Detection and sealing technology of river-goaf water supply channel and their application

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Abstract

To ensure safe mining in a riverside mine, the source of goaf water is judged by the hydrochemistry method. Besides, the transient electromagnetic combined drilling detection method was firstly used to detect the watered goaf distribution and the water supply channel. The research results show that there is a simple water-conducting structure between the goaf and the Kuqa River. After the channel is blocked, the apparent resistivity of the goaf presents a high resistance characteristic, and the volume of water evacuation reaches 0. The water damage in the goaf has been effectively controlled, and the research results have been applied to the adjacent mines.

Keywords: Transient electromagnetic method; Drilling prospecting method; Hydrochemistry method; Goaf water; Grouting

Introduction

Mine water inrush accident is an associated disaster of mining engineering, which seriously affects the safety of coal mines (Garcia et al. 2017; Losekann et al. 2020). According to incomplete statistics, from 2000 to 2021, there were 550 coal mine water disasters and 2,600 deaths in China. Among them, water inrush disasters in goaf accounted for a large proportion of accidents, reaching more than 85%, and most of them were major and extraordinarily serious accidents (Wang et al. 2012; Odintsev et al. 2015; Liang et al. 2016). Therefore, it is necessary to strengthen the investigation of goaf water, identify the supply water source, and cut off the supply channel.

At present, little research has been done on preventing and controlling water hazards in goafs near rivers. The key to prevention and control lies in judging the supply water source, identifying the water replenishing channel, dredging the goaf water, and blocking the water replenishing channel. In the implementation case, the buried depth of the goaf is shallow, and it is close to the river. The overlying rock in the goaf is mainly sand and gravel, and cracks are widely developed, making it difficult to identify the water source and the channel. Therefore, this practice uses the hydrochemistry method to identify the source of the goaf water, uses the 'transient electromagnetic + drilling' method to accurately detect the distribution of the goaf water and the water replenishing channel, uses the grouting method to block the channel and continuously observes the amount of the goaf water. The research results are expected to provide a reference for the governance of goaf water in shallow coal seams near rivers.

Project profile

Basic geological conditions

The test area is located in the A'ai mining area in Xinjiang, China, near the floodplain of the Kuqa River. There are 5 mineable coal seams inside the mine, with an average coal thickness of 3.0m. It is a near-horizontal coal seam without an obvious fracture structure. The coal seam has a simple occurrence and is suitable for mechanized mining. The internal strata of the minefield are mainly the lower Jurassic Talichike Formation (J1t), the Quaternary Upper Pleistocene aeolian colluvium (Q3eol+col), and the Quaternary Holocene alluvial-pluvial (Q4al+pl).

The surface water in the field is not developed, but the east-west gully

is developed. From the existing mine observation, no strong aquifer was found in the roof and floor of the coal seam, mainly weak aquifer and water-resisting layer. The borehole permeability coefficient of coal seam roof and the floor is 0.286 m / d, the unit water inflow is 0.097 L / s·m, and the unit water inflow is less than 0.1 L / s·m, which is a weak water-rich aquifer.

1.2 Survey scope and method

As water inrush accidents have occurred in adjacent mines, the exploration area is 0.13 km2 in the northeastern boundary of the minefield, as shown in figure 1. The surface gully is developed in the detection area. The transient electromagnetic method is selected for detection to adapt to complex terrain and sensitively reflect the water-bearing structure and water-conducting structure. At the same time, it is assisted in drilling detection to improve the accuracy of measurement.

This transient electromagnetic method uses V8 multi-functional electromagnetic method detector. The transmitter emission voltage can reach up to 140 V, meeting the detection requirements of large current and large depth. The launch and reception are synchronized by GPS satellites. LCD large window real-time display voltage attenuation curve and apparent resistivity curve. Given the burial depth of the target layer in this area is about 40 – 150 m, the transient electromagnetic method exploration test on the ground preferentially selects the emission boundary with 240 m × 240 m side length, and the repetition rate is 25 Hz. There are seven transient electromagnetic survey lines in the survey area. The survey line is arranged along the east-west direction. The line distance is 40 m and the point distance is 20 m. A total of 251 measuring points are arranged. The arrangement of measuring points is shown in Figure 1. At the same time, two water exploration and drainage drilling fields are arranged in the return airway of the coal seam and the transportation of the coal seam. A total of 10 boreholes were constructed, of which 3 boreholes entered the water area of the mining area, and the other 7 boreholes passed through the coal seam.

