An Interdisciplinary Response to Mine Water Challenges - Sui, Sun & Wang (eds)
©2014 China University of Mining and Technology Press, Xuzhou, ISBN 978-7-5645-0125-5

Advanced Prospecting and Composite Identification Method for Ultrahigh Pressure-Loaded Water-conducting Hidden Collapse Columns

Shijie Tong
Renlou Coal Mine, Wanbei Coal & Electricity Group Co., Ltd., Suzhou, Anhui, China

Abstract Water-conducting hidden collapse columns are highly disastrous geological structures posing enormous challenges to prospecting. In order to realize advanced judgment and precise prospecting of hidden collapse columns, the author puts forward a composite prospecting method which combines advanced geological judgment, water quality advanced warning, geophysical prospecting and drilling-based delimitation. For advanced geological judgment, development rules of collapse columns in the mining area can be identified on the basis of hydrogeological conditions and historical disastrous condition analysis for collapse columns. For water quality advanced warning, such data of water points as water flow, water quality, water temperature and water pressure can be monitored and analyzed to identify deep-lying, high-temperature, high-hardness and stable pressure-loaded water sources. For geophysical prospecting, abnormal target areas are delimited through a composite surface-to-subsurface geophysical prospecting technology. For drilling-based delimitation, directional drilling technology is applied, successfully identifying the spatial location and bounds of collapse columns. In conclusion, systematic advanced judgment and precise advanced prospecting for the water-conducting hidden collapse columns in Roadway II5_1 of the Renlou Coal Mine help provide a significant geological basis for advanced responses to such concealed columns and prevention of major water disasters as well as a technical basis for the prospecting of water-conducting collapse columns under similar conditions.
Keywords ultrahigh pressure-loaded, water-conducting collapse column, advanced prospecting, composite identification method, water calamity prevention

Introduction

Water inrush originating from Ordovician limestone aquifers and conducted by Karst collapse columns constitutes one of the severest and costliest types of water inrush disasters in coal mines. It is indicated by statistics that several of the most serious water inrush incidents in history were incured from collapse columns (Yin et al. 2004). In terms of geological origin, the hidden collapse columns are normally deep-buried and hard to be prospected. As for research on the control & prevention of collapse columns-induced water inrush, it is concentrated mostly on post-disaster treatment, while there are few achievements in research on advanced prospecting and control steps. In recent years, there is an explosion of problems with coaling mining above high/ultrahigh pressure water sources, posing an escalating impact on Ordovician limestone aquifers. As the impact of the hidden collapse columns are attracting more and more concerns, effective methods of advanced prospecting and preventative treatment for collapse columns have become one of the most important tasks of water inrush prevention now.

Two water-conducting karst hidden collapse columns were discovered and treated during the production of the Renlou Mine affiliated to Wanbei Coal Electricity Group Co., Ltd. Taking the trial production in 1996 for example, water inrush incident of a collapse column conduction nature happened to the initial working face, i.e. Working Face $7_2$22, the water inrush reached 34,570 m^3/h to flood the whole mine, resulting in a huge loss of RMB350 million yuan. In 1999, a roadway of Working Face $7_2$18 had water quality abnormality, from which it is inferred that there may be a water-conducting collapse column ahead. Then advanced treatment steps are taken by combining subsurface prospecting and surface drilling, grouting and blocking (Duan 2005). It is demonstrated by the two collapse columns bared in the mine that there exists a geological setting conducive to the formation of collapse columns

(Fang et al. 2008); moreover, along with the increase of the mining depth, Ordovician limestone faces an increasing water pressure, water inrush from the hidden collapse column will be more serious, therefore, closer monitoring must be conducted on the hidden collapse columns during coal production.

