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Evaluation on floor water inrush danger of Weibei during mining over pressurized water and prevention countermeasures to the water disaster

With increasingly high comprehensive mining intensity to the coal resources and wider mining width of the mining area, the mines of Chenghe No.2 mineral are getting deeper and deeper and the hazard from the high pressure water of Ordovician limestone of #5 coal bed bottom is getting increasingly intense, which will seriously influence safety production of the mines. Therefore, how to liberate the under draught coal reserves of #5 water body is a difficult problem as well as the key issue to ensure safety production of the mines. As for this, the first author will combine with the hydrogeological condition of Chenghe No.2 mineral in this article, and adopt standardized water bursting coefficient method to evaluate the water insulation capability of Taiyuan formation #5 coal floor upon comprehensive analysis on influencing factors of floor water inrush, to consider whether to divide #5 coal floor under water-diversion failing zone thickness into different compensated mining areas, having predicted water inrush probability of the mining area in the future, and to release the coal reserves threatened by Ordovician water disaster. The result shows: (1) Among the factors that influence #5 coal floor water inrush of Chenghe No.2 mineral, head pressure of the aquifer is motive power of water inrush, the floor strata lithology and its combination feature are safety barrier for confined water extraction, and geological structure is in most cases the channel of floor water inrush; in accordance with the latest stipulations on mine water prevention and control and design specifications on coal mine water prevention, the first author takes 0.06MPa/m and 0.1MPa/m as boundary conditions of critical water inrush coefficient, divides #5 coal floor water-resisting layer into compensated mining extremely dangerous zone, dangerous zone and exploitable zone; (2) As to areas that mining above the pressured water are inapplicable in consideration of the coal floor water-diversion failing zone, latest water bursting coefficient formula can be adopted to realize safe compensated mining, which has reduced danger of floor water inrush, and satisfied the requirements of safe compensated mining of this mining area; (3) Without considering condition of the water-diversion failing zone, it can liberate compressed coal reserves of #5 coal floor that are threatened by Ordovician limestone water disaster and enhance the recovery ratio of coal resources; (4) Based on the evaluation results of floor water inrush danger, the author has proposed major water disasters to the coal floor and prevention countermeasures, which has provided valuable reference for safety compensated coal mining above seam floor pressure-bearing water body of Chenghe minerals and even Weibei coalfield, brought tremendous social and economic benefits, is of practical significance for realization of green coal mining, and will drive local economic development, thus worth being generalized and applied.

Keywords: *Water inrush; evaluation; prevention; confined aquifer.*

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1. Introduction

1.1 Hydrogeological conditions of the mine

After two expansions, Chenghe No.2 mineral has verified production capacity of 690,000t and actual production capacity of 650,000t in 2006. It is located at Shigou village, Yaotou town, Chengcheng county, [2]Shaanxi province, in southwest (orientation 236^{o}) of Chengcheng county with straight-line distance of 6km and road distance of 10km. Chengcheng county is adjacent to Baishui county and Pucheng county in west, to Heyang county and Dali county in east and south, and Huangling county and Luochuan county of Yan'an city in north, with area of 1,112km^2 and population of 380,000.

Chenghe No.2 mineral is situated in west of Chenghe mining area. Its stratum system is close to neighbouring Dongjiahe and Quanjiahe coal mines. Its bed rock is mainly exposed in Majiagou, two sides of Yuzihe-Yaotougou ravine, and both sides of Luohe river, and the other section within the mineral rights range is covered by loess. It lies in Weibei loess plateau gully region where the terrain is full of ups and downs, ravines and gullies are criss-cross, with gully density of 1.55km/km^2, the loess gullies and loess plateaus are interlaced, with largest gully undercutting depth of above 80m, and the gullies stretch from north to south. The longest ravine within the mining area is Qiaogou with length of 3km and average gully width of 20m. The plateau is broad and covered by loess with loess layer width of 0~107m. The vegetation coverage is poor, so the groundwater erosion and gravitational erosion is extremely serious. The terrain within this area is high in north and low in south, with relative height difference of 150~200m, is 500~689m above sea level.

Chenghe No.2 mineral coal measure strata are coal-bearing formation of Permo-carboniferous system. The coal-bearing formation is divided into lower Permian series Shanxi formation and upper carboniferous series Taiyuan formation. The coal measure strata have largest thickness of 122.66m, smallest thickness of 81.61m, and general thickness of 102m. The coal mine has 11 coal seams, namely No.1, No.2, No.3, No.4, No.5 upper, No.5, No.6, No.7, No.8, No.9 and No.10 coal seams, with coal bearing ratio of 6%. Among them, No.5 coal seam belongs to wholly minable seam with stable sedimentation within the mineral rights range, No.3, No.5 upper, and No.10 coal seams belong to partial minable seams, and the other coal seams are partially distributed or only seen in horizon.

#5 coal seam is located at upper parts of Taiyuan formation, the prospect whole coal dots within the mineral rights range are wholly mineable. The thickness of coal seam is 2.38~6.51m, and average thickness is 4.34m. The coal seam has complicated structure, generally 2 layers of dirt bands, and partially up to 4 layers of dirt bands. It has little change in thickness, with coal thickness variable coefficient of 19%, being wholly mineable coal seam with stable sedimentation and the largest mine thickness. #5 coal seam is 9~30.70m away from #10 coal seam, generally 17m. The coal seam depth is 130~441m, floor level 260~455m, and mineble area 12.516km^2. #5 coal seam has large thickness wholly and little change in thickness, belonging to the primary mineable coal bed of the mine.

According to the water level observation data from long-term hydrological observation holes, the maximum water level of Ordovician limestone rock water is +389.7m (1985) and currently dropped to +375m. Thickness of the water-resisting layer from #5 seam floor to the Ordovician limestone top surface is 23.62 (DY33)~52.76m (CH6-1). The lithology is mainly siltstone, quartz sandstone and aluminous mudstone, and there is good condition for lithological combination, which has provided favourable conditions for exploitation of water bearing layer. For the reason that fissure confined water of the Ordovician limestone karst has good connectivity and rich watery, etc., this area belongs to mineral deposit mainly with floor karstic fissure water. According to the known information, Chenghe No.2 mineral #5 coal seam belongs to mining over pressurized water. The Ordovician limestone top surface is less than 28m away from #5 coal floor (the nearest point), so that there might be possibility of Ordovician limestone water inrush.

1.2 Analysis on factors influencing #5 coal floor water inrush

The essence for floor water inrush on compensated mining working face of Chenghe No.2 mineral #5 coal seam is that the confined water under the coal seam breaks through obstruction of the water-resisting floor along inner passage of coal face water-resisting floor rock mass, and pours upward into the working face goaf in outburst, delayed or stagnant forms. As a kind of comprehensive hydrogeological phenomenon, whether to exploit #5 coal seam under confined water is subject to the following several factors, that is, geological structure, floor strata lithology and its combination feature, aquifer watery and head pressure, etc.

I. Geological structure

The geological structure is mainly fracture structure which is one of the main controlling factors for water inrush during compensated mining on Chenghe No.2 mineral #5 coal floor, including faulted scale, fault density, fault transmissibility, and fracture development degree, etc.