Identification method of water source and water supply channel

Water source

The hydrochemistry method was used to analyze the water source of goaf water. The chemical composition of groundwater is the product of long-term interaction between groundwater and its environment. There are seven kinds of Cl^-, SO_4^{2-}, HCO^{3-}, Na^+, K^+, Ca^{2+}, Mg^{2+} which are the most widely distributed and abundant ions in groundwater. These ions' relative content and absolute content change with the changes of hydrogeological conditions or another external environment, so groundwater forms various water quality characteristics. By analyzing the content of seven main ions, the source of groundwater can be judged. 5 water samples were taken

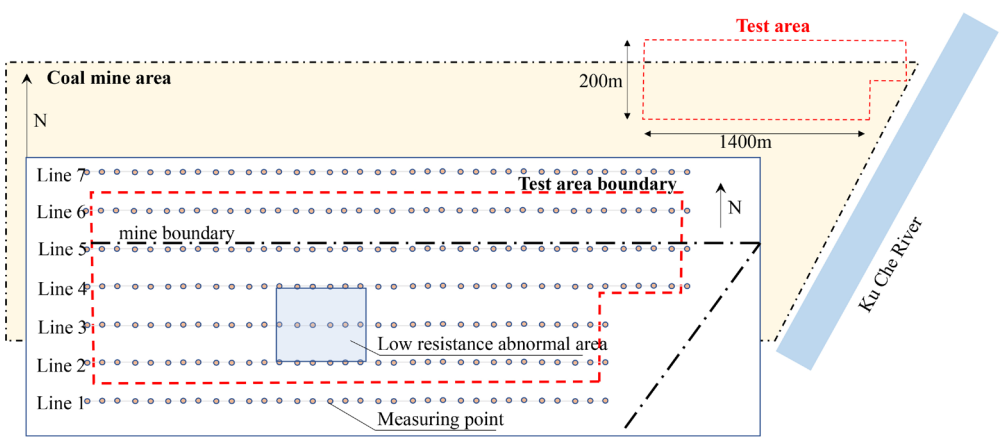
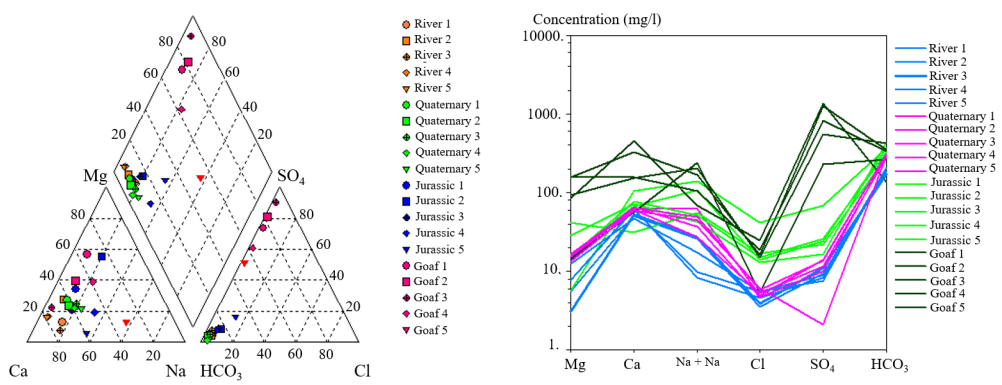


Figure 1 *Transient electromagnetic method measuring line layout plan*

Table 1 Main hydrochemical characteristics of groundwater sampling points

Sample source	number	cation / (mg·L^{-1})			anion / (mg·L^{-1})		
		$Na^+ + K^+$	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^{2-}	HCO_3^-
Kuqa river	1	12.92	50.34	5.55	3.55	9.27	183.48
	2	8.69	46.97	12.43	5.50	7.59	205.51
	3	13.70	52.16	3.11	3.94	10.95	170.98
	4	4.92	61.40	7.79	5.53	8.84	209.23
	5	4.14	62.34	7.68	4.57	8.36	210.88
Quaternary	6	13.52	61	16.39	5.25	11.52	281.05
	7	18.39	65.99	15.24	4.75	9.94	305.45
	8	24.72	63.21	16.7	5.85	13.74	314.35
	9	22.53	59.94	13.41	6.17	2.11	296.18
	10	31.18	62.24	14.95	4.93	13.99	321.07
Jurassic	11	21.28	71.24	28.47	12.94	16.46	434.09
	12	27.96	31.18	41.72	17.12	22.14	283.25
	13	25.97	77.61	15.46	14.96	25.92	324.07
	14	53.77	66.61	16.16	13.93	24.28	371.73
	15	70.33	103.67	5.63	41.84	68.31	371.73
Goaf Water	16	52.01	155.89	160.84	18.47	826.13	338.71
	17	83.61	324.35	157.36	16.06	1274.98	352.01
	18	34.62	453.13	84.48	24.57	1350.92	137.17
	19	101.23	152.3	93.43	15.07	553.4	427.39
	20	119.92	56.39	14.32	5.35	227.18	263.84



