PostMinQuake: Diagnosis of Post-Mining Induced Seismicity in Former European Hard Coal Basins

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Abstract

The PostMinQuake research project aims to identify mechanisms, relevant parameters and dependencies causing post-mining seismicity in several European hard coal regions. To better understand the processes that cause micro-seismicity in closed mines, it is necessary to study the geology, mining methods, post-mining situation, and monitoring of seismic activity and water table in the basin of interest. The mine of interest in Germany is Hamm, located in the Ruhr Basin, where mining ceased in 2010. Up to 60 events per year have been registered here, all with local magnitude below 2.5.

Keywords: Micro-Seismicity, Water Table, Post-Mining, Hard Coal

Introduction

Underground mining methods aim to extract minerals from the subsurface and they have an influence on the geological environment and on the use of the land surface. This influence is accentuated in coal and metal ores mines, since large quantities of rock are extracted and transported to the surface (Didier *et al*. 2008). When operating an underground coalmine, the water has to be pumped. When closing these mines, pumping of mine water resumes and the mine water raises, which allows water to flow into the mine workings and into altered or fissured areas (Wolkersdorfer 1996). Ground movements can be caused, amongst others, by hydrogeological and hydrological changes through water drainage and flooding (Busch *et al*. 2012). These ground movements that occur during mine water's rebound, which affect the stress field of the rock mass and can trigger interdependencies of the geomechanical properties, may cause damage to buildings and other infrastructures in the surface (Melchers *et al*. 2019).

The Research Fund for Coal and Steel (RFCS) has granted funding for the PostMinQuake project, for which several partners in Czech Republic, France, Germany and Poland gather information to better understand the processes that cause micro-seismicity in former hard coal regions.

In order to study the relation between water table and micro-seismicity, it is important to gather the following information in the basins of interest: geology, mining methods, monitoring protocols (seismicity and water level), and post-mining situation. Once this information is gathered, the analysis of the data starts to identify similar approaches and develop a synthesis of good practices, compulsory and desired improvements, and the elaboration of criteria of hazard rating. In Hamm, mining ceased in 2010 and the Seismological Observatory of Ruhr University Bochum monitors the seismic events in the area, while RAG Aktiengesellschaft does the same for the water level.

The goal of the project is to elaborate a final guideline to help the mining industry and decisionmaking bodies to manage the risks of post-mining micro seismicity, and it could be of interest in old petroleum reservoirs when converted to store H2 or when developing geothermal energy.

Geology and Mining in Hamm

Germany has had a long history of hard coal mining in basins as the Ruhr Area. The mine "Bergwerk Ost" (BW Ost) in Hamm closed

on 30 September 2010, although other mines continued the activity until the government agreed to put an end to hard coal production by the end of 2018 (Melchers *et al.* 2019).

The BW Ost was the result of merging the former mines Haus Aden (Oberaden), Heinrich Robert (Hamm) and Monopol (Bergkamen) in 1998, which covered an entire area of 285 km^2. It is located in the eastern part of the Ruhr Area.

The coal strata in the Ruhr Basin originated around 300 million years ago during the Carboniferous and consists of an alternating sequence of clay, silt and sandstones up to 2,500 m thick with embedded coal seams (Hahnhe & Schmidt 1982). Towards the end of the Carboniferous, the deposits were folded, broken and altered into numerous ditch and horst clods by mountain-building processes. The folded structure contains several saddles, which main axes' trend is southwest-northeast. Besides the transverse disturbance, further tectonic elements occurred. The Carboniferous surface observed in the south of the area at a height of approximately 100 m above sea level also emerged due to recent lifting processes in the south, around 2° to 3° to the northern limit of the lower part, located approximately 750 m above sea level (AMSL). The basement, made up of rocks from the Palaeozoic Era, was essentially formed during the Variscan orogeny formation in the Upper Carboniferous. The formations during this period formed through compressions in the earth's crust: the typical SW-NE stroking fold structure with high towering saddles and hollows, and a folding intensity that becomes weaker towards the northwest, shown in Figure 1.

Post-mining in Hamm

The Seismological Observatory of the Ruhr University Bochum (RUB) has a wide seismological network in the Ruhr area. The catalogue of seismic events complied by this seismological observatory during the last years of mining operation (between 2004 and 2010) in Hamm show a total of 3,770 earth tremors, of which 3,657 had a local magnitude $M_L < 2$.

Since the mine closed on 30 September 2010, there was a relative calm situation in terms of earth tremors (Busch *et al.* 2017), when only 204 events occurred between then and the end of 2021. Only 7 of these events had a local magnitude $M_L > 2$. All the events that occurred since the mine closed are shown in Figure 2. It can be observed that these events occurred within the mined area (delimited by the blue dashed line).

In Figure 3, it is shown how the water table rose between 2010 and 2021 and it can be observed how the rise speed increased on an average of 964% in the four water stations since the beginning of 2020 and the end of 2021.

The occurrence of seismic events increased at the beginning of 2020, as shown in Figure 4. When comparing the data from the last two figures, it can be observed that the fastest the water raised, the more seismic events were produced.

