



SAPIENZA
UNIVERSITÀ DI ROMA

Environmental geophysics

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***Seismic borehole methods:
cross-hole (CH) and down-hole (DH)***

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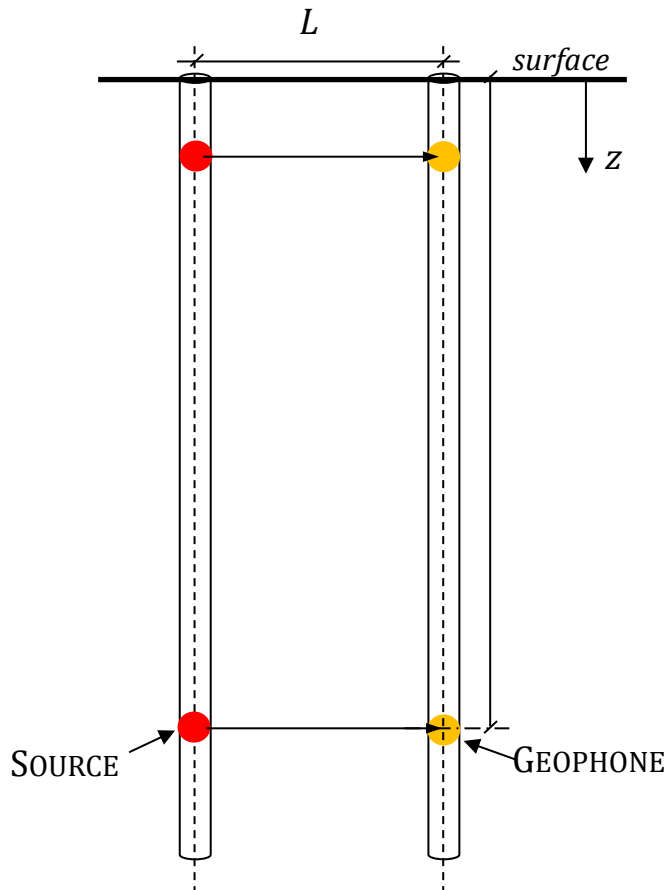
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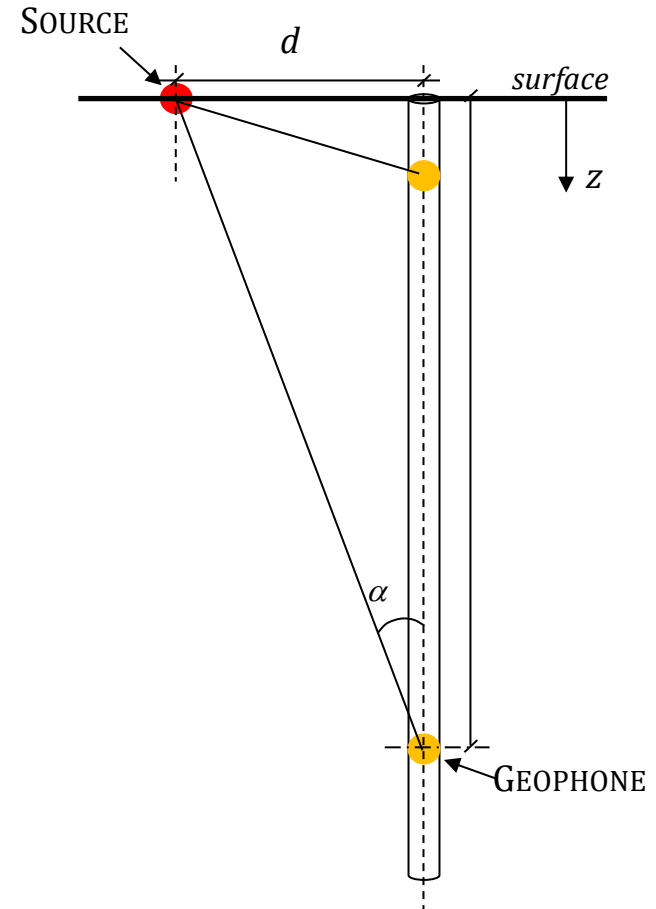
Borehole seismic methods



Cross-hole (CH)