In 2010, water inrush incurred from an anchor bolt of the roof during the construction of Roadway $II5_1$. Various types of prospecting were conducted, i.e. subsurface prospecting, surface geophysical prospecting, chemical prospecting and drilling. Through general analysis, the conclusion was drawn that there was a water-conducting collapse column. However, the specific location is unclear and further prospecting and treatments are needed. In order to completely remove the collapse column, advanced prospecting and identification methods are taken to the ultrahigh pressure-loaded water-conducting hidden collapse column. A composite prospecting technology is developed to combine advanced geological judgment, water quality advanced warning, geophysical prospecting and drilling-based delimitation into one entity. Therefore, an important geological basis for conducting pre-disaster prospecting of ultrahigh pressure-loaded and water-conducting hidden collapse columns, performing grouting for treatment and preventing drastic disasters is provided accordingly.

Basic background condition

Location of the Mine

Located at the Linhuan Mining Area in the north of Anhui Province. Renlou Mine is about 30 km from the boundary between Suixi County and Mengcheng County in southwest of Suzhou City, the mine is under the joint jurisdiction of Nanping, Suixi and Xutuan, Mengcheng. The mine is bounded by a boundary fault and the Suntuan Mine on the north, Fault F_7 and Xutuan Mine on the south, Fault F_{23} on the southeast, the plane projection of the -800 m contour line of Seam 3_1 on the east, and the outcrop line of Seam 11 on the west. The mine measures 4-7 km breadthwise and 8-11 km lengthwise, totaling an area of 42.0705 km^2. The range of mining depth is -315-720 m (fig. 1).

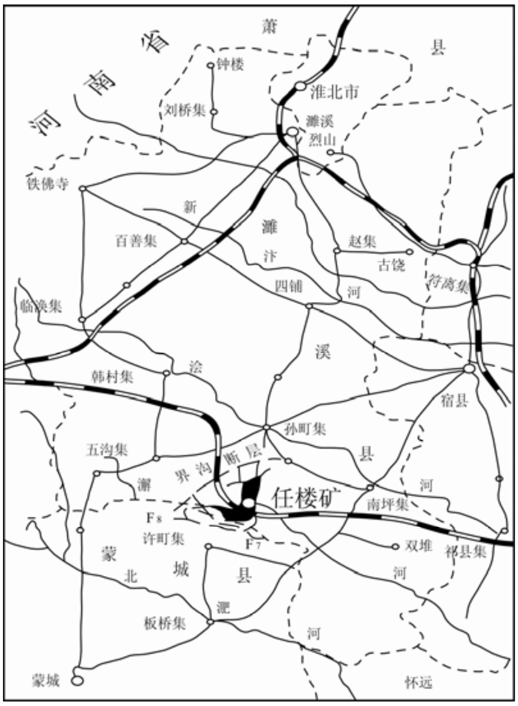

Fig. 1 Location of the Renlou Mine

Hydrogeological background

The greater coalfield of which the Renlou Mine forms a part is a totally hidden coalfield with an overburden of Quaternary loose aquifers. The coal-measure strata belong to the Permo-Carboniferous period and the basement of the coal measure comprises Ordovician karst limestone. The direct water-impregnated aquifers include the sandstone fissured aquifers in the roof and floor of the coal measure. The indirect water-impregnated aquifers include the Quaternary aquifer at the bottom of the Quaternary strata, the sandstone fissured aquifer in the coal measure, the limestone aquifer in Taiyuan Formation and the Ordovician limestone aquifer (hereinafter referred to as "QLA"; 290 m away from Seam 7_2). If there isn't special giant water-conducting perpendicular structure, it may be impossible to occur direct inrush of QLA water.

Water inrush in roadway II5$_1$

During the morning shift on June 8, 2010, water inrush occurred at a rate of roughly 1 m^3/h where an anchor bolt of the roof is located when the construction of Roadway II5$_1$ came to roughly 28 m ahead of Point G_{33}. Chemical assay results show that total hardness is 8.34°dH and there is no permanent hardness. After the construction progressed to 31.5 m ahead of Point G_{33} on June 9, the volume of water inrush are increased slightly that makes water flow in the three water detection holes in the roof be about 30 m^3/h. From the night shift on June 10, permanent hardness began to occur until total hardness rose to 60.58°dH, permanent hardness came to 48.81°dH, water temperature came to 41℃ and flow rate came to 8 m^3/h on Nov. 7, 2011. According to the preliminary water analysis for the frontal roof of Roadway II5$_1$, the occurrence of permanent hardness plus the general rise in total hardness and permanent hardness is indicative of the likelihood of a makeup of deeper-lying high-hardness water.

