# Interaction between reservoir and basement revealed by $CO_2$ induced seismicity at Decatur

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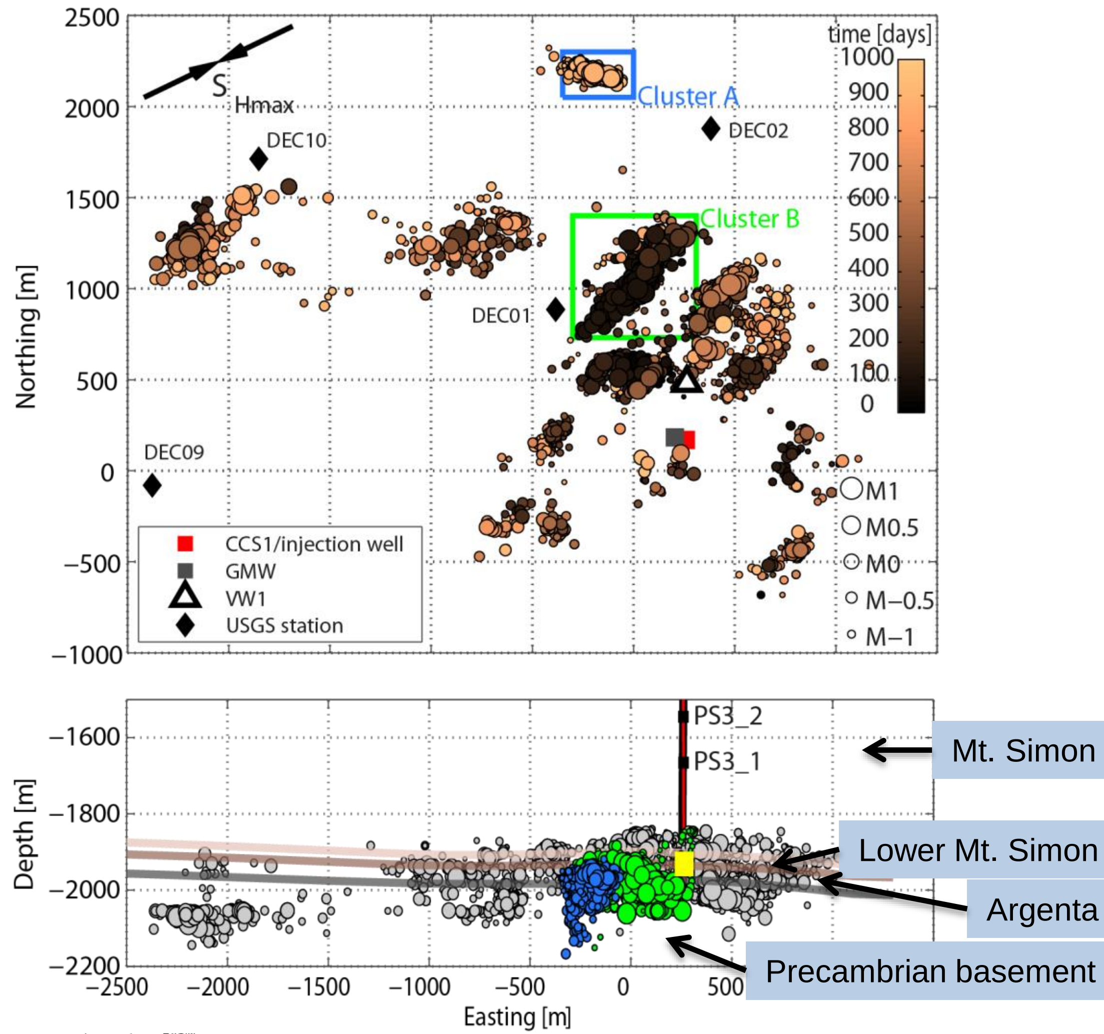
Schatzalp 2nd induced seismicity workshop
March 16, 2017

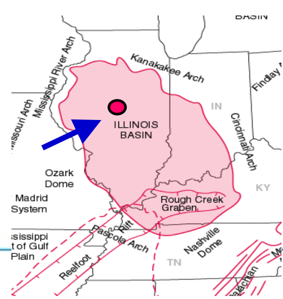
# Outline

- IBDP CCS site
- Event characterization using waveform cross-correlation
  - Formation distinction
  - Spatial & temporal sub-cluster analysis
- Statistical & physical source parameter variations
- Conclusions

# IBDP CCS site

- Inject 1 million metric tons of $CO_2$ into Mt. Simon sandstone (460 m thick) at ~1.9 km depth over three years.
- Microseismic monitoring includes borehole & surface sensors.
- Microseismic activity started shortly after injection began.
- Over 17,000 microseismic events detected by borehole strings.
- Events occur in distinct clusters.





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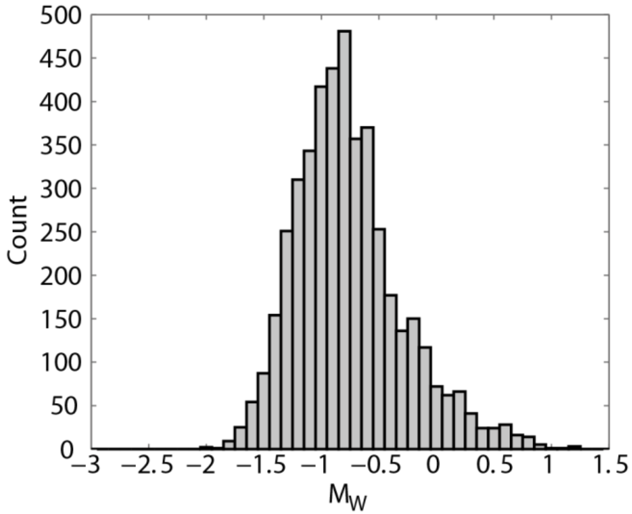
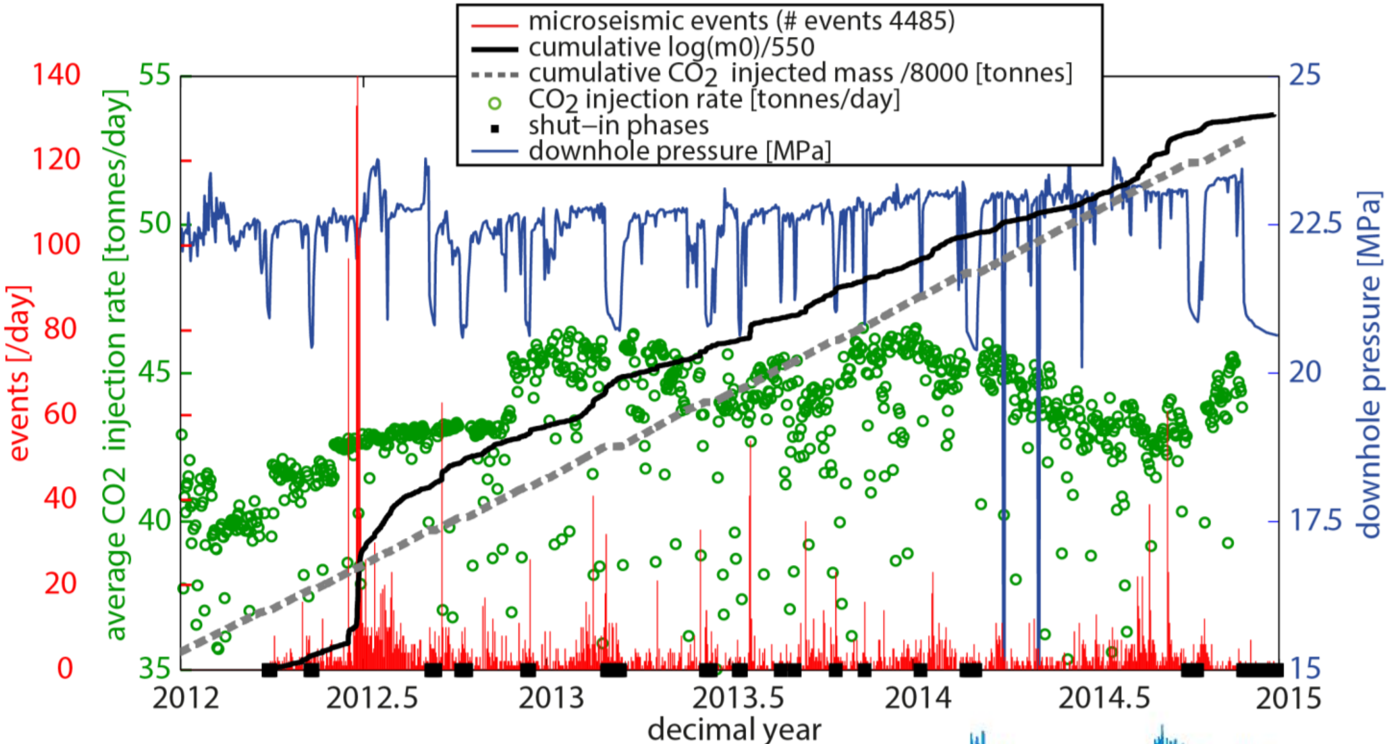
# IBDP Decatur CCS site

