



# Caractérisation et suivi de la stabilité des masses rocheuses par méthodes sismiques passives

*Characterizing and monitoring rock slope stability using passive seismics*

50 ans de l'ADRGT



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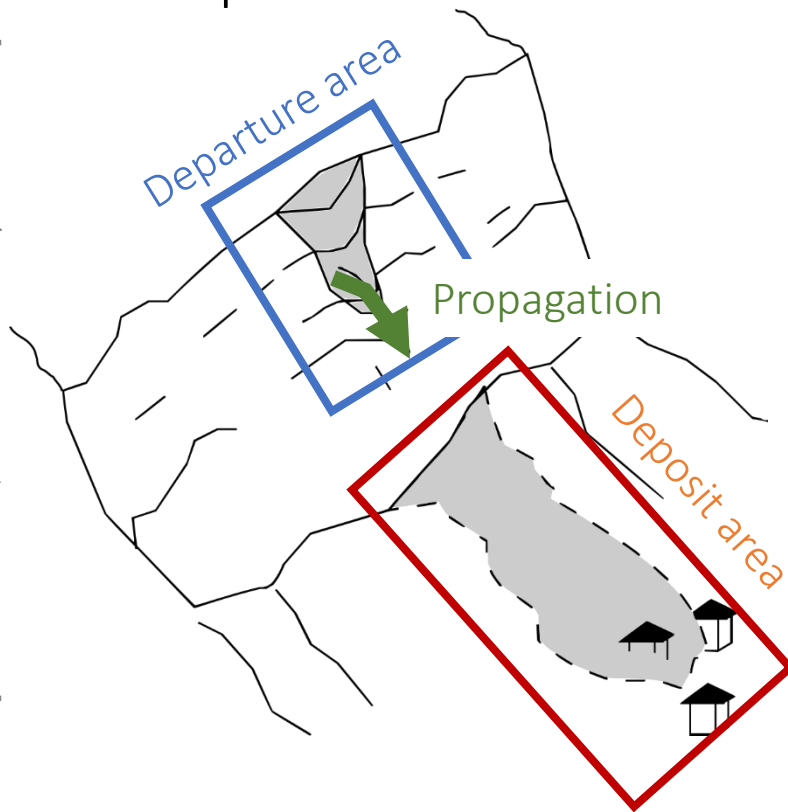
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## Rockfall phases

[D'Amato 2017, drawn from Frayssines 2005]

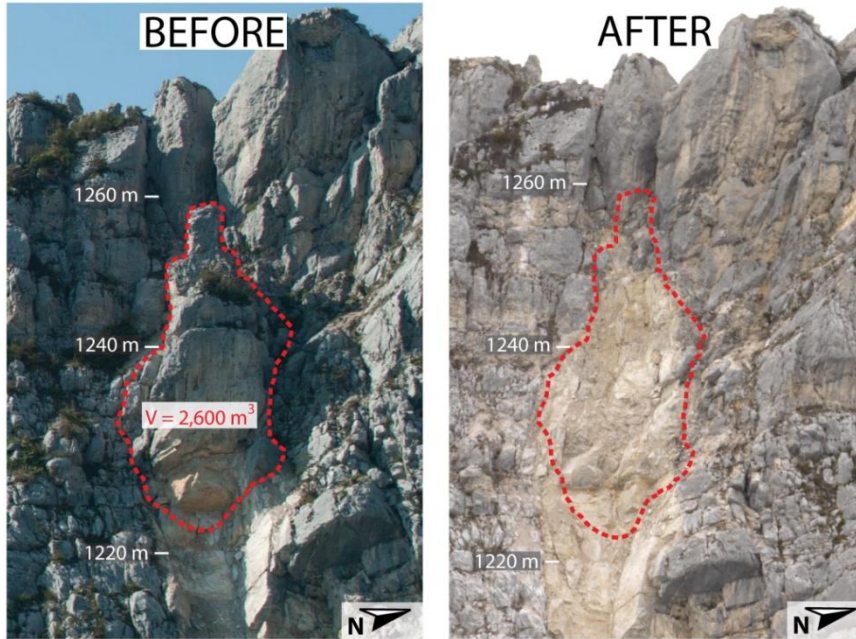


### Phases

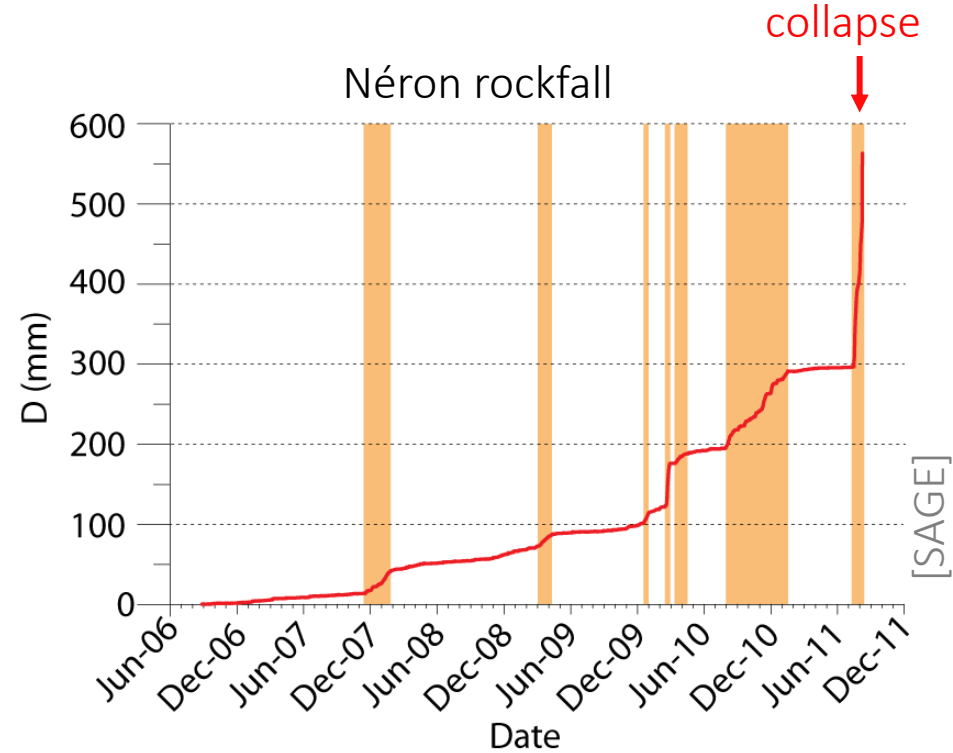
- Pre-rupture
  - Rupture
  - Propagation
  - Deposit
- ← Precursory signals?
- ↑ Generally fast...  
↓ and often too late



## ■ Precursory signals



[Bottelin et al. 2014 NHESS]



### Displacement monitoring

Monitoring ground surface changes or fracture opening rate

- Extensometers [e.g. Fukuzono 1985; Voight, 1989; Suwa et al. 2010]

