The seismotectonic significance of the 2008-2010 seismic swarm in the Brabant Massif (Belgium)

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Seismic activity in Belgium

Seismic Activity 1970-2014

Aeromagnetic map of Belgium as background

Earthquake depth
- < 10 km
- 10-20 km
- >20 km

The Brabant Massif
Hainaut
Ardennes
Lower Rhine Embayment

Belgium

The Netherlands
France
Germany

Seismic Swarm

51.6°N
51.0°N
50.4°N
49.8°N
49.2°N

3°E
4.5°E
6°E
7.5°E
The 2008-2010 Walloon Brabant Seismic Swarm

Time History of Seismicity

- Cumulative number of events
- Frequency
- Magnitude $M_L$

Temporary network fully operational

△ Temporary network deployed during the seismic swarm

△ Permanent stations

Increasing epicentral distance

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The graph shows the cumulative number of seismic events over time, with a significant increase in activity starting in September 2008. The temporary seismic network was deployed during the swarm, and permanent stations are also indicated on the map.
The 2008-2010 Walloon Brabant Seismic Swarm

Aim of this study
- Seismotectonic significance of the seismic swarm?
- Link between local geology and the swarm?

Methodology
- Location improvement by cross-correlation
- Aeromagnetic filtering
Relocation by cross-correlation

- Waveform similarity of co-located events at local station OTT
- Improvement of P- & S-wave arrivals allow event location improvement

![Map with stations OT2, OT4, OT3, OTT, CT-St-E, CSE, OT1]

![Graphs showing clusters and cross-correlations]

Maximum correlation coefficient

![Heatmap showing correlation coefficients]

![Spectrogram of seismic events]

HypoDD

![Figure showing cross-correlations of events recorded at OTT]
After relocation:
- Improved epicentre and hypocentre distribution
- 1.5 km long, 5-7 km deep, NW-SE fault structure
- Absolute error of swarm location +/- 200m

Focal Mechanisms
- Of largest events only
- Consistent left-lateral strike-slip
- Regional stress tensor WNW-ESE

Van Noten et al. 2015. Tectonophysics
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Waveform comparison of the 2008-2010 swarm and a $M_L$ 4.0 event in epicenter area in 1953

Van Noten et al. 2015. Tectonophysics
Seismotectonic significance of the swarm?

- Arcuate shape of the Brabant Massif (BM)
- Pronounced NW-SE lineaments
- Low background seismicity in the BM, yet, few large $M_L > 4.5$ seismic events occurred in the BM
- 2008-2010 seismic swarm at southern border

Aeromagnetic map of Belgium - Geological Survey 1994

- Van Noten et al. 2015. Tectonophysics

B' B

Earthquake magnitude scale

- $M < 2$
- $2 < M < 3$
- $3 < M < 4$
- $M > 4$

Stratigraphic column

- Mousty 492 Ma
- 505 Ma

- >4500 m
- ~25 Ma

Cambrian

- Tubize 530 Ma
- 538 Ma

High magnetic
rock formation

Van Noten et al. 2015

Tectonophysics

Steep tectonic slate belt

Sintubin et al. 2009

Comptes Rendus Geoscience 341
Aeromagnetic analysis of epicenter area

- Total magnetic field RTP = influence of shallow + deep sources (deep + shallow)
- Aeromagnetic highs due to magnetized Lower Cambrian Tubize Formation
- Magnetic lows = slaty Lower Cambrian Mousty Formation

Total Field, reduced-to-pole assuming Earth’s local magnetic field 1/1/1994 (I=65.8, D = -2)
Matched bandpass filtering: methodology

Separating short-wavelength that originate from shallow depths from long-wavelength anomalies that generally originate at greater depths.

Jef Phillips 1997 (USGS)

1. Amplitude spectra along a profile
2. Calculation of frequency-amplitude spectra
3. Finding “natural” breaks that correspond to equivalent depths
4. Calculation of anomaly map through the inverse transform

= carefully chosen bandpass filter

<table>
<thead>
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<th>SW</th>
<th>NE</th>
<th>Filter 1</th>
<th>Filter 2</th>
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<tbody>
<tr>
<td>C</td>
<td>C'</td>
<td>P0</td>
<td>P0</td>
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<tr>
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</tr>
<tr>
<td>C</td>
<td>C'</td>
<td>P4</td>
<td>P4</td>
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</tbody>
</table>

- Filter 1
  - P4: 0.05 km, 0.045 km
  - P3: 0.20 km, 0.19 km
  - P2: 0.55 km, 0.47 km
  - P1: 2.14 km, 1.18 km
  - P0: 7.27 km, 4.55 km
Separating short-wavelength that originate from shallow depths from long-wavelength anomalies that generally originate at greater depths.

Jef Phillips 1997 (USGS)

SW Amplitude spectrum

1. Amplitude spectra along a profile
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Useful for seismology? Hell yeah!
Generate different aeromagnetic maps that represent sources near hypocenter depths.
Aeromagnetic bandpass filtering applied to epicentre area

By applying different filters, different “depth maps” can be made. The seismic swarm is limited in size and located in the poorly magnetic shaly Mousty Formation.
Seismotectonic significance of the swarm?

1. Magnetic filtering demonstrates that the fault is:
   • bordered by magnetic bodies with different orientations
   • bordered by rocks of different ‘stiffness’
   • limited in size

   = isolated structure in a shaly rock body

2. Limitation in size explains the restriction in seismicity

3. Orientation fits the NW-SE structural grain of the BM

4. This study shows the importance of inherited fault structures in an intraplate seismotectonic setting

5. Limited seismic hazard due to fault fragmentation

References