- Most events with $M_w < 0$.
- Injection at very low pressure (< 1 MPa)
- No obvious correlation with plume migration – events far from the injection





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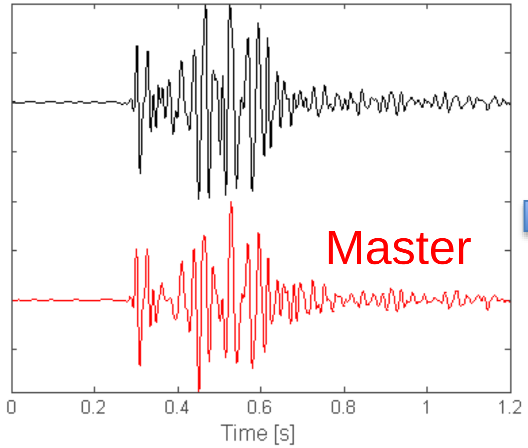
# Event characterization using waveform cross-correlation

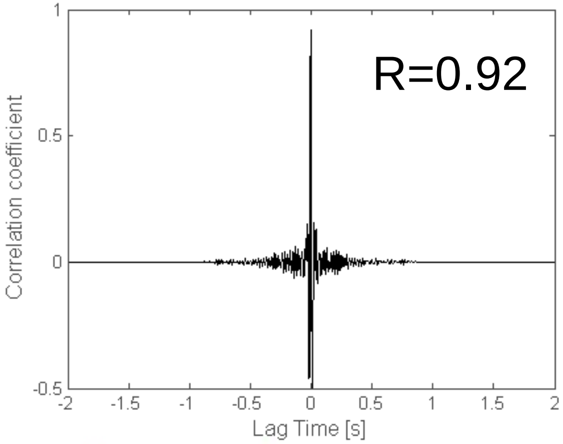
- Distinguish between events in the reservoir and in the basement:
  - Triggered by different mechanisms (pressure-driven versus stress-driven)
  - Hydraulic connection between reservoir & basement?

- Need better depth resolution to identify basement and reservoir events → waveform x-correlation technique

