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Article

Study on the Water Source for Filling the Weak Rich (Conductive) Water Aquifer in the Changxing Formation Limestone of Coal Seam Roof

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Abstract: With the increase of mining range from shallow coal seam outcrops to deep mining and the improvement of mining intensity in the mining area, there has been a phenomenon of no water inrush in shallow coal mines and abnormal water inrush in deep coal mines in karst landform areas of Guizhou. The project conducted a study on the water source of water inrush in the Xinhua mining area of Jinsha County, Guizhou Province. The research results indicate that the overlying Changxing Formation limestone of the Longtan Formation is a weak (conductive) aquifer, and there is no possibility of water inrush in normal stratigraphic blocks. The spatiotemporal distribution characteristics of the water inrush working face have verified that the Changxing Formation limestone in the shallow mined area has been damaged by mining activities, resulting in a large number of cracks in the rock mass and the formation of a large-scale water accumulation area, becoming a water source for the water inrush in the working face below and a fast supply channel for atmospheric precipitation. The analysis of surface water and mine water quality data shows that the water quality types of mine water and surface water are basically the same, and they are HCO₃-SO₄-Na type water. The correlation curve between mine water inflow and atmospheric precipitation verifies that the cycle of atmospheric precipitation supplying the mine in Jinyuan Coal Mine is about 10 months before pit closure, and 1 month after pit closure; The Changxing Formation limestone serves as a water-conducting channel, and atmospheric precipitation serves as a source of replenishment for mine water. The research results provide scientific basis for the treatment of atmospheric precipitation water damage in sudden water inrush mines (areas) under similar hydrogeological conditions.

Keywords: Changxing Formation limestone; weak (conductive) aquifer; mine water source for filling; atmospheric precipitation

0. Introduction

Guizhou Province is the main coal production area in the karst areas of southwestern China, and atmospheric precipitation is one of the main sources of water supply during coal mining [1–4]. When mining coal seams near shallow outcrops, there is a clear correlation between mine water inflow and atmospheric precipitation. However, when mining deep coal seams, the intensity of atmospheric precipitation recharge is significantly weakened, and the correlation is not significant [5]. The Changxing Formation limestone in the Xinhua mining area has a wide range of outcrops on the surface, which can directly receive atmospheric precipitation replenishment and indirectly fill the mining area with water. The Changxing Formation limestone is a weakly rich (permeable) water

bearing layer, with good water content in local structures and developed karst gaps and caves. It can be used as a water-conducting channel for atmospheric precipitation to supply deep mining areas. The mines located near the coal seam outcrop in the mining area have not experienced any water inrush accidents during the mining period. With the increase of the goaf area and mining intensity of various coal mines in the mining area, some mines that mine deep coal seams have started to experience roof water inrush accidents, causing the working face to be flooded and even causing casualties.

Most scholars have analyzed the correlation between mine water inflow and atmospheric precipitation, and studied that the source of mine water inflow during the mining of shallow coal seams in southwestern karst mining areas is atmospheric precipitation [3,6]. However, there is a lack of further research on the water inflow caused by deep coal seams during mining. In the study of methods for studying atmospheric precipitation infiltration, researchers Mo Lianhong, Fan Juan, and others [7] conducted inorganic and organic hydrochemical analysis in the Xiaotun mining area to study the use of atmospheric precipitation as a water source for mine recharge. However, the application of this method is complex and not conducive to widespread application by on-site engineering and technical personnel. Different scholars have used drilling [8,9], research through supply channels [5,10] and other methods to study the supply water source of mine roof, and have achieved certain results. However, due to the large amount of engineering or high technical difficulty, these methods are difficult for on-site engineering and technical personnel to master, which is not conducive to on-site application. Some scholars have proposed a way for separating water to supply mines by studying the separation space between the limestone of the Changxing Formation and the strata of the Longtan Formation [11,12], but no research has been conducted on the supply source of continuous water inflow from the working face. This article studies the spatiotemporal relationship between different water inrush mines, water inrush working faces, and goaf in the Xinhua mining area. By using comprehensive methods such as hydrochemical analysis combined with the relationship between atmospheric precipitation recharge mine time and recharge intensity, a large amount of existing hydrogeological data of mines is collected and used to analyze the recharge channels and water storage space of atmospheric precipitation, the hydrochemical relationship between atmospheric precipitation and mine water, and the correlation between mine water inflow and atmospheric precipitation, It has been determined that the source of sudden water in the deep mining face of the mining area is atmospheric precipitation.