Chenghe No.2 mineral is located in middle part of Weibei coalfield. If water inrush happens on compensated mining working face of Jingtian #5 coal seam, the reason is disclosure of minor fault in most cases. The regional structure is restricted by North Qinling fold belt and influenced by Weihe graben, and, due to function of north-south crushing stress, the overall orientation is west-east trend, leaning to north. There is undulated gentle uniclinal structure. The fault structures are well developed in Heyang, south of Chengcheng line and west Luohe, with fault trend of mainly NEE and nearly EW, and most of them are normal fault. While, in north of this line, fault is rare, and the geological structure is mainly brachy-axis fold. Connection, wedge-out, turn and composite parts of the fault are slack. The physical properties of the stratum are inferior, thus apt to suffer from deformation and fracture and instability and forming strong permeable channels after wedge of confined water. The more intensive the fault is, the better is the transmissibility and the more likely will be the water inrush.

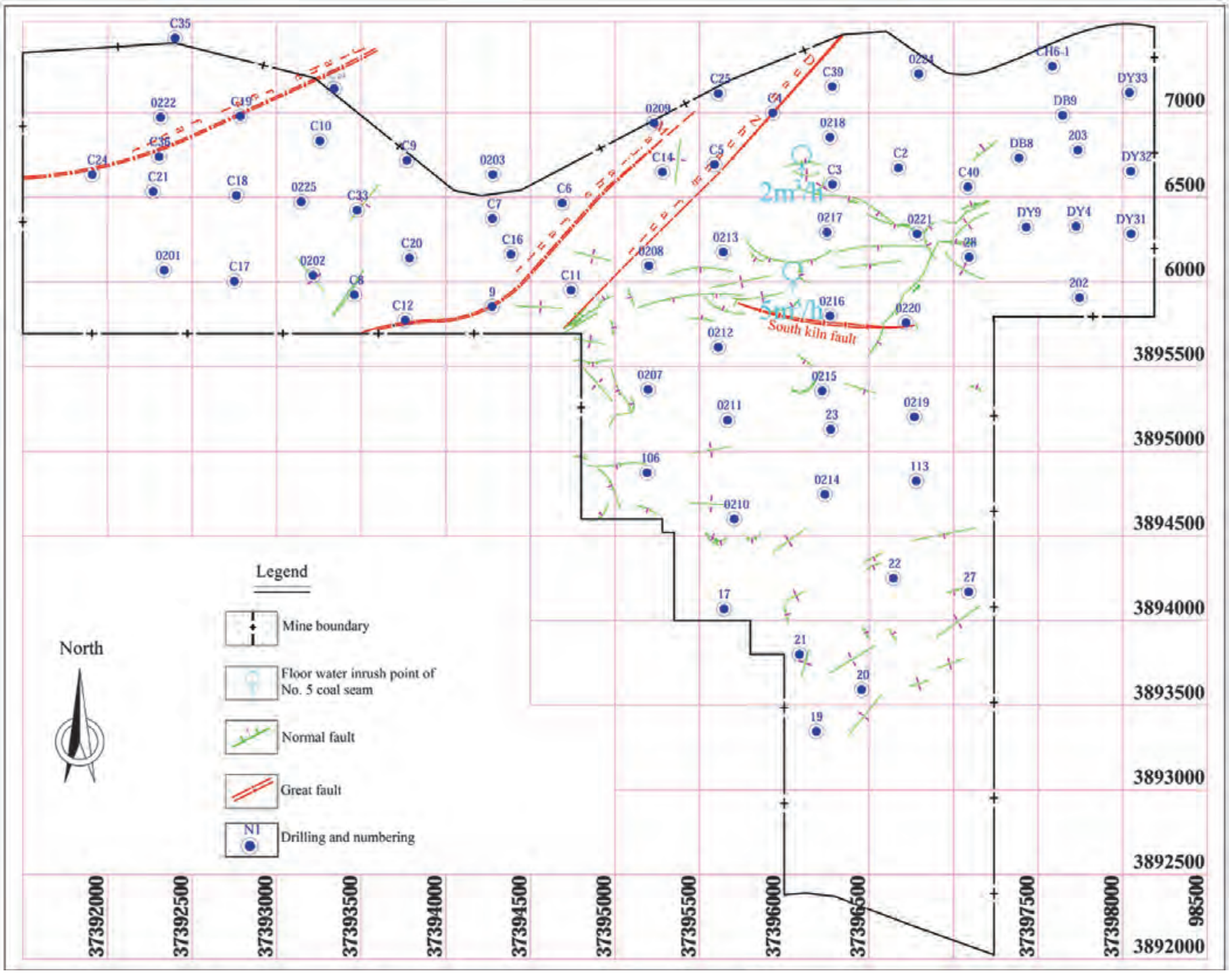

Fig.1 Composite diagram on geological structure complexity and water gushing points of Chenghe no.2 mineral

Chenghe No.2 mineral has seen floor water inrush for several times since mining, and water inrush through fault is the main water inrush type. On both sides near the fault plane, there is a lot of pinniform wrenched fracture and separation fracture forming fractured zones, including tectonite zone and fault affected zone. The tectonite zone of transmissibility is the main channel for the fault to exert hydraulic connection between the limestone and Ordovician limestone. The fault affected zone includes large scale of secondary fault that often becomes water inrush lot. Most of the water gushing points of Chenghe No.2 mineral lie in the fault affected zone. When the exploitation influences integrity of the floor strata, the fracture formed by the floor strata will connect with the structural fracture within the fault affected zone, and then confined water will squeeze into the mine along the fracture, and water inrush happens. During exploitation of #5 coal seam, when the fault cuts the coal series or cuts the coal series and Ordovician limestone at the same time, the Ordovician karst water and floor Taiyuan formation and Benxi formation confined water may break through the weak zone and become direct water filling factor of the mine.

As to Ordovician limestone fault zone, when Ordovician limestone aquifer is disclosed or the fault zone is very near to the Ordovician limestone aquifer, the fault structure developed in Ordovician limestone may become the channel for water inrush in mine. When Ordovician limestone top surface lacks aluminous mud stone or the mud stone is thin, the Ordovician limestone rock water may rise to the upper formation through the structural fracture and cause water inrush. Middle Ordovician Fengfeng formation section II aquifer of the coal series basement has rich watery, abundant supply sources, and complicated runoff conditions, being the main safety loophole during mining. The fault throw among Majiahe normal fault, Fangjiahe normal fault and Duanzhuang normal fault is large and makes the upper wall coal measure strata connect with the lower Ordovician limetone, and then the Ordovician limestone rock water will supply the coal measure strata aquifer, which will threaten the coal mining activities. Moreover, these normal