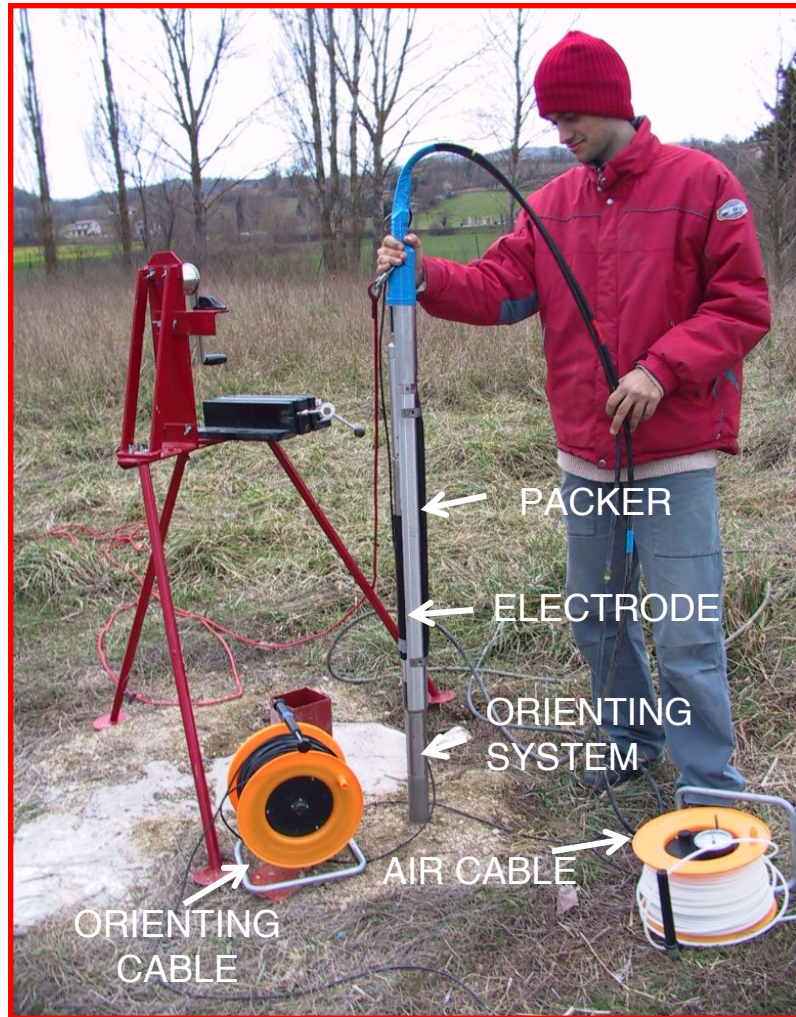


Down-hole (DH)



Cross-hole equipment

Borehole source (Sparker)



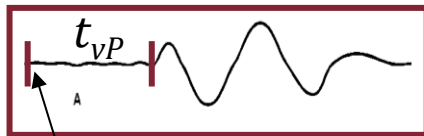
Borehole receiver (3C geophone)



Cross-hole — P- and S-wave data acquisition

For each station (depth) we extract only the geophone component (trace) recording the appropriate motion: L and T for P and SH waves, respectively.

P-wave trace (L-component)

