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SOURCES OF GROUNDWATER INFLOWS INTO THE "CZATKOWICE" LIMESTONE QUARRY IN SOUTHERN POLAND

POCHODZENIE DOPŁYWÓW WÓD PODZIEMNYCH DO KAMIENIOŁOMU WAPIENI „CZATKOWICE" W POŁUDNIOWEJ POLSCE

Lower Carboniferous limestone has been extracted in the "Czatkowice" open-pit hill-slope quarry in southern Poland since 1947, 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. Inflows into the quarry combine into one stream flowing gravitationally to the doline under the pile in the western part of the quarry. This situation does not cause a dewatering need. Extending eastward mining and lowering of the exploitation level lead to increased inflows.

Keywords: limestone quarry, groundwater, monitoring

W kopalni odkrywkowej „Czatkowice" (S Polska) typu stokowego od 1947 roku eksploatowane są wapienie dolnego karbonu dla potrzeb hutnictwa, budownictwa oraz rolnictwa. W rejonie Czatkowic można wyróżnić dwa piętra wodonośne: czwartorzędowe – porowe oraz karbońskie, tworzące zbiornik wód podziemnych typu szczelinowo-krasowego. W utworach karbońskich wydzielić można dwie pionowe strefy o różnej charakterystyce hydrodynamicznej. Pierwsza z nich, to strefa wietrzenia, a druga to strefę spękań i fug międzyławicowych. Na najniższym poziomie eksploatacyjnym kamieniołomu (poziom +315 m n.p.m.), od ponad 30 lat obserwuje się wypływy wód podziemnych do wyrobiska kopalni. W pracy odniesiono się do dwóch hipotez dotyczących genezy tych wypływów: a). ze strefy aeracji, b). ze strefy saturacji. Dopływy do kamieniołomu łączą się w jeden strumień płynący grawitacyjnie do doliny

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pod hałdą w zachodniej części kamieniołomu. Sytuacja ta powoduje brak konieczności odwadniania. Rozszerzenie wydobycia na wschód i obniżenie poziomu eksploatacji prowadzić będzie do zwiększenia dopływu wody do kamieniłomu.

Słowa kluczowe: Czatkowice, kamieniołom wapieni, wody podziemne, monitoring

1. 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.

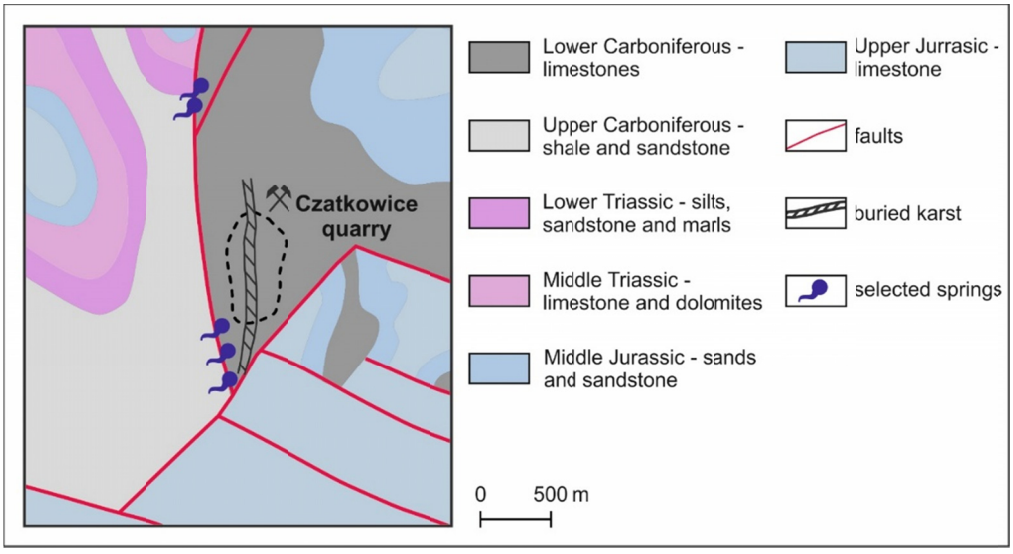

Fig. 1. Geological map of the Czatkowice area (after Leśniak & Motyka, 1991)

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. Limestone 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 limestone 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.

