Natural gas storage seismic monitoring

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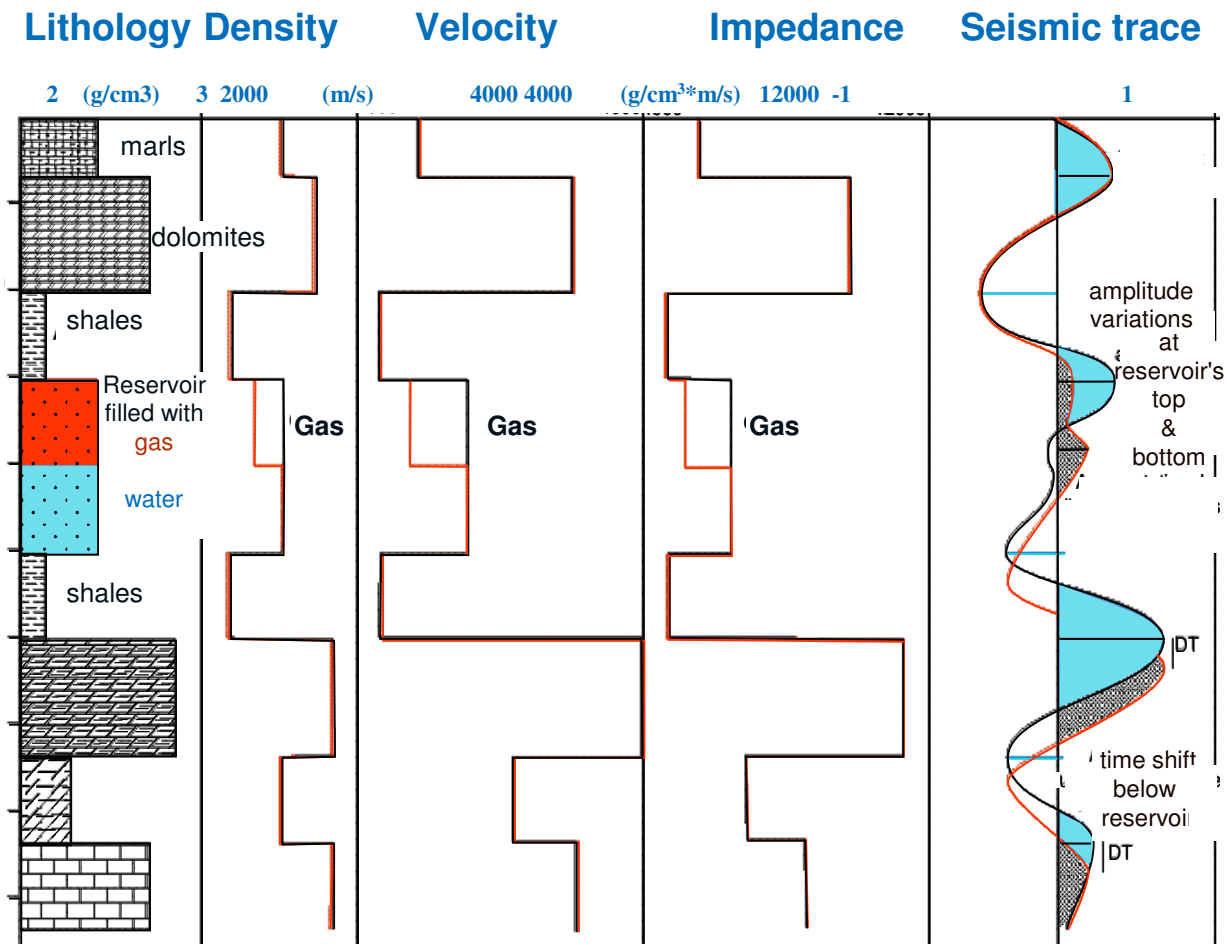
Gas storage monitoring: a 30 years experience

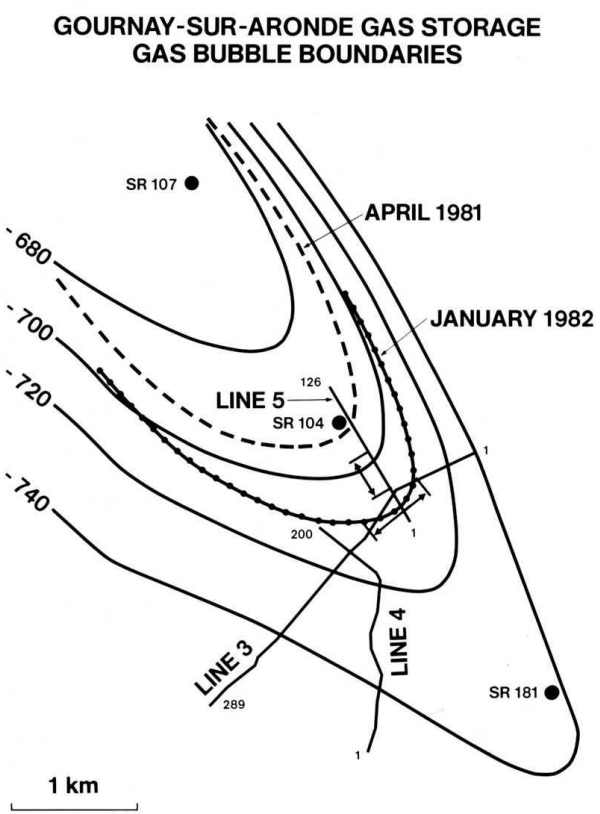
- 1980s surface surveys
  - fluid substitution: time shifts, amplitude variations
- 1990s
  - Time-Lapse differences, stress effects
  - Permanent downhole arrays and well seismics
- 2000s
  - Permanent recording with permanent sources and receivers