Geological predictive analysis

Roadway II5$_1$ is located inside the protective pillar of the industrial square, with a design length of 493.3 m and a floor elevation of -718.6-720.1m. The range of the working face is 25m±Roof 5$_1$. The minimum vertical distance of the roof from the bottom of the overlying Quaternary aquifer is about 440 m, and the minimum vertical distance of the floor from the bottom of the first limestone stratum of the underlying Taiyuan Formation is about 210 m.

According to the early-stage exploration data, the strata of Working Area II5$_1$ is a monoclinic form and the mode of occurrence is 90°∠16°±. In terms of lithological characters, the exposed lithologies of roadway include (1) The first rock type is grayish fine sandstone comprising primarily medium-bedded quartz with slight occurrence of dark mineral and calcareous argillaceous cement; (2) The second rock type is gray massive mudstone with slight occurrence of alumina material and scaly phytolith. Normal Fault DF_8 is bared 3 m (floor) and 12 m (roof) ahead of Point G_{33} (T-714.5), featuring a mode of occurrence of 295°∠60-69°H=10 m and the occurrence of a 1m shattered fault zone with no water seepage. There are several small developed faults in the central and lower parts of the fine sandstone making up the frontal fault surface, and there is no developed deep and large fault structure in the working area.

To sum up, the following conclusions may be drawn from the two collapse column-associated water inrush incidents happened in Renlou Mine, analysis of karst development conditions and local geological geological structure investigation: a) Renlou Mine has the geological structure and hydrodynamic conditions necessary for karst development (Fang et al. 2008); b) Comprehensive analysis excludes the water-conducting fault as the cause for abnormal water occurrence in Roadway II5$_1$. Therefore, it can be inferred from the above advanced geological judgment that there is suspected occurrence of deep water source-conducting collapse columns based on the development of local fissures and faults and the exclusion of the fault as a water-conducting media for Roadway II5$_1$.

Early warning and identification of water quality

Water inrush flow analysis

Water inrush occurred at an initial flow of roughly 1 m^3/h where an anchor bolt of the roof in Roadway II5$_1$ is located roughly 28 m ahead of Point G_{33}. The flow climbed slightly at 31.5 m ahead of G_{33}, with three water detection holes in the roof coming to an aggregate flow at rate of about 30 m^3/h. The single hole (size: Ø32 mm) featured a maximum rate of 16 m^3/h, which stands steadily at 8 m^3/h after initial grouting and sealing, indicating no tendency of a downturn. See Fig. 2 for details of the observed water flow.

Fig. 2 *Aggregate flow curve of the water point 28.5m ahead of Roadway II5$_1$ (-720 m)*

The comprehensive analysis of stable make-up water sources are made based on the increases of effluent water and stability of water flow after being sealed.

Analysis of water temperature change

The water temperature stood at 33℃ on 8 June 2010, then, it was increased gradually, it reached to 41℃ on Nov. 29, 2011 (see fig. 3 for details). Normally, the geothermal gradient of the Renlou Mine features an increase of 3℃/100 m; therefore it can be inferred that the local normal geothermal temperature stood at 34-36℃, indicating an abnormality of water temperature in Roadway II5$_1$.

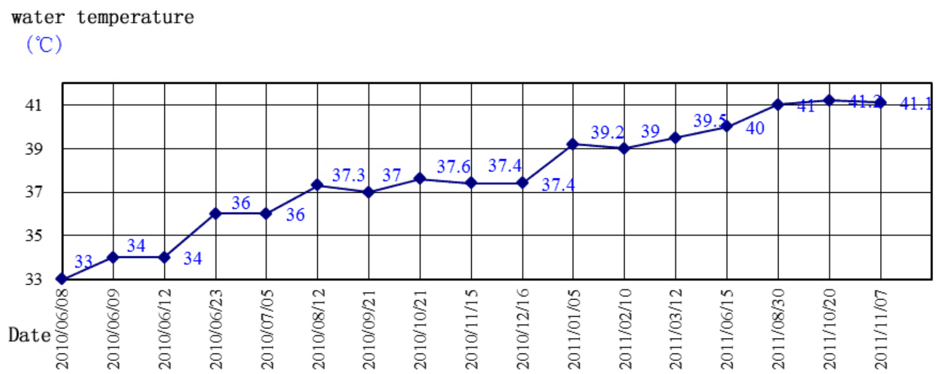

Fig. 3 *Water temperature change curve of the water inrush points in Roadway II5$_1$*

