Sources of groundwater inflows into the "Czatkowice" limestone quarry in southern Poland

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Abstract Lower Carboniferous limestone has been extracted in the "Czatkowice" open-pit hill-slope quarry in southern Poland since 1948, for the needs of metallurgical and building industries, as well as farming. We can distinguish two aquifers in the Czatkowice area: the Quaternary porous aquifer and the Carboniferous fissure-porous one. Two vertical zones representing different hydrodynamic characteristics can be indentified in the Carboniferous formations. One is a weathering zone and the other one the zone of fissures and interbedding planes. Groundwater inflows into the quarry workings have been observed at the lowest mining level (+315 m above the sea level (asl)) for over 30 years. This study concerns two hypotheses of the sources of such inflows originating either from (a) the aeration zone or from (b) the saturation zone.

Key words limestone quarry, groundwater, monitoring

Introduction

Lower Carboniferous limestone has been extracted in the "Czatkowice" quarry since 1947. Initially, limestone was used as building material and later delivered to the ironworks. "Czatkowice" is a hill-slope quarry, situated on the slope of the Krzeszówka stream valley. Limestone mining operations are conducted close to several high-capacity water springs, called the Czatkowice Water Springs (Fig. 1) from which water is supplied to the nearby town of Krzeszowice and neighbouring locations. For that reason, the attention of hydrogeologists has been concentrating for over 40 years on the establishment of the lowest possible mining level at which limestone extraction does not threaten with the degradation of water-source capacity.

It was found during the stage of documenting the Czatkowice limestone resources that the groundwater tables were situated at the levels from +315 to +323 m asl and those in the east section of the quarry from +330 to +350 m (asl). It was established in the mid-1970's that the +315 m asl level, being on the boundary of the lowest ordinate of the groundwater table, within the concession, was a safe mining level which would not affect the capacity of the Czatkowice Water Springs. In 1974, a groundwater-table monitoring system was implemented upon installation of piezometers in the "Czatkowice" quarry. Limestones started to be mined on the level in question in 1976. Small outflows appeared at the +315 m asl level in the east section of the quarry in the mid-1980's. Their total output was increasing with time. Outflow water penetrated limestones at that level and that is why it was not necessary to drain the quarry. The present study discusses the issue of the origin of water appearing in the outflows of the "Czatkowice" quarry and how the outflows affect the Czatkowice Water Springs.

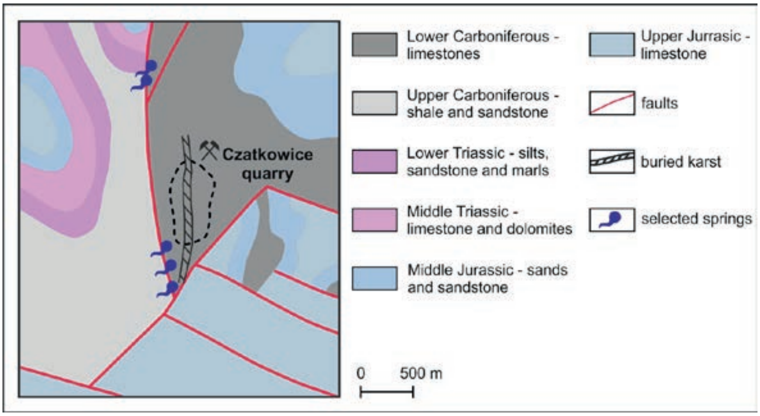

***Figure 1**. Geological map of the Czatkowice area (after Leśniak, Motyka 1991).*

Geological and hydrogeological setting

The oldest indentified formations of Czatkowice belong to the Carboniferous rocks and they are of two types in lithological terms. The Lower Carboniferous formations consist of limestones and the Upper Carboniferous ones of coal-bearing clastic rocks. The Krzeszówka stream fault, running along the stream's valley, is the boundary of the outcrops of the Lower and Upper Carboniferous formations (Fig. 1).

Locally, the Triassic clastic and carbonate rocks and single sand shoals and sandstones of the Middle and Upper Jurassic limestones are situated on the Upper Carboniferous formations in the west wing of the Krzeszówka stream fault. The elevated west wing of that dislocation is formed by the Lower Carboniferous Czatkowice limestones, locally covered by the Middle Jurassic sands and sandstones and the Upper Jurassic limestones. The limestones mined in the "Czatkowice" quarry create a shear displacement structure, adjacent to the slope of the Krzeszówka stream fault (Fig. 2). They also constitute the main aquifer level in the quarry surroundings.

