Mine Water Disaster Issues of Carboniferous and Permian Coalfields at Eastern China and Their Technical Countermeasures- A Case Study on Wanbei Mining Areas

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ABSTRACT

The coal bed of Eastern China coalfields is mainly composed of Carboniferous and Permian coal measures strata, where mining safety is threatened by a variety of water disasters especially at the Wanbei mining areas. In this study, we first introduce the main mine water disasters in the East China Coalfields such as Cenozoic loose stratum “bottom containing” water inrush, sandstone fracture water inrush, Carbonic and Ordovician limestone Karst water inrushes, Column collapse water inrush, water related environmental pollution and resource loss, and the like. We then expatiate on 1) several measures for water disasters prevention and control with Wanbei Coal-Electricity Group as an example, including in-advance rigorous problem explorations, and mine water inrush mechanisms and related forecast and early-warning technology, as well as key technologies, 2) eight-in-one water disaster prevention and control work system, 3) "water-control and green mining" concepts, and 4) the prospective of future development.

Keywords: East China; Wanbei Coal Mines; Mine water issues; Technical countermeasures

INTRODUCTION

The coal beds of coal mines in Eastern China are mainly composed of Carboniferous and Permian coal measures strata bounded by the Cenozoic loose layer at the top and Middle Ordovician carbonate rocks at the bottom. Because the former often contain multiple sand aquifers and the latter is the most water-rich regional aquifer, they are the main water sources causing mine water disasters. During the past two decades, water inrushes occurred in more than 220 mines in China, causing more than 8,000 deaths, and economic losses of more than 30 billion RMB[1]. These incidents occurred particularly in mines of the Carboniferous and Permian coalfields in Eastern China.

The Wanbei coal mining area is complicated because of geological, tectonic and hydrogeologic factors. It belongs to the Xuhuai region, Luxi subzone, Huabei stratigraphic zone and has bedrock covered by the Cenozoic loose layer and stratigraphic structure composed, in geologic time sequence, of Cambrian, Ordovician, Carboniferous, Permian, Tertiary and Quaternary rocks. The tectonics of the coal-mining area is well developed with a total of more than 50 faults with falls ≥100 m [2]. Most water inrushes are sourced directly from the roof and floor, with fracture water as the main source. Some floor inrushes from Karst water sources also occur to a lesser extent. In addition, the mining area has other features that present a potential water filling risk, such as water-conducting karst collapse columns, aquifers at the bottom of loose layers in the limestones of the Taiyuan group at coal bed's floor, and at sandstone fractures of the coal bed's roof and floor [3]. In the history of mining, all types of typical and representative water disasters and severe water disasters have occurred in this area.