1. Overview of Mining Area

1.1. Basic Information of the Mining Area

The Xinhua mining area (referred to as the mining area) is located in Jinsha County, Bijie City, Guizhou Province, southwest of Jinsha County. All coal mines in the mining area are distributed in the northwest wing of the Qianxi anticline of the coal mine Jinsha, and in the southeast of the No. 15 coal seam outcrop (Figure 1). There are 39 pairs of production and construction mines in the mining area, with a designed production capacity of 0.3-1.5 million tons per year.

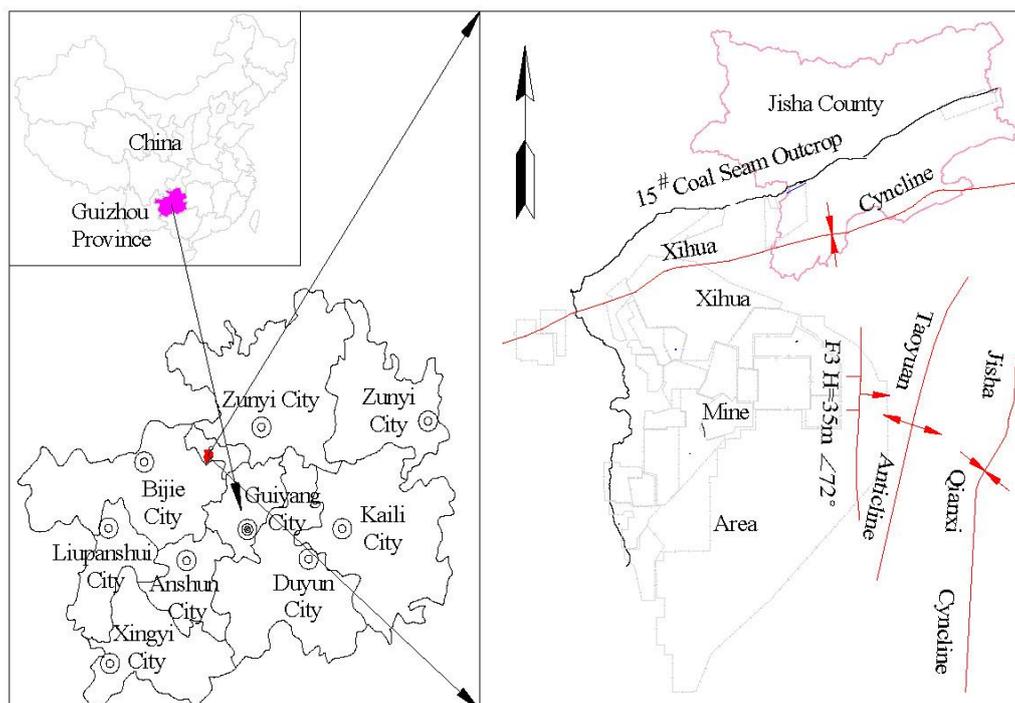


Figure 1. Location map of Xinhua mining area.

1.2. Introduction to Geology and Hydrogeology of Mining Areas

The main strata that have an impact on the mining of coal bearing strata in the Xinhua mining area, from old to new, include the middle Permian Maokou Formation (P_{2m}), the upper Permian Longtan Formation (P_{3l}), the Changxing Formation (P_{3c}), the lower Triassic Yelang Formation (T_{1y}) and Maocaopu Formation (T_{1m}), and the Quaternary (Q). The coal bearing strata are the Permian Longtan Formation (P_{3l}).

The mining area is located on the west wing of the Jinsha Qianxi syncline, and the overall strata are in a monocline structure, with local undulations forming a secondary fold structure. During exploration and production, only one fault structure with a drop greater than 30m was exposed near the southwest boundary of the mining area (within the scope of the Jinsha Longfeng coal mine) in the coal mines within the mining area; During construction and production, various coal mines have exposed small faults with varying drops. The strata in the mining area have a dip angle of 65° - 155° , with dip angles ranging from 0° - 27° , generally 5° - 10° .

The Longtan Formation (P_{3l}) in the mining area is a coal-bearing stratum, mainly composed of gray and dark gray thin to medium thick layers of siltstone, sandy mudstone, and mudstone, interbedded with fine sandstone, calcareous mudstone, and 4-7 layers of limestone and mudstone, containing 12-15 layers of coal and 2-6 layers of minable coal seams. Among them, the 4[#], 9[#], and 15[#] coal seams are the main mining coal seams in most mines, and the 5[#] coal seam is most of the minable coal seams with a thickness of 0.45-5.55m and an average of 1.68m; The thickness of the 9[#] coal seam is 0.59-9.95m, with an average of 2.77m. The coal seam is 39.70-76.22m away from the Changxing Formation limestone, with an average of 53.31m (see Figure 2).