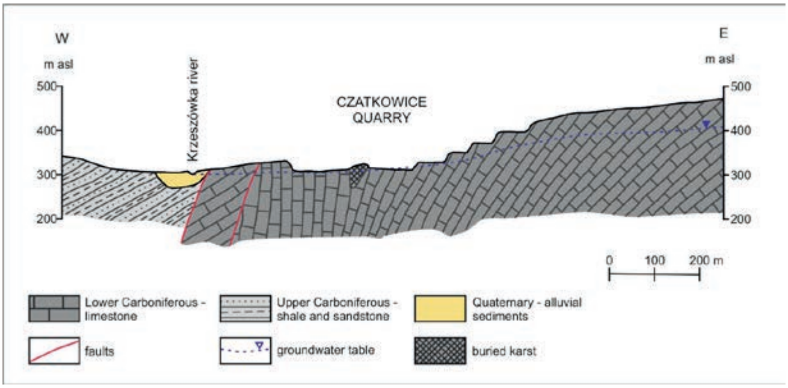

***Figure 2**. Geological cross-section of the limestone deposit area in Czatkowice (after Leśniak, Motyka 1991).*

The Czatkowice limestones contain an aquifer of the fissure-porous type (Leśniak, Motyka 1991). The porosity matrix is not essential for groundwater conductivity and storage. Hydraulic conductivity coefficients usually amount to 10^{-11} m/s (Borczak et al. 1994). Fractures in interbedding planes are the main groundwater conductivity and storage systems. They are characterised by a small hydraulic capacity of the fraction of a percentage point and fairly large conductivity. The fissure space filtration coefficients range from 6.7×10^{-7} to 1.1×10^{-3} m/s (Leśniak 1991).

The system of karst voids is very important for the development of water relationships in the "Czatkowice" quarry area. The drilling results indicated that the main system of karst channels that deliver water to the Czatkowice Water Springs is located about 45 m below the current water table in the quarry, i.e. at the level of ca. +260 m asl ordinate.

Two distinct vertical hydrodynamic zones can be identified in the quarry. In the upper one, reaching more or less the third mining level, i.e. ca. +370 m asl ordinate, numerous karst formations occur, developed mainly along the bedding planes, next to a thick network of fissures of various origins. Those are usually caverns with secondary karst clay filling (Fig. 3a). The other zone whose lower boundary is not known as it is located below the lowest mining level (+315 m asl) is primarily dominated by fissures and interbedding planes (Fig. 3b). Those are the main groundwater-flow channels. Small karst voids, partly filled with residual clays, developed along some of those fissures and interbedding planes. The previously mentioned karst channel systems are located in that zone. The Czatkowice source waters are flowing out of them.

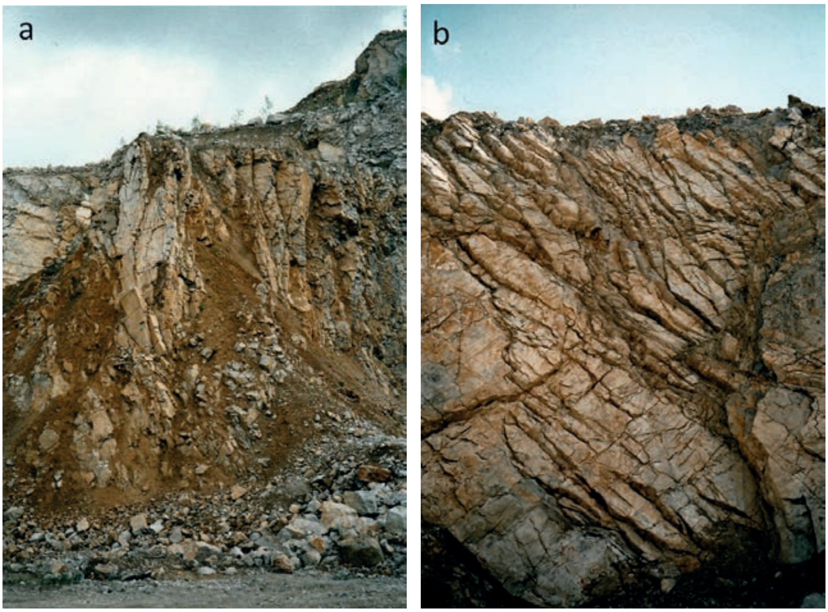

Figure 3. *Vertical arrangements of the Czatkowice limestone layers in the "Czatkowice" quarry.*