### Limitations

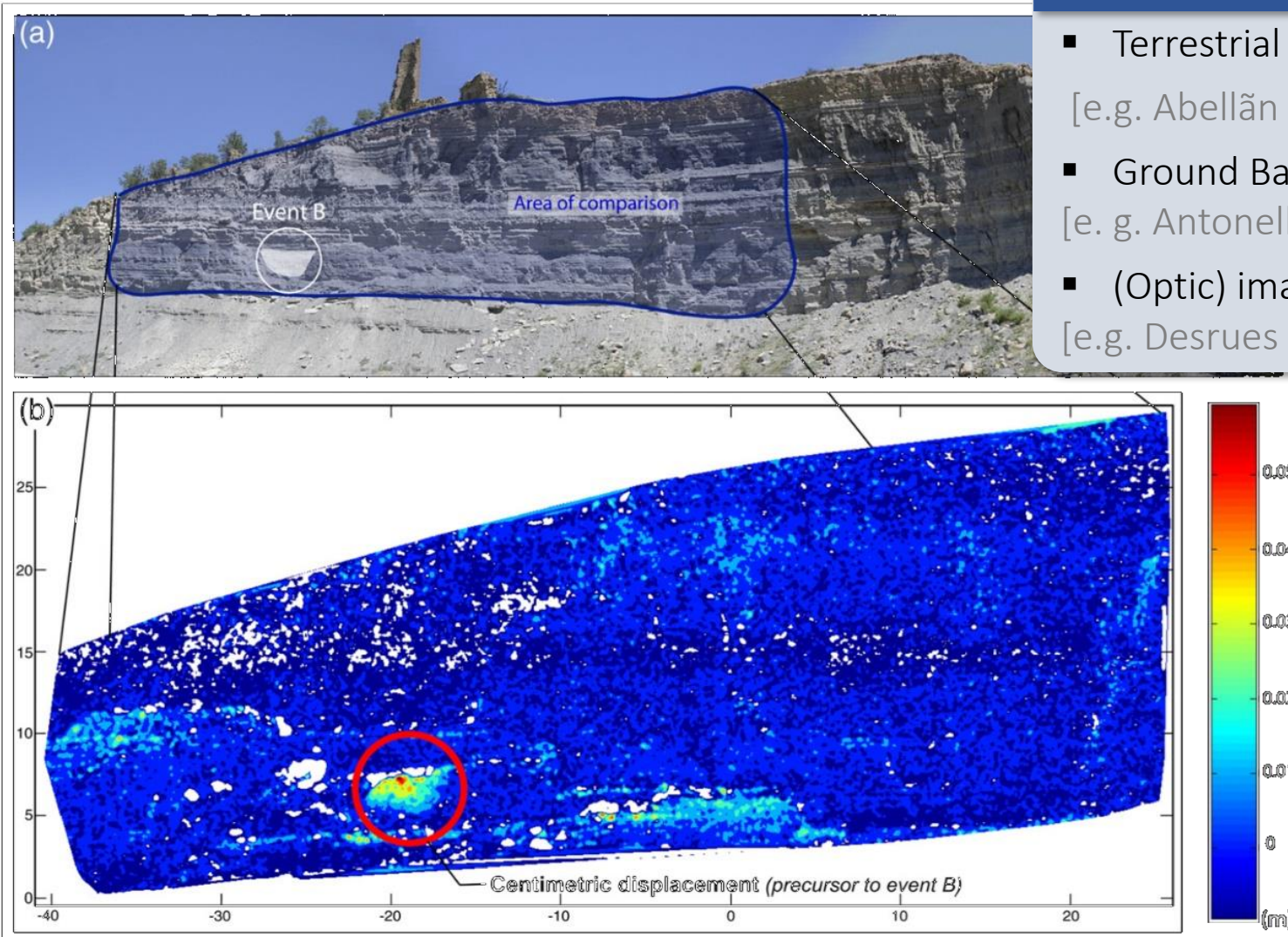
- Punctual in time and/or space



## ■ Precursory signals

### New techniques

- Terrestrial Laser Scan  
[e.g. Abellán et al. 2009, 2010]
- Ground Based-SAR  
[e.g. Antonello et al. 2004]
- (Optic) image correlation  
[e.g. Desrues et al.]



[Abellán et al. 2010]



## ■ Precursory signals

### Displacement monitoring

Monitoring ground surface changes or fracture opening rate

### Limitations

- Punctual in time and/or space
- **Surface displacement only**
- Late alert
- Threshold definition

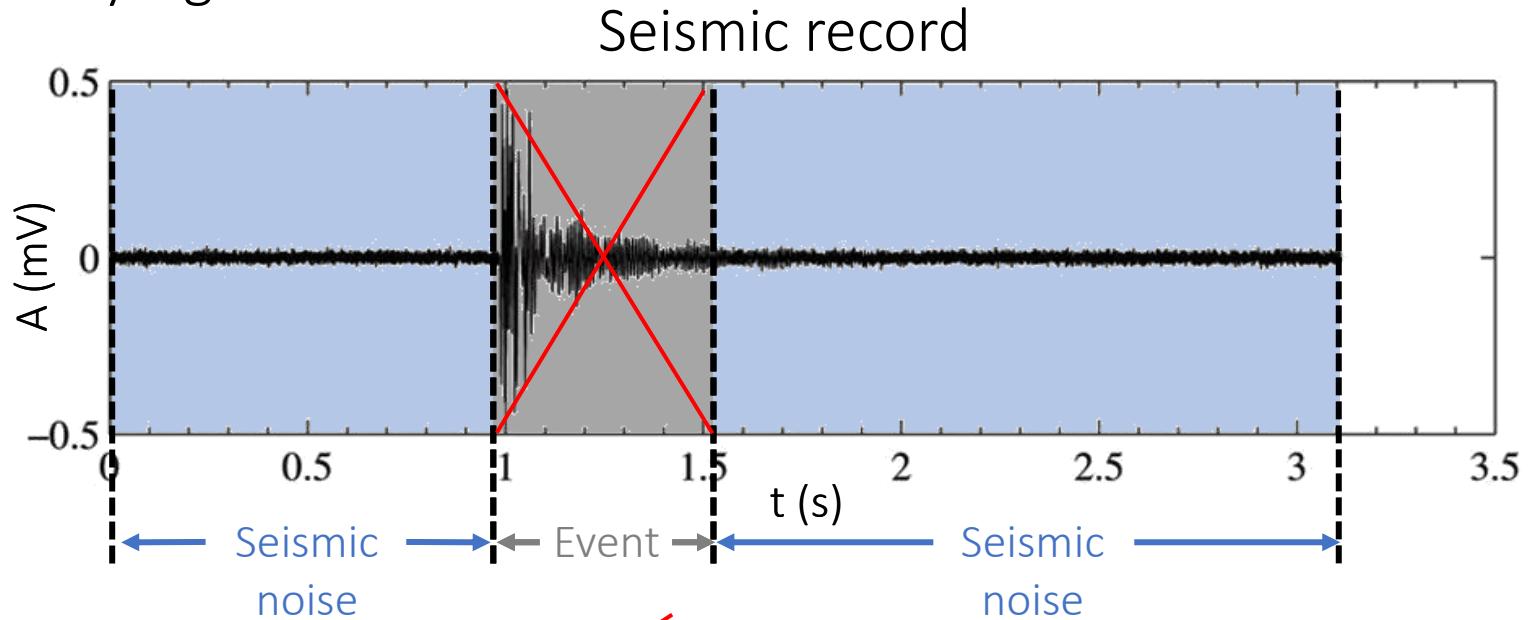
Need for complementary, global, in depth imaging/monitoring parameters.



Geophysics? Mechanical dynamics? SHM ?



## ■ Precursory signals



### Seismic Events

- Micro Ruptures
- Detection, Classification, Statistics & Location

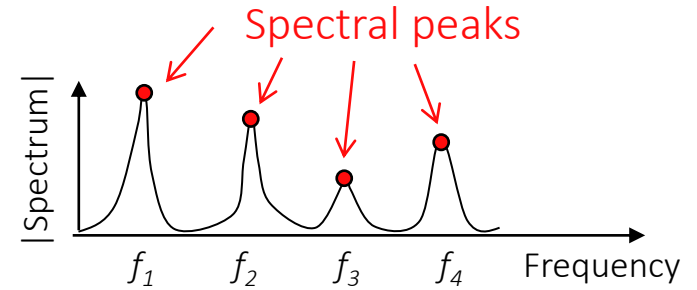
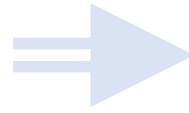
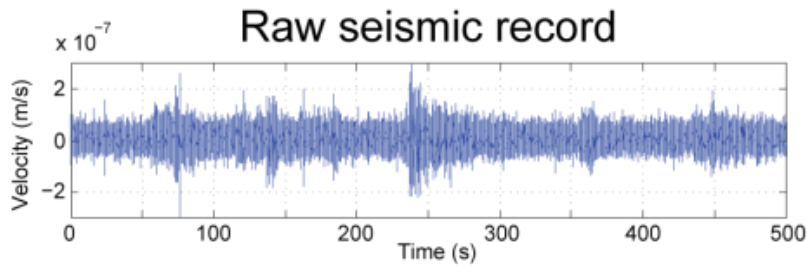
[Spillmann et al. 2007, Senfaute et al. 2009, Lévy et al. 2011, Amitrano et al. 2010, 2012; Occhiena et al. 2012]

### Seismic Noise Recordings

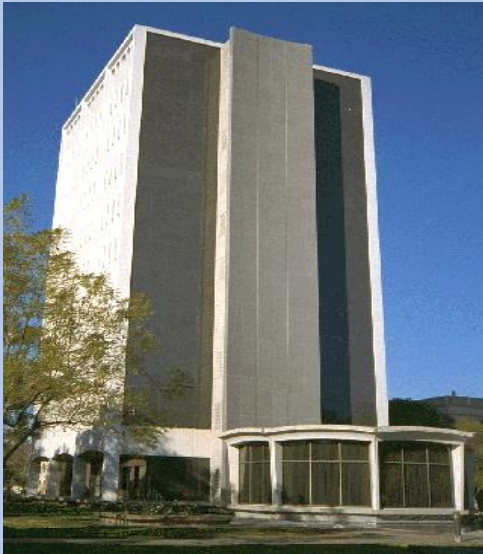
- Noise cross-correlation
- Spectral monitoring – Resonant Frequency Technique



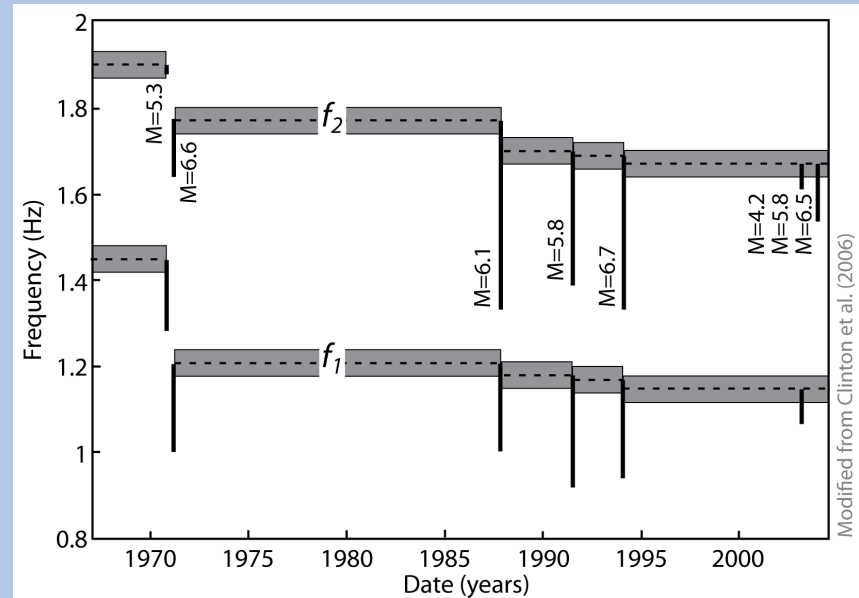
- Information contained in seismic noise