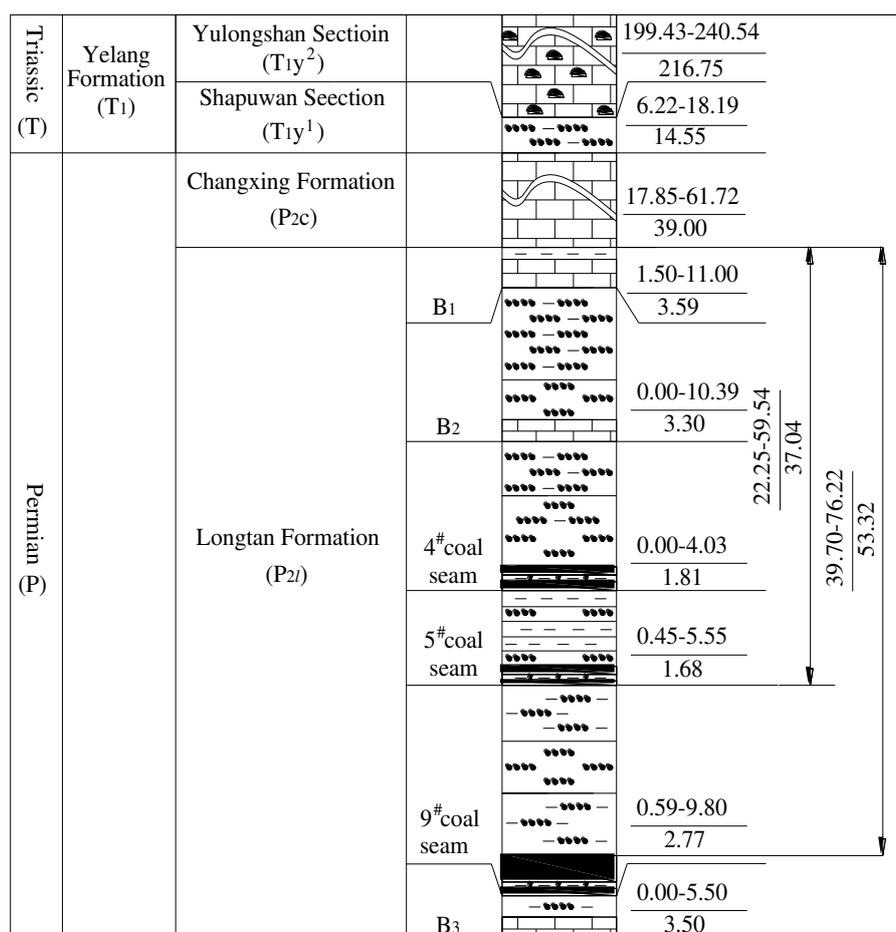


Figure 2. Comprehensive bar chart of coal bearing strata in Xinhua mining area.

The main aquifers in the mining area include the Triassic Yelang Formation Yulongshan section (T1y²) limestone, the Permian Changxing Formation (P2c) limestone, and the Permian Maokou Formation (P2m) limestone. The coal bearing strata of the Longtan Formation (P2l) are weakly rich water layer and impermeable layers. The aquifer that can directly fill water into the coal bearing strata of the Longtan Formation is the overlying Changxing Formation limestone and the underlying Maokou Formation limestone. The limestone of the Changxing Formation (P2c) is in integrated contact with the Longtan Formation, with a thickness of 17.85-61.72m and an average of 39.00m. The lithology is mainly gray to dark gray thick layered limestone. The lower part of the limestone contains nodular flint nodules and flint bands, rich in animal fossils and fossil debris. When mining coal seams 9[#] and above in the mining area, the main aquifer that affects the safety production of the mine is the Changxing Formation limestone aquifer.

1.3. Water Inrush Situation in Coal Mines in the Mining Area

Since April 2016, comprehensive mechanized coal mining technology has been widely applied in various mines within the mining area, significantly improving the mining height and scale of coal seams. As the mining scope of each mine expands and the number of closed pit mines continues to increase, the number of mines with water inrush in the mining area is gradually showing an increasing trend. In the mining area, Linhua Coal Mine, Jinji Coal Mine, Guiyuan Coal Mine, Longfeng Coal Mine of Lindong Company, Tenglong Coal Mine and other mines have successively experienced water inrush from the roof of the 9[#] coal seam working face, seriously affecting the safety production of the mine. According to the mining data of the 9[#] coal seam working face in each mine, the mining height of the 9[#] coal seam is between 2.2-3.5m. During the production period of the working face, the normal water inflow is 20-470m³/h, and the water inflow is generally between 80-800m³/h (Table 1).

