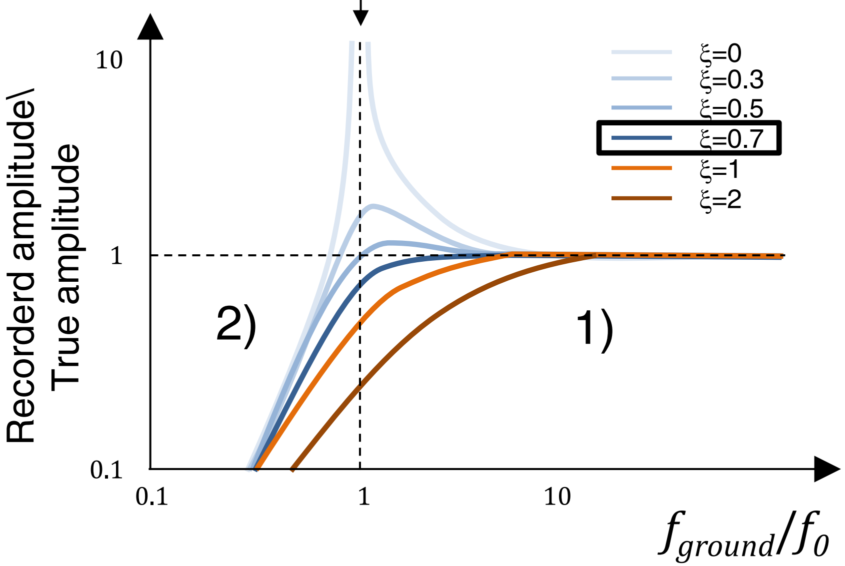
Without any damping $\xi$=0 (harmonic oscillator)

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

**Resonant frequency** amplitude → ∞

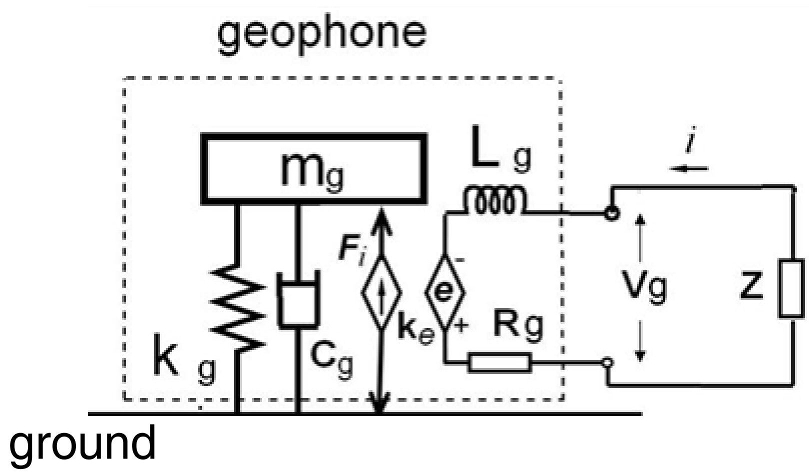
1) If $f_{ground} >> f_0$ the mass moves at the same amplitude of the ground

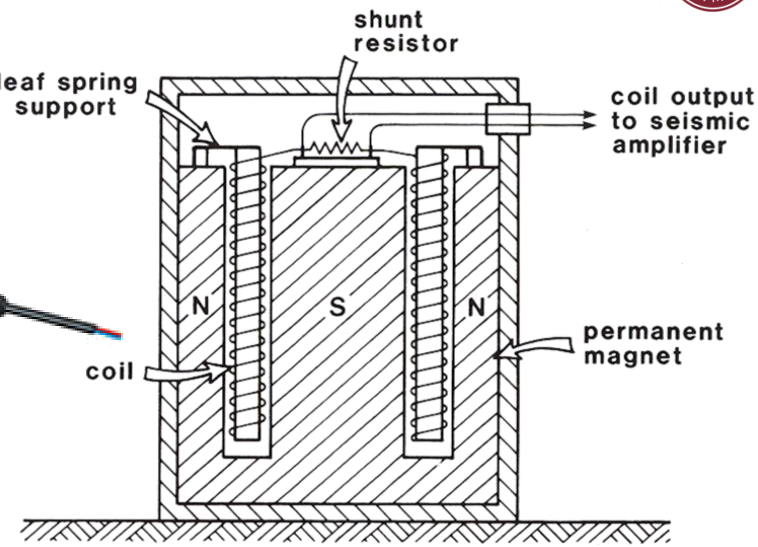
2) If $f_{ground} << f_0$ the mass does not move relatively to the ground



