Origin Analysis of Groundwater Hydrogeochemical Facies in Pingdingshan Coal Mine Area, Henan Province, China

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ABSTRACT

By means of Q-mode cluster analysis, trilinear diagram, SO_4/HCO_3-SO_4 correlation chart and isotopic correlation analysis, the study based on hydrogeochemical and isotopic data represents the distribution characteristics and creation of groundwater hydrogeochemical facies. For the sake of determination, evolutionary pattern of hydrogeochemical facies origin is presented. This would be of tremendous help to ascertaining the groundwater creation, distribution and migration laws, using the technique of mine water control while deep-lying mining.

Four hydrogeochemical facies are divided in the mine area according to the origin: rainwater-type hydrogeochemical facies (deep or shallow); hydrogeochemical facies of surface water type; rainwater and surface water type as transitive hydrogeochemical facies: contaminated hydrogeochemical facies. The creation of groundwater has both developing laws in the whole mine area and differently chief features in each mine. The principal recharge by precipitation occurs in regional deep-lying circulation and, meanwhile, common recharge of partial rainwater together with surface water into mine area prevails in regional shallow-lying circulation. Mine water control should take the form of those which groundwater drainage is a dominant measure simultaneously in connection with water supply for exploitation and utilization in groundwater resources.

INTRODUCTION

Hydrogeochemical facies grows up into a conception being pregnant with meaning in recent years according to the extended meaning in lithofacies and geochemical facies. By the origin analysis, three questions have successfully been settled as these: 1 hydrochemical creation and its evolution environment; 2 origin of hydrochemical components in groundwater; 3 groundwater creation and circulation. By the analysis which comprise Q-mode cluster, trilinear diagram and others, this contribution givec largely the fruit of our study on hydrochemical creation and evolutional process, and the investigation of hydrochemical component origins, so as to deal with the problems of circulation pattern and creation of groundwater. The results have already proved and enriched the hydrogeological information obtained ever before in accordance with the analysis of hydrodynamic field, revealing the hydrogeological laws in mine area as described by the following: 1 there are four origins about hydrogeochemical facies in mine area; 2 two shallow-lying circulation patterns and one deep-lying circulation pattern occur in mine area; 3 water control measures, as for deep-lying development, should match with the recharge conditions and circulation pattern of groundwater.

The mine area dominated by tectonics lies in northern Pingdingshan City where a perfect system of karstic groundwater occurs. Two sides of the Cambrian limestone faulted under the influence of Guodishan fault. In the meantime, there remains limestone, sandstone and mudstone in the fractured zone to form the water-resisting faults. A great difference of hydrogeological conditions exists at the both sides of the fault, which creats two subsystems (Fig. 1).