Table 1. Statistics of water inrush points in mines in Xinhua mining area.

Coal mine	Water inrush working face	Location of water inrush	Structure of water inrush site and working face situation	Water inrush time (year, month, day)	Sudden water volume (m ³ /h)	Elevation of water inrush point (burial depth) (m)	Water inrush point number
Guiyuan Coal Mine	10903	276m has been mined, in the middle of the working face	Near the fault	2016.6.16	280	783(367)	G-1
	10901	80m has been mined, and the lower part of the working face	Between two faults	2019.2.30	160	833(415)	G-2
	10905	74m has been mined, and the lower part of the working face	Near the fault	2020.3.10	229	747(421)	G-3
		143m has been mined, and the lower part of the	Near the fault	2020.5.12	150	751(436)	G-4

	working face					
	425m has been mined, and the lower part of the working face	Near the fault	2020.11.8	290	776(433)	G-5
	247m has been mined, and the lower part of the working face	Normal stratigraphic blocks (slow advancement of the working face)	2021.10.13	210	808(394)	G-6
10908	341m has been mined, and the lower part of the working face	Normal stratigraphic blocks (slow advancement of the working face)	2022.2.14	80	807(439)	G-7
	161m has been mined, and the lower part of the working face	Near the fault	2019.7.15	150	728.5(431.5)	G-8
2093	237m has been mined,	Near the fault	2019.11.23	470	729.8(432.6)	G-9

		and the lower part of the working face					
		270m has been mined, and the lower part of the working face	Near the fault	2019.12.10	350	730.9(439.4)	G-10
Jinji Coal Mine	1905	71m has been mined, and the lower part of the working face	Normal stratigraphic blocks, near the near starting cut of the working face	2018.12.20	200	877.5(366.1)	J-1
		202m has been mined, and the lower part of the working face	Expose the fault location	2019.7.22	160	979.3(146.2)	L-1
Lindong-longfeng Coal Mine	5914	365m has been mined, and the lower part of the	Normal stratigraphic block, stop mining position	2020.3.24	210	977.8(127.4)	L-2

Tenglong Coal Mine	1091	working face 163m has been mined, and the upper part of the working face 536m has been mined, and the upper part of the working face 465m has been mined, and the lower part of the working face	40m Normal stratigraphic block segment, 40m away from the shorting cut of the nearby working face	2020.4.19	80	1047.3(342.7)	T-1
			Normal geological blocks, slow mining in the working face	2020.11.11	800	1047.4(350.1)	T-2
	10903		Near the fault	2022.6.19	Collapse water and gangue	993.4(274.1)	T-3

2. Hydrogeological Characteristics of Limestone in Changxing Formation

The Changxing Formation limestone is stably developed in the entire area, with a thickness of 17.85-61.72m and an average of 39.00m. The lithology is mainly composed of gray to dark gray, medium to thick layered chert limestone. The limestone of the Changxing Formation is exposed on the surface of most mines within the mining area (Figure 3), and the landform mostly presents a steep cliff state, and Small dissolution depressions and sinkholes are locally developed, and the terrain is generally lower than the surrounding low-lying areas. During the exploration period, the boreholes constructed by various coal mines in the mining area exposed this layer of limestone, and the effective karst rate exposed by the boreholes was 1.2-1.6%. Locally developed karst caves in limestone, with drilling revealing cave heights ranging from 0.18 to 8.74 meters. Some caves are filled with yellow mud. Expose the partial leakage of the limestone drilling hole, with a leakage rate of 17.5%. The burial depth of the leakage points is less than 367.4m, and the lowest elevation is 922.16m.