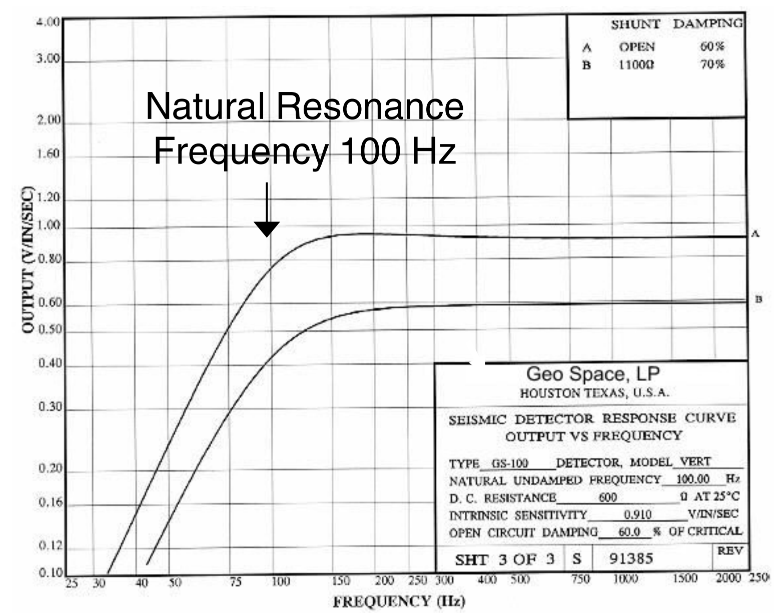
# Geophones (vertical or horizontal)

Convert ground motion into electricity

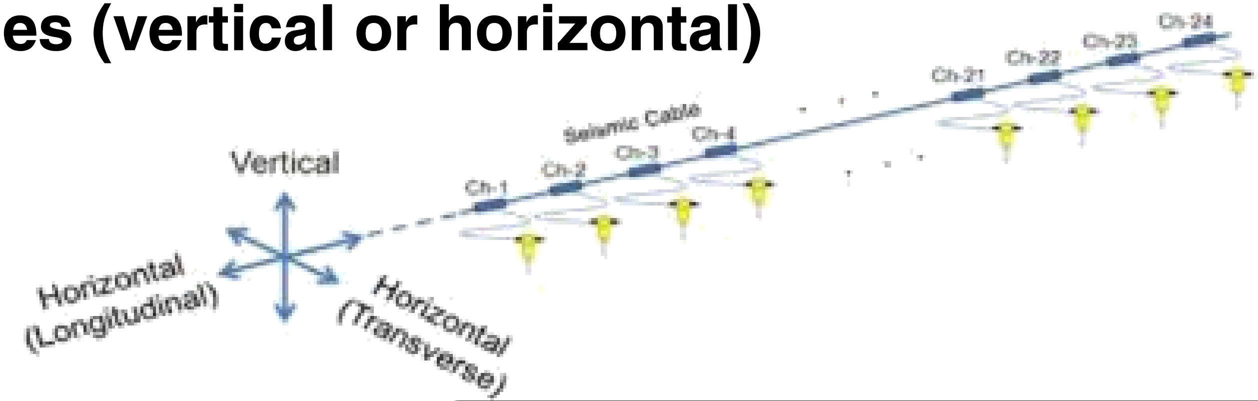



The ground motion produces a variation of the electromagnetic flux inducing electric current in the recording circuit