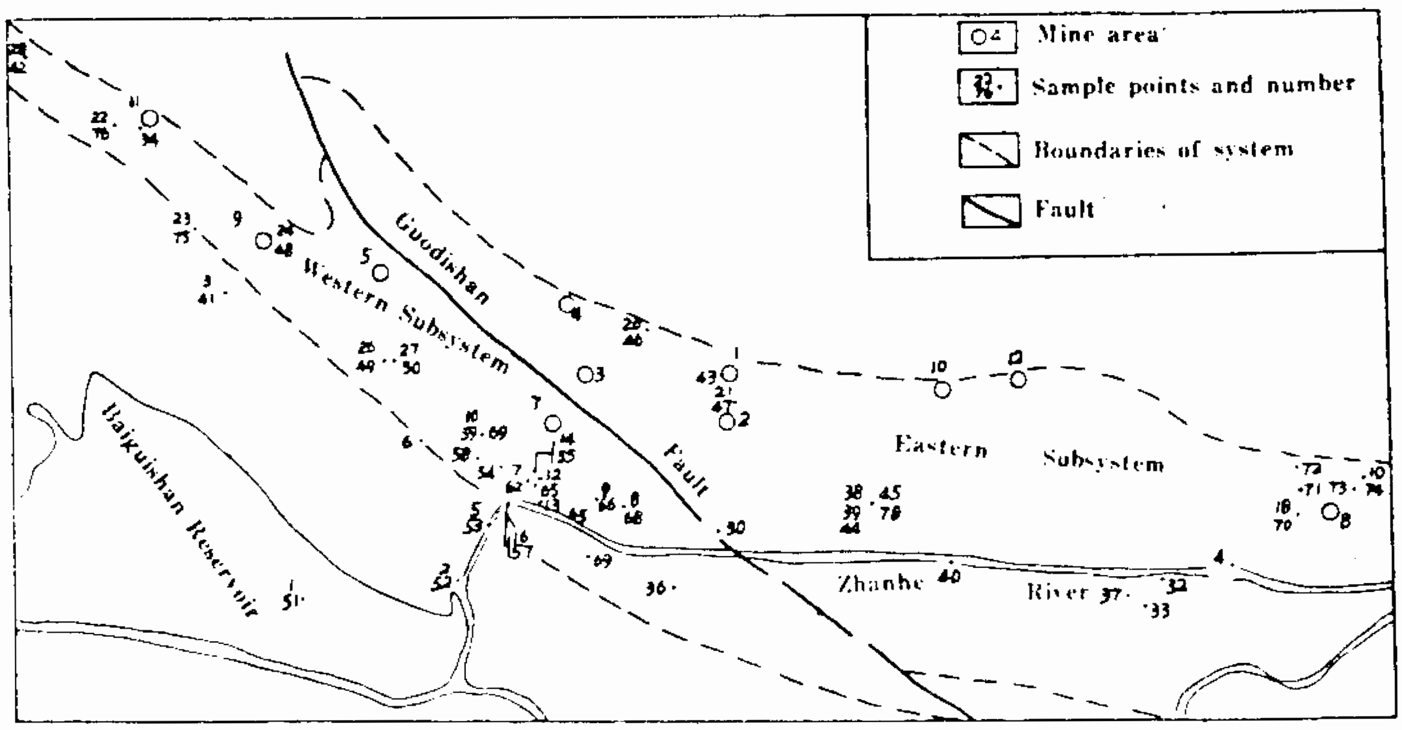

Figure 1. System Classfication and Sample Points in Pingdingshan Mine Area

In 1987-1988, samples about atmospheric precipitation, surface water and groundwater from different aquifers were respectivly taken during low-water period and high-water period so as to analyse the stable isotope ^{18}O and deuterium combined at the same time with chemical analysis. In total, 99 samples of stable isotope and 57 samples of hydrochemistry received a complete laboratory analysis besides accumulated data of hydrochemistry from the whole mine area (Fig. 1).

HYDROCHEMICAL CHARACTERISTICS OF GROUNDWATER SYSTEM IN MINEAREAS

Spatial Variations of Hydrochemical Characteristics in Mine Areas

1. Horizontal Variation Chrasteristics

The hydrochemical patterns show the evolutionary trend along the line as HCO_3-Ca-→ HCO_3-Ca.Mg-→HCO_3.SO_4-Na.Ca from the eleventh mine area in the west to the eighth mine area in the east. In these mine areas, however, where the total dissolved solids are increasingly high, it is up to 0.12-1.03 g/1 . SiO_2 of the groundwater varies from 14 to 24 mg/1, CO_2 from 8 to 18 mg/1 and the temperature at 15-36°C. Various ions represent an apparent law for Na^+ and Cl^- increased from west to east, but SO_4^{-2} and HCO_3^- as the anion and Ca^{2+} and Mg^{2+} as the cation are in the process of concentration. In the eighth and the first mine areas groundwater temperature is over 43°C, and simultaneously CO_2 gas is given out of the groundwater. That $CaCO_3$ and $MgCO_3$ are seperated out and sedimented comes of the concentration of Ca and Mg decreased. Groundwater in these mine areas in just in a weak oxido-reduction environment. That Eh from vest to east decrease from -333mv to -374mv indicates a tendency which the weak oxido-reduction environment turn into a reducing environment.

2. Vertical variation Characteristics

Vertically, hydrochemical characteristics of groundwater vary from the upper to the lower in different aquifers in Pingdingshan mine area. Groundwater in the Permian sandstone is formed by a 1 g/l total dissolved solids, with HCO_3-Na type. The groundwater of the aquifers in the Tertiary marlite, the Permian limestone and the Cambrian limestone is a low minaralized fresh water by a 0.2-0.6 g/l total dissolved solids. On the other hand, hydrochemical characteristics of groundwater vary with depth. The total dissolved solids are gradually high with the buried depth of groundwater increased and the complicated hydrogeochemical types are developed. The variations of potential (Eh), under the action of oxidizing reduction, can make the transition from weakly oxidizing environment to poorly reducing environment.