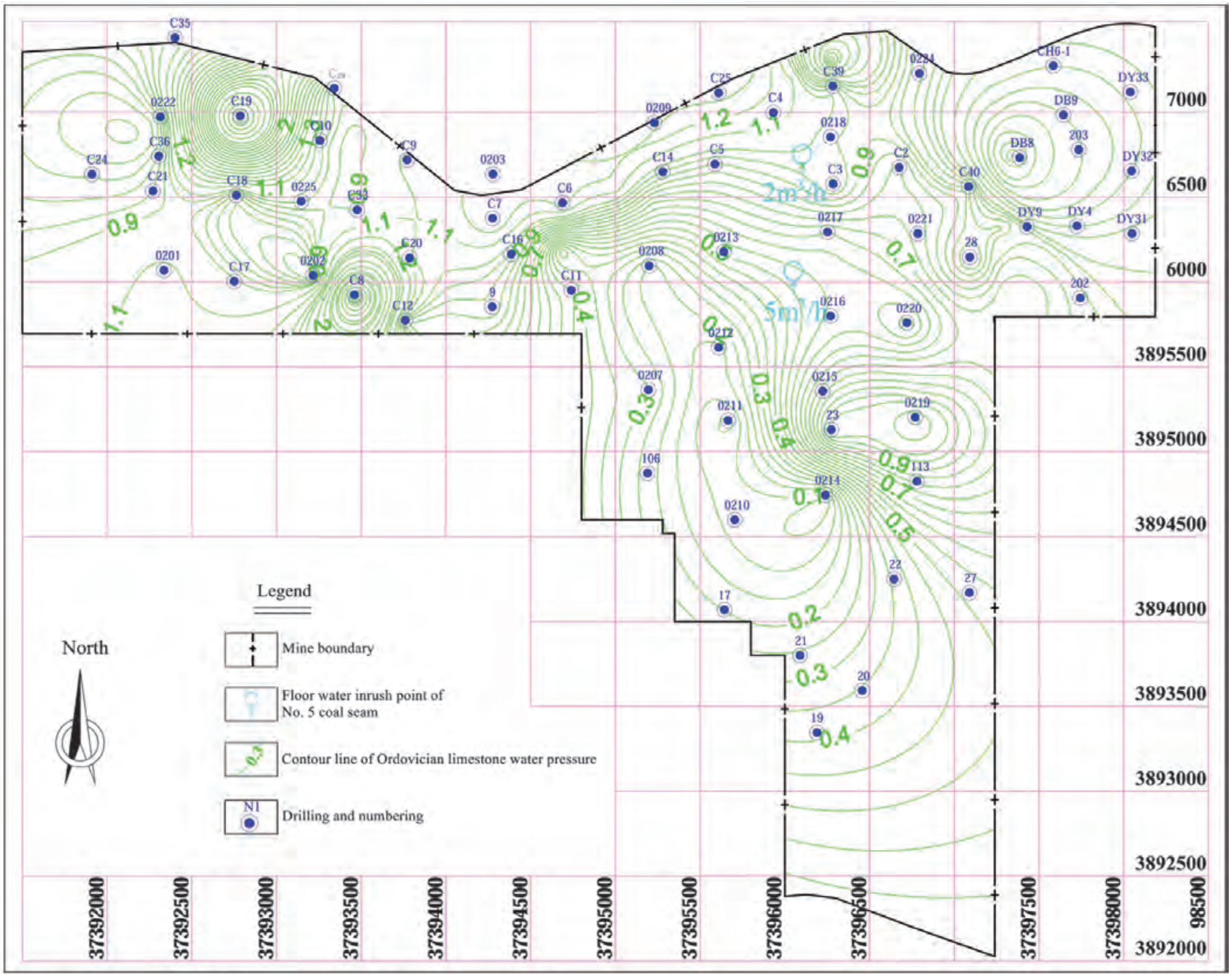

Fig.2 Composite diagrams of Chenghe no.2 mineral ordovician limestone aquifer water pressure and water gushing points

fault fracture zone is broad and has strong transmissibility, being the water filling and diversion channels of coal measure strata. For example, when Quanjiahe coal mine underwent outflow test in 1989, the water level of #15 drill hole that is about 7.4km away from the drainage center dropped from +383.436m to +383.189m, with drop of 0.25m, while the neighbouring #13, #12 and #9 drill holes are respectively about 4.92km, 6.7km and 8.2km away from the drainage center, with very little drop in water level. This indicates that #15 drill hole lies in strong runoff zone, which is probably related to Majiahe fault near the hole. In addition, Quanjiahe Mineral II horizontal 21503 working face has fault in Tanyangzhuang and meets a derived normal fault, with fall of only 18m but water inflow of 40m^3/h, which forces the working face to retreat and increases the fault waterproof pillar.

II. Floor stratum lithology and its combination feature

Chenghe No.2 mineral #5 coal seam is the primary mineable coal bed currently. The distance between Ordovician limestone top surface and #5 seam floor is generally about 27m. The lithology between #5 coal seam and Ordovician limestone strong aquifer is dominated by mudstone, sandy mudstone, and sandstone. Except three aquifers, the majority of stratum belongs to water-resisting layer. For the reason that the aquifers are cut off between and there exists no hydraulic connection, the environment is relatively closed. Soft rock with good water tightness and hard rock with poor water tightness but strong Ordovician limestone water resistance alternately constitute the lithology, which has positive functions on prevention and control of compensated mining.

III. Aquifer watery

Investigation on development degree and watery of limestone karst should be strengthened during prediction and prevention of Chenghe No.2 mineral #5 coal seam lower floor water inrush. The aquifer that has close relation with Chenghe No.2 mineral field floor water inrush is K_2 limestone and Ordovician limestone, and the water inrush source is

Ordovician limestone rock water. In order to verify watery of K_2 limestone and Ordovician limestone of Chenghe No.2 mineral, TEM (transient electromagnetic method) and direct current electric method or other geophysical prospecting should be adopted during working face tunnelling period and before recovery to detect the confined watery zone under the compensated mining working face. From analysis on all previous water inrush conditions of Chenghe No.2 mineral and in combination with the physical drilling data, it is found that the most majority of water gushing points are located within the abnormal watery zones verified by geophysical prospecting. Therefore, to verify Ordovician limestone watery is of great significance for prevention of floor water inrush.

IV. Aquifer head pressure

Currently, #5 coal seam is the major mining seam of Chenghe No.2 mineral. According to the water level observation data from long-term hydrologic observation holes, the highest water level on records of Ordovician limestone rock water is +389.7m and currently dropped to +375m. To exploit #5 coal seam under +375 water level is threatened by Ordovician limestone rock water, and it is easier to cause floor water inrush at rupture and fracture development zones. It•fs expected that Ordovician limestone rock water will exert great influence on second level deep and third level mining of #5 coal seam. Ordovician limestone rock water will cause extremely great threat especially when the excavation area meets large-scale rupture or collapse column water diversion, so that productive geology research must be strengthened to timely grasp the change of geological conditions and guarantee safety mining by taking corresponding measures.

Known from former hydrogeological data of Chenghe No.2 mineral, there is a karst fracture confined aquifer formation with weak~medium watery between Taiyuan formation #5 coal seam and Ordovician limestone aquifer. The aquifer formation is mainly composed of upper carboniferous Taiyuan formation quartz sandstone and K_2 limestone and characterized by abundant water, large water pressure, and close distance with #5 coal seam, etc., and imposes extremely large threat to safety production of #5 coal seam.

Therefore, after analysis on the hydrogeological condition of Chenghe No.2 mineral, combination with water bursting coefficient, and basing on head pressure borne by the water-resisting layer floor (water-resisting layer), water-resisting layer thickness (as the main basis) as well as the disturbance and rupture thickness of the floor water-resisting layer due to mining, the author has respectively calculated water bursting coefficients of each construction drill hole, drawn water bursting coefficient contour map, and judged water inrush risk of #5 coal seam and mining division under pressure, which has provided scientific basis for realizing safe compensated mining and liberating #5 coal seam threatened by Ordovician limestone rock water, and is of very important practical significance.

2. Safety evaluation indexes for compensated mining

In this article, water bursting coefficient method is adopted as the evaluation standard for floor compensated mining conditions during establishment of compensated mining division model of Chenghe No.2 mineral #5 coal floor, with the meaning that water inrush may happen when the water pressure borne by each meter of effective water-resisting layer exceeds critical water pressure value. In accordance with Stipulations on Mine Water Prevention and Control and GB51070-2014 Design Specification on Coal Mine Water Prevention and Control issued in 2015, relation between the safety coal (rock) pillar size and actual thickness between the coal floor and the aquifer top should be considered and calculated.