Seismic monitoring: amplitudes and time shifts



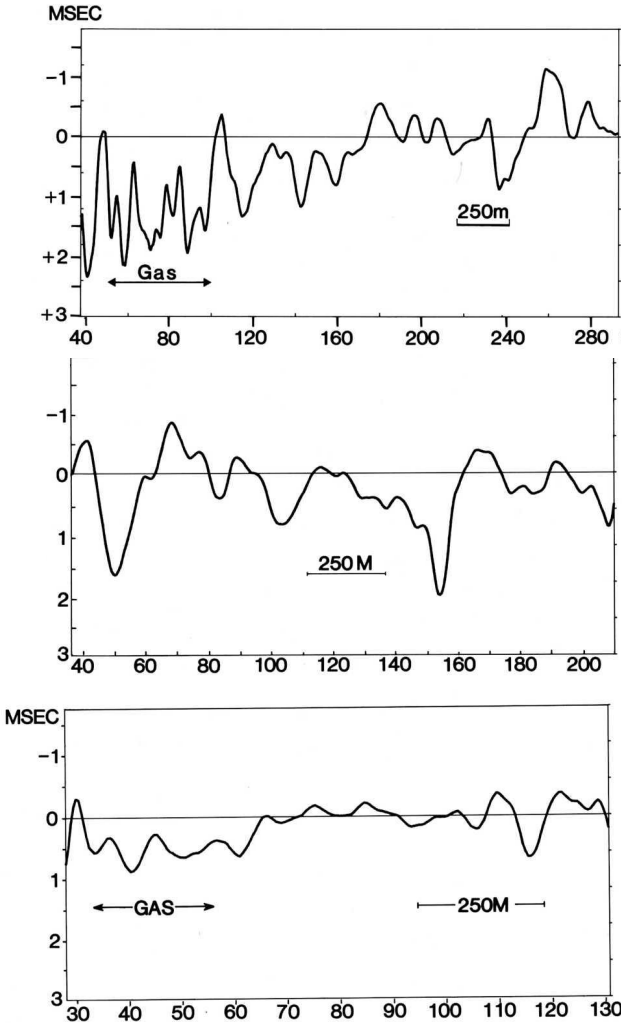
Gournay-sur-Aronde
Time shifts

April 1981 – January 1982

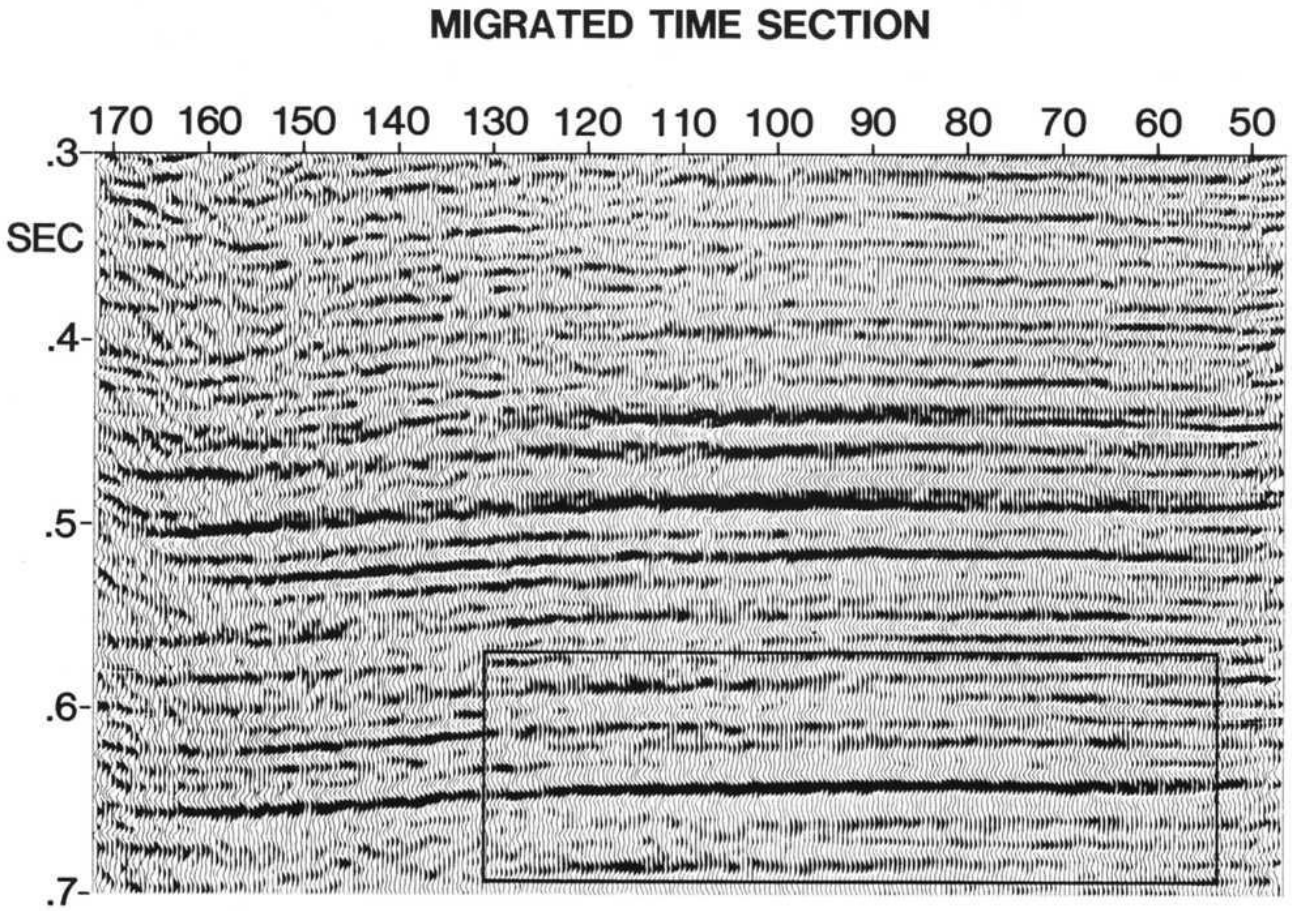


Blondin E. and Mari J.L., 1986,
Detection of gas bubble boundary movement,
Geophysical Prospecting, **34**, 73-93