(a) Piper *(b) Schoeller*

***Figure 2** Water chemical characteristics of various water sources*

from the Kuqa River, 5 Quaternary water samples, 5 Jurassic water samples, and 5 goaf water samples. These 20 water samples were tested for laboratory water quality. The specific water sample test results are shown in Table 1.

Draw the Piper diagram and Schoeller diagram of water chemistry, as shown in Figure 2. By analyzing Figure 2 and Table 1, it can be seen that the ion concentration variation characteristics of surface water and Quaternary water samples are similar, and

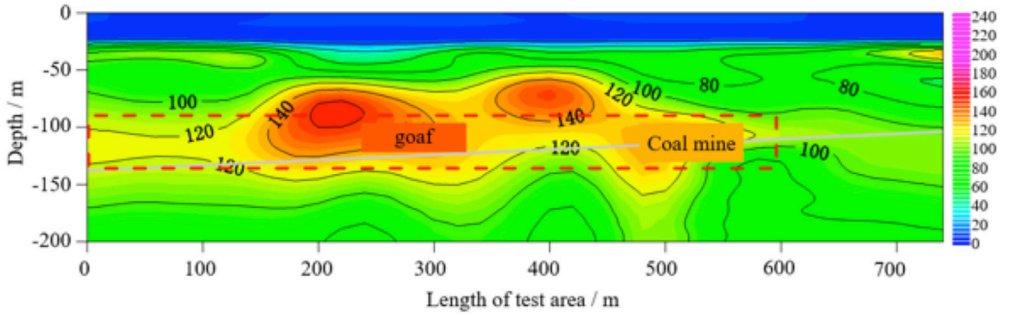


Figure 3 *Apparent resistivity section of line 3*

the water chemical types of both are mainly HCO_3-Ca (Mg). There is a clear hydraulic connection between surface water and the Quaternary. The obvious difference between the goaf water sample and the other three water sources is that the SO_4^{2-} content in the water quality is greatly increased.

Although the ion content in the water quality of goaf water is different from that of other water sources, its hydrochemical characteristics are similar to those of other water sources, especially the cation curves of the Kuqa River and the Quaternary water quality. Therefore, it can be considered that the goaf is supplemented by the Kuqa River and the Quaternary water sources. It is concluded that there must be a water replenishing channel between the surface river and the goaf.

Water supply channel

Based on the transient electromagnetic survey line in Figure 1, the apparent resistivity profile of the detection area is obtained. On the apparent resistivity cross-section diagram, the abscissa represents the distance between the measuring point and the zero point of the measuring line, the longitudinal coordinate is the depth, and the indicated position of the coal seam is marked by a gray solid line. Since the No. 3 survey line spans the goaf, the No. 3 survey line is selected as a typical survey line apparent resistivity profile for analysis, as shown in Figure 3. According to the results of survey line exploration and interpretation, there is a large range of water accumulation in the old goaf in the geophysical exploration area, with an area of about 53435m^2.

At the same time, according to the drilling method, it was found that the cumulative drainage volume of the three boreholes was about 96,000 m^3 within 2 months, accounting for about 75% of the estimated total goaf static reserves, but until the end, the goaf water pressure was still 0.3MPa. For this reason, it can be inferred that there is a stable supply of water sources in the goaf. Through the analysis of the apparent resistivity section of the No. 3 survey line, the hydraulic channel is located in the roof of the coal seam near the position of the water silo below the main inclined well, and the corresponding surface is located on the west bank of the Kuqa River.

Change of water quantity in goaf

Sealing method of the water supply channel

The water replenishing channel is blocked by grouting, and the drill field should be arranged above the water outlet of the goaf. The grouting drilling field is located on the surface just above the water outlet of the goaf. A total of 8 drilling holes are constructed.