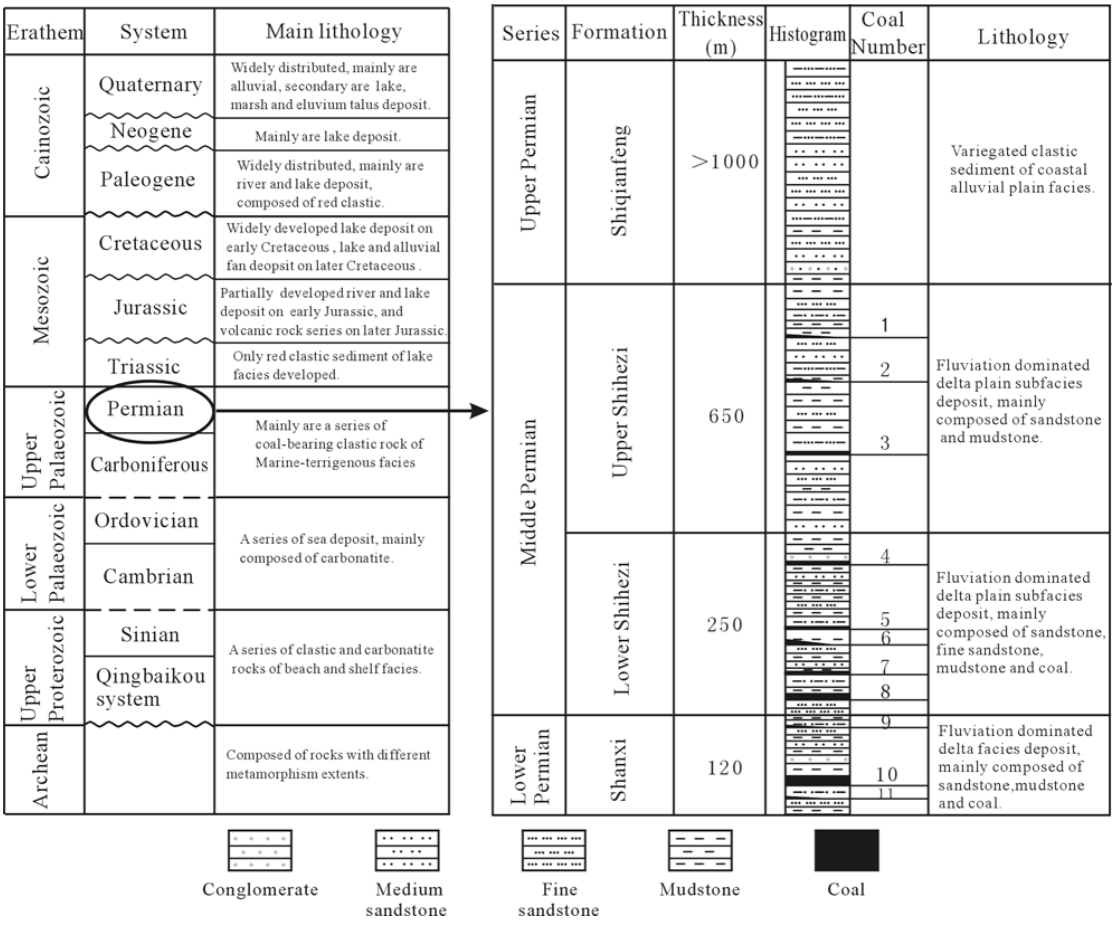


Figure 1 Stratigraphic integrated histogram

MAIN MINE WATER ISSUES IN WANBEI MINING AREA

The main mine water issues in Wanbei mining area include: 1) great threats to the mining faces positioned at shallow depth, caused by the well-developed Quaternary water-bearing strata located on the bottom of the Cenozoic loose layer and water-rich "ancient gullies" in some areas; 2) threats from abundant fracture water to the coal bed roof sandstones (faults), especially at new coal mine zones and faces; 3) threats from the confined aquifer to safely mining the No.10 coal bed floor, where the water inrush coefficient of high pressure limestone exceeds its critical value; 4) potential threats to safe production from many insidious karst collapse columns located near the coal-mining areas; 5) potential water hazards from goaf water in the mining areas; 6) potential environmental pollution from a large amount of mine water which flows in at an average rate of 310m^3/h and is highly mineralised, including high hardness, and some harmful elements if directly discharged [4]; and 7) a potential decrease in groundwater level, subsidence of the industrial complex located nearby, and the damage of mine shafts resulted from subsidence during coal production which consumes great amounts of municipal water mainly from the surface loose layer.