Time shift curves



Gournay-sur-Aronde
Amplitude variation: dim spot



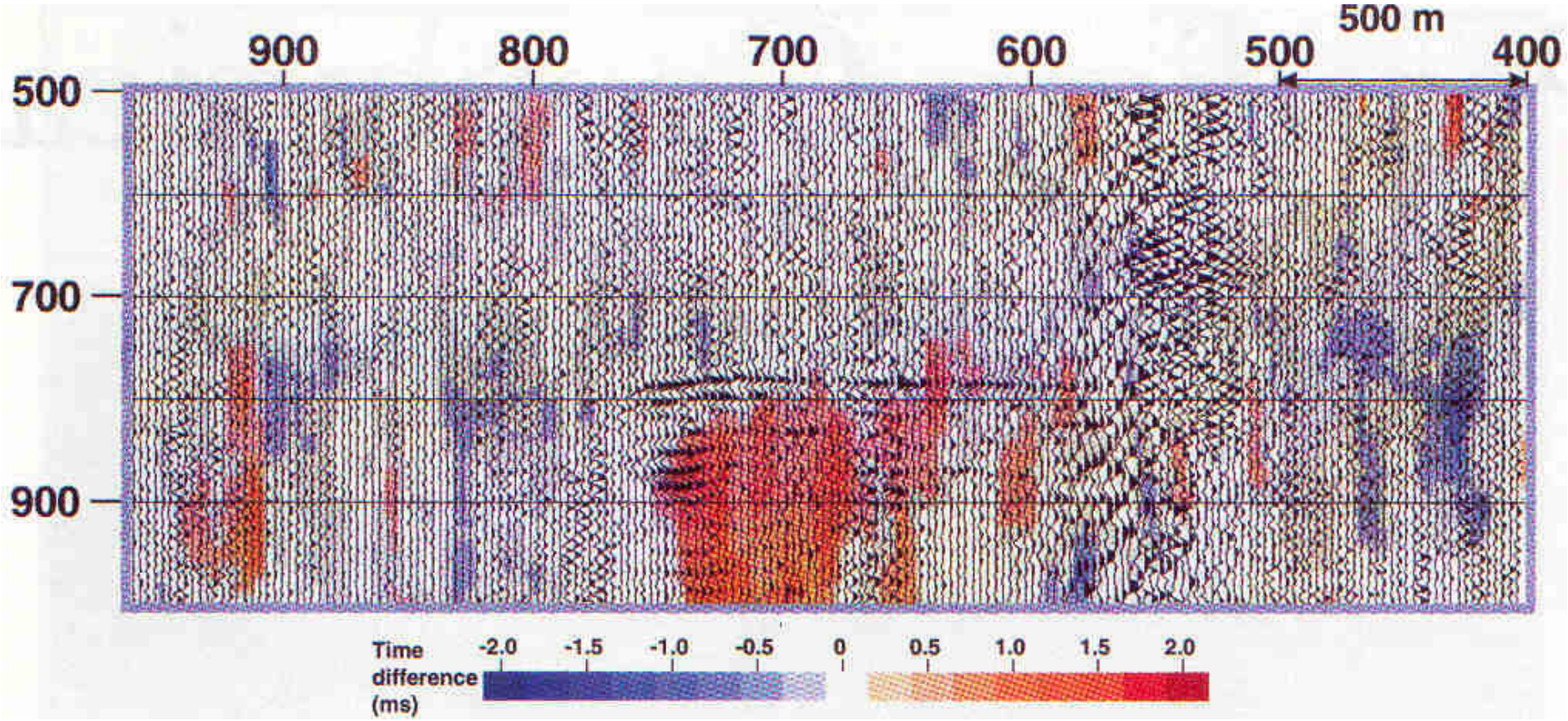
Blondin E. and Mari J.L., 1986,
Detection of gas bubble boundary movement,
Geophysical Prospecting, **34**, 73-93

reservoir

gas

Céré-la-Ronde

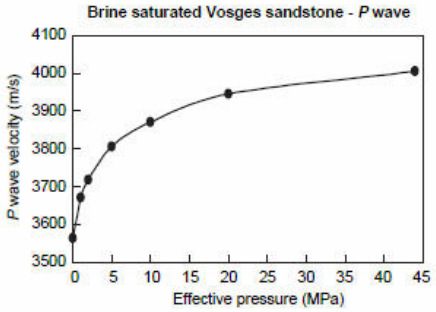
Time-lapse differences Surface seismics

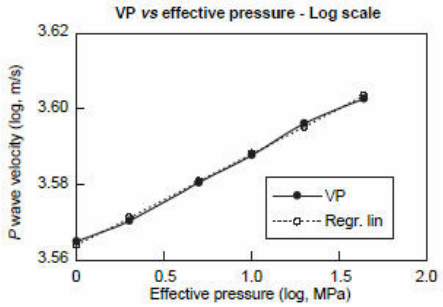


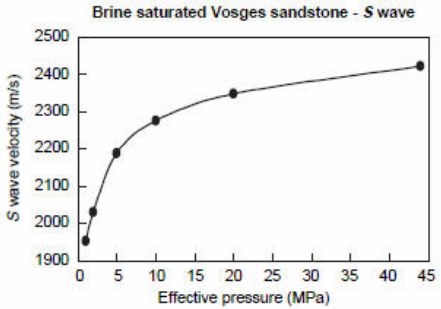
Meunier et Huguet, 1998, Céré-la-Ronde: A laboratory for time-lapse monitoring in the Paris Basin, *The Leading Edge*, **17**, 1388-1394

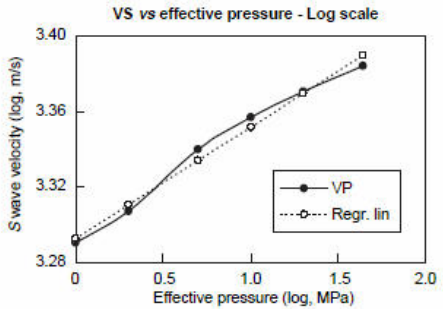
Velocity dependence on effective pressure

Céré-la-Ronde
Fluid substitution and stress effects







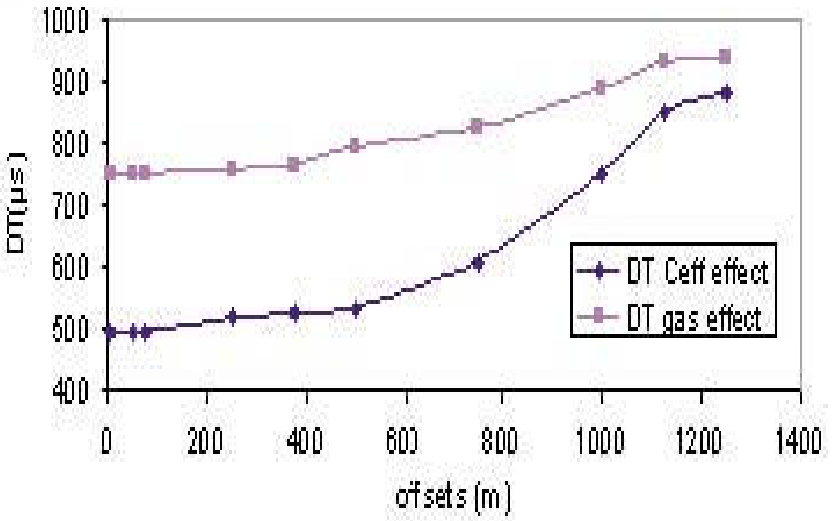


Rasolofosaon & Zinszner (2003), Characterization of reservoir rocks for seismic monitoring studies. Laboratory measurement of Hertz and Gassmann parameters, *Oil and Gas Science & Technology*, **58**, 615-635