Water in the "Czatkowice" quarry

Several years after limestone mining had started at the +315 m asl level, small water outflows appeared under the east slope (Fig. 4a). Water sank into the ground after covering a short distance (Fig 4b). The total output of those outflows was insignificant and it was not measured because water quickly disappeared in the floor of the open-pit quarry. Monitoring of the output was implemented in 1991 and established at 4-5 L/s. That rate was maintained more or less until mid-1992. The outflow output strongly depended on precipitation and it ranged from 0.5 to 4.5 L/s in 2011. In 2012-15, however, despite such fluctuations, the total output ranged from 4 to 20.5 L/s (Fig. 5).

***Figure 4**. Water outflow in the "Czatkowice" quarry.*

Two different views have been expressed on the origin of the above-described outflows: (a) water is coming either from the saturation zone, i.e. due to the fact that an underground aquifer was cut through by a mine working; or (b) infiltrating water is flowing out. The first hypothesis was formulated on the basis that the groundwater table was indentified on the area. It was subjected to monitoring activities at various mining levels. The other hypothesis was formulated on the basis of the measurements of changing water-table levels at the piezometers distributed at various mining levels, the chemical composition of the water samples collected from those piezometers, and the essential geological factor: nearly vertical arrangement of rock layers (Fig. 3) that facilitates infiltrating water penetration along the interbedding planes into the open pit.

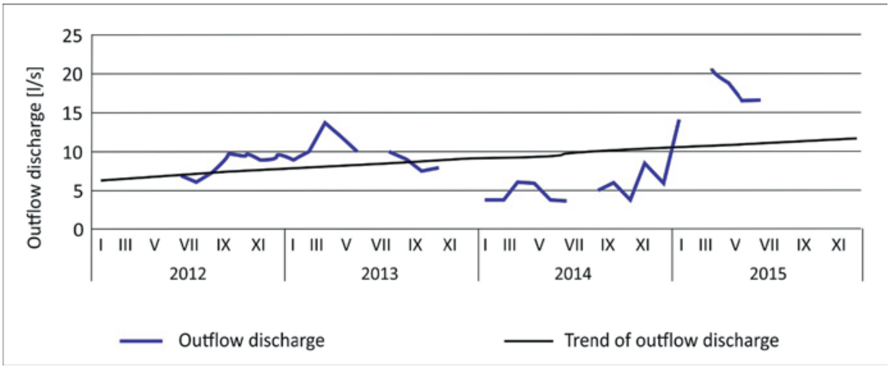

***Figure 5**. Fluctuations of the capacity of water inflow (l/s) into the working at Sub-Level 310 in 2012-15.*

The amplitudes of water-table fluctuations in the piezometers placed in the first hydrodynamic zone reached 16 m. At the same time, large hydraulic gradients were recorded between the water levels at various piezometers distributed in that zone, reaching up to 16‰, which could indicate the presence of micro-reservoirs, with limited mutual hydraulic contact between them. In the second hydrodynamic zone, the amplitudes of water-table fluctuations were reaching only 6 m (Fig. 6).

