Exploration of Cambrian limestone groundwater runoff zones based on underground tracer tests

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Abstract To detect the occurrence conditions of Cambrian limestone (CL) groundwater runoff zones in Pingdingshan Coalfield No.2 mine and Wuzhai mine, the underground tracer tests of CL are investigated. The results show that groundwater velocity and permeability coefficient of CL aquifers is up to 3 011 m/d and 3 4233 m/d, which proved the existence of groundwater runoff zones. Reverse fault and fault fracture zone on both sides of No.2 mine fault is a key factor affecting the spatial distribution of runoff zone in CL aquifers. The determination of CL runoff zone lays the foundation for controlling water hazard from coal floor.

Key words Cambrian limestone groundwater, Intensive runoff zone, Tracer tests, Permeability coefficient.

Introduction

In the North China Coalfield (NCC), Ordovician or Cambrian limestone (CL) aquifers are the main water disaster threat in the process of overlying coal seam mining. Pingdingshan Coalfield is located in the NCC, the water disaster in the process of 2_1 and 1_5 coal mining is the floor CL aquifers, with large thickness, high temperature, high pressure and uneven karst development. By the influence of complex fault distribution and groundwater flow in coalfield, the runoff zones of the CL aquifers are developed. The runoff zones play an important control role in the CL water pressure, water temperature, and water inflow and water inrush. Therefore, the study on the distribution and water control characteristics of runoff zones will have the vital significance to the prevention and control of coal seam floor limestone water hazard.

Based on the connectivity test and mine geological data of No.2 and Wuzhai mine of the Pingdingshan Coalfield, the distribution characteristics and formation mechanism of the concentrated runoff zones of CL aquifers is analyzed to provide a theoretical basis for the prevention and control of mine floor water disaster.

Background of the research area

The No.2 mine and Wuzhai mine is located in the southwest wing of Likou syncline, the footwall of Guodishan fault (Fig. 1). The stratum trends at 100º- 120ºand plunge at 10º-30º, while the dip angle is 8º- 12º.There are 9 large and medium sized faults exposed in No.2 mine and Wuzhai mine field. Except for No.2 mine reverse fault, the vertical displacement of the other faults is small and short, which have little effect on coal mining. The No.2 mine reverse fault is located in the south centre of No.2 mine and Wuzhai mine. The hanging wall (northern part) rose and the footwall (southern part) dropped, striking at 90º- 145°, plunging at 0°- 55, with an extent of 5 km. The dip angle is 25°- 50, with a 5- 40 m vertical displacement, which increased with the decreasing of depth.

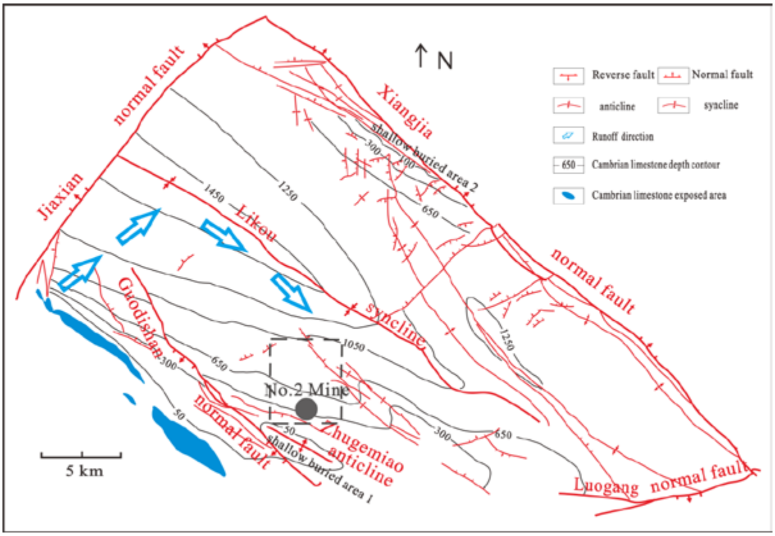

Figure 1 *Geological structure and buried depth distribution of the CL in Pingdingshan Coalfield*

The thick CL aquifers accept the ground water recharge from overlying Quaternary strata (with thickness of 20 – 50 m) near the Zhugemiao anticline. After that, the groundwater flowed along the direction of rock tendency from shallow to deep or along the fault fractured zone to the north east. Then, the drawdown funnel was formed in No.2 mine and Wuzhai mine, due to the control of draining depressurization.

Arrangement of traces tests

The tracer test is an effective method to detect the water conductivity of faults, the hydraulic connection between different aquifers, the movement state of the limestone groundwater, the direction of the extension of the runoff zone and estimate the groundwater flow velocity. To detect the distribution of runoff zones of the CL aquifers in No.2 mine and Wuzhai mine, 2 tracer tests were carried out in the mine from December 4 to 7, 2013 and March 14 to 15, 2014. The launching point (LP) is located in the fracture zone of No.2 mine main roadway west at an elevation of –86 m. Six receiving points (RP) were set in the underground water outlet in the first experiment, 4 of them are located in No.2 mine, and the other are located in Wuzhai mine (Fig. 2). The target layers are the CL aquifers, and the groundwater samples were collected from the receiving point of the CL aquifers. The launching and receiving data of tracer tests are shown in Tab. 1.

