Ground heave induced by mine water recovery

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M. Heitfeld, M. Mainz, M. Mühlenkamp, K. Schetelig
Ingenieurbüro Heitfeld – Schetelig, Aachen, Germany

H. Sahl
EBV Aktiengesellschaft, Aachen, Germany

ABSTRACT:
In some European countries many mines were closed in the last years. The resulting mine water recovery often takes decades and leads to more or less intensive ground heave movements.
This paper deals with the special problems of ground heave due to mine water recovery at the example of the mining district of Erkelenz. In this mining district, situated about 30 km northeast of Aachen, hard coal was extracted between 1914 and 1997 down to a depth of about -780 mNN (i.e. 780 m below the average sea level of Amsterdam).
Together with mining operations, the mine water drainage measures ceased, resulting in a continuous mine water recovery with mostly uniform heave movements. Since the rising mine water reached the overlaying sediments in the year 2000, an increasing number of surface damages were observed along a fault system (Rurrand-fault and Meinweg-fault) situated at the southwest margin of the Horst of Wassenberg. After a description of the geological-hydrogeological conditions within the mining district of Erkelenz, the performed investigations are presented and causes of the different ground heave movements are discussed.

1 INTRODUCTION

In some European countries, mining activity presently is decreasing significantly and mines are closing down. After cessation of mining operation, the drainage measures terminate and the former mine workings get flooded. This process often needs decades and in most cases it leads to some ground heave movements at banking level.

Ground heave hereby is caused by unloading due to uplift by rising mine water, possibly supported by additional effects due to swelling processes in rock and soil containing clay. Ground heave can be partly compensated by settlements caused by saturation of the loose rockmass overlaying the exploitation areas of the mine.

As long as the ground heave takes place evenly distributed, the impact on buildings is negligibly small. In some cases however, the heave movements are discontinuous, i.e. differential heaves occur within close ranges. Alike differential settlements, these differential heaves can damage surface structures severely.

After a description of the ground heave processes at the example of the abandoned hard coal mine area of Erkelenz in Germany, the other influencing factors are discussed.

2 ABANDONED HARD COAL MINING DISTRICT OF ERKELENZ (GERMANY)

The hard coal mining district of Erkelenz is situated about 30 km northeast of Aachen in the Lower Rhine Basin (Fig. 1). This area was mined since the year 1914. The hard coal extraction ceased with the closure of the last mine Sophia-Jacoba in December 1997. After cessation of mine drainage, the rise of mine water took place within the complete former mining area on a widely uniform level (Heitfeld et. al. 2004).

During the year 2000, the mine water level reached the overlaying sediments. Simultaneously a "damage line" originated running approximately parallel to the Rurrand-fault system (Fig. 2). This damage line has a length of about 10-12 km and shows differential heaves of up to 8 cm within a range of less than 10 m.