(1) Consideration on influence of floor mining (working condition 1)

If the calculated safety coal (rock) pillar size is smaller than the actual thickness between the coal floor and the aquifer top, the safety degree of mining over confined aquifer shall meet the requirements. In accordance with requirements of "design method on waterproof safety coal (rock) pillars during mining over water body," the relation among the designed floor waterproof safety coal (rock) pillar thickness (h_a) and the water diversion rupture zone (h_1) and water-blocking tape thickness (h_2) shall meet the following requirements:

$$h_a > h_1 + h_2 \quad \text{...} \quad (1)$$

Formula (1) has taken the influence of water diversion rupture zone into consideration, and the formula for floor water inrush prediction model is:

$$T_s = P/(M-h_1) \quad \text{...} \quad (2)$$

where: T_s – water bursting coefficient•CMPa/m; P – water pressure borne by the coal floor, MPa; M – thickness of floor water-resisting layer, m; h_1 – thickness of coal floor water-diversion rupture zone, m.

(2) Without consideration on floor mining influence (working condition 2)

If the calculated safety coal (rock) pillar size is greater than the actual thickness between the coal floor to the aquifer top, the following methods may be adopted for evaluation, i.e., the formula of floor water inrush prediction model being:

$$T_s = P/M \quad \text{...} \quad (3)$$

Adopt formula (2) as the standard formula for evaluating safety of floor compensated mining. Remarkable effect has been achieved in past application of the water bursting coefficient shown in Formula (2) which has wide range of application and has liberated a large number of coal resources threatened by water disaster, especially where there is specific threshold value in water inrush possibility division. However, in combination with actual mining condition of Chenghe No.2

TABLE 1: TABLE ON WATER INRUSH RISK DIVISION STANDARDS

Division no.	Water bursting coefficient T_S (MPa/m)	Water inrush danger level	Evaluation results	Proposed governing measures
I	$T_s < 0.06$	Small	Mineable zone under pressure	Direct mining
II	$0.06 < T_s < 0.1$	Relatively large	Dangerous zone of compensated mining	Slip casting into water-resisting layer
III	$T_s > 0.1$	Large	Extremely dangerous zone of compensated mining	Slip casting on top surface of Ordovician limestone

mineral, the influence of water diversion rupture zone induced by mine ground pressure should be taken into consideration. Therefore, a comparative analysis on formula (2) and formula (3) under two working conditions is adopted during evaluation of Taiyuan formation #5 coal seam compensated mining of Chenghe No.2 mineral.

According to the latest code requirements of Stipulations on Mine Water Prevention and Control, the water bursting coefficient of the block section with floor destructed by structure is generally no greater than 0.06MPa/m, and the coefficient of normal block section is no greater than 0.1MPa, i.e., if the water bursting coefficient is equal to or smaller than 0.06MPa/m, the coal mining will not be influenced by Ordovician limestone rock water; and if the water bursting coefficient is greater than 0.06MPa/m, the coal mining will be threatened or influenced by Ordovician limestone rock water. Therefore, 0.06MPa/m and 0.1MPa/m are adopted as the critical value of Chenghe No.2 mineral floor water inrush coefficient. Water inrush risk evaluation division standard (shown in Table 1) is:

(1) if $T_s < 0.06$ MPa/m, the floor water inrush threat is small, being mineable zone under pressure;

(2) if 0.06MPa/m < T_s < 0.1MPa/m, the floor water inrush threat is relatively large, being dangerous zone of compensated mining;

(3) if T_s > 0.1MPa/m, the floor water inrush threat is large, being extremely dangerous zone of compensated mining.

According to the above confined water pressure borne by water-resisting layer floor, water-resisting stratum thickness and floor mining fracture depth, the author uses these three factors to establish a model and adopts water inrush risk division standard to conduct division evaluation on compensated mining of Chenghe No.2 mineral #5 coal seam. It respectively calculates the water bursting coefficients of each construction drillhole within the mine, adopts critical water inrush coefficients of 0.06MPa/m and 0.1MPa/m as boundary conditions, divides Chenghe No.2 mineral #5 coal floor water-resisting layer into extremely dangerous zone of compensated mining ($T_s > 0.1$), dangerous zone of compensated mining ($0.06 < T_s < 0.1$) and mineable zone under pressure ($T_s < 0.06$), and draws water bursting coefficient contour map to divide mining zones under pressure of Chenghe No.2 mineral.

3. Evaluation on floor compensated mining conditions

Ordovician limestone rock water is the most important water inrush source threatening mine safety. Basing on existing drillhole data of Chenghe No.2 mineral, the author establishes compensated mining division model of floor water-resisting stratum water inrush under two kinds of working conditions while considering (not considering) floor mining fracture depth, calculates the water bursting coefficient of Chenghe No.2 mineral #5 floor water-resisting layer, and evaluates the conditions for floor compensated mining. Studying the water resisting property of Taiyuan formation lower #5 coal floor water-resisting layer through contrast on results under two kinds of working conditions has laid a solid foundation for liberating the coal resources threatened by Ordovician limestone confined water.

3.1 SELECTION OF PARAMETERS

3.1.1 Selection of water level elevation of Ordovician limestone aquifer

The Ordovician limestone water level elevation actually observed by Chenghe Mining Bureau is +370~+382m currently. According to the mine water level monitoring data of many years, the highest water level of Chenghe No.2 mineral Ordovician limestone water is +375m. Therefore, if coal seam with elevation lower than +375m is exploited, the mine will be threatened by Ordovician limestone rock water. In addition, the lower the elevation is, the greater Ordovician limestone rock water inflow and threat there will be. So, +375m is taken as the water head height of Ordovician limestone rock water in this calculation.

3.1.2 Thickness of water-resisting stratum

The lithology between Chenghe No.2 mineral #5 coal seam and Ordovician limestone strong aquifer is dominated by mudstone, sandy mudstone, and sandstone, and except K_2 aquifer the majority of stratum belongs to water-resisting layer. The space between Ordovician limestone top surface and #5 coal floor is generally 27m. Due to expansion of floor