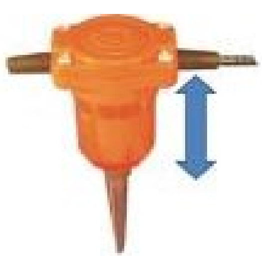


## Geophones (vertical or horizontal)




**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

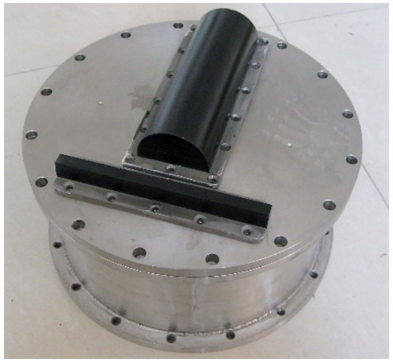
Horizontal 50 Hz-geophone

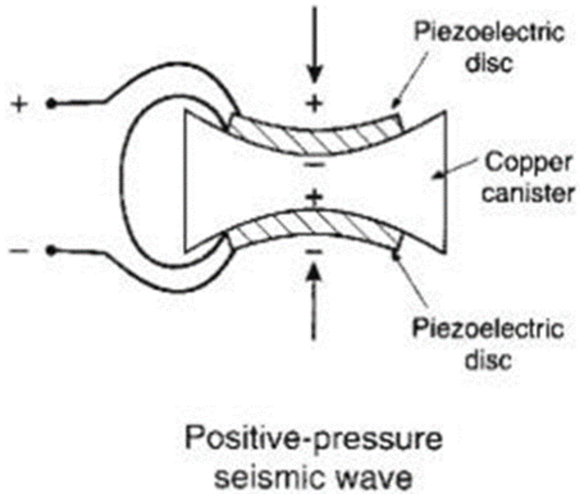
## hard soils, rocks and pavements

geophones mounted on land streamers

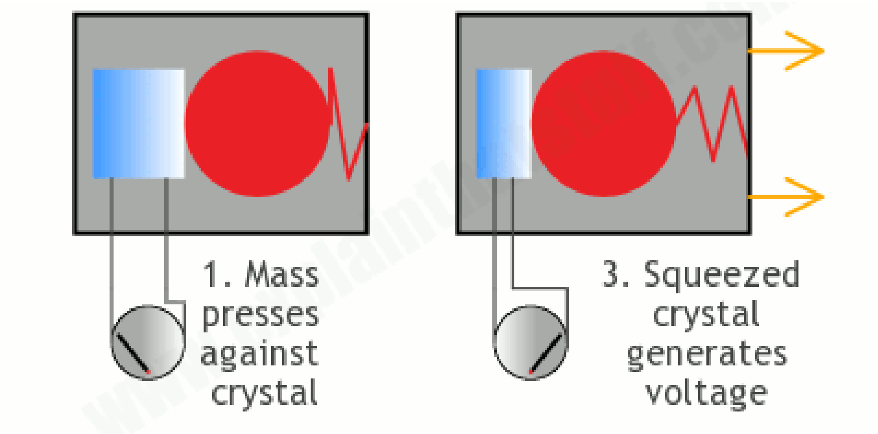
**Transducer**

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



