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Abstract

Hydrogeological aspects of fault zones on various scales in the Roer Valley Rift System

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Abstract

The impact of faults on the groundwater flow system in the Roer Valley Rift System (RVRS) is demonstrated with examples from outcrop scale to regional scale. Faults in the RVRS can form strong barriers to horizontal groundwater flow as well as enhanced vertical groundwater flow paths at the same location. The strongly anisotropic hydraulic conductivity distribution within fault zones has important implications for the modeling of groundwater flow in sedimentary aquifer systems that are cut by faults. In this study, the hydraulic behavior of fault zones is studied at different scales. An outcrop study over the Geleen Fault zone shows deformation mechanisms as particulate flow and clay smearing in great detail. Qualitative and quantitative image analysis allows for an estimate of the micro-scale variation of the hydraulic properties within a fault zone. Additional core-plug measurements indicate that the damage zone around fault zones may form preferential flow paths. On a larger scale, observations over the Peel Boundary fault near the village of Uden also indicate that vertical groundwater flow close to the fault is enhanced, which results in a discharge of the underlying aquifers at the location of the fault zone. Finally, on a regional scale, hydraulic head patterns around the lignite mining areas in Germany show the importance of faults and the variation of their hydraulic properties to regional groundwater flow patterns.

Keywords: Faults; Groundwater flow; Unconsolidated sediments; The Netherlands

1. Introduction

Numerous studies carried out by the oil-industry show that faults exert an important impact on the regional system of fluid flow in sedimentary basins (e.g. England et al., 1987; Knipe, 1997). Surprisingly, there has been far less attention to the impact of faults on groundwater flow at more shallow levels, although data are often more abundant compared to oil-related studies. The present study is focused on the impact of faults on the groundwater flow regime in the Roer Valley Rift System (RVRS) in the southeastern Netherlands and adjacent areas in Germany and Belgium (Fig. 1). Water-supply companies in the southeastern part of the Netherlands rely on groundwater stored in a system of aquifers comprised of by fluvial and marine sediments of Quaternary and Tertiary age. These unconsolidated sediments are cut by active normal faults, of which the most important are the Peel Boundary Fault zone and the Feldbiss Fault zone which bound the RVRS. From the few earlier studies in this area, it is known that these faults have an important impact on groundwater flow (e.g. Ernst and De Ridder, 1960; Stuurman and Atari, 1997). There-

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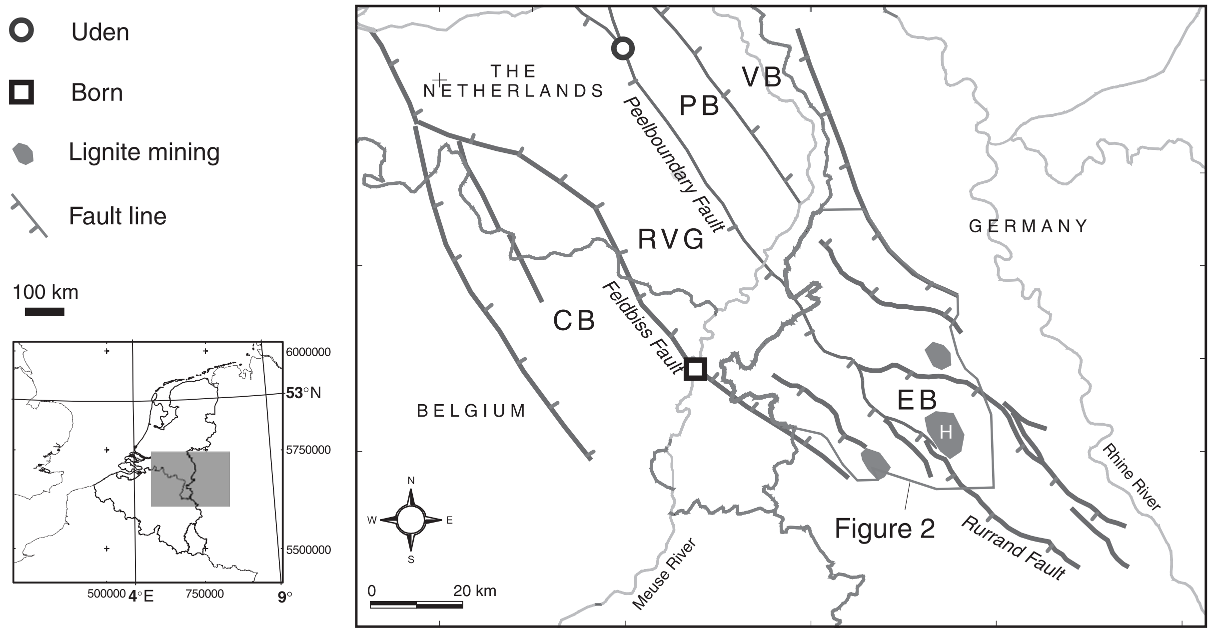