Temporal Variation of Hydrochemical Characteristics in Mine Area

1. Annual Variations

As compared by hydrochemical data, it has been found that chemical types in groundwater get more complex as time goes, which leads to an apparant tendency of increasing the total dissolved solids in mine area. For example, three water types which contained HCO_3-Ca, HCO_3-Ca.Mg, HCO_3 -Ca.Na before 1984 developed into the existing four water types including HCO_3-Ca, HCO_3-Ca.Mg, HCO_3-Ca.Na.Mg and HCO_3.SO_4-Na.Ca. In western subsystem before 1984, groundwater by a 0.2-0.5 g/l total dissoved solids changed into the existing value at a 0.3-0.93 g/l TDS; also from 0.5-0.93 to 0.55-1.00 g/1 in eastern subsystem in the same period.

2. Seasonal Variations

Almost no variation occurs about the hydrochemical types in groundwater during low-water period or high-water period, but in high-water period the TDS of groundwater are decreased to a low 0.015 g/1 in the west and 0.005-0.010 g/1 in central area during high-water period.

ISOTOPE CHARACTERISTICS IN GROUNDWATER SYSTEM OF MINE AREAS

Horizontally, there are less heavy isotopes contained in the eastern subsystem, and the δD and $\delta^{18}O$ are relatively low. In the eastern subsystem, δD is less than - 60 ‰ and $\delta^{18}O$ less than -7.87 ‰. The heavy isotope values become rather low from No. 2 mine area to No. 8 mine area or from west to east. A high value of δD (>-58.15 ‰) and $\delta^{18}O$ (>-7.4 ‰) occurs in the western subsystem besides low values in the deep-buried sample points, which indicates an increased tendency from west to east. Vertically, δD and $\delta^{18}O$ at different aquifers are increasingly low from the upper to the lower or from shallow to deep as descrided by the following lines as: Quaternary porous water > Tertiary limestone water > Permian limestone water > Permian sandstone water > Cambrian limestone water. According to the characteristics of isotopic fluctuation, the characteristics of rainwater, of surface water and of groundwater are shown:

a) The stable isotope values are increased during dry season and decreased during rainy season.

b) Groundwater regime flunctuates continuously in the western subsystem than in eastern one.

c) There is little variation on isotope values of mine water recharged in the form of precipitation, but great variation of isotope values occurs in the mine water recharged by surface water.

d) Great variation of stable isotope values occurs in surface water and rainwater, and little variation in the groundwater.

HYDROGEOCHEMICAL FACIES IN THE PINGDINGSHAN MINE AREAS

For the sake of clarity, chemical data from surface water and rainwater are presented in Fig. 2, and groundwater data are shown in figure 3. The hydrogeochemical characteristics have been considered before the facies divided. Based on major anion and cation content of water in the map area and selected two boundary lines respectively at 40 and 60 percentile of $HCO_3 + CO_3$ as the principal facies and Ca + Mg ppm as subsidiary facies (Fig. 2,3). Thus, three principal facies and nine subsidiary facies have been identified as follows (Table 1).