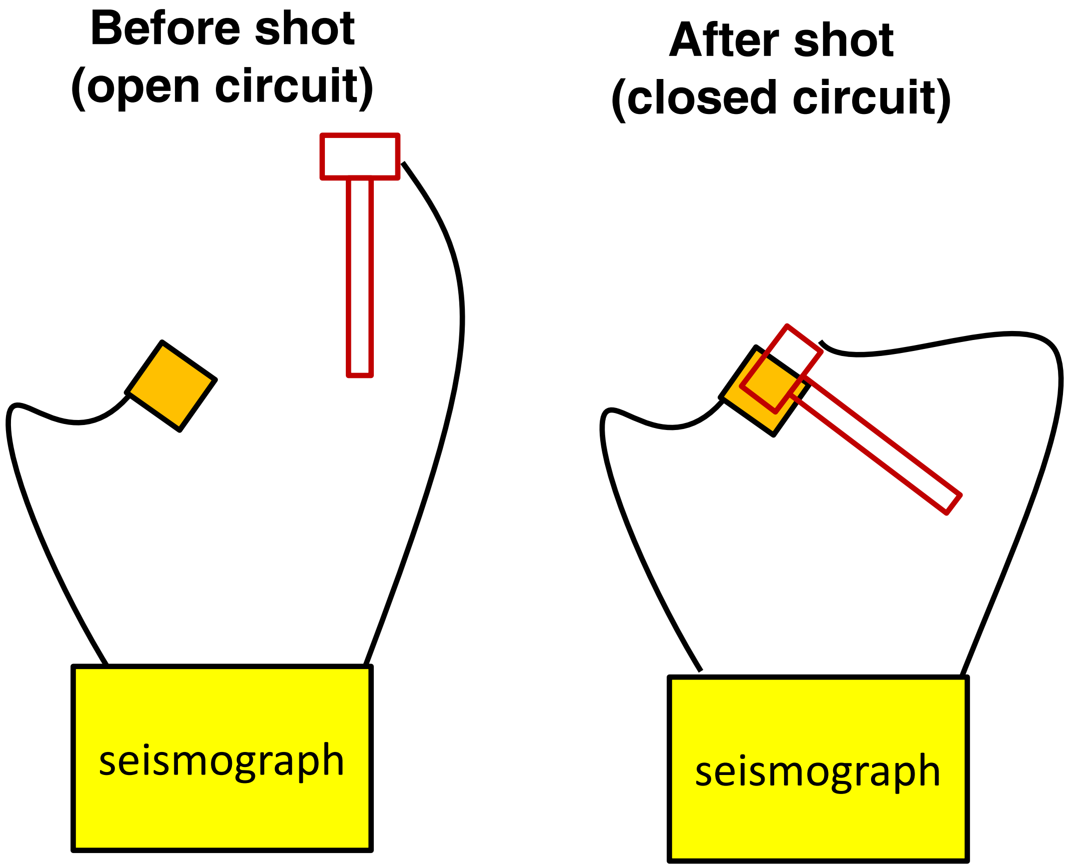



**Piezoelectric effect**: shifting of the positive and negative charge centres in the material as an effect of an applied load result in a recorded voltage difference



# 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.




# 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*

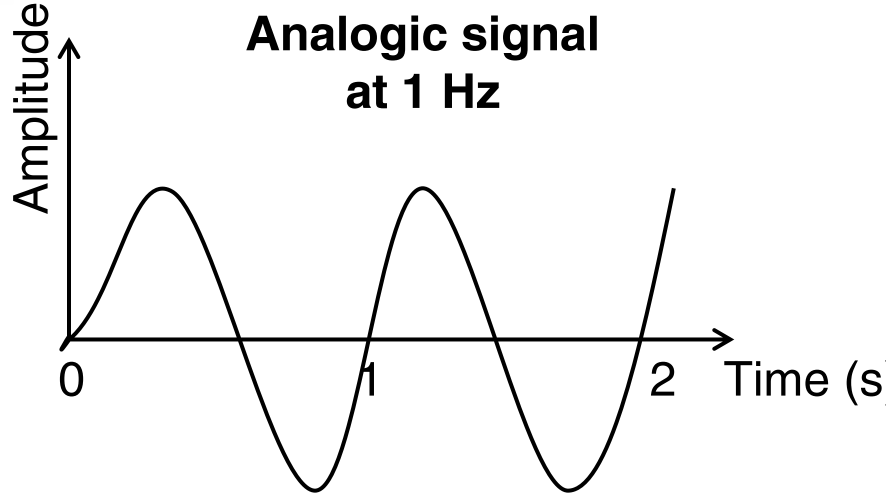
Not too long: *too much allocated memory*