Conclusions

We could observe that the rise of the water level was more constant until beginning of 2020, when 130 seismic events with an average M_L of 1.36 occur during 9 years (i.e. 14 events

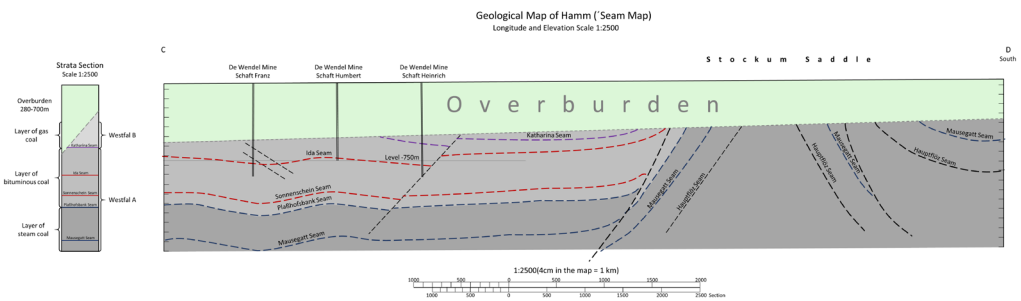

Figure 1 *Geological structure of Hamm (based on Busch et al. 2017)*

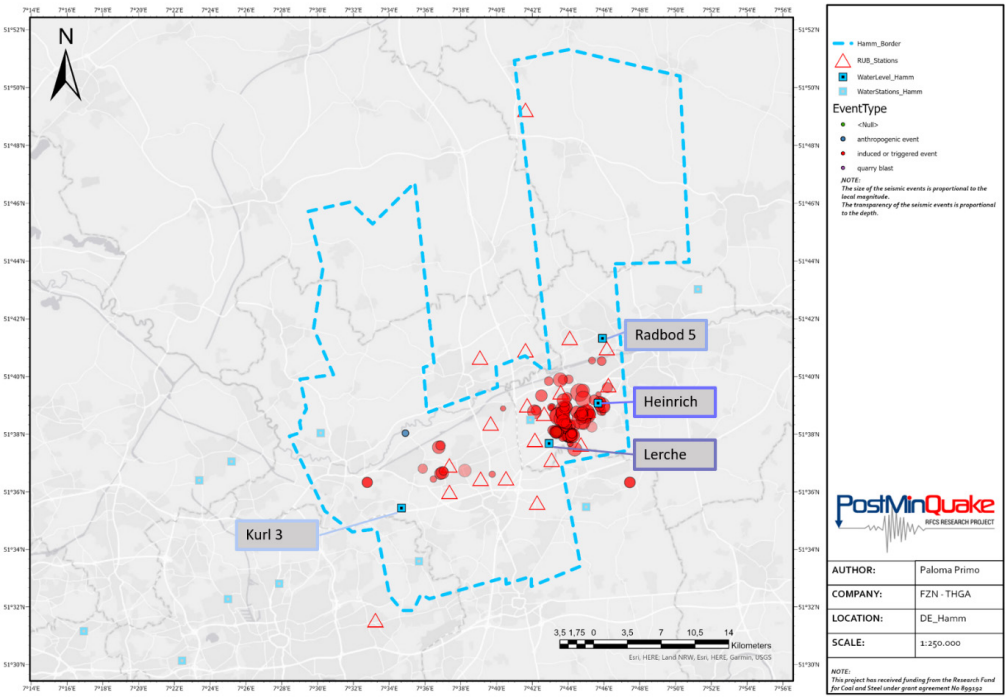

Figure 2 *Spatial distribution of post-mining seismicity in Hamm from 2010 to 2021. Circles denote earthquake epicentral locations (size proportional to the local magnitude); red triangles, the seismic stations; and blue squares, RAG's water stations (based on data from Seismologisches Observatorium der Ruhr Universität Bochum 2021; RAG Deutsche Steinkohle 2021)*

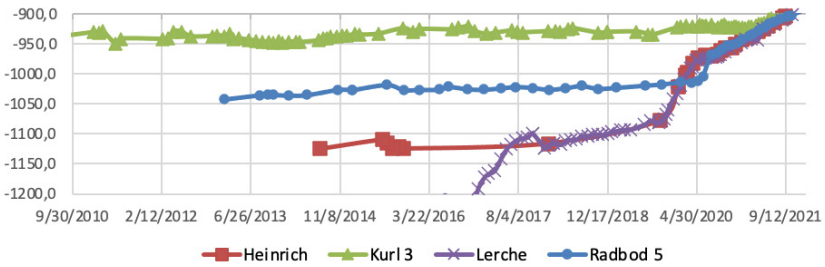

Figure 3 *Mine water table in water stations in Hamm (based on data from RAG Deutsche Steinkohle 2021)*

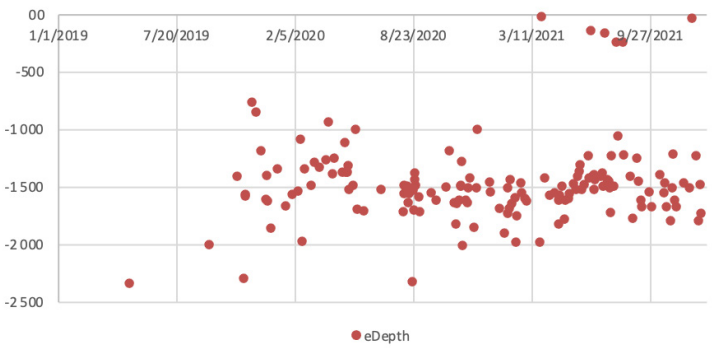

Figure 4 *Depth at which the seismic events occurred in Hamm between 2019 and 2021 (based on data from Seismologisches Observatorium der Ruhr Universität Bochum 2021)*

per year). Since 2020 until now, the rise speed per year of the water level increased on an average of 964%, and 119 seismic events with an average M_L of 1.31 occurred in the last two years (i.e. 60 events per year). Despite being early to withdraw any conclusion, it seems logical to say that there is a direct relation between the velocity at which the water raises in the former coalmine and the occurrence of induced seismic events.

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