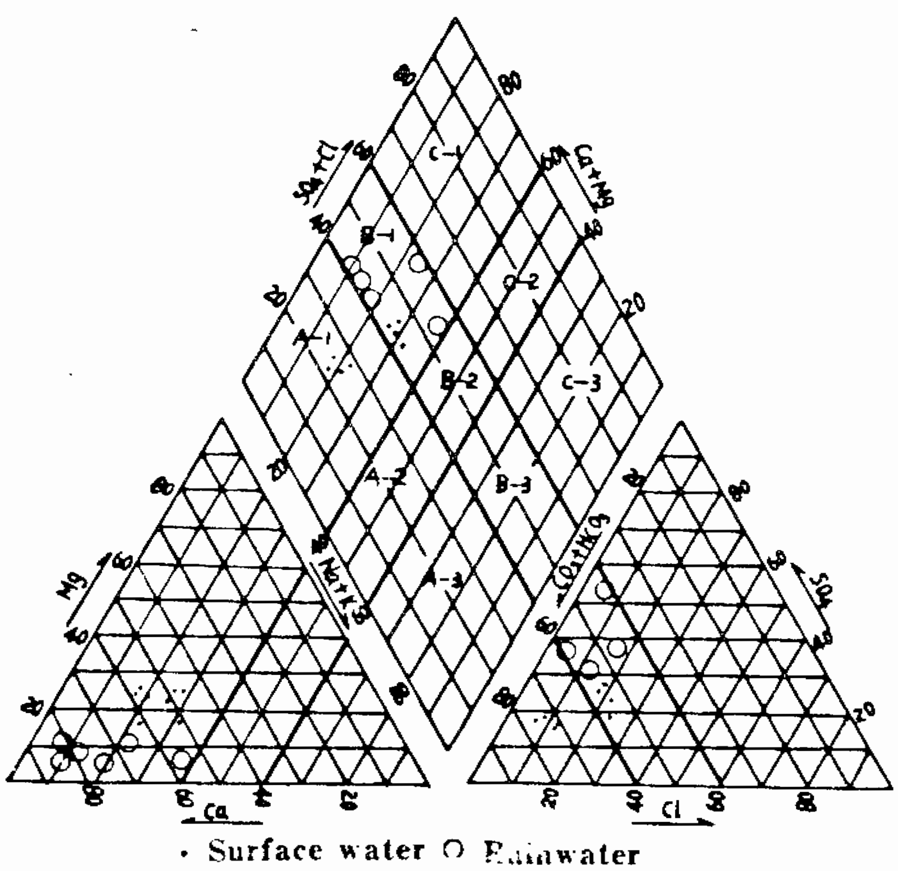

Fig. 2 Trilinear Diagram of Rain-water & surface water samples

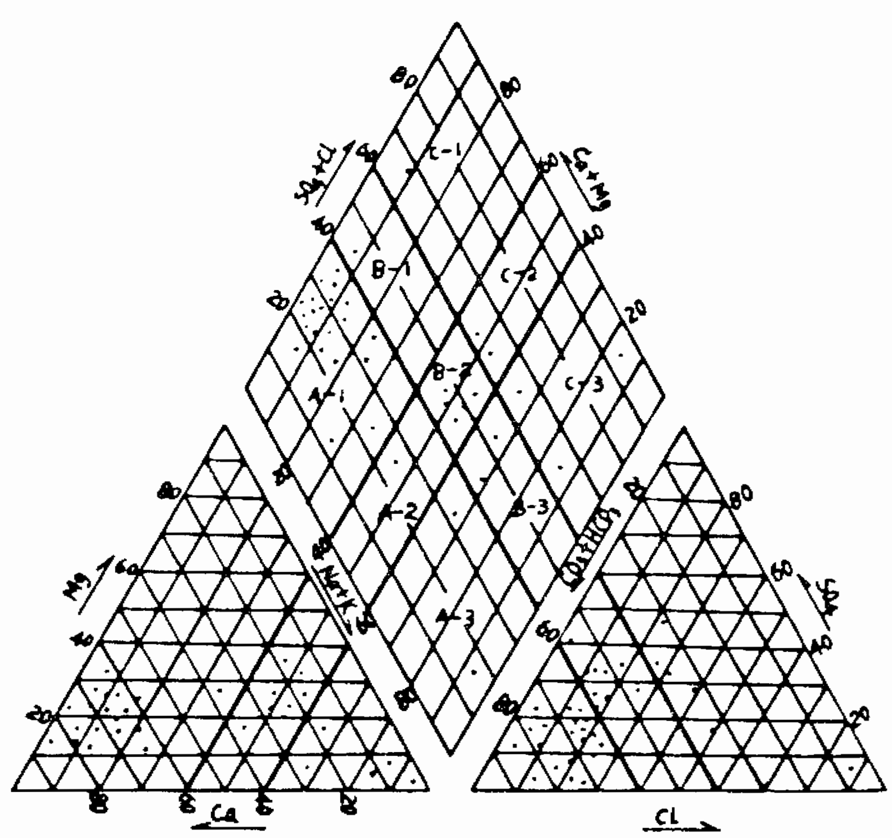

Fig. 3 Trillinear Diagram of groundwater samples

Table 1. Classification of Hydrogeochemical Facies

Facies principal	Facies subsidiary	distribution area
	A-1 HCO_3-Ca.Mg	surface water, Cambrian water, mine water of No.2,5,7,11 mine
A HCO_3	A-2 HCO_3-Ca.Mg.Na	boreholes water of No.7 mine
	A-3 HCO_3-Na	sandstone aquifer water
	B-1 $HCO_3.SO_4$-Ca.Mg	rainwater, Quaternary aquifer water, shallow water in No. 7 mine
B $HCO_3.SO_4$	B-2 $HCO_3.SO_4$-Ca.Mg.Na	groundwater of No.8 mine
	B-3 $HCO_3.SO_4$-Na	boreholes water of No.7 mine
	C-1 SO_4.Cl-Ca.Mg	Quaternary aquifer water
C SO_4.Cl	C-2 SO_4.Cl-Ca.Mg.Na	boreholes water of No.7 mine
	C-3 SO_4.Cl-Na	boreholes water of No.7 mine

ORIGIN ANALYSIS OF HYDROGEOCHEMICAL FACIES

The origin of hydrogeochemical facies in Pingdingshan mine area are different. The recharge respectively by rainwater and surface water individually occurs in the aquifers under the action of water-rock interaction. The mixed recharge simultaneously by rainwater and surface water is also produced in the aquifers. In addation, artificial tracer technique can creat a tremendous influence on the origins of the hydrogeochemical facies. Consequently, four origins are classified in the mine areas.