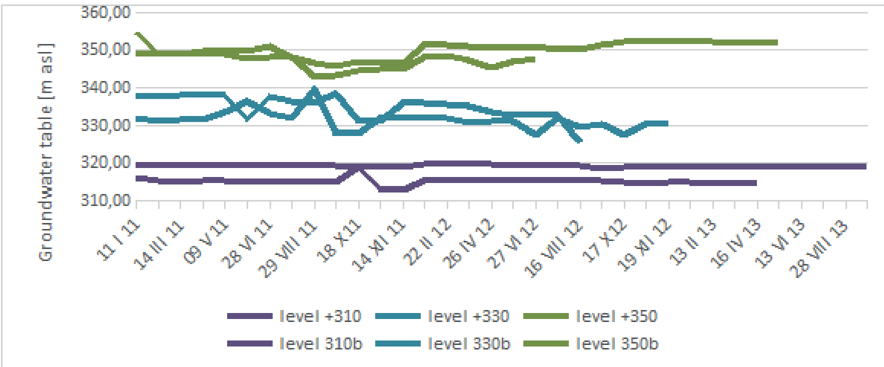

***Figure 6**. Fluctuations of the water-table levels on the piezometers of the "Czatkowice" quarry.*

General mineralisation of two water samples collected from the piezometers at the level of 350 amounted to 212 mg/L and 259 mg/L, respectively. The type of less mineralised water was $CaHCO_3$, and that with higher mineralisation: Ca-Mg-HCO_3-SO_4. Water samples collected from five piezometers installed at the level of 330 represented higher mineralisation than those collected from the higher level of +350 m asl. The values ranged from 221 to 391 mg/L, and the water types were the following: Ca-HCO_3, Ca-HCO_3-SO_4, Ca-Mg-HCO_3, and Ca-Mg-HCO_3-SO_4. The last water group, collected from three piezometers located at the level of +310 m asl, represented the highest mineralisation, ranging from 426 to 453 mg/L. Waters belonged to the types of Ca-HCO_3-SO_4 and $CaHCO_3$. Mineralisation of quarry outflows ranged from 373 to 436 mg/L, while the hydrochemical types of water samples collected from those outflows were the following: Ca-HCO_3 and $CaHCO_3SO_4$. The chemical composition of water outflows in the quarry indicated a similarity to that of the second hydrodynamic zone samples.

It seems that the tendency of increasing outflow output at the level of +310 m asl, identified in recent years, supports the conception claiming that water is arriving from the aeration zone. The increasing outflow output was associated with the shift of the mining face, with the subsequent enlargement of the depression near the quarry. Since the floor of the mining level cuts through the groundwater table only in the east section, with its west section located above the water table, water originating from the outflows penetrates the pit bed and thus it is not required to pump it out of the quarry (Fig. 7).

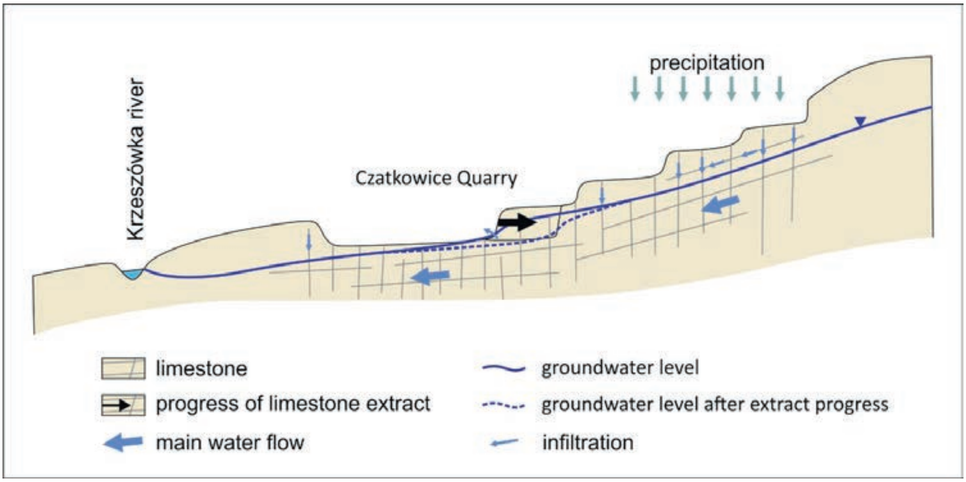

***Figure** 7. Water flows within the "Czatkowice" quarry.*

Conclusions

The Lower Carboniferous limestones are mined in the "Czatkowice" quarry. They belong to the shear displacement structure and their layers are arranged vertically. The limestones create a fissure-porous reservoir of groundwater in which we can distinguish two vertical hydrodynamic zones. In the first one, located next to a thick network of fractures, numerous karst formations occur, usually in the form of caverns filled in with karst clays. In the other zone, the hydraulic network is composed mainly of the interbedding planes and fissures, with small and rare karst formations along.

In the east section of the lowest mining level, water is flowing out at several places. The outflows are integrated in one stream which penetrates the floor of the mining level at which the outflows occur. Consequently, no water removal from the open-pit quarry is required. The trend of the increasing total output of outflows, indentified in 2012-15, makes the authors of this study accept the hypothesis that the outflows originate from the saturation zone rather. The increasing outflow outputs are caused by the relocation of the mining face at that level in the eastern direction, with the enlargement of the depression located in that area (Fig. 7).

Literature

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