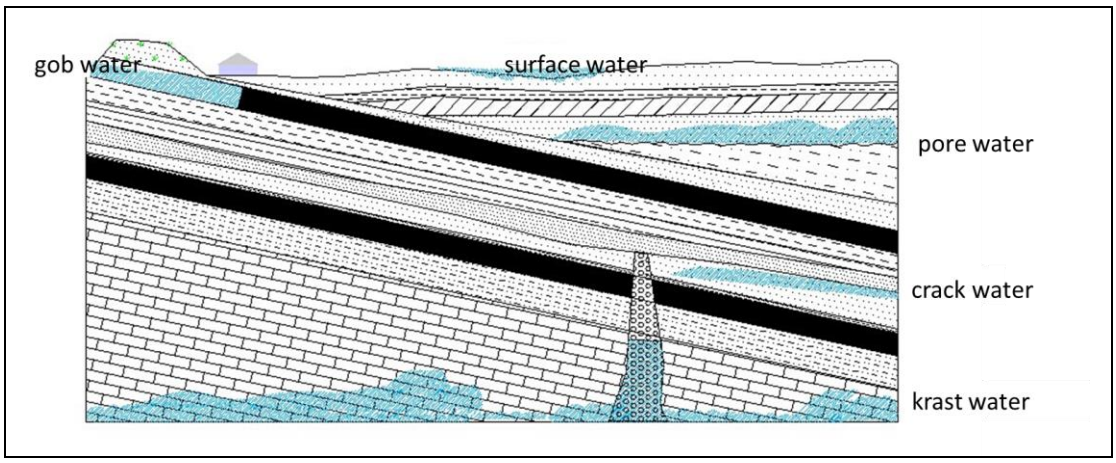


Figure 2 Schematic of coal mine water disasters

TECHNICAL COUNTERMEASURES AGAINST MAJOR MINE WATER ISSUES

Management System

It is necessary to establish 1) an effective three-in-one coal mine water disasters prevention and control system, consisting of a leadership subsystem, a technology management subsystem, and a technology, finance, and materials safeguard subsystem, 2) a sound eight-in-one coal mine water disasters prevention and treatment operation system of exploration, prediction, underground drilling, evaluation, measures, examination, monitoring, and protection, with the aim to form a complete mine water forecast and treatment pattern of "full members' attention, advanced equipment, leading technology and sound system.

Technical concept of water-controlling mining

The concept of water-controlling mining is proposed as 1) optimizing the rules for responding to catastrophes caused by sudden changes in rock and water coupling mining-induced rock fractures through the means of artificial and controllable factors such as pillar scale and mining sequels; 2) mastering the inherent and universal laws between catastrophe mechanisms and the natural/man-made controllable factors, i.e. understanding i) the enclosure conditions and control mechanisms of coal bed mining-induced fracture generation and propagation, as well as ii) the formation laws of channels connecting inrush water and collapsed sands; 3) proposing new water-controlling mining technical theory and engineering methods of coal seams subject to water inrush; 4) establishing and improving the water hazard prevention and treatment platform; and 5) completing the transition from passive water prevention and treatment to active water control. Overall, the following three objectives should be achieved: 1) water-protection and green mining; 2) safe and economic mining; and 3) clean production and resource conservation.

Exploration of advanced fine examination techniques of mine hydrogeological conditions

"Forecast and predict, explore when with doubt, investigate before digging, and mining after control" are not only the basic principles, but also the basic procedure of coal mine water disaster prevention and treatment. The exploration of mine hydrogeological conditions is based on forecasting and prediction [5]. In recent years, studies on the implementation of advanced fine examination techniques of mine hydrogeological conditions at Wanbei mine areas are mainly focused on the following areas:

1) High precision 3-D seismic exploration techniques: A series of processing techniques have been applied to achieve high precision 3D seismic exploration such as i) high-density, wide-azimuth 3D seismic data acquisition technology, ii) high-precision iterative static correction, pre-stack noise removal, amplitude maintaining, resolution improvement, pre-stack shifting processes, iii) forward modeling guidance, multi-character analysis, and comprehensive 3D visualization analysis [6].

2) Ground and underground collaborative, integrated advanced exploration techniques: Combined applications of the ground electric surveying, ground 3D seismic exploration, and dynamic data processing and interpretation with underground advanced geophysical exploration and advanced shield drilling exploration were implemented to accurately explore the hydrogeological tectonics, water-rich abnormal areas, and various water inrush risks for the purpose of safety production.

3) Underground multi-parameter monitoring and pre-warning and advanced exploration and treatment techniques of insidious water-bearing and -conducting karst collapse columns: Based on previous determination of insidious collapse columns, a management idea integrating "Geological pre-judgment, hydrological pre-warning, geophysical positioning, and drilling control" was implemented for active and preventive treatment. An online testing platform was established and studies on rapid identification of both water inrush sources and channels based on water quality, temperature, amount, and potential outflow points were conducted. Based on pre-judgment and following pinpoint positioning of collapse columns by integrated geophysical probing, both the underground roadway sealing-off and the ground, high-precision angle directional boreholes as well as multiple borehole combined dislocated grouting were jointly used for prevention of insidious collapse columns. Many such columns were found in advance and successfully treated, thus avoiding the occurrence of water inrush accidents.