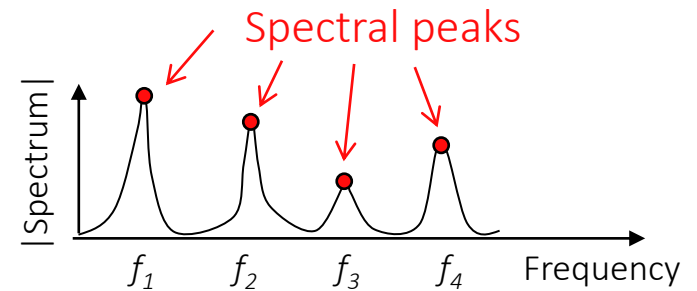
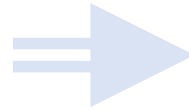
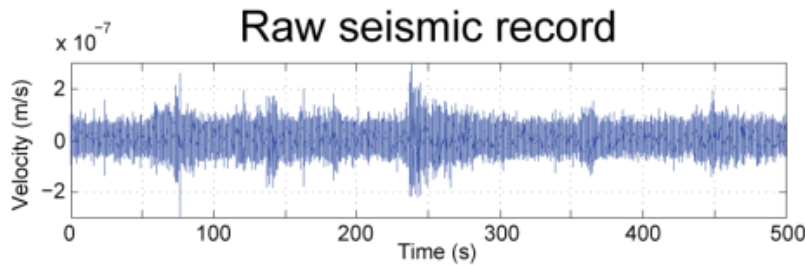
## Civil Engineering



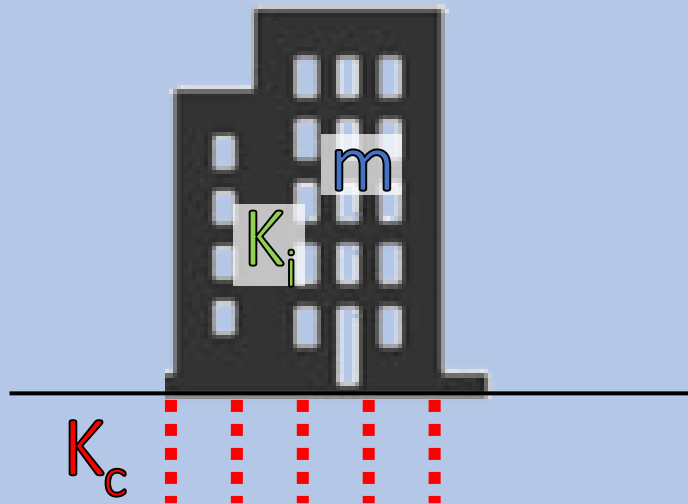
Millikan Library [Clinton et al. 2006]



## Information contained in seismic noise



## Civil Engineering



### Resonant Frequency

$$f_i = F(m, K_i, K_c)$$

building  
mass

internal  
rigidity

Soil-  
structure  
interaction

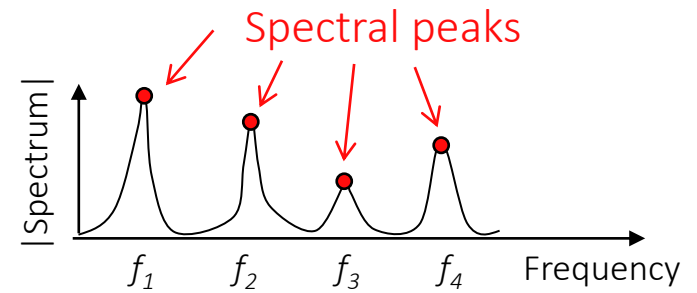
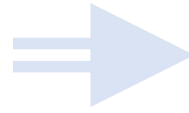
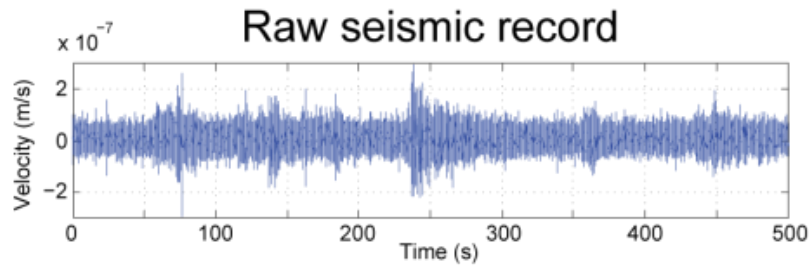
+ geometry

Millikan Library [Clinton et al. 2006]





## Information contained in seismic noise



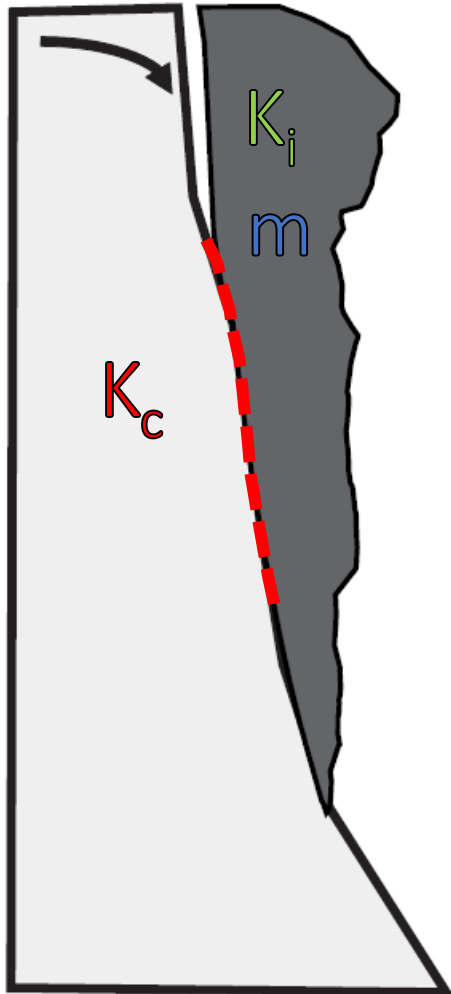
## Natural structures

### Field Work *Noise Recording*



### Data analysis *Signal processing*





[Lévy et al. 2010, Lévy 2011]

## Resonant Frequency

$$f_i = F(m, K_i, K_c)$$

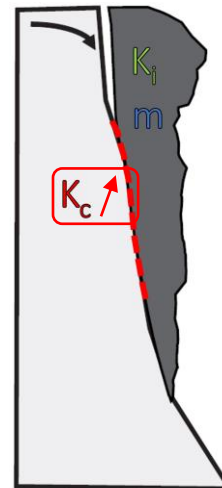
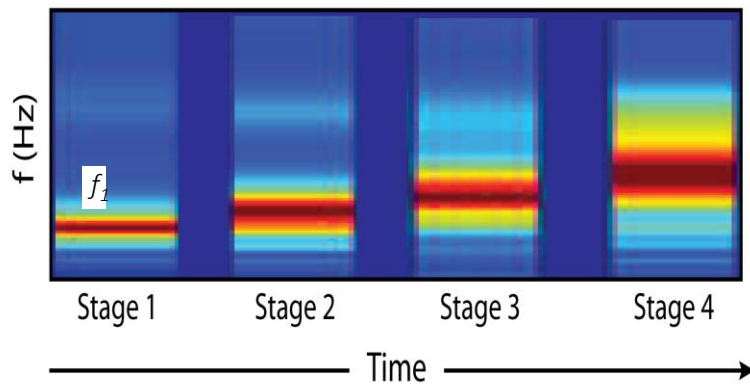
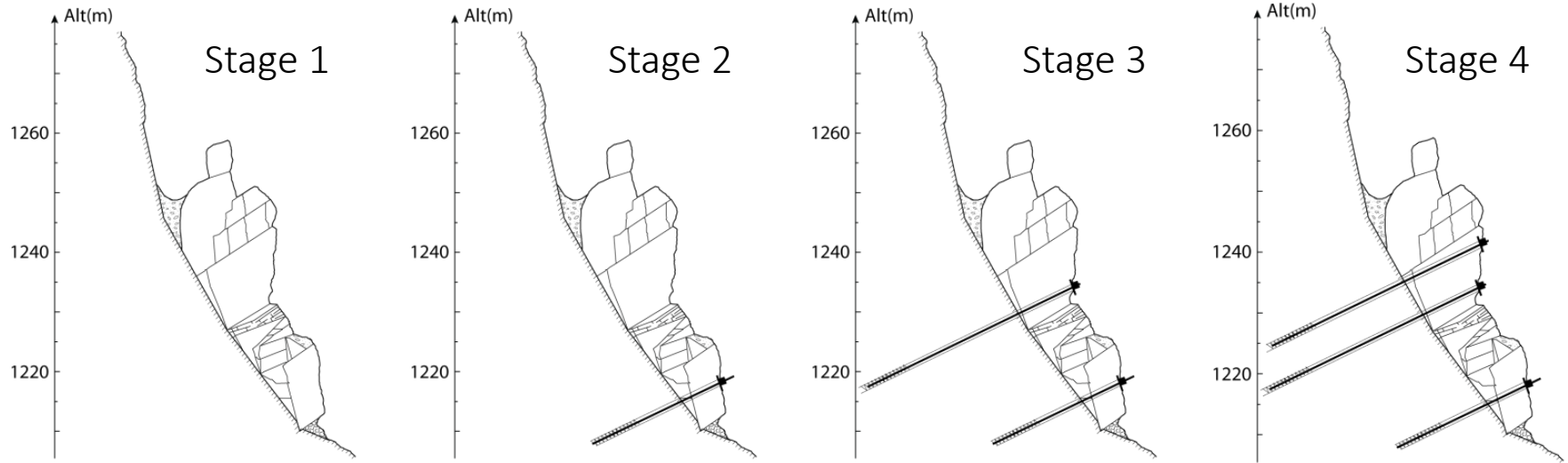
column  
mass