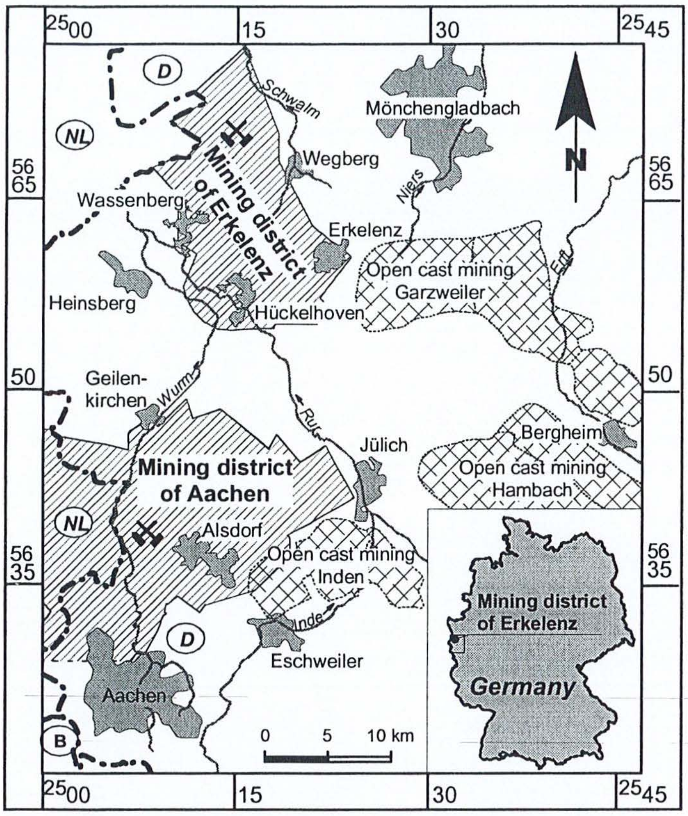

Figure 1. Hard coal mining district of Erkelenz. Situation.

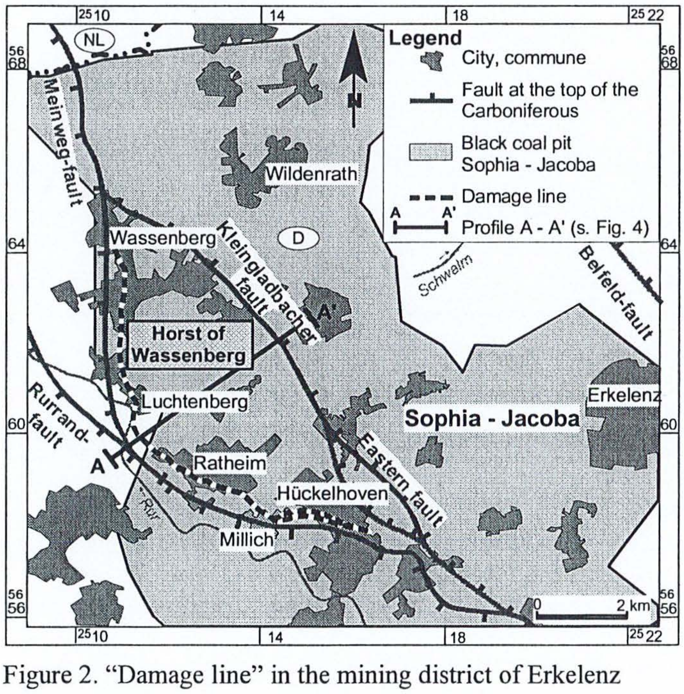

Figure 2. “Damage line” in the mining district of Erkelenz

3 GEOLOGY

The mining district of Erkelenz is a part of the NW-SE striking “Horst of Erkelenz”, composed of Carboniferous and younger sediments and situated within the Lower Rhine Basin. This basin originated in Eocene age and is filled by Upper Cretaceous, Tertiary and some Quaternary sediments.

The part of the Horst of Erkelenz with the most significant uplift is the “Horst of Wassenberg” located at the SW-margin (see Fig. 3). The NW-SE striking Horst of Wassenberg has got a length of about 10 km and a width of about 4 km.