2. Material and methods

2.1. 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 limestone 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 sandstone of the Middle and Upper Jurassic limestone 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 limestone, locally covered by the Middle Jurassic sand and sandstone and the Upper Jurassic limestone. The limestone 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.

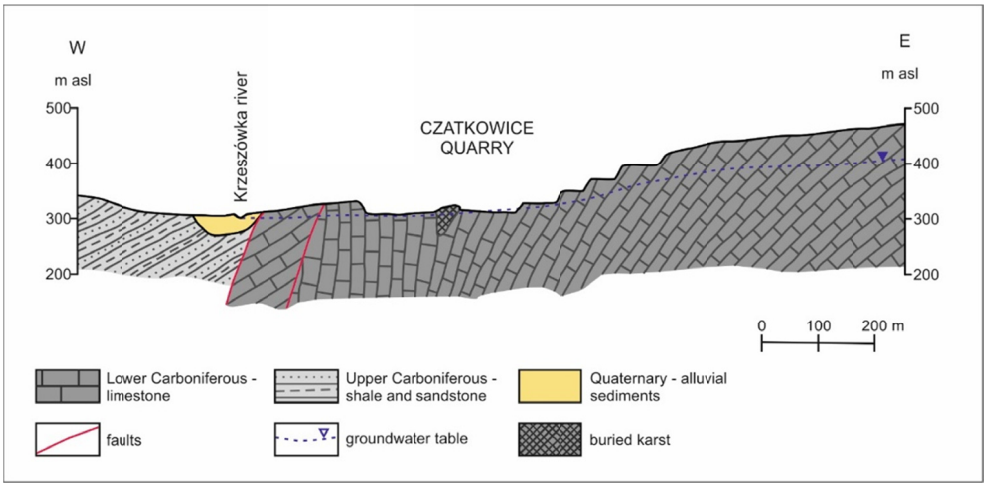

Fig. 2. Geological cross-section of the limestone deposit area in Czatkowice (after Leśniak & Motyka, 1991)

Carbonate rocks are characterised by very intricate structure of groundwater conductivity and storage system. In the limestone and dolomites, where matrix porosity (sensu Choquette, Pray 1970) is significant for groundwater flow and storage (type of grain and oolithic rocks), are

mainly tipple porosity aquifers: karst-fissures-porous (Motyka, 1998; Zuber & Motyka, 1998). In double porosity aquifers, Atkinson (1977) determined two types of groundwater flow: conduit flow through open conduits and diffuse flow through matrix porosity, or a thick network of fissures hydraulic conductivities.

The Czatkowice limestone contain an aquifer of the fissure-porous type (Leśniak & Motyka, 1991). The porosity matrix is not essential for groundwater flow and storage. Hydraulic conductivity coefficients usually amount to 10^{-11} m/s (Borczak et al., 1994). Fractures in interbedding planes are the main groundwater flow and storage features. They are characterised by a small hydraulic capacity of the fraction of a percentage point and fairly large conductivity. The fissure hydraulic conductivities range from 6.7×10^{-7} to 1.1×10^{-3} m/s (Leśniak & Motyka, 1991). The fissures and bedding planes are the main groundwater conductivity and storage system. The greater fissures and karst channels may be considered as a part of conduit flow, and bedding planes and thick network of fissures as a part of diffuse flow.

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), in large part it is an epikarst area (Mangin, 1975). 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 and storage systems. Small