4) Efficient, precise, and directional drilling exploration techniques: A series of techniques and measures such as borehole precise positioning and whipstocking branches, underground long-distance, nearly horizontal directional drilling, measurement while drilling, and safe and efficient construction in drilling and grouting were taken to achieve efficient, accurate, and directional drilling exploration.

5) Mixing water sources recognition techniques: The conventional water chemistry, trace elements, stable isotopes, and other means were applied to systemically study the primary control mechanisms of water chemistry in multiple aquifers. Combination of mathematical statistics, neural networks, and other measures was used to establish a water-sources identification model suitable for mine water prevention and treatment. An identification method for water source containing rare earth elements, a proportion calculation method for mixed water sources in mine were

proposed for the first time, which solved the technical difficulty in fast identification of mixing water sources at multiple water-bearing strata, and pioneered the studies on the mines' mixing water source.

6) Ongoing research projects include the seismic and electromagnetic method combined ground hydrogeophysical prospecting technique for mine water, the advanced exploration techniques integrated with roadway-borehole electromagnetic method, drilling and geophysical exploration, and the like.

Research on mine water inrush mechanisms and its forecast and pre-warning technology

Wanbei mining area is one of the earliest areas for studies and application of mine water inrush prediction and pre-warning technology. In this area, a series water hazards forecast and early warning techniques such as prevention and control of floor limestone water inrush, goaf water inrush, and roof's Cenozoic bedrock water inrush have been consecutively implemented, a mine water quality monitoring system and water chemistry information database of various water-filled and water-bearing strata were established, a water source identification model and calculation software were developed, and an effective early warning of mine water disasters was completed. In addition, researches in the mining area are focused on the deep-mining induced water hazard evaluation and prediction technologies as well as the real-time face water inrush forecast and early warning technologies. Considering the three prerequisites for the occurrence of mine water disasters (water sources, channels, and amount), a real-time, linear, and planar monitoring and early warning was implemented to achieve the goal of simultaneous monitoring and warning of mining-induced deformation and water inrush potentials. For example, a series of researches were conducted on water inrush prediction and early warning techniques of 1) floor limestone water at 6112 Face, II621 Face, and II615 Face of Hengyuan Coal Mine, 2) gob water from adjacent faces at 6131 Face of Qidong Coal Mine and 1018 Face of Wugou Coal Mine, and 3) Cenozoic roof and aquiferous floor at 7131 Face of Qidong Coal Mine. These researches on water inrush prediction and early warning techniques were effectively applied in water disaster prevention at mine faces.

Research and implementation of mine water disaster control technology

After years of research and innovation, Wanbei Coal Electricity Group co. Ltd. has solved a series mine water hazard control issues and constructed relatively complete and advanced coal mine water disaster prevention and treatment technology systems. Firstly, the insidious water-bearing and -conducting column collapse forecast and control technology has successfully detected insidious hazards in advance, thus avoiding many water inrush accidents in a timely manner. Secondly, the coal seams mining techniques under Cenozoic loose layer aquifers have been improved by using seam roof pre-split blasting and gangue backfill mining and implemented to effectively prevent and treat roof water inrush and sand downpour disasters. Thirdly, the coal seams mining technique on floor limestone confined water has been applied to perform a series of advanced face floors exploration, grouting reinforcement for ground floor ,and aquifer improvement, thus efficiently controlling limestone floor water inrushes. Fourthly, advanced

detection techniques of roof and floor sandstone fracture water were used to monitor and discharge water in a targeted manner, thus ensuring safe production. Below is an application example of presplit blasting technique for the face roof under confined water.

