Probing the micromechanics of small earthquakes
or: How hot do faults get?

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Annika Greve and Marcel Mizera have left the project
Work package 1: magnetism

- Paleomagnetic laboratory Fort Hoofddijk in final stage of renovation
- Strain partitioning – Papaku fault zone, IODP Hikurangi subduction margin, New Zealand
Anisotropy of magnetic susceptibility

Stage 1
Settlement and compaction

Stage 2
Tilting

Stage 3
Tectonic strain

Kmin: vertical
Kmin tilted: Kint-Kmax: girdle
Kmin, Kint, Kmax: well defined
Kmax: intersection lineation

Limit of detection AMS = 0.002, i.e. 1% anisotropy is easily detected
AMS interpretation Papaku fault zone

Hanging wall: NE-SW shortening

Overall anisotropy a few per cent, well measurable with AMS

Footwall: E-W shortening
Fluid motion in the Papaku fault zone

High NRM = more magnetic minerals

High $\chi$ = more magnetic minerals

High $B_c$, $B_{cr}$ = greigite ($Fe_3S_4$)

High ARM/IRM = more magnetite ($Fe_3O_4$)

High $SIRM/\chi$ = greigite
Background vs. ‘anomalous’ sediment

Pyrite (FeS₂) signature

‘Anomalous’ fault zone sediment

‘Base line’ sediment

Greigite (Fe₃S₄) signature

Greve et al., 2021, JGR
**Fluid motion scenario**

Hanging wall: folded, fractured, bedding parallel alignment of clay minerals

Main brittle fault zone
brecciated, fractured, ductile

Subsidiary fault zone
lower intensity, mostly ductile deformation

Lower ductile deformation zone
decreasing deformation

Footwall: mostly undeformed,
bedding parallel alignment of clay minerals

Anomaly ‘A’
ca. 304-312 mbsf

Anomaly ‘B’
ca. 334-351 mbsf
Frictional heating experiments

Goethite-bearing gouge from Yingxiu-Beichuan Fault
Magnetite produced due to frictional heating

~10-100 mg samples
Smaller and in situ?

Yang et al., 2019, JGR
Quantum Diamond Magnetometer (QDM) set up
Pilot Slochteren sandstone image (Harvard QDM)
Work package 2: frictional heating

Slip is localized in Principal Slip Zones (PSZ) in nature and experiments.

Width of PSZ and amount of localization important for heat and fluid budget during seismic slip.
Slip localization

**Three approaches so far:**

- Numerical modeling of fast slip using the Discrete Element Model method
- Experiments at low velocity with strain markers
- Experiments at high velocity at INGV – Rome – on hold for obvious reasons
3D numerical direct shear model

(a) Homogeneous model

(b) Fine-grained model

- Does slip localize in gouges with a homogeneously distributed grain size at seismic slip velocity? \(\rightarrow\) Homogeneous model
- If not, how much grain size reduction is required for slip localization? \(\rightarrow\) fine-grained model
- What is the physical mechanism for strain localization? \(\rightarrow\) 3D animations
- What parameters might influence localization of slip? \(\rightarrow\) Isolate material characteristic and vary its value

- Implement frictional heat at grain contacts and couple the pore fluid network to explore the effect of fluid on heat generation.
What parameters might influence localization of slip?

- Interparticle friction

- More localized slip for weaker faults =>

  Localized slip $\Rightarrow$ high temperature $\Rightarrow$ weakening

  $\downarrow$ more localization

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\begin{array}{c}
\mu = 0.1 \\
\mu = 0.5 \\
\mu = 0.75
\end{array}
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Sliding dominant

Rolling dominant

Hung et al., manuscript in preparation
Next steps

1. Quantify low velocity slip localization from strain marker experiments (movie below)

2. Implement contact heating in DEM + coupling to pore network model

3. Medium velocity experiments with IR temperature measurements

4. High velocity experiments at INGV Rome
Call for Papers

Induced seismicity - a global phenomenon with special relevance to the Dutch subsurface

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