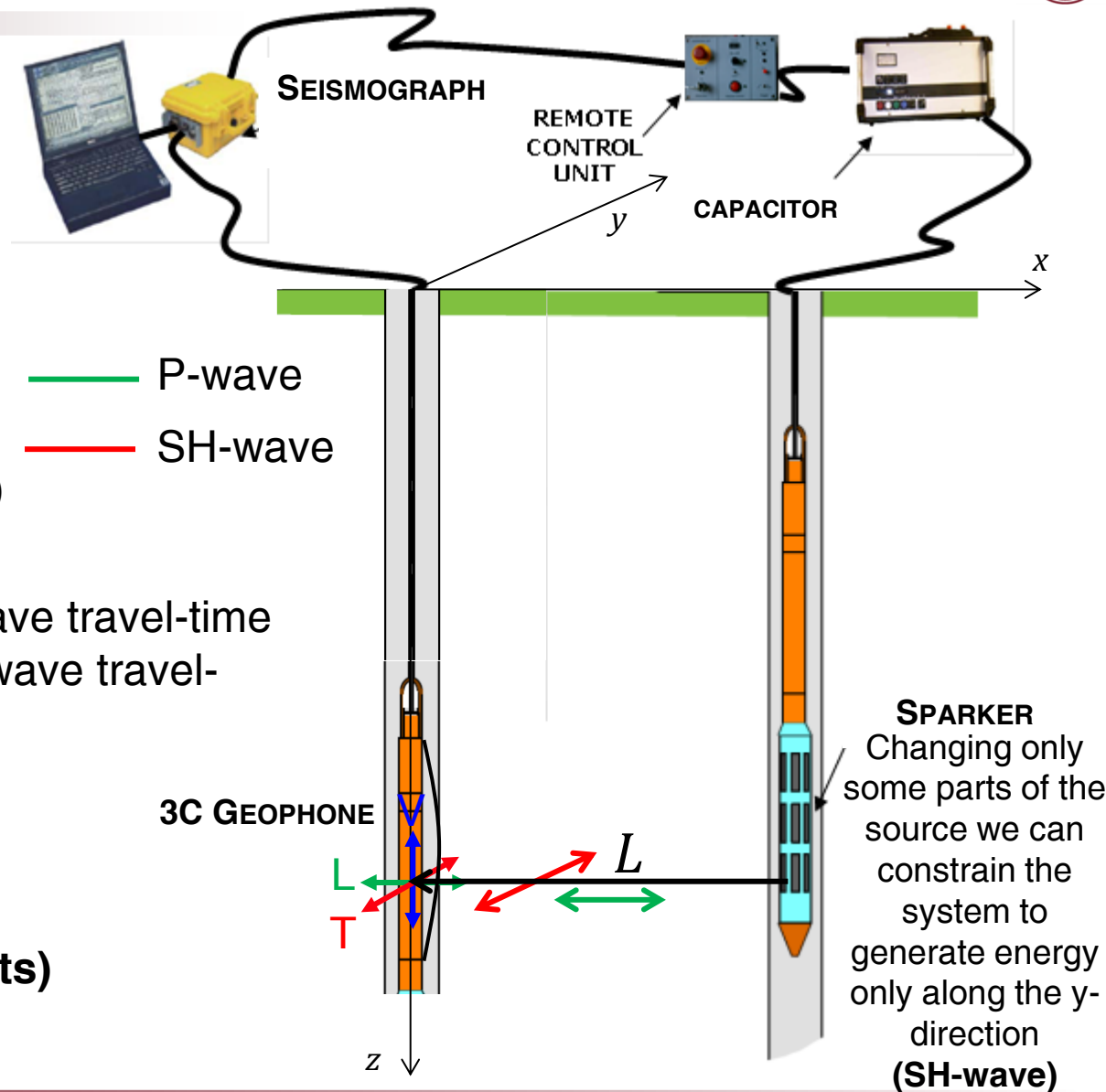


shot instant
(zero-time)

$t_{v,P}$ = P-wave travel-time
 $t_{v,S}$ = SH-wave travel-time



S-wave traces (T-components)



Cross-hole - Processing

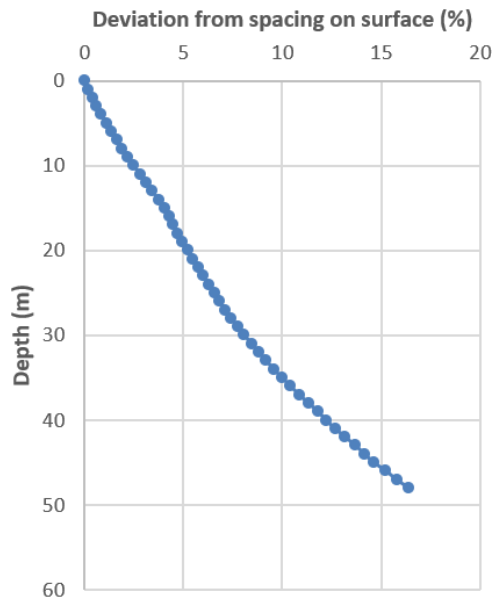
$$v_{P,i} = \frac{L}{t_{vP,i}}$$
$$v_{S,i} = \frac{L}{t_{vS,i}}$$

