Seismic amplitude anomalies revealed by the monitoring of underground CO_2 injection

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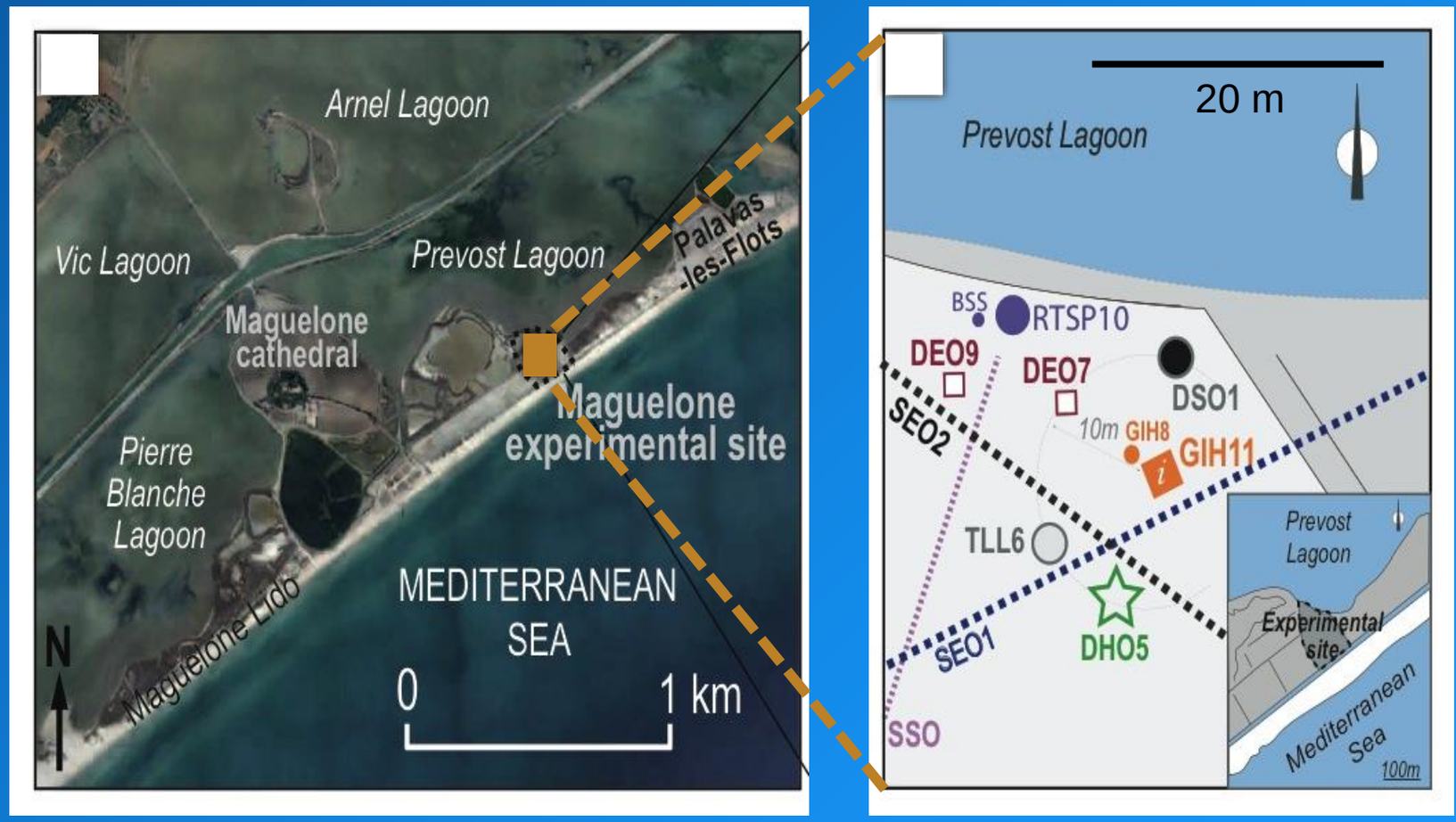
Introduction

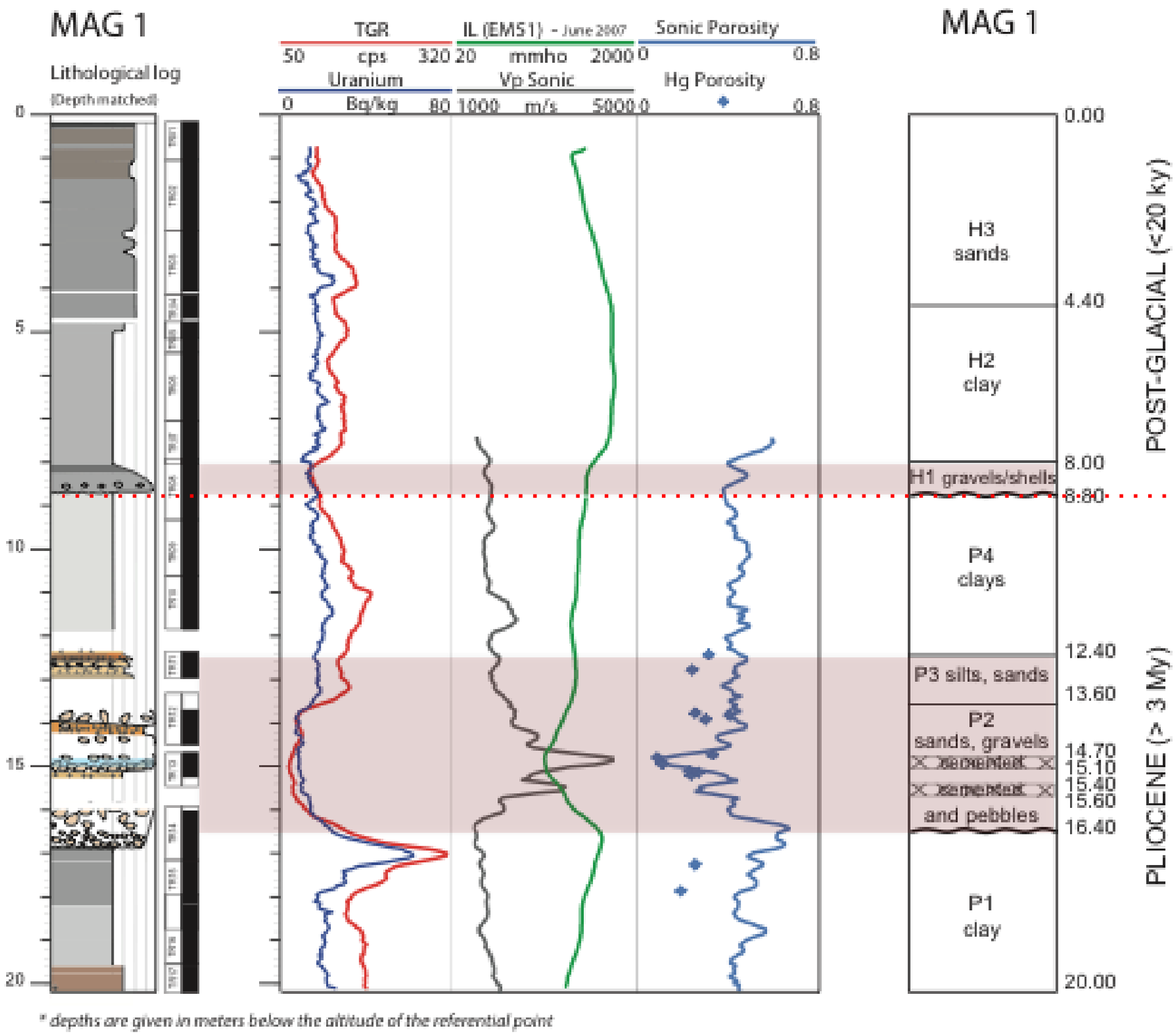
- Objective : design of geophysical tools for in-situ real-time monitoring of underground processes.
- Application to $C0_2$ injection/storage monitoring.
- Measurements of seismic parametesr changes in relation to gas injections.
- *Research supported by EU FP7 research projects MUSTANG/PANACEA and TRUST.*

The Maguelone site

The Maguelone experimental site

- Located on the coastal lido near Montpellier.
- Clastic reservoirs targeted for gas injections at 8-9 m and 13-16 m depth.
- Equipped with a set of nearby surface and downhole instruments dedicated to the monitoringof complementary parameter .





