Dewatering, Flooding and Stratification of the Nikolaus-Bader small-scale Gold Mining Shaft in Austria

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Abstract

To investigate density stratification in flooded underground mines, the 10 m deep Nikolaus-Bader shaft in Biberwier/Tyrol, Austria was pumped out and the subsequent flooding process was observed. After a short time, a density stratification developed, which collapsed in late autumn and built up again in spring. By means of data loggers, measuring pressure, temperature, and electrical conductivity in four different depths of the flooded shaft, a long-term monitoring of the water body is possible, from which conclusions can be drawn about temporal factors for the formation and collapse of density stratification.

Keywords: Underground Mine, Stratification, Flooding

Introduction

In the 1920s to 1940s, while searching for gold within moraine material deposited by the Fernpass mountain slide, Nikolaus Bader of Lermoos, a village in Tyrol, Austria sank a 10 m deep shaft near the Loisach springs. As profitable gold mining never took place, the shaft was forgotten and only rediscovered in a flooded state in 1999 (Wolkersdorfer *et al*. 2007). Since 2004, regular examinations of the water quality and depth profile measurements have been carried out in the shaft. It has been shown that the occurrence and breakdown of stratification occurs at different depths. Stratification of mine water is of relevance pertaining to mine flooding events worldwide, as stable stratification can reduce the need for extensive mine water treatment (Wolkersdorfer 2008; 2017). Highly mineralised and consequently mostly more contaminated mine water usually remains in deeper areas of the mine pools, while relatively less mineralised mine water discharges near the surface (Mugova and Wolkersdorfer 2019). Due to the nature of occurrence, as well as the long-term stability and breakdown of stratification, it is very difficult to monitor the processes in a mine several hundred to a thousand metres deep, hence the 10 m deep Nikolaus-Bader-shaft was selected in 2019 as an investigation shaft for long-term observation.

Investigation

Description of the shaft and previous research

Named after the local pharmacist, miner and businessman Nikolaus Bader, the 2 × 2 m wide and 10 m deep shaft has been flooded since the 1930s. It is located near the Loisach springs close to the village Biberwier in the district of Reutte (Außerfern, Tyrol, Austria). There is no discharge at the shafts surface, so it can be assumed that the shaft water mainly interacts with the groundwater body. In the area of Biberwier, the mesozoic rocks of the Fernpass syncline are covered by material from the Fernpass mountain slide and moraines (till). These moraines belonged to a glacier whose origin is located in vicinity of the Swiss Alps, which explains the gold bearing till (Eichhorn *et al*. 2017). Mining with these low gold concentrations was however ultimately not feasible. Due to its greater residence and contact time with the debris of the toma hills and the till (Table 1), the water from the Nikolaus-Bader-shaft is slightly more mineralised than that from the Loisach river. This is particularly noticeable in the case of calcium and hydrogen carbonate.

Table 1 Water analyses from the Nikolaus-Bader-shaft, the river Loisach and the drinking water well (2005 – 2020); EC: electrical conductivity; Redox: redox potential corrected to standard hydrogen electrode.

Parameter	Outflow drinking water supply Biberwier	Nikolaus-Bader-shaft	River Loisach approx. 300 m downstream of the shaft
pH, –	7.3 – 8.3	7.1 – 7.2	7.7 – 7.9
Redox, mV	62 – 436	64 – 383	62 – 426
EC, µS/cm	365 – 406	381 – 477	367 – 401
Temp, °C	7.5 – 8.7	5.7 – 9.2	7.6 – 9.1
Ca, mg/L	33 – 49	64 – 68	47
Mg, mg/L	23	16	24
Na, mg/L	0.6 – 1.3	0.4	1.3
K, mg/L	0.5	0.7	< 1
Cl, mg/L	4.7 – 7.4	1.1 – 3.9	7.4
HCO_3, mg/L	174 – 210	240 – 255	220
SO_4, mg/L	25 – 29	17 – 22	30
NO_3, mg/L	1.2 – 1.4	1.0	1.2
U, µg/L	5.8 – 6.4	0.2 – 2.2	5.9

Potentially toxic metals are not present in elevated concentrations in the shaft water; interestingly, a water sample from the deepest part of the shaft showed gold concentrations above the detection limit.

Depth measurements of electrical conductivity and temperature, conducted mainly between 2004 and 2006 at various depths in the shaft, showed a density stratification that is linked to seasonal changes and in some cases disappears altogether (Fig. 1). In May 2019, immediately before the start of the experiment, existing stratification in the shaft could be confirmed.

