Spatial organisation of deformation in sandstones: Controlling factors and impact on fluid flow

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What do (can) we know about fault zones at depth?

Host rock properties
- Faults cut known reflectors
- Tied to wells

Throw
- Fluid pressures
- Timing (depth of deformation)

Can these macroscopic (measureable) fault zone properties be used to make predictions about the small scale (grid block scale) flow properties of the faults?

Thanks to the Fault Analysis Group, Dublin
What are Deformation Bands?
Deformation features in high porosity sandstones

- Grow by addition of individual strands at DB edges
- **Evolution of single DBs** to DB zones and slip surfaces
- **Porosity and permeability decrease with respect to host rock**

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Fossen and Bale, 2007

Wibberley et al., 2007

Host rock - CDB

20 cm

2 mm
## Geological setting – Provence and Utah areas

<table>
<thead>
<tr>
<th>Location</th>
<th>Field Area</th>
<th>Geological Setting</th>
<th>Lithologie</th>
<th>Burial Depth</th>
<th>Max. Fault length</th>
<th>Max. offset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provence, France</td>
<td>Orange</td>
<td>Mezozoic cratonic basin. Three faulting phases related to Pyrenean shortening, Oligocene extension and Miocene strike-slip faulting.</td>
<td>Cenomanian soft sandstones</td>
<td>460 m (± 10m)</td>
<td>DB &gt;10m Faults 50m</td>
<td>DB 1m Faults 10m</td>
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<tr>
<td></td>
<td>Bédoin</td>
<td></td>
<td>Turonian sands</td>
<td>660m (± 80m)</td>
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<td>Massif d'Uchaux (Boncavaï quarry)</td>
<td></td>
<td>Cenomanian sands</td>
<td>560 m (± 180m)</td>
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<tr>
<td>Utah, USA</td>
<td>Big Hole fault</td>
<td>Fault related folding and uplift. Laramide Orogeny (90-37 Ma).</td>
<td>Navajo sandstones</td>
<td>1.5 to 3 km</td>
<td>Fault 4.1 km</td>
<td>Faults 29 m</td>
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</table>
Deformation maps in Utah sandstones
Deformation maps in Utah sandstones

Elodie Saillet: Deformation in High Porosity Sandstones
Deformation maps in Provence sands

Boncavaï normal fault

Boncavaï strike slip fault
Microstructural evolution

**Provence, late Cretaceous sands**

![Micrographs of Provence sandstones](image)

**Utah, Navajo sandstone**

![Micrographs of Utah sandstones](image)

DBs — Slip surfaces

Elodie Saillet: Deformation in High Porosity Sandstones
Microstructural – Evidence of grain fracturing

Provence, late Cretaceous sands

Utah, Navajo sandstones
Skeleton porosity values

**Provence, late Cretaceous sands**

- Host rock
- Bands
- Fault zones

**Utah, Navajo sandstones**

- Host rock
- Single bands
- Band clusters
- Fault zones

- Porosity (%)

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Elodie Saillot: Deformation in High Porosity Sandstones
Skeleton porosity values

**Provence, late Cretaceous sands**

**Utah, Navajo sandstones**

![Diagram showing porosity values for different rock types and fault zones.](image-url)
Gas permeability measurements
Data summary (with $P_C = 50$ MPa)

Khr: host rock sample
Kp: sampling $//\$ to the deformation direction
Kn: sampling $\perp\$ to the deformation direction

*Saillet and Wibberley, accepted, AAPG Bulletin*
Exploring k scenarios

A) sealed slip surfaces
Flow through fault core only at narrowest points

B) open slip surfaces
Flow where slip surfaces cross fault core

Does fault core thickness depend on macroscopic properties?
• Host rock
• Throw
• Burial history

(Lunn, Shipton & Bright 2008)
also levels off?
Provence, unlithified sands: Microstructure: dominated by crushing. DB porosity = 25-30%, SS porosity = 15%

Macrostructure: generally parallel strands, mean core width 90 (+?) cm

Utah, lithified sandstones: Microstructure: fracturing and crushing Pressure solution DB porosity = 10%
SS porosity < 1%

Macrostructure: anastomosing strands, mean core width 5-10 cm
Now lithified sands: *Microstructure:* dominated by crushing. DB porosity = 25-30%, SS porosity = 15%

*Macrostructure:* generally parallel strands, mean core width 90 (+?) cm

Utah, lithified sandstones:
*Microstructure:* fracturing and crushing
Pressure solution
DB porosity = 10%
SS porosity < 1%
*Macrostructure:* anastomosing strands, mean core width 5-10 cm

Fault interpretation by Alan Gibbs, 2008
From the Virtual Seismic Atlas
seismicatlas.org
Thank you!

Quarry of “Le Cros”, Bédoin...
In front of the “Mont Ventoux”... For people who like “Tour de France”!