# Temporal aliasing and sampling rate

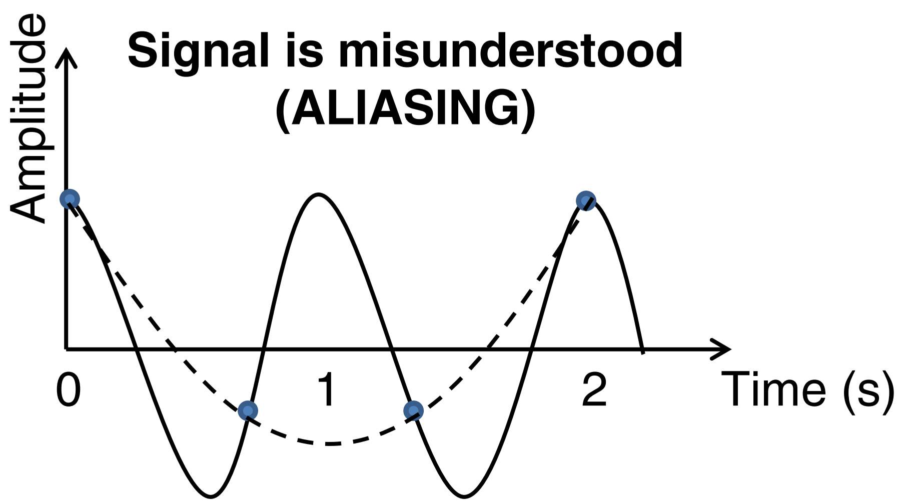
**Sampling rate** $\Delta t$: it depends on the signal frequency. Should be at least higher than the Nyquist frequency:

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

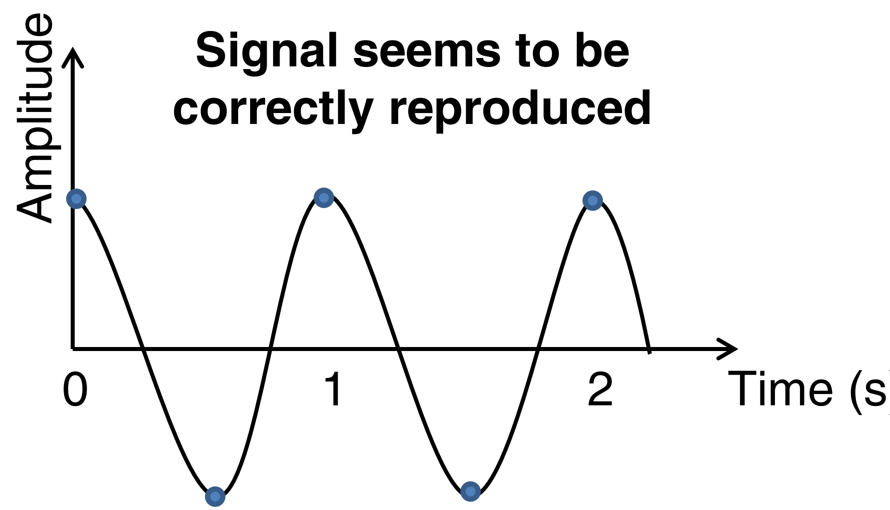
$$\Delta t \leq \frac{1}{f_{Nyq}} \leq \frac{1}{2\max(f_S)}$$




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

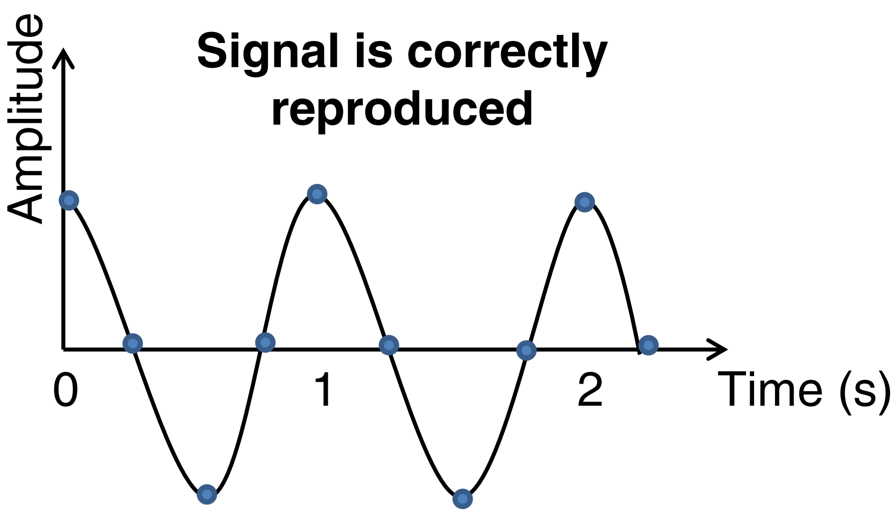
**Sampling rate** $\Delta t$: it depends on the signal frequency. Should be at least higher than the Nyquist frequency:

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

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

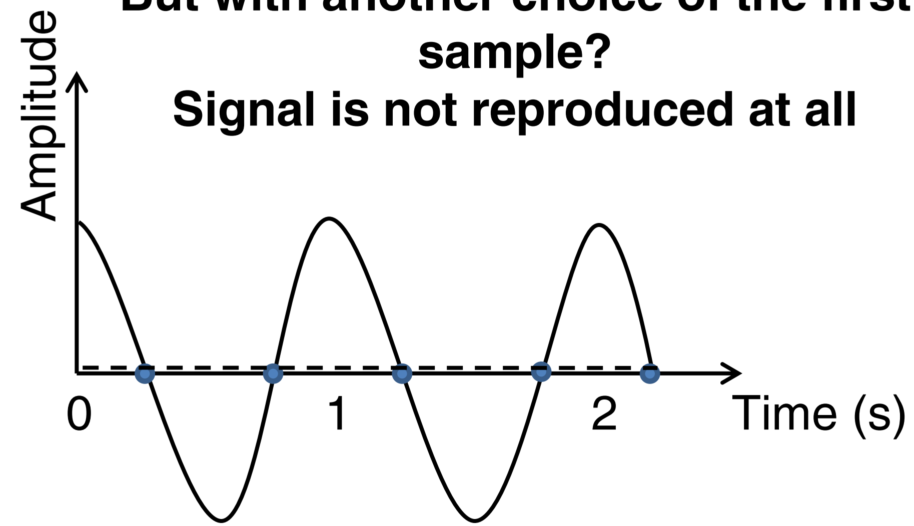
Sampling at 4 Hz
1 sample each 0.25 s

**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**

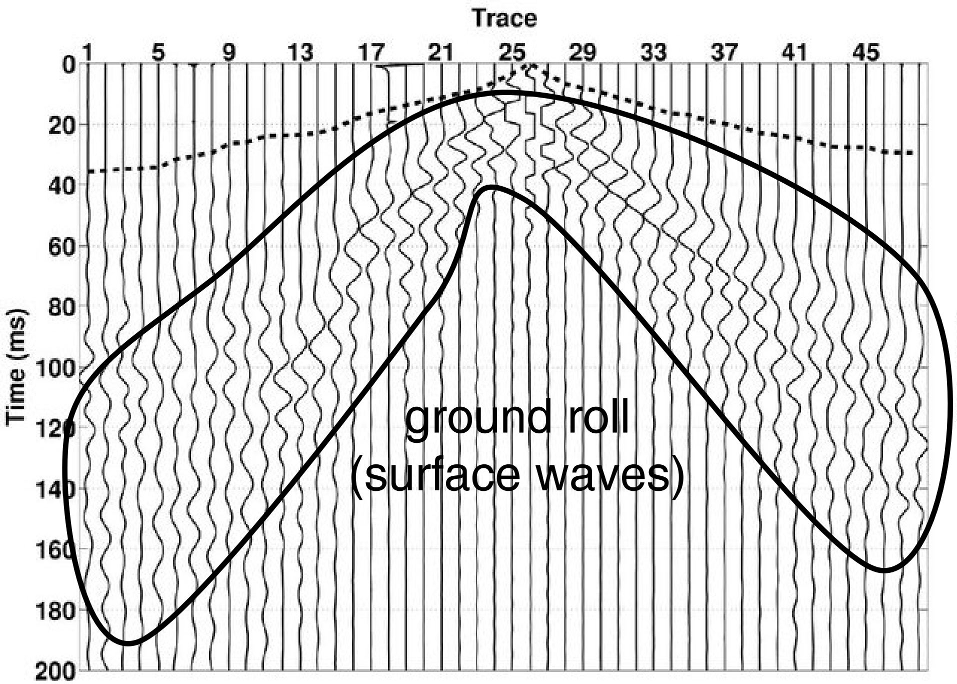



$$\Rightarrow \quad \boxed{\Delta t \leq \frac{1}{4\max(f_S)}}$$

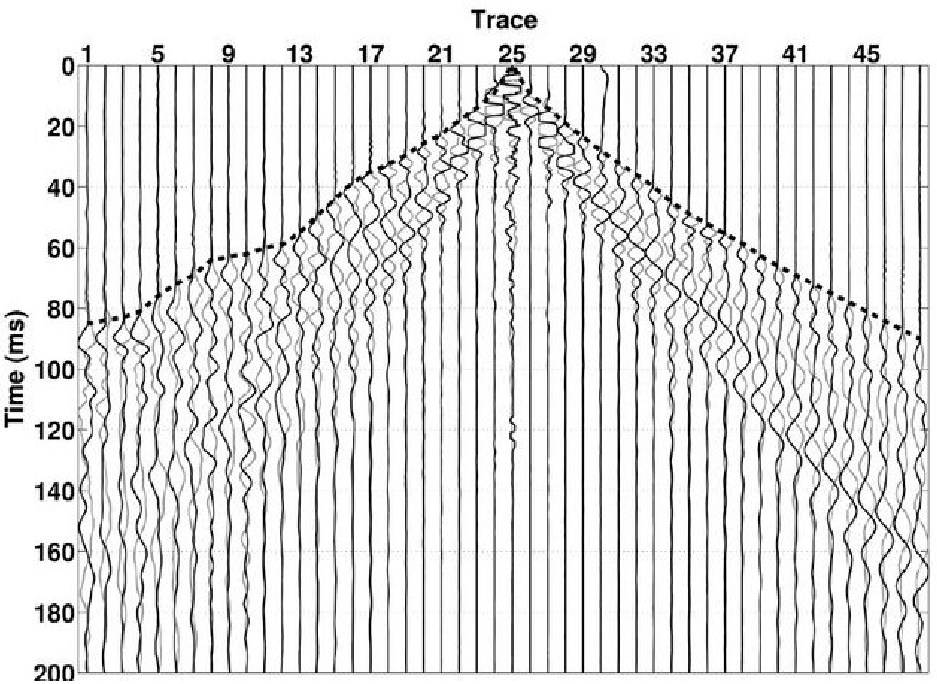
# Seismic instruments – P- and S-wave shot gather

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)**

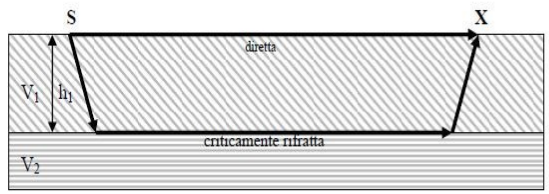