Transient electromagnetic exploration results

Geophysical exploration is carried out by arranging transient electromagnetic method survey lines on the ground to detect the water accumulation in the original goaf after water drainage and grouting plugging of the aqueduct channel and evaluate the effect of grouting water blocking and water drainage to control the goaf. The detection results are shown in Figure 4. It can be seen that the old goaf of the No. 3 surveying line has the characteristics of high resistance as a whole, and the goaf water has been evacuated.

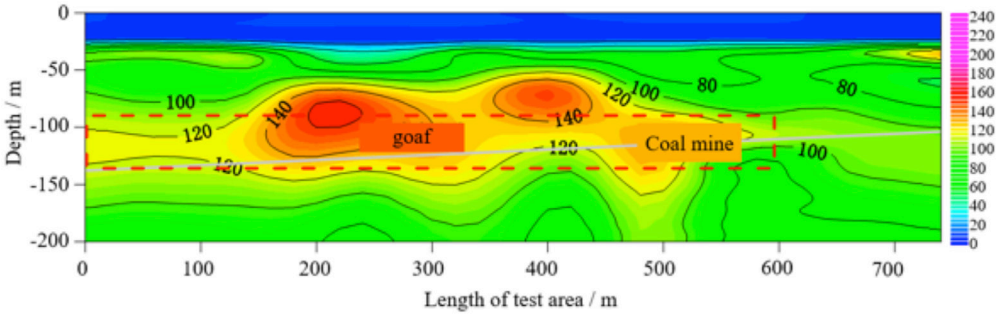


Figure 4 *Apparent resistivity section of line 3 after water plugging*

Drilling exploration results

The relationship between the water discharge per unit time and the evacuation time of the three drainage holes is shown in Figure 5. It can be seen that the drainage volume per unit time of the ZK9 drilling hole was 0 after February 19; the water drainage volume per unit time of ZK4 drilling hole and ZK10 drilling hole was 0 or close to 0 on March 24, and the goaf water was dredged. After the evacuation volume per unit time of each drainage hole reaches 0, there is no rebound in the drilling volume in the following days, indicating that the goaf supply water source has been cut off, the gob no longer has a stable supply water source, and the surface drilling grouting seals The effect of blocking the hydraulic channel is remarkable, and the purpose of blocking the water replenishing channel between the river and the goaf is achieved.

Conclusions

(1) Through the transient electromagnetic detection technology, it was proved that the area of the goaf water area is about 53435m^2, and the suspected low resistance abnormality of the water conduction channel was found in the east of the No. 3 survey line, and the water replenishing channel was determined.

(2) Through the water quality test and characteristic analysis of the goaf water, Quaternary aquifer water, Kuqa River water, and other aquifers and water bodies, it is determined that the Kuqa River water has a continuous direct supply to the goaf water, which is the water source for the goaf. A comprehensive detection system combining goaf water hazard exploration, drilling, and geochemical exploration has been formed.

(3) The comprehensive treatment technology combining ground grouting drilling to plug the water replenishing

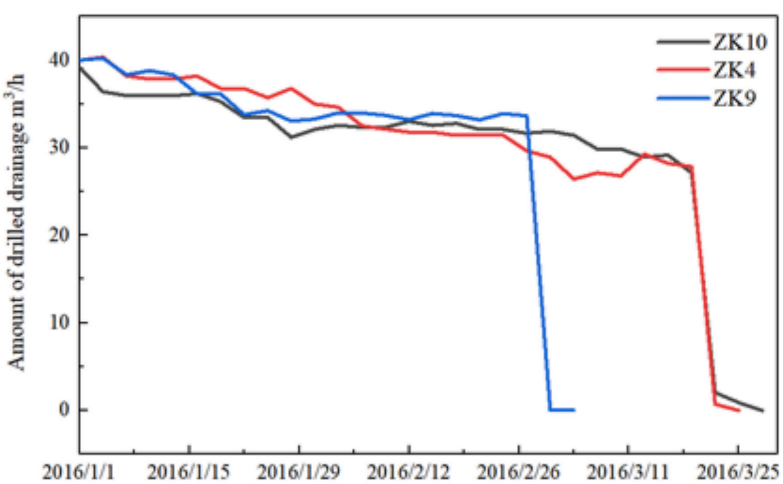


Figure 5 *Change curve of goaf water amount after plugging and draining*

channel and drilling and dredging was used to control the goaf water damage, and comprehensively evaluated the governance effect of the goaf water damage utilizing transient electromagnetic exploration and drilling exploration, which proves that the comprehensive management of goaf water damage has a good effect.

