

Earthquake relocation in the Ardenne (Belgium): identification of active structures in intraplate context

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Abstract

Notable tectonic activity exists in the Belgian Ardenne and Eifel mountains in Germany. The strongest known seismic event in northwest Europe occurred in this area, near the Belgian city of Verviers, on 18 September 1692 with a magnitude estimated around 6 1/4 [1]. In the seismic hazards and risks perspectives, it is important to provide « scientifically supported » hypothesis on the possible seismogenic structure that generated the earthquake but also to realize an inventory of the sources of large earthquakes.

Therefore, we used present day seismic patterns to identify and characterize the active structures. The precise earthquakes relative locations obtained by relocating all events are evidencing some earthquake alignments and groupings.

We also carried out reconnaissance surveys in the area where a well-located seismic sequence occurred in 1989-1990. These surveys include different methods: ERT, GPR, H/V, relative gravity measurement, etc. The results are very promising in identifying the main geological structures that could be associated with the Hockay fault zone.

The 1692 Verviers earthquake

The knowledge of the 18 September 1692 September has greatly improved during the last ten years by the numerous new documents found in different record-offices in Belgium, Germany, The Netherlands and France. Alexandre et al. [1] propose a synthesis on the event with a new macroseismic map of the earthquake in terms of the EMS-98 macroseismic scale, from which a better epicenter location is suggested, within the area of Verviers-Soiron-Herve-Montzen.

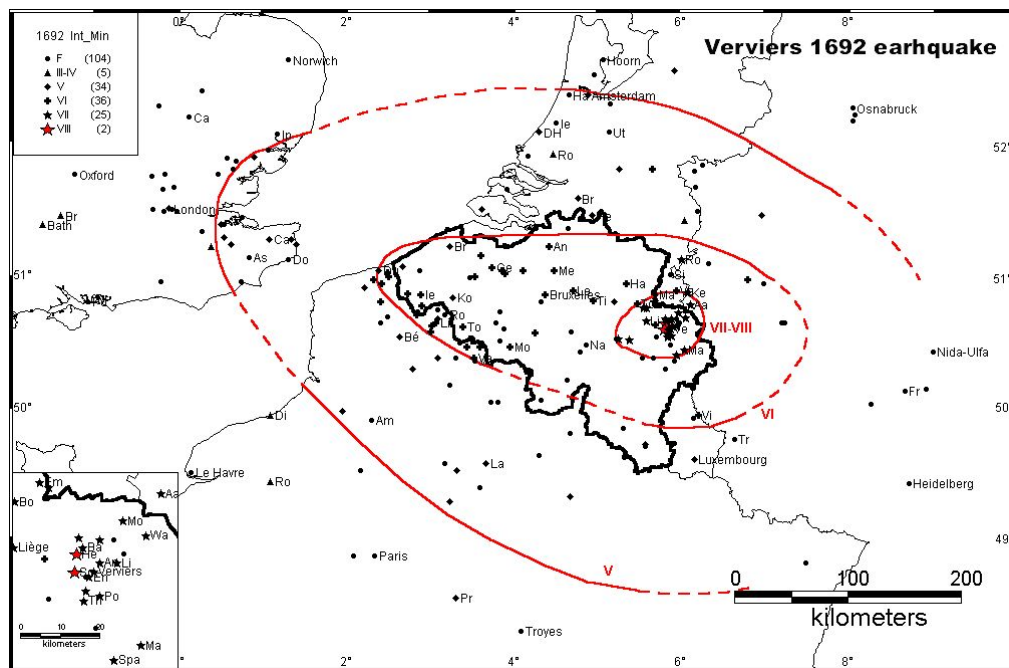


Figure 1 – The earthquake of 18 September 1692 – intensity information

In the epicentral area, substantial to heavy damage and sometimes complete destruction are described as a matter of fact for large buildings (castles and churches) and for houses. The ground shaking also appeared as violently felt by the people and it produced effects on the environment. From many sources reporting about the earthquake, it appears possible to classify the effects of the earthquake and to suggest ranges of intensity values on the EMS-98 macroseismic scale [2]. For the most affected villages, most of them in the Limburg Duchy, the descriptions mention that some number of houses was ruined with the consequence that inhabitants were injured or died. This is the case in Herve, Ensival, Soiron, Charneux, Waucumont-Battice, Walhorn. The terminology used in the sources suggests that some buildings suffered damage of grade 4 to 5 in the damage classification of the EMS-98 macroseismic scale [2]. An important