TABLE 2: COMPUTATION SHEET ON WATER BURSTING COEFFICIENT OF 5# COAL MINE OF CHENGHE NO.2 MINERAL

Drill holes Hole no.	Floor water-resisting layer thickness (m)	Ordovician limestone artesian head value (m)	Floor mining fracture depth (m)	Water bursting coefficient T_S (MPa/m)		Drop rate of water bursting coefficient %
				Working condition 1	Working condition 2	$(T_{S1}- T_{S2})/T_{S1}$
9	28.9	88.7	10	0.047	0.031	34.60
23	30	106.8	10	0.053	0.036	33.33
28	43.6	109.1	10	0.032	0.025	22.94
201	28.6	116.7	10	0.063	0.041	34.97
202	37.2	60.4	10	0.022	0.016	26.88
203	21.9	129.7	10	0.109	0.059	45.66
207	48	31.1	10	0.008	0.006	20.83
208	22.1	17.8	10	0.015	0.008	45.25
209	16.4	131.6	10	0.206	0.080	60.98
211	29.8	3.4	10	0.002	0.001	33.56
212	24.4	13.4	10	0.009	0.005	40.98
213	22.1	50.9	10	0.042	0.023	45.25
214	30.1	2.5	10	0.001	0.001	33.22
216	29	56.4	10	0.030	0.019	34.48
217	20.3	63.5	10	0.062	0.031	49.26
218	29.8	95.4	10	0.048	0.032	33.56
219	26.8	123.1	10	0.073	0.046	37.31
220	28.6	47	10	0.025	0.016	34.97
221	45	97.8	10	0.028	0.022	22.22
222	16.5	78	10	0.120	0.047	60.61
224	21	108.2	10	0.098	0.052	47.62
225	18.8	94.3	10	0.107	0.050	53.19
C1	19.7	115.9	10	0.119	0.059	50.76
C2	20.7	79.4	10	0.074	0.038	48.31
C3	49	101.4	10	0.026	0.021	20.41
C4	16.8	113.1	10	0.166	0.067	59.52
C5	18.5	87.5	10	0.103	0.047	54.05
C6	17.9	122.5	10	0.155	0.068	55.87
C7	25.7	130.2	10	0.083	0.051	38.91
C9	16.9	115.5	10	0.167	0.068	59.17
C10	24.5	101.8	10	0.070	0.042	40.82
C11	31.1	46.3	10	0.022	0.015	32.15
C12	28.5	86.1	10	0.047	0.030	35.09
C13	21.3	70.9	10	0.063	0.033	46.95
C14	20.7	92.5	10	0.086	0.045	48.31
C15	22.8	26.3	10	0.021	0.012	43.86
C16	25.4	91.9	10	0.060	0.036	39.37
C17	19.5	93.3	10	0.098	0.048	51.28
C18	16.1	76.9	10	0.126	0.048	62.11
C20	22.8	110	10	0.086	0.048	43.86
CH5-1	25.1	163.7	10	0.108	0.065	39.84
C21	19	79	10	0.088	0.042	52.63
C22	22.9	159.2	10	0.123	0.070	43.67
C23	25.2	18.8	10	0.012	0.007	39.68
C24	34.5	75.1	10	0.031	0.022	28.99
C25	25.2	133	10	0.088	0.053	39.68

C26	15.3	123.8	10	0.234	0.081	65.36
C27	18.3	133.5	10	0.161	0.073	54.64
C28	23.4	108.6	10	0.081	0.046	42.74
C29	21.6	97.9	10	0.084	0.045	46.30
C30	19.8	113.3	10	0.116	0.057	50.51
C32	20.5	144.1	10	0.137	0.070	48.78
C33	11.7	90.7	10	0.534	0.078	85.47
C35	21.9	104.2	10	0.088	0.048	45.66
C36	16.5	74.8	10	0.115	0.045	60.61
C37	18.5	109.6	10	0.129	0.059	54.05
C39	16	98.8	10	0.165	0.062	62.50
C40	28.3	97.2	10	0.053	0.034	35.34
CH6-1	52.8	152.9	10	0.036	0.029	18.94
DB9	38.5	110	10	0.039	0.029	25.97
DY31	34.3	63.3	10	0.026	0.018	29.15
DY32	34.1	73.4	10	0.030	0.022	29.33
DY33	23.6	110.4	10	0.081	0.047	42.37
DY9	26.1	53.8	10	0.033	0.021	38.31
DY4	38.4	71.3	10	0.025	0.019	26.04
13	20.3	56.2	10	0.055	0.028	49.26

Notes: The above data show partial drill hole conditions of Chenghe no.2 mineral; working condition 1 – water bursting coefficient (T_{S1}) if consider the thickness of water-diversion failing zone, and working condition 2 – water bursting coefficient (T_{S2}) if not consider the thickness of water-diversion failing zone.

fractures induced by mining on original fault and fracture basis, the fault or fracture intensive belt makes the fracture depth of floor strata increase compared with that of intact floor strata, and the higher floor fracture depth makes the thickness of the effective water-resisting layer of Chenghe No.2 mineral #5 coal mining floor decrease. So, under working condition 1, the influence of floor mining fracture depth is considered, and the effective floor water-resisting stratum thickness should be floor water-resisting layer thickness minus the floor mining fracture depth; while, under working condition 2, the influence of floor mining fracture depth is not considered, the floor water-resisting layer thickness is the thickness of all layers from #5 coal floor to Ordovician limestone top surface.

Under the two kinds of working conditions, the underlie K_2 watery section of #5 coal floor will be subject to slip casting to enhance the effective thickness and integrity of the water-resisting layer and improve its water-resistance performance. Because K_2 section aquifer is transformed into water-resisting layer, thickness of coal series aquifer is not to be subtracted. Therefore, the thickness of underlie K_2 watery stratum of #5 coal floor can be neglected when calculating the thickness of water-resisting stratum thickness.

3.1.3 Thickness of coal floor mine pressure disturbance and failing zone

(1) Theoretical formula [theoretical analysis and numerical simulation of compensated mining coal floor fracture depth]

As for theoretical analysis on floor fracture depth of Chenghe No.2 mineral #5 coal seam typical working face during recovery period, the author will apply plastic theory to calculate the thickness of floor rock water-diversion failing zone, as well as stope terminal rock mass failure zone depth calculation method.

$$h_{11} = 0.5x_a \cdot \cos\delta \cdot \sec\left(\frac{\pi}{4}+\frac{\delta}{2}\right) \cdot \exp\left[\left(\frac{\pi}{4}+\frac{\delta}{2}\right)\tan\delta\right] \quad \text{... (4)}$$

$$h_{12} = 1.57\gamma^2 H^2 L_s \big/ 4R_c^2 \quad \text{... (5)}$$

where, h_{11}, h_{12} – theoretical value for thickness of water-diversion failing zone, m;

x_a – coal seam plastic failure zone, x_a = 5.6m;

δ – floor rock internal friction angle, δ = 32.5º;

R_c – the weighted average of floor rock uniaxial compressive strength, R_c = 20MPa;

H – mining depth, H = 300m;

L_x – coal face stope width, L_x = 100m;

γ – rock mass volume weight, γ = 2100kg/m^3;

Substitute the parameters into formula (4)~(5), and obtain floor mining fracture depth h_{11} = 9.71m and h_{12} = 3.89m.

(2) Empirical formula

In combination with the geological conditions of Chenghe No.2 mineral #5 coal seam, the literature [theoretical analysis and numerical simulation of compensated mining coal floor fracture depth] applies mathematical statistics method to work out the empirical formula of the thickness of water-diversion failing zone:

$$h_{13} = 0.0117H + 6.25\ln L_s - 22.52 \quad \ldots \quad (6)$$

According to GB51070-2014 Design Specification on Coal Mine Water Prevention and Control, the statistical formula method comprising mining depth, inclination and working face stope width is used to calculate the thickness of floor water-diversion failing zone by the following formula:

$$h_{14} = 0.0085H + 0.1665\alpha + 0.1079L_s - 4.3579 \quad \ldots \quad (7)$$

where, α – coal bed pitch, $\alpha = 5^{o}$.

Substitute the parameters into formula (6)~(7) and obtain floor mining fracture depth h_{13} = 9.78m and h_{14} = 8.99m.

(3) Obtain the thickness of coal floor water-diversion failing zone in combination with field test

From 1986~1989, Chenghe mining area was a main test point of “Comprehensive Control of Ordovician Karst Water of North China Type Coal Mines” industrial tests. Coal floor packer test was conducted in Quanjiahe coal mine of Chenghe Mining Bureau, and the test results indicated the thickness of the mining failing in-band under #5 coal floor was 10m.

After theoretical calculation (9.71m and 3.89m) and empirical formula calculation (9.78m and 8.99m) on water-diversion failing zone thickness of Chenghe No.2 mineral #5 coal seam, and consideration on the industrial test of “Comprehensive Control of Ordovician Karst Water of North China Type Coal Mines” in 1986~1989, coal floor packer text is conducted in Quanjiahe coal mine of Chenghe Mining Bureau, and the test results show the thickness of mining failing in-band under #5 coal floor is 10m. In final comprehensive analysis, 10m will be taken as the value for thickness of floor water-diversion failing zone in floor water inrush risk division evaluation of Chenghe No.2 mineral.

According to selection of the above evaluation parameters, the author respectively establishes floor water inrush compensated mining division model under two kinds of working conditions to conduct evaluation for conditions of floor compensated mining. Under these two working conditions, relevant calculation data of #5 coal seam water inrush coefficient are shown in Table 2.

3.2 Evaluation results

3.2.1 Evaluation results under working condition I

According to confined water pressure borne by Chenghe No.2 mineral water-resisting layer, water-resisting stratum thickness, and the disturbance and water-diversion failing zone thickness of the floor water-resisting layer due to mining, the author has respectively calculated the water bursting coefficients of each construction drillhole and drawn water bursting coefficient contour map is shown in Fig.3.

It can be seen from Ordovician limestone water bursting coefficient contour map 3 under working condition 1:

(a) Extremely dangerous zone of compensated mining (zone III)

If T_s > 0.1MPa/m, the water inrush threat is great, and the contour line of T_s = 0.1MPa/m is basically distributed along 0224, 0225, 0222, 0203, C4, C18, C32, C37 and C39 drill hole line. North of the contour line belongs to extremely dangerous zone of compensated mining with T_s > 0.1MPa/m, and this area is mainly distributed in mine second level deep part and the vast majority of third level.

(b) Dangerous zone of compensated mining (zone II)

If 0.06MPa/m < T_s < 0.1MPa/m, the water inrush threat is relatively great, belonging to dangerous area of compensated mining.

(c) Mineable zone under pressure (zone I)

If T_s < 0.06MPa/m, the water inrush threat is small, and the contour line of T_s = 0.06MPa/m is basically distributed along C15, C16, C24, 6, 0202 and 0208 drillhole line. South of the contour line belongs to mineable zone under pressure with T_s < 0.06 MPa/m, and this area is mainly distributed in south of third level, western boundary and second level superficial part.

Seen from the floor water inrush distribution points of Chenghe No.2 mineral #5 coal seam exploited working face, floor water inrush is basically concentrated in dangerous zone of compensated mining with 0.06MPa/m < T_s < 0.1MPa/m and mineable zone under pressure with T_s > 0.04MPa/m.

Moreover, seen from Fig.3, within the whole Chenghe No.2 mineral, the water bursting coefficients are getting increasingly large from south to north and the coal mining risk is on the rise. At the same time, under the influence of vertical water-diversion channel fault, collapse column and fracture intensive belt, etc., the floor disturbance and failing zone depth of Chenghe No.2 mineral #5 coal floor might be greater than 10m, and thus cause the floor water bursting coefficient to get bigger. In addition, due to existence of water-diversion channel and deep exploitation, the floor Taiyuan formation limestone faces are changed into quartz sandstone, the fracture is developed, the alumina mudstone gets thinner, and water-resisting performance of the floor water-resisting layer declines, so the Ordovician limestone rock water in deep mining area will impose greater threat on mine safety.

Currently, with deepening of #5 coal mining level of Chenghe No.2 mineral, the compressed coal reserves will gradually increase, and the compressed coal reserve of compensated mining extremely dangerous zone (red zone in Fig.3) with T_{s1} > 0.1MPa/m reaches approximately ten million tonnes. So, if the coal resource of extremely dangerous zone threatened by Ordovician limestone rock water cannot be utterly liberated, there will be huge economic losses.

3.2.2 Evaluation results under working condition 2

According to the confined water pressure borne by #5 coal seam water-resisting layer of Chenghe No.2 mineral and the thickness of water-resisting stratum, etc., the author has

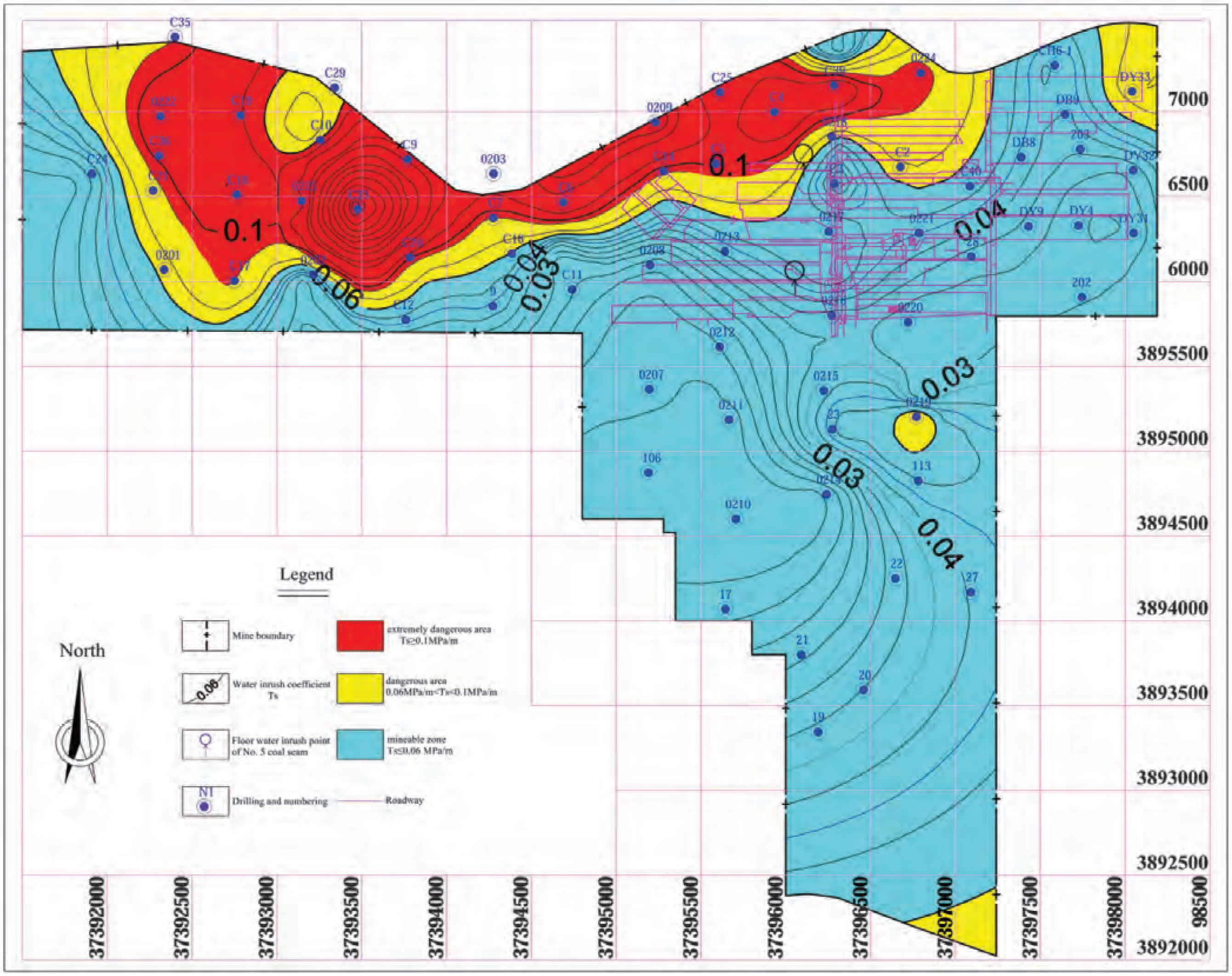

Fig.3 #5 coal floor water bursting coefficient contour line and compensated mining division under working condition 1

respectively calculated the water bursting coefficients of each construction drillhole and drawn water bursting coefficient contour map as shown in Fig.4.

It can be seen from Ordovician limestone water bursting coefficient contour map 4 under working condition 2:

(a) Dangerous zone of compensated mining

0.06MPa/m < T_s < 0.1MPa/m is mainly distributed in north of the mine field, and the water inrush threat is great, belonging to dangerous zone of compensated mining.

(b) Mineable zone under pressure

If T_s < 0.06MPa/m, the water threat is small, the vast majority of the mine field belongs to mineable zone under pressure, and such area is mainly distributed in south of third level, western boundary and second level superficial part, etc.

Seen from floor water inrush distribution points of #5 coal seam exploited working face of Chenghe No.2 mineral currently, the floor water inrush is basically concentrated in mineable zone under pressure with T_s < 0.06MPa/m.

Therefore, it is expected that the Ordovician limestone rock water will exert great influence on #5 coal seam second level deep part and third level exploitation. Especially when the excavation area is subjectsd to large-scale fracture, structure or collapse column water diversion, the threat of Ordovician limestone rock water is extremely great. At the same time, the floor fracture depth after coal mining and the maximum floor water-resisting capacity after mining should also be considered. Production of geological research must be strengthened to timely grasp change of geological conditions. In order to realize safety in mining, floor probing technique, floor reinforcement technology and drilling verification technique, etc. are adopted during #5 coal mining of Chenghe No.2 mineral after combination with evaluation results of water inrush danger coefficient, thus guaranteeing safety in mining of #5 coal bed of Chenghe No.2 mineral.

3.2.3 A contrastive analysis on the results under two kinds of working conditions

Under working condition 1, due to consideration of the

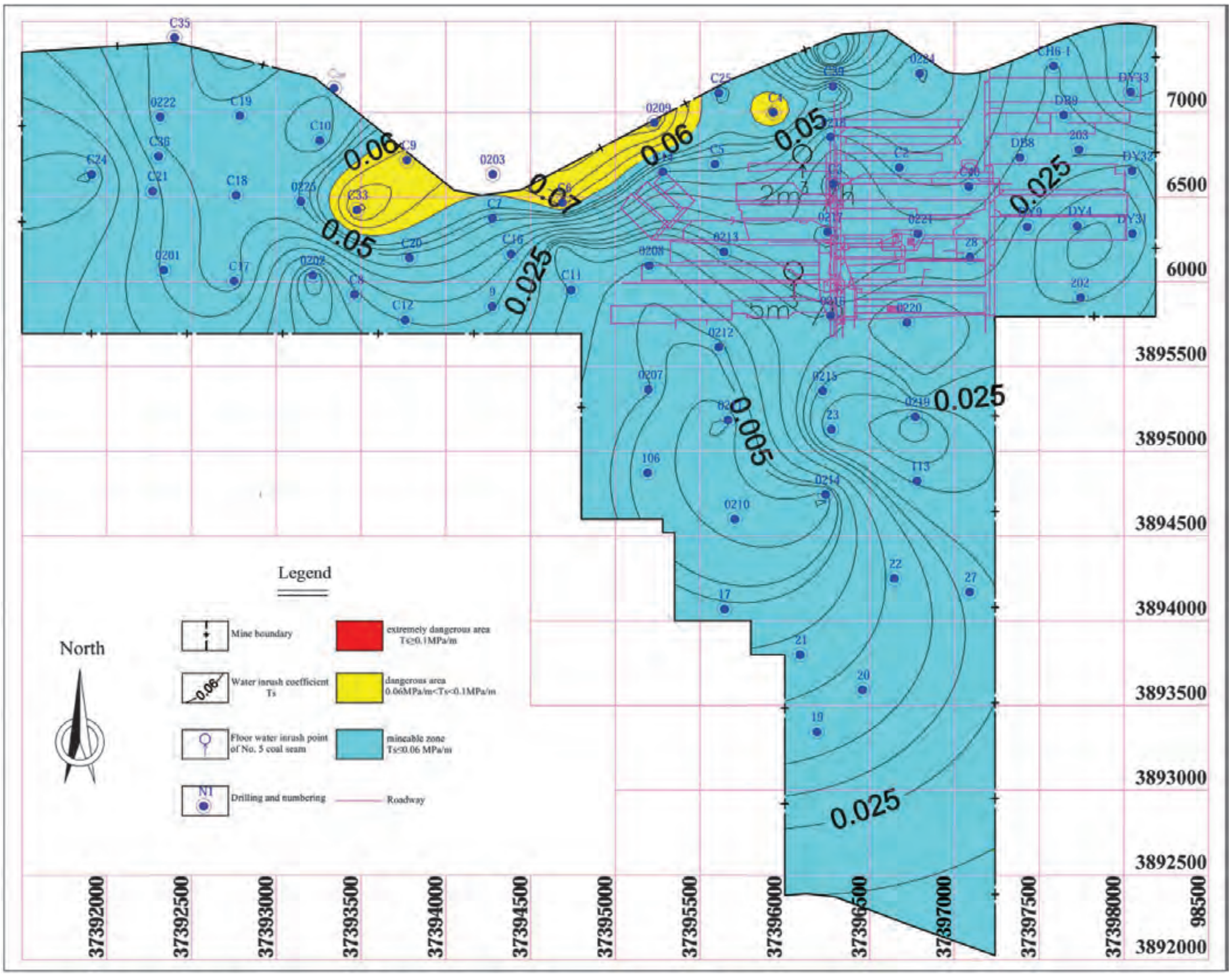

Fig.4 #5 coal floor water bursting coefficient contour line and compensated mining division under working condition 2

influence of floor disturbance and destruction, the thickness of floor effective water-resisting layer decreases, which has increased the water inrush probability of coal floor. In area (Area I and Area II in Fig.3) with small water bursting coefficient, the floor water-resisting thickness is able to meet the requirements of compensated mining, and the floor water bursting coefficient can be controlled within critical value of safety compensated mining 0.06~0.1MPa/m. However, within the deep part of second level and the vast majority of third level of Chenghe No.2 mineral #5 coal seam, there exists extremely dangerous area of compensated mining (Area III in Fig.3) where water bursting coefficient is greater than critical value 0.1MPa/m; under working condition 2, because the influence of floor disturbance and fracture depth is not considered, the area (Area III in Fig.3) where safety compensated mining is impossible under working condition 1 has satisfied basic compensated mining conditions, and the water bursting coefficient value (T_{s1}) has also dropped 18.94%~83.47% from former (T_{s2}). In addition, the water bursting coefficient of the whole mine is basically controlled within the coal seam mineable critical value 0.1MPa/m, thus meeting the safety in mining requirements of Chenghe No.2 mineral #5 coal seam. However, this does not necessarily mean that mining is possible, because combination with actual field condition is required, such as fault, water-diversion fracture development condition, limit hydraulic pressure of confined water, etc, and combination of DC electric method, floor slip casting, etc. are also required.