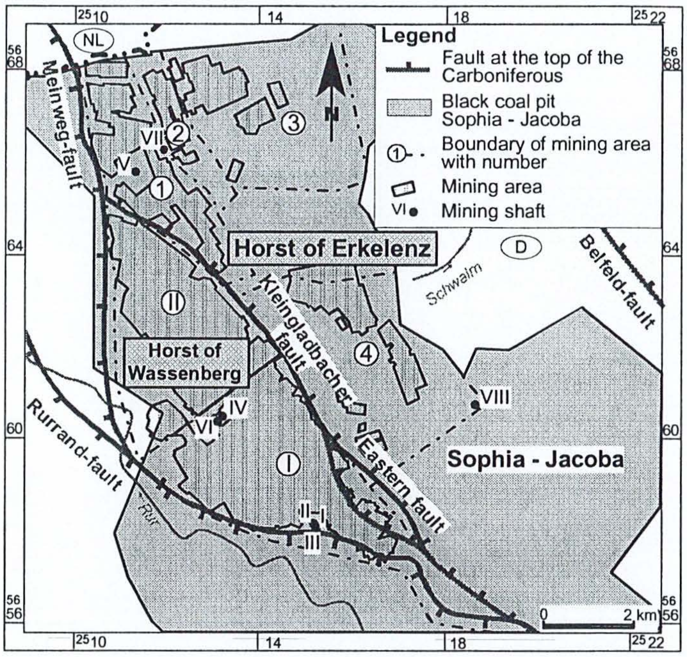

Figure 3: Tectonic setting and exploitation areas of the hard coal mining district of Erkelenz

In the Southwest, this structure is marked-off by the Rurrand-fault system and in the West by the Meinweg-fault. These fault systems dip into southwestern or western direction and along them the Carboniferous sediments have sunken up to 1000 m (see Fig. 4).

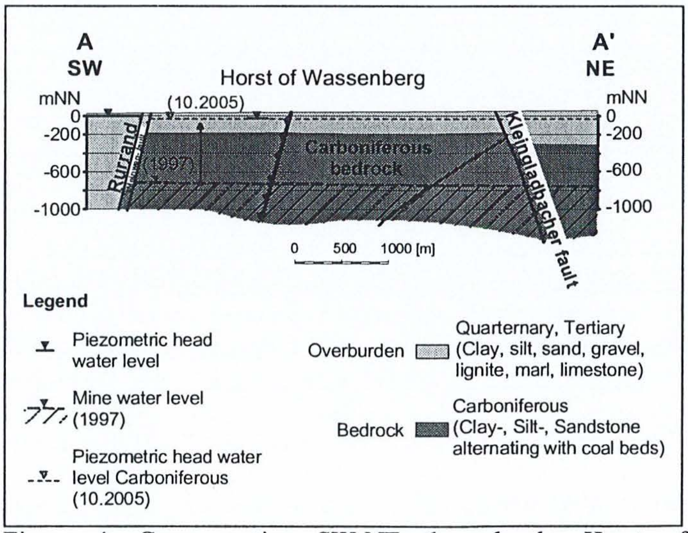

Figure 4. Cross section SW-NE through the Horst of Wassenberg

The Rurrand-fault system is one of some major NW-SE-striking fault systems intersecting the Lower Rhine Basin and well investigated by the exploration for the adjacent large open cast lignite mines of Hambach and Garzweiler (see Fig. 1). In the Northeast, the Horst of Wassenberg is confined by the Kleingladbacher fault and the Eastern fault. Along these fault systems, the Carboniferous sediments moved downwards up to 150 m.