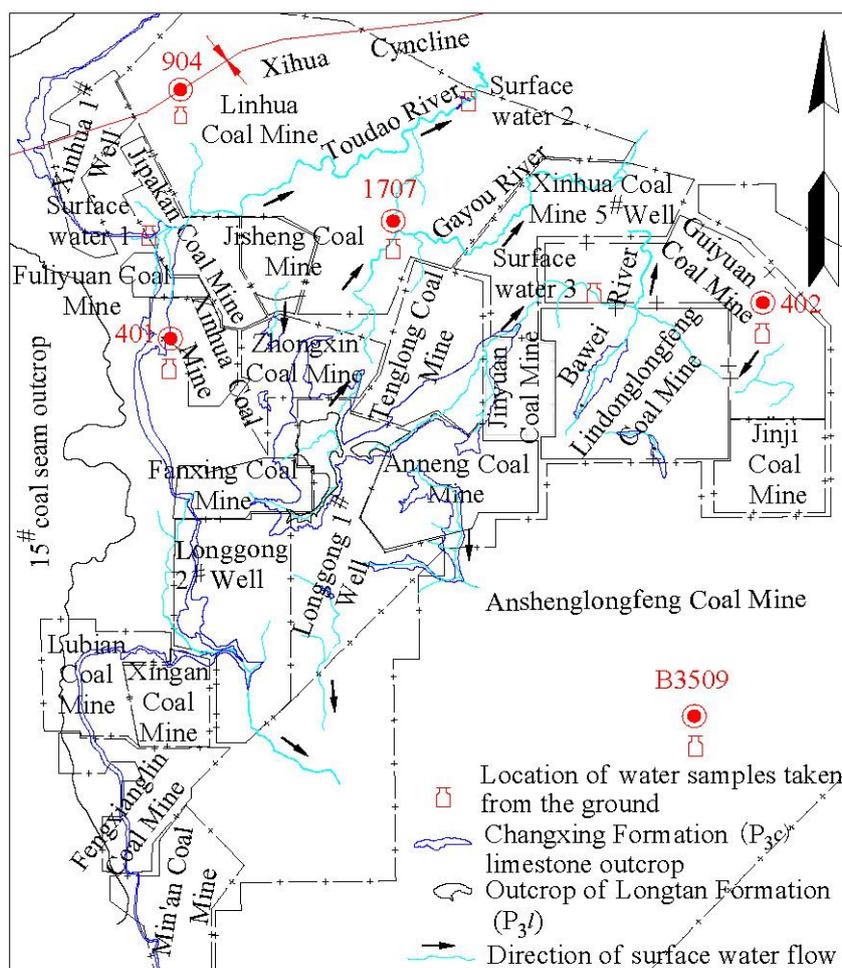


Figure 3. Layout plan of Changxing Formation outcrop distribution and ground water sample location.

The water level of the limestone aquifer in the mining area is greatly affected by terrain and surface weathering and erosion [13,14], resulting in the highest water level of the Changxing Formation limestone reaching 1436.62m and the lowest being 1063.59m. The pumping test data of various coal mines within the Xinhua mining area shows that only one borehole (Linhua Coal Mine) in the Changxing Formation limestone measured a unit water inflow q of 0.1418 L/m • s, while the rest of the boreholes were between 0.0000041 and 0.0127 L/m • s; The permeability coefficient K measured by the pumping test of only one borehole in the mining area is 0.1079m/d, while the other boreholes are between 0.0000026 and 0.004 m/d.

Based on comprehensive analysis, the limestone of the Changxing Formation is generally a weakly water rich (conductive) aquifer, with poor connectivity of dissolution gaps and weak water conductivity; In areas with well-developed structures, karst development and good water abundance may lead to water inrush during mining. The limestone of the Changxing Formation is commonly exposed within the mining area and can be replenished by atmospheric precipitation. Under the conditions of fissure development caused by mining damage [5,15], the limestone of the Changxing Formation can supply the mining site through karst, fissure and other channels.

3. Research on Water-Inrush Sources

3.1. Spatial and Temporal Distribution Characteristics of Water Inrush Working Face

After nearly 20 years of continuous mining, the coal mines in the mining area have gradually formed a large area of goaf from the surface coal seam outcrop to the deep. After April 2016, with the large-scale adoption of comprehensive mechanized coal mining technology, the height of coal seam

mining has been significantly increased compared to blast mining technology and high-grade conventional mining technology, basically achieving the full height of one-time mining of medium thick coal seams, and the maximum mining height of some mines has reached 3.6m. With the significant increase in the scope of goaf and the completion of mining of coal seams 9[#] and 5[#] near shallow outcrops, a large area of goaf has been formed in the mining area. The impact of large-scale mining has resulted in a large area of surface mining fracture damage [16–18], while the fractures generated by mining also lead to the primary dissolution gaps and caves in the Changxing Formation rock mass, further improving the conditions for atmospheric precipitation to infiltrate the mining site [2,5,15,19,20], increasing the speed of atmospheric precipitation infiltration into the mining site, and increasing the amount of water that atmospheric precipitation infiltrates into the goaf. With the infiltration of a large amount of atmospheric precipitation, goaf areas with water storage conditions have gradually become direct or indirect filling water sources for filling mines in mining areas. Especially in the central coal mine (mining 9[#] coal seam) and Jinyuan coal mine (mining 5[#] and 9[#] coal seams) located in the large exposed area of Changxing Formation limestone in the middle of the mining area, after the completion of resource extraction, the goaf formed after the closure of the pit has formed a huge space for water accumulation. This type of goaf is not only a water storage space after atmospheric precipitation infiltration, but also the accumulated water in the goaf can be replenished to the mining area below its elevation through the Changxing Formation aquifer (Figure 4).