Considering an abnormal water temperature which exceeds the normal geothermal temperature, it is preliminarily concluded that the water source is a deep-lying high-temperature water source.

Water quality advance warning

During the morning shift on June 8, 2010, water inrush occurred at an initial flow rate of roughly 1 m^3/h where an anchor bolt of the roof in Track Roadway II5$_1$ was located roughly 28.5 m ahead of Point G_{33}. Chemical assay results showed that total hardness was 8.34°dH and there was no permanent hardness. During the night shift on June 10, permanent hardness began to occur until the total hardness increased to 60.58°dH and the permanent hardness stood at 48.81°dH on Nov. 7, 2011. Between initial water inrush on June 8, 2010 and Nov. 2011, the total hardness increased from 8.34°dH to 60.85°dH and the permanent hardness increased from 0°dH to 48.81°dH. On the whole, there was a trend of increases in total hardness and permanent hardness (see fig. 4).

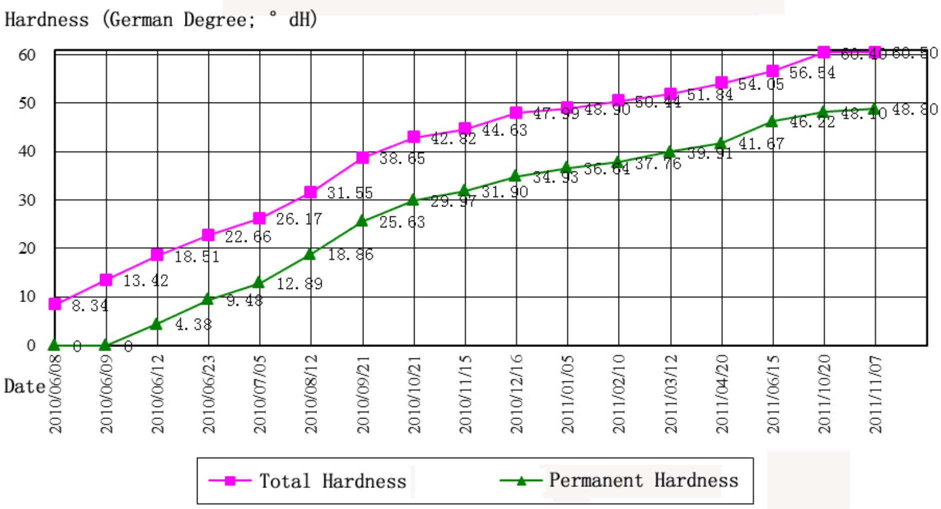

Fig. 4 *Water hardness change curve of the water inrush points in Roadway II5$_1$*

Because of the occurrence of permanent hardness plus the general trend of increases in total hardness and permanent hardness for the water inrush in the roof of Roadway II5$_1$, there might be a makeup of deeper-lying high-hardness water (Ge et al. 2007).

Considering such abnormalities as increases in water inrush of Roadway II5$_1$, water temperature, water hardness and water pressure, it is concluded that the water points might receive water makeup from deep-lying, high-temperature, high-hardness and steady sources of water (Gui 2005). It is confirmed that there might be a suspected karst hidden collapse column where the frontal Roadway II5$_1$ is located on the basis of the above advanced geological judgment. The column might constitute a serious threat to the workplace safety of the mine.