problem for a reliable assessment of intensity is the assessment of the vulnerability of the different types of constructions at the epoch of the earthquake. It is generally accepted that the vulnerability classes of traditional houses range from A to B. Considering that houses are of vulnerability class A, “few” damage of grade 4 means intensity VII, “few” damage of grade 5 corresponds to intensity VIII.

Using intensity geographical distribution, Alexandre et al. [1] estimate the magnitude as ranging between 6 and 6 ¼. Therefore, it is the largest known historic earthquake which occurred in Northwest Europe.

Seismic activity in the Ardenne-Eifel region

The recent seismic activity in the North of the Belgian Ardenne has its own characteristics compared to that in the neighbouring regions (Liège and Lower Rhine Embayment seismo-tectonics zone). From the analysis of fault-plane solutions, Camelbeeck [3] has shown that present tectonic deformation range from pure strike-slip to pure normal faulting. When it was possible to identify the fault plane from the two nodal planes of the mechanism, it generally strikes NNW-SSE and the strike-slip mechanisms are sinistral.

From September 30, 1989 till April 16, 1990 a seismic swarm occurred in the Hautes-Fagnes along the Hockai faulted zone, a morphological structure defined by Ahorner [4] from the alignment of previous seismic activity and described by Demoulin [5]. During that period 452 micro-earthquakes were recorded by a mobile seismic network of 4 stations and the permanent Belgian seismic network. Seven events had a magnitude greater than 2 over the whole period.

It has been possible to locate precisely 92 events of the sequence. The epicenters can be divided into two groups that limit a northern segment and a southern segment of an alignment of 12 km in a NNW-SSE direction. The southern segment is 1.7 km long. The northern segment (to the border of the Stavelot Massif) was active in the beginning of the sequence but most of the events could not be located with precision, because the local temporary network was not already installed. At the opposite, the location of the events in the southern segment is better fixed because it was possible to evaluate station corrections for P- and S-waves.

The precision of the earthquake location allow obtaining an image at depth of the fault zone having generated the swarm. The distribution of the hypocentres (figure 2) represents a fault plane with an azimuth of 330° and a dip of 70° to the east.