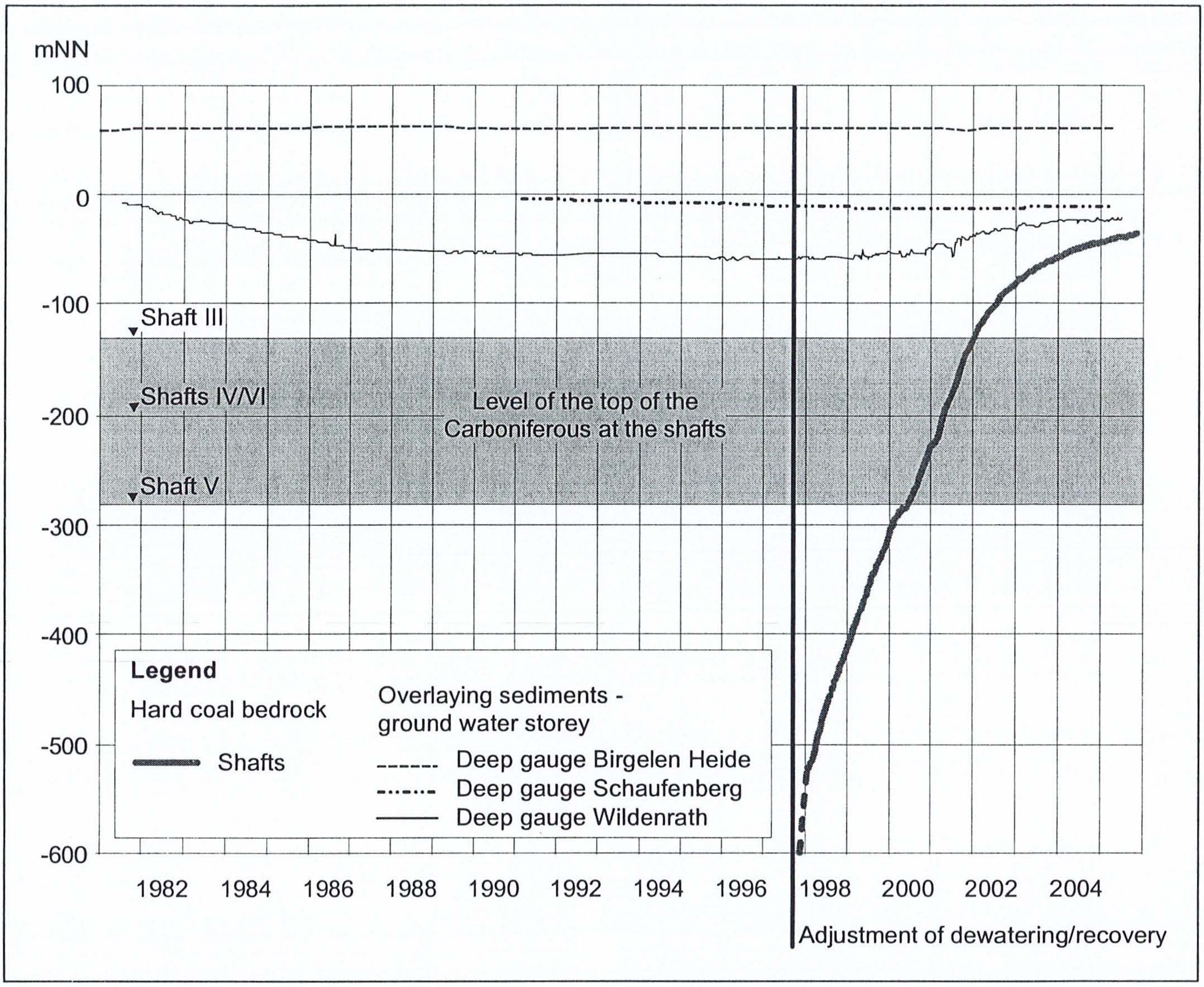

Figure. 5: Rise of mine water level. Gauges in the aquifer overlaying the top of the Carboniferous bedrock

The folded Carboniferous bedrock, containing the hard coal, is covered by sandy and silty limy sediments from Upper Cretaceous to Quaternary age of about 150 m thickness in the southern part of the Horst of Wassenberg and up to 350 m thickness in the Northwest.

In the overlaying sediments, a few groundwater storeys exist. The groundwater storeys 01 and 02 are the deepest ones, situated directly above the Carboniferous bedrock. The overlaying groundwater storeys are separated by some Tertiary clayey sediments, the Ratinger beds.

4 MINING ACTIVITY

The first mining activity within the district of Erkelenz started in 1914 in the mine Sophia-Jacoba in the southeastern part of the Horst of Wassenberg (see Fig. 3, mining area I). Since 1946, hard coal also was extracted in the nortwestern part (mining area II). In the area of the Horst of Wassenberg, mining activities reached down to a depth of about -750 mNN. In these areas, mining ceased in 1980.

Northeastern and eastern of the Horst of Wassenberg, mining activities commenced in 1978 within the mining areas 1 to 4. In these areas, exploitation took place in depth of about -300 to -780 mNN. The last mines were closed in 1997.

5 MINE WATER RECOVERY AND HYDROGEOLOGICAL SITUATION

5.1 *Rise of mine water level*

After the dewatering in the mine Sophia-Jacoba had stopped in 1997, mine water recovery started with a rapid rise of about 100 m/year until 2001. During this period, a mine water level of -150 mNN was reached (see Fig. 5). The mine water rose rather uniformly throughout the whole Carboniferous mining district of Erkelenz.

In the year 2000, the mine water reached the overlaying sediments in the northern part of the Horst of Wassenberg. At the end of the year 2001, the complete Carboniferous bedrock on the Horst of Wassenberg was filled with groundwater (see shaft III in Fig. 5). Since then, the rise of the mine water level is significantly slower. The actual rate is in an order of magnitude of about 8 m/year.

At the end of 2005, the mine water level in the Horst of Wassenberg reached about -35 mNN. Considering the deepest water level during mining operation of about -780 mNN, the total rise of the mine water level adds up to 745 m.

5.2 *Consequences of the mine water recovery for the groundwater situation in the overlaying sediments*

Before the dewatering procedures associated with the exploitation of hard coal started, the natural groundwater level in the overlaying sediments was recorded at about 50 to 60 mNN.

The dewatering of the mine Sophia-Jacoba caused a continuous lowering of the lower groundwater level in the overlaying sediments. This effect was recorded in the gauges of the lower groundwater storey 01. Fig. 5 shows two examples of groundwater level changes within the Horst of Wassenberg (gauge Schaufenberg) and in the area northeast of the Horst of Wassenberg (gauge Wildenrath). In the upper groundwater storeys of the overlaying sediments, no influence of the dewatering was detected (gauge Birgelen Heide).

The changes of the groundwater level show differences between single gauges depending on the geological situation (e.g. faults, nonexisting clayey beds). At the Horst of Wassenberg, the groundwater level was dropping down to -11 to -12 mNN in 1999/2000 (see Fig. 5, gauge Schaufenberg). Northeast of the Horst of Wassenberg, the groundwater level reached -60 mNN (see Fig. 5, gauge Wildenrath).

Due to the cessation of dewatering, the mine water in the Horst of Wassenberg reaches the overlaying sediments since about the year 2000. Records show rising groundwater in gauges within the lower groundwater storeys. The rate of the groundwater recovery currently is about 1.5 m/year.

The upper groundwater horizons in the overlaying sediments were not affected by the rising mine water level up to now.

Southwest the Horst of Wassenberg, no rise of groundwater levels occurred after the cessation of dewatering in the mine Sophia-Jacoba. This means, that the Rurrand-fault and the Meinweg-fault seem to act as a hydraulic barrier between the Horst of Wassenberg and the southwestern and western area.

5.3 *Influence of the open cast lignite mines in the vicinity of the mining district of Erkelenz*

In the area southwest and northeast of the Horst of Wassenberg, a continuous lowering of the groundwater level in the overlaying sediments takes place due to the mine drainage of adjacent open cast lignite mines in the southeast (e.g. Hambach and Garzweiler, see Fig. 1).

Several groundwater storeys in the overlaying sediments are affected by this dewatering; the lowering of the groundwater level reaches a maximum of about 50 m southwest of the Horst of Wassenberg.

6 GROUND HEAVE

Geodetic monitoring systems were installed within the mining district of Erkelenz, controlling ground heave as well as displacements of the ground level caused by dewatering measures for the adjacent open cast lignite mines Hambach and Garzweiler (also see Fig. 1). During the hard coal extraction in the period 1953-1997, the documentation of ground subsidence was the main goal of the geodetic measurements. In the northeastern part of the Horst of Wassenberg, subsidences of up to 4 m were recorded (see Fig. 6).

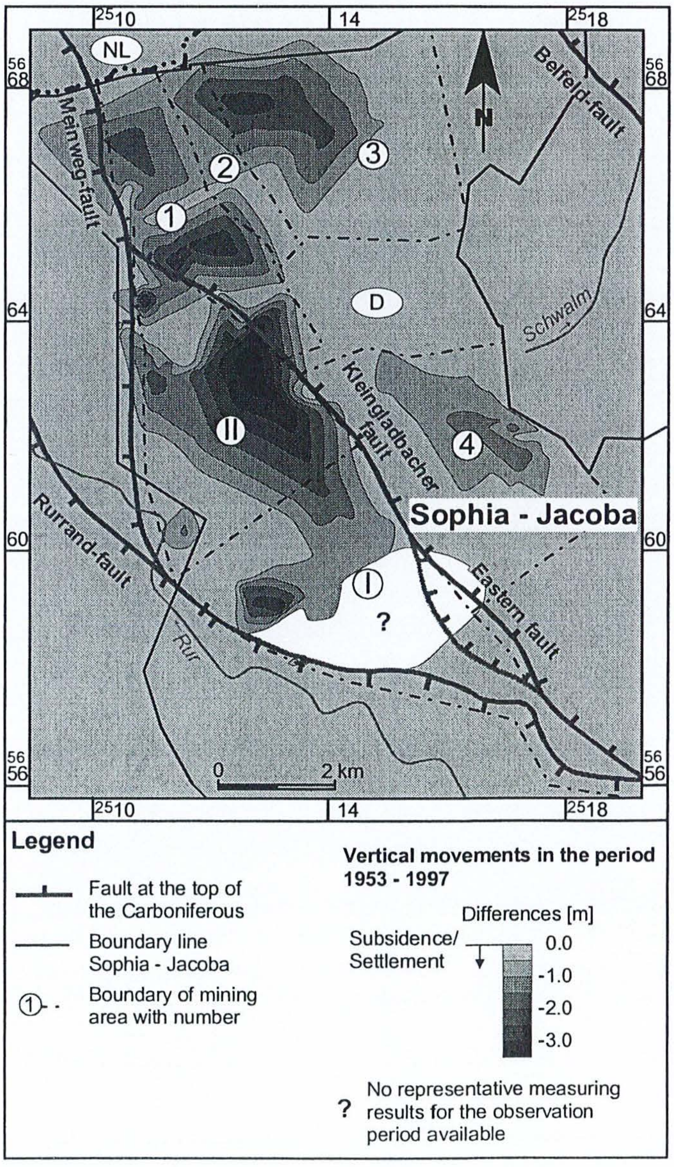

Figure 6. Ground subsidence within the mining area of Sophia-Jacoba. Hard coal exploitation period 1953-1997

During the same period, the settlements caused by dewatering for the lignite mines reached a magnitude in a range of about 10 cm in the area around the Horst of Wassenberg.

After cessation of pumping in the hard coal mining area of the Horst of Wassenberg, ground heave up to a maximum of 15 cm was recorded (see Fig. 7). The maximum rates of 1-4 cm per year were detected in the area of the Horst of Wassenberg and around the mining areas northeast of the Kleingladbacher fault.