Fig. 1. A mapview of the Roer Valley Rift System (RVRS) with locations of sites that are discussed. RVG = Roer Valley Graben, VB = Venlo Block, PB = Peel Block, CB = Campine Block, EB = Erft Block.

fore, a better understanding of the relation between the presence of faults and anomalous groundwater flow patterns is essential. In this study, examples from the RVRS on several scales show a variety of hydrogeological aspects of faults.

2. Examples

2.1. The hydraulic properties of a fault zone on the outcrop scale

In outcrop, the distribution of hydraulic conductivity in the damage zone that has formed around the main fault plane shows in detail the impact of tectonic deformation on the hydrogeologic structure of the fault zone. Mechanisms like clay smearing and particulate flow are important because they alter the hydraulic characteristics of the fault zone. These mechanisms can be studied on micro-scale using qualitative image analysis techniques applied on thin-sections that are obtained from box-core samples. Quantitative image analysis on these thin-sections allows for an estimate of the distribution of hydraulic conductivity within the box-core by application of the well-known Kozeny–Carman relationship. In addition, core-plug samples, on which hydraulic conductivity is measured in the laboratory, can be used to visualize the distribution of hydraulic conductivity on a meter scale. We obtained data in a trenched outcrop over the Geleen Fault zone that is part of the Feldbiss Fault zone near the village of Born (Fig. 1). Results based on these techniques indicate that damage zones around faults in unconsolidated sediments can act as paths of preferential vertical groundwater flow (Bense et al., in press).

2.2. Groundwater flow over the Peel Boundary Fault near the village of Uden

At a location over the Peel Boundary Fault near the village of Uden (Fig. 1), the fault zone acts as a barrier to horizontal groundwater flow while vertical groundwater flow along the fault takes place between otherwise hydraulically separated aquifers. Here, the Peel Boundary Fault forms the boundary between the Peel Block and the Roer Valley Graben. It is visible as a ~ 3-m-high topographic scarp in the landscape. On the topographically higher Peel Block, groundwater levels are close to the surface as a result of the strong resistance to horizontal groundwater flow of the Peel Boundary Fault. The hydraulic head difference over the Peel Boundary Fault at this location is about 4 m over a distance of only 5 m. Vertical hydraulic head gradients indicate that, potentially, at the higher Peel Block, seepage is occurring while in the lower Roer Valley Graben, an infiltration potential is indicated by piezometric levels. Measurement of shallow groundwater temperatures in horizontal profiles perpendicular to the Peel Boundary Fault shows that seepage on the Peel Block close to the fault scarp occurs in discrete zones that may be associated with structural heterogeneities, like, for example, secondary splay faults that are visible on aerial photographs. An analysis of the ratios of the hydraulic gradients over the fault and the two adjacent tectonic blocks also