As shown by SO_4/HCO_3-SO_4 correlation chart (Fig. 4), line 6 parallels and lies bellow line 4, 5. It has been pointed out that the groundwater recharge source of No.8 mine area (facies B-2 $HCO_3.SO_4$-Ca.Mg) is as similar as that of No. 2,5,11 mine area (facies A-1 HCO3-Ca.Mg) with the same lixivation mechanism but diffferent lixival degrees Thus, the rainwater is the recharge source of groundwater.

Similarly, as seen by isotope correlation chart (Fig. 5), line 2,3 are almost in parallel with line 4, which shows the areas. Accordingly, facies A-1 (HCO_3-Ca.Mg), facies A-3 (HCO_3-Na), facies B-1 ($HCO_3.SO_4$-Ca.Mg) and facies B-2 ($HCO_3.SO_4$-Ca.Mg.Na) all belong to the rainwater origin .The recharged mine areas are mainly No.2, 8, 11 mine areas and the confined aquifers in No.5 mine area.

Table 2. Cluster Analysis Results of Samples (1988.4)

Type	Subtype	Group	Limit value	Sample number	Sample location
I	I1	I1-A	0.985	1, 2, 5, 6, 7, 8, 9, 10, 11	reservoir, trunk canal, No. 7 mine
		I1-B		3, 4, 21, 22, 23, 24, 26, 28	No. 2, 5, 11 mine area
			0.956		
	I2			32, 34, 35, 36 37, 38	rainwater, Quatarnary water
			0.928		
II	II1	II1-A	0.960	13, 14	boreholes of No. 7 mine area
		II1-B		31, 33	Quatarnary water
			0.952		
	II2			17, 18, 19, 20, 27	groundwater of No. 8, 2 mine

Table 3. Cluster Analysis Results of Samples (1988, 9)

Type	Subtype	Limit value	Sample number	Sample location
III	III1	0.970	40, 48, 49, 53, 62, 66, 67, 75, 76	trunk canal, No. 5 7, 11 mine area
	III2		54, 58, 56, 60	boreholes from No. 7 mine area
		0.943		
IV	IV1	0.951	43, 46, 47	No. 1,2 mine area
	IV2		70, 71, 72, 73, 74	No. 8 mine area