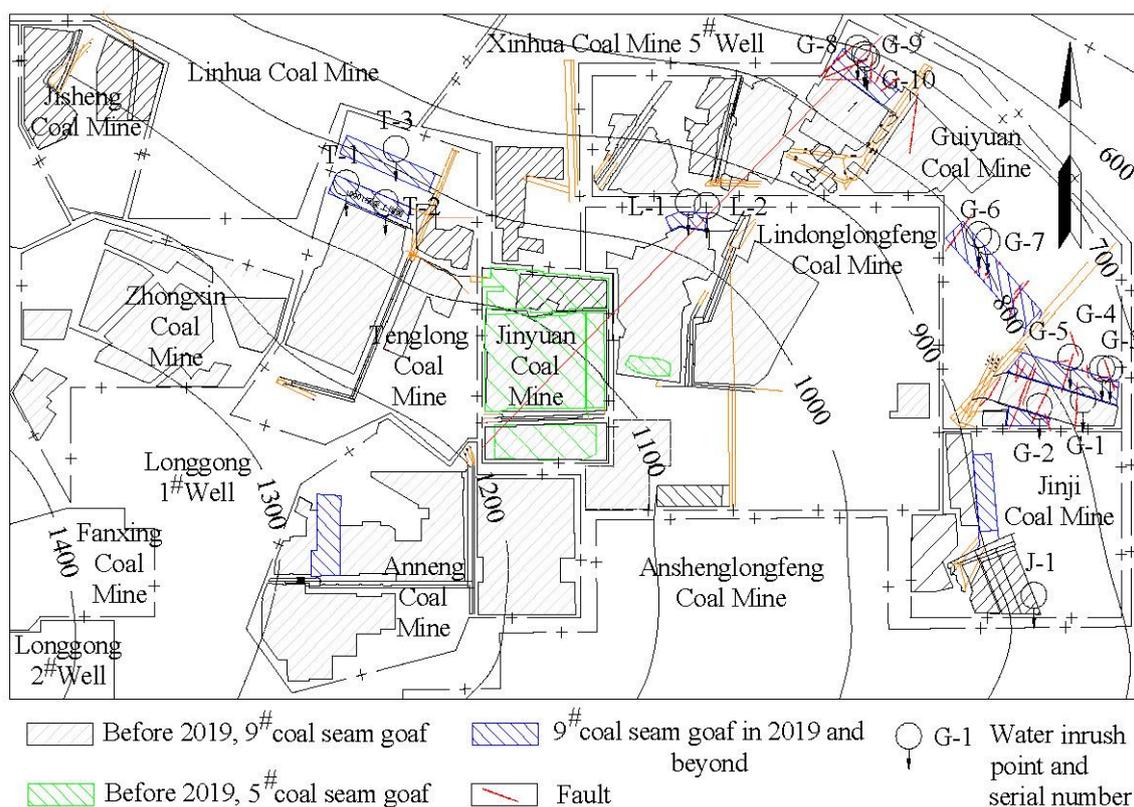


Figure 4. Distribution map of water inrush points in the working face of Xinhua mining area.

Each mine in the Xinhua mining area adopts a downward mining method to arrange working faces, and in the initial stage of mining, shallow working faces are first mined. According to statistical data, with the increase of mining depth, the first water inrush accident occurred at the 10903 working face of Guiyuan Coal Mine in the mining area on June 16, 2016, with a water inrush volume of 280m³/h, an elevation of 783m, and a burial depth of 367m. Afterwards, after the last lower limit working face (lower limit elevation 1115.3 m) of the north wing of the 5[#] coal seam in Jinyuan Coal Mine (wellhead elevation 1201.5 m) was fully mined in 2019, adjacent mines below the lowest mining

elevation of the 5[#] coal seam experienced roof water inrush during the mining of the 9th coal seam, with water inrush ranging from 80 to 800 m³/h; The elevation of the water inrush point in the 9[#] coal seam working face of each mine varies from 728.5 to 1047.4 meters, and the burial depth ranges from 127.4 to 439.4 meters (Table 1).