➢ Increased relative depth resolution

➢ Formation distinction possible





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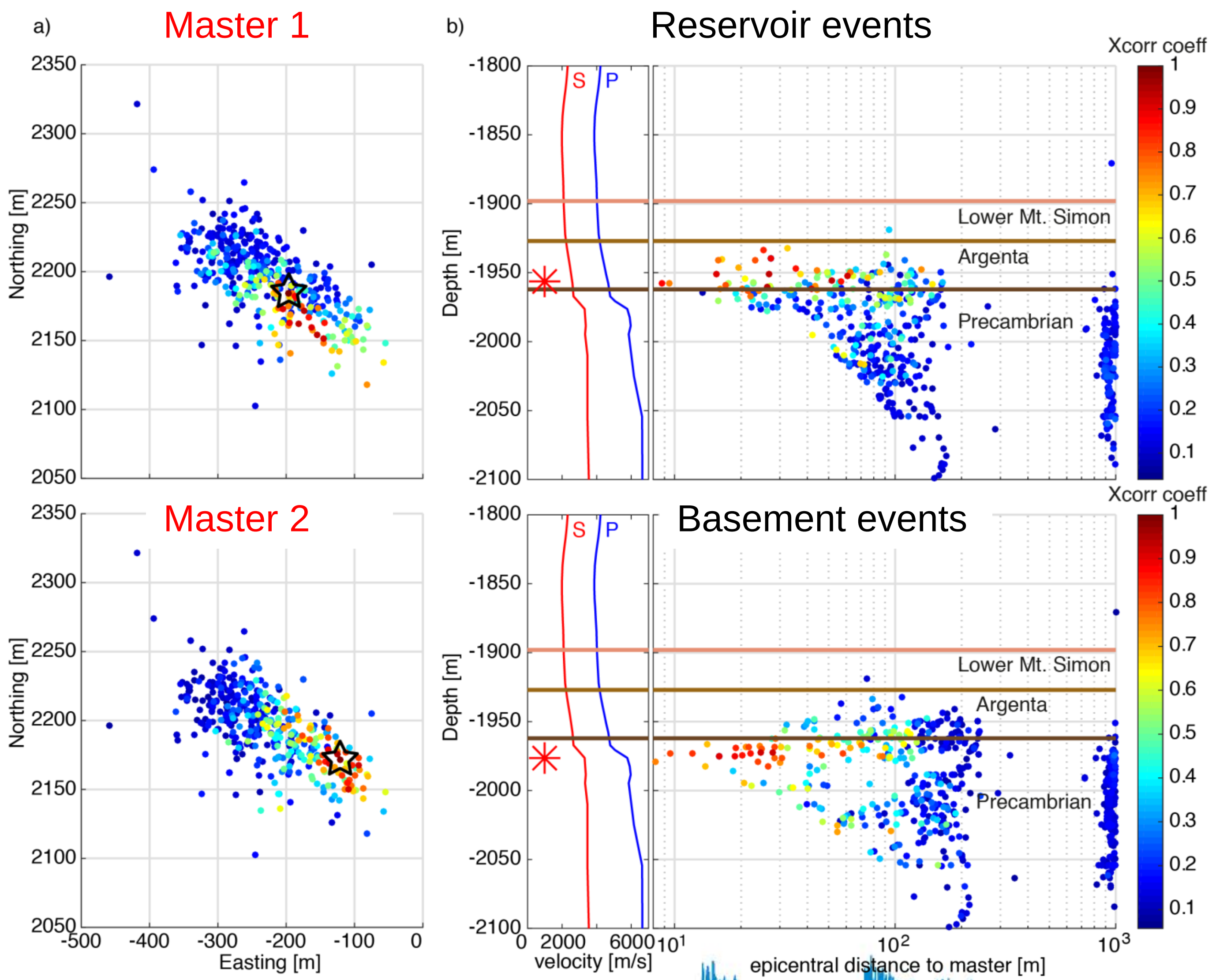
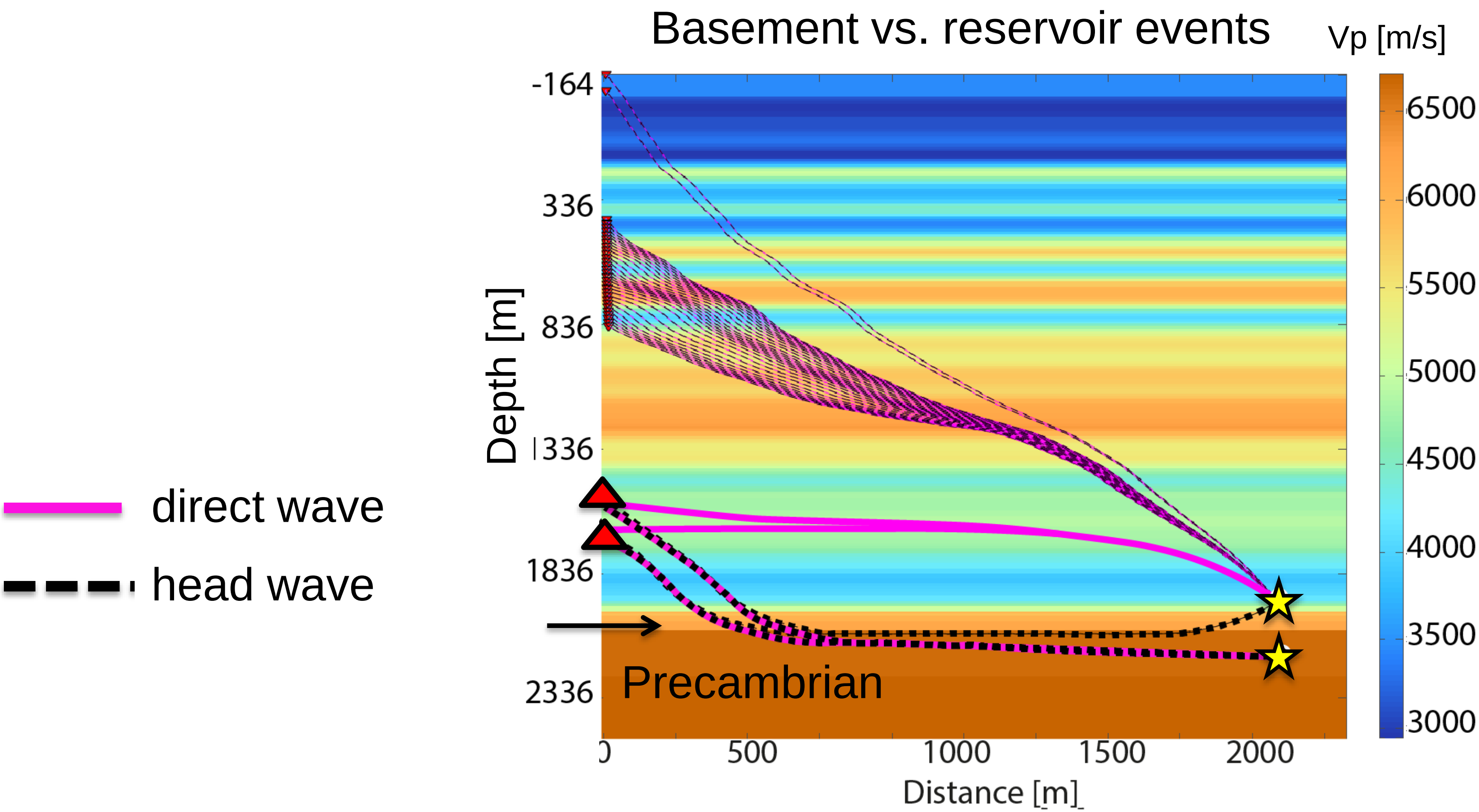
# Event characterization using waveform cross-correlation