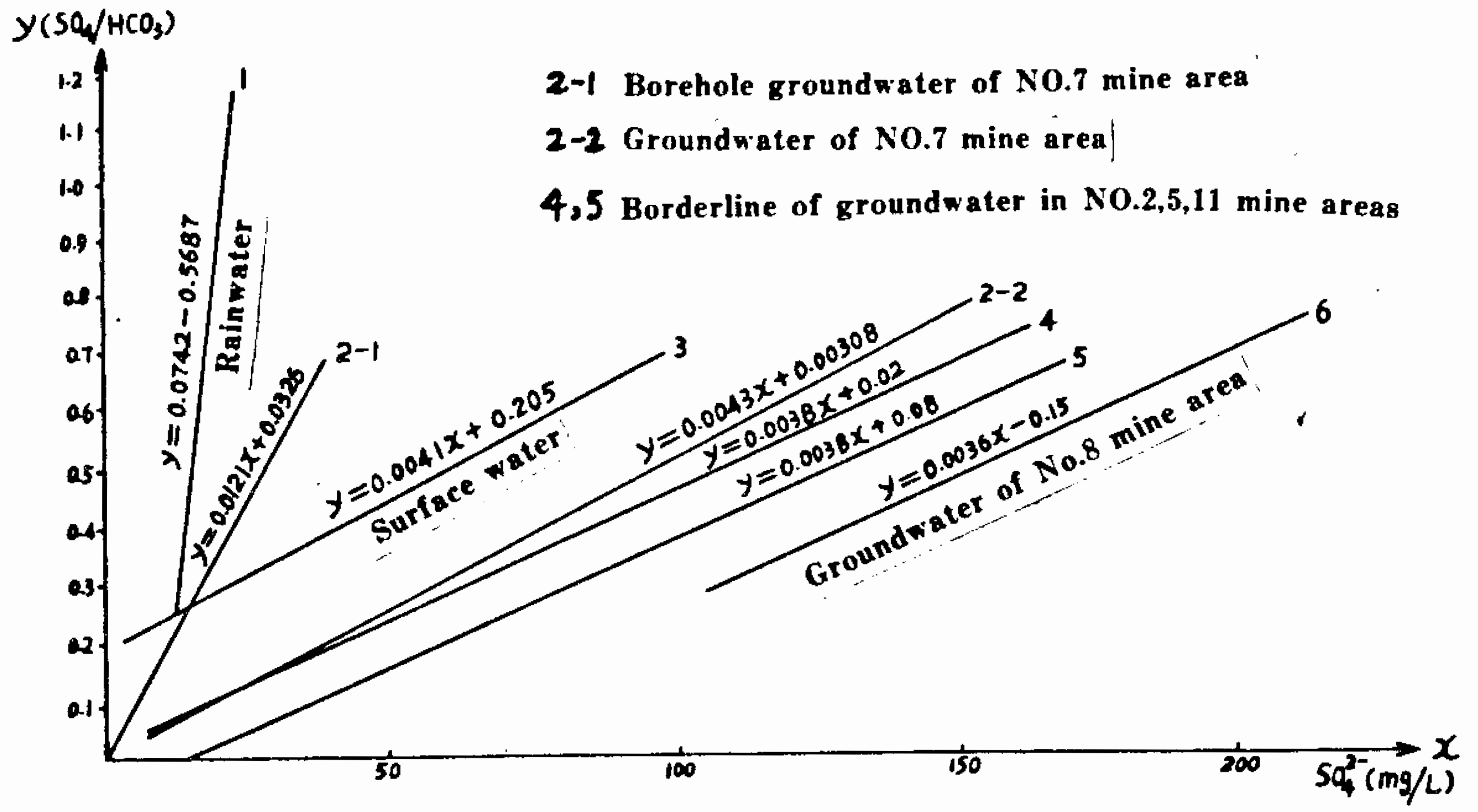

Figure 4. SO_4 / HCO_3 - SO_4 Correlation Chart

Hydrogeochemical Facies of Rainwater Type

This facies is formed after the rainwater recharging groundwater and while evolving chemical compositions under the action of water-rock interaction, and characterized by the complex chemical types, by the increasingly high TDS and by a reflection of isotopic values in the rainwater with the duration of water-rock interaction.

As recognized by the results of Q-mode cluster analysis (Table 2,3), type I2 and II1-B is composed of rainwater and Quaternary water of wells, corresponding with the subsidiary facies B-1 (HCO_3.SO_4-Ca.Mg) and C-1 (SO_4.Cl-Ca.Mg). The hydrochemical type in mainly HCO_3-Ca indicated by a 0.25 g/l TDS, reflecting the rainwater origin of facies B-1 and C-1.