Hertz-Mindlin model

$$V = k\sigma_{eff}^{h}$$

Time shift versus source-receiver offset

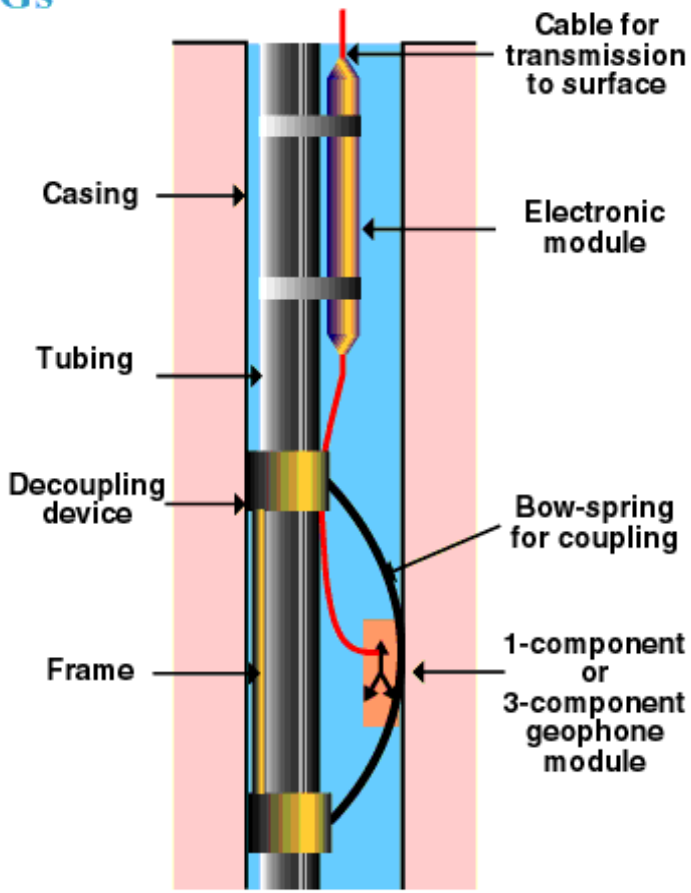


Vidal, Huguet & Mechler, 2002

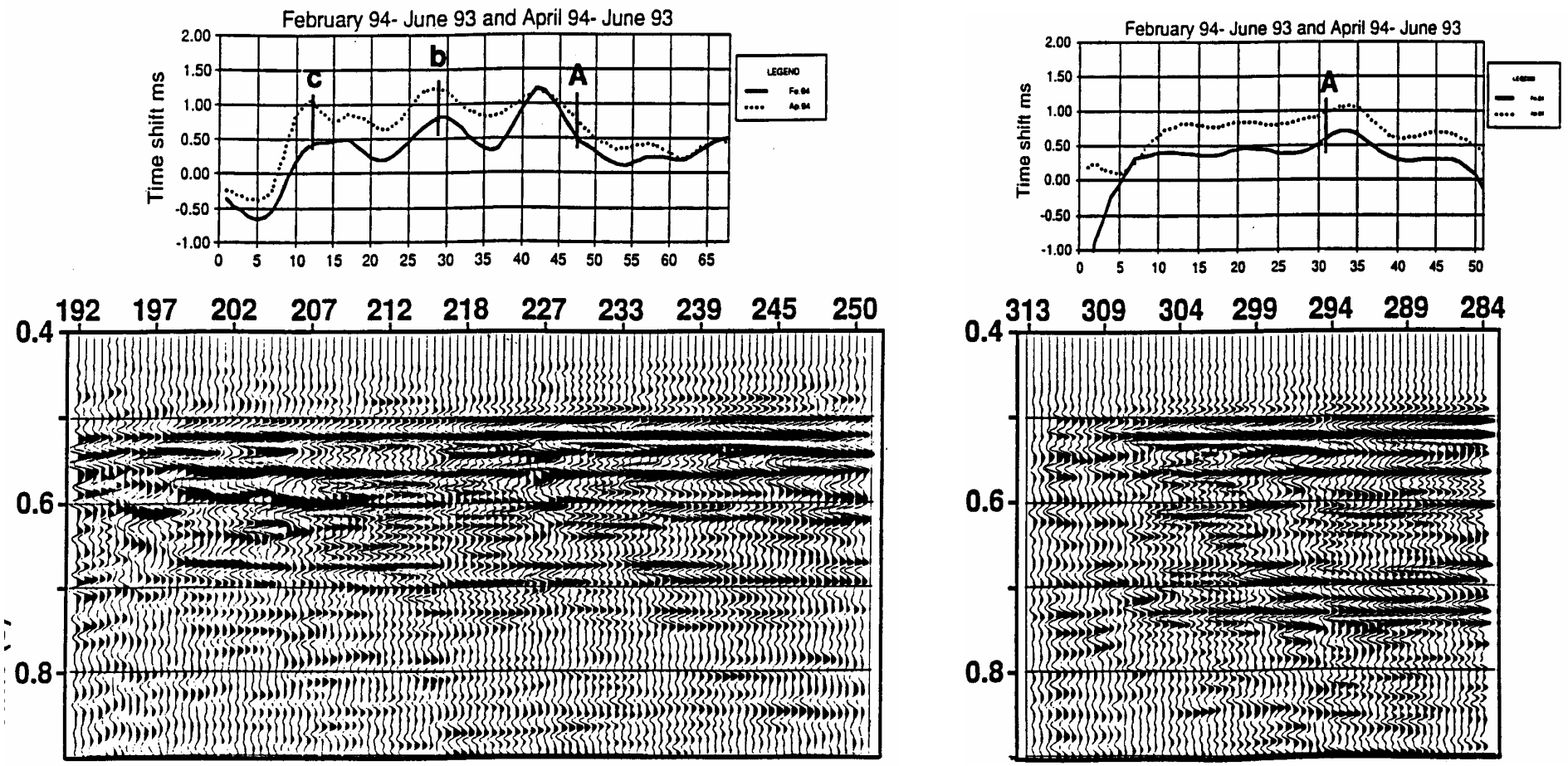
Permanent Downhole Geophones

Instrumentation of a GdF production well with an array of PDGs

Diagram of a PDG



Céré-la-Ronde
Walk away – time shifts



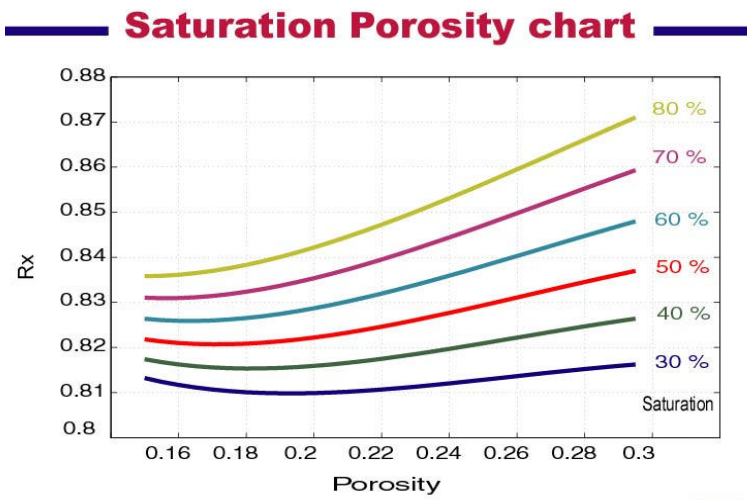
Dumont, Fayemendy, Mari.and Huguet, 2001,