internal  
rigidity

contact  
rigidity

+ geometry

## Application to rock bolting works?

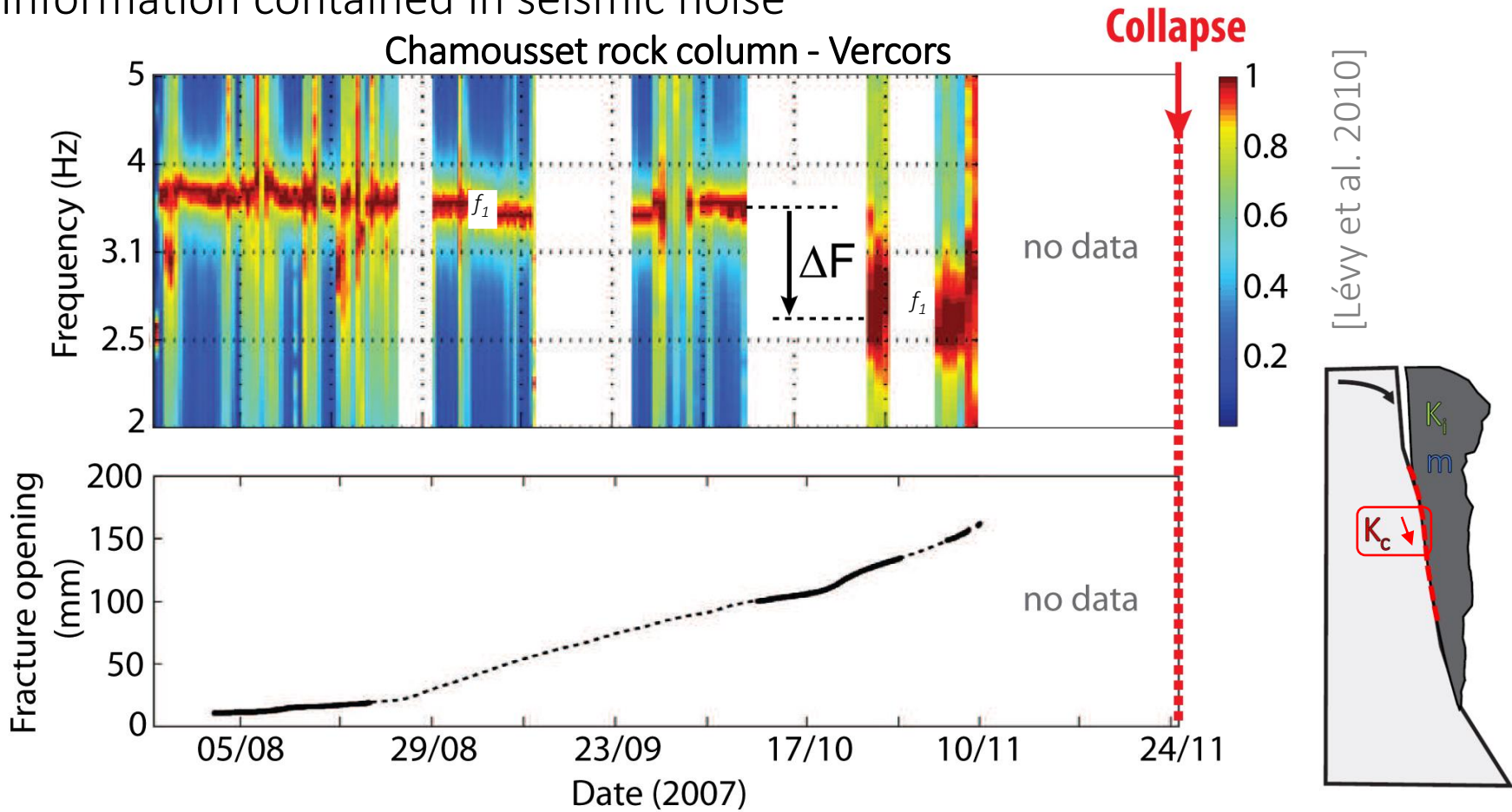


**Idea**

Monitor increases in  $K_c$  during reinforcement works through  $f_1$  time-series?

[Bottelin et al. 2017]

- Information contained in seismic noise



## Idea

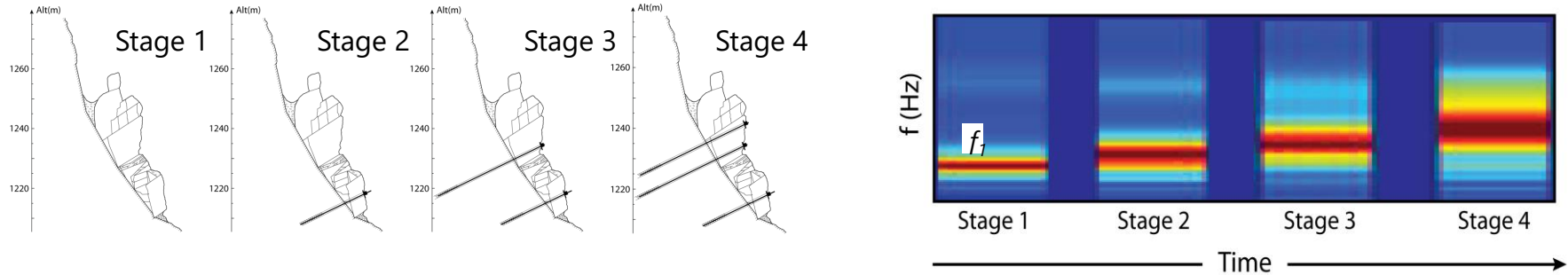
Monitor drops in  $K_i$ ,  $K_c$  prior to rockfall through  $f_1$  time-series?

[Lévy et al. 2010; Bottelin et al. 2010-2014; Valentin et al. 2016; Colombero et al. 2015, ...]