One velocity
value at each
depth for both
waves

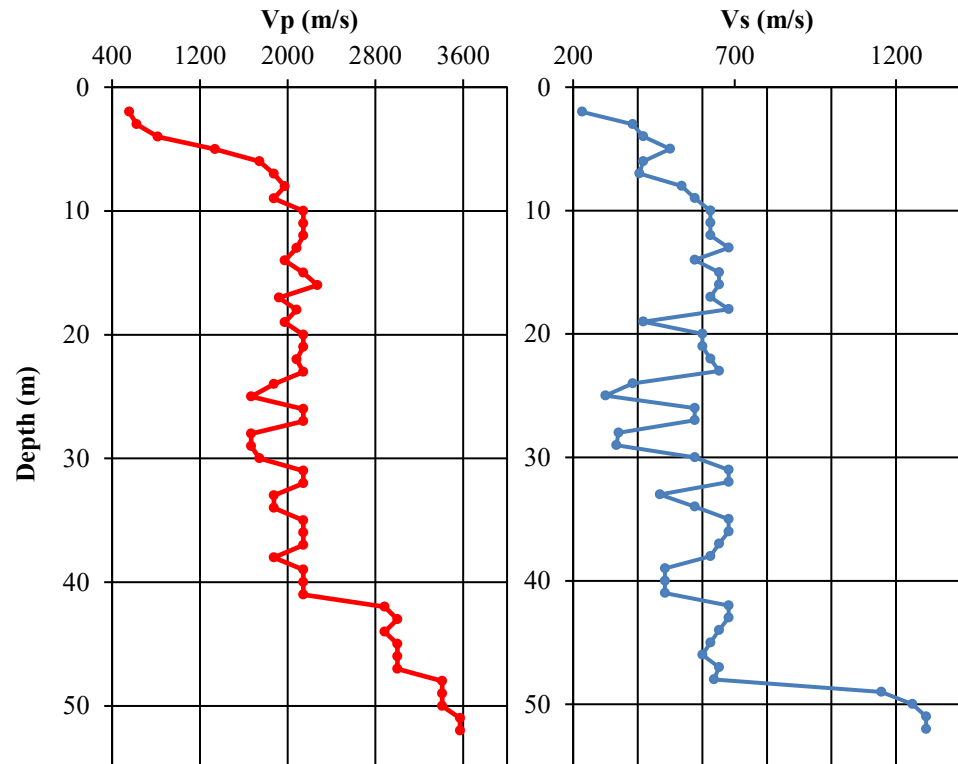
$$v_{P,i} = \frac{L_i}{t_{vP,i}}$$

$$v_{S,i} = \frac{L_i}{t_{vS,i}}$$

But **L** is not constant: we need to
measure the borehole deviation
with a **clinometer** to **correct L** for
each station (depth)