Underground gas storage: Estimating gas column height and saturation with time-lapse seismic, *Petroleum Geosciences*, **7**, 155-162

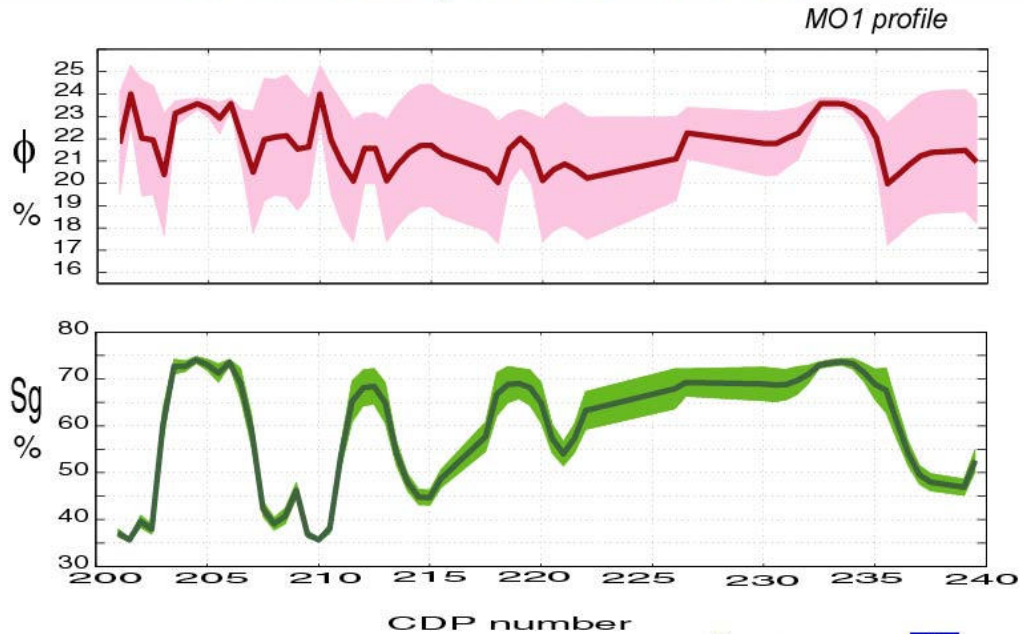
Céré-la-Ronde

Estimation of gas saturation from time shifts and Gassmann's relation

saturation index :

$$R_x = \left(\frac{H_T}{H_T + \Delta t} \right)^2 = \left(\frac{V_P^g}{V_P^w} \right)^2$$

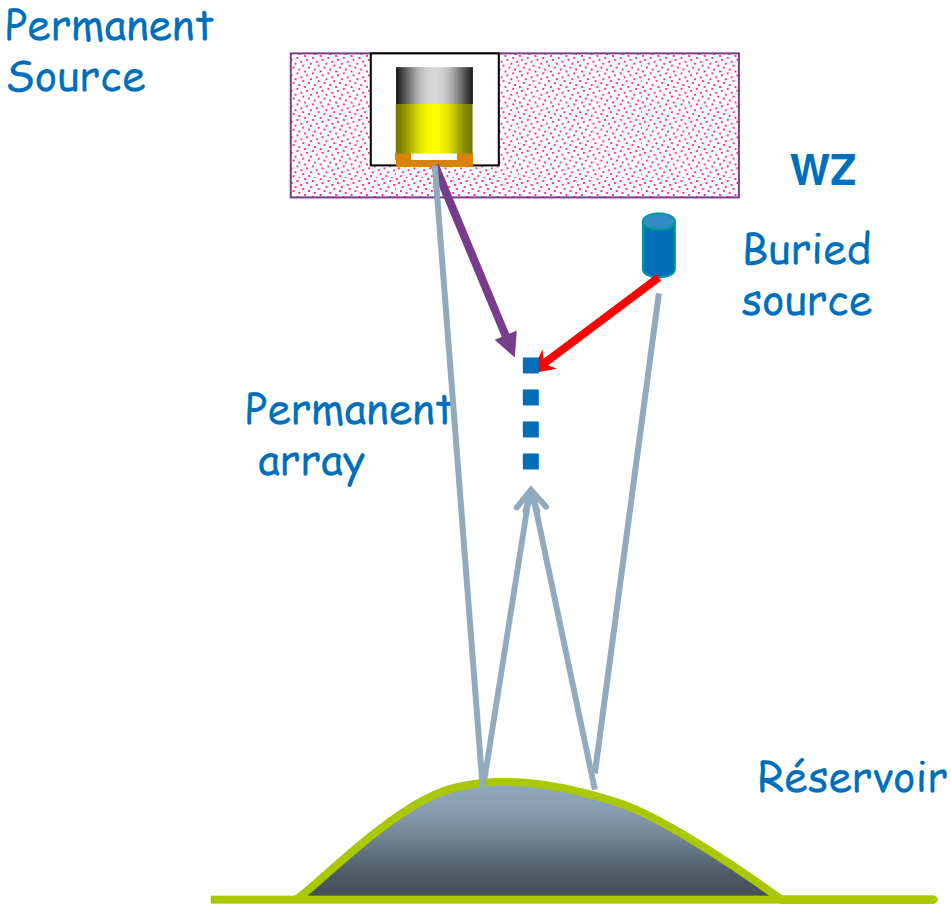




Mari, Fayemendy, Dumont and Huguet.,2000, Saturation Estimation Using Both Seismic and Well Data, EAGE-SAID Conference

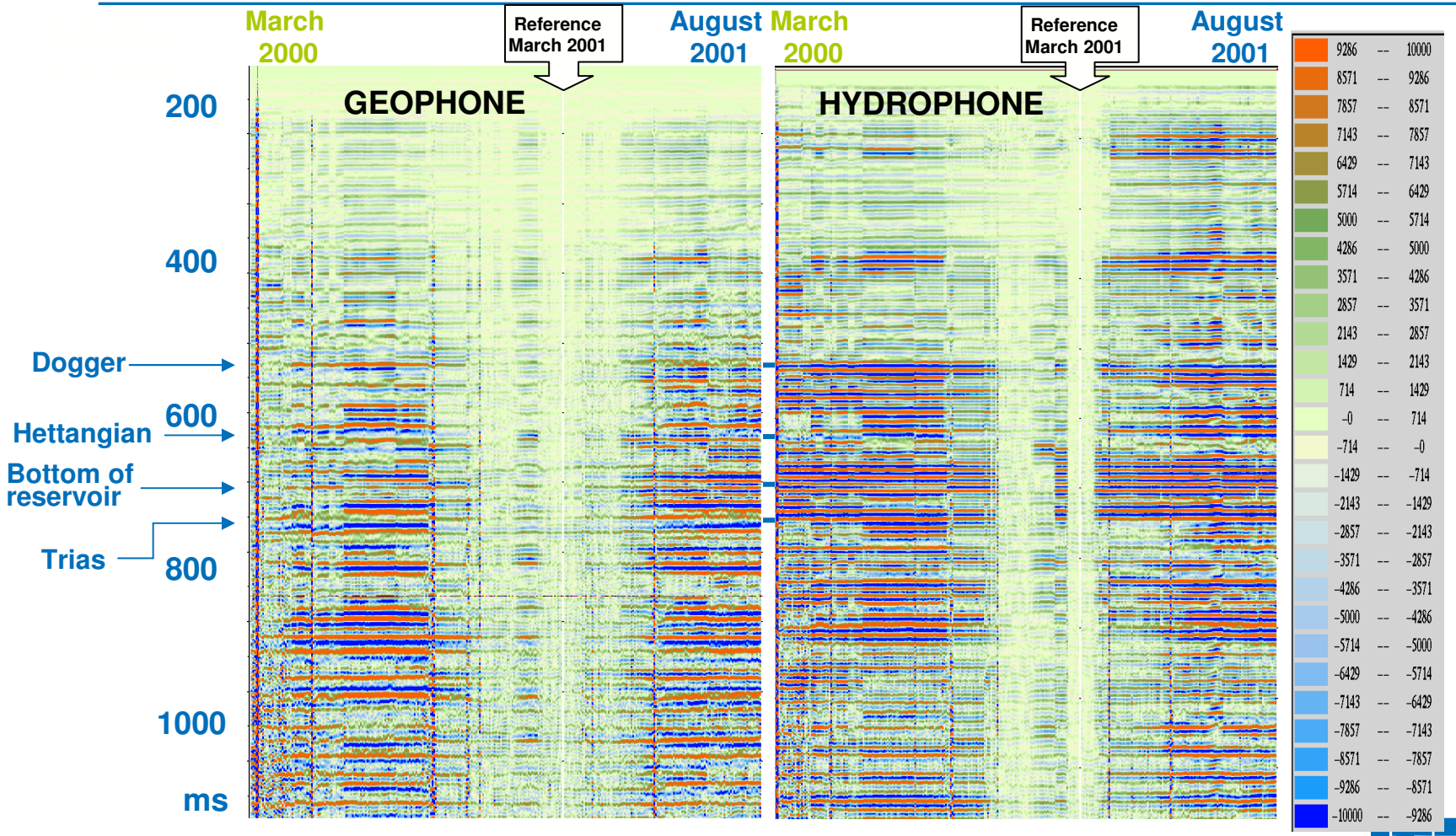
Seismovie

Permanent sources and receiving arrays

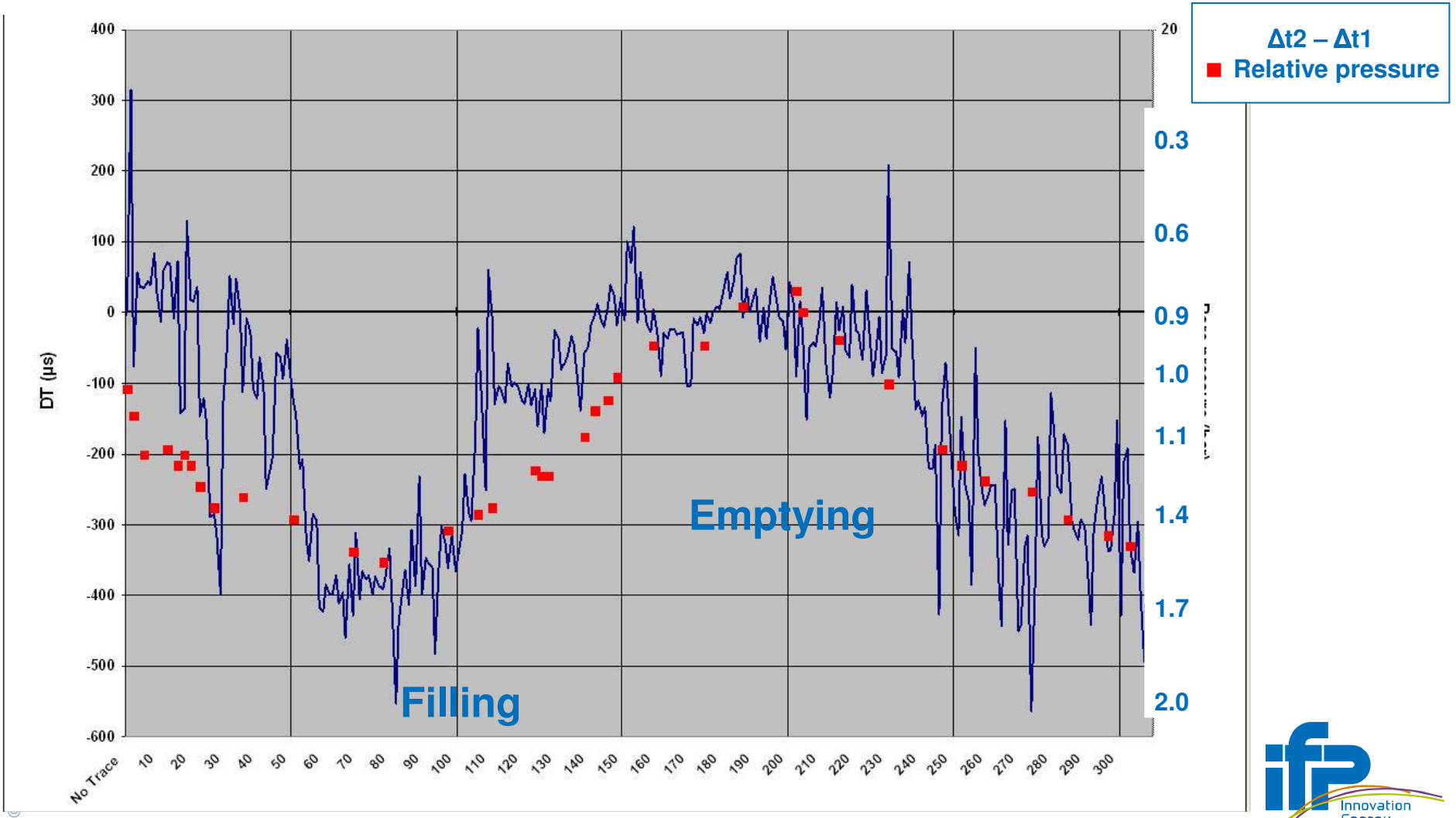


Céré-la-Ronde

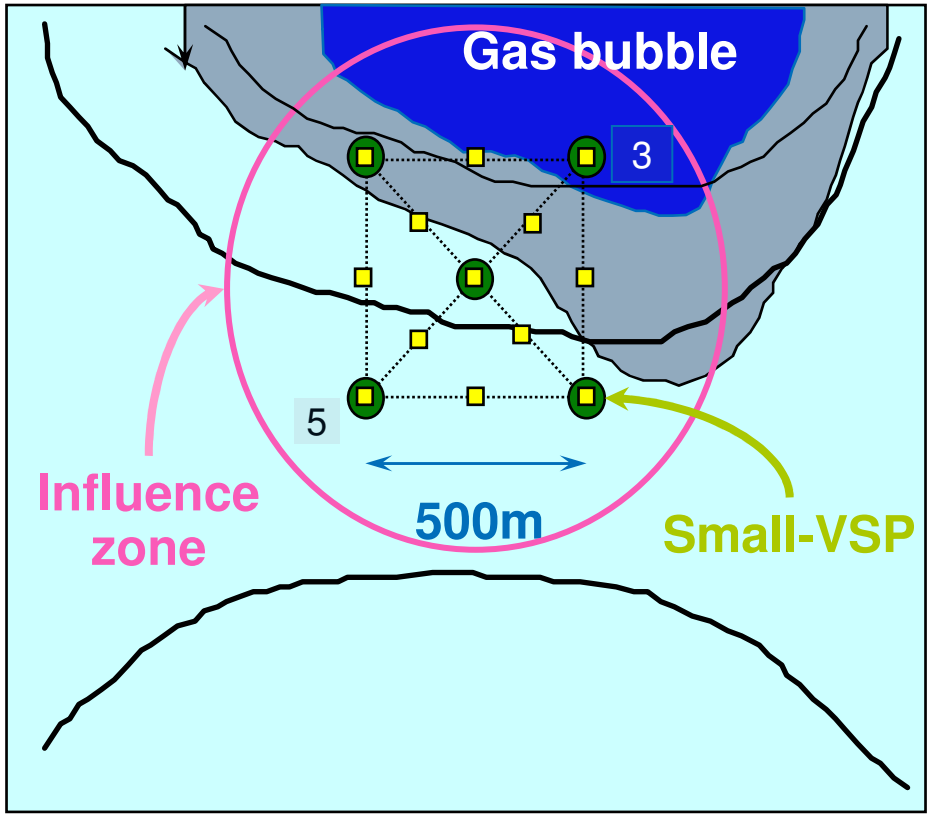
Differences with reference trace

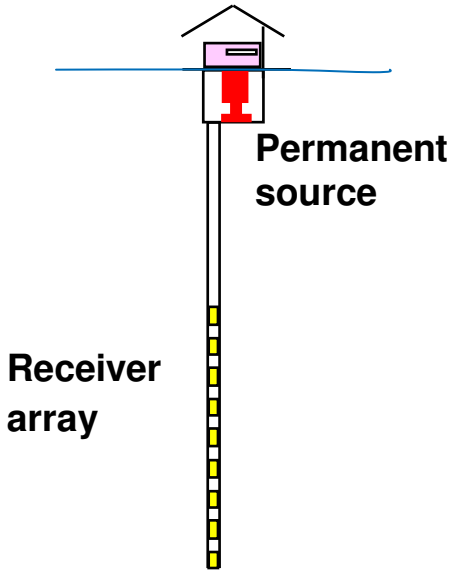


Céré-la-Ronde
Time shifts *&* well pressure



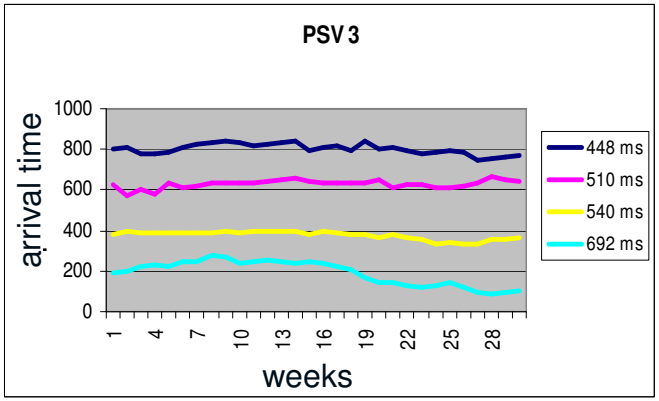
Saint-Clair-sur-Epte
Permanent source and receiver array