3.3 Floor major water disaster and prevention

3.3.1 Principle on prevention of mine water

Seeing from prevention of mine water, we can divide water source of the water-filled aquifers of this mine into upper part and lower part. Water filling source of the upper part is water from the three aquifer formations of the quaternary system and carboniferous-persian period, which is characterized by weak watery, poor supply conditions, slow cycle alternation, restricted water capacity, and can be discharged by unwatering; while water filling source of the lower part is water from aquifer formations of Ordovician limestone. Although there is no direct connection between current production and lower water-filling source, the lower part of Ordovician limestone aquifer group has rich watery, karst aquifer with large water-storage volume, abundant supply, and good connectivity, so it is unreal for unwatering within a short time. It is supposed to gradually dewater and decompress in order to prepare condition for development of future lower coal group.

3.3.2 Implementation of floor water prevention

(1) Prevention by water diversion in fault zone

As for small fault crevice water diversion, if the gushing water comes from the roof, ditches should be built to drain or as sump, and a pump is required to timely drain the water; if the water comes from floor coal series aquifer, capping, blocking, and pumping are necessary, and comprehensive treatment is also required, such as to irrigate the roadway's sides, to drill into the deep, and conduct slip casting to block off the structural fracture, etc.

(2) Prevention by karst collapse column water-diversion

By reason of existence of Ordovician limestone karst fracture aquifer, great importance must be attached to karst collapse column. In case of water bursting of karst collapse column, some new prevention technique emerging in recent years may be adopted as the geological condition as required.

(1) Collapse column "three-section" water shutoff technique

If the collapse column is well developed, leave a cavity in the roof after water bursting of the collapse column. Under flowing water condition, drill by targeting at the roof cavity of the collapse column, fill up the mine and compact it, to make the flowing water become osmotic flow. After completion of filling up, fill the lower part of the collapse column, cast slip, increase resistance, intercept water source, reduce flow rate to establish reinforcement section, re-cast slip in middle part to intercept the water source and establish water-stop section, and this is the well-known "three-section" water shutoff technique.

(2) Direct blocking technique

If the collapse column is under development, drill directly from the ground to target at the collapse column, fill the drillhole with sand stone to form sand cushion and then reinforce by slip casting. In order to block the interspaces that are within the collapse column and with various shapes and different sizes, to drill from different positions or to drill from the same position but to different depths is required, as well as repeated pouring of sandstone and cement paste. Such kind of slip casting technique is suitable for underground watercourse of karst collapse column under stagnant water.

(3) Water-diversion prevention of sealing poor drillholes

In case of sealing poor drillholes during excavation, detection should go first, and then comes the construction. As to draining poor drillholes of Ordovician limestone aquifer, ground and underground blocking should be combined for treatment, and if necessary, the water may be connected to the water supply system.

(4) Prevention of Ordovician limestone rock water

Ordovician limestone karst water is the major threat during mining of Chenghe No.2 mineral deep #5 coal. Because Ordovician limestone rock water belongs to high confined aquifer water, the water pressure is an important force source of coal floor destruction. The higher the water pressure is, the bigger is the destructive power; the lower the water pressure is, the smaller is the destructive power. Therefore, if safety in mining is to be realized, water pressure of the floor high confined aquifer must be controlled under a certain value, or the thickness of floor water-resisting layer should be greater than certain critical value, to make the mining crack and water pressure crack mutually uncorrelated, to avoid the water-diversion fault or collapse column, and this can avoid occurrence of floor water inrush. During specific prevention, geological detection before production or during productive process should be strengthened. Combination among geophysical prospecting, chemical prospecting and drilling, as well as between surface-underground pumping test and dewatering test, is needed to conduct three-dimensional integrated exploration on purpose.

For the reason that Chenghe No.2 mineral is simple in structure, its floor lithology belongs to hard and soft alternate composite structure, and it has good water proof performance, the mineable area under pressure generally will not be subject to floor water inrush accident except in case of water conductive structures. Water prevention and control technical measure under compensated mining should be taken for floor water disaster threatened area of Chenghe No.2 mineral. Reinforce Taiyuan formation #5 coal floor by grouting to enhance the water-resisting performance of the water-resisting layer, and realize safety compensated mining. Transform the coal floor water-resisting section and K_2 aquifer by comprehensive grouting, transform K_2 aquifer into relative water-resisting layer, increase the thickness of effective water-resisting layer, block the waterpower channel between aquifers, prevent the Ordovician limestone rock water from supplying K_2 aquifer, and block water head intrusion fractured zone of the Ordovician limestone rock water.

Therefore, specific compensated mining design plan must be formulated for areas where floor water inrush may happen. Reinforce the aquifer floor by grouting, find out faults above 5m within the mining area via comprehensive exploration and in combination with actual hydro geological data, define main water-diversion channels and latent water diversion structure, and delineate the danger zone influenced by water disaster, to provide scientific basis for mine water prevention, and solidly put an end of floor water disaster accident.

4. Conclusions

(1) This article has conducted a detailed analysis on factors that influence #5 coal floor water inrush, generalized four major influence factors, i.e., geological structure, floor stratum lithology and its combination feature, aquifer watery, and aquifer head pressure. From further analysis, it is realized that the aquifer head pressure is not only the power of water inrush, but also one of the principal factors that determine occurrence of water inrush and the water volume; the floor stratum lithology and its combination feature are retarding factors of Chenghe No.2 mineral floor confined water inrush, as well as the safety curtain of confined water mining; geological structure is often the channel of floor water inrush, and the vast majority of water inrush, especially large-scale water inrush, is related to geological structure. The principal contradiction and principal aspect of the contradiction can be found during prevention and control of floor water inrush, to conduct prediction and prevention with emphasis, and to play an important role in realize compensated mining of Chenghe No.2 mineral.

(2) As for floor film water-resisting layer, to consider the floor mining influence is necessary. The author has established in this article floor compensated mining division model with and without water-diversion failing zone thickness, and adopted water bursting coefficient as the standard to judge floor safety in mining above confined water in accordance with Stipulations on Mine Water Prevention and Design Specification on Coal Mine Water Prevention and Control, taken 0.06MPa/m and 0.1MPa/m as the boundary conditions for critical water inrush coefficient, divided #5 floor water-resisting layer into dangerous zone of compensated mining, dangerous zone of compensated mining, and mineable zone under pressure, calculated the water bursting coefficient of each drillhole under the two kinds of working conditions, drawn #5 coal floor water bursting coefficient contour line and compensated mining division map under the two kinds of working conditions, and conducted a contrastive analysis on the results of these two kinds of working conditions, and drawn the conclusion that safety in mining is impossible for coalfield when considering floor water-diversion failing zone, but is possible when not considering floor water-diversion failing zone where the water bursting coefficient has dropped 18.94%~83.47% and Chenghe No.2 mineral #5 safety compensated mining is satisfied.

(3) According to the evaluation result of Chenghe No.2 mineral Taiyuan formation #5 floor water inrush dangers, the author has proposed the major floor water disasters and counter measures, including fault zone water-diversion prevention, karst collapse column water-diversion prevention, water-diversion prevention of poor drillholes, and prevention of Ordovician limestone rock water, which are of favourable practical significance.

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