3.2. Chemical Analysis of Water Inflow in the Working Face

During the exploration period, coal mines in the mining area took water samples from the Changxing Formation aquifer, surface water, and other water samples for comprehensive water quality analysis. Water samples were taken from the production and mine working faces of the sudden water mine and sent to qualified third-party water quality testing institutions for comprehensive analysis (Table 2), ensuring the accuracy of water quality testing. The water sample analysis results in the surface streams and rivers within the mining area indicate that the surface water near the exposed limestone of the Changxing Formation is mainly HCO₃•SO₄-Na type water, with a total dissolved solid content of 515.50-907.50mg/L. The limestone water of Changxing Formation (water sample elevation 794.7m~883.83m, burial depth 333.42m~409.30m) is mainly composed of HCO₃•SO₄-Na (Na+K)•Ca, HCO₃•SO₄-Ca•Na(Na+K) type water, with a total dissolved solid content of 168.00-279.50mg/L. After water inrush occurred on the roof of the working face in the coal mines, a water sample (collected at an elevation of 776-985m and buried at a depth of 172-450m) was taken for full analysis. The water quality types were HCO₃-Na and HCO₃•SO₄-Na, with a total dissolved solid content of 327.76-892.59mg/L.

According to the data in Table 1, a Piper diagram of the hydrochemical properties of surface water, Changxing Formation limestone water, and water outlet points was drawn according to the classification of Shukarev hydrochemical types [21–23] (Figure 5). According to the Piper diagram, surface water is generally located in low-lying areas, and residential water flows into rivers. The water quality is significantly affected by residential activities. The upstream of the river is mainly supplied by spring water, with less human influence. The content of Ca²⁺+Mg²⁺ is relatively high, accounting for more than 70% of the cation content; After passing through residential areas, the proportion of sodium ions gradually increases, and the Na⁺+K⁺ content gradually increases from around 27% to over 85%. According to the analysis of the on-site water intake location, the sampling location for water sample 3 is located near the source of the river, receiving replenishment from the limestone spring water in the Yulong Mountain section, with the highest proportion of Ca²⁺ cations. Water sample 2 is located at the outcrop of the Changxing Formation, with a low-lying terrain and a gathering place for residents. The Na⁺ content accounts for the highest proportion of cations. Water sample 2 is located at the outcrop of the limestone formation in the Yulong Mountain section. The river water is diluted by the limestone water in the Yulong Mountain section, resulting in a decrease in Na⁺ content and an increase in Ca²⁺ content.

Table 2. Water quality analysis results of surface water, Changxing Formation limestone water, and mine water.

Water sample location	Surface water(mg/L)			Changxing Formation (P ₃ c)Limestone Water(mg/L)					Mine water(mg/L)			
Cation	Ca ²⁺	23.55	45.89	112.04	65.38	17.01	60.17	47.62	52.75	4.80	21.15	15.66
	Mg ²⁺	4.20	14.73	10.20	8.60	6.15	3.40	8.19	14.14	1.46	8.07	8.55
	Na ⁺	257.83	280.60	54.79	15.54	38.90	30.05	10.60	72.93	344.00	115.00	96.50
	K ⁺	1.85	2.86		1.33	1.74	7.10		1.30	1.50		
Anion	NH ₄ ⁺	0.05	0.16	0	0	1.02	0	0	0	2.4	1.0	0.52
	HCO ₃ ⁻	469.61	558.68	288.85	142.54	137.53	163.66	106.90	192.09	642.17	249.27	227.40
	CO ₃ ²⁺	7.24	4.34	0	0	0	0	0	0	45.57	0.00	0.00
	SO ₄ ²⁺	196.54	305.41	175.34	58.45	25.31	60.81	58.45	153.12	150.00	104.00	80.00