Qidong Mine coal measure stratum is covered by Cenozoic thick loose layers. Its bottom aquifer (the Quaternary aquifer) directly overlays the coal-bearing strata, and has characteristics of greatly varied lithologic composition, thickness, and water richness, as well as complicated ancient riverbed distribution condition, which directly threaten its safety exploitation. Since the operation of Qidong Coal Mine, its eight fully mechanized faces, Faces $3_2$22, $7_1$14, $7_1$12, $7_1$30, $7_1$21 and others, consecutively underwent 17 support failure accidents, among which, 15 ones were accompanied by water inrush. On November 25, 2001, both support failure and water inrush occurred at the first mined $3_2$22 Face, resulting in flooding the mine. The analysis of the Face data found that the development of damage to hard overburden stratum induced by fully mechanized mining was very large, the relationship between the maximum damage height of the overburden stratum and the mining depth didn't meet the general mining rules which complied by other mines in the hard overburden stratum exploitation. Under the conditions of Quaternary high water pressure and original fissures' great angle, longitudinal cracks development, the damaged height of overlying rocks sometimes increases significantly. Therefore, roof water disaster prevention and control for Qidong Coal Mine should focus on the determination of types and rational sizes of coal seam roof pillars and supports, the specific methods are as follows:

1) Roof's advanced pre-split blasting:

According to the physical characters of roof strata, advanced pre-split blasting of the face roof was taken. With the mining advancing, the construction blast parameters were constantly adjusted to reduce the periodic weighting step distance and the two-zone height of the roof. The measured two-zone height was 43 m, 10 m lower than that in the previous similar mining faces.

2) Comprehensive monitoring of roof water seepage physic field:

Through the monitoring of early warning boreholes in the face, the characteristics of ground electric field parameters of roof deformation and failure, as well as the migration of roof water seepage in its face mining process were measured to rightly forecast the face mining states.

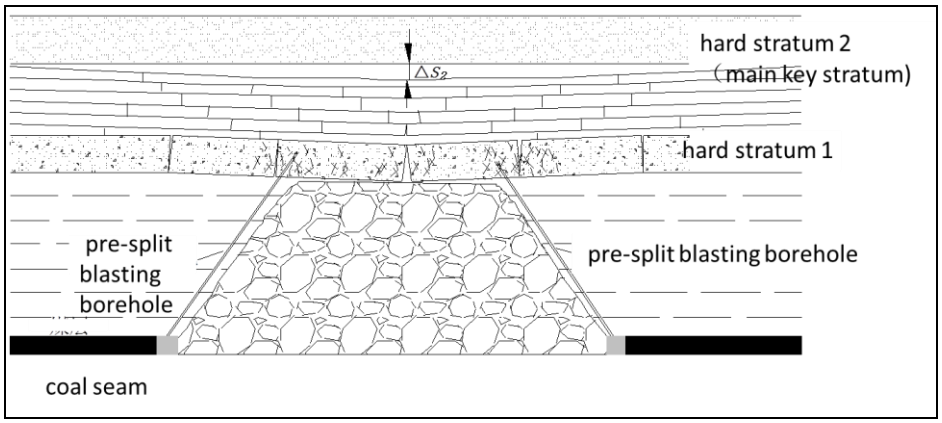
3) Application of high resistance supports:

According to the combination of roof rock properties, high resistance supports were used to strengthen the face's supporting capacity for preventing support failure, water inrush, and roof caving, etc.

4) Ground monitoring and early warning:

Through long monitoring boreholes into the Quaternary strata, the level of water in the strata was real-timely tested; then, according to the relationship between the level of water and the cycle of

periodic weighting, face mining advanced scientifically under a reasonable wall pressure to avoid support failure.



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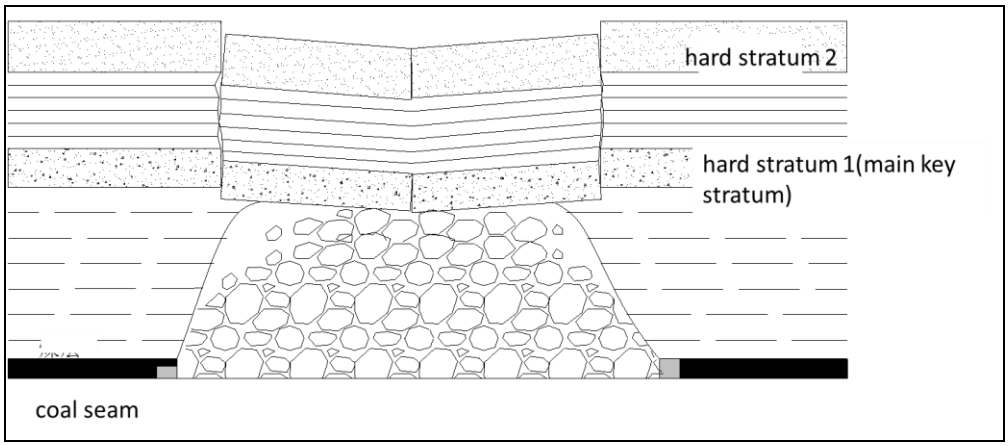

