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Application of Water Chemistry and Isotope Analysis in the Coal Mine Hydrogeology Prospection

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Abstract Based on the comprehensive analysis of the water chemistry and isotope data from the main water filling aquifer, it is found out that the tenth limestone and the Ordovician aquifer in the wellfield have an independent recharge-runoff-discharge system, which have weak hydraulic connection under natural state. And, the thirteenth and fourteenth limestone aquifer and the tenth limestone and the Ordovician aquifer have hydraulic connection. Under influence of excavation and water-conducting fault, groundwater between its aquifers has closer relation. This conclusion is consistent with the pumping test conclusion, thus demonstrating the creditability of the achievements.
Keywords water chemistry, isotope, hydrogeological prospection

Introduction

After occurrence of 2010' "8.17" fault groundwater inrush accident, Linkuang Group approved the mine hydrogeology type of Tianzhuang Coal Mine as the "complex" type. Subsequently, Tianzhuang Coal Mine conducted supplementary hydrogeological exploration engineering and achieved rich pumping test data, the water chemistry data and isotope data. This paper, based on such background and premise, takes the water chemistry and hydrogen and oxygen isotopes data as the basis; in addition, on the basis of supporting aquifer hydraulic connection data, the paper attempts to explore functions of water chemistry and hydrogen and oxygen isotopes in analyzing the aquifer hydraulic connection and recharge water sources, so as to provide some useful references for future similar project exploration.

Overview of mine hydrogeology

The main mining coal bed of Tianzhuang Coal Mine is a kind of $\text{sixteenth}_{\text{upper}}$ and seventeenth coal bed of the Carboniferous System Taiyuan Formation, and groundwater sources threatening the coal bed mining mainly refer to the $\text{tenth}_{\text{lower}}$ limestone, thirteenth and fourteenth limestone and Ordovician aquifer water (fig.1). The spacing between the thirteenth and fourteenth limestone is 6.2 m, which is integrated as a single layer locally, both of them have unified water level and dynamic change characteristics. When considering the impact on the safe mining of the lower coal group, it can be treated as the same karst fissure pressure-bearing aquifer. The tenth limestone water is the direct water charge source of the sixteenth coal and the thirteenth and fourteenth limestone water and Ordovician limestone water is the indirect water charge source of floor of the sixteenth and seventeenth coal bed. The hydrogeology of the tenth limestone aquifer is generally weak, the water abundance of the thirteenth and fourteenth limestone aquifer is from weak to moderate and the water abundance of Ordovician aquifer is generally from strong to extremely strong (CNACG 2012; Lai et al. 2014).

Water chemistry features of the tenth limestone aquifer

Due to significant influence of the under-shaft drainage, the water chemistry type plane distribution regularity of the tenth limestone aquifer is not obvious; the overall regularity is that the TDS value is less than 1,000 mg/L (except 7-exploration and 1-hole, 5602 hole, recharge 12-hole and coal mine roadway water intake point); multiple water intake points

Na^{+}+K^{+} content has reached the level of classification, thus representing the inheritance features of the Quaternary aquifer water source.

Water chemistry features of the thirteenth and fourteenth limestone aquifer

The west area of the wellfield or the area close to the suboutcrop has low K^{+}+Na^{+} content; the water chemistry type is commonly $HCO_3 \cdot SO_4$-Ca·Mg type or $SO_4 \cdot HCO_3$-Ca·Mg type; the TDS value is generally less than 800 mg/L, which has the Ordovician karst water features. For the east area of the wellfield, the TDS is 1,000~2,000 mg/L and the water chemistry type is SO_4-Ca·Mg, SO_4-Ca·Na type, thus reflecting the stagnation groundwater characteristics, which is generally consistent with overall features of Ordovician water chemistry field(Zhang et al. 2014, Wang et al. 2009). fig.2.

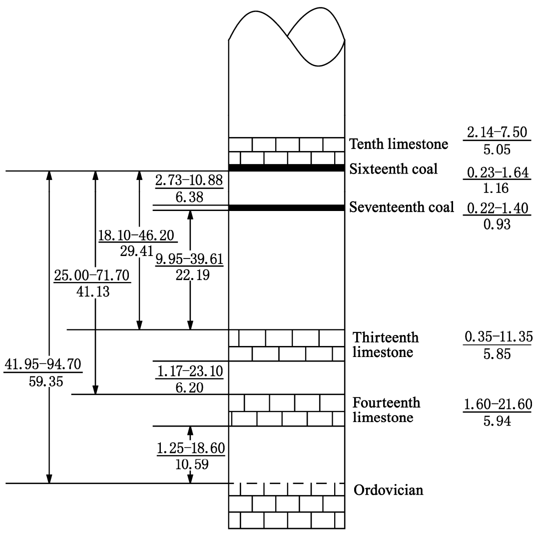

__Fig. 1__ Each aquifer spacing relationship graph

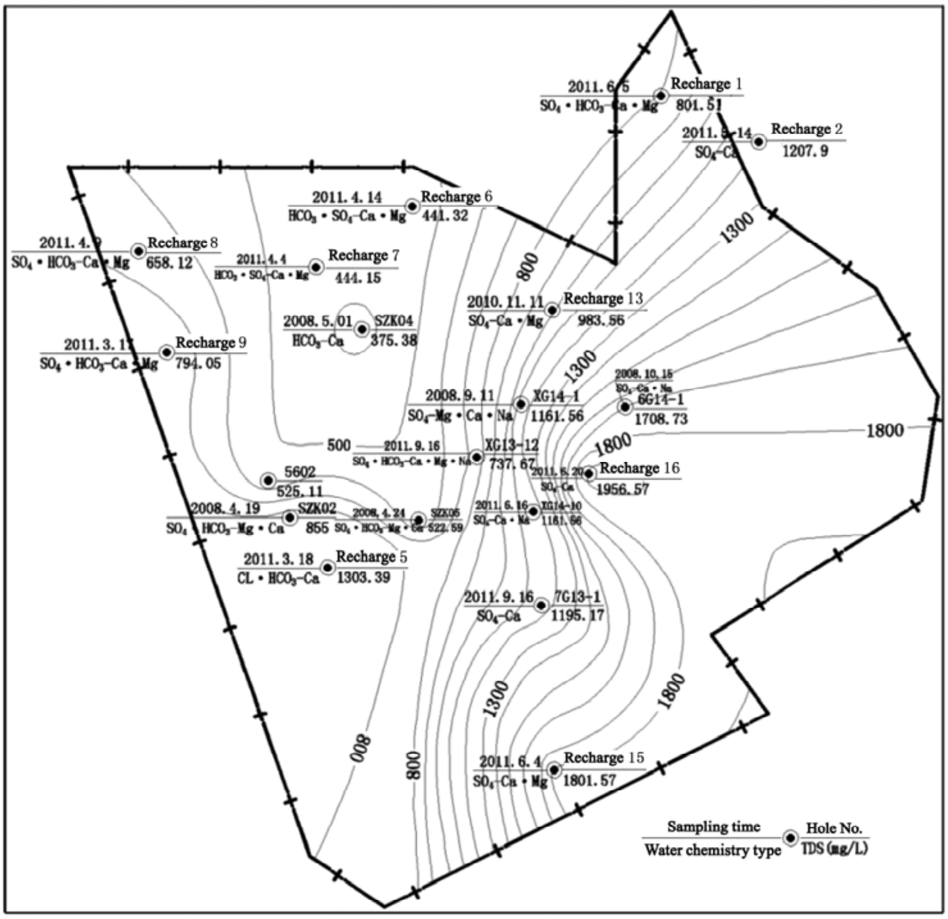

__Fig. 2__ TDS isogram of the thirteenth and fourteenth limestone aquifer

During the water drainage test period, groundwater dynamics of Ordovician and the thirteenth and fourteenth limestone observation hole is a strong evidence, as shown in fig.3.

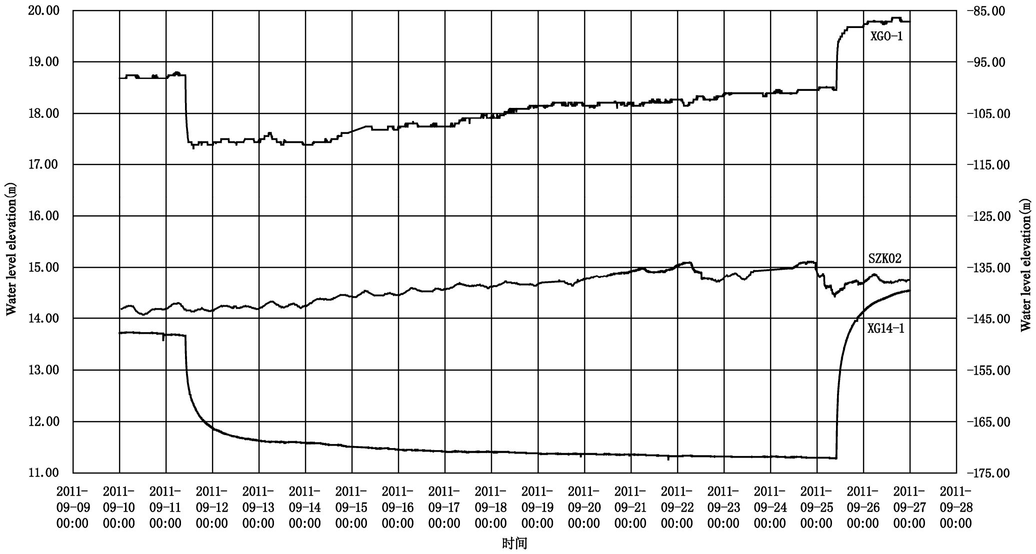

Fig.3 *Dynamic water level curve graph of observation holes*

However, some boreholes have higher Na^+ content and become an obvious marks for difference between Ordovician water quality, representing that its surrounding thirteenth and fourteenth limestone and Ordovician aquifer hydraulic connection is relatively weak.

These facts mean that the thirteenth and fourteenth limestone and Ordovician aquifer have wide hydraulic connection, but there also exist areas with weak hydraulic connection locally.

Features of the Ordovician water chemistry field

During supplementary hydrogeology Prospection period of Tianzhuang Wellfield, rich water chemistry data has been acquired through the sampling and water chemistry analysis . The water chemistry field features are as shown in fig.4 and fig.5.

Fig.4 shows that, the borehole TDS content in the east of the groundwater divide is 1,356.06~3,221.2mg/L. According to the water chemistry data of 10 boreholes (including recharge 4 holes), the water chemistry type is SO_4-Ca·Mg and SO_4-Ca type, thus reflecting the stagnation groundwater characteristics. The borehole TDS content in the west of groundwater divide is 354.35~901.82 mg/L. According to the water chemistry data of 9 boreholes, the main water chemistry type is HCO_3·SO_4-Ca·Mg, followed by SO_4·HCO_3-Ca·Mg type. The area in the east of the groundwater divide has obvious water chemistry characteristics: TDS value increases gradually from west to east, water chemistry type changes to SO_4-Ca type from SO_4-Ca·Mg type; the strong runoff zone in the west of the groundwater divide has smaller TDS value and less obvious regularity, thus reflecting good groundwater circulation condition and locally complex water inflow direction.

The water chemistry type and TDS content have obvious differences, showing that the water chemistry field is different. Different water chemistry fields reflect different runoff and infiltration and conduction of the groundwater flow field. High consistency between the water chemistry field and groundwater flow field prove the west part of Tianzhuang Wellfield is located on the strong karst water runoff belt and its east area is a relative stagnation area.

In addition, TDS value of recharge 6 and recharge 10 is smaller than 500 mg/L and these two boreholes has the best water abundance (water abundance is extremely strong), thus illustrating that the hydrodynamic condition will control the karst development, water abundance and water chemistry. The recharge 4's water quality is worse than that of surrounding boreholes, which is related to its position (in the axis of Gucheng syncline), larger embedding depth of the aquifer and unsmooth runoff circulation.

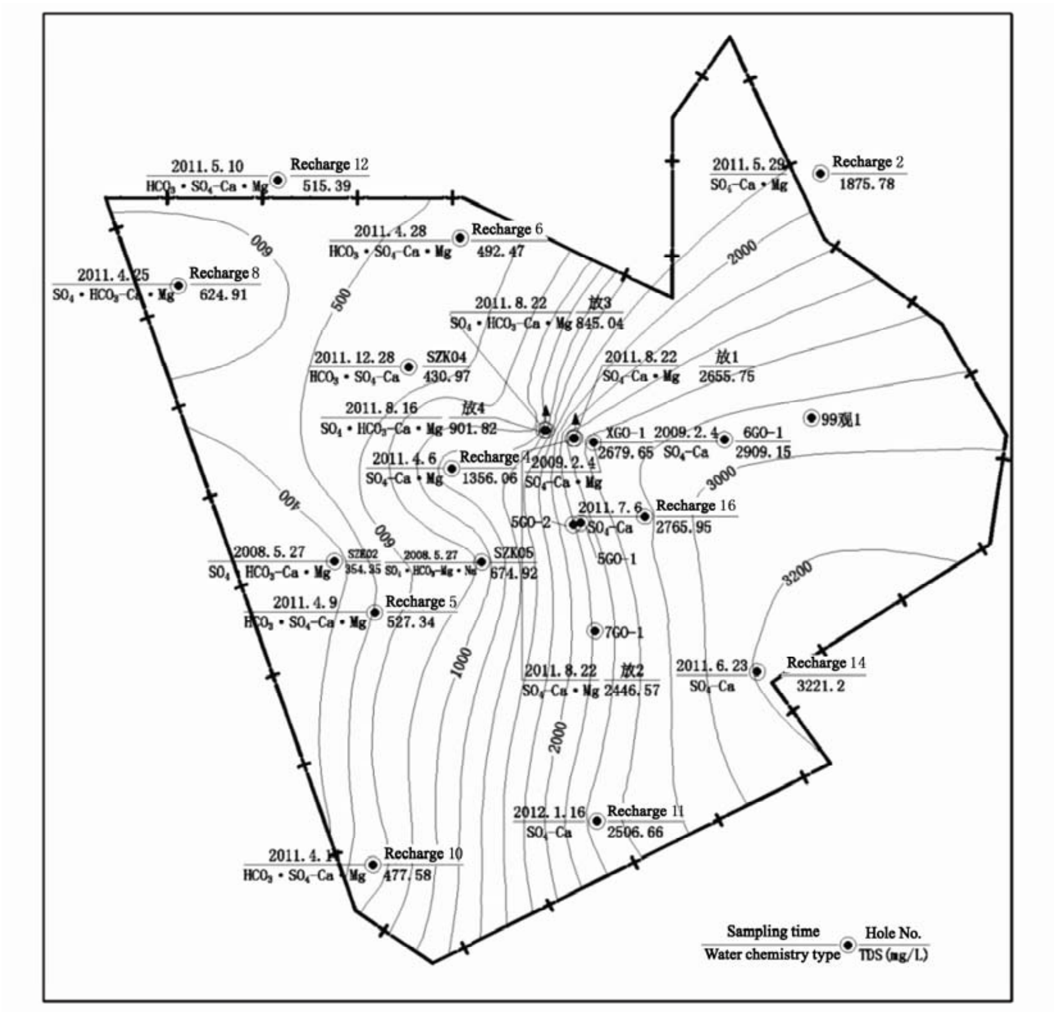

Fig. 4 *TDS isogram of Ordovician water*

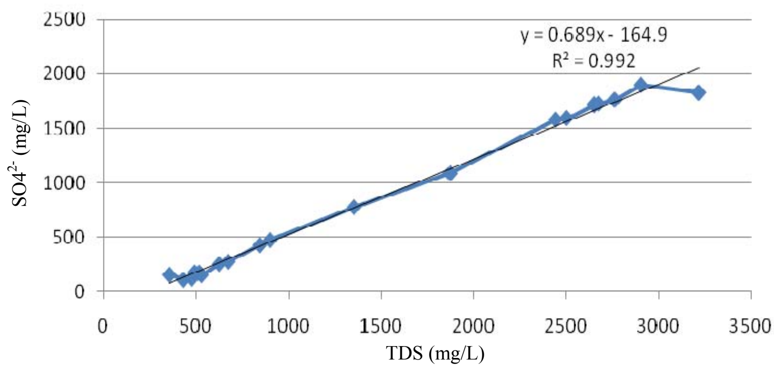

Fig. 5 *Correlation of TDS~SO_4^{2-} content*

Fig.5 shows that, TDS and SO_4^{2-} have linear correlation, which reveals that the regional water chemistry formation is mainly due to gypsum dissolution and accompanying dedolomitization effect (according to Ca^{2+}~SO_4^{2-}, Ca^{2+}~HCO_3^- ion correlation analysis, the dissolution of carbonate rocks in this area stops almost; water calcite, dolomite in water are basically saturated; in addition to gypsum dissolution, dedolomitization reaction also occurs. The correlation analysis is omitted) and the regional runoff position.

Indication significance of δ ^{2}D and δ ^{18}O

The exploration has gained 35 isotope samples, including 1 rain sample, 1 Q sample, 11 tenth limestone samples, 12 thirteenth and fourteenth limestone samples and 10 Ordovician samples. For δ ^{2}D and δ ^{18}O values of the water sample, except Ordovician recharge 12, XGO-1, tenth_{lower} limestone recharge 1 and recharge 12 isotope samples are inconsistent with the overall regularity and not projected onto China atmospheric precipitation chart, the rest are projected onto China atmospheric precipitation chart fundamentally (fig.6). They have obvious regularity and the analysis is as follows(CNACG 2012, Lai 2014).

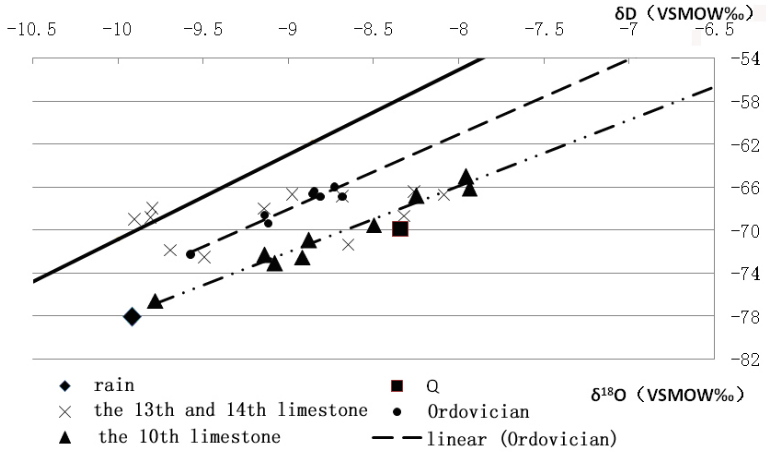

Fig. 6 *δD-δ^{18}O curve graph between groundwater and rain*

(1) The rain isotope sample in the region and Q isotope sample can be connected as a straight line almost parallel to China atmospheric precipitation line, but it is under China atmospheric precipitation line, thus showing that the regional China atmospheric precipitation environment is slightly different from China regional atmospheric precipitation environment. The straight line between the rain isotope sample and Q isotope sample can be made as the regional rain line.

(2) On the basis of making the straight line between the rain and Q isotope sample as the regional rain line, the sample can be relatively concentrated distributed near the top of the regional rain line, thus reflecting that the regional groundwater has a close relation with the atmospheric precipitation, namely same as supply by the atmospheric precipitation. The δ ^{2}D and δ ^{18}Ovalues of 35 isotope samples are higher than that of the rain sample, indicating that certain evaporation occurs before atmospheric precipitation enters into the aquifer.

(3) The Ordovician trend line and the tenth limestone trend lines are parallel to China atmospheric precipitation line and respectively independent, which also have obvious laws, indicating that the main water filling aquifer tenth limestone and Ordovician aquifer in the wellfield have their own recharge-runoff-discharge system. In the natural state, the tenth limestone and Ordovician aquifer has independent recharge-runoff-discharge system, the

hydraulic connection is weak and hydraulic connection may occur at the suboutcrop of limestone rock when influenced by water-conducting fault or mining.

(4) The thirteenth and fourteenth limestone isotope sample is complex, 3 samples are close to China atmospheric precipitation line, 5 samples are close to Ordovician line and 4 samples are close to the tenth limestone line, fully indicating that the thirteenth and fourteenth limestone aquifer and the tenth limestone and Ordovician aquifer all have hydraulic connection and their connection with the Ordovician water is closer. When being influenced by mining and water-conducting fault, groundwater connection between its aquifers is closer and the mine hydrogeology conditions tend to be more complex.

Through the above analysis, it is found out that the result of isotope analysis is almost the same as that of group drilling water drainage test, thus illustrating the scientificity and credibility of the achievements.

Groundwater dating by tritium isotope

Introduction to tritium content

Tritium is a kind of radioactive isotope of hydrogen, with the code of ^{3}H or T and atomic weight of 3.016049, which was discovered in 1939. The natural tritium is produced in the upper atmosphere at a height of 10-20 km, which is produced when the high-speed neutron of the cosmic ray (with energy more than 400 Mev) rushes out from the stable nitrogen atom of the atmospheric layer and generates nuclear reaction.

The tritium in natural water mainly includes two kinds of origin: Natural tritium and artificial nuclear explosion tritium. According to the monitoring data in 1949 and 1950, it is found out that the average tritium concentration of the atmospheric precipitation is 5~10 TU.

Artificial tritium is primarily produced in a nuclear test in the air. The first nuclear test was carried out in the air at the end of 1952, but a lot of artificial tritium display in atmospheric precipitation occurred in early 1953. From 1954 to 1963, due to constant nuclear tests, a lot of artificial tritium was produced, which destroyed the natural tritium balance. The peak value of tritium concentration in 1963' northern hemisphere atmospheric precipitation appeared, which amounted to thousands of TU.

According to data of domestic seven monitoring stations from 1986 to 1998 (Liu 2001), it is found out that the tritium concentration in the atmospheric precipitation also shows a decrease trend year by year. The data of Shijiazhuang monitoring station shows that the tritium value of the regional atmospheric precipitation decreased to 20~25 TU around 1998 from about 65 TU around 1986. After 2000, it decreased to below 20 TU (Liu 2001).

Tritium isotope features of Tianzhuang coalfield

The tritium value concentration of the rain sample is 7.56 TU, and the average tritium concentration value of the groundwater is shown in Table 1.

The analysis is as follows

(1) Supposing that Tianzhuang Wellfield groundwater is supplied by atmospheric precipitation before 1950, if calculating according to the average tritium concentration of 5~10TU(Lai et al. 2014) and the tritium half-life period of 12.43 a of the atmospheric precipitation of the time, the tritium concentration in the current groundwater shall be close to zero; therefore, isotope test results confirm that the aquifer groundwater precipitation is supplied by the atmospheric precipitation since 1950.

(2) The rain tritium value is 7.56 TU, Q tritium value is 8.84 TU, average tritium value of the tenth limestone is 10.16 TU, average tritium value of the thirteenth and fourteenth limestone is 9.01TU, average Ordovician tritium value is 8.14 TU, indicating the aquifer groundwater is mainly supplied by modern atmospheric precipitation (shorter than 5~10 years)(Lai 2014).

***Table 1** Test result of tritium isotope*

Horizon	Hole No.	Average Tritium Value (TU)	Horizon	Hole No.	Average Tritium Value (TU)
	Rain	7.56		Recharge 16	6.69
Q_{lower}	5602	8.84		Recharge 1	9.73
	5602	9.34		Recharge 5	8.57
	5602 upward	13.57	Thirteenth and fourteenth limestone	Recharge 6	13.45
	5602 downward	15.88		Recharge 7	5.54
	5602 middle	9.94		Recharge 8	5.68
	Recharge 10	6.78		Recharge 9	10.50
Tenth limestone	Recharge 1	6.5		Average value	9.01
	Recharge 12	9.56		Recharge 10	6.56
	Recharge 3	11.34		Recharge 12	9.54
	Recharge 4	9.78		Recharge 14	8.83
	Recharge 7	8.89		Recharge 16	5.74
	Recharge 9	18		Recharge 2	7.43
	Average value	10.16	Ordovician	Recharge 4	10.20
	5602	9.32		Recharge 5	7.89
Thirteenth and fourteenth limestone	XG13-1	11.59		Recharge 6	8.95
	XG14-4	8.31		Recharge 8	8.08
	Recharge 13	10.23		Average value	8.14

(3) The 5602 downward tenth limestone tritium concentration value is 15.88TU, the 5602 upward tenth limestone tritium concentration value is 13.57 TU, the recharge 6 hole's thirteenth and fourteenth limestone tritium concentration value is 13.45 and the recharge 9 hole's tenth limestone tritium concentration value is 18 TU, indicating that the groundwater has some "nuclear explosion" moment ^{3}H (Lai 2014), namely, it has the atmospheric precipitation 50 years ago.

(4) When comparing according to the tritium concentration value, it is found out that the tenth limestone > the thirteenth and fourteenth limestone > Ordovician (table 1), but the formation depth of Tianzhuang Coal Mine is the tenth limestone < the thirteenth and fourteenth limestone < Ordovician (fig.1), indicating that the groundwater tritium value has an obvious vertical variation characteristics; the tritium value of water decreases with the increase of groundwater embedding depth and the average tritium concentration of from shallow to deep water decreases in turn, showing that the deep groundwater age is older, which is regarded as "old water" and shallow groundwater age is relatively young.

References

CNACG (2012) First exploration bureau geology prospection institute. Supplementary Hydrogeology Prospection Report of Shandong Tianzhuang Coal Min Handan, Hebei

Lai YW, Li BJ, Wang ZQ, et al. (2014) Application of group drilling pumping test and isotope analysis in the coal mine hydrogeology prospection. Coal Geology of China 26 (1)

Sun ZY, Liu Guanq (2011) Industrial and mining water chemistry features of China coal Pingshuo No. 3 Shaft and reflection to hydrogeology conditions . Coal Geology of China 23 (4)

Wu Q (2002) Coal mine water disaster prevention and control . Xuzhou, Jiangsu: China University of Mining and Technology Press

Wang JC, Xu YC, Yue ZC (2009) Invisible water leakage mechanism and prevention and control method of ordovician limestone aquifer drilling . Chinese Journal of Rock Mechanic and Engineering 28 (2)

Xue YQ (1997) Groundwater dynamics . Beijing: Geological Publishing House 1997

Zhang XL, Jing JF, Hou YX, Liang B (2014) Analysis on hydrogeology conditions of southern jingfang coal mine in Changzhi, Shanxi. Coal Geology of China 26 (1)