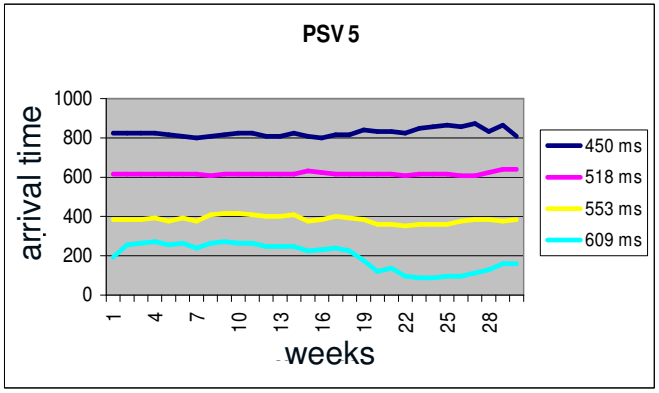


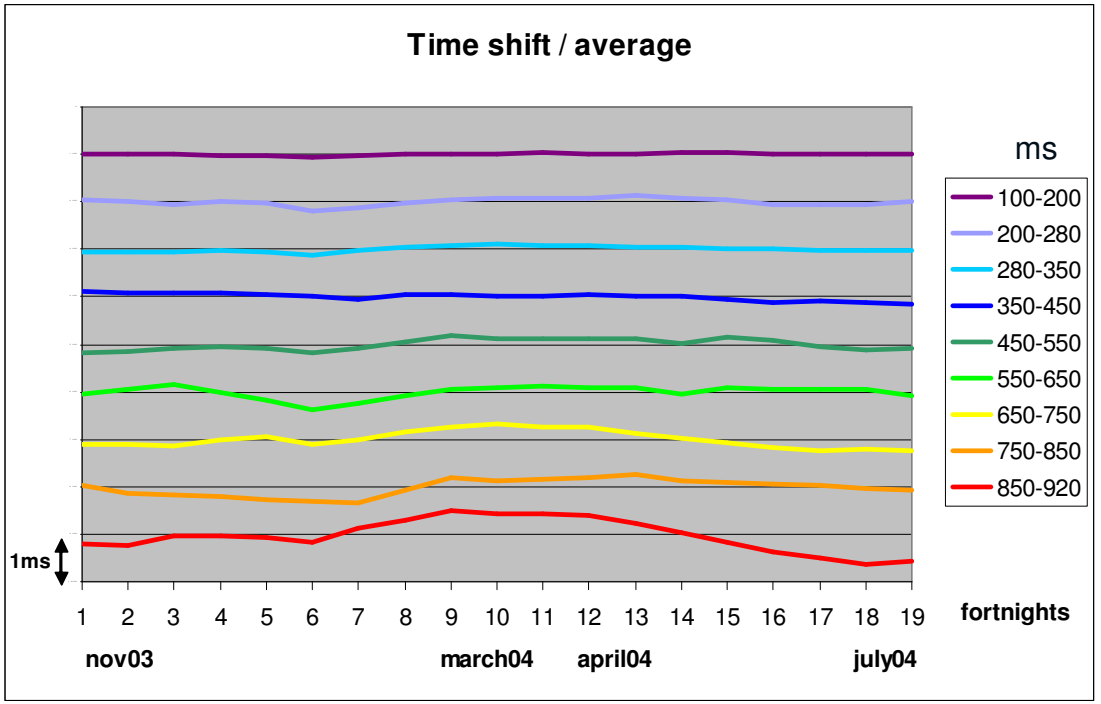


Geophones + Hydrophones
100-220 m, Δz = 5 m

Saint-Clair – Time shifts



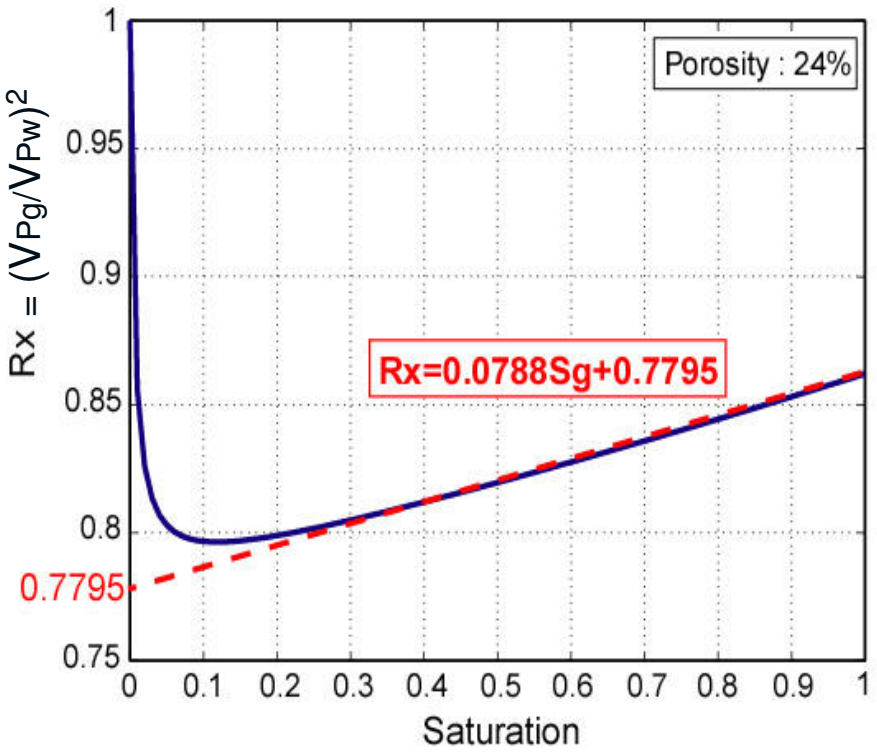




central array

Saturation estimation

Twice more difficult for CO_2



$$V_P^2 \approx \frac{K_{dry}}{\rho_{frame}}\left(1-\frac{\delta\rho_{fluid}}{\rho_{frame}}\phi \;\; S_w\right)$$

Whitman & Towle, 1992

fluid densities:

brine: 1.05 g/cm³

methane: 0.1 g/cm³

carbon dioxide : 0.6 g/cm³

methane: $\delta\rho \approx 1$ g/cm³

CO_2: $\delta\rho \approx 0{,}5$ g/cm³

Conclusions

- Porous space compressibility, sensitive to fluid content and stress effects contribute to time and amplitude variations in seismic data
- Permanent source and receiver patterns enable us to measure time shifts of a few tenths of millisecond
- Amplitude variations depend strongly on acoustic impedance contrasts
- Derivating saturations from time and amplitude variations remains a difficult issue