Acknowledgments

The authors thank all co-organizers for hosting the IMWA 2022 Conference. Amy Kokoska, Hetta Pieterse as well as Glenn MacLeod provided critical comments on earlier versions of this text.

References

Bogoslovsky, V. A., & Ogilvy, A. A. (1977). Geophysical methods for the investigation of landslides. Geophysics, 42(3), 562-571.

Bai, D., Meju, M. A., Lu, J., Wang, L., & He, Z. (2003). Numerical calculation of all – time apparent resistivity for central loop transient electromagnetic method. Chinese Journal of Geophysics, 46(5), 998-1010.

Chalikakis, K., Plagnes, V., Guerin, R., Valois, R., & Bosch, F. P. (2011). Contribution of geophysical methods to karst-system exploration: an overview. Hydrogeology Journal, 19(6), 1169-1180.

Chang, J., Su, B., Malekian, R., & Xing, X. (2019). Detection of water-filled mining goaf using mining transient electromagnetic method. IEEE Transactions on Industrial Informatics, 16(5), 2977-2984.

Danielsen, J. E., Auken, E., Jørgensen, F., Søndergaard, V., & Sørensen, K. I. (2003). The application of the transient electromagnetic method in hydrogeophysical surveys. Journal of applied geophysics, 53(4), 181-198.

Fitterman, D. V., & Stewart, M. T. (1986). Transient electromagnetic sounding for groundwater. Geophysics, 51(4), 995-1005.

Garcia, L. C., Ribeiro, D. B., de Oliveira Roque, F., Ochoa – Quintero, J. M., & Laurance, W. F. (2017). Brazil's worst mining disaster: corporations must be compelled to pay the actual environmental costs. Ecological applications, 27(1), 5-9.

Hu, X. W., Zhang, P. S., Yan, J. P., & Guo, L. Q. (2014). Improvement of means for interpretation of advanced water detection of tunnels by the transient electromagnetic method. Chinese Journal of Geotechnical Engineering, 4, 11-19.

Jing-cun, Y. U., Zhi-xin, L. I. U., Shu-Cai, L., & Jin-yun, T. (2007). Theoretical analysis of mine transient electromagnetic method and its application in detecting water burst structures in deep coal stope. Mei T'an Hsueh Pao (Journal of China Coal Society), 32.

Jiang, Z. H., Yue, J. H., & Liu, S. C. (2007). Prediction technology of buried water-bearing structures in coal mines using transient electromagnetic method. Journal of china university of mining and technology, 17(2), 164-167.

Kneisel, C., Hauck, C., Fortier, R., & Moorman, B. (2008). Advances in geophysical methods for permafrost investigations. Permafrost and periglacial processes, 19(2), 157-178.

Losekann, C., Dias, T. H., & Camargo, A. V. M. (2020). The Rio Doce mining disaster: legal framing in the Brazilian justice system. The Extractive Industries and Society, 7(1), 199-208.

Liang, D. X., Jiang, Z. Q., Zhu, S. Y., Sun, Q., & Qian, Z. W. (2016). Experimental research on water inrush in tunnel construction. Natural Hazards, 81(1), 467-480.

Li, X., Wu, J. J., Cao, D. M., Shen, M. F., & Li, C. (2006). Advanced geologic forecasting for unfavorable geological body with water-transient electromagnetic method. Journal of Geotechnical Investigation & Surveying, 3, 70-75.

Odintsev, V. N., & Miletenko, N. A. (2015). Water inrush in mines as a consequence of spontaneous hydrofracture. Journal of Mining Science, 51(3), 423-434.

Spies, B. R. (1980). A field occurrence of sign reversals with the transient electromagnetic method. Geophysical prospecting, 28(4), 620-632.

Shi, X. X., Yan, S., Fu, J. M., & Chen, M. S. (2009). Improvement for interpretation of central loop transient electromagnetic method. Diqiu Wuli Xuebao, 52.

Wang, Y., Yang, W., Li, M., & Liu, X. (2012). Risk assessment of floor water inrush in coal mines based on secondary fuzzy comprehensive evaluation. International Journal of Rock Mechanics and Mining Sciences, 52, 50-55.

Yang, H. Y., Deng, J. Z., Zhang, H., & Yue, J. H. (2010). Research on full-space apparent resistivity interpretation technique in mine transient electromagnetic method. Chinese Journal of Geophysics, 53(3), 651-656.