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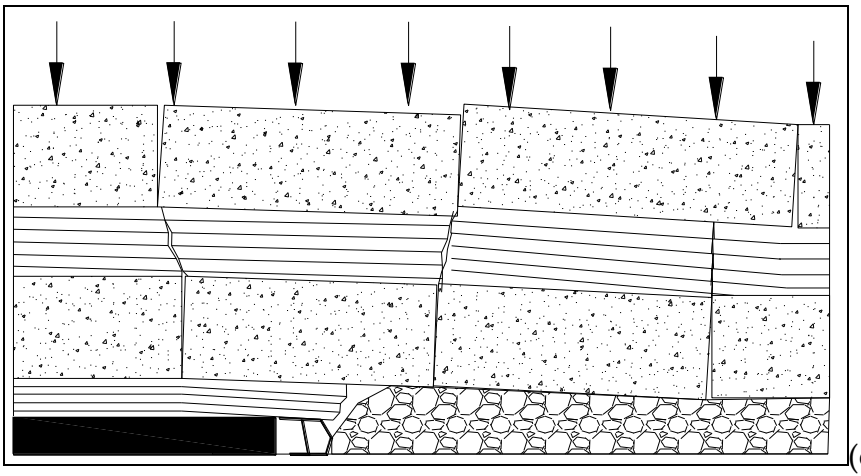

(c)

Figure 3 Schematic of face roof pre-split blasting

Mine water resources utilization technology

Wanbei mining area actively launches a series of researches on groundwater hydrogeochemistry, mining area water environment and quality assessments, mine water resources reclamation and utilization, forms the mine water drainage and supply combined technology, the reasonable mine surface water and underground water adjustment and distribution technology, the mine waste-water treatment and reclamation technology, and the three-in-one optimized management technology of mine water discharge, water supply, and eco-friendliness [7]. The mining area has installed the water treatment device to each mine in the area, and the treated mine water is used for mine coal production and living water, achieving 100% mine water process and utilization .At the same time, the utilization of mine water directly reduces the water withdrawal from the surface loose layer, and protects the natural balance of the surface phreatic water, thus avoiding sink age of surface water level, subsidence of the industrial squares, well-bore failure, and other issues caused by excessive water withdrawal from the surface loose layer and having very significant benefits to environments and society.

CONCLUSIONS

Wanbei Coal Electricity Group uses" water-controlling exploitation", safety and efficiency as its motto, prevention of mine water disasters as its focus, and with exploration, forecast, prevention and treatment, and comprehensive utilization of mine disasters as its main line. The group conducted a series of in-depth researches from the aspects of 1)mine water containing laws, 2) hydrogeologic precise exploration techniques, 3) water inrush mechanisms and forecast and early warning techniques, 4) water hazards prevention and treatment techniques,5) mine water resources utilization techniques, to develop and apply such key technologies as 1) the prevention and treatment of mine water disasters, 2) the comprehensive utilization of mine water resources, and 3) the protection of water environment, and takes a lot of measures to tackle the challenges of mine water issues and form a comprehensive prevention and treatment and management system to prevent and control mine water disasters and coordinate water resource and eco-environment protection with the hope to achieve harmonious development between human and nature.

Overall, Wanbei Electricity and Coal Group has formed a set of advanced coal water disaster prevention and treatment technologies and management patterns and ensured safe mining and production for consecutive 13 years. These techniques have been widely promoted and applied to North China Coal Mines located in the eastern China with significant benefits and achievements. In 2014, Wanbei Electricity and Coal Group established the National Engineering Technology Research Center for Coal Mine Water Disaster Prevention and Control to improve China's overall technological level, tackle coal mine water issues and promote safe, eco-friendly, and healthy development of the coal industry.

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