Composite geophysical prospecting locating

It is confirmed that there exists a water-conducting hidden collapse column on the basis of the above advanced geophysical judgment and water quality advance monitoring. Therefore, the Paper puts forward the adoption of a composite geophysical locating technology which combines surface prospecting and subsurface prospecting. At the surface level, the collapse column is prospected by employing 3D reflection seismology and TEM (Transient Electromagnetic Method). At the subsurface level, advanced prospecting is conducted for Roadway II5$_1$ and the frontal side and roof & floor of Roadway II5$_1$ by employing five methods, i.e. TEM, high-resolution resistivity imaging, parallel electrical method, seismography and GPR (Ground Penetration Radar) (Liu et al. 2008). The target area is therefore contoured, providing a basis for drilling results verification.

Surface geophysical prospecting

As a first step, surface prospecting based on 3D reflection seismology and TEM (Transient Electromagnetic Method) is conducted above Roadway II5$_1$. The results are listed as follows:

(1)A fissure development zone occurs in the west vicinity of the water point, since reflected waves feature irregularity and incoherence where the top boundary of the Ordovician limestone aquifer is located;

(2)There is a suspected collapse column about 350 m from Roadway II5_1;

(3)There are water-abundant zones distributed in different layers southeast of Roadway II$5_{1,}$ with abnormal superimposition. Also, there are water-abundant zones distributed in the roof of Seam 5_1 and floor of Seam 7_2 southwest of Roadway II5_1.

Subsurface geophysical prospecting

(1)TEM: It is found that there is a strongly water-enriched body lying 60-110 m away from Roadway II5_1, 20-65 m horizontally away from Roadway II5_1 and 30 m perpendicularly away from the floor;
(2)TEM plus parallel electrical method: strongly water-enriched bodies are found: one lies 0-50 m from the Roadway II5_1 and 70-100 m and 65-110 m horizontally from Roadway II5_1; and the other lies 30-80m horizontally from Roadway II5_1. Two water-abundant zones are discovered..
(3)Seismography plus High-resolution Resistivity Imaging: A developed fissure zone occurs 160 m behind Roadway II5_1 and 50-80 m away from the roof. 130-20 m from Roadway II $_1$ lies a strongly water-enriched and developed fissure zone, which is hydrodynamically associable with deeper water-bearing rock strata. The structure, along with the rock mass fissures, fracture zone or rock strata interface, forms an underlying water-conducting passage.
(4)High-resolution Resistivity Imaging: Three abnormal low-resistivity zones occur within 10-90 m of Polygonometric Point G34 in the direction of Roadway II5_1. It is suspected that the abnormal zones are attributable to relatively developed fault fissures and relative water enrichment.
(5)TEM: There is obvious abnormal low-resistivity, which is attributable to water enrichment as a result of fissure development in local strata.
(6) GPR: Three abnormal zones are found in the roof, one abnormal zone is found in the floor and one abnormal zone is found ahead of the heading end.