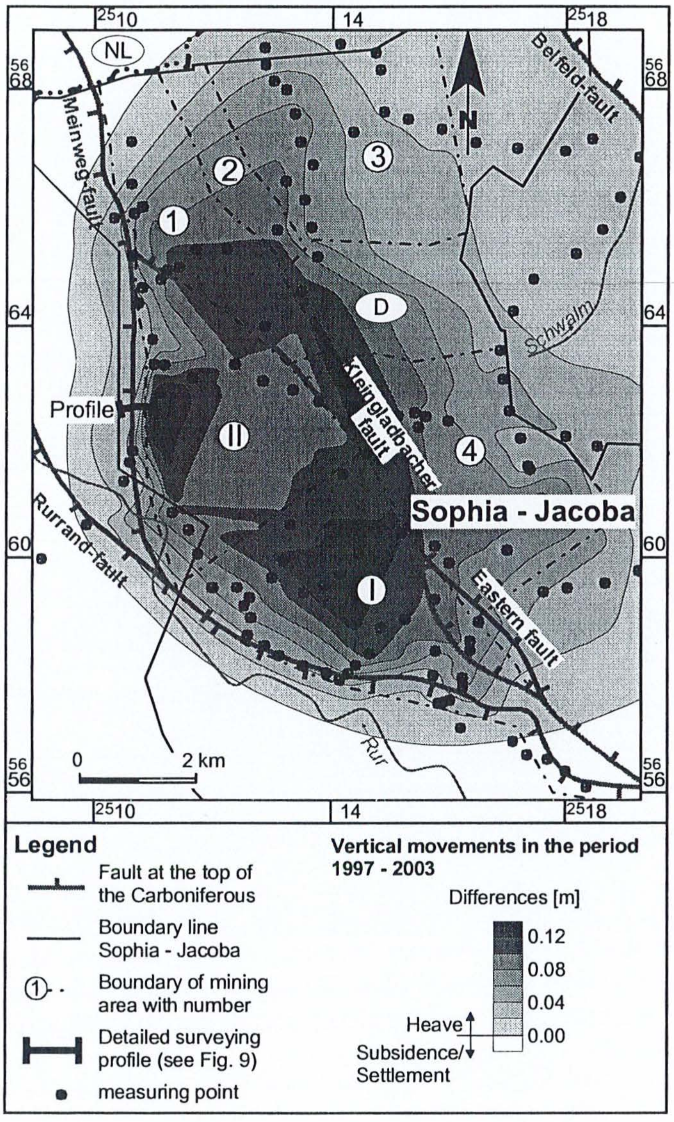

Figure 7. Ground heave within the mining area of Erkelenz after the cessation of hard coal mining (period 1997 - 2003)

During the mine water rise within the Carboniferous bedrock, the rather uniform ground heave of around 1-2 cm mentioned above took place; in the main areas of heave around Ratheim, Wassenberg and Wildenrath, a maximum heave of up to 7 cm was observed. In these main areas of heave, there was a maximum uplift rate of 1-2 cm per year. Until the year 2000, no damages at buildings occurred.

This has changed since the mine water has reached the top of the bedrock. After the year 2000, the ground water level in the overlaying sediments started to rise as well. In the period between 2001 and 2003, a maximum heave of 3-4 cm per year was recorded. In the main part of the Horst of Wassenberg, the continuing ground heave process reached its maximum. In the eastern and southeastern direction, the rate of ground heave decreases continuously (see Fig. 7); beyond a distance of about 5 km from the former mining areas, no uplift was recorded.

At the southwest margin of the Horst of Wassenberg, close to the Rurrand-fault and the Meinweg-fault, there is a different development in ground movements. In this place, significant differential heaves occurred within a very small range, depicted by the closely spaced surface contourlines in Fig. 7.

In these areas, the formerly described "damage line" developed (see Fig. 2). The first damages at buildings, caused by differential heave of the ground, occurred in the year 2000, contemporaneous with the mine water reaching the younger sediments overlaying the Carboniferous bedrock at this place. Up to present, 120 objects were affected by ground heave. Nine buildings could not be repaired and had to be torn down. One of these buildings that was damaged too severely to be rebuilt, is shown in Fig. 8. The back of the building is based on ground which was more affected by ground heave than the front side.

Figure 8. Building that had to be torn down because of the damages caused by ground heave

After the occurrence of the first damages due to ground heave, a detailed geodetic monitoring system with a spacing down to less than 5 m vertical to the damage line was installed in the centre line of the damages. Fig. 9 shows a typical example of the results. A very sharp displacement line with differences in ground movements of up to 8 cm could be determined.

On the Horst of Wassenberg, ground heave still is progressing, although at smaller rates. Southwest of the damage line, i.e. beyond the Meinweg-fault and in the main Tertiary basin, also a slight ground heave takes place up to a distance of 400-800 m from the fault. As shown in Fig. 9, there were ground heaves of about 2 cm between 2001 and 2004 in a distance of about 450 m west of the damage line.

At greater distances, no ground heaves take place. In these areas, the subsidences due to dewatering for the lignite mines prevail. Between 1997 and 2003, subsidences in a range of about 1.5 cm were recorded.

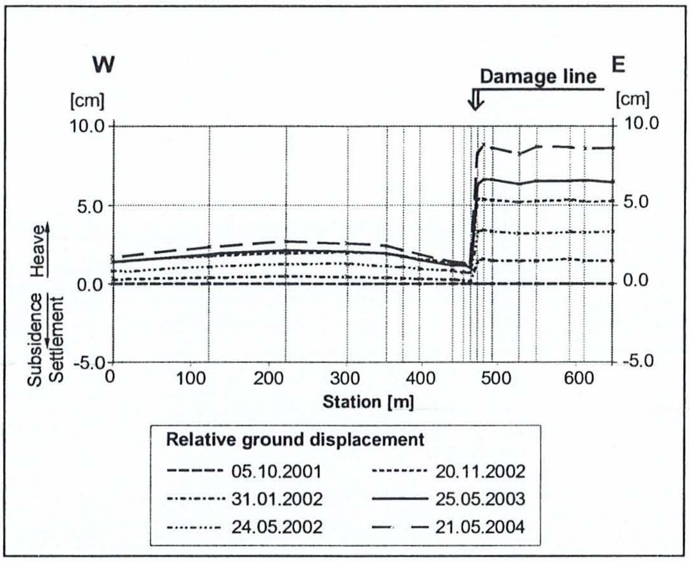

Figure 9. Detailed geodetic measurements across the damage line, Horst of Wassenberg

The described example shows, that under specific geological conditions the impact of mine drainage measures and the subsequent cessation of pumping does not only affect the hydrological situation, but also ground movements can occur and the question of reimbursement of damages can arise. Such damages from heave are not limited to the areas where surface damages occurred during the hard coal extraction. In the present case, extractors of the groundwater and the hard coal are involved.

In the literature, ground heave after cessation of water abstraction also is described by Poettgens (1998) and Goerke-Mallet (2000). Both authors assume ground heave after mine water recovery to be mainly caused by the reduction of vertical stresses through buoyancy resulting in vertical strain.

7 PROPOSALS FOR RESEARCH PROJECTS

Under which geological and hydrogeological conditions can differential ground heave movements occur?

The Rurrand-fault system is an active tectonic fault and the epicentres of some earthquakes were recorded along this fault and along similar tectonic structures of the Lower Rhine Basin. The tectonic faults mostly are filled with clayey material and form a hydraulic barrier between the adjacent aquifers or hydrological provinces. Do such hydraulically effective faults cause the development of sharp displacement lines?

What are the mechanisms of the ground heave of the formations southwest of the Rurrand-fault and Meinweg-fault along a strip of 400-800 m immediately parallel to the fault? Are there some kind of tractive forces effective?

Do other influencing parameters exist which can affect the degree of ground subsidences or ground heave? In the present case, the described phenomena are not influenced by any swelling effects of expansive clay minerals in the Carboniferous bedrock as assumed for another ground heave case study described by Oberste-Brink (1940). Is it possible, that swelling processes of clay minerals in the overlaying sediments are playing a major role in the development of the occurred ground heaves?

Soft silty and clayey soils or beds containing organic matter can lead to significant ground subsidence after lowering the groundwater level. These displacements may be irreversible and may lead to uneven morphology after cessation of the groundwater abstraction.

From dam construction works, the phenomenon of ground settlements due to saturation is well known (Brauns et al. 1980, Breth 1972). It has to be investigated, whether such processes also can take place in the disintegrated bedrock of mining areas.

A specific research proposal has been submitted to funding agencies. Such fundamental research will be helpful in view of further closures of mines in Europe and overseas. It also would be helpful to be able to predict possible future damage zones and to develop recommendations for urban und rural planning in possibly affected regions.

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