1-D velocity models



Down-hole equipment

P-wave source



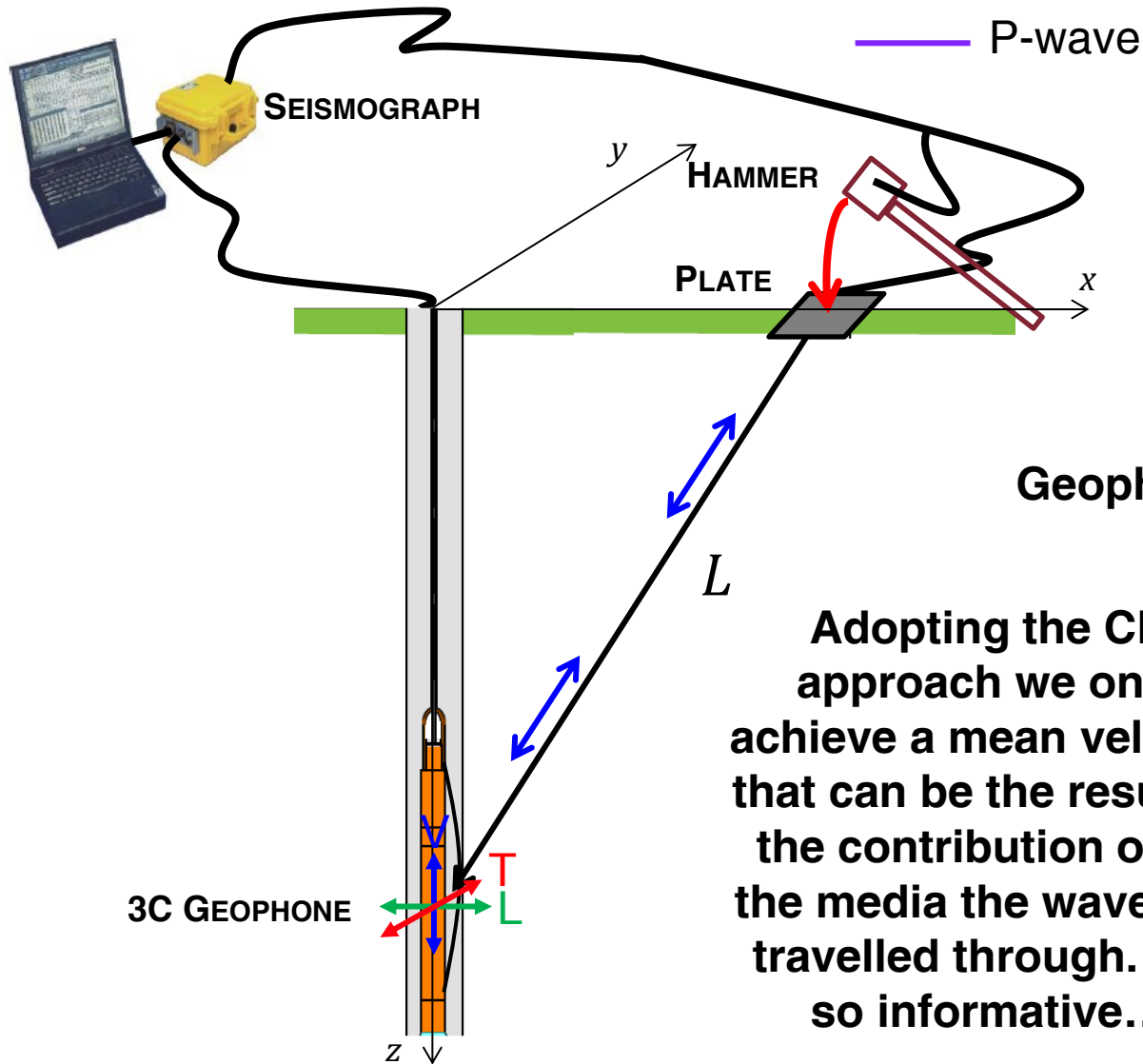
S-wave source



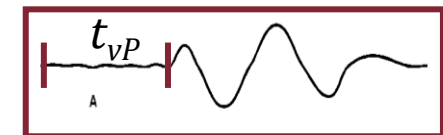
Borehole receiver (3C geophone)



Down-hole – P-wave acquisition



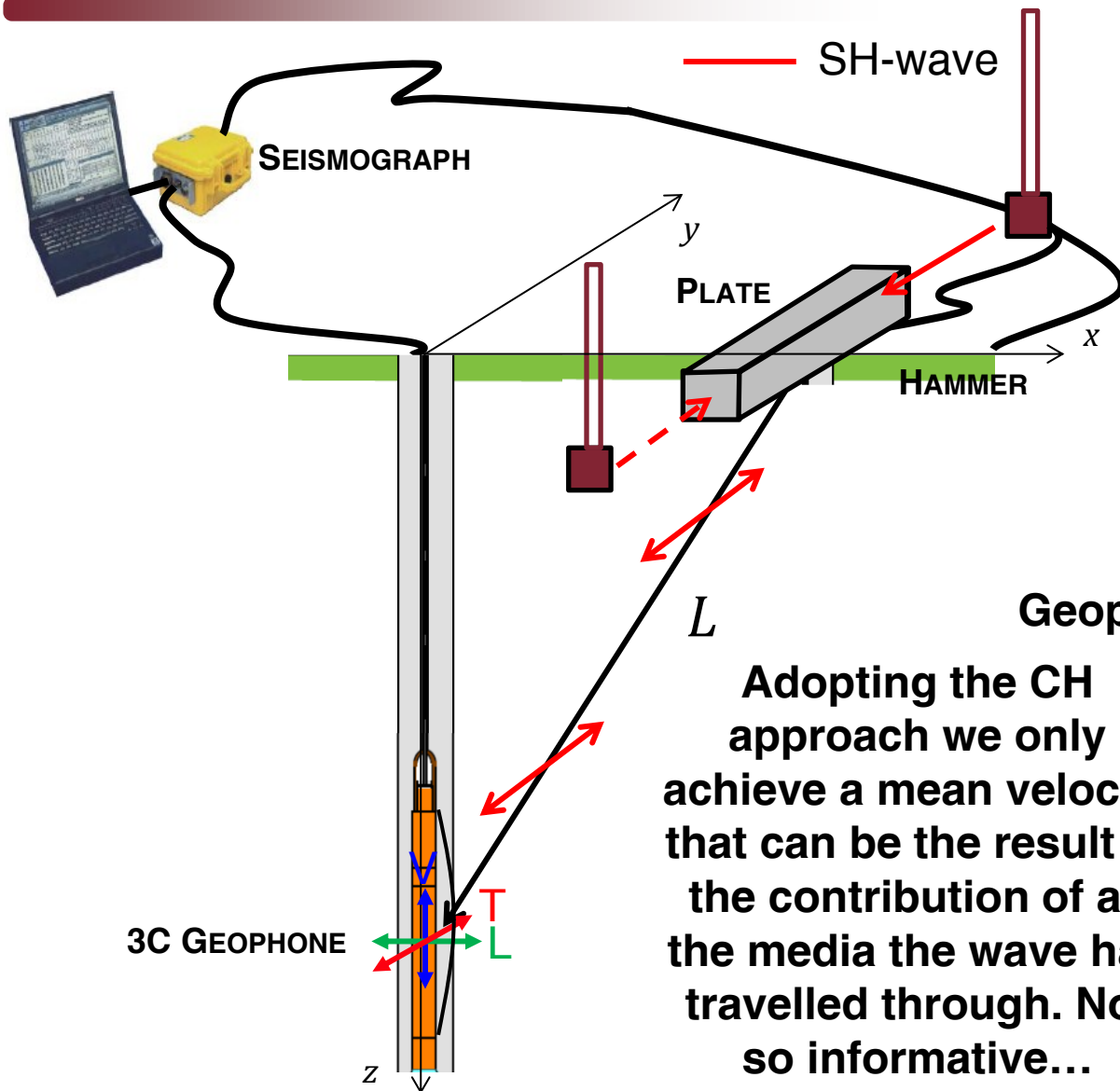
Geophone signal (V-component)



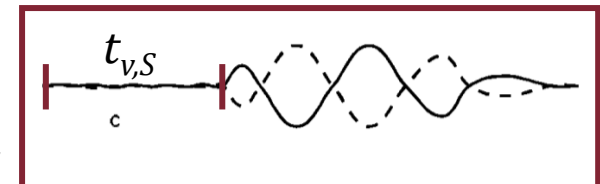
$$\overline{v_P} = \frac{L}{t_{vP}}$$

Adopting the CH approach we only achieve a mean velocity that can be the result of the contribution of all the media the wave has travelled through. Not so informative...