Iodide ion was used as a tracer because this element was undetectable in the CL groundwater prior to testing. The concentration of potassium iodide released at the LP was 250 mg/L, and the iodide ion concentration was 184.028 mg/L. Two hundred and sixty four water samples were collected during the two tests, and water samples were sent to the laboratory to determine the iodide ion content using ICS-1100 ion chromatography system. Tracer concentrations at RPs as well as travel times from the LP to RPs are presented in Tab. 2. Obviously, the iodide ion was detected in varying degrees from each RP.

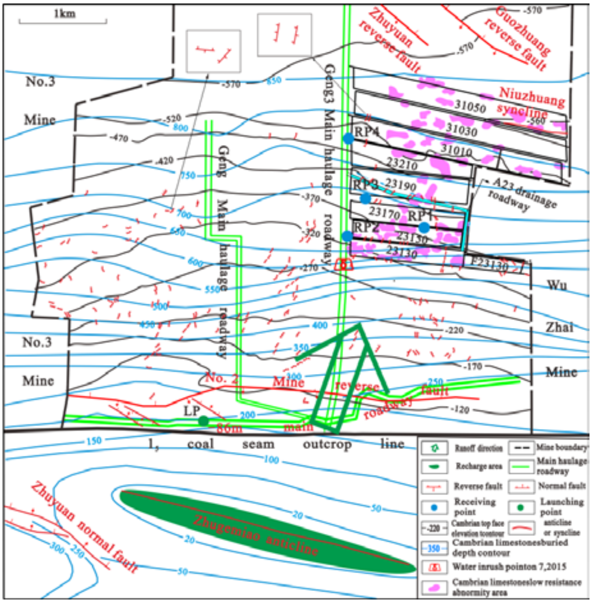

Figure 2 *Location of the launching point and receiving points of the tracer tests*

Table 1 *Location and parameters of the LP and RPs*

Test point	Location	Water level elevation of CL (m)	Distance to LP (m)	Water surface slope
LP	−86 m main roadway in No.2 mine	−86	0	
RP1	23170 air alley in No.2 mine	−395	3 162.54	0.0977
RP2	The intersection of 23130 air alley and Geng3 main haulage roadway in No.2 mine	−320	2 548.23	0.0918
RP3	23170 haulage alley in No.2 mine	−400	3 003.81	0.1045
RP4	The intersection of 31010 air alley and Geng3 main haulage roadway in No.2 mine	−500	3 587.75	0.1154
RP5	21020 haulage alley in Wuzhai mine	−400	3 791.79	0.0828
RP6	−320 m main haulage roadway in Wuzhai mine	−330	4 040.57	0.0604

Table 2 *Time and traces concentration of the LP and RPs*

Test point	The first time		The second time		Note
	Concentration (mg/L)	Time (h)	Concentration (mg/L)	Time (h)	
LP	184.028	0	184.028	0	The first time is 10:30 a.m., February 6, 2013; The second time is 9:30 a.m., March 14, 2014
RP1	0.008	50.00	0.073	18.50	
RP2	0.376	52.00	0.007	16.50	
RP3	0.017	45.50	0.095	17.50	
RP4	0.009	70.83	0.003	22.50	
RP5	0.011	30.50	No samples		
RP6	0.008	16.50	No samples		

Connectivity test of concentrated runoff zone

The CL groundwater velocity, using the distance between the LP and RPs, and the tracer travel time was calculated (Tab. 3). The estimated groundwater velocity is between 1 176 and 5 877 m/d, and its mean value is 3 011 m/d. The velocity value of No.2 mine and Wuzhai mine are respectively 2 656 m/d and 4 430 m/d.

Table 3 *Calculated values of groundwater velocity and permeability coefficients*

Mine name	Location	The first time		The second time	
		Velocity (m/d)	Permeability coefficient (m/d)	Velocity (m/d)	Permeability coefficient (m/d)
No.2 mine	RP1	1 518	15 537	4102	41 993
	RP2	1 176	12 811	3706	40 376
	RP3	1 584	15 162	4119	39 421
	RP4	1 215	10 534	3826	33 162
Wuzhai mine	RP5	2 983	36 035	—	—
	RP6	5 877	97 304	—	—

According to the hydraulic gradient and groundwater velocity, permeability coefficient of the CL aquifers in No.2 mine and Wuzhai mine could be calculated by using Darcy's law (Tab. 3). The estimated permeability coefficient is between 10 534 and 97 304 m/d, with a mean value of 34 233 m/d. The permeability coefficient of No.2 mine and Wuzhai mine are respectively 26 124m/d and 66 669 m/d.