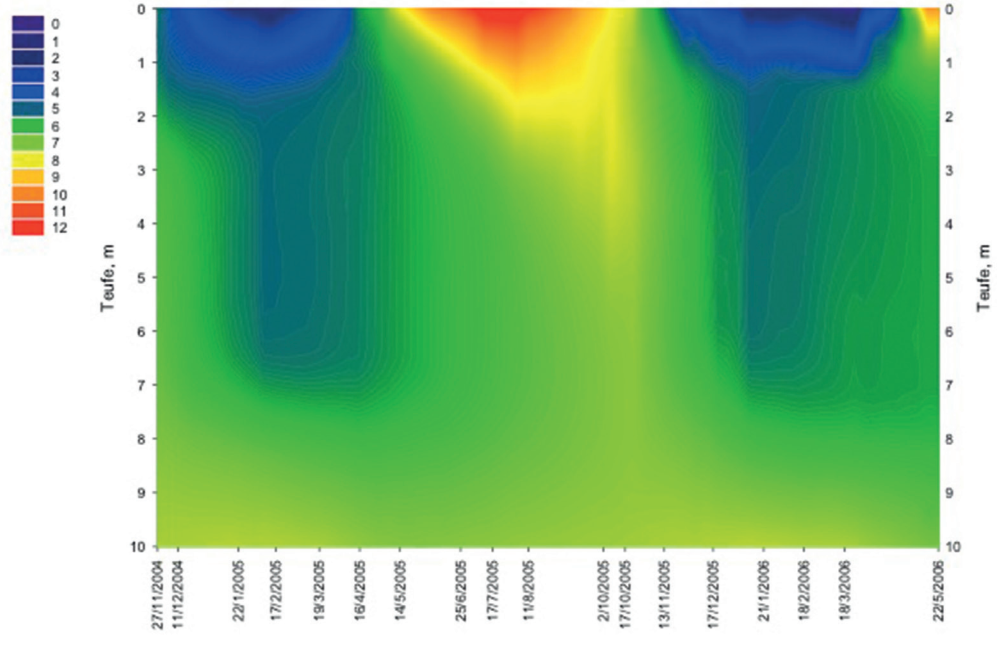

Figure 1 Temperature-depth diagram of the Nikolaus-Bader-shaft with 18 depth-dependent measurements between November 2004 and May 2006.

Objective and implementation of the experiment

To understand the occurrence, breakdown and, most importantly, the long-term stability of stratification in flooded mine shafts, an ongoing monitoring of the shaft water body was begun in June 2019. With aid of a submersible pump, the shaft was dewatered almost empty within a time frame less than 3 hours, and the displaced shaft water was discharged into the nearby Loisach river. As it turned out, the water preserved the original shaft lining, which was in very good condition. A visual inspection and a drive-through with a camera was possible. Water inrush into the shaft from the upper shaft walls could not be observed, leading to the conclusion that interaction with the groundwater body only takes place in the lower area without shaft lining. Before pumping, CTD-Diver data loggers (Van Essen Instruments) were inserted at four different depths (0.8 m, 2.5 m, 7 m and 8 m). These were the approximate depths of the previously observed stratification withing the shaft water body. The data logger at 8 m deep was temporarily lowered to a depth of 9.4 m, just below the surface of the remaining shaft water, to monitor the rebound rate. Values of electrical conductivity, water temperature and pressure are recorded in 15-minute intervals and made available by remote data transmission. In addition, hourly data from the semi-automatic weather recording system (TAWES) in Ehrwald, about 5 km away, is also considered for evaluation.

Results and Discussion

After the pumps were switched off, immediate flooding of the shaft began, primarily through influxes of groundwater in the deepest part of the shaft. By extrapolating the flooding process, the total depth of the shaft could be estimated to be between 9.6 and 9.7 metres. From the first data logger, which was initially installed at a depth of 9.4 m, to the near-surface data logger at a depth of 0.8 m, natural flooding continued for about 25 days. Mine water rebound rates of 0.4 m/d (assuming rise from 9.4 m to 0.8 m) were calculated, which is consistent with visual observations at the onset of flooding. Rebound rates correlated to depth, with greater velocities of up to 0.9 m/d being observed in deeper areas of the shaft, which decreased to less than 0.1 m/d near the surface of the shaft. A possible explanation for these differences is evident in the flooding process itself. There is an increased inflow of water between depths of 9.0 m and 8.0 m, which feeds the rising water. Up to a depth of approximately 2 m the water column builds up steadily, and thus the elevated pressure of the water column prevents a further rapid rise of water within the shaft. Close to the surface, precipitation or infiltration water enters laterally into the shaft at much lower velocities, hence the rebound rates are lower in the upper shaft area. Based on the calculated rebound velocities, kf-values around $1 \cdot 10^{-7}$ m/s were determined for the inflow area by kf-value determination for transient pumping tests, with slightly permeable material (silt to silty sand) around the shaft. This confirms that the area of the inflowing groundwater is moraine material, which is consistent with the historical information provided by Nikolaus Bader to the mining authorities, and with information mentioned in a hydrogeological report by Schuch (1981).

The objective of the pumping experiment and observations following flooding is to verify whether the stratification between different water bodies at 0.8 m, 2.5 m, 7.0 m and 8.0 m encountered in earlier investigations would occur again and if it would remain stable. Values for temperature and electrical conductivity at different depths over time (Fig. 2, Fig. 3) show a horizontal curve, especially at 7.0 m and 8.0 m depths. These 2 curves show convergence about 73 days after the start of flooding. For 16 weeks, the stratification was stable and indicates the formation of a homogeneous water body in the area between 7.0 and 8.0 m, and probably above and below. Fluctuations in temperature and electrical conductivity are more evident in the water body closer to the surface (data logger at 0.8 m), as the curve is more uniform at 2.5 m, 7.0 m and 8.0 m. On 2019-10-12, the upper stratification collapses, and about one month later, as of 2019-11-10, there is no more stratification detectable in the shaft. Only one homogeneous water body with the same temperature and electrical conductivity exists. From mid-May 2020, the redevelopment of an upper, separated water body is visible in the temperature and less evidently in the electrical conductivity curve. Around the data logger at 2.5 m deep, another water body develops again beginning of July 2020. Due to stratification two separated waterbodies redeveloped over summer 2020, until stratification completely collapsed again end November 2020. Thus, the occurrence and breakdown of stratification observed since 2004 can be confirmed, a repeating annual pattern is evident.

According to the TAWES weather data in Ehrwald, it appears that there is a connection between the beginning of frost and the breakdown of the stratification. At the beginning of November 2019, the upper stratification collapsed after several hours of continuous sub-zero temperatures. Mixing of the entire water body took place after further persistent frost in December. A possible explanation is that due to low air temperatures, the surface water infiltrating and flowing into the shaft has low temperatures and the density differences in the shaft are so small that a stable stratification cannot be maintained. The collapse of the stratification in 2020 is also related to a longer period of frost. To make more precise statements about water pathways in the bedrock, geophysical measurements are to be carried out in the vicinity of the shaft.

Conclusion

Findings deducted from long-term investigations concerning the occurrence and breakdown of stratification, such as that transpiring at Nikolaus-Bader-shaft, should be investigated in detail and ought to be used as an in-situ mitigation measure for future mines, abandoned mines or mines that have already been flooded. After pumping out the 10 m deep Nikolaus-Bader-shaft near Biberwier, complete flooding took place within just one month, and two months later stratification had re-occurred. A general trend can be seen; at the beginning of the frost period inflow of water with low temperatures into the shaft, probably causes the complete collapse of the stratification, and during the spring and summer months stratification re-develops again. These initial results of the long-term observation suggest that findings could be applicable to deeper mines with near surface inflow.

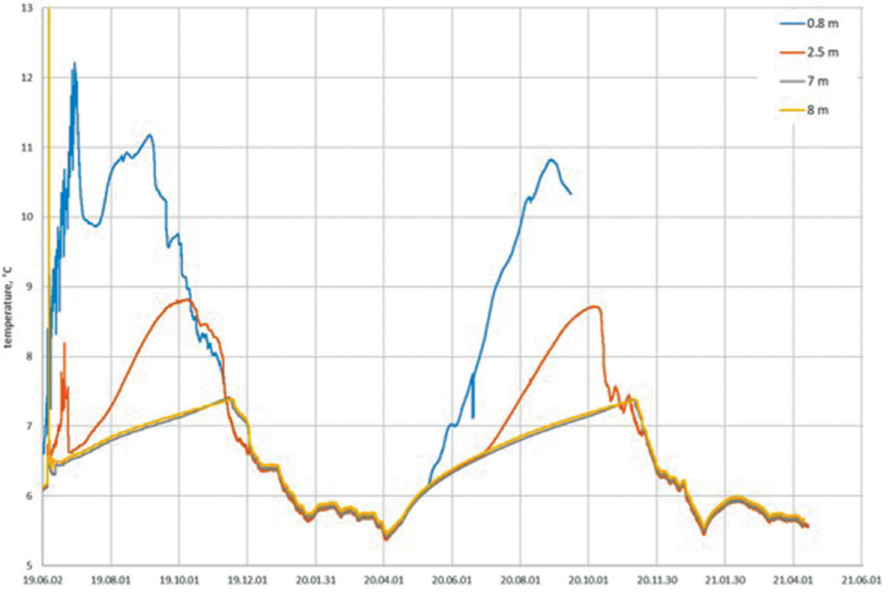

Figure 2 *Time dependent temperature log at Nikolaus-Bader-shaft in 0.8 m, 2.5 m, 7.0 m and 8.0 m depth (deflection at 2020-06-20 is due to a modification on the data logger).*

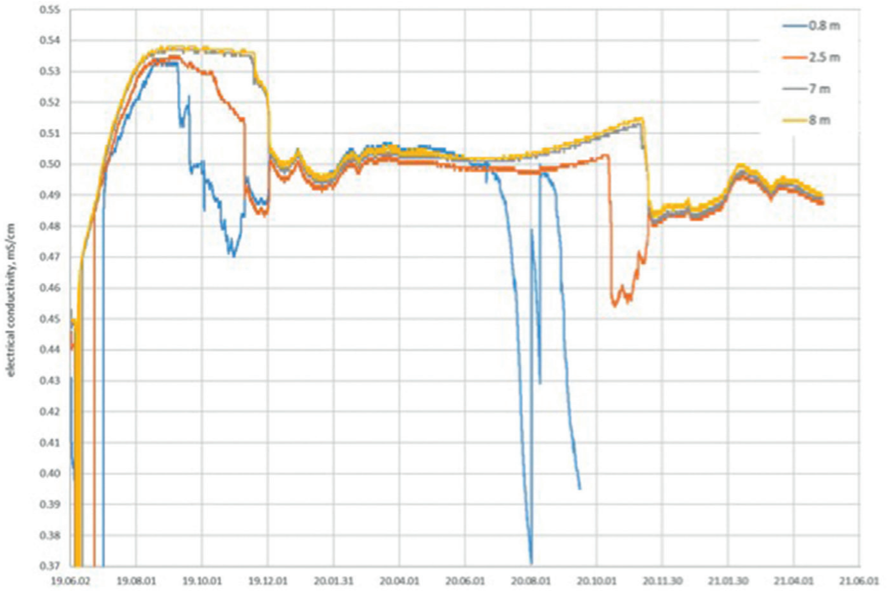

Figure 3 *Time depended electrical conductivity log at Nikolaus-Bader-shaft in 0.8 m, 2.5 m, 7.0 m and 8.0 m depth.*

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References

Eichhorn R, Lehrberger G, Loth G, Loth R, Plass D, Pürner T, Rohrmüller J (2017) Auf den Spuren des bayerischen Goldes – 20 Goldene Geotope. Bayerisches Landesamt für Umwelt, München

Mugova E, Wolkersdorfer C (2019) Stratification in Flooded Underground Mines – State of Knowledge and Further Research Ideas. Paper presented at the Mine Water – Technological and Ecological Challenges (IMWA 2019), Perm, Russia:40–44.

Schuch MF (1981) Bericht über die Ergebnisse der Hydrogeologischen Untersuchungen im Bereiche des Weißen-, Mitter- u. Finstersees. Michael F. Schuch, Innsbruck, p 14

Wolkersdorfer C (2008) Water Management at Abandoned Flooded Underground Mines – Fundamentals, Tracer Tests, Modelling, Water Treatment. Springer, Heidelberg

Wolkersdorfer C (2017) Mine Water Hydrodynamics, Stratification and Geochemistry for Mine Closure – The Metsämonttu Zn-Cu-Pb-Au-Ag-Mine, Finland. In: Wolkersdorfer C, Sartz L, Sillanpää M, Häkkinen A (eds) IMWA 2017 – Mine Water & Circular Economy. vol I. Lappeenranta University of Technology, Lappeenranta, p 132-139

Wolkersdorfer C, Göbel J, Hasche-Berger A, Hanneberg A (2007) Führer zum Montan-Wanderweg Silberleithe (Guide to Mining Trail Silberleithe). Bergwerksverein Silberleithe Tirol, Biberwier