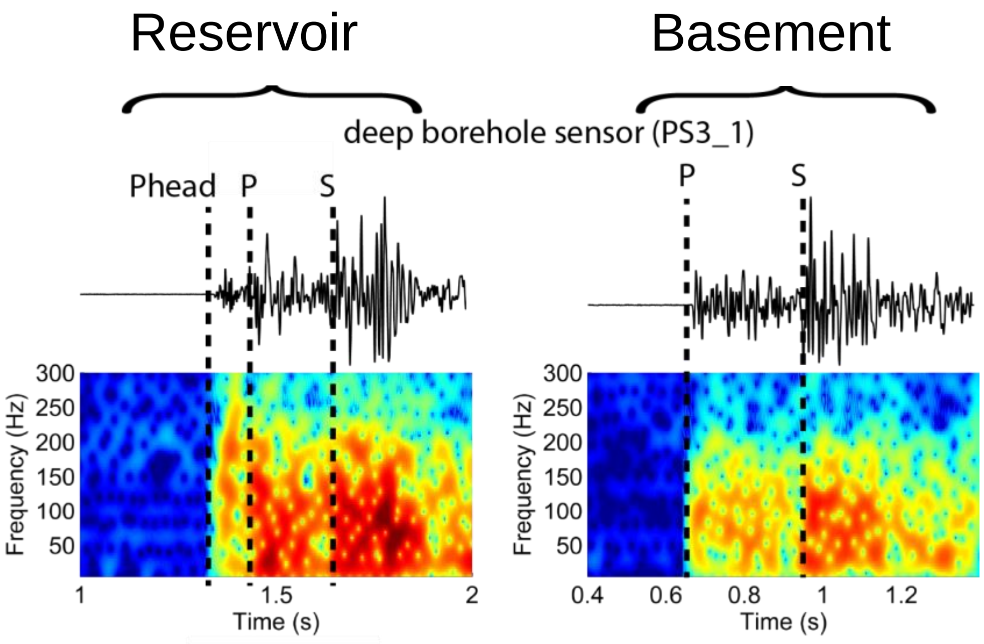


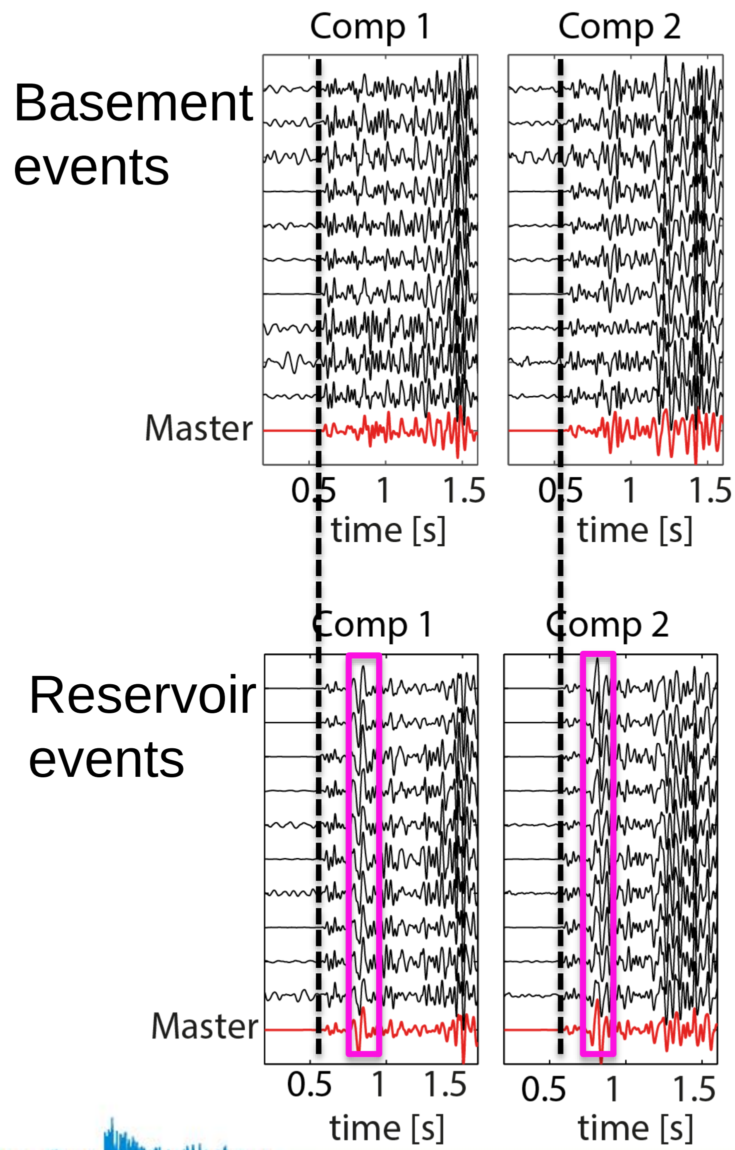
# Event characterization using waveform cross-correlation




- Theoretical ray diagrams for reservoir & basement events.
- Different waveform signature: head wave and direct wave arrivals clearly visible for reservoir events

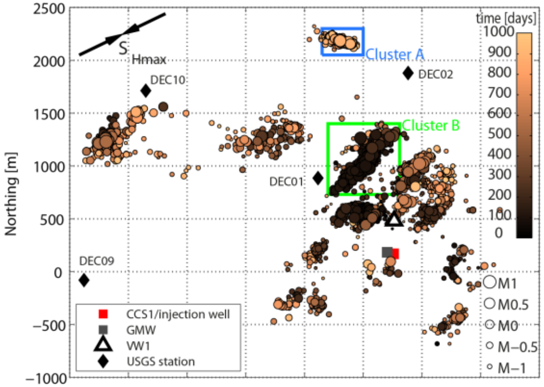
# Event characterization using waveform cross-correlation

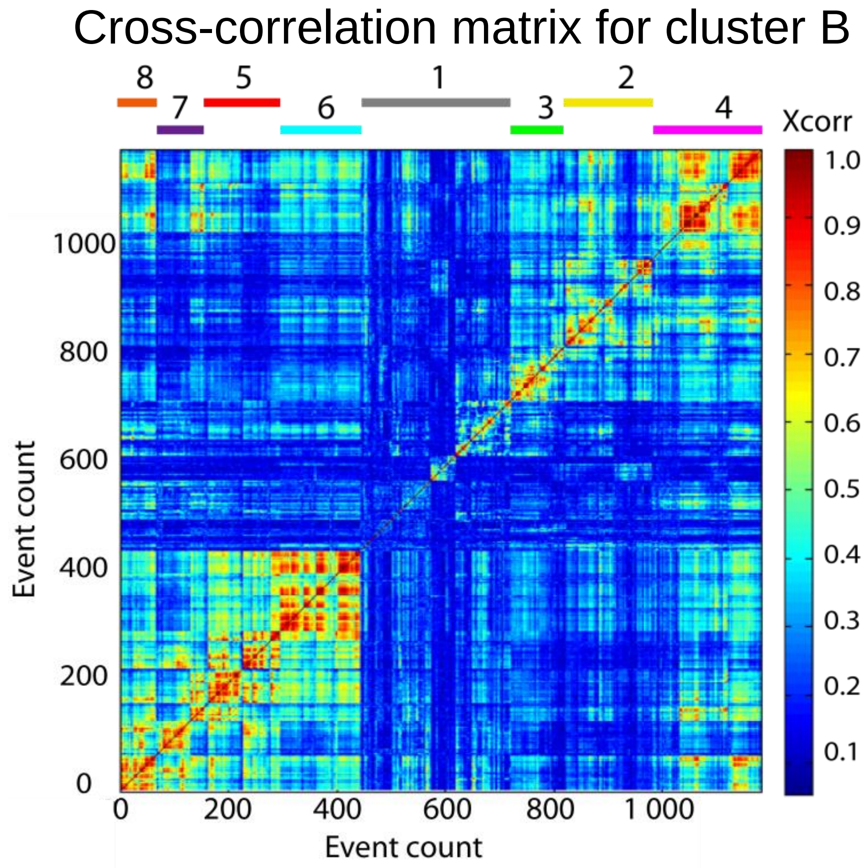


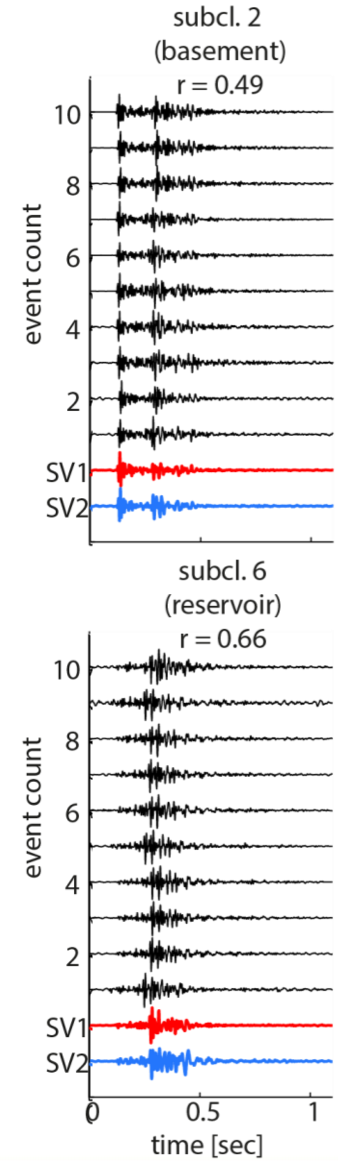



# Event characterization using waveform cross-correlation

## Sub-cluster analysis of cluster A and B

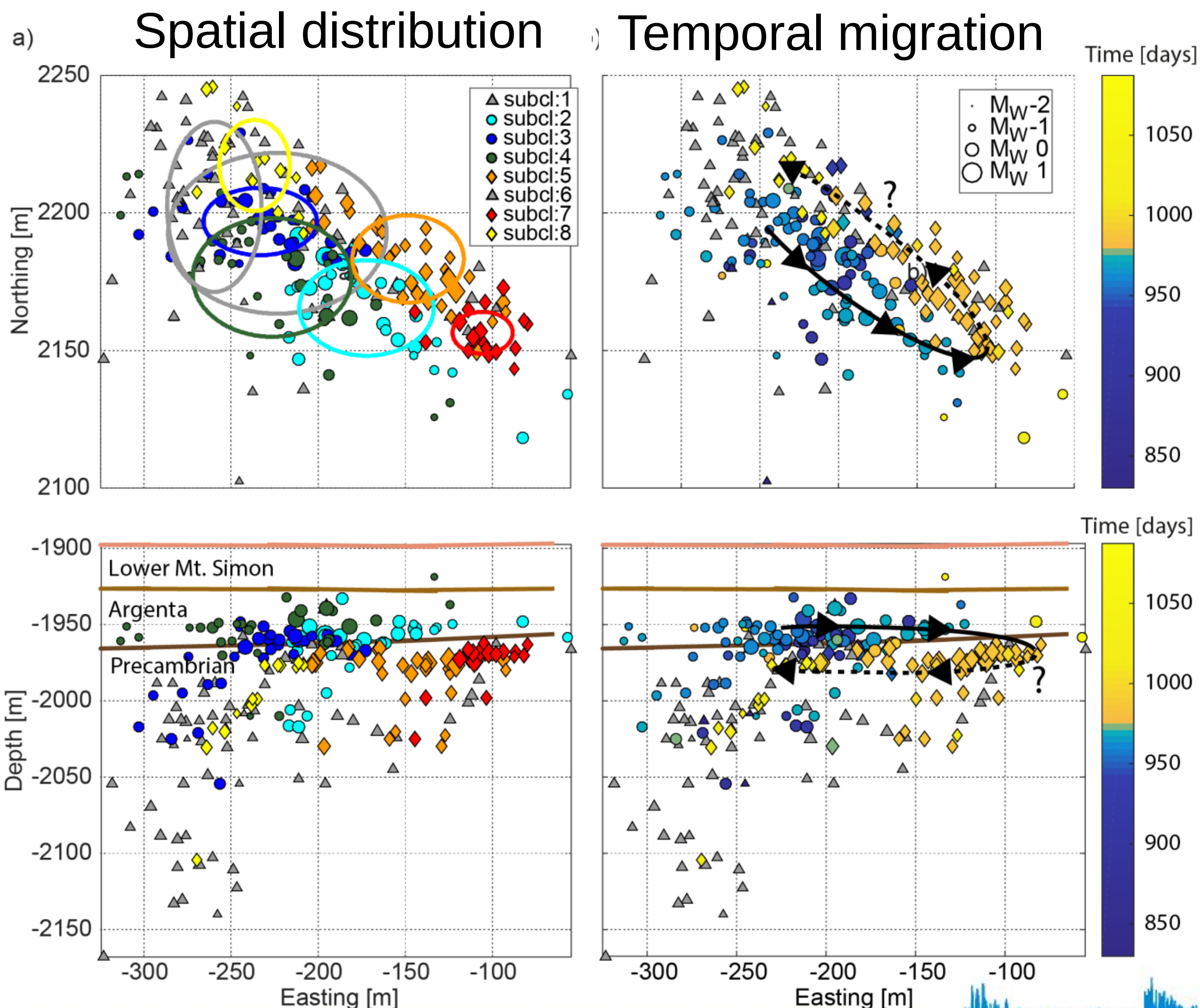


# Event characterization using waveform cross-correlation

## Cluster A




- Strong degree of spatial clustering.
- Separate events occurring within different layers with much more confidence.
- Migration of events from the reservoir into the basement over the course of 100-200 days.





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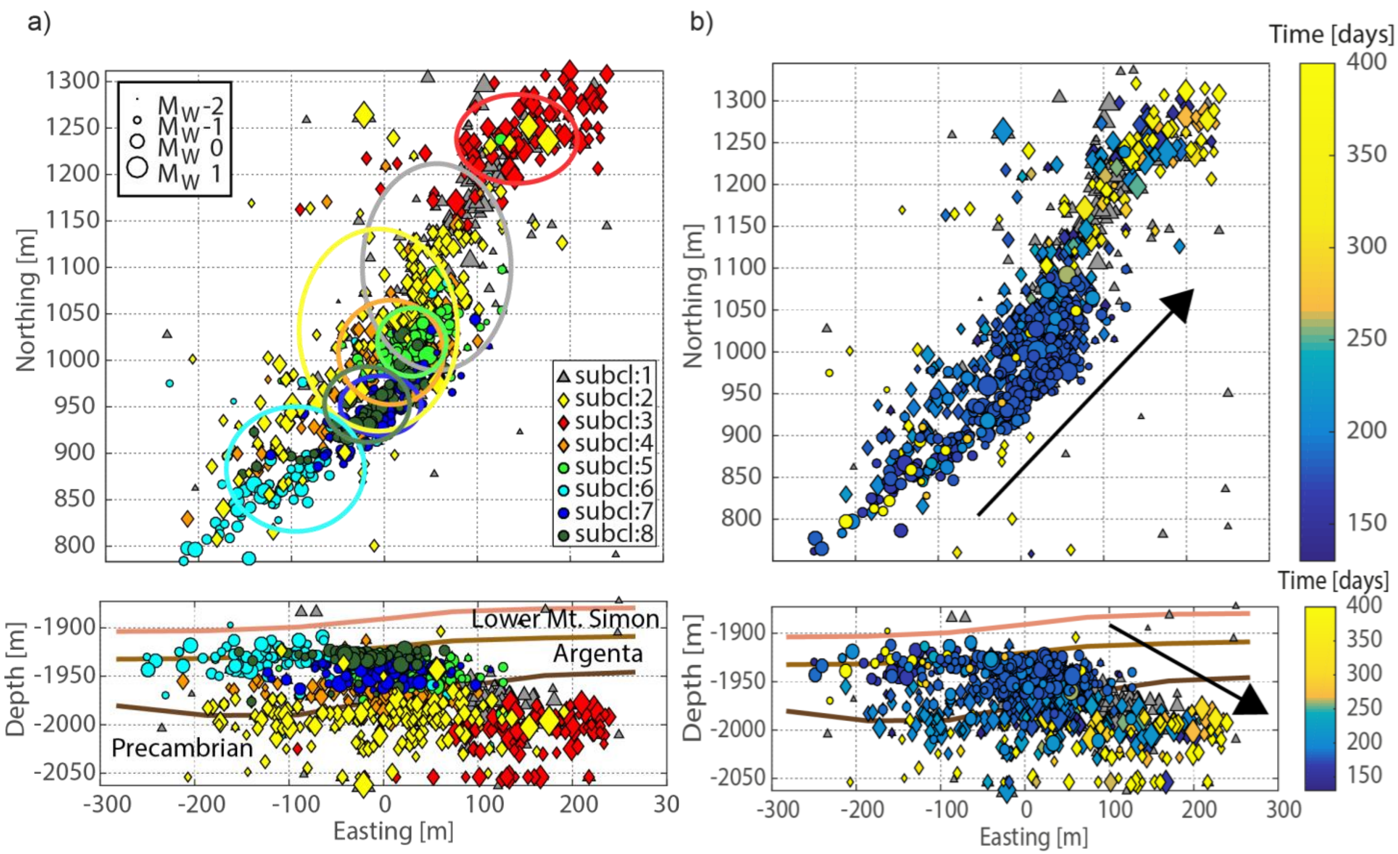
# Event characterization using waveform cross-correlation

## Cluster B

### Spatial distribution

### Temporal migration




- Strong degree of spatial clustering.
- Separate events occurring within different layers with much more confidence.
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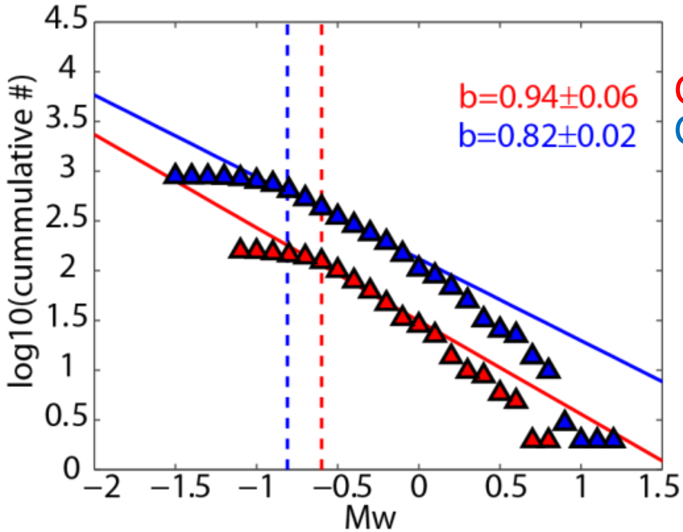
# Statistical & physical source parameter variations

## b-value

- b-value is the slope of the Gutenberg-Richter law. $log10(N) = a - bM$

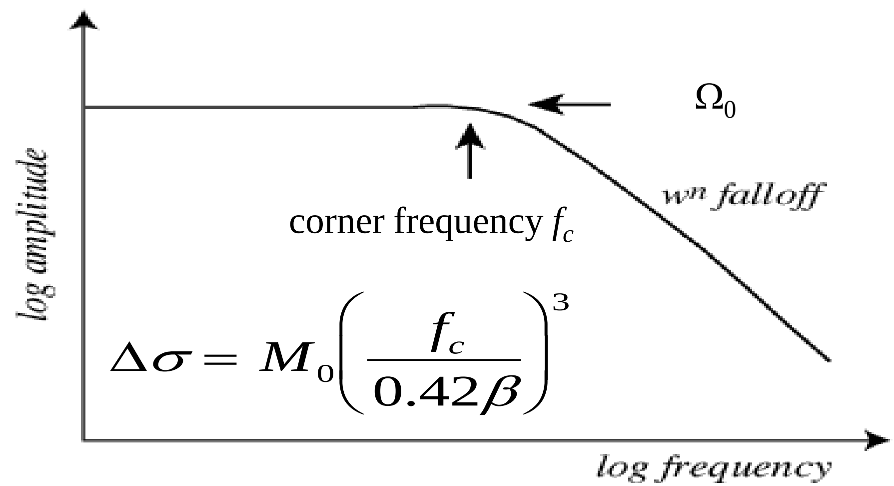


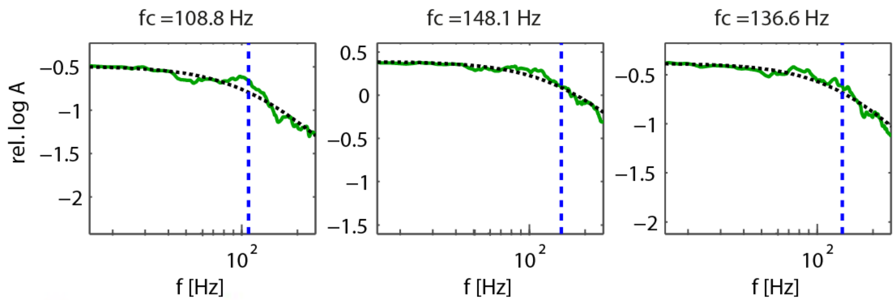

- Average b-value points to reactivation of pre-existing fractures rather than creation of new fractures.

➡ b-value & stress drop can be linked to in-situ reservoir stress state

## stress drop Δσ

- The difference between the state of stress before and after the earthquake is called the stress drop.





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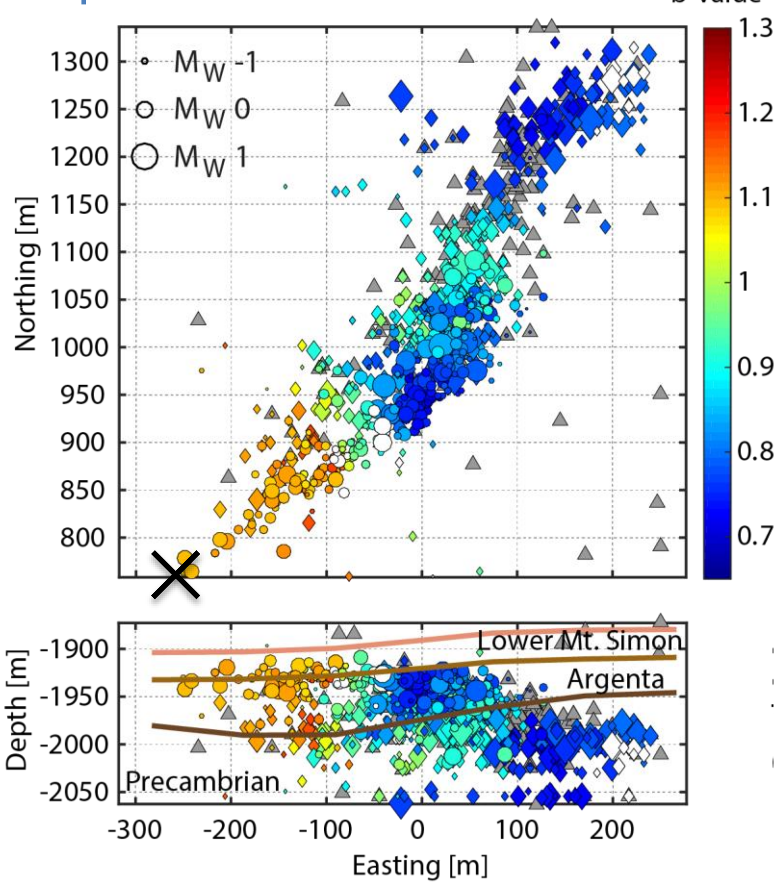
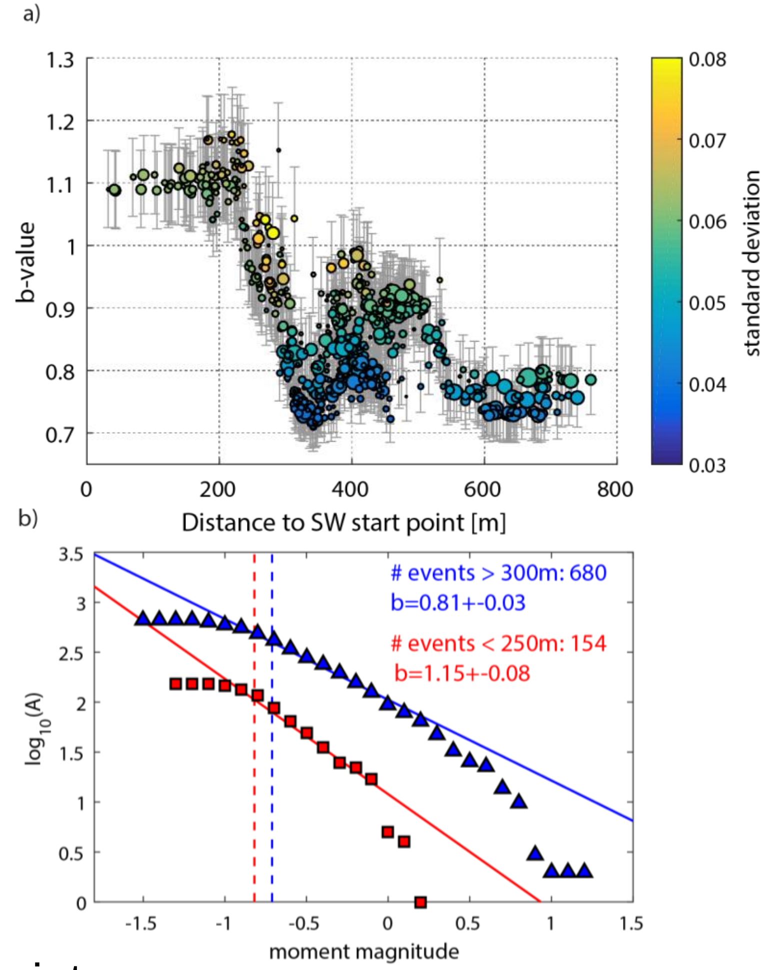
# Statistical & physical source parameter variations

## Spatial b-value variations

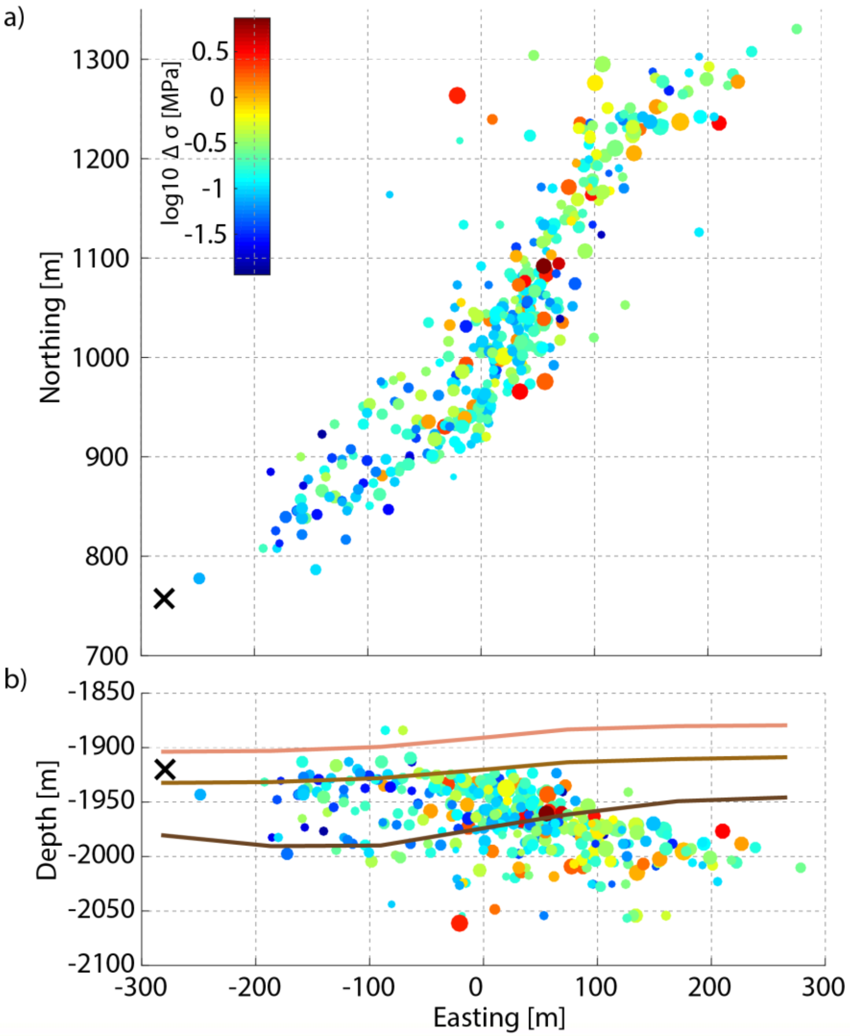


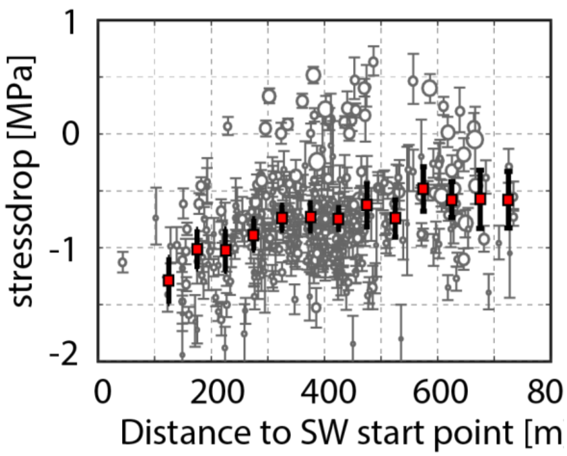




- High b-values at the cluster nucleation point.
- Decrease of b-value with distance.
- Could suggest some fluid percolation process.

# Statistical & physical source parameter variations

## Spatial stress drop variations




- Lower stress drops around nucleation point and increase towards the Northeast.
- Change in b-value along the same direction.
- Further evidence for a fluid-driven process at the cluster level.
- Signs of pressure diffusion in the seismicity of cluster B.
- Possible punctual hydraulic connection between reservoir and basement i.e., confined to faults.

# Conclusions

- Seismicity within a cluster exhibits signs of pressure diffusion, both through the spatio-temporal evolution of seismicity but also through source parameters such as b-value and stress drop.

- We achieve high relative depth resolution using waveform cross-correlation, which reveals seismicity migration patterns from sediment into basement.

- Eventually, a punctual hydraulic connection (such as, e.g., a basement-connected fault) causes migration into the basement. → may explain clustering of seismicity (i.e., weak crust around those areas).

- The lesson for fluid injection close to basement requires identification of sub-seismic basement-connected faults for proper long-term risk mitigation.

# Thank you for your attention!

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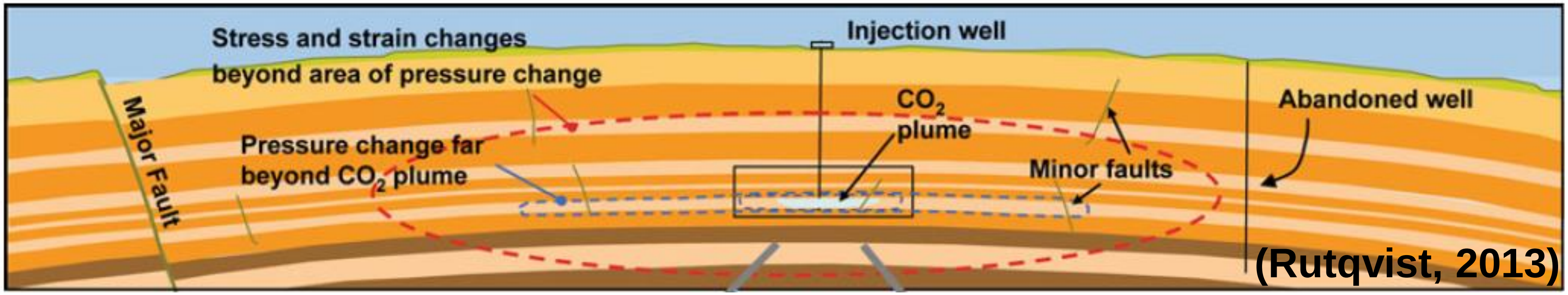
This work was supported as part of the Center of Geological Storage of $CO_2$, an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science.

Data for this project were provided, in part, by work supported by the U.S. Department of Energy under award number DE-FC26-05NT42588 and the Illinois Department of Commerce and Economic Opportunity.

# Induced Seismicity and CCS




- Fluid injection (fracking, $CO_2$, geothermal) causes (micro)seismicity
- Adequate microseismic monitored network should be in place
- The good:
  - Small microseismicity can be used to track fluid front & characterize the reservoir
- The bad:
  - Need to assess risk for prolonged injection or fault reactivation
- The ugly:
  - Brittle deformation undesired in seal - we need to ensure $CO_2$ reservoir seal integrity through microseismic monitoring → requires precise event depth control.



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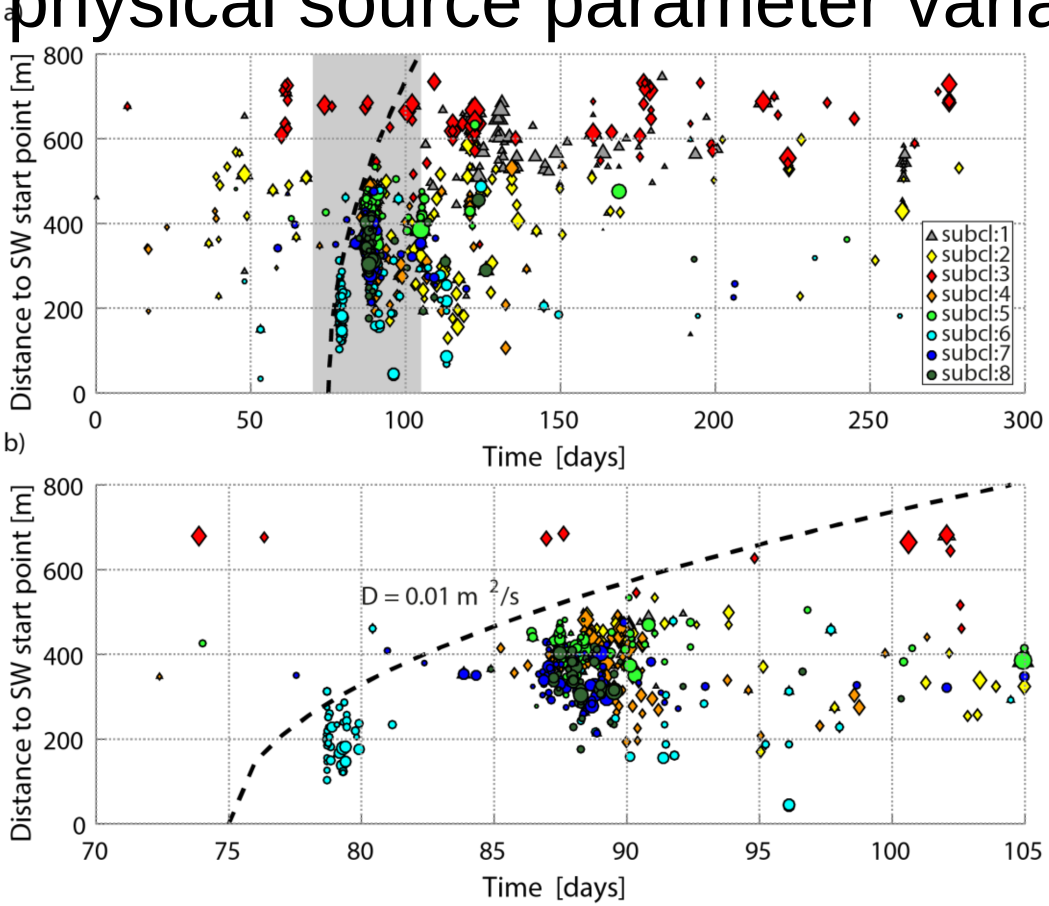
# Statistical & physical source parameter variations




$$r = \sqrt{4\pi D t}$$

- Signs of pressure diffusion in the seismicity of cluster B.
- Strongly simplifying assumptions with a hydraulically isotropic and homogeneous medium.
- Possible punctual hydraulic connection between reservoir and basement i.e., confined to faults.