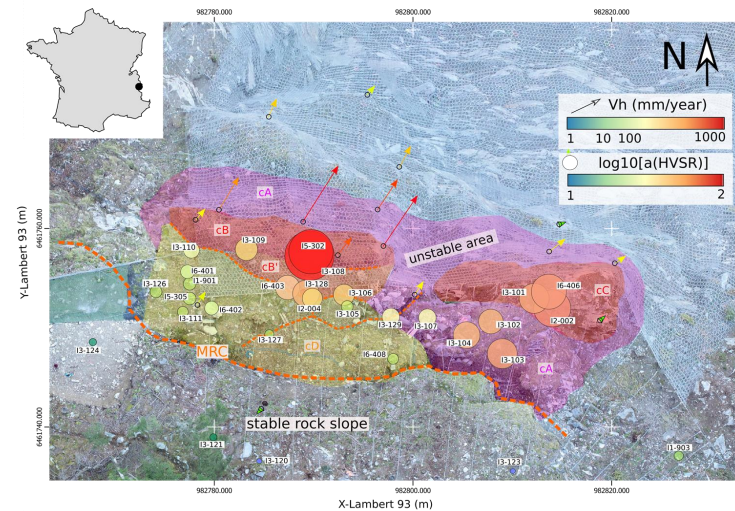




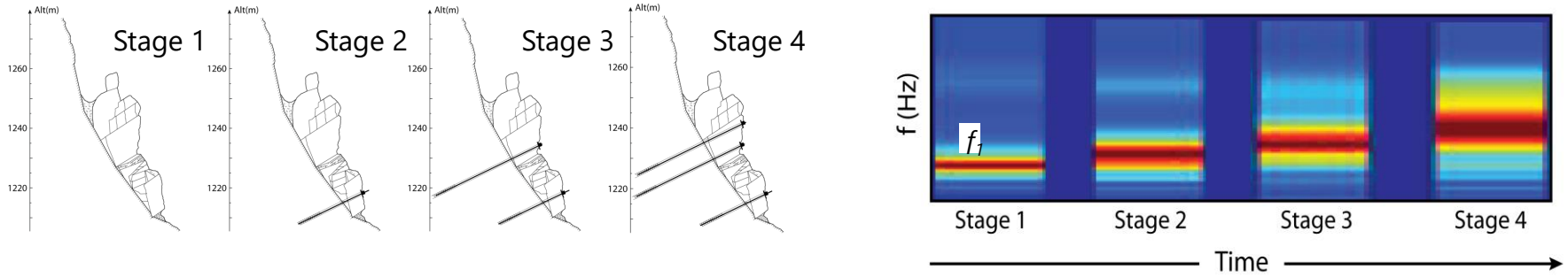
## A. MONITORING ROCK REINFORCEMENT WORKS - LA BOURNE



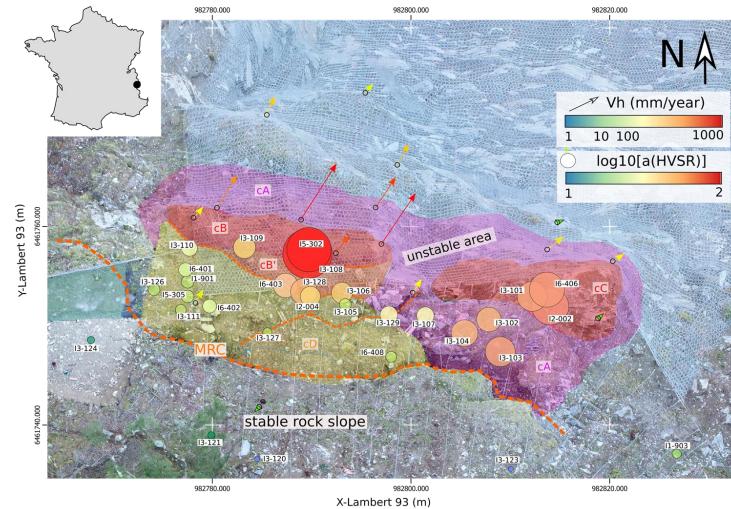
## B. CHARACTERIZING AND MONITORING ROCK SLOPE UNTIL ROCKFALL – LA PRAZ



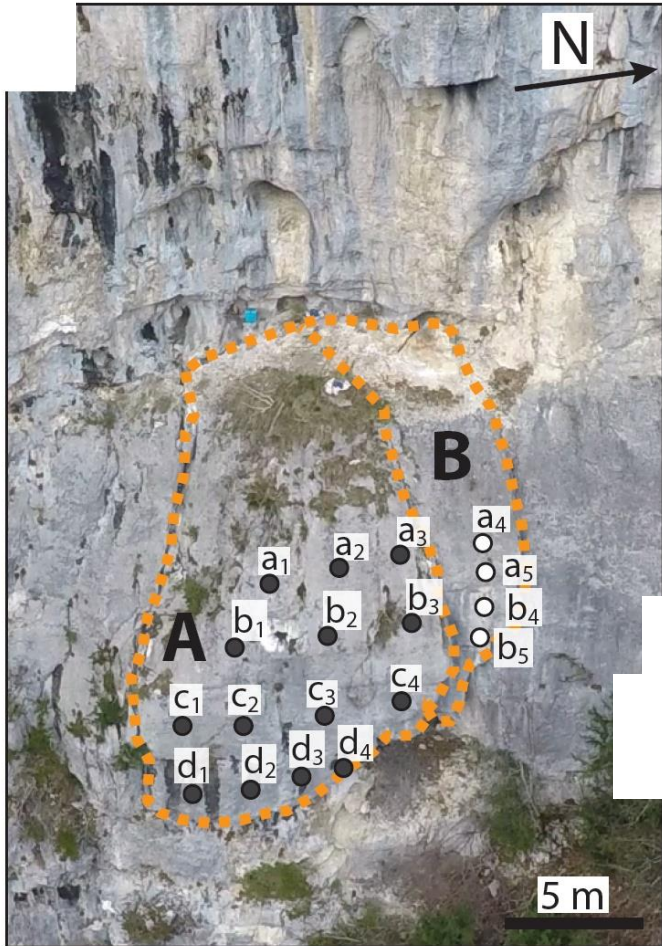
# A. MONITORING ROCK REINFORCEMENT WORKS - LA BOURNE



# B. CHARACTERIZING AND MONITORING ROCK SLOPE UNTIL ROCKFALL – LA PRAZ



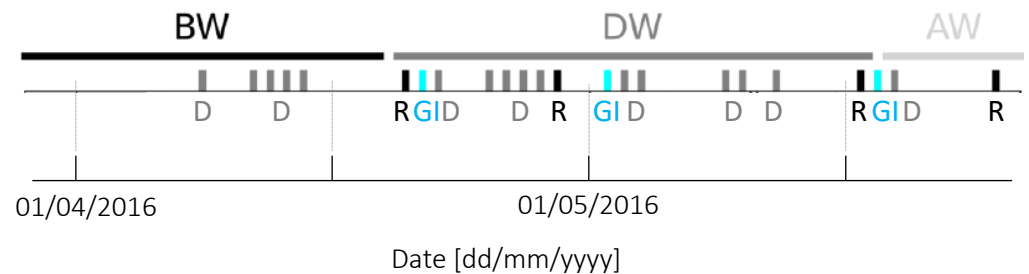
## ■ Site description



### Features

- ~750m<sup>3</sup> rock column (5x10x15m)
- Massive Urgonian limestone
- 18 rock bolts, CMC type (14 + 4)
- 5 to 12.5m in length
- Cement grout leaks at column's toe: rock/bolt coupling?

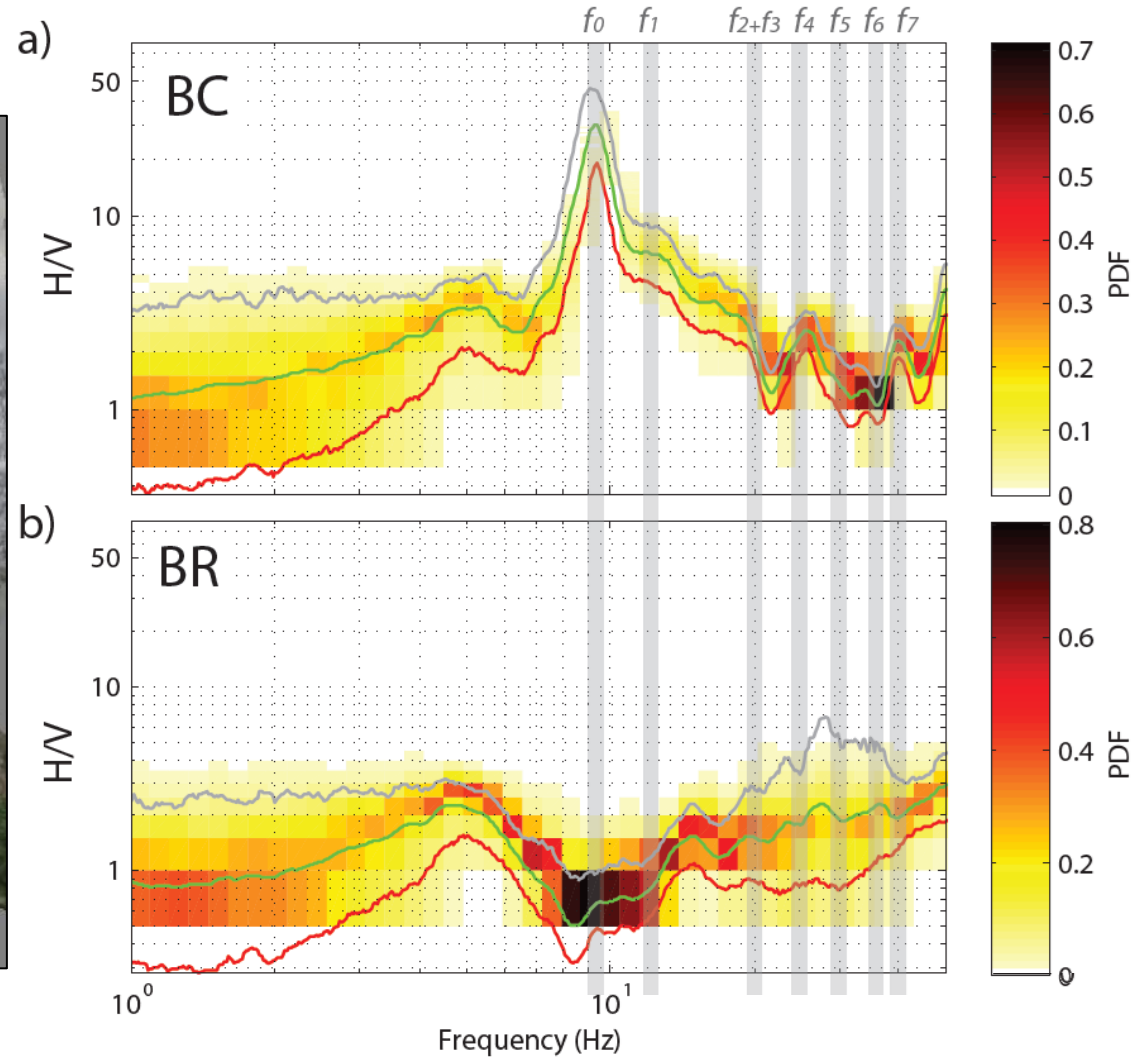
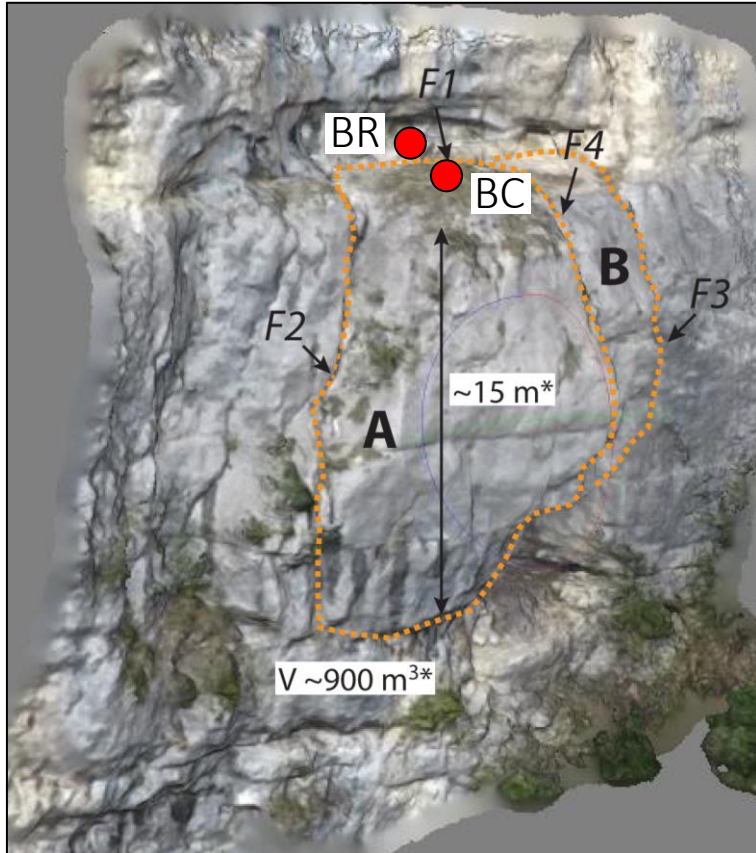
Reinforcement work schedule



[Bottelin et al. 2017 Eng Geol]



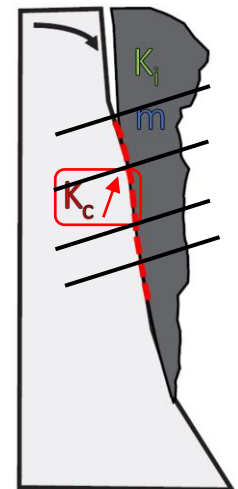
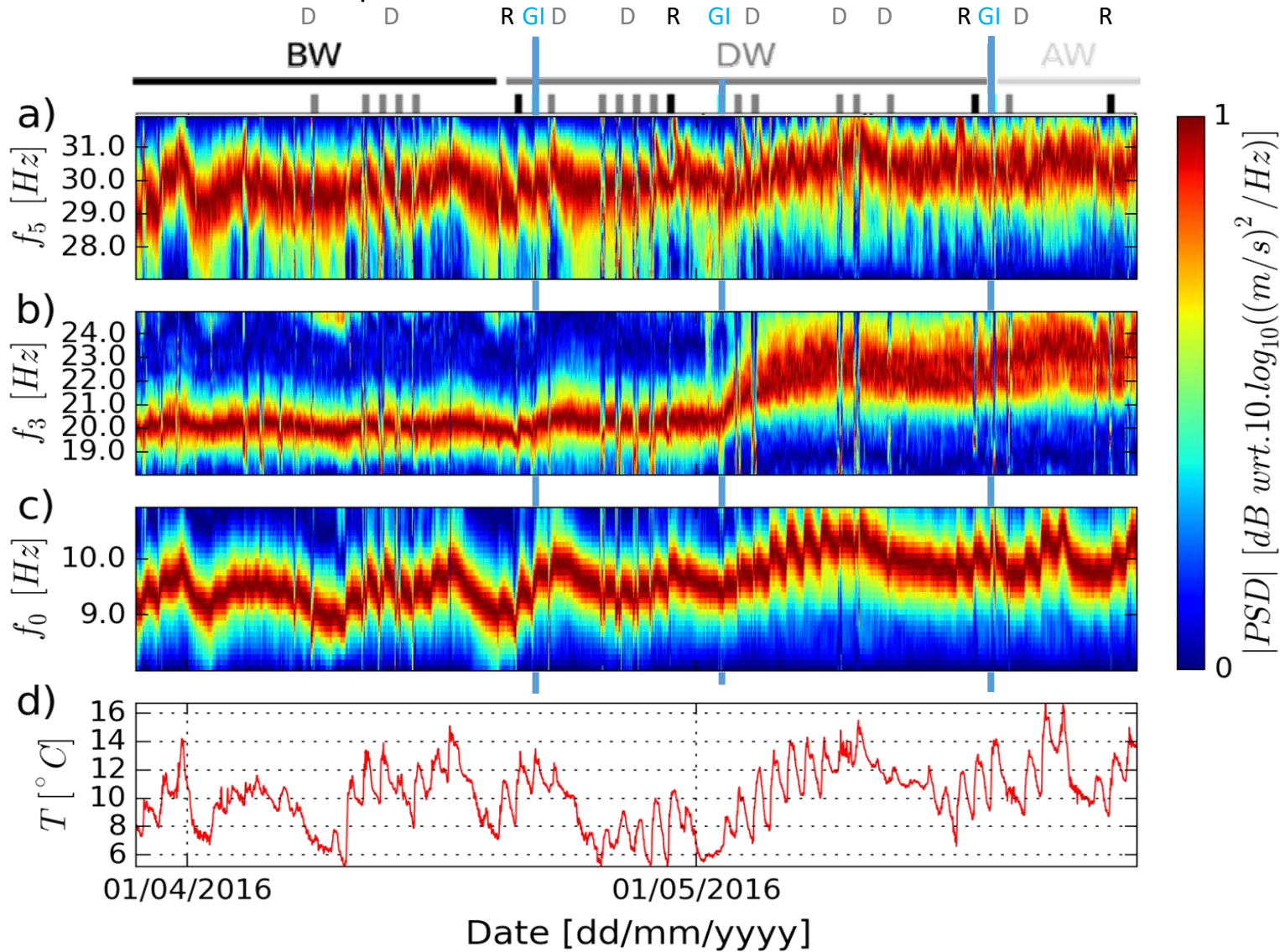
## ■ Results – Before Works



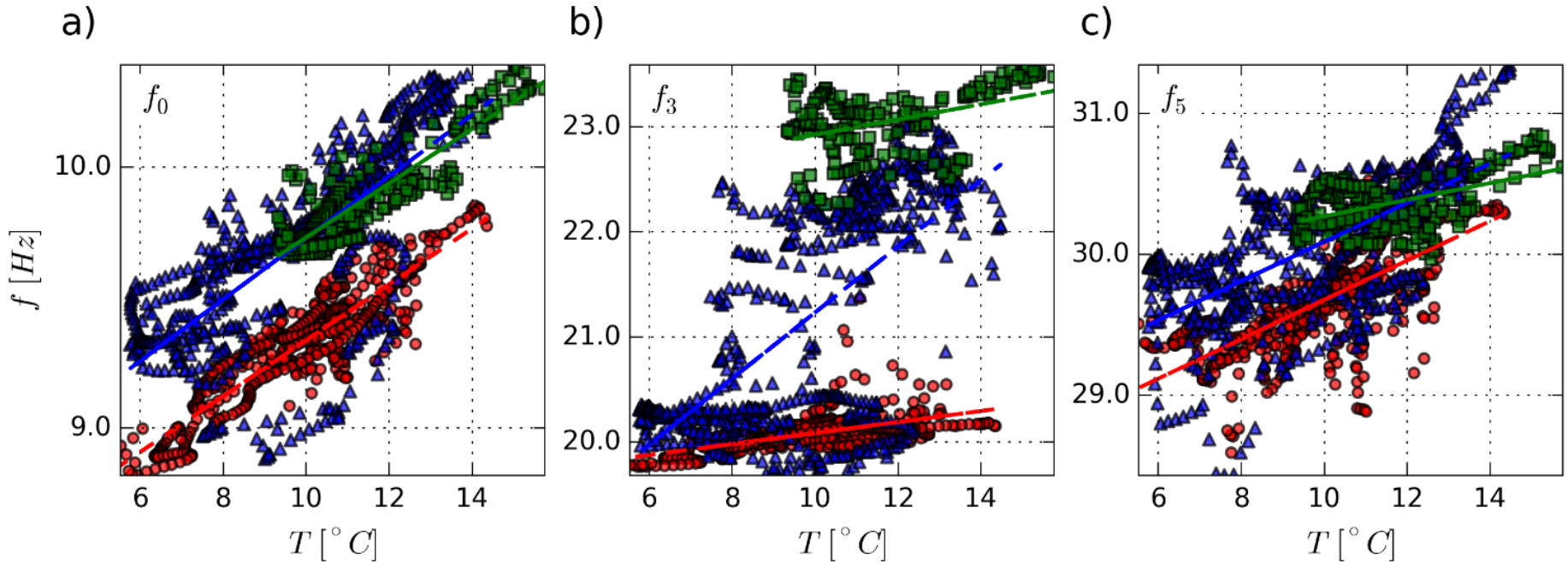
[Bottelin et al. 2017 Eng Geol]



## ■ Results – Whole period

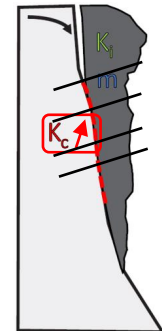


## ■ Results – Whole period

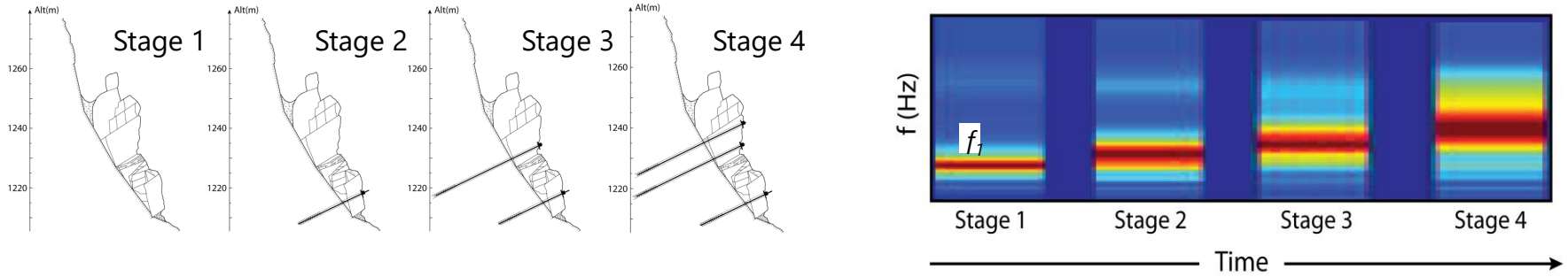


### Key results

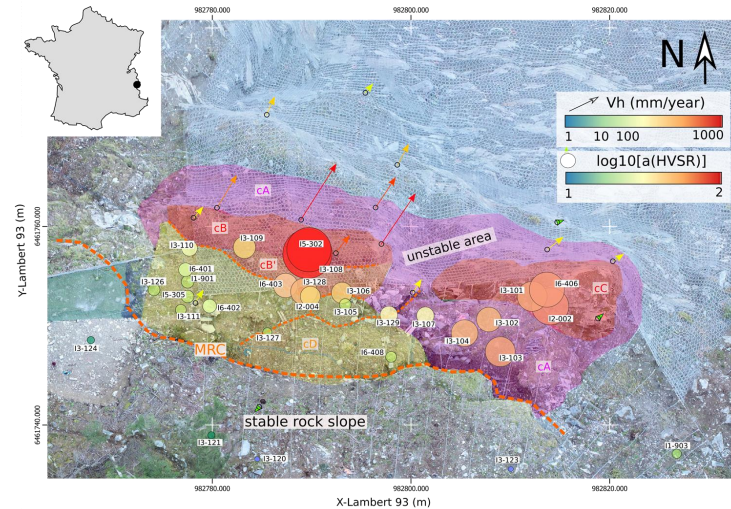
- First case study of rock bolting monitoring with seismic noise
- Clear increase in resonance frequencies related to bolt grouting (+8%, +17%, +1%)



# A. MONITORING ROCK REINFORCEMENT WORKS - LA BOURNE

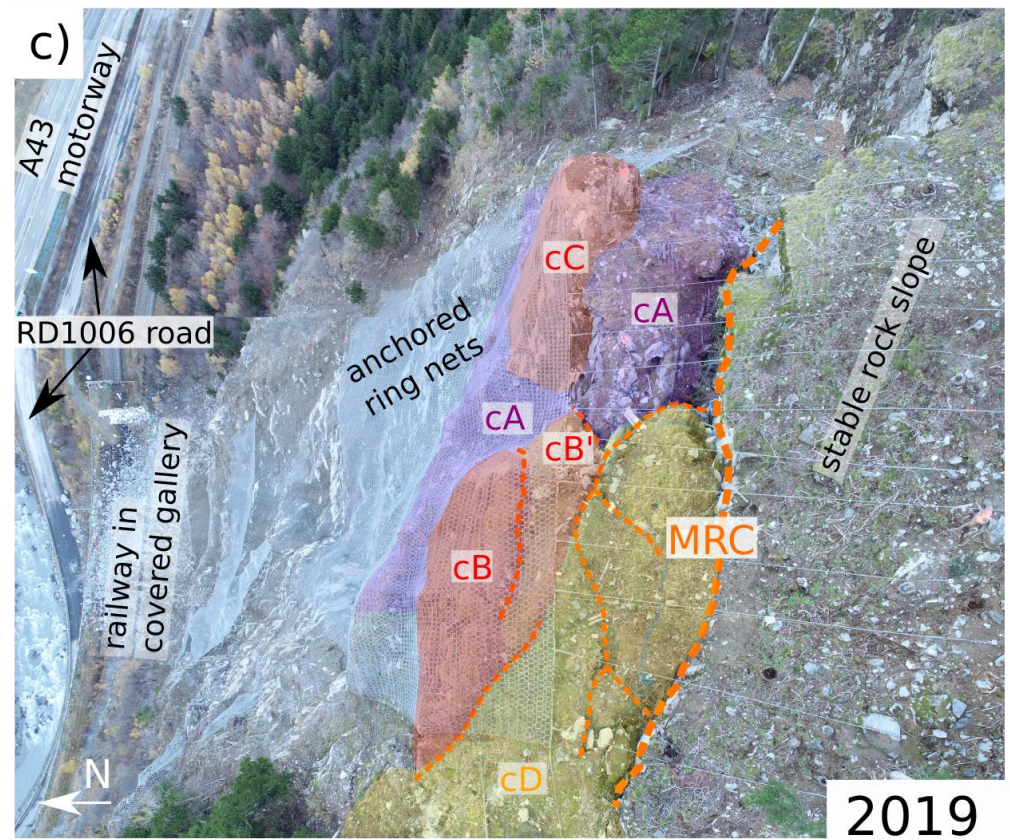
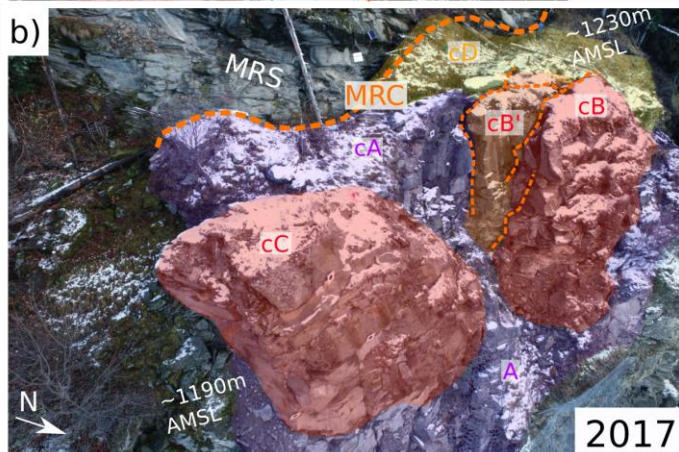
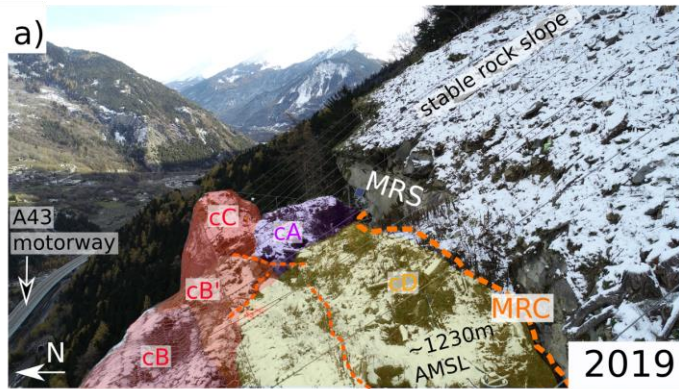


# B. CHARACTERIZING AND MONITORING ROCK SLOPE UNTIL ROCKFALL – LA PRAZ





## ■ Site description



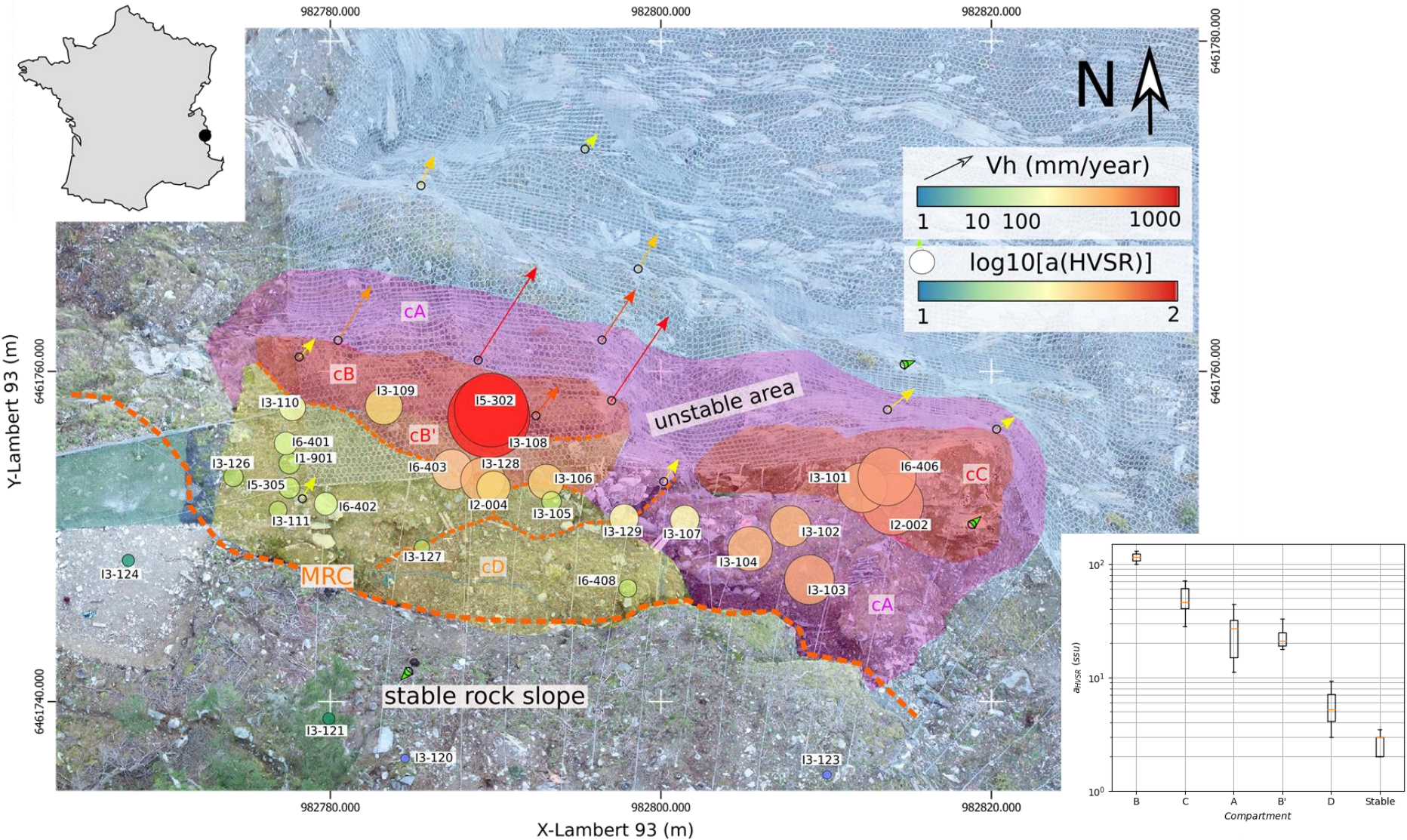
### Features

- ~15 000 m<sup>3</sup> highly fractured rock slope
- Bedded sandstone / shale alternance
- 250m above covered railway, RD1006, Arc river
- Compartments cA, cB, cB', cC, cD



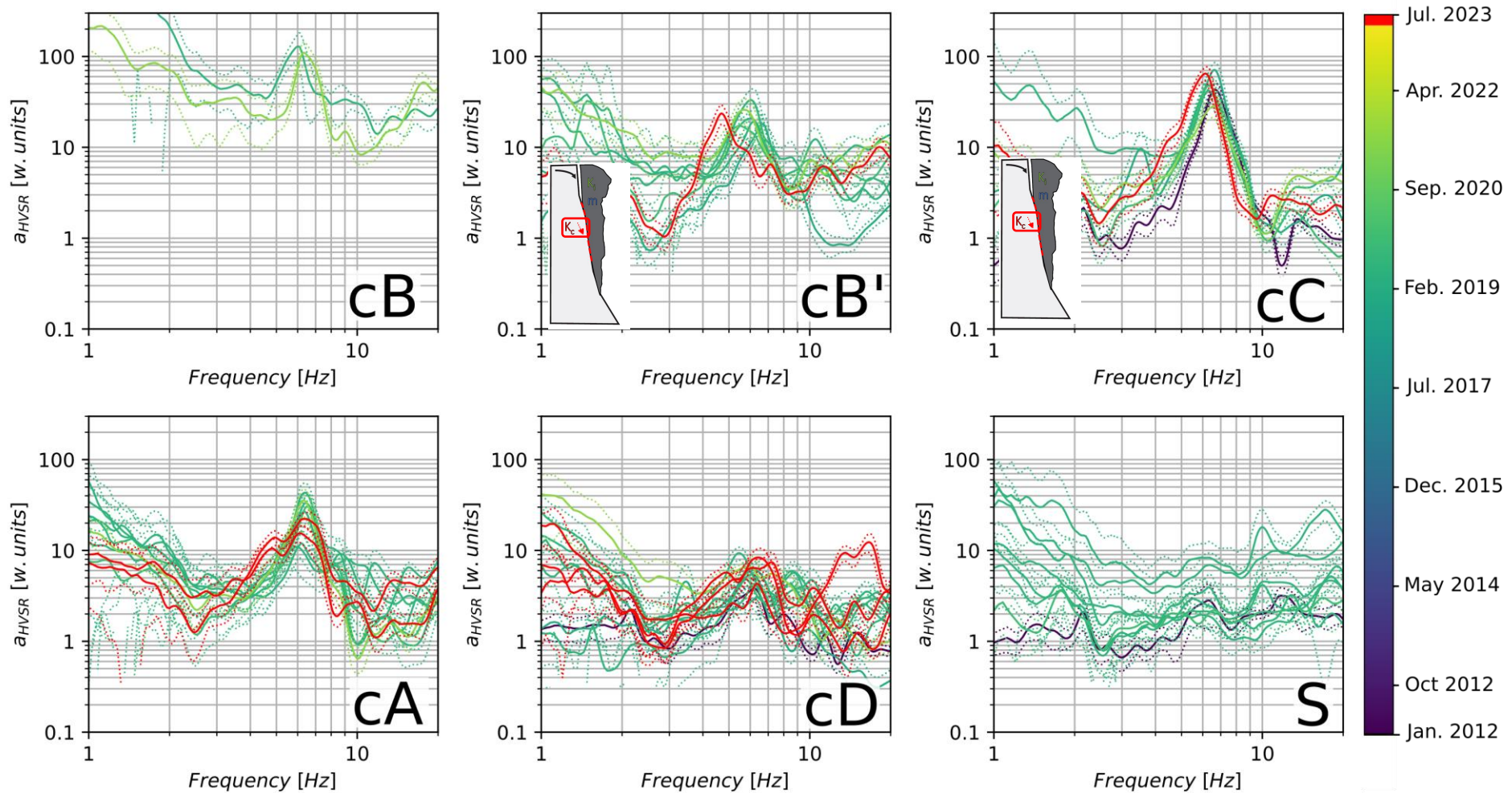


## ■ Passive seismic mapping

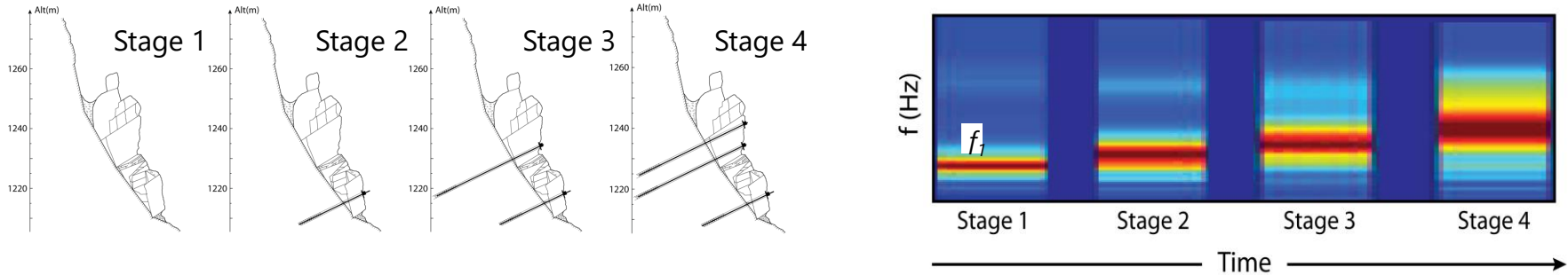




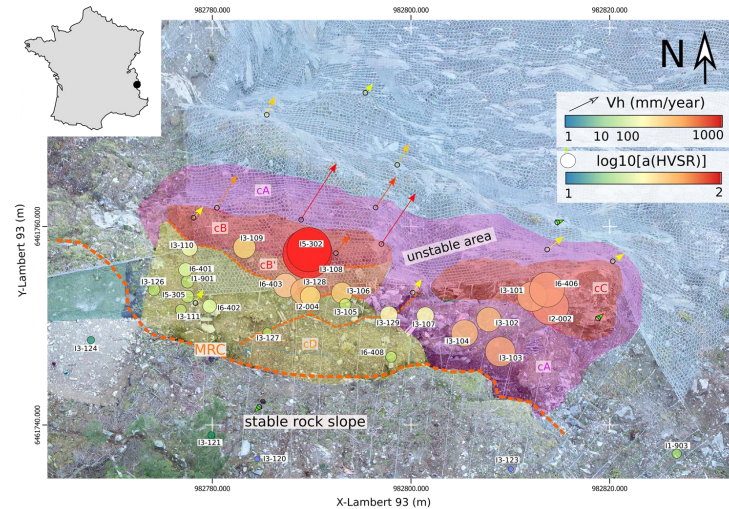
- Passive seismic change detection



## A. MONITORING ROCK REINFORCEMENT WORKS - LA BOURNE



## B. CHARACTERIZING AND MONITORING ROCK SLOPE UNTIL ROCKFALL – LA PRAZ



## For further discussion

✉ p.bottelin@sage-ingenierie.com

- Bottelin et al. (2017) Monitoring rock reinforcement with ambient vibrations: La Bourne case study (Vercors, France), *Engineering Geology*, Vol. 226, pp. 136-145
- Bottelin et al. (2019) Geophysical methods for mapping Quaternary sediment thickness: Application to the Saint-Lary basin (French Pyrenees) *Comptes Rendus Geoscience* Volume 351, Issue 6, August–September 2019, Pages 407-419
- Bottelin, P., Baillet, L., Mathy, A. *et al.* (2020) Seismic study of soda straws exposed to nearby blasting vibrations. *J Seismol* Vol, 24, pp. 573–593. <https://doi.org/10.1007/s10950-020-09922-7>
- Bottelin et al. (2020) Préservation de stalactites fistuleuses exposées à des tirs de mine: cas des grottes de Choranche Journées Nationales de Géotechnique et de Géologie de l'Ingénieur – Lyon 2020
- Bottelin et al. (2021) Toward Workable and Cost-Efficient Monitoring of Unstable Rock Compartments with Ambient Noise, *Geosciences* 2021, 11(6), 242; <https://doi.org/10.3390/geosciences11060242>
- Guillemot, A.; ... & Bottelin P. (2022) Changes in resonance frequency of rock columns due to thermoelastic effects on a daily scale: observations, modelling and insights to improve monitoring systems, *Geophysical Journal International*, Volume 231, Issue 2, November 2022, Pages 894–906, <https://doi.org/10.1093/gji/ggac216>

## Acknowledgements