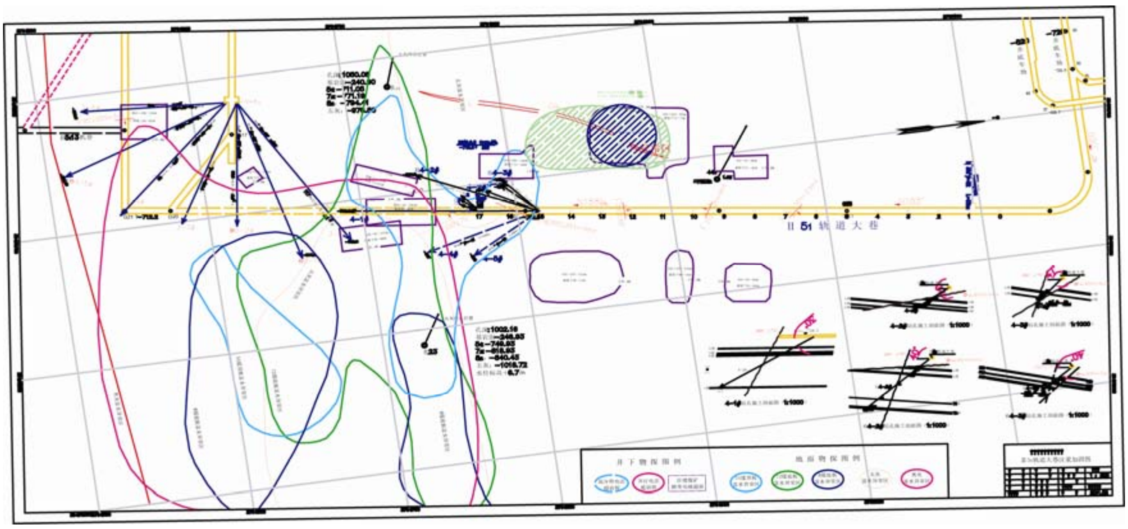

Fig. 5 *Composite feophysical figure for the water-conducting collapsed column*

Based on the comprehensive analysis of the above geophysical prospecting achievements and other data, the water-conducting passage of Roadway II 5_1 is a water-conducting collapse column, which is located 65-115 m behind Roadway II 5_1 and 38-65 m horizontally away from the roof according to preliminary analysis (see fig. 5). The above results may be used as the target area of prospecting in surface drilling.

Drilling-based delimitation

Based on the early-stage advance judgment of the hidden collapse columns, we have implemented the composite geophysical prospecting to determine the key target area for drilling verification. As per above study, drilling-based verification is used to investigate the spacial location and development information on the collapse column, The following holes have been drilled such as surface holes (drilled for verification purposes), subsurface holes (drilled in the roadway) and surface directional drilling & grouting holes (Ge 2007). The drilling and verification of the abnormal zones identified by composite geophysical prospecting reveal the source of the water inrush and the spatial locating & development of the water-conducting hidden collapse column.

(1)Subsurface Drilling & Exploration: Altogether 19 holes in three groups are drilled for Ginney $II5_1$ exploration, and six holes are drilled for Roadway $II5_1$ exploration.
(2)Surface Directional Drilling (or cross drilling; see fig. 6): Altogether four holes are drilled to explore the collapse column (the first of these holes succeeded in revealing the column) and one branch hole is drilled to explore the superimposition abnormality of the subsurface geophysical prospecting. All four holes of the former type succeeded in revealing the collapse column.

The above drilling operation succeeded in precisely identifying and delimiting the spatial location, boundary and height of development of the collapse column. Meanwhile, the drilling operation proved the reliability and effectiveness of the judgment & exploration method for hidden collapse columns, thereby providing an important reference of the identification and spatial locating of hidden collapse columns.

Major Conclusions

1)Through an analysis of the development rules of collapse columns and the historical records of collapse column-related water inrush, the Paper helps define the hazard of hidden collapse columns, thereby providing an advanced theoretical basis for collapse column treatment.

2)The paper approaches the preventative exploration and treatment of collapse columns. Also, it suggests a composite, systematic exploration method, which combines advanced geophysical judgment, water quality advanced warning, geophysical prospecting and drilling-based delimitation to precisely locate columns spatially and identifying their form of development.

3)The drilling-based exploration of collapse columns involve the adoption of high-precision directional drilling of multiple holes to effectively and precisely delimit the boundary of collapse columns, provide a basis for follow-up treatment.

References

Duan ZW (2005) Fast identification and exploration of water-conducting hidden collapse columns in the Renlou Coal Mine. Journal of Xi'an University of Science and Technology 24(3): 268-270

Fang P, Wang HL (2008) Preliminary analysis of the genesis and distribution rules of karst collapse columns. Coal Engineering (11): 84-85

Ge HQ (2007) Application of directional drilling technology to the treatment of collapse columns. China Coal Field Geology 19(A01): 19-20

Ge JD, Wang JM (2007) Study on geochemical advanced warning on water-conducting collapse columns in the Renlou Coal Mine. Coal Engineering (9): 85-88

Gui HR (2005) Study on the hydrogeophysical and geochemical behavior and discrimination mode of groundwater in the Wanbei Mining Area. Hefei: University of Science and Technology of China, Doctoral Dissertation

Liu ZX, Liu SC, Yu JC (2008) Application of composite geophysical exploration technology to collapse column. Geophysical and Geochemical Exploration 32(2): 212-215

Yin SX, Wu Q, Wang SX (2004) Preliminary study on characteristics and genesis of karst collapse columns in north China coal mines. Chinese Journal of Rock Mechanics and Engineering 23(1): 120-123

