Seismic anisotropy analysis at the Low-noise underground Laboratory (LSBB) of Rustrel (France)

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Seismic experiments

- Structural studies
  - 3D seismic tomography
  - Seismic interferometry
  - Reflection seismics

- Methodological developments
  - Time reversal
  - Joint inversion of different data types (e.g. seismics & electric resistivity)
  - Anisotropy time lapse studies
Anisotropy

- In a fractured system, elastic waves propagate at different velocity parallel and perpendicular to the fractures:
  - Velocity in water: 1.5 km/s
  - Velocity in limestone: 5 km/s
- Parallel to fractures, velocity controlled mainly by rock
  - Perpendicular to fractures: Average velocity water/rock
The experiment

- 120 hammer blows on the wall of the anti-blast gallery
- Waves were recorded by 120 geophones on the wall of the main gallery
- Departure angles of the rays between $+50^\circ$ (0/0 towards 100/120, “NE”) and $-50^\circ$ (120/0 towards 0/100, “SE”)
Recorded P-wave travel times vs. offset

The two branches are interpreted as the effect of velocity anisotropy.
As simple first approximation, the arrival times “t” can be described by the following formula (“d” is offset):

\[
t(d, \alpha) = \frac{d}{v + \frac{\Delta v}{2} \cos(2(\alpha - \alpha_0))}
\]

By inversion of the measured arrival times, we search the average velocity “v”, the difference between maximum and minimum velocity “\(\Delta v\)” and the direction of maximum velocity “\(\alpha_0\)” (\(\alpha_0 = 0\) : direction perpendicular to anti-blast gallery).
Results

Evolution of adjustment error as function of $\alpha_0$

$v_0: 4.72$ km/s; $\Delta v: 0.84$ km/s; $\alpha_0: 45^\circ \Rightarrow 9\%$ anisotropy
Velocity perpendicular to the gallery

- No tendency, cannot explain data
Analysis of velocity vs. angle

Calculation of average velocity for binned ray directions (every 5°, 2σ uncertainty)

Results:
\[ v_0 = 4.69 \text{ km/s} \]
\[ \Delta v = 0.9 \text{ km/s} \]
\[ \alpha_0 = 43° \]
Anisotropy: 10%
Anisotropy and fractures

The direction of maximum velocity coincides with the predominant direction of fractures in the karst massif.
Isotropic seismic tomography

Without taking into account the anisotropy, tomography gives unrealistically low and high velocities in areas of relatively low ray coverage.

Red circles: artifacts!
Future plans: electric conductivity

- Electric conductivity should show similar anisotropy effects:
  \( \sigma_{\text{Limestone}} \): very small
  \( \sigma_{\text{Water}} \): high

\[ \Rightarrow \text{high conductivity parallel to fractures (current may propagate mainly through fractures)} \]
Low conductivity perpendicular to fractures
Future plans: joint time-lapse study of conductivity and velocity

- Air compared to water:
  - lower conductivity
  - lower velocity

- Compared to limestone:
  - similar conductivity
  - much lower velocity

⇒ Drying-up of fractures should
  - increase seismic P-wave anisotropy
  - reduce conductivity anisotropy