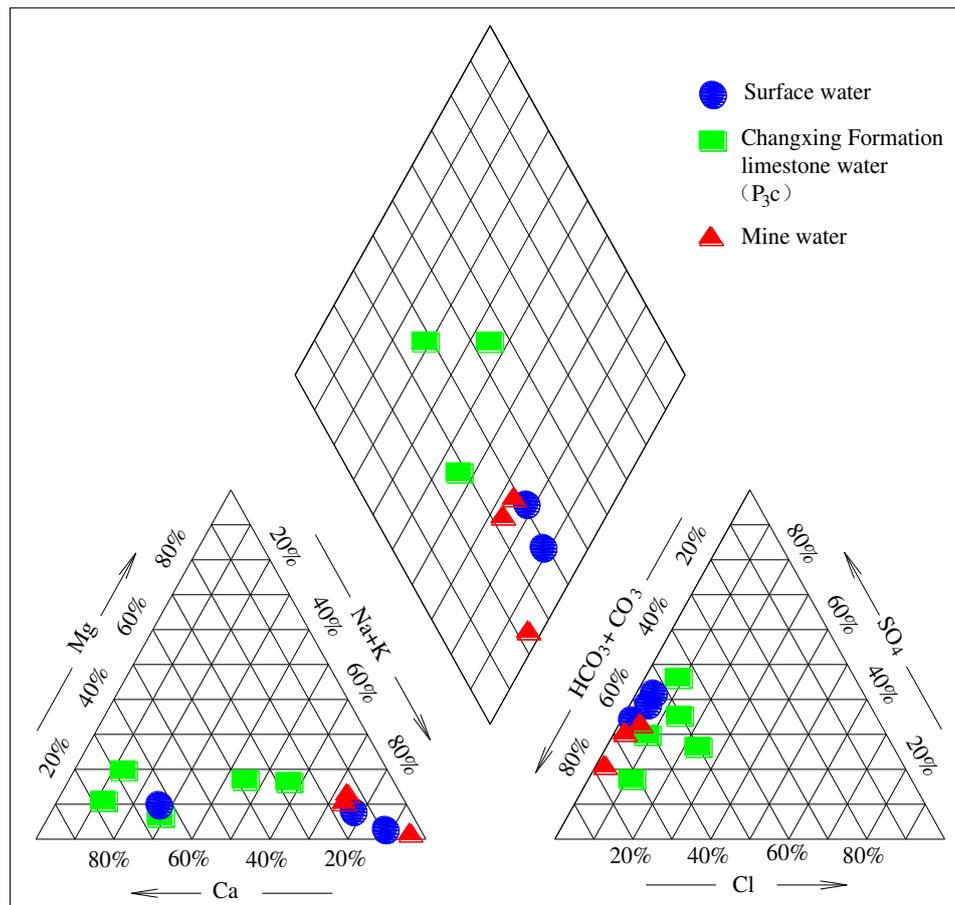


Figure 5. Piper three line diagram of surface water, karst water, and mine water.

In the original state before being affected by mining damage, the limestone in the Changxing Formation experienced slow or even stagnant groundwater flow (permeability coefficient between 0.0000026 and 0.004 m/d) due to undeveloped karst, and relatively fast groundwater flow (permeability coefficient up to 0.1079 m/d) in locally developed karst areas, resulting in the water quality type of the limestone in the Changxing Formation changing from HCO₃•SO₄-Ca water to HCO₃•SO₄-Ca•Na water, and then gradually changing to HCO₃•SO₄-Na•Ca water. The diversity of water quality types in the limestone water of the Changxing Formation indicates that under closed conditions, the limestone water of the Changxing Formation is mainly composed of HCO₃•SO₄-Ca; Under micro permeable conditions, the limestone water in the Changxing Formation can receive surface water replenishment, and the water quality type changes to HCO₃•SO₄-Ca•Na. In areas with karst development, a large amount of groundwater is supplied by surface water, and the water quality is significantly affected by human activities. Na ions in cations are clearly dominant. The changes in the water quality of the aquifer in the Changxing Formation indicate that after being damaged by mining activities, the cracks in the limestone of the Changxing Formation can become a water channel for surface water to supply the mining area.

The water quality analysis of mine water shows that the main water quality type of mine water is HCO₃•SO₄-Na type, which is basically consistent with the water quality type of surface water. Surface water is the supply source of mine inflow, and the Changxing Formation limestone can become a supply channel for surface water and atmospheric precipitation to supply mine water.

3.3. Analysis of the Correlation between Mine Water Inflow and Atmospheric Precipitation

Due to long-term weathering and erosion by rainwater, low-lying sites and ditches have gradually formed at the exposed limestone of the Changxing Formation in the mining area. The river water surface is generally wide, the water flow is slow, and it is easy for atmospheric precipitation to

collect and infiltrate. Under long-term dissolution, seasonal streams and gullies are widely distributed near the outcrop of the Changxing Formation (Figure 3), which increases the intensity of atmospheric precipitation and surface water infiltration into the limestone of the Changxing Formation, and prolongs the time for atmospheric precipitation and surface water infiltration into the limestone of the Changxing Formation. In the karst landform area of Guizhou, there is a close relationship between mine water inflow and atmospheric precipitation, which is the main source of mine water supply [24,25]. During the mining of shallow coal seams, atmospheric precipitation can quickly replenish the mine, and the shortest time it takes to replenish the coