Brittle/Ductile Transition and Rupture Dynamics: Experiments on Gypsum

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Outline

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Christmas Tree Model

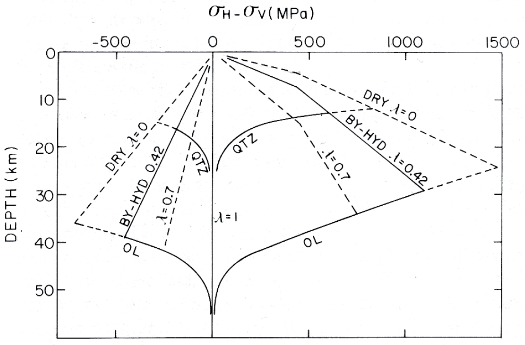

Figure: Brace W. & Kohlstedt D.L., JGR 1980.

This view is quasi-static: no influence of slip velocity, and no correlation with seimic/aseismic behaviour.

A Renewed View

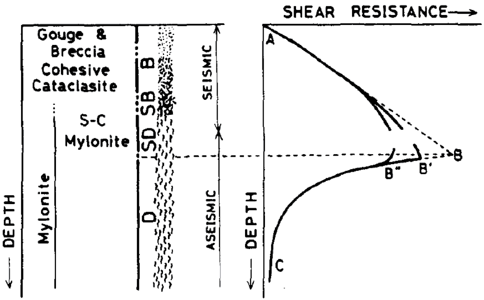

Figure: Shimamoto T., JSG 1989.

Experiments on halite. The effect of slip and slip rate is clearly emphasized (out of equilibirum diagram ?). The relation with seismic/aseismic behviour is assumed.

More Complexity

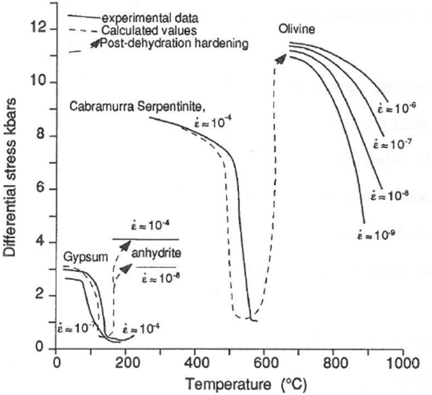

Figure: Brodie K. & Rutter E., APG 1985

Dehydration : weakening and then hardening (stiffer reaction products).

Our Approach

Use new technologies to describe as precisely as possible the behaviour of rocks at the brittle/ductile transition.

Material Used

- Need for a rock that experience B/D transition and dehydration under laboratory conditions,
- Gypsum is OK.

Experimental Devices

- Triaxial Apparatus, P_c up to 100 MPa and T up to 200°C,
- Elastic wave velocities measurement,
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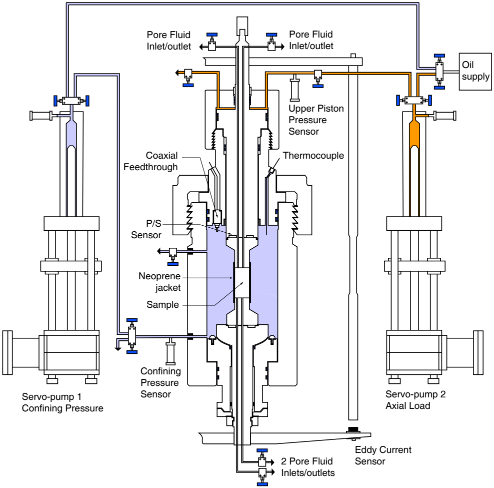
Tri-axial Rig @ ENS



Sample Set-up

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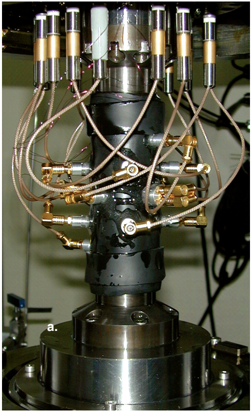
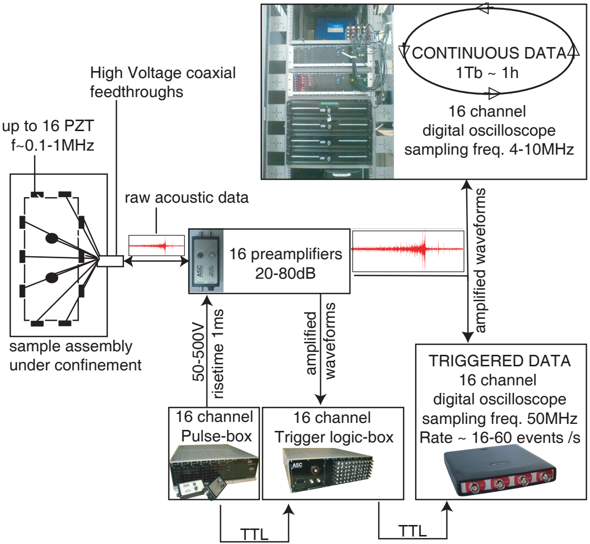


AE Recording System



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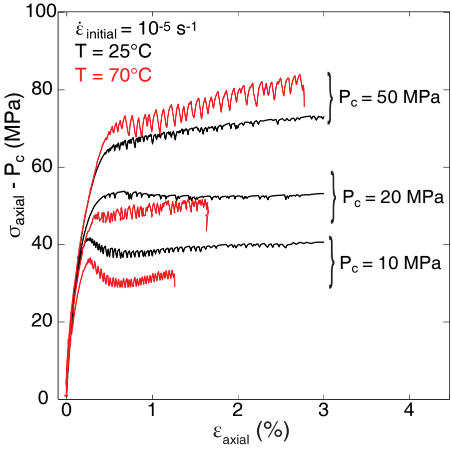
Stress-strain Behaviour



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- Brittle behaviour: single shear band,
- Numerous stress drops during the “ductile” behaviour.

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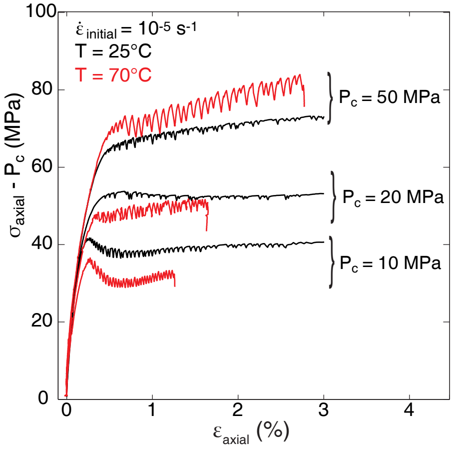

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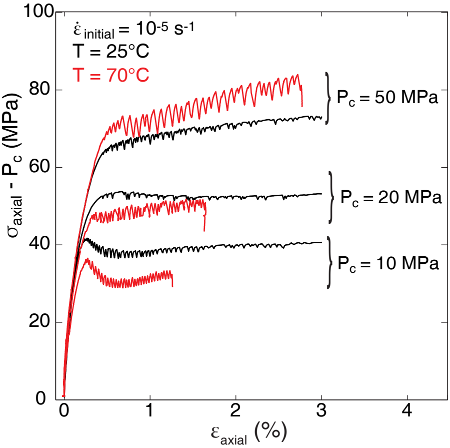

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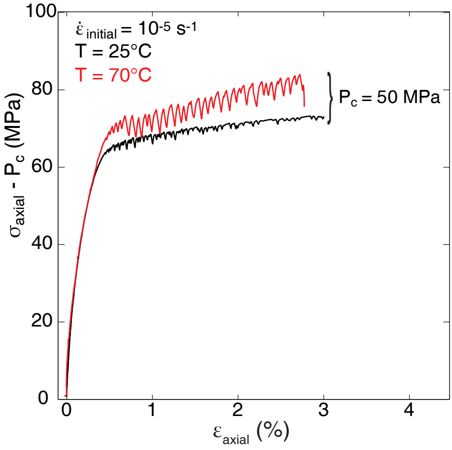

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Microstructural Observations

Numerous shear bands at $P_c = 50$ MPa

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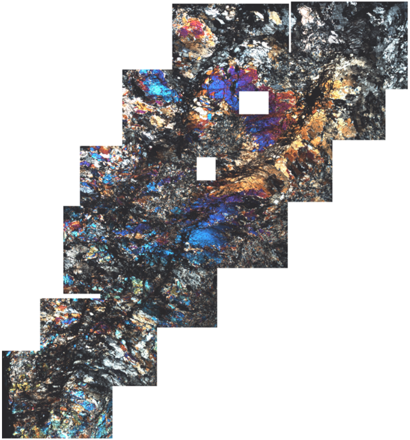
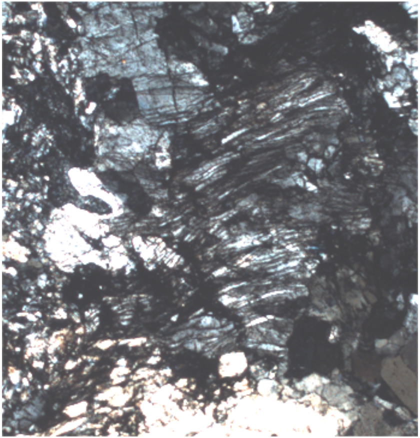


Presence of plastic deformation (kinks) and crack opening

Microstructural Observations



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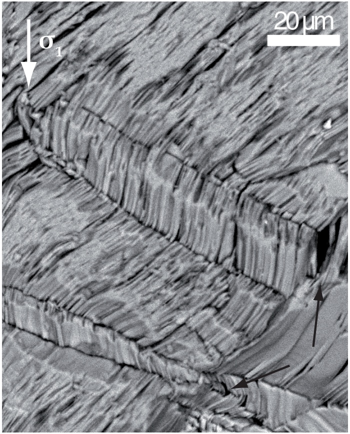

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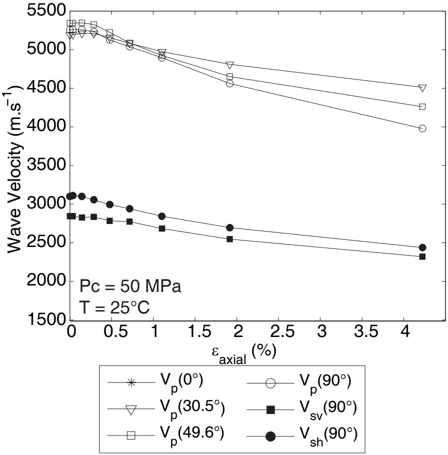
Continuous, linear decrease of wave velocities with increasing axial strain.



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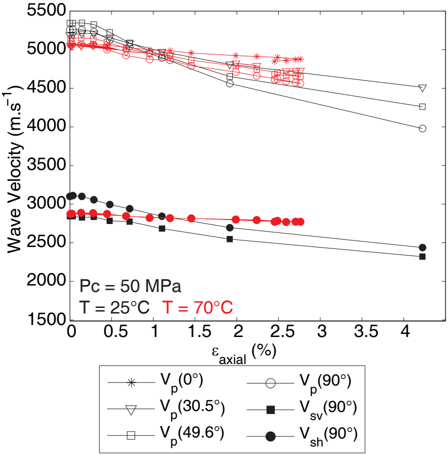
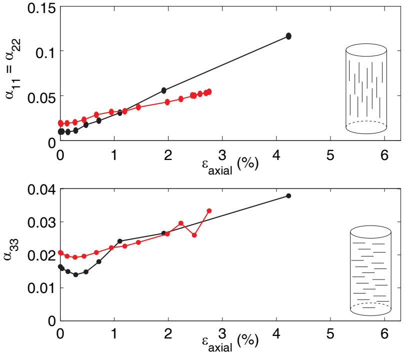


Interpretation in Terms of Crack Density



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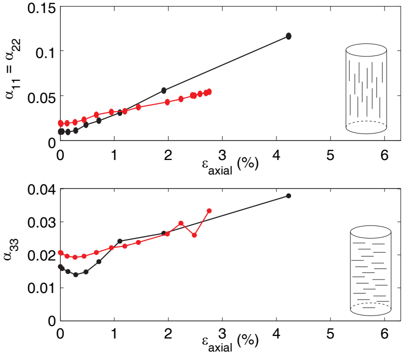

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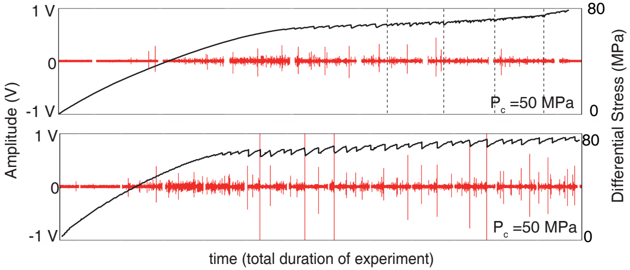
Lethal Weapon: Continuous Records (Mini Richter System)



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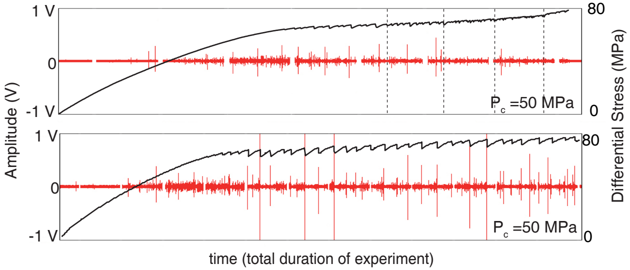

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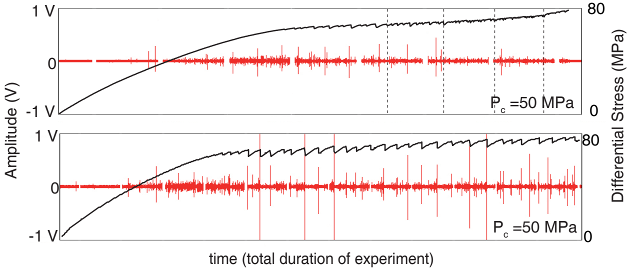

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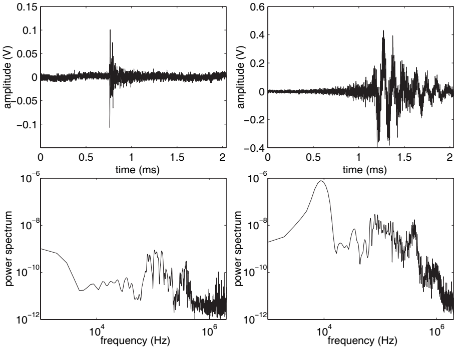
Various Types of AE



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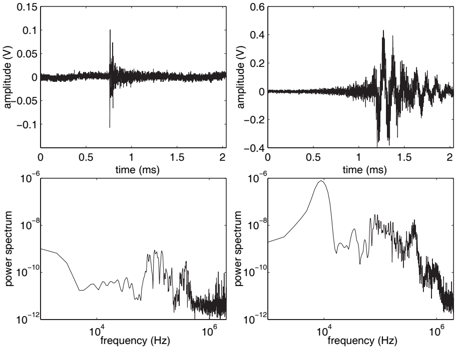

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Duration of a Stress Drop Event

Assuming that

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we can estimate the duration of an event by measuring the duration of the HF activity within the large AE signal.

Processing

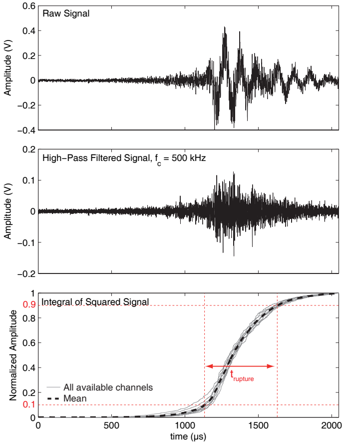
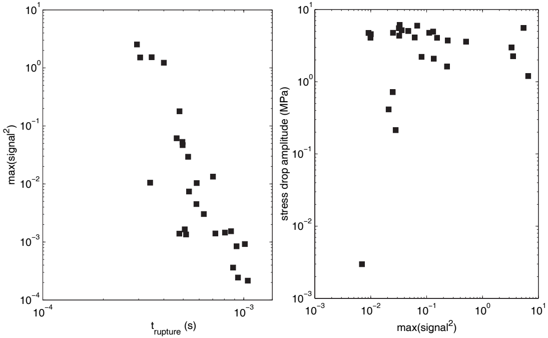


Figure: Low Frequency AE processing.

Scaling Laws



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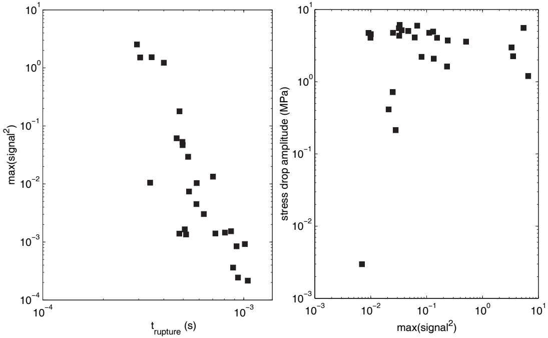

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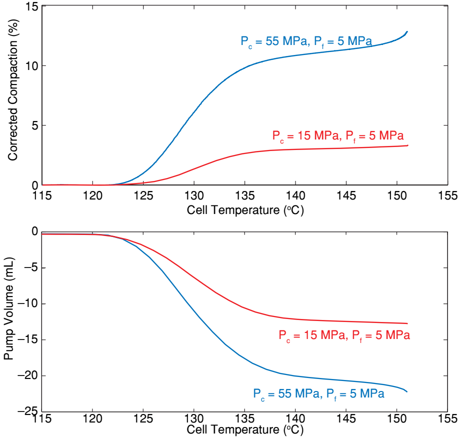
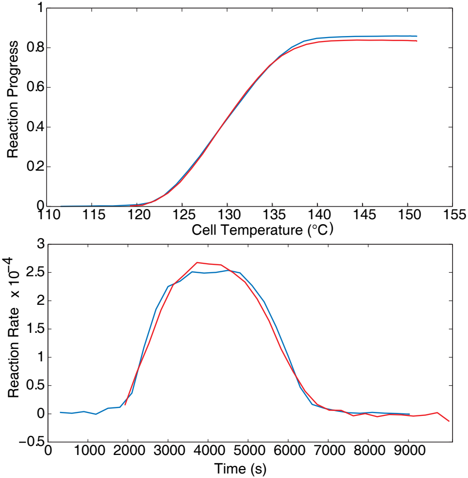
Compaction and Fluid Volume Change



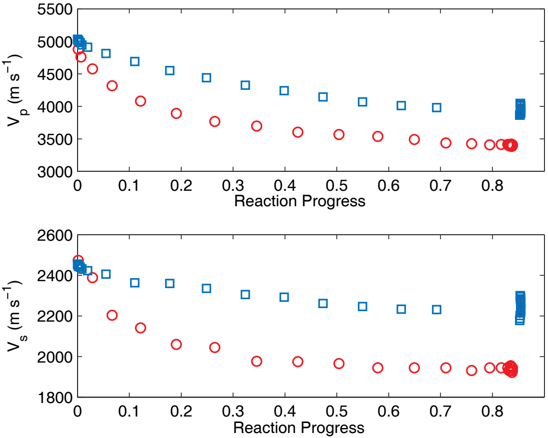
Hydrostatic tests, drained at $P_{\text{fluid}} = 5$ MPa.

Reaction Progress



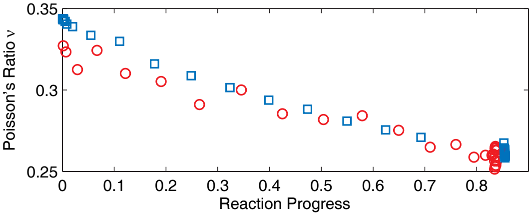
Reaction rate calculated from pore volumometry and compaction.

Dramatic Decrease



Decrease of both V_p and V_s. Increase post-reaction due to time dependent compaction at elevated P_c.

Poisson's Ratio



Poisson's ratio actually *decrease* ! $\longrightarrow$ gypsum is remplaced by a stiffer phase (bassanite).

Interpretation

Differential, Self-Consistent Effective Medium:

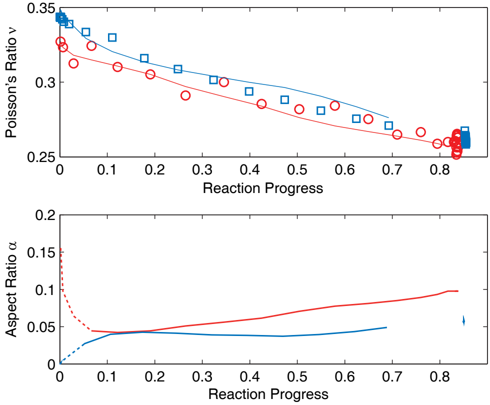
$$\begin{cases} \dfrac{1}{K}\dfrac{\mathrm{d}K}{\mathrm{d}\Phi} & = -(1-\zeta)P_\alpha(\nu,\zeta), \\ \dfrac{1}{G}\dfrac{\mathrm{d}G}{\mathrm{d}\Phi} & = -Q_\alpha(\nu,\zeta), \end{cases} \tag{1}$$

where

$$\zeta = \frac{K_f}{K}. \tag{2}$$

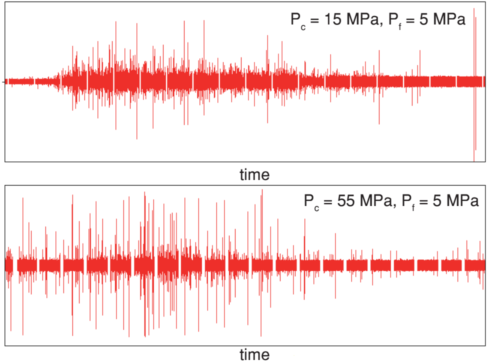
$\rightarrow$ Calculation of V_p, V_s as functions of porosity and pore aspect ratios (α). P_α, Q_α are complex functions of parameters.

Inversion Results



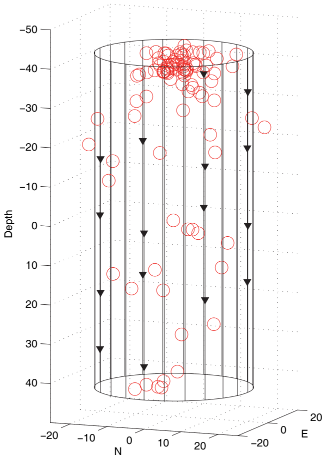
Fit with rather opened cracks, $\alpha \lesssim 0.1$.

Full Waveforms



Large number of AEs during the dehydration, nothing before, nothing after.

Locations



NB: Most AEs have implosive focal mechanisms.

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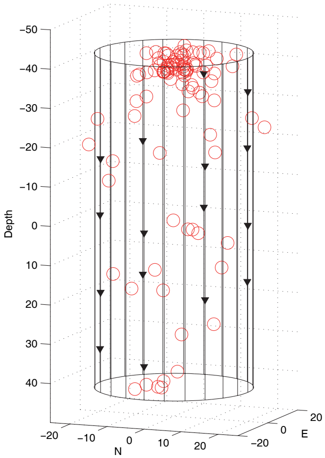

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What we learned

- Gypsum has an interesting semi-brittle behaviour: suitable for the B/D transition study in the lab.
- There are large AEs associated with a plasticity induced phenomenon (shear banding and kinks).
- Dehydration is characterized by an important compaction and strong velocity decreases.
- Poisson's ratio tends to *decrease* during dehydration.
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