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

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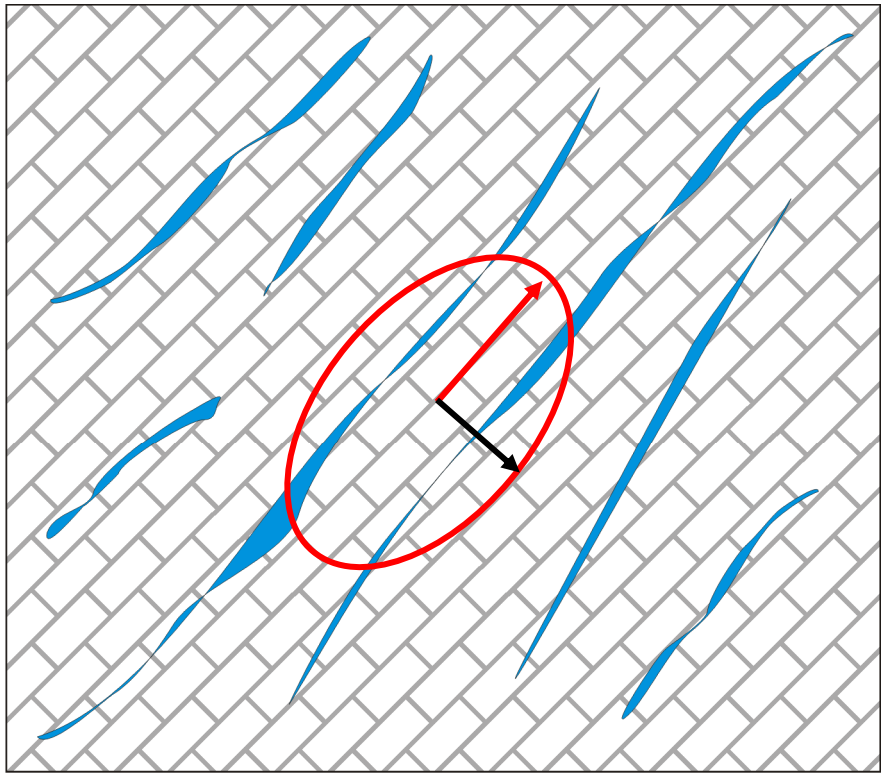
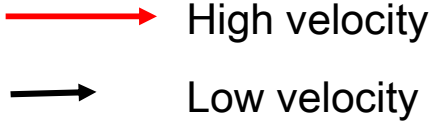
Seismic experiments

- 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

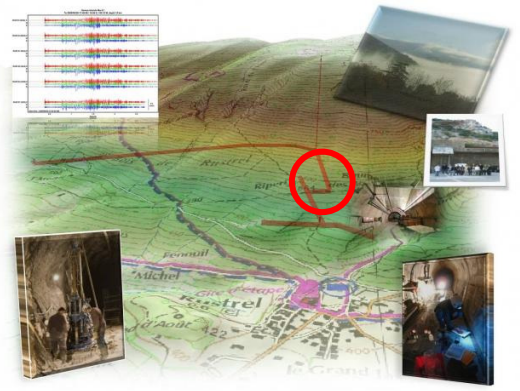


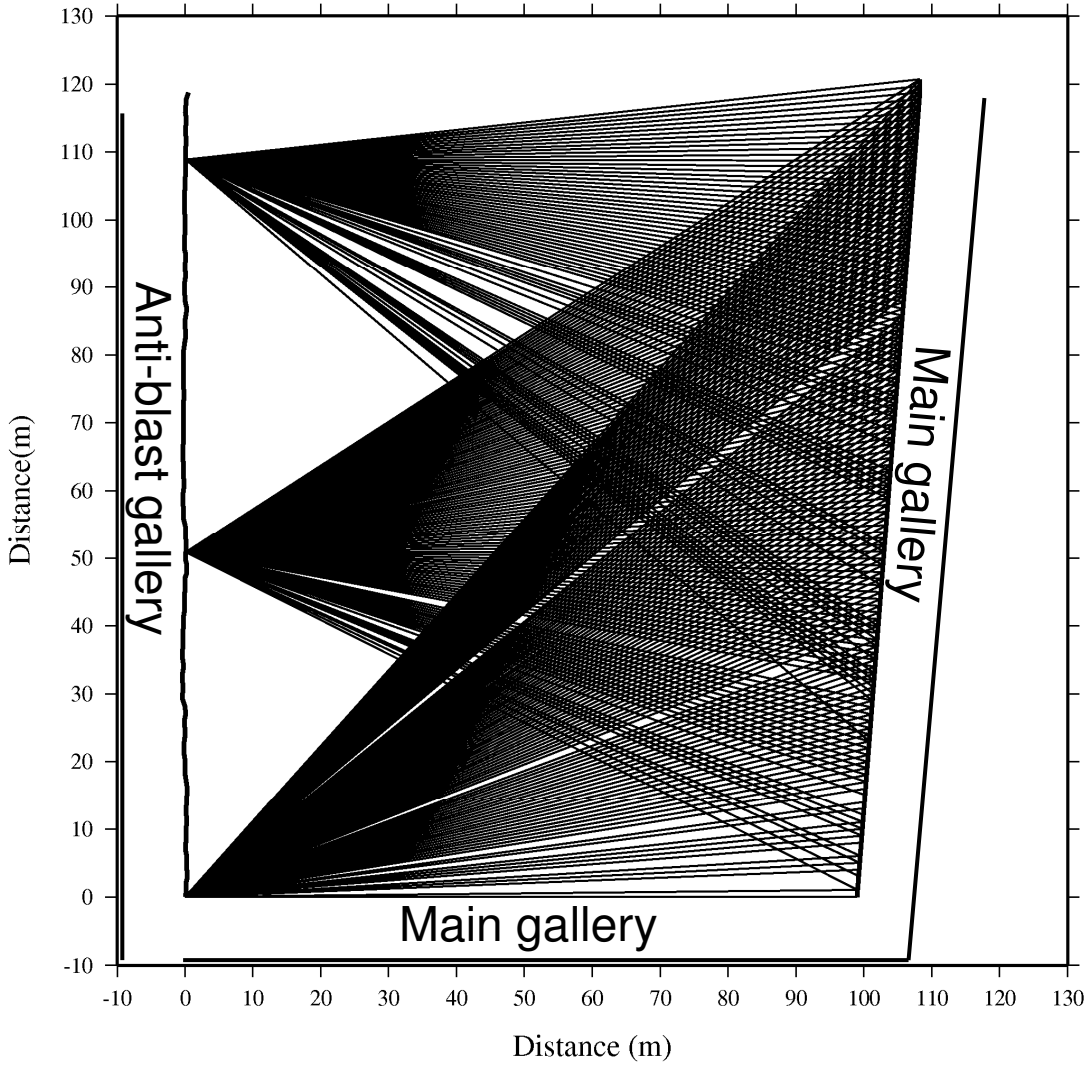


- In a fractured system, elastic waves propagate at different velocity parallel and perpendicular to the fractures:
- Velocity in water: 1.5 km/s
  Velocity in limestone: 5 km/s
- Parallel to fractures, velocity controlled mainly by rock

  Perpendicular to fractures: Average velocity water/rock

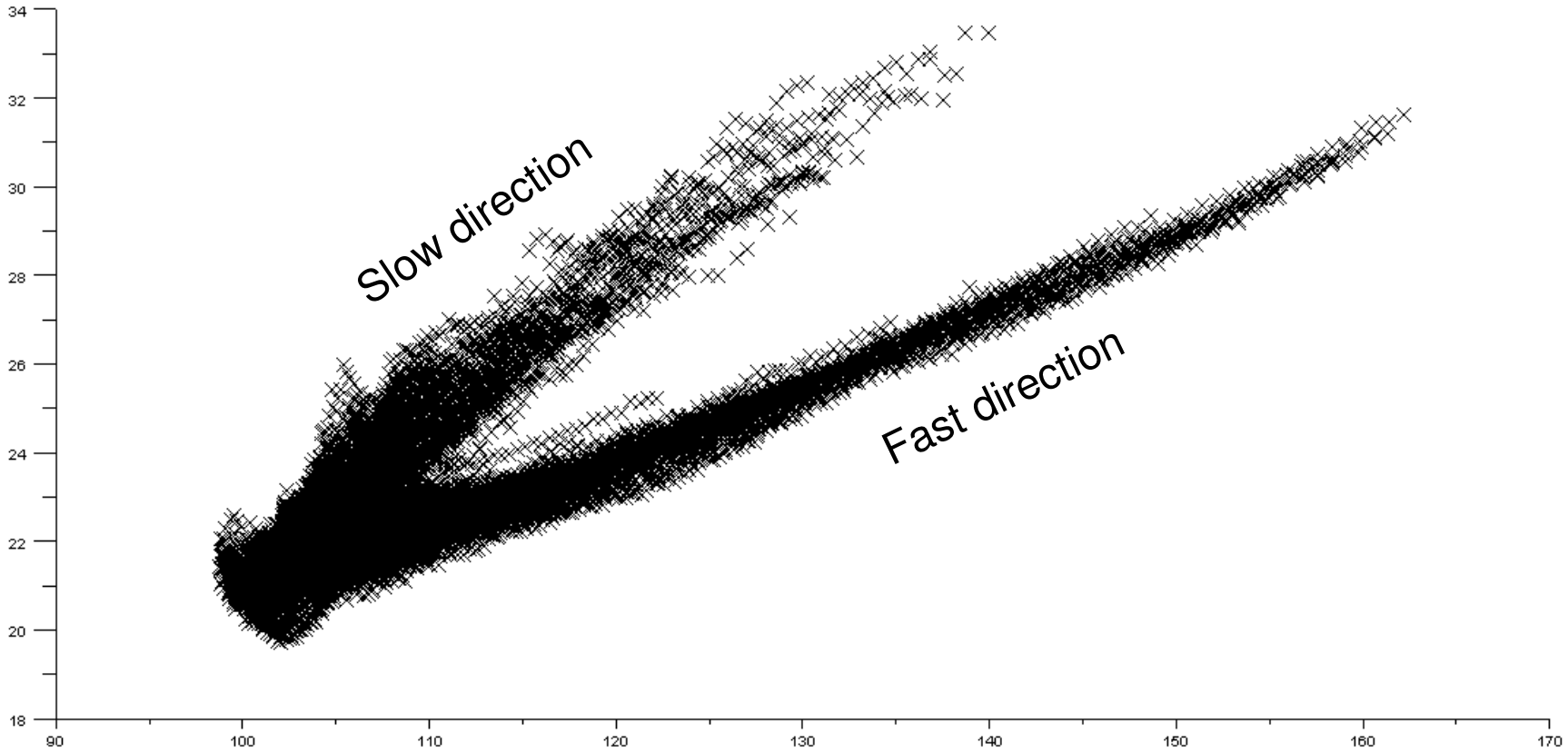
The experiment





- 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° (0/0 towards 100/120, “NE”) and -50° (120/0 towards 0/100, “SE”)

Recorded P-wave travel times vs. offset



The two branches are interpreted as the effect of velocity anisotropy

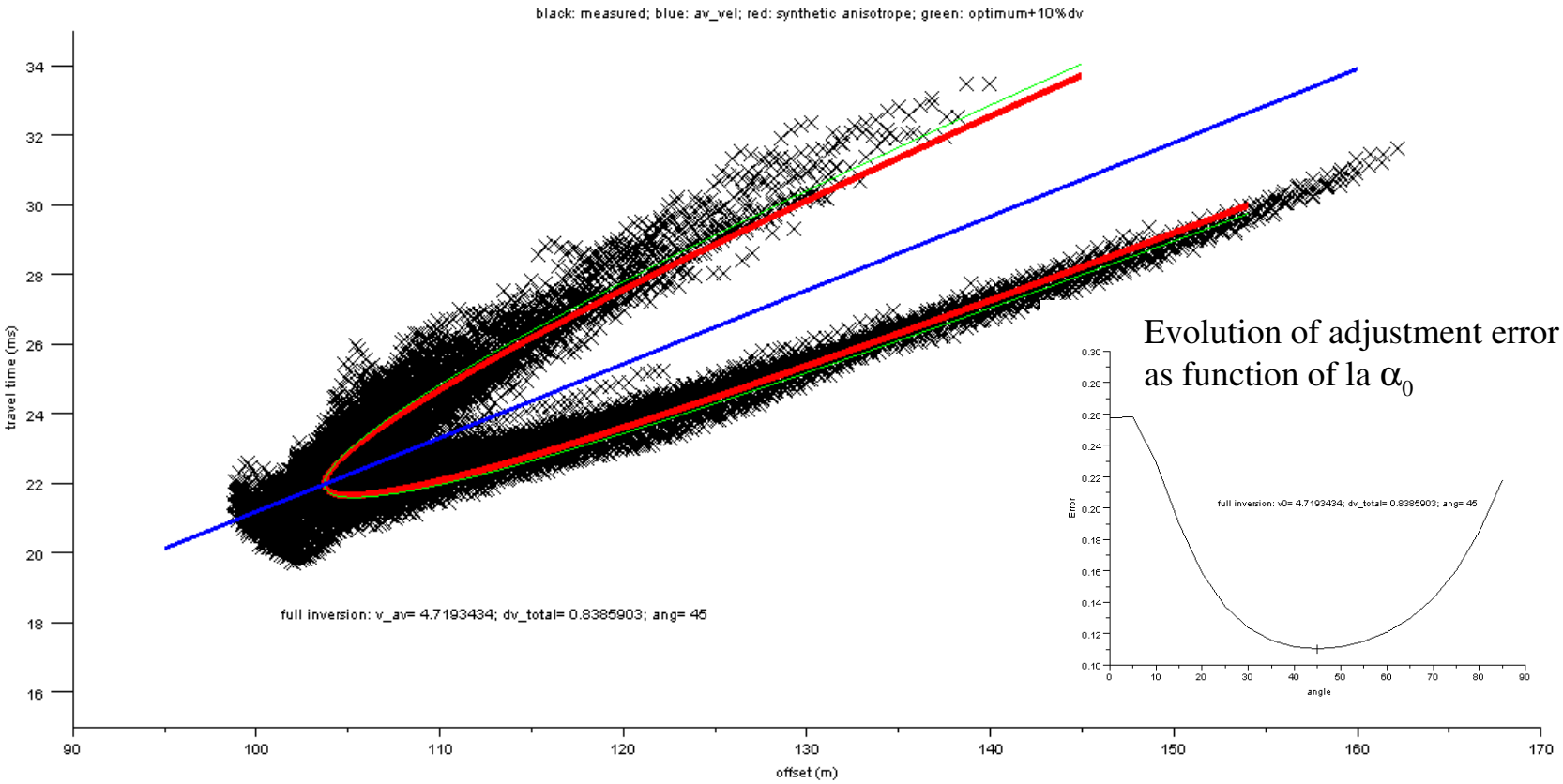
Anisotropy modelling

- As simple first approximation, the arrival times “t” can be described by the following formula (“d” is offset):

$$t(d,\alpha) = \frac{d}{v + \frac{\Delta v}{2}\cos\left(2\left(\alpha - \alpha_0\right)\right)}$$

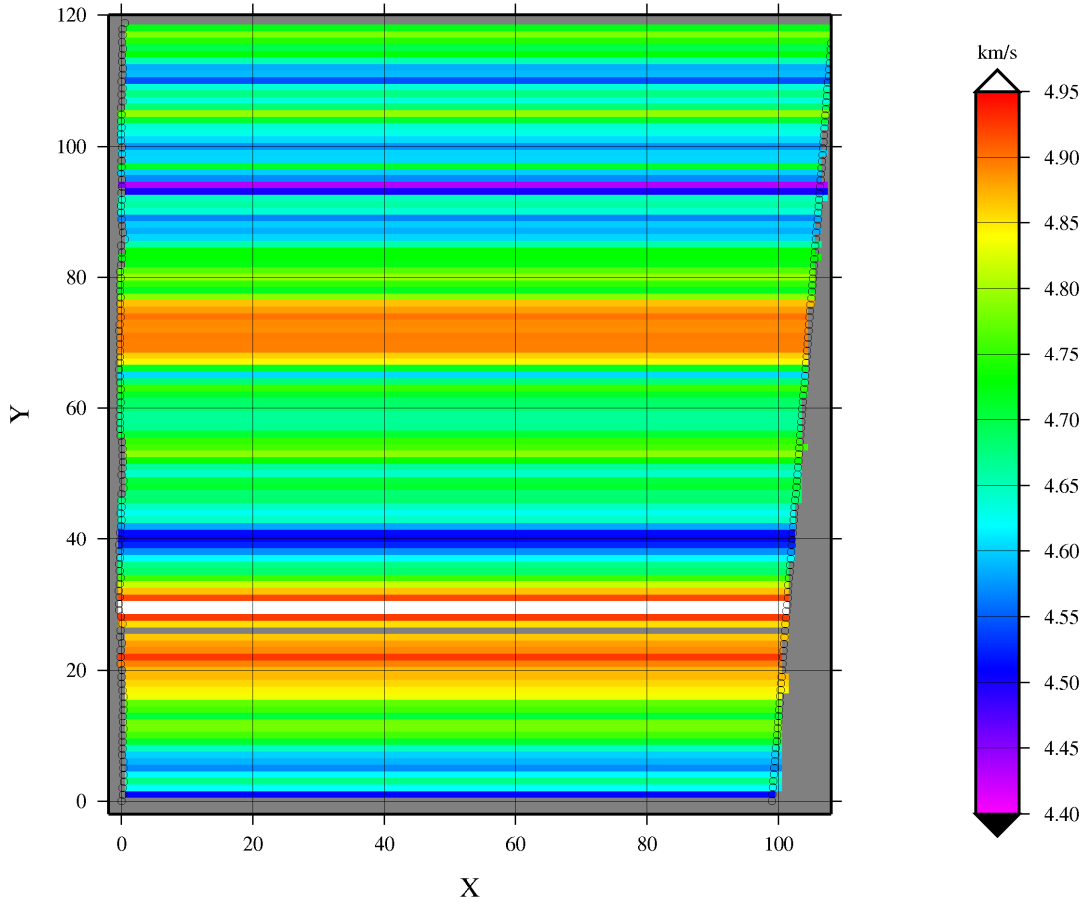
- By inversion of the measured arrival times, we search the average velocity “v”, the difference between maximum and minimum velocity “Δv” and the direction of maximum velocity “α_0”
(α_0 =0: direction perpendicular to anti-blast gallery).

Results



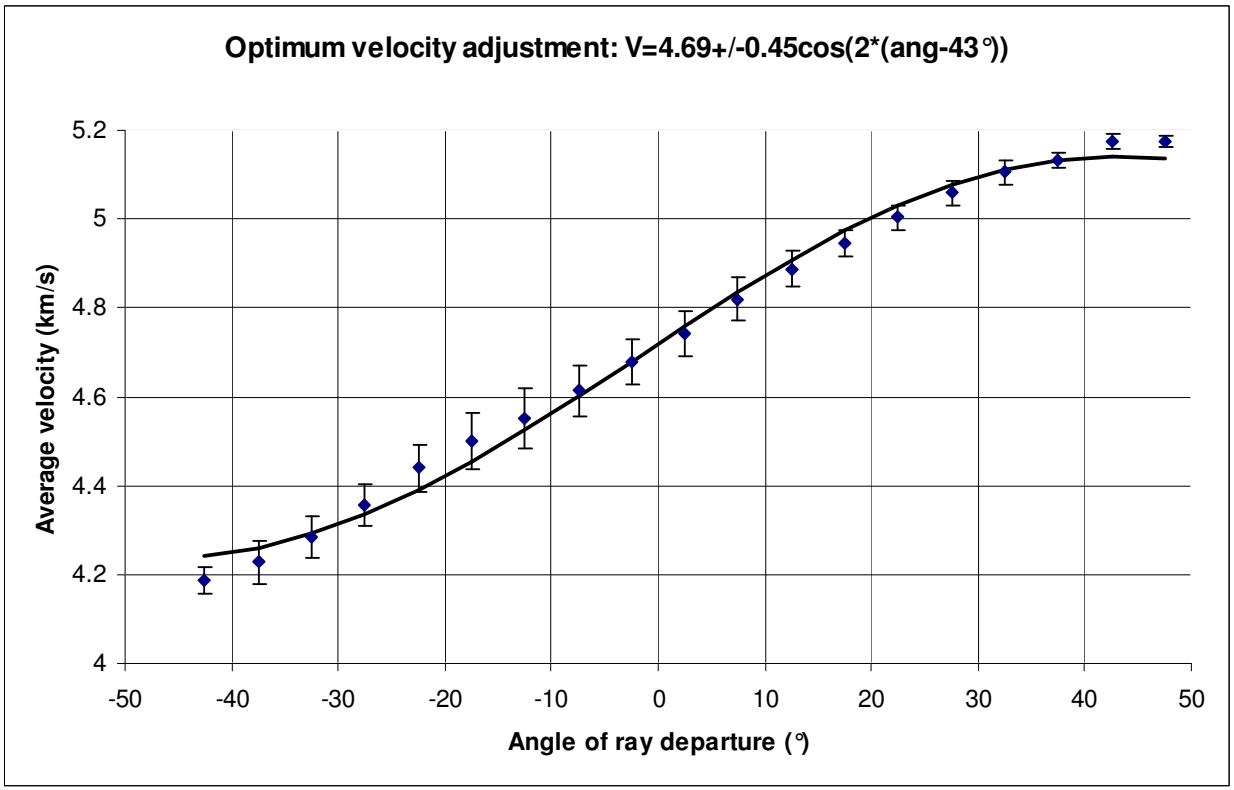
v_0: 4.72 km/s; Δv: 0.84 km/s; α_0: 45° $\Rightarrow$ 9% anisotropy

Velocity perpendicular to the gallery



- No tendency, cannot explain data

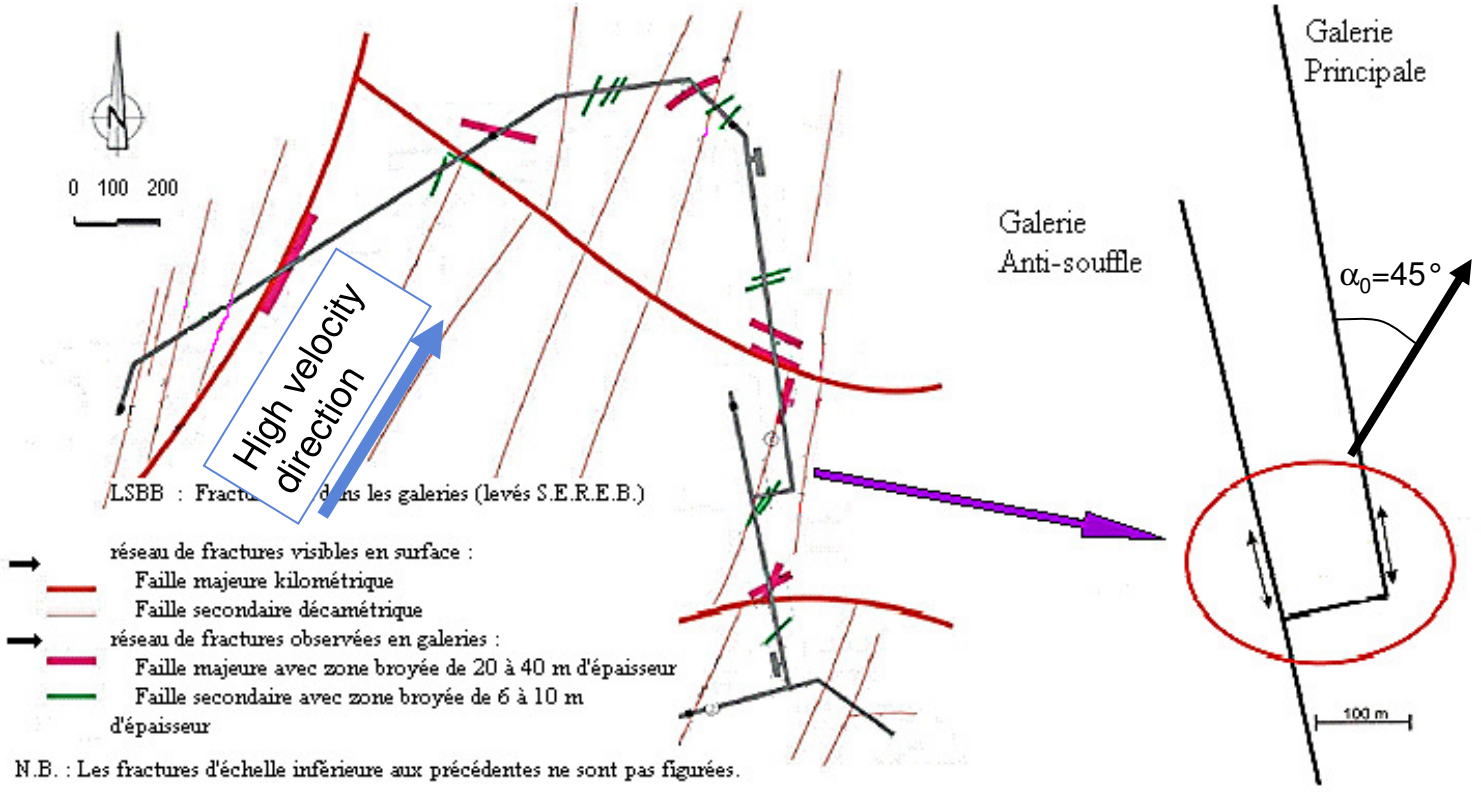
Analysis of velocity vs. angle



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

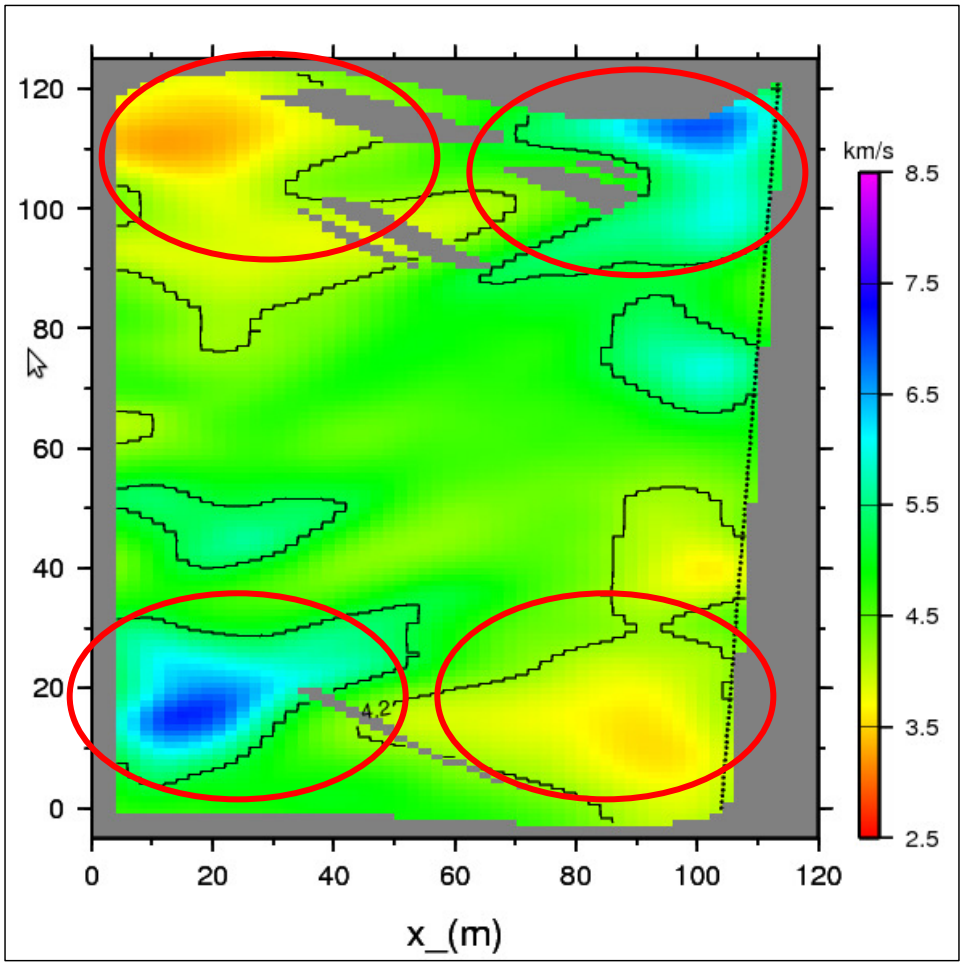
- Results:
  v_0 = 4.69 km/s
  Δv = 0.9 km/s
  α_0 = 43°
  Anisotropy: 10%

Anisotropy and fractures

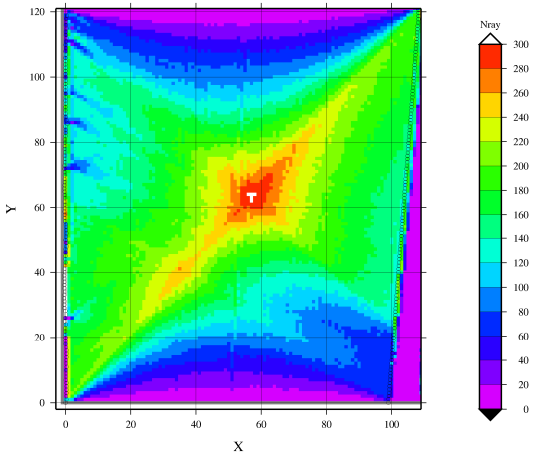


The direction of maximum velocity coincides with the predominant direction of fractures in the karst massif.

Isotropic seismic tomography



Red circles: artifacts!



Ray coverage (red: 300 rays/m²)

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

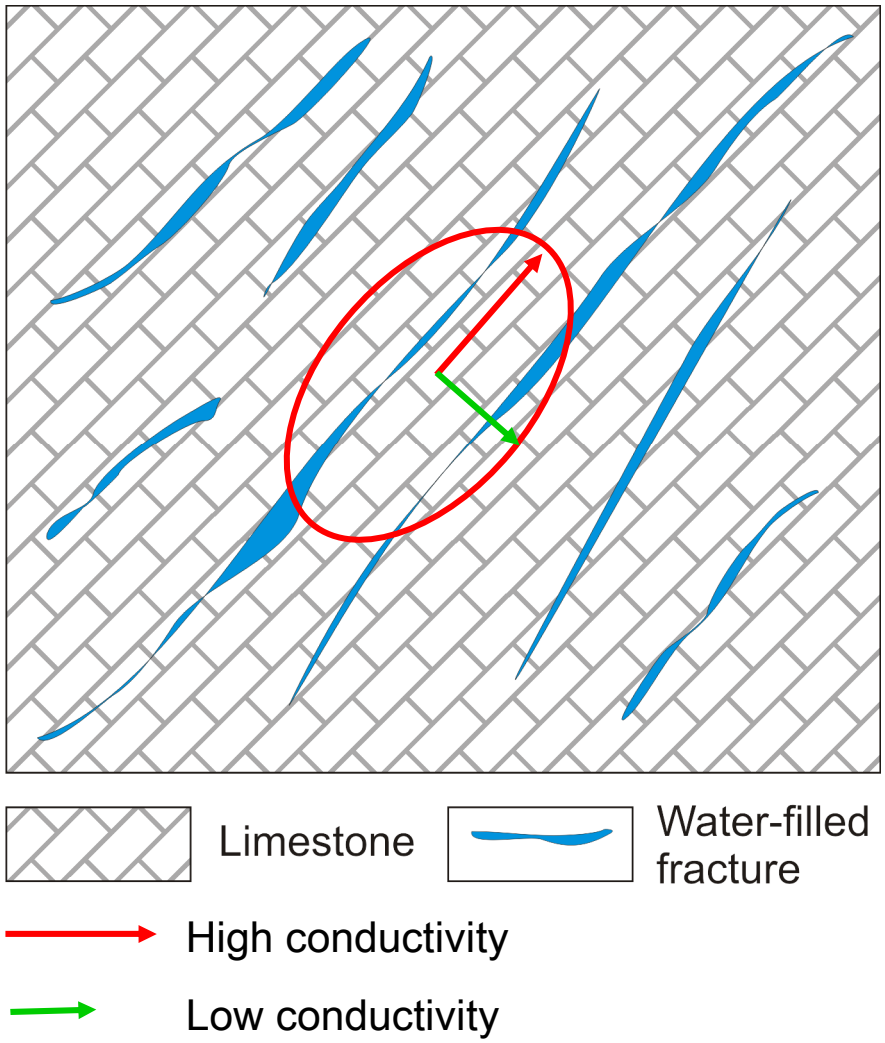
Future plans: electric conductivity

- Electric conductivity should show similar anisotropy effects:

  $\sigma_{Limestone}$: very small

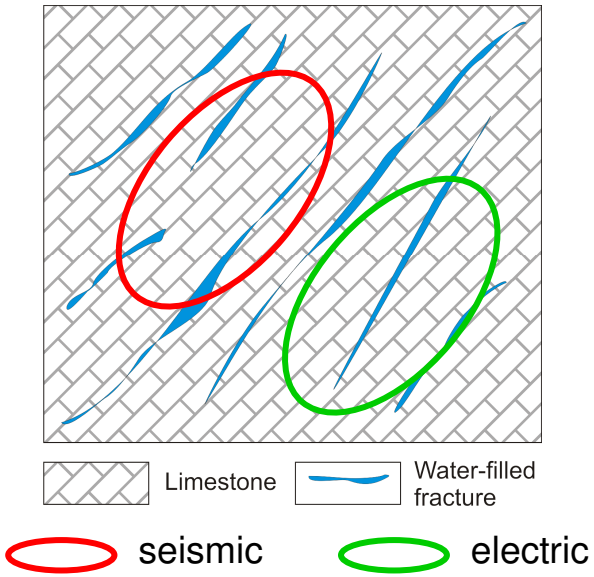
  σ_{Water}: high
- $\Rightarrow$ high conductivity parallel to fractures (current may propagate mainly through fractures)

  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