Down-hole – SH-wave acquisition



Geophone signal (T-components)



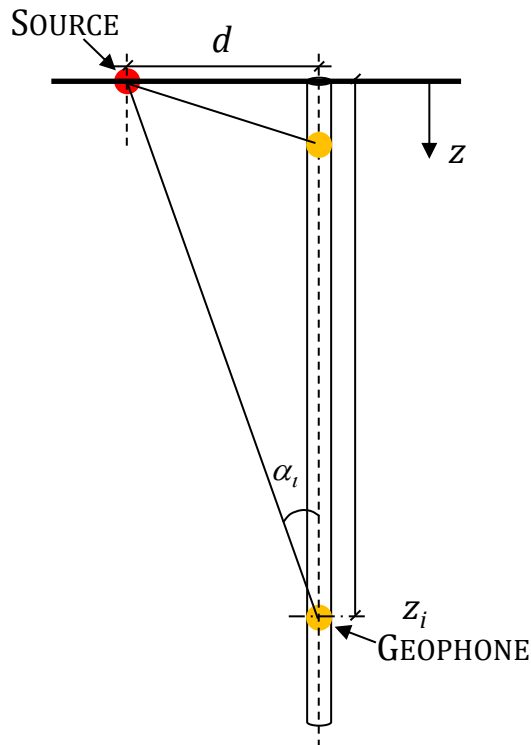
$$\overline{v_S} = \frac{L}{t_{vS}}$$

Adopting the CH approach we only achieve a mean velocity that can be the result of the contribution of all the media the wave has travelled through. Not so informative...

Down-hole – Data acquisition and picking

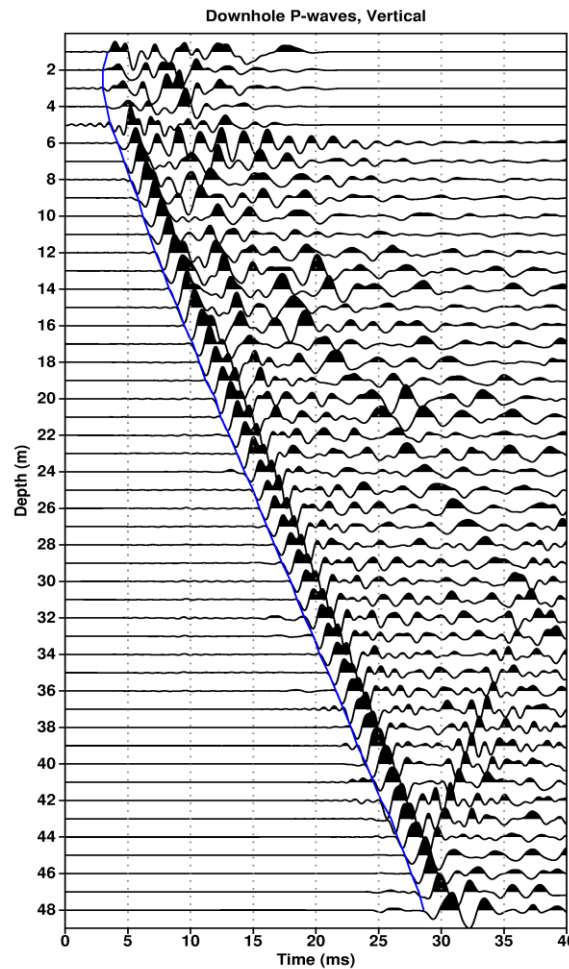
Therefore, the DH data processing workflow is slightly different...

Data acquisition

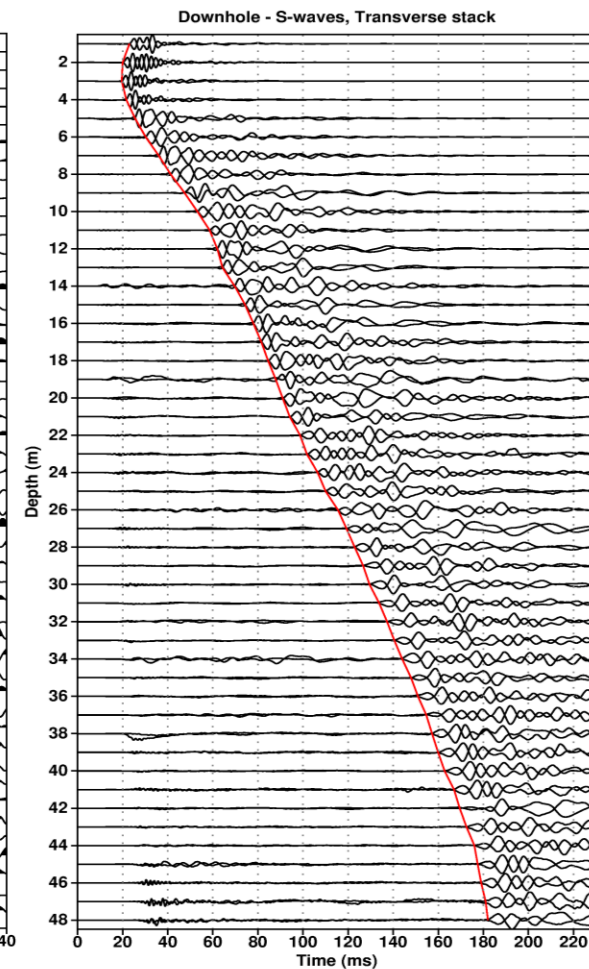


Traces and picked travel-times

P-wave



S-wave



Down-hole - Processing



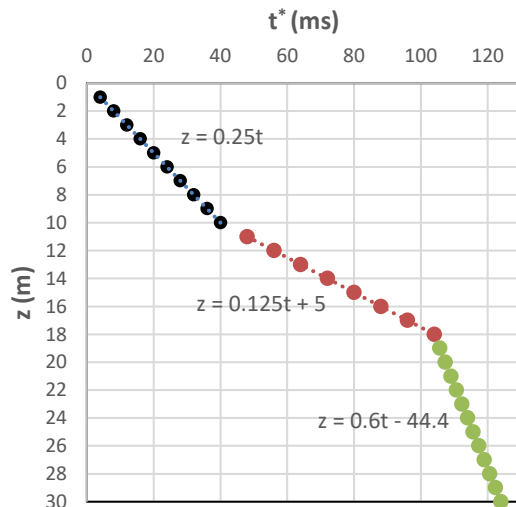
1. Travel-times correction (for both waves)

$$t_i^* = t_i \cos \alpha_i$$

$$\alpha_i = \tan^{-1} \left(\frac{d}{z_i} \right)$$



2. Knee-method (corrected time vs. depth)



The slopes of the trend lines are the layer velocities

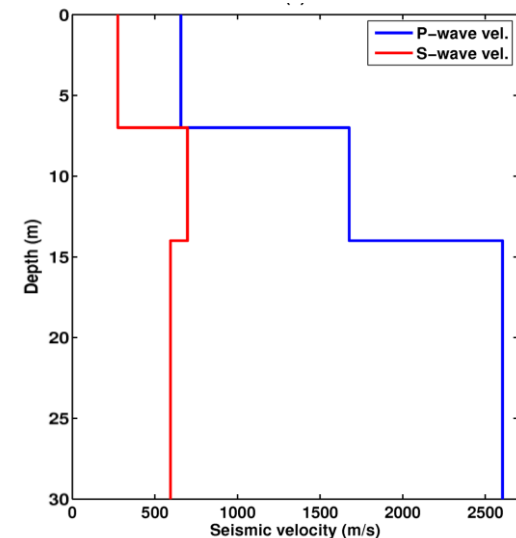


4. Model interpretation (with prior information)

z (m)	Vp (m/s)	Layer	Label
1	800	LAYER 1	vadose zone
10	800		
10	1847	LAYER 2	uncontaminated aquifer
18	1847		
18	1515	LAYER 3	contaminated aquifer
22	1515		



3. 1-D velocity models



Downhole in seismic design

EUROCODE 8 (IN ITALY NTC2018)

Seismic macrozonation (peak ground acceleration)

Assessing local effects: topographic effects + soil category (through DH)