According to the existing research results, when the permeability coefficient is greater than 50 m/d, it can be defined as the strong permeability aquifer. The permeability coefficient of the CL in No.2 mine and Wuzhai mine is far greater than 50 m/d, which illustrates the existence of runoff zones in CL aquifers. The field geological survey shows that the visual width of the LP is about 30-60 cm, which extends from north to west. Its extension is very deep and can be heard to contain water flow, which can prove the existence of the runoff zones in CL aquifers.

Genetic analyses of the runoff zones

The 3 middle size normal faults on both sides of the LP, which are parallel to each other, are distributed in the range of 600 m. It strike at north-west and plunge at north-east, with 15 m displacement. The northwestern part pinch out in the southern part of the No.2 mine reversed fault. At these composite zone of fault and thin out site, the strata are fractured and karst landscapes are developed. Therefore, it becomes a fractured zone with strong water permeability. The strike of the LP fracture zone is consistent with the medium normal fault, which could be caused by the medium normal fault. In brief, the fractured zone in the medium normal faults laid the foundation of the concentrated runoff in the CL groundwater, which in the south part of No.2 mine reversed fault.

As can be seen from Fig. 3, the CL aquifers at both sides of No.2 mine reversed fault were not entirely disconnect by the fault, and still maintained a certain continuity, which has no effect on groundwater flow. According to drilling data, in 29 boreholes, with the CL exposed, 50% of them are distributed on both sides of the No.2 mine reverse fault. This illustrates the CL karst landscapes were relatively developed on both sides of the fault. Therefore, the hydraulic connection of the CL aquifers on both sides of fault is close. The exposed information in the tunnel at the north side of No.2 mine reverse fault and the working face illustrated that small faults were well developed in the Geng2 mining area, with zonal distribution (Fig. 3). The average density of faults was 73 strip/km^2. These small faults mainly strike at NE, with the larger dip angle. This made the CL extremely broken, and also provided a channel for the groundwater flow from southwest to northeast and from shallow to deep.

According to the distribution of faults and fracture zones, the movement mechanism of iodide tracer could be obtained. The tracer injected into the site first flowed westward along the fracture zone. After flowing through the No.2 mine reverse fault, it flowed along the fault zone to the northeast. Then the iodide tracer could be detected when arriving at No. 1, 2, 3, 4, 5, 6 RPs.

The results of the tracer tests and the analysis of the fault fracture zone shows that the CL groundwater runoff zones were developed at both sides of No.2 mine reverse fault. The runoff zones are: from the LP at −86 m main roadway to the working face 23130, 23170 of No.2 mine and working face 21020 of Wuzhai mine. But at the RP4 (elevation of -500 m), the iodide concentration was the lowest of the 2 tracer tests, which illustrated the hydraulic connection between deep groundwater and shallow groundwater of the CL is not close. That means the groundwater runoff zone has not reached the depth of -500 m. Plane and vertical distribution of the CL groundwater runoff zones in No.2 mine and Wuzhai mine could be further determined by geophysical prospecting, hydro-geological boreholes and the exposed condition of tunnel.

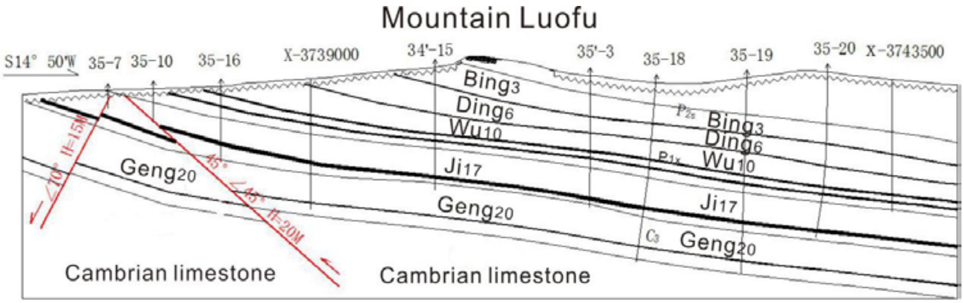

***Figure 3** Section map of inverse fault in No.2 Mine of Pingdingshan Coalfield*

Conclusions

The groundwater velocity of the CL groundwater in No.2 mine and Wuzhai mine estimated by the tracer test is 3 011 m/d. The permeability coefficient of the aquifers is 34 233 m/d. The above results proved the existence of the CL groundwater runoff zones.

Within No. 2 mine, small faults are well-developed, and have an average density of 73 strip/km^2. Well-runoff tunnels are developed within these fault zones. Indeed, small faults control the runoff of the CL groundwater.

The runoff zones provide a well channel for the CL groundwater in No.2 mine and Wuzhai mine that flow from southwest to northeast and the flow from shallow to deep plays an important role in the process of disaster prevention in coal mine.

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