# Seismic acquisition, processing and inversion

**Seismic sources for P- and S-wave generation**


**P-wave source** | **S-wave source**

**Wave propagation**

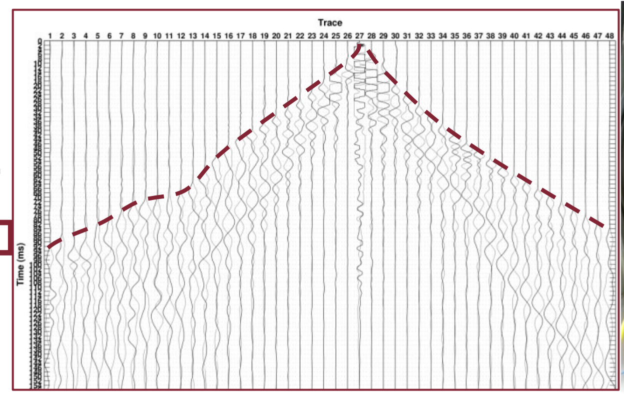



**Geophones/transducers (P- and S-wave receivers)**


**P-wave geophones** | **S-wave geophones**

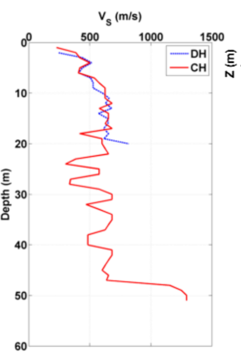
**Recording - A/D converting Seismograph**

**Shot gathers Picking of travel-times**




**Processing and/or Inversion Velocity model**

**1-D model**




**2-D models**