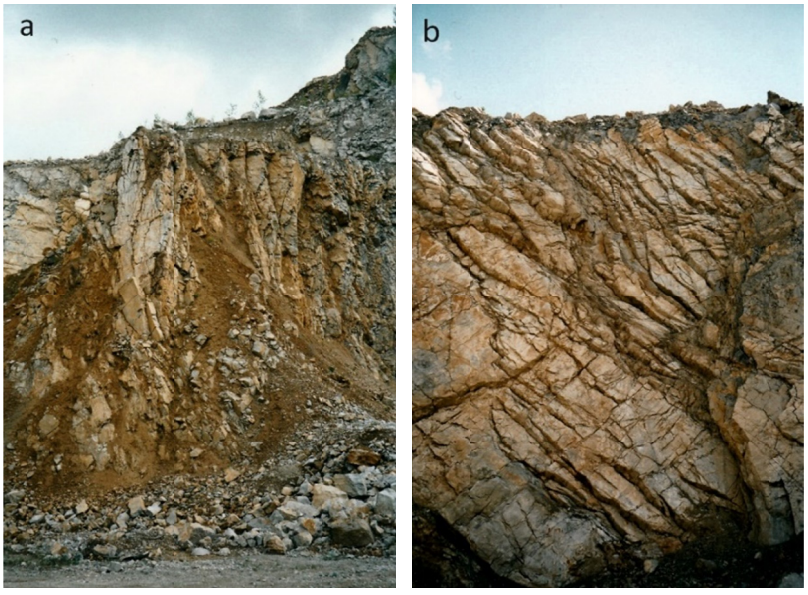

Fig. 3. Vertical arrangements of the Czatkowice limestone layers in the "Czatkowice" quarry

karst voids, partly filled with residual clays are crucial for the development of groundwater flow pattern along some of those fissures and interbedding planes. Numerous karst features occur in that zone. The Czatkowice source waters are flowing out of them. The radiometric tritium analysis results indicated mixture of recent infiltration water with a significant component of older distal water circulation (Zuber & Motyka, 1994).

2.2. 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 infiltrated into the pit 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 the discharge reached 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).

Fig. 4. Water outflow in the "Czatkowice" quarry

3. Results and discussion

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. Additionally, zone of aeration in carbonate rocks with well-developed epikarst zone, is intricate hydraulic system where the groundwater-flow channels are difficult to define (Bakalowicz, 1995).

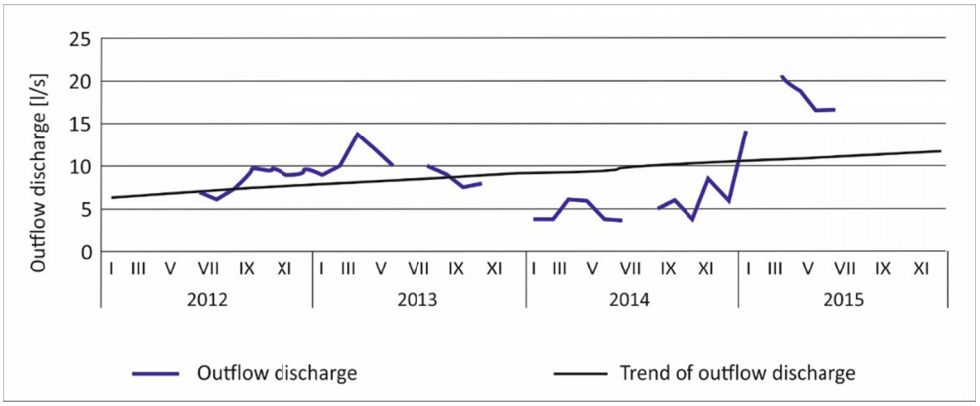

Fig. 5. Fluctuations of the water discharge (L/s) into the working at Sub-Level 310 in 2012-15

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 hydraulic contact between them. In the second hydrodynamic zone, the amplitudes of water-table fluctuations were reaching only 6 m (Fig. 6).

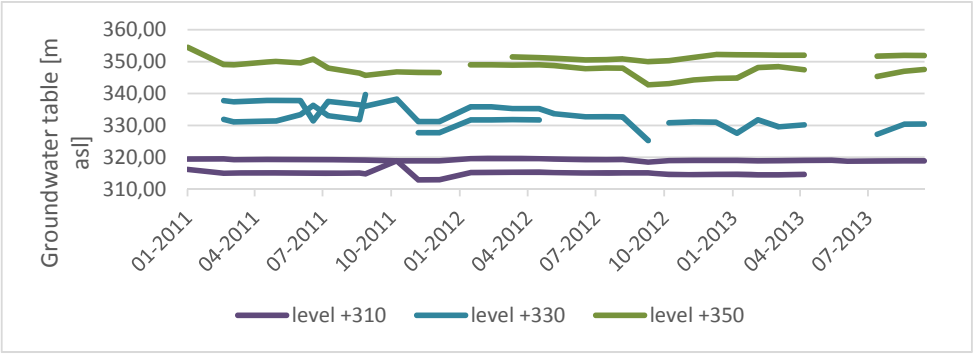

Fig. 6. Fluctuations of the water-table levels on the piezometers of the "Czatkowice" quarry

General mineralisation of three water samples collected from the piezometers at the level of 350 amounted to 196 mg/l and 235 mg/l, respectively. The type of less mineralised water was Ca-HCO_3, and that with higher mineralisation: Ca-Mg-HCO_3-SO_4. Water samples collected from three 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 232 to 289 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 four piezometers located at the level of +310 m asl, represented the highest mineralisation, ranging from 312 to 453 mg/l. Waters belonged to the types of Ca-HCO_3-SO_4 and Ca-HCO_3. Mineralisation of quarry outflows ranged from 406 to 436 mg/l,

while the hydrochemical types of water samples collected from those outflows were the following: Ca-HCO_3 and Ca-HCO_3-SO_4. The chemical composition of water outflows in the quarry indicated a similarity to that of the second hydrodynamic zone samples (Fig. 7).

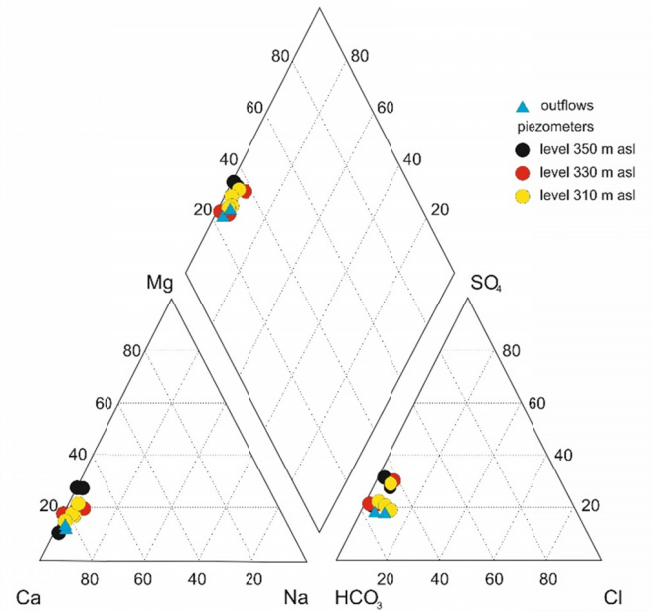

Fig. 7. Piper Diagram

Increasing outflow was at the level of +310 m asl, indentified 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. 8).

4. Conclusions

The Lower Carboniferous limestone are mined in the "Czatkowice" quarry. They belong to the shear displacement structure and their layers are arranged vertically. The limestone 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 features along.

In the east section of the lowest mining level, water is discharging 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

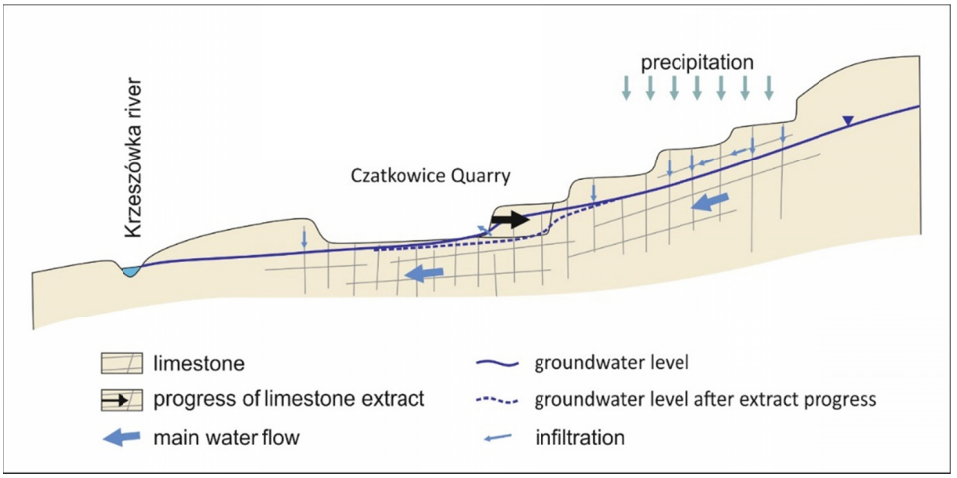

Fig. 8. Conceptual model of flow pattern within the "Czatkowice" quarry

of the increasing total output of outflows, indentified in 2012-15, makes the authors of this study to accept the hypothesis that the outflows originate rather from the saturation zone. 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. 8).

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