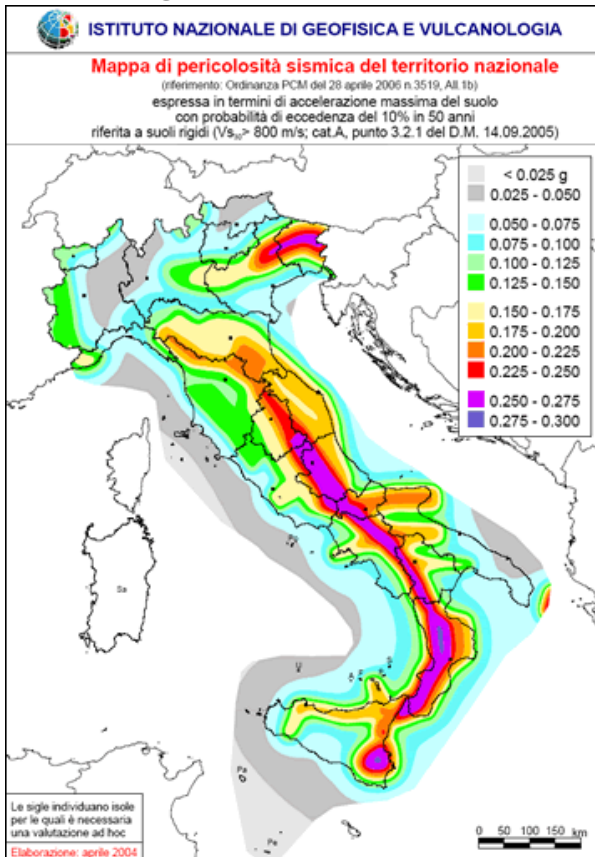
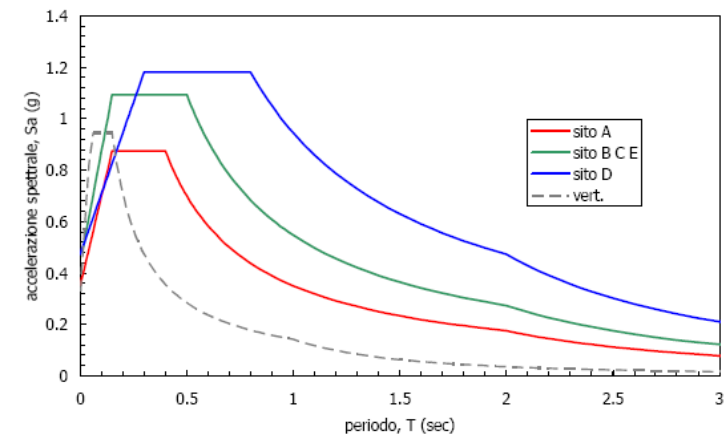
$$v_{s,eq} = \frac{H}{\sum_{i=1}^N \frac{h_i}{V_{s,i}}}$$



- A. $v_{s,eq} > 800$ m/s
- B. $360 < v_{s,eq} < 800$ m/s
- C. $180 < v_{s,eq} < 360$ m/s
- D. $v_{s,eq} < 180$ m/s
- E. C- or D-type soils having thicknesses lower than 20 m directly overlying bedrock



Seismic response spectra



CH vs. DH

CH

PROs

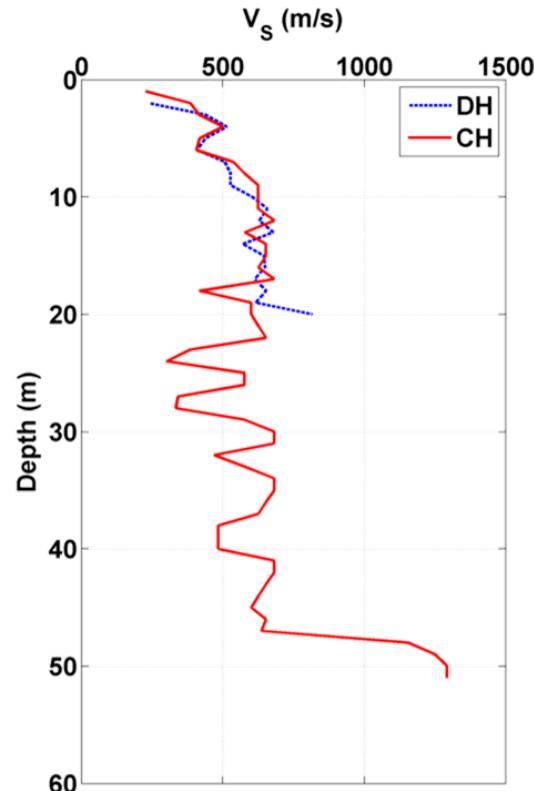
More detailed & deeper

- Signal strength almost constant with depth
- Higher DOI and resolution
- Lower of surface noise (vibrations, wind etc.

CONs

Slower, more expensive

- 2 boreholes
- Need for clinometric measurements
- Slower due to more complex and/or heavy sources



DH

PROs

Faster, cheaper

- 1 borehole
- Faster due to lighter and easy-to-work sources
- No need of additional equipment

CONs

Less detailed & shallower

- Signal strength decreases with depth
- Refractions & reflections should be considered
- Lower DOI and resolution