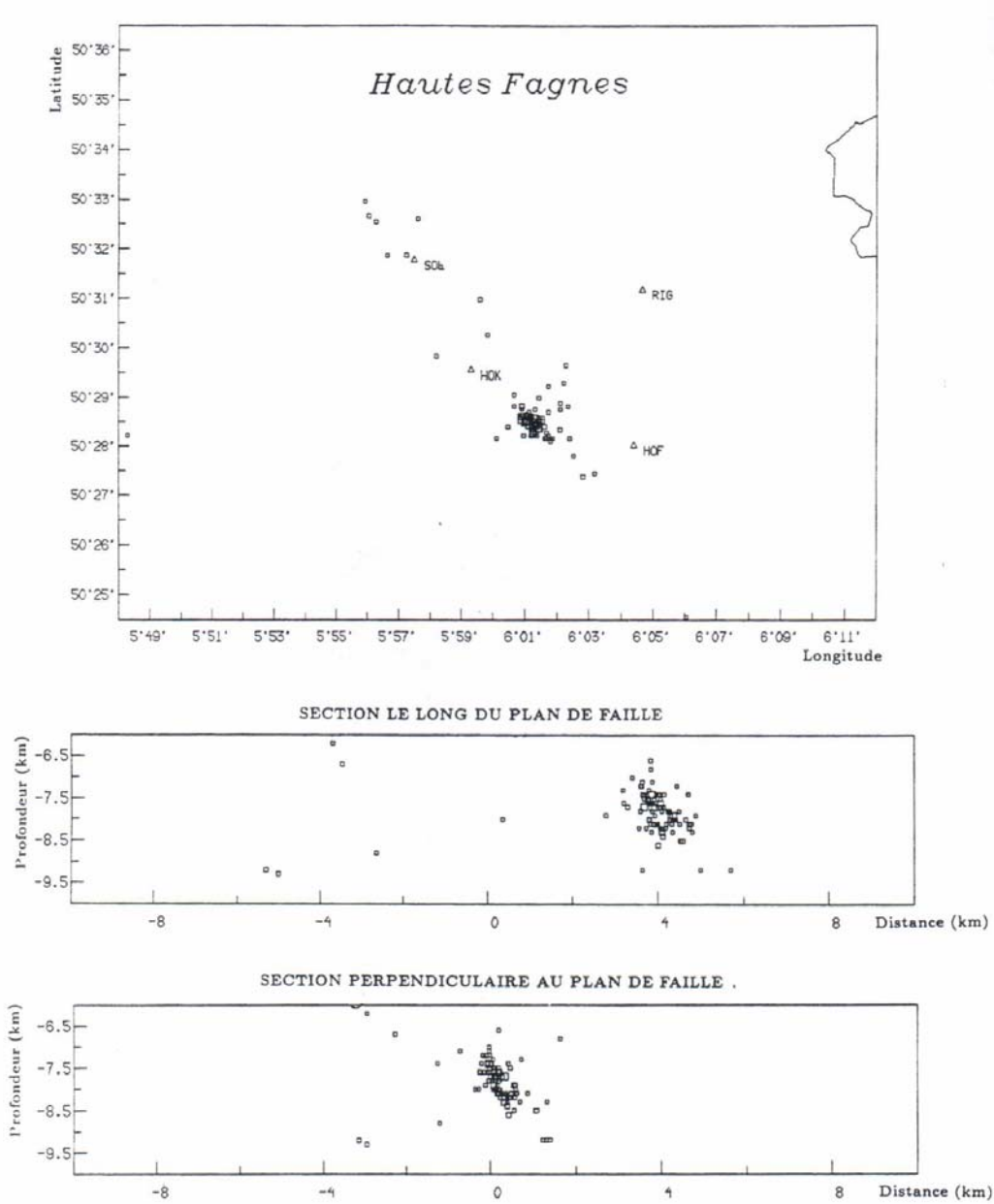


Figure 2: Hautes-Fagnes seismic sequence (1989-1990)-(up) Epicentre location; (center) Longitudinal cross-section along the fault; (down) Transversal cross-section perpendicular to the fault. From Camelbeeck [3].

The Hautes-Fagnes seismic sequence – geologic and geomorphic framework

Fault-plane solutions of the 1989-1990 earthquake sequence can be classified in three different groups [3]. Nevertheless, most of the earthquakes have a mechanism in good agreement with the fault geometry deduced from the repartition of the hypocentres. The fault plane corresponds to a fault azimuth of $346^{\circ} - 349^{\circ}$ and a dip of 70° to the east.