Type 2 consists of sandstone water with the HCO_3.SO_4-Na.Ca, HCO_3 - Ca.Mg and HCO_3-Na types in No. 2,5,8 mine areas, corresponding repectively with the subsidiary facies (B-2, A-1 and A-3). On the basis of hydrogeological conditions, three subsidiary facies have been proved to be the origin of rainwater in the evolution process along facies lines as: rainwater → A-1 (HCO_3- Ca.Mg) → B-2 (HCO_3.SO_4-Ca.Mg.Na). Their flow patterns are: rainwater → groundwater in No. 2, 5 mine areas → groundwater in No.8 mine area. The subtype (IV4) in cluster analysis result is made up of the groundwater in No.2 mine area, corresponding with facies A-1 (HCO_3-Ca.Mg), and subtype IV2 is composed of the groundwater in No.8 mine area, corresponding with facies B-2 (HCO_3.SO_4-Ca.Mg.Na). The rainwater origin is characterized by an evolutionary trend along facies lines as: rainwater → facies A-1 (HCO_3-Ca.Mg) → B-1 (HCO_3.SO_4-Ca.Mg), and their flow patterns are like this: rainwater → groundwater of No.2 mine area → groundwater of No.8 mine area.

Hydrogeochemical Facies of Surface Water

This facies can be developed because while the groundwater is directly recharged by sufrace water. Both hydrochemical charasteristics and isotope values may reflect the surface water charasteristics due to the week water-rock interaction.

In group I1-A (Table 2), the groundwater in No.7 mine area is recharged by the surface water, and with HCO_3-Ca.Mg type by a 0.2-0.4 g/1 TDS, correspondling with facies A-1 (HCO_3-Ca.Mg). Line 2-2 (Fig.4) is representative of groundwater (No. 7 mine area) in parallel with line 3 as surface water. It is obvious that the groundwater in No.7 mine area belongs to the surface water origin.

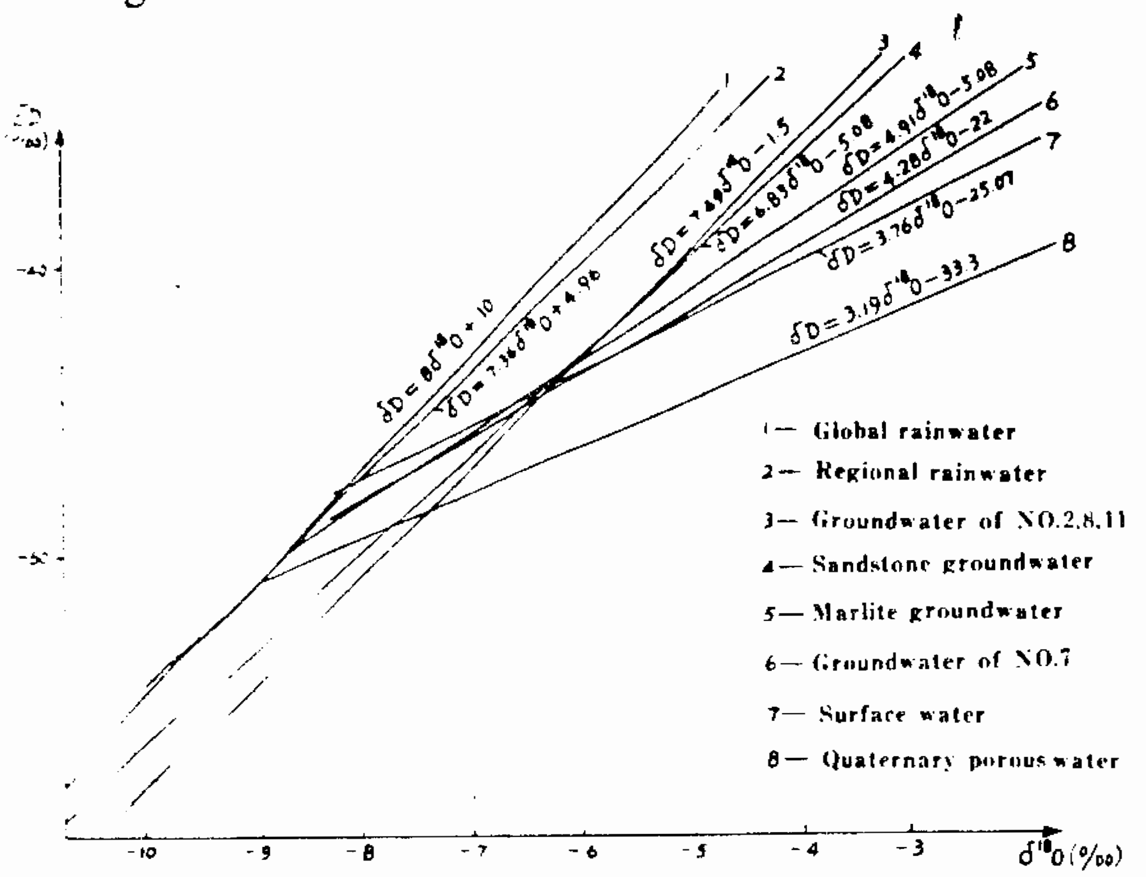

Figure 5. δD - $\delta^{18}O$ Correlation Chart

In addition, the stable isotope values of groundwater in No.7 mine area are analogous to that of the reservoir and Zhanhe River water, and such is an indication of surface water body. As for facies A-1 classification, it has been found that groundwater is formed in No.7 mine area and recharged by surface water, and the analytical results tally with the practical situation.

Transitive Hydrogeochemical Facies of Rainwater and Surface Water Types

Group I1-B of cluster classification of groundwater is made up of the Zhanhe River water, the shallow groundwater in No. 11, 5 mine areas, and the Cambrian water from boreholes, corresponding with facies A-1 (HCO_3-Ca.Mg). Many of shallow groundwater lie in the limestone area recharged not only by precipitation but by the penetration of Zhanhe River water. The isotope values in the shallow groundwater in No. 5, 11 mine area are those between rainwater and surface water. Facies A-1 (HCO_3-Ca.Mg) in the shallow groundwater of No. 11,5 mine areas is the transitive facies of rainwater and surface water types.

Contaminated Hydrogeochemical Facies

In the groundwater observation wells of No.7 mine area, there are the abnormal phenomenon appeared as far as their TDS and hydrogeochemical types are concerned. The ionic contents of Cl^- and Na^+ are very high, which results in forming HCO_3.Cl-Na and Cl-Na types. On these grounds, facies A-2, B-3, C-2 and C-3 are dominant in groundwater of observation wells. The analysis results show that the contaminated groundwater is produced by the artificial tracer test putting a lot of NaCl in the observation well of No.7 mine area, so that the groundwater of observation wells can not be representative of the hydrochemical types of groundwater in No.7 mine area.

CONCLUSIONS

On the basis of studing the origins of hydrogeochemical facies, the determination of origin evolution and the flow pattern attach significance to the hydrogeochemical facies.

There are two shallow-lying circulations and one deep-lying circulation occurred in Pingdingshan mine areas, the shallow-lying circulations including the recharge of rainwater type in No. 11-5 mine areas and surface water types in No.7 mine area. And the deep-lying circulation belongs to the recharge of rainwater type.

First of all, in the process of future deep-lying coal mining, the mine drainage will be mainly the stored resources of karstic groundwater, if groundwater recharge mode is never influenced by the environment changing. Secondly, it is neccessary to carrying on the problem of the deep-lying mine water control in the areas.

In shallow-lying circulation areas recharged by surface water the measures should be taken of penetration control combined with drainage. The outcroped areas of limestone in northern drunk canal paving with stones prevent surface water from recharging. In confined aquifer of mine area, the drainage boring shoud be made so as to achieve the purpose of mine water control.

In shallow-lying circulation, the groundwater, with regard to the recharge by rainwater, should be drained away. The drainage boring has been drilled in the confined aquifers with the aim of reducing water pressure.

In the deep-lying circulation area recharged by rainwater, the optimal drainage measures can be taken due to the low recharge speed of groundwater. Under the condition of ensuring safety in mining, the drainage should be reduced as far as possible

so as to achieve the purposes that drainage is dominant, combining with water supply and that the groundwater is utilized rationally and exploited.

About facies A-1 (HCO_3-Ca.Mg) groundwater, it can be as the potable water because of its fine water quality. Facies B-2 (HCO_3.SO_4-Ca.Mg.Na) groundwater may be in view of its rational utilization and exploitation owing to the fine mineral water. Facies B-1 (HCO_3.SO_4-Ca.Mg) groundwater can be fully utilized after pretreatment.

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