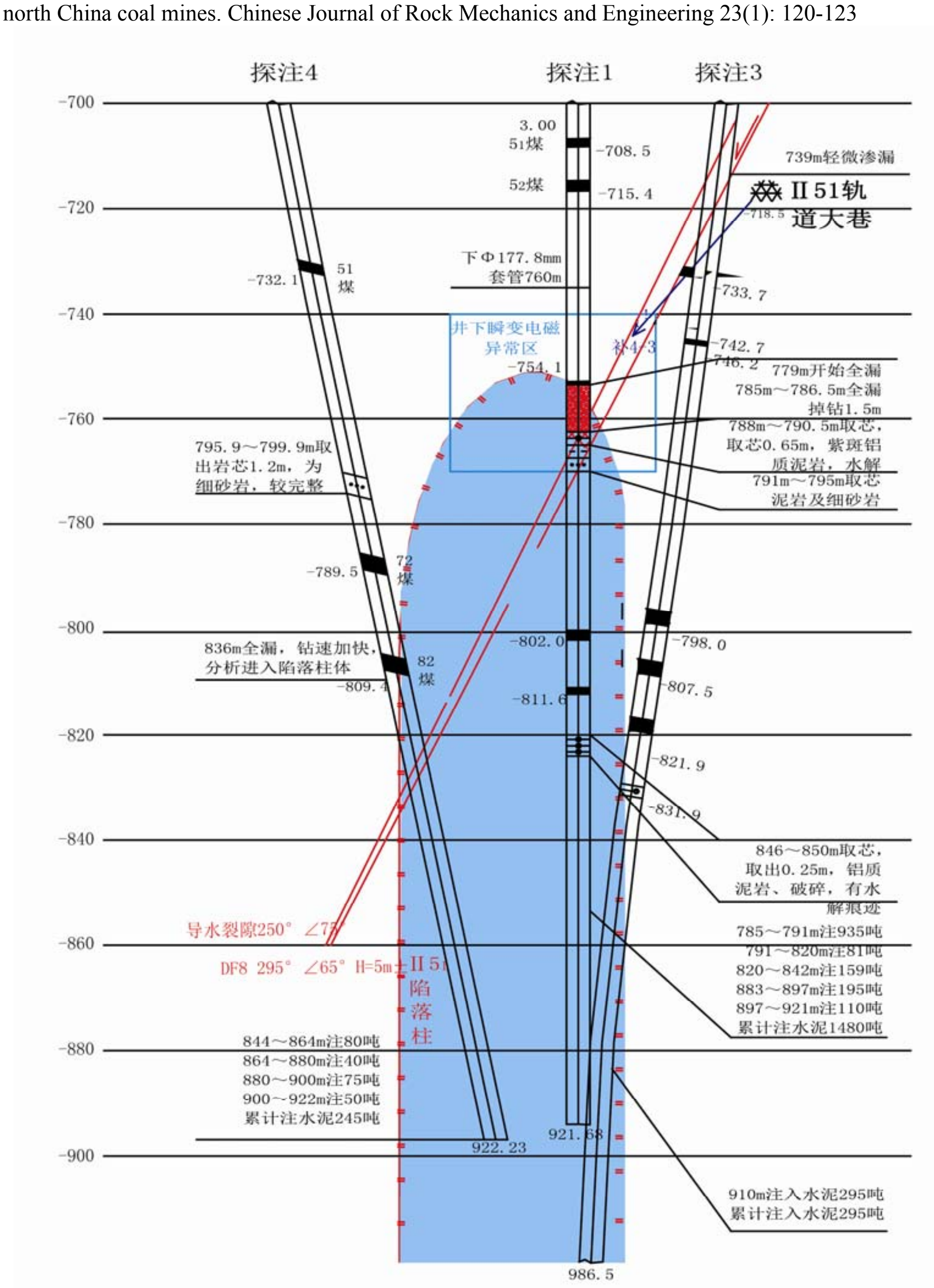

Fig. 6 *Surface direction drilling-based delimitation of the concealed column (part)*