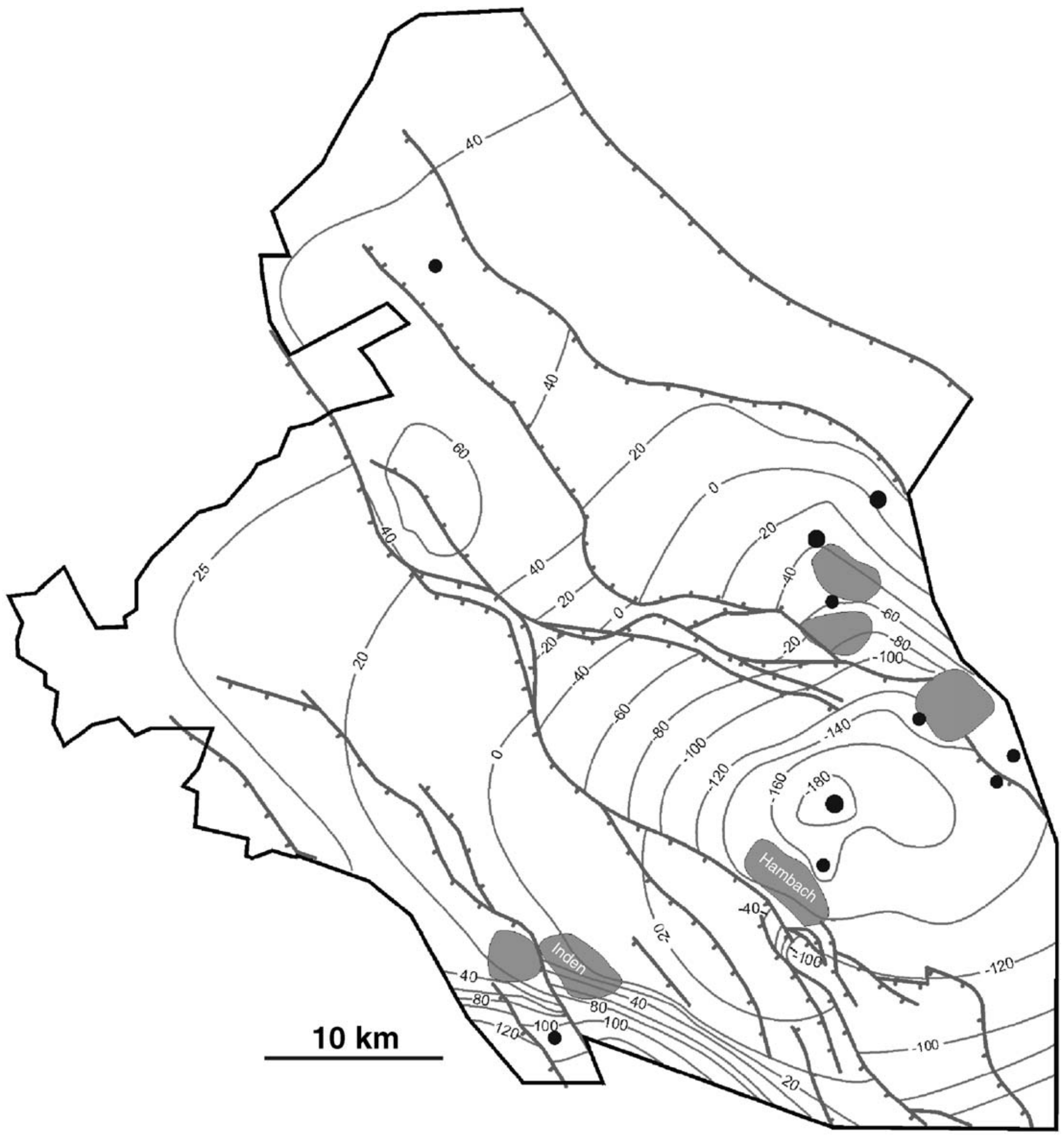

Fig. 2. Hydraulic head pattern in the lignite mining area in middle deep aquifers. The pattern is the result of huge groundwater extractions (redrawn after Wallbraun, 1992).

indicates that the groundwater system is discharged through vertical groundwater flow close to the fault zone.

2.3. Regional groundwater flow around the lignite mining area in the German part of the RVRS

On a regional scale, the effects of faults on groundwater flow are very clearly illustrated by the spatial distribution of hydraulic heads around the lignite mines in the German part of the RVRS (Fig. 2; after Wallbraun, 1992). In these areas, groundwater fluxes are strongly enhanced as a result of the groundwater extractions that take place to make open-pit mining possible at depths of over 500 m. Therefore, extreme hydraulic head differences of more than 70 m exist over, for example, the Rurrand fault which forms the extension of the Peel Boundary Fault into Germany. Although most faults in this area form strong barriers to groundwater flow, structures associated with overstepping faults can locally strongly reduce the effective sealing effect of the faults (Fig. 2). The cone of depression in the hydraulic head pattern that has developed on the Erft Block as a result of the groundwater extraction is propagating through this structure, effecting hydraulic heads in the Roer Valley Graben. It is evident that a good understanding of the hydrogeological implications of this kind of structures is essential to the management of the groundwater extractions in the mines while the magnitude of the impact of the mining industry on regional groundwater resources is already a point of discussion for more than a decade (e.g. Stuurman, 2000).

3. Conclusions

Faults form essential elements in the description and management of the groundwater flow system in the southeastern parts of the Netherlands and the adjacent areas in Germany. Hydrogeologic characterization on several scales shows that faults in the unconsolidated sediments of the Roer Valley Rift System are heterogeneous and strongly anisotropic features where vertical groundwater flow can be enhanced, whereas horizontal flow is hampered. These findings have important implications for modeling studies that concentrate on faulted aquifer systems. Faults should be considered as zones where otherwise separated aquifers can be hydraulically connected which can lead to vertical exchange of, for example, contaminants or salt water.

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