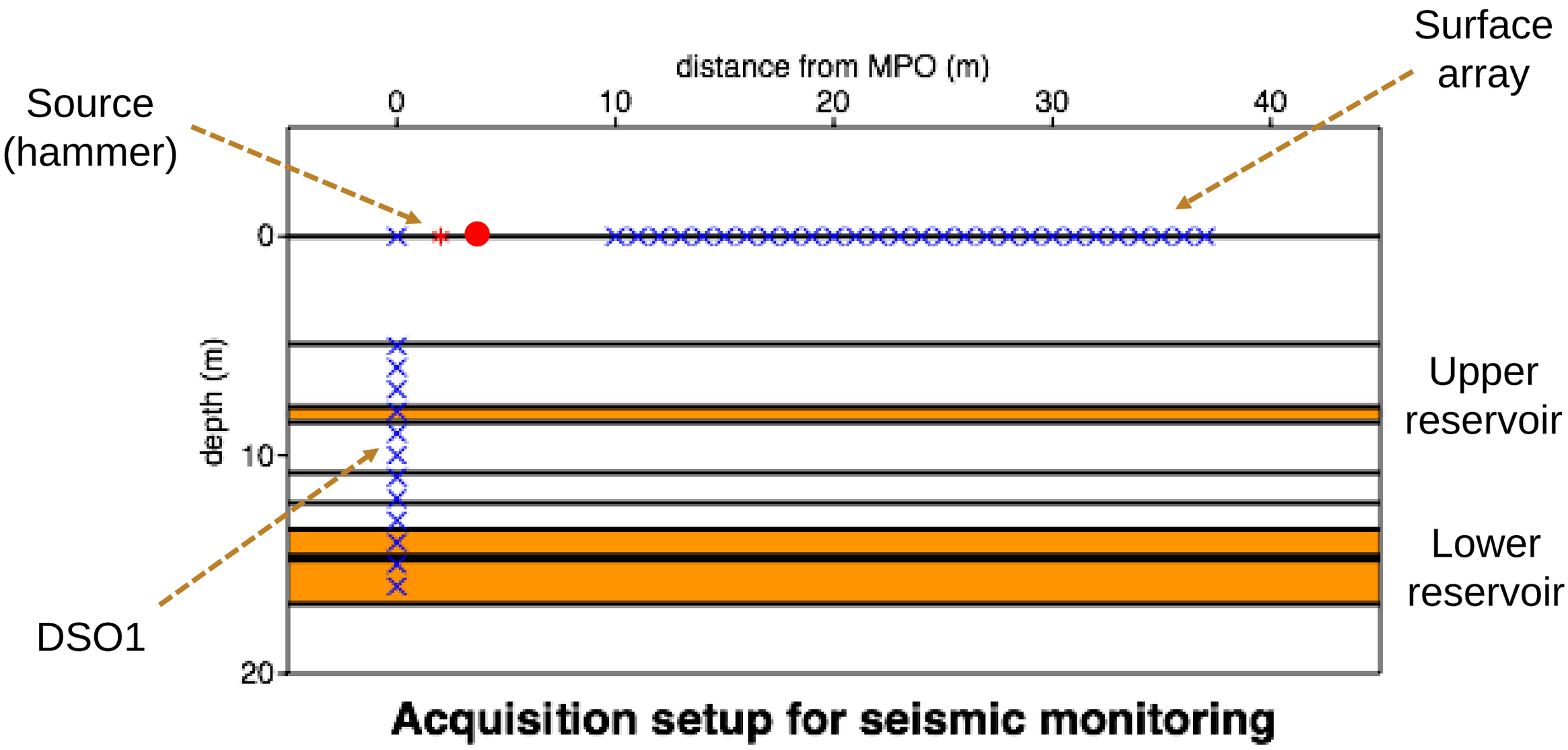
Upper reservoir

Lower reservoir

Sedimentological and petrophysical setting at Maguelone

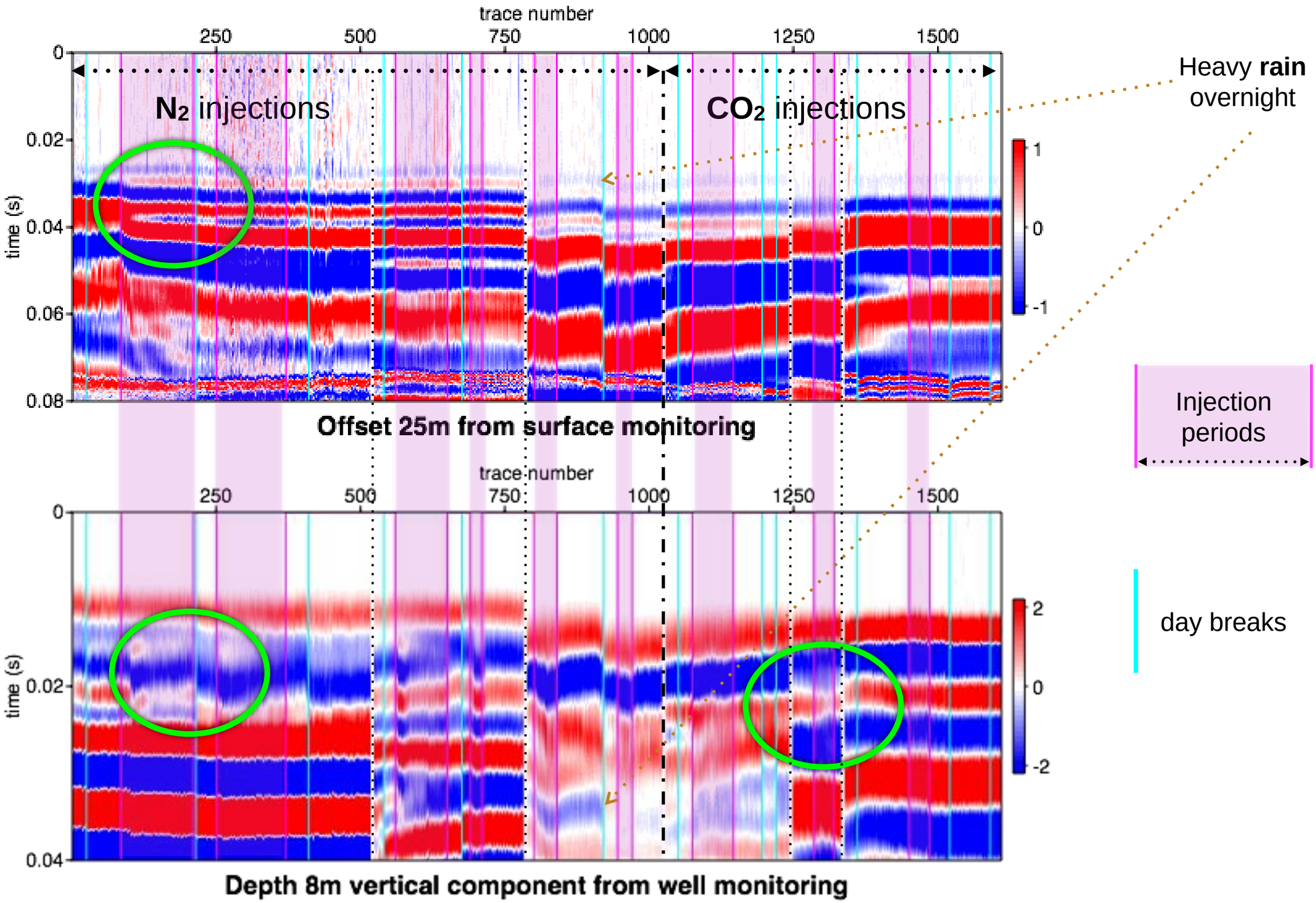
Gas injections : 2012 - 2015

- Baseline measurements (2010 & 2012)
- 3 N_2 test injections (03/12 to 11/12)
- 3 $C0_2$ injections (01/13 to 10/15)
- Control measurements (10/12, 06/13 & 06/15)

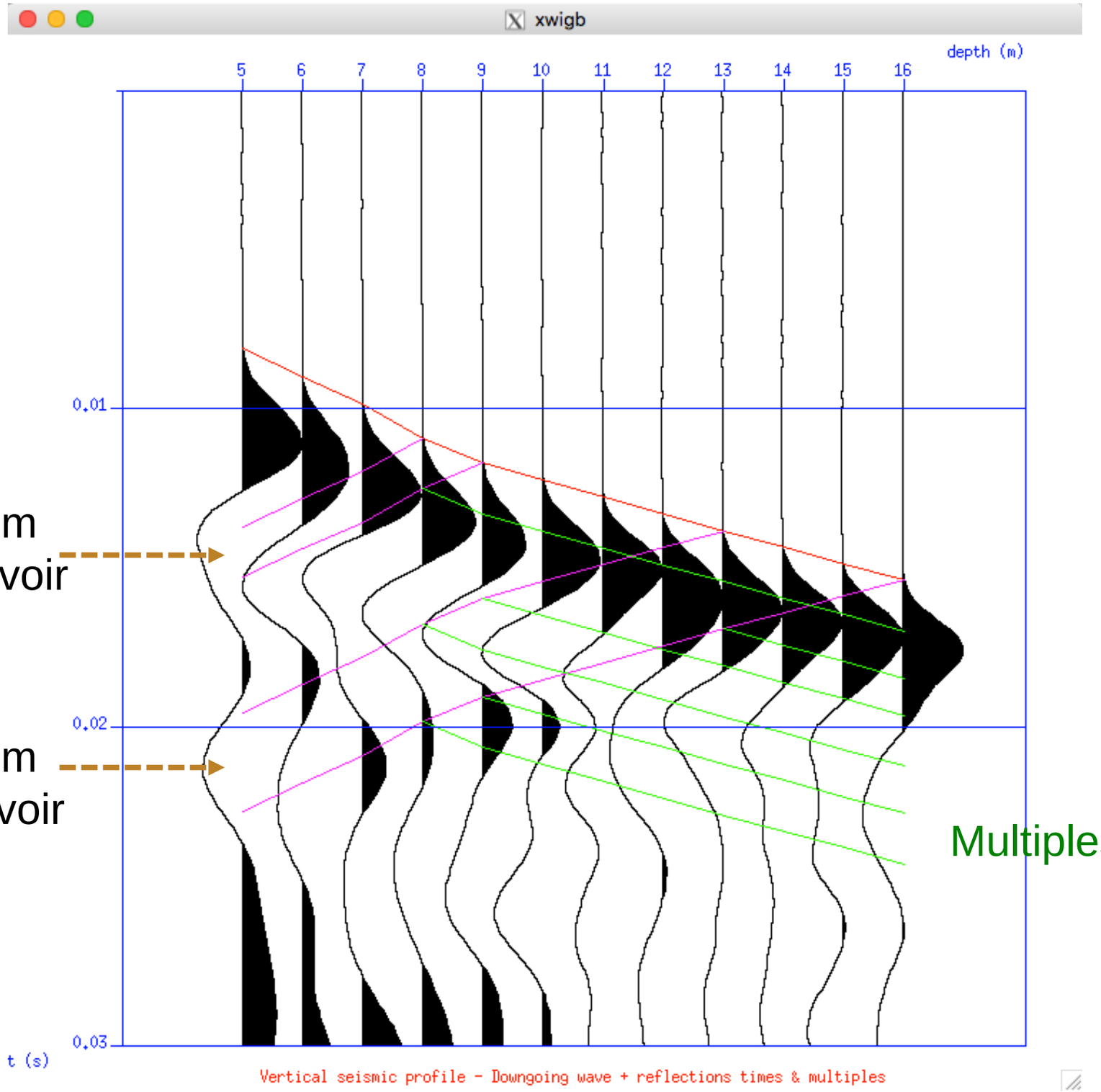


Acquisition setup for seismic monitoring

Compilation of 6 gas injection experiments: impact on arrival times



Downhole seismic observatory RSTP-10 before injection (Dec 2015; vertical component)



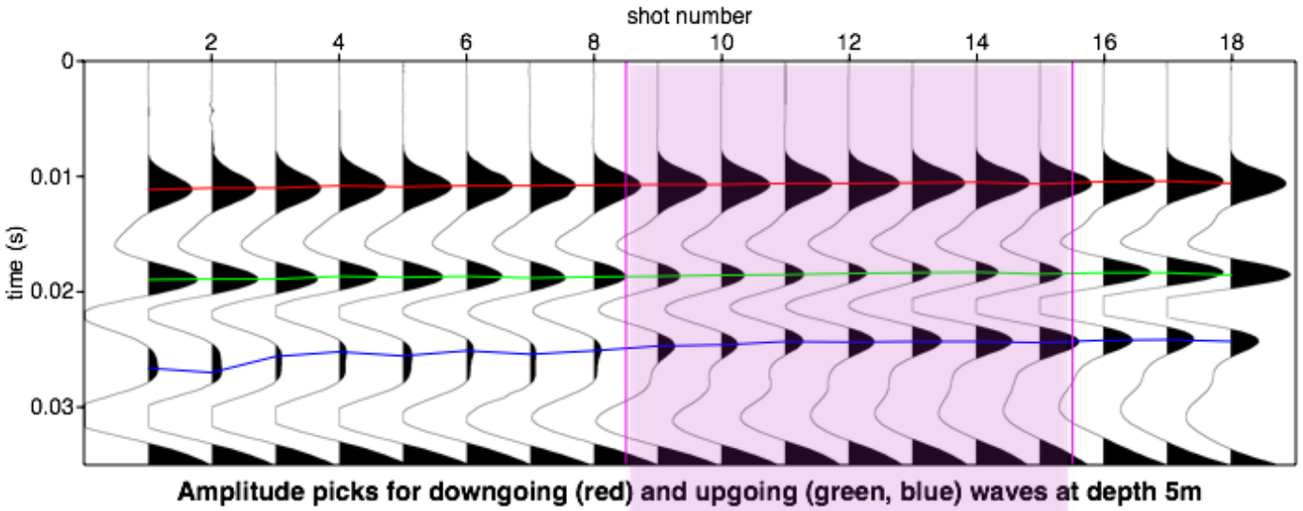
Reflections from the upper reservoir

Reflections from the lower reservoir

Multiples

Geophone at 5 m depth (vertical component) - $C0_2$ injection (8 to 9 m depth) – Dec 2014

Injection period

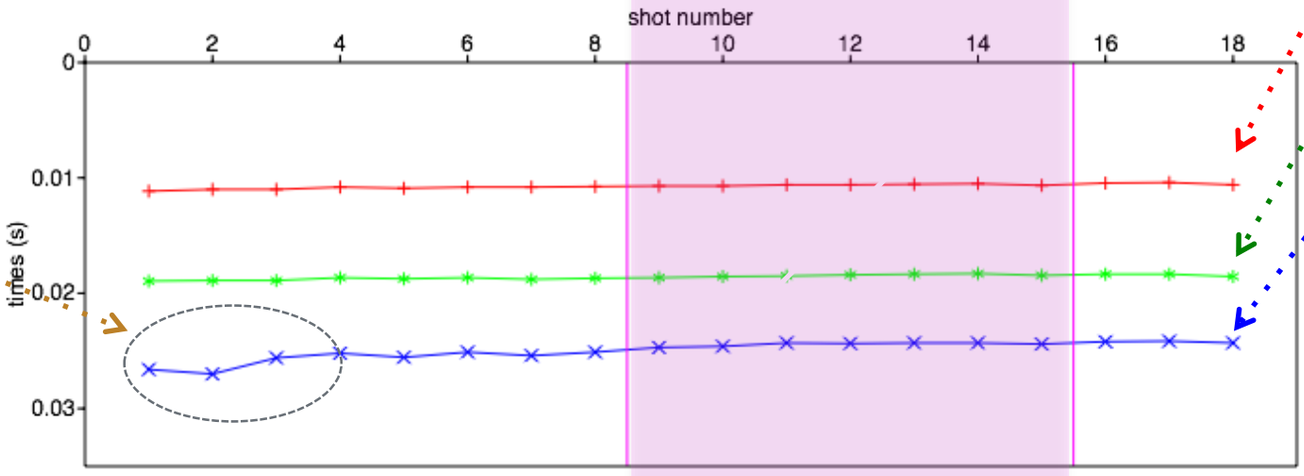


Downgoing wave

Upper reservoir reflection

Lower reservoir reflection (with two-way transmission through upper reservoir)

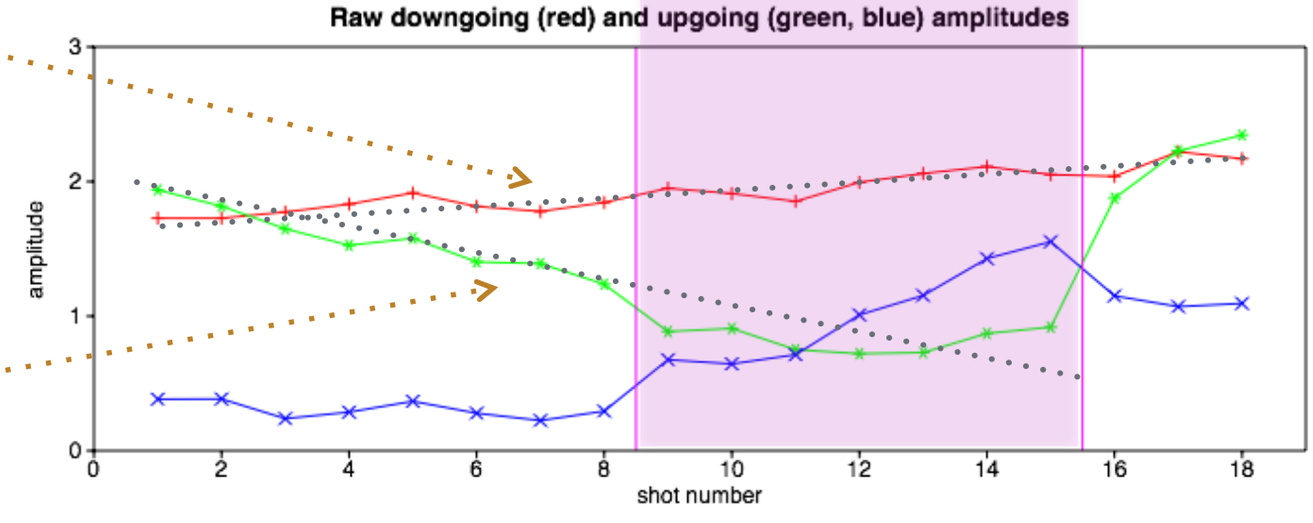
Amplitude changes due to in-situ **natural** gas production



Times : **hardly no change.**

Soil **compaction** at source due to hammering

Natural gas **release** due to repeated hammering



Amplitudes : **clear changes.**

Modelling of seismic amplitudes

1D (vertical) modelling

- Reservoir bulk density : $\rho_b = (1-\phi).\rho_m + \phi.(1-S_g).\rho_w + \phi.S_g.\rho_g$

- Density change with gas injection in the reservoir : $\Delta\rho = -\phi.S_g.\rho_w$ (ρ_g <<< ρ_w)

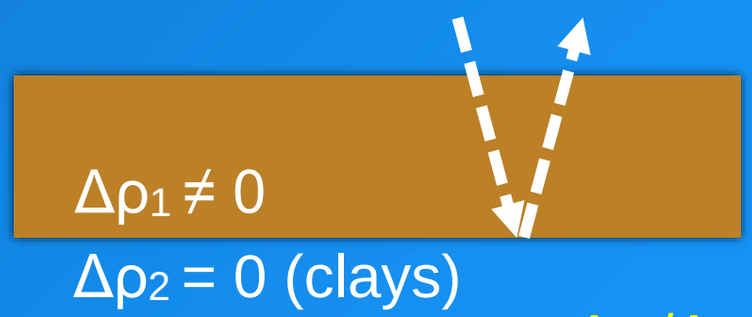
- Reflected amplitude ratio :

$$\frac{A_{ns}}{A_{ws}} = \frac{1 + \frac{\Delta\rho_2.V_2 - \Delta\rho_1.V_1}{\rho_2.V_2 - \rho_1.V_1}}{1 + \frac{\Delta\rho_2.V_2 + \Delta\rho_1.V_1}{\rho_2.V_2 + \rho_1.V_1}}$$

- Reflection at reservoir top

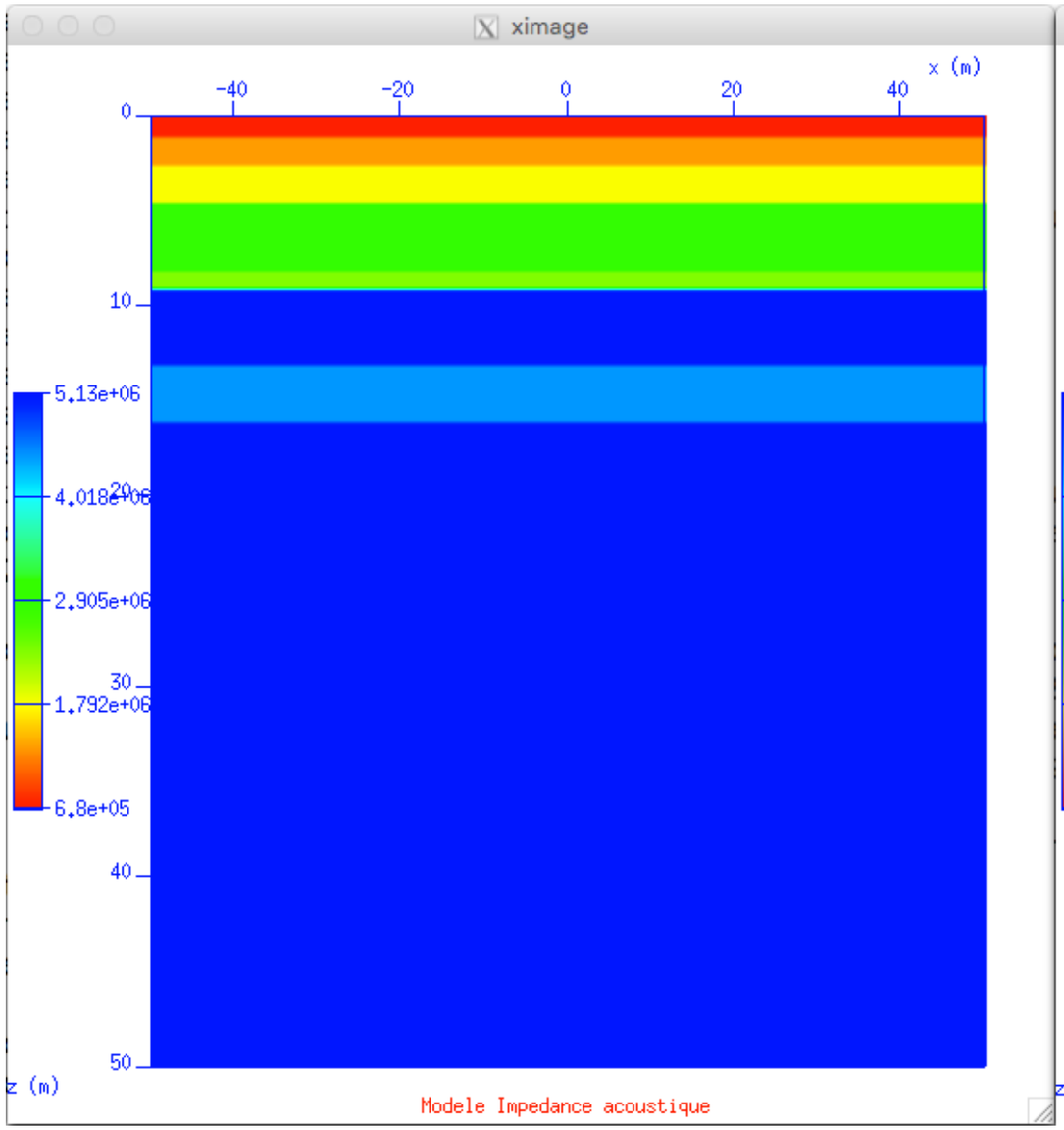
A_{ns}/A_{ws} (with gas/no gas) = **1.36**

- Reflection at reservoir bottom

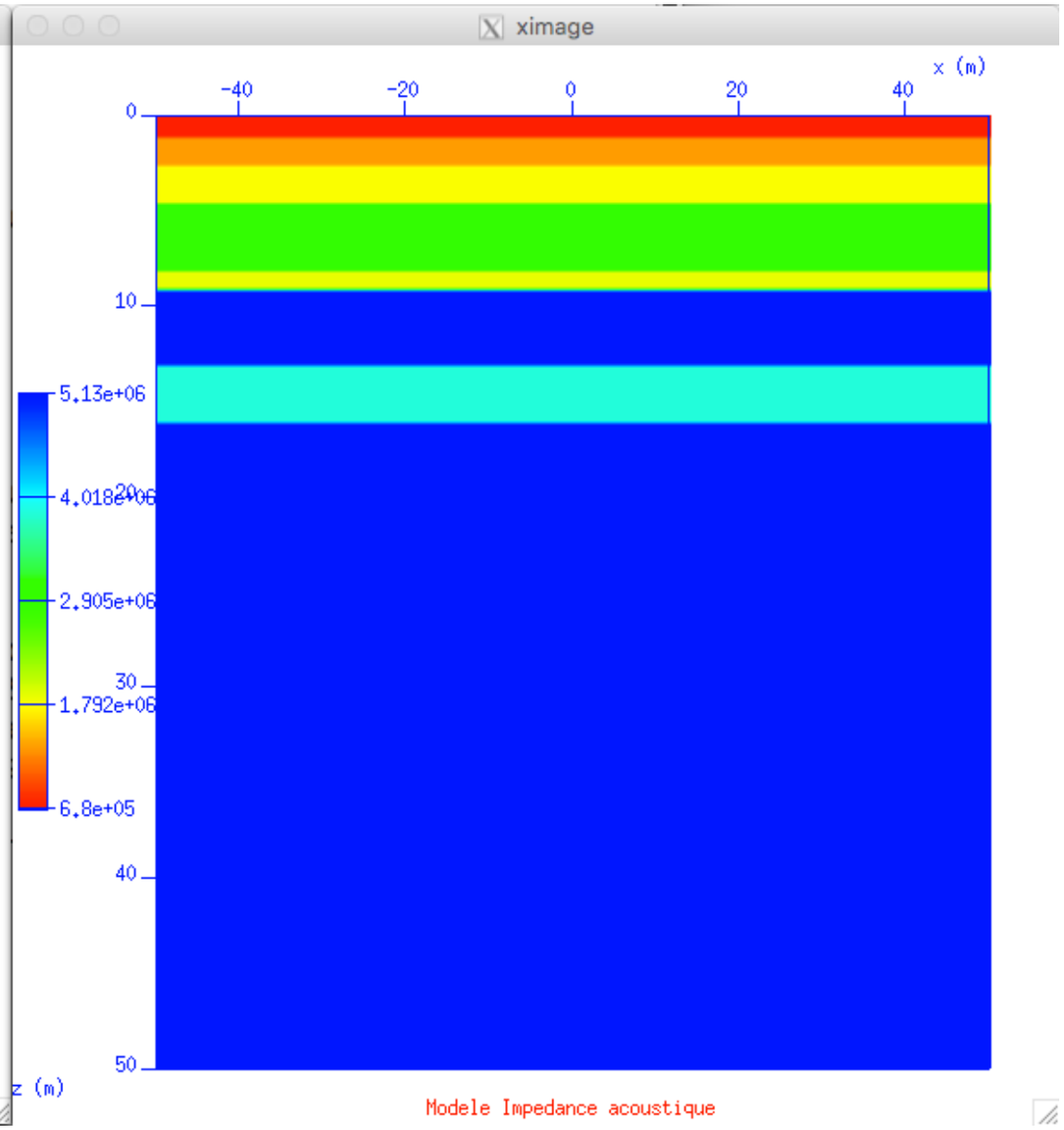


A_{ns}/A_{ws} = **1.14**

2D Modelling: acoustic impedance model changes (density changes only)

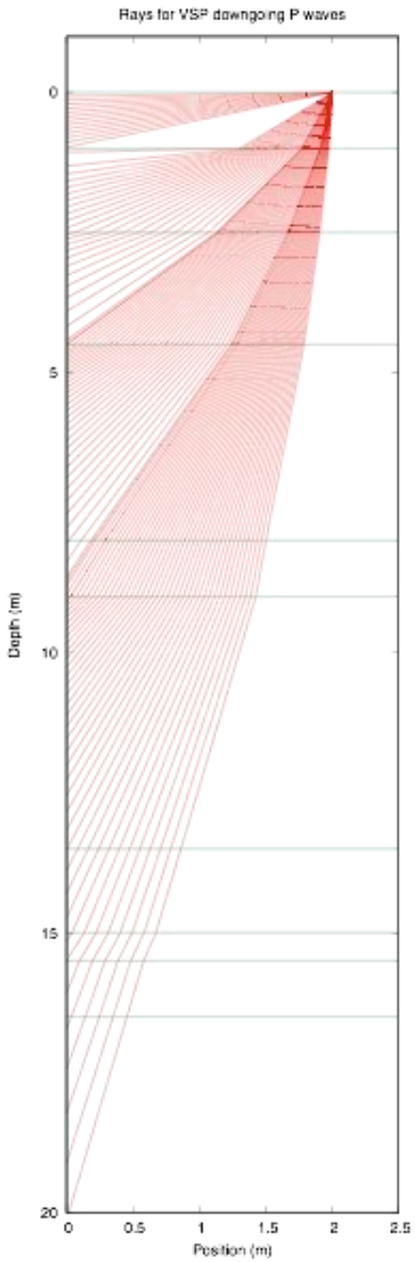


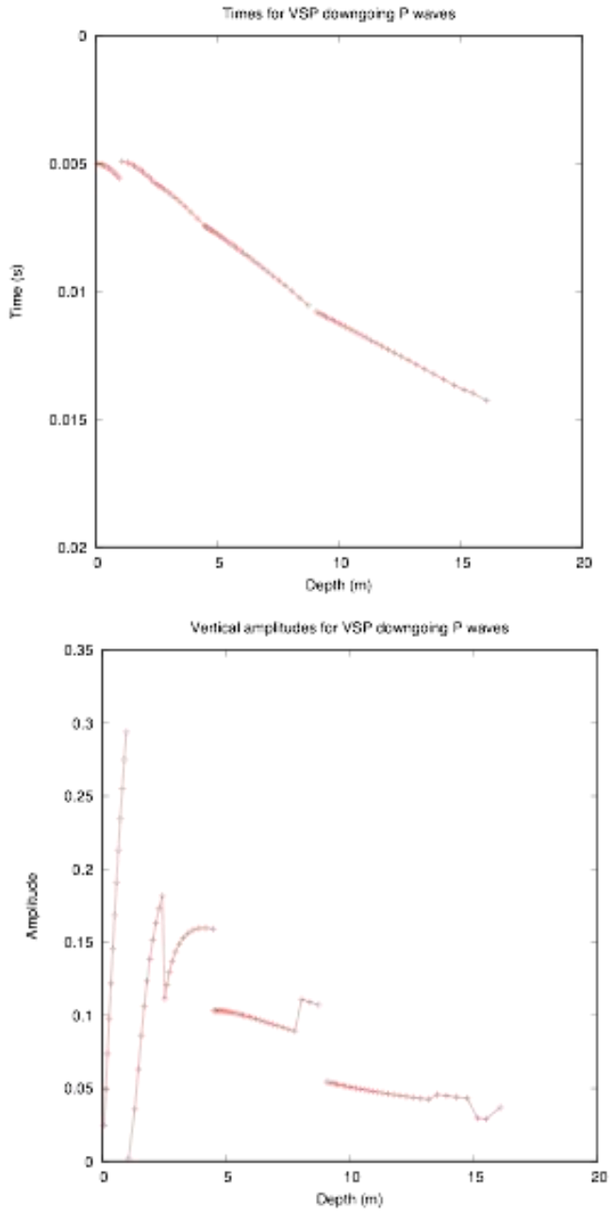
No injection

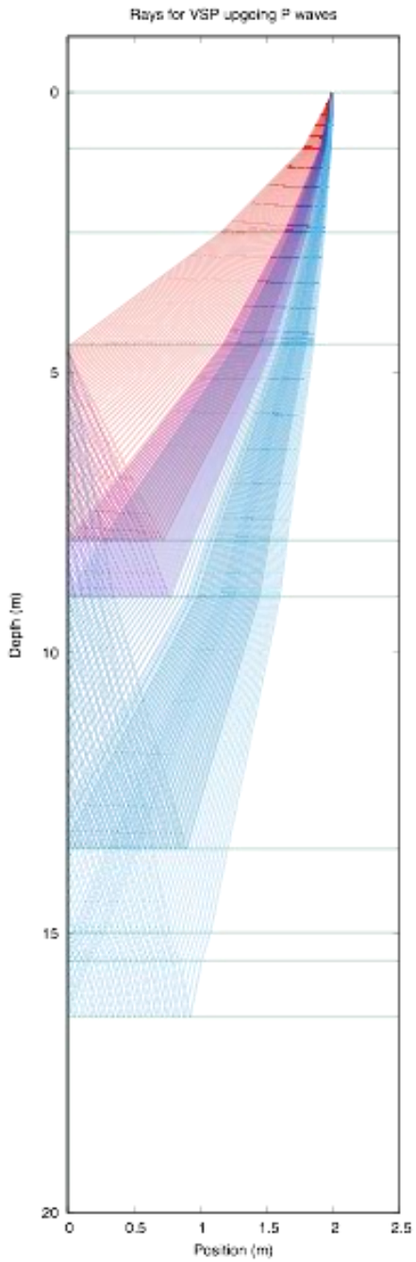


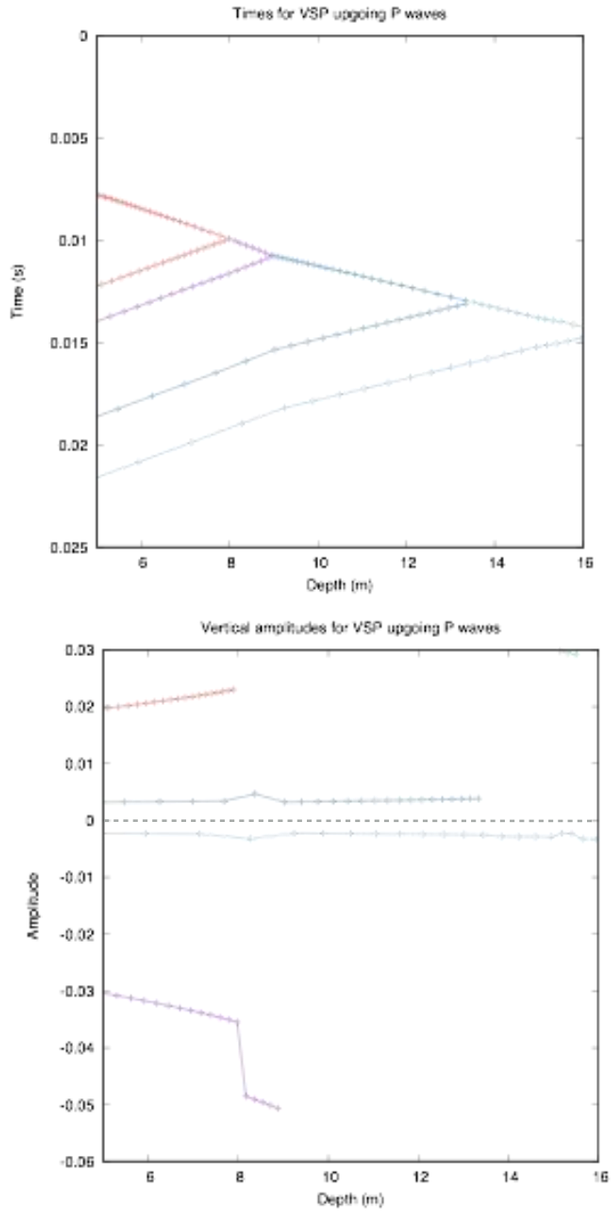
Gas injection

2D Modelling: ray computation for blocky model









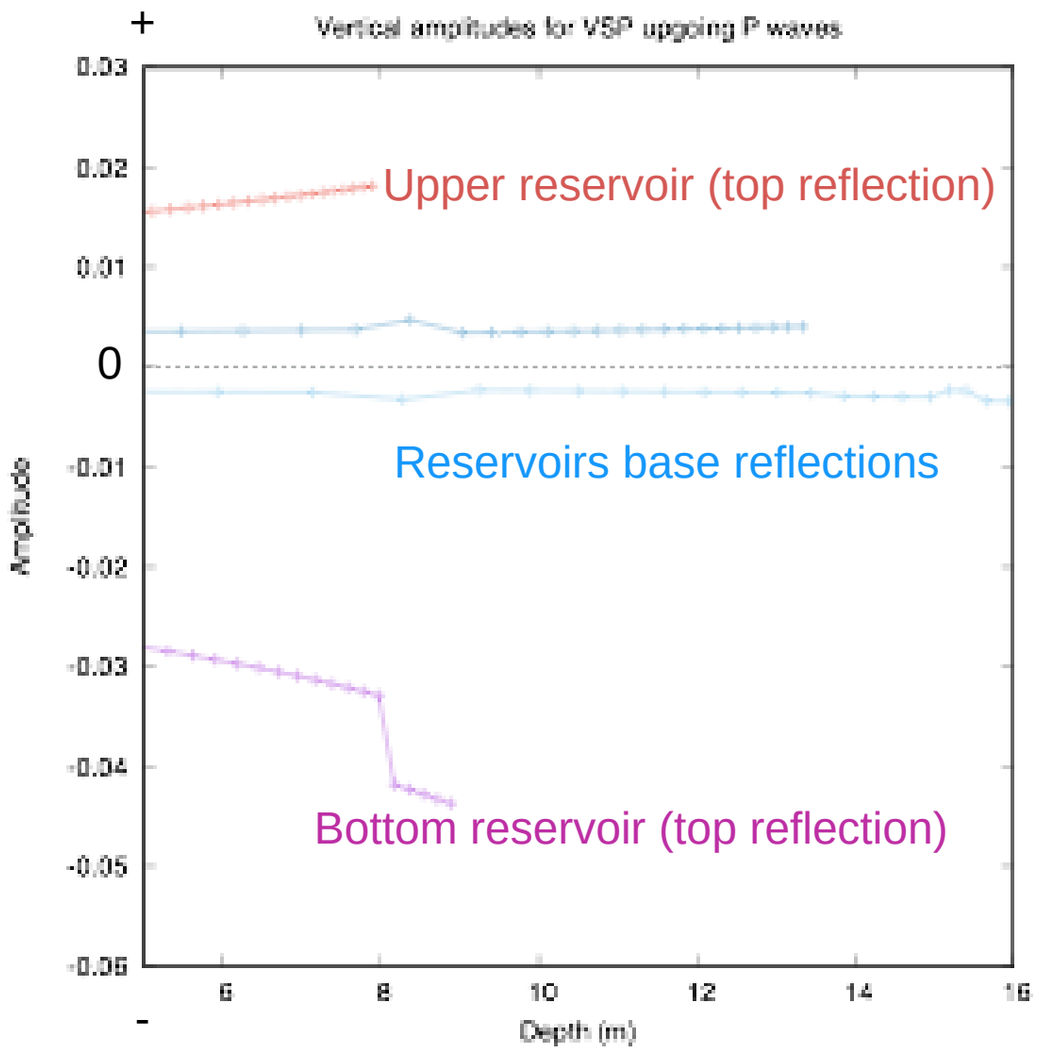
Times

Amplitudes

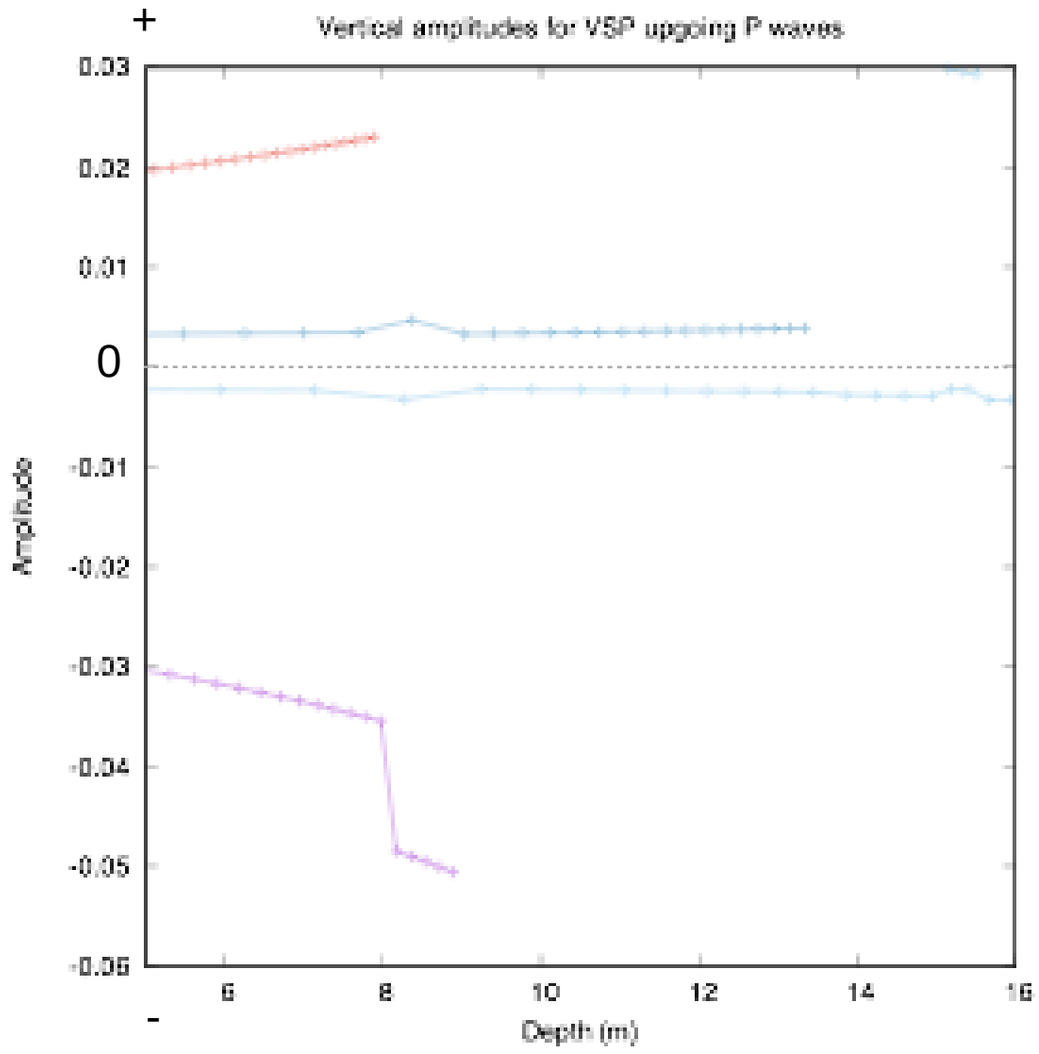
Downgoing wave

Upgoing waves

2D Modelling: comparison of ray amplitudes

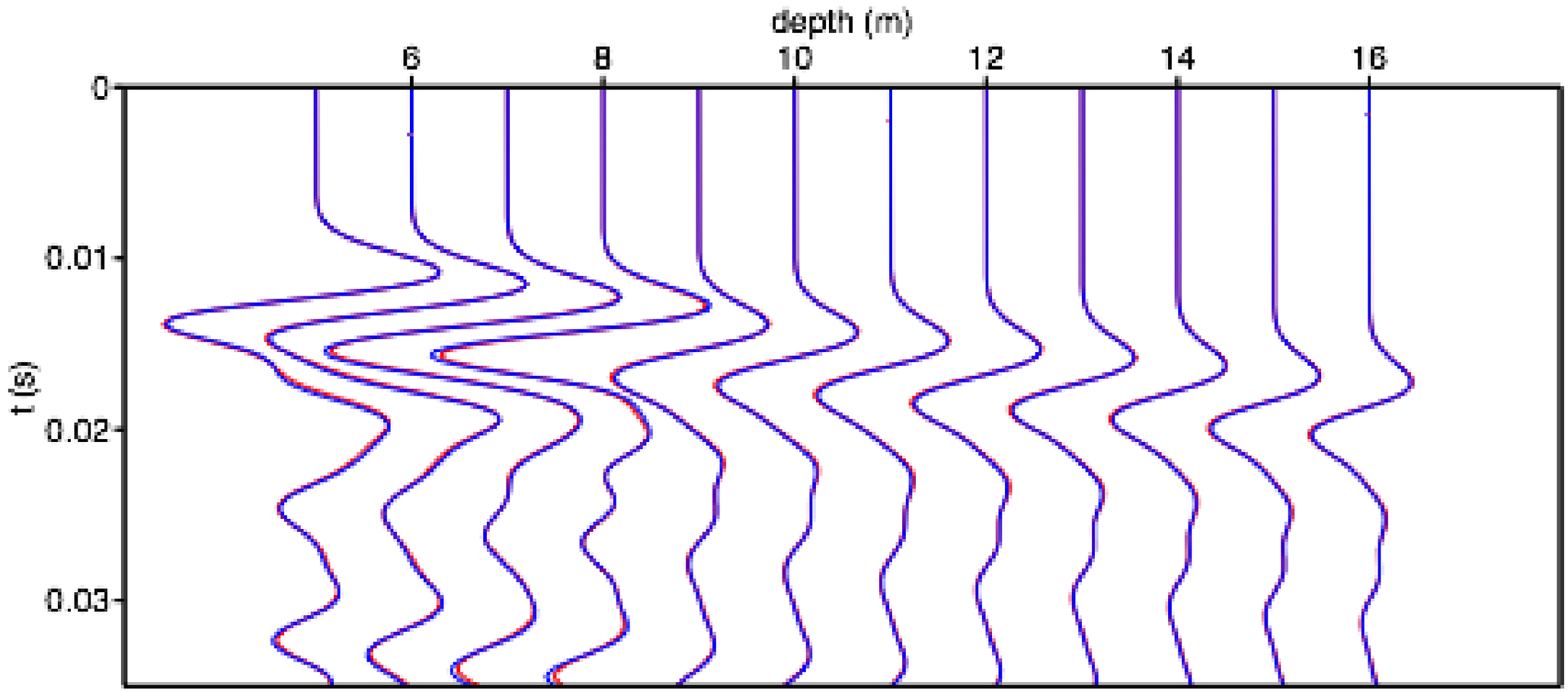


No injection



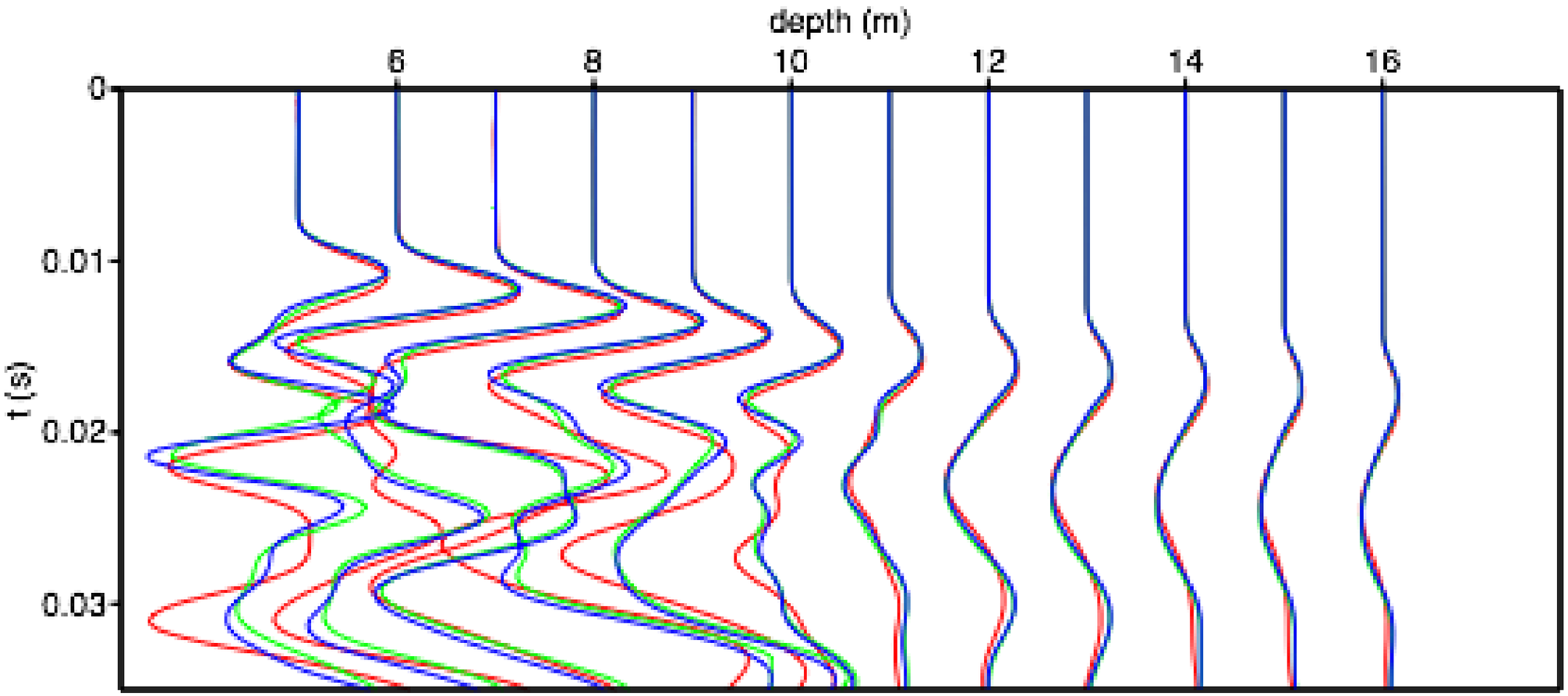
Gas injection

2D Modelling: amplitude changes with/without injection



Simulated VSP without (red) and with (blue) gas injection

Field data: amplitude changes with/without injection



Observed VSP before (red), during (green) and after (blue) gas injection

Conclusions and perspectives

- The SIMEx experiment at Maguelone has revealed clear seismic amplitudes anomalies linked with gas injection.
- Changes in interface seismic reflectivity should generate small amplitude changes. It cannot explain the high amplitude changes recorded during experiments.
- Volumetric amplitude attenuation should be taken into account, with poro-elastic theory, drainage and imbibition effects and patchy saturation. This should produce high quality factor changes for small saturation changes.

Thank you for your attention