CONTROL OF STRUCTURES ON VERTICAL REPLENISHMENT OF GROUNDWATER IN FOURTH MINE

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ABSTRACT

Having analysed boundary conditions of water replenishment, structures, discharging test and level dynamic of Daqing aquifer and Ordovician limestone aquifer, compared these data with results gained from existant blocking project in one allotment of Fourth mine, Fengfeng, North China, the paper deduced three following conclusions. (1) Ordovician karst water recharges vertically Carboniferous Daqing aquifer. (2) Heterogencity of karst water is principally related to tensile fractures perpendicular to bedding surface, which were concentrated in local upwarps controlled by folding structures especially where the occurrence of strata changed abruptely. (3) Vertical recharge zone was situated in local upwarps where Ordovician limestone and Carboniferous limestone correspondent to each other and so does their level dynamic feature under different conditions. From the conclusions, vertically recharged zone was deduced and verified by groutting project. As the result, the discharge of mine decreased by more than 90%, and expenses of electricity for dewatering was reduced by 3.92 million China's Yuan each year, and the life of mine increased by more than 10 years.

INTRODUCTION

The Fourth Mine is located between Jioushan and Goushan hilles in the west of Fengfeng Coal Field, Hebei Province. There are seven mineable seams. The three uppers were completely extracted but the deep part of the four lowers, being threatened by Daqing limestone water (a Carboniferous aquifer) and water from middle Ordovician limestone, hasn't be mined. Their shallow part is being mined at present. With a capacity of 0.5 million tons/year, the mine can last only 3 to 4 years. In order to prolonge the life of mine, a great deal of hydrogeological work have been carried out. Since 1972, ten water-discharging tests have been conducted, each of them costed 0.1 million China's Yuan. Because the hydrogeological conditions are very complex, the views have been divergent on the way and position of recharge as well as the approach to water-controlling. The debate lasted ten years and even led two different groups (the "vertical" and "lateral") among our specialists.

Since 1983, vaste studies have been made by Institute of Geology and Exploration, CCMRI, Ministry of Coal Industry and Fengfeng Coal Mining Administration in Fourth Mine. Basically, the replenishment channels of Daqing aquifer were found out. Two water-controlling projects provided good results.

HYDROGEOLOGICAL CONDITIONS

In the northern part of the mine, there was a graben formed by Yangerzhuang Fault and Wuancheng Fault (strike E-W). A intrusive igneous mass was present to the north of the graben and constituted northern aquiclude boundary. In the east part, existed Hecun Syncline approximately S-N and Goushan Fault with throw of 1000 m. To the southeast of the mine was located a concentrated discharging area for Fengfeng Coal Field--Heilongdong serial springs. To the wast there were Ordovician limestone outcrops recharged by great amount of rainfall. Because the mine was just in the joint position of E-W tectonics and Neocathaysian tectonic system, fault fissures have been very developed, and most of them were N-E strike steep normal faults which produced a lot of horsts and graben blocks of different size. Moreover, because the mine is situated in the "water entrence" of groundwater for mine area from western mountain region, karst water flowing conditions are very good, and karst caves and fractires developed not only in lower Ordovician limestone, but also in the upper Daqing limestone. Degree of karstification was different in different blocks even in the same block, depending on their position in structures.

INFERENCE OF RECHARGE WAY

The mine has four production section. The present study, with special regard of Daqing aquifer, was carried out in one of them.

Hydrogeological boundary conditions

Daqing was exposed in the southwest of studied section. The outcrops were 14 m wide and above the groundwater level and recharged by a little of rainfall. Two steep normal faults of N-E strike (F_8 and F_6) constituted respectively northern and eastern boundaries. They jointed gradually towards the northeast. The elevation of strata between the two faults led to form a horst-shaped structures (Fig. 1). Stratigraphically, the interval from Daqing to Ordovician aquifer was 35 meters. However, in the studied zone, the former was elevated because of the horst and the latter was descended outside the two faults. So the interval increased. As the result, Daqing inside the allotment was much higher than the exterior Ordovician limestone. From all these it was concluded that the studied zone couldn't be recharged laterally but vertically by Ordovician limestone.

Feature and filled materials of boundary faults. According to the data obtained from shafts, two boundary faults were exposed in more than eight places by mining. In fault zone, 3-4 cm thick gouge was often met and the rocks were crushed and compacted.

The two walls of the faults showed tension marks. Although the-

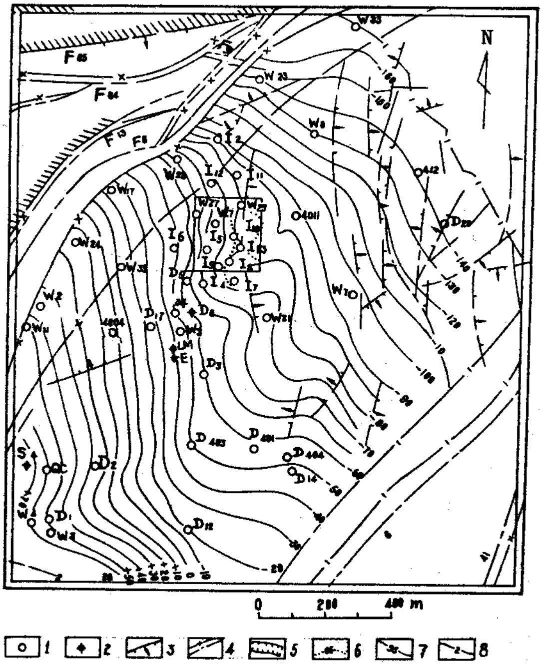

Fig. 1. Contour map of Daqing limestone

1. hole, 2. hole set 3. fault, 4. intersection of fault with seam, 5. horst, 6. original contours, 7. verified contours, 8. coal outcrop

ir mechanical strenght was somewhat weakened, this kind of compacted faults couldn't conduct water because under the condition of static equilibrium the confined water head applied to the fault zone wasn't big enough to exceed the mechanical strenght of fault zone. One extraction had destroied static equilibrium status, the key point of analysis should be put on the fault F_8. The reason for this was that there were imbricate structures formed by a series of steep faults at external side of F_8, while to the northeast of F_8 existed an Ordovician limestone horst. This part of F_8 was certainely serviousely affected by Ordovician limestone water.

Displacement and activities of F_8. The throw of F_8 varies greately in different sections. It reached its maximum (about 200 m) at the southwest part, then decreased gradually at the northeast even had only 26 m locally (e.g. nearly hole I_2) where Daqing limestone was closest to external Ordovician limestone and F_8 was jointed to F_{13}. It should be possible for this part to conduct water when the static equilibrium had been destroied. However, the hydraulic pressure of Ordovician limestone water became weak near Daqing limestone due to its gradual head loss. Even if Ordovician water had ascended through fault zone and recharged laterally Daqing along bedding surfaces, the amount of water remained very small. So the boundaries of studied zone were almost confined.

Tenth water-discharging test. The test lasted more than 20 days. The discharge kept stable (26 m^3/min). Water discharged in 20 days reached 749000 m^3. The total water-storing space calculated from porosity of Daqing (2.5%) was only 675000 m^3 (4000(L) x 1350 (W) x 5(H) x 2.5% $\approx$ 675000 m^3). That is to say, the volum of water discharged in 20 days exceeded the total water-storing space. In fact, the static reserve of Daqing kept nearly unchanged before and after the test. That fact demonstrated that Daqing limestone had an abundant suppling source. Because the boundaries were confined, it was deduced that its principal recharged water couldn't come laterally.

Recharge conditions of outcrops and water quality analysis. No surfacial water body existed inside the studied zone. Majority of outcrops of Daqing were covered by 0 to 20 m thick loess. The recharge of rainfall by infiltration wasn't big enough to produce above-mentioned huge discharge. Water quality analysis indicated that Daqing water and Ordovician water had similar characteristics, both were of HCO_3-SO_4-Ca-Mg with mineralization degree of 0.2 to 0.6 g/l. In sum, Daqing had been recharged principally by Ordovician limestone water, say "vertical recharge" in the paper.

Materials spurted from holes

There was vertical recharge in the vicinity of hole D_6. The basis of the deduction was as follows. (1) High water pressure: During drilling D_6, as soon as the bit had reached the surface of Daqing, the rod was bent by powerful water pressure, then the hole spurted yellow water with mud and stone of 4 to 10 cm in diameter. (2) Big discharge: Once the rod had been lifted, the discharge attained 15 m^3/min, and remained 10 to 11 m^3/min after one week. (3) Silt and rocks spurted was up to 200 m^3, most of rocks were angular. Lithologically, there were argillaceous shale, ferrous nodules, limestone and others. All of these characteristics showed that Daqing in that zone had high pressure and a very abundant recharge source, and a zone of concentrated structural fractures passed Penchi series then connected Ordovician limestone aquifer to Daqing. Vertical water-conducting channels were present at some extent.

Conditions of vertical structural space

Structural fractures were developed and rich in water where vertical channels existed. The statistics from about 70 holes indicated that considerable holes didn't reach the bottom of Daqing and the thickness of Daqing was essentially stable. In order to use fully the information from the holes to analyse the relief of Daqing bottom and the relation of structural space and underlying water-resisting layers with groundwater, contour map of Daqing limestone surface was constructed with interval of 5 m and in scale 1:5000 (Fig. 1). The map gave four following important characteristics.

(1) Where local upwarping structures existed, discharge was often big, depending upon the amplitude and occurrence change as well as dimension of upwarpings. In intensive upwarping zone with abrupt change of occurrence and big influencing extent, for example around holes W_3, D_3, D_{17}, hole sets D_6 and LM, the discharge was big. Under the contrary conditions, the discharge was very small, for instance, around D_1, W_4, W_3, D_{403}, D_5 (Fig. 1, Table 1).

Table 1. Discharge of holes

class	I					II						III					
hole No.	D_6 (7 holes)	LM 10	W_3	D_3	D_{17}	S (4)	QC	D_{12}	W_{28}	D_{14}	D_{404}	D_1	W_4	W_3	D_5	D_{403}	D_{401}
discharge (m³/min)	25.3	12.5	7	3.5	3.5 to 2.5	10	3	3	15	1	1	0.1	0.1	0.2	0.1	.36	.2 to .3

(2) Holes located in local upwarping structures in Daqing were very sensitive to drawdown and recovery of head, particularely W_{27}, W_{28}, W_{24} followed by W_{33}, I_2, W_{29}, W_{23} (Fig. 2).

(3) Holes in upwarpings met extramely developed tensile fractures perpendicular to bedding surface.

(4) Amount of discharged water wasn't obviousely correlative with the scope of fault.

Four above-mentioned characteristics demonstrated that normal fault were not the real water-storing structures. Water-storing space was principally formed by tensile fractures vertical to bedding surface. The fractures were concentrated in some sections possessing upwarping structures. The most evident one of them was nearby hole set D_6.

Contour map of Ordovician limestone surface (Fig. 3) indicated some upwarpings. The most important one was around W_{34}, which coincided with that of Daqing limestone. That coincidence was probably one of necessary conditions for structural fractures to extend vertically and finally develop vertical channels.

Analysis of vertical water source

Analysis of dynamic level observation of Daqing and Ordovician water provided following characteristics of vertical water source under different situations.

Observation of level before discharging. From isopiestics before discharging (Fig. 4), the general trend showed the high level in the west and the low one in the east. And in the west, high level was located in the northern part and the lower in southern part. The area of high level was situated in the northwest of allotment. Nearbly hole set D_6, there was a network recharging water to its vicinity. Because in this section, Daqing limestone gained water from Ordovician aquifer. So its level was higher than that in its vicinity and so did its discharge.

Observation of tenth discharging test. Isopiestic of the tenth discharging test of Daqing aquifer made in +90 level (Fig.6) indicated that in the section from holes D_6 to I_4, the level was also high. This high level wasn't temporary one caused by poor hydraulic connection with discharging wells and their poor sensibility to drawdown, but a stable ore which had a good sensibility to drawdown and good hydraulic connection with discharging wells as well as an abundant replenishment from Ordovician aquifer. The section of high level from D_6 to I_4 (Fig. 6) corresponded to the zone of low level of Ordovician aquifer (Fig. 7). Vertical replenishment of Daqing limestone from Ordovician aquifer resulted in low level of Ordovician aquifer. That coincidence and dynamic feature demonstrated the vertical replenishment.

In short, the two following characteristics can show vertical replenishment of hole set D_6. Firstely, there existed structural space of developed vertical channels. Secondely, change of levels proved dynamic feature of vertical hydraulic connection. By these characteristics it was possible to predict vertical replenishment of aquifers.

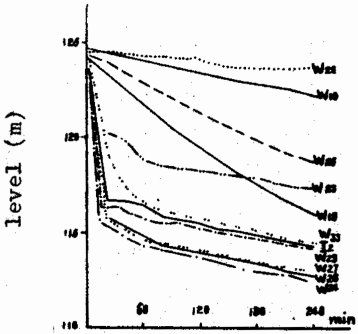

Fig.2. Duration curve of Daqing water in tenth test (26.43 m^3/min)

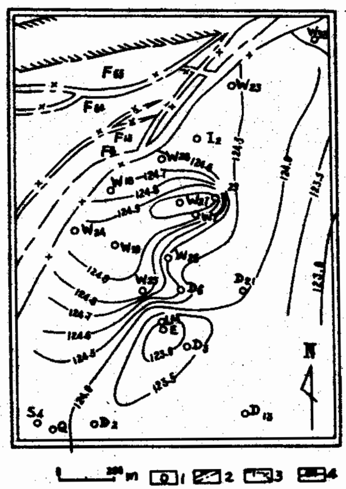

Fig.4. Isopiestics before discharging
1. hole, 2. fault, 3. allotment boundary, 4. isopiestic

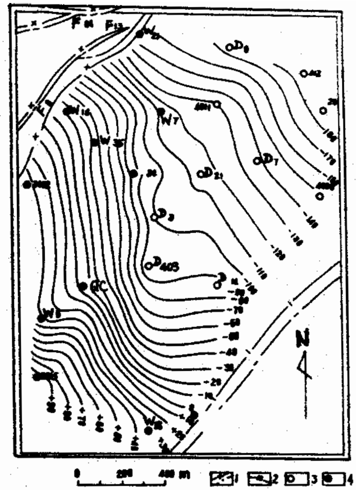

Fig.3. Contours of Middle Ordovician limestone surface
1. fault, 2. contours, 3. hole in Daqing, 4. hole in Ordovician limestone

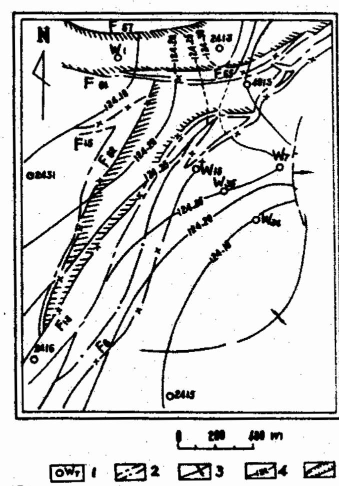

Fig.5. Contours of level recovery of Ordovician aquifer
1. hole, 2. fault, 3. synclinal axe, 4.isopiestic, 5.horst

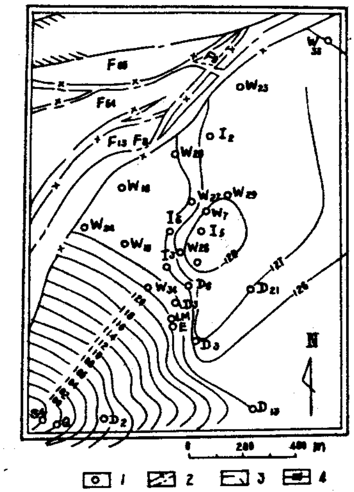

Fig.6. Isopiestics of Daqing during discharging at +90 level

1.hole, 2.fault, 3.allotment boundary, 4.isopiestic

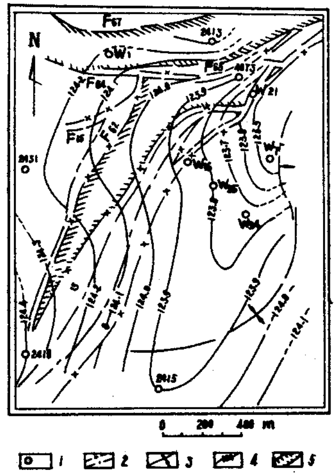

Fig.7. Isopiestics of Ordovician limestone during discharging

1. hole, 2.fault, 3.synclinal axe, 4.isopiestic, 5. horst

PREDICTION AND VERIFICATION OF POSITION OF VERTICAL CHANNELS

Prediction of position

Prediction from structural space. Analysis of structures indicated that Daqing aquifer was possessed of potential structure-forming conditions in inclining and upwarping part of syncline and lower wall of fault. The most important part was inclining part of syncline since in this part there was a 3 m throw-normal fault extending along the axis and existed a zone of abrupt change of occurrence. Furthermore depressed colums were present nearby. From statistics made in mine, the closer to lowe coal seams, the more depressed colums were exposed, around which fractures were more developed and occurrence of strata changed greately. In other words, obvious change of occurrence and cracks as well as structural fractures were related to possible hidden depressed colums. Therefore, it was logic to conclude existence of structural conditions for development of vertical channels in the studied zone.

From contours of Daqing limestone surface, it can be seen clearly that there was second small upwarp to the noth of D_6 in the section from W_{27}, I_5 to W_{29}. Just like the first section of vertical replenishment, it coincided with that one which can be seen from contours of Ordovician limestone (around W_7). So it was considered as second section of vertical replenishment for Daqing aquifer.

Pridiction from vertical source. Studies of structural space of vertical channels provided a clear understanding about the locations of groundwater. However, groundwater can move only when it has some difference of hydraulic head. Water source of Daqing aqifer essentially depended on the difference between it depth and the hydraulic head of Ordovician limestone water. That is to say, the bigger the difference was, the better the conditions to form vertical source were. The comparative analysis of hydraulic head of Ordovician limestone and the depth of Daqing limestone showed that the section of the best conditions to form vertical source was located in inclining part of syncline, because in this part, Ordovician hydraulic head was the highest and Daqing limestone was deeper.

From the dynamic feature of Daqing and Ordovician water and isopiestics of Daqing water before discharging test (Fig. 4) and those of Ordovician water after recovery of Daqing water level (Fig. 5), it was evident that a zone of high level existed to the north of D , i.e. around W_{27}, I_5, W_{29}. Isopiestics of Daqing water during the tenth discharging test at +90 level (Fig.6) and those of Ordovician water at the same time (Fig. 7) indicated also the coincidence of section of high level of Daqing water around W_{27}, I_5 and W_{29} with section of low level of Ordovician water around W_7. Therefore from the dynamic feature of vertical hydraulic connection of Ordovician water with Daqing water in different situations, the second vertical recharge section for Daqing limestone was predicted around W_{27}, I_5 and W_{29}.

Prediction from reaction after first phase of groutting project.

(1) Change of level around hole set D_6. Lowering of Daqing level in north side was obviously different to that in the south side after D_6 had groutted. To the south of D_6, lowering was bigger and strata above +90 level were approximately dewatered, while to the north of D_6, it was very small (Table 2). In addition, the amplitude of lowering before and after groutting was very different in D_6. To the south of D_6, the drawdown of level after groutting was much bigger than it was before groutting. This proved another vertical replenishment section.

(2) Observations of discharging test after groutting D_6. After groutting, the section of high level to the south of D_6 dispeared. However, that to the north persisted around W_{27}, I_5 and W_{29}, which was closely connected with discharging holes and vertically recharged by Ordovician aquifer.

Table 2. Drawdown before and after groutting D

section	to the south of D_6						to the north of D_6				
hole / drawdown (m)	E_4	D_{20}	D_3	D_2	W_{25}	W_{19}	I_2	W_{33}	W_{18}	W_{29}	W_{23}
before	8.6	10	14	7.7	5.25	3.52	1.86	2.59	2.5	1.21	1.33
after	3.57	6.4	9.93	6.7	3.74	2.48	3.74	3.65	3.26	3.12	2.32

Synthetical studies of the above-mentioned resulted in a water-controlling project with regard of second replenishment section around W_{27}, I_5 and W_{29}. Seven holes distributed in sector were drilled on the surface around I_5. Table 3 presented the some data of the project.

Table 3. Some data of holes for the project

hole	I_{12}	I_{11}	I_{10}	I_{13}	I_8	I_7	I_3
direction to I_5	NE6	NE24	NE73	NE87	SE69	SE45	SE41
distance to I_5 (m)	215	260	92	115	85	140	70
depth below Daqing (m)	15.29	13.92	14.50	12.65	13.34	14.61	15.62

From the table, it can be seen that all holes passed through the bottom of Daqing limestone, then went into coal-bearing strata for more than 10 m and had the same structures availiabla to seal and plug up vertical water-conducting channels. In regard to emplacement, I_{10}, I_9 and I_{13} were located in the center of predicted section of vertical replenishment, while I_7, I_{11} and I_{12} in its boundaries.

Results of vertication

Drilling verification. From data of core, the limestone in holes I_8, I_9, I_{10} was greatly broken and had very developed karstified fissures and traces of water erosion with yellow mud in the upper of Daqing. On the other hand, circulation liquid leaked a lot($>$250 l/min) when holes met Daqing limestone. That fact demonstrated also that the vicinity of four holes were situated in a zone of concentrated developed karstified fissures. If we consider the zone from the predicted section of vertical channels(around W_{27}, I_5 and W_{29}), it can be seen clearly that the four holes were just in the center of predicted section. By the contrary, I_7, I_{11} and I_{12} were in the boundary of the section. Therefore, drilling proved the correctness of prediction for position of vertical channels.

Geophysical verification. Results given by electromagnetic sonding in hole (Fig. 8) showed the attenuation coefficient in I_4, I_8, I_9, I_{10}, W_{29} was bigger than 0.7 db/m and there was an anormal zone. It wasknown that the thickness of Daqing limestone was essentially stable in the allotment. If the electrical parameters of rocks kept constant, the loss of electromagnetic energy, i.e. attenuation coefficient should have been the same for the equal distance. When there are conducting channels, electromagnetic absorption and the coefficient will increase even produce anormalies.

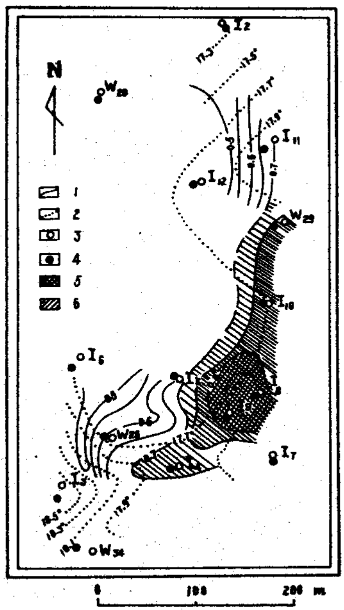

Fig. 8. Result of geophysical survey

1. isopleth of apparent attenuation coefficient, 2. thermoisopleth, 3. hole, 4. projected position of hole when it met Daqing, 5. high electromagnetic anormaly, 6. anormaly

The thermo-logging indicated that the area of thermoisopleth was located between I_4 and W_{29}. The temperature in that area was 17.7°C, which coincided with that in Ordovician (in W_7, it was 17.65°C). The coincidence of temperature demonstrated that Daqing limestone was vertically recharged by Ordovician water and their hydraulic connection was very close. So the prediction for zone of vertical channels in Daqing limestone was proved correct.

Groutting verification. I_9 was injected 812 tons of cement. After the groutting, the level of Daqing aquifer descended by 10 to 16 m in the studied zone. And I_{10} was groutted 1303.51 tons, the level dropped greatly, for example, drawdown in W_{33} was 91.37 m, 92.13 m in I_{12}. The average drawdown in whole allotment reached 77.56 m and the discharge of mine was reduced by 90%. By contrary, I_{11}, I_{12}, I_{13} were injected a little of cement and couldn't produce a magnificentdrawdown. I_8 was only 30 m away from I_9. After I_9 was groutted, I_8 was plugged up. The big decrease of discharge verified the principal vertical channels around I_{10}, I_9, I_8 and W_{29}. This zone was just the centre of predicted section of vertical channels. Therefore, the prediction was proved very successful.

CONCLUSION

The study and water-controlling practices verified vertical replenishment and predicted successfully vertical channels in Fourth Mine. Statistic analysises revealed heterogencity of karst water principally related with tensile fractures perpendicular to bedding surface. The fractures were concentrated in local upwarping zones, especially in edges of abrupt change of occurrence controlled by folding structures. The results of the study has a guiding importance for karst water-controlling in coal mines of the same type in North China.