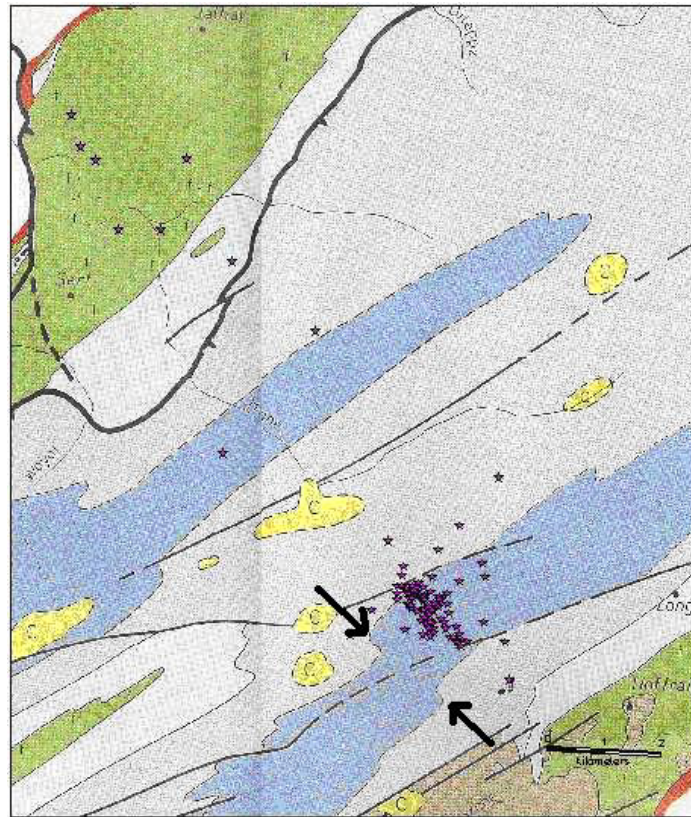


Figure 3: The seismic swarm (stars) plotted on a part of the geological map of the Stavelot Massif [6]. The arrows indicated a probable sinistral strike-slip fault which could correspond to the surface expression of the fault that generated the Hautes-Fagnes seismic swarm.

Therefore, fundamental information for the study of active faults in the region is that the transversal NNW-SSE faults and particularly the Hockai Fault, that crosscut the local geology in the Hautes-Fagnes and the Vesdre area, could still be

active. It is also interesting to compare (figure 3) the location of the earthquakes of the southern segment of the seismic swarm with the recent geological map of Geukens [6]. One kilometre to the west of the seismic swarm, the Cambrian formation of the Revinium 3-4 makes a bend to the northwest. It seems that this formation could be displaced by a sinistral transverse fault, although the probable fault is not mapped by Geukens. However such a fault is in good agreement with the observations of the focal mechanism of the seismic swarm.

Improved locations in the Ardenne-Eifel region

Identifying the seismogenic structures just by looking at the scattered regional seismicity (figure 4) is difficult and justifies the use of tools and techniques that improve the relative location between earthquakes. COMPLOC [7] is one of these relocation tools and has the advantage to propose the SSST method [8]. This “Source-Specific Station Terms calculation” allows the calculations to take the ray velocity heterogeneities in the crust into account.

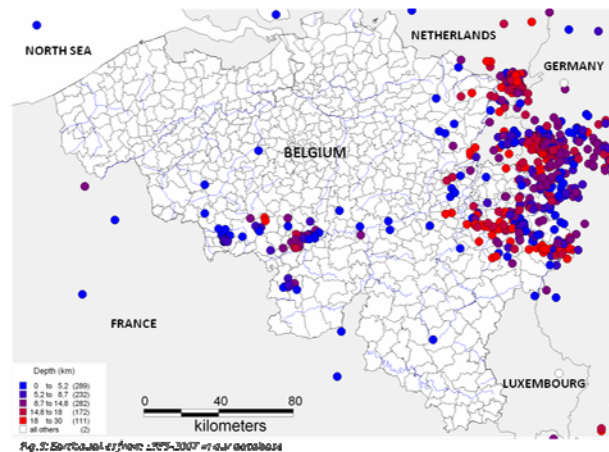


Figure 4: Belgian seismicity, 1985-2007, coloured by focal depth.

This tool has already proved its power in real cases, but generally on huge datasets (in California, e.g.). The Belgian dataset contains around 1000 events since 1985 (modern network). Despite this relative small amount of events, the result (figure 5) evidences some very interesting earthquakes alignments and groupings.

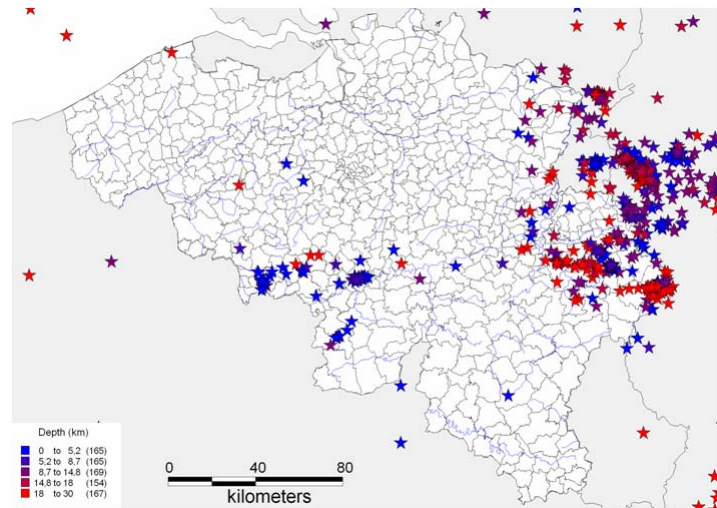


Figure 5: *COMPLOC* relocated Belgian seismicity, 1985-2007, coloured by focal depth

Amongst these, the alignment near Büllingen (figure 6 left), particularly well defined, and the Hockai Fault Zone (figure 6 right), underlined by the swarm in 1989-1990, will be investigated in order to try to identify surface evidences of the structures.

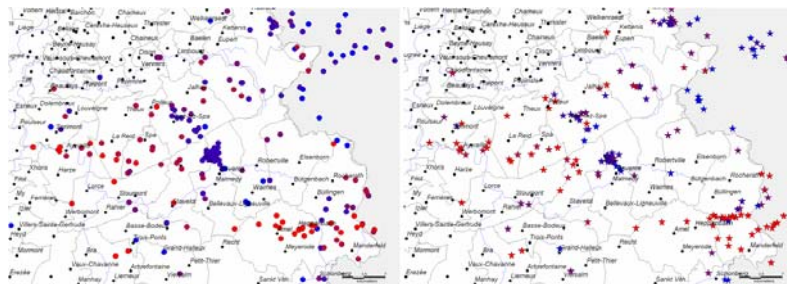


Figure 6: Close up on the Ardenne region. (left) Earthquakes in the Belgian catalog, (right) relocated earthquakes. The colour scale is shared with Figure 5.

Preliminary field investigations at La Vecquée

The “La Vecquée” crest, 2km West of the town of Hockai, is crossed by the Hockai Fault Zone and situated where the projection of the fault underlined by the 1989-1990 swarm is suspected to affect the surface. The multidisciplinary survey recently conducted includes ERT, GPR, H/V, relative gravity measurements, hand auger, etc. The analysis of this dataset is not yet finished, so we will only illustrate one example.

One long West-East ERT profile (figure 7) shows sharp lateral contrasts that could be interpreted as geological limits. These contrasts are in good agreement with the idea of NNW-SSE transverse faults crossing the profile. The first contrast on the left seems to vertically offset the average resistivity “layer” and could be interpreted as a normal fault. Now that these contrasts are identified, another field trip has to be planned to measure shorter profiles in order to improve the spatial resolution.

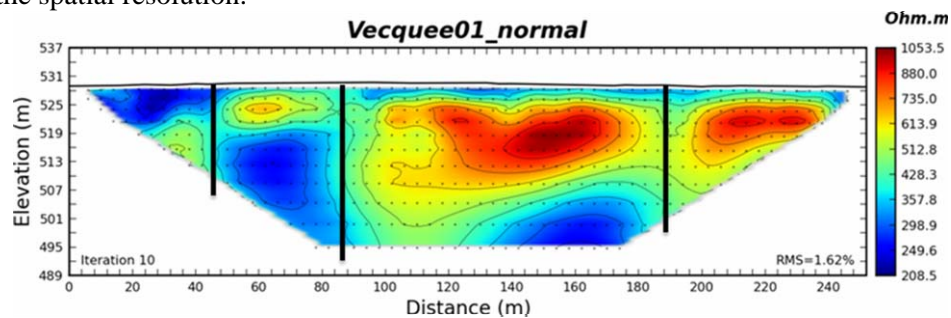


Figure 7: Long West-East ERT profile. The vertical black lines highlight the main contrasts.

Conclusion - discussion

The epicentral location of the 1692 earthquake is now well constrained near the city of Verviers, thanks to the numerous reliable records used to synthesize a new macroseismic map.

The relocation process has improved the relative location between earthquakes. In some regions, clear alignments can be seen. This is the case for the Hockai Fault Zone as well as for the area near the town of Büllingen.

The preliminary reconnaissance on the Vecquée crest has shown some interesting lateral contrasts that will need to be investigated more in detail. Anyway, these contrasts are in good agreement with the hypothesis of transverse faults in the HFZ.

Acknowledgements

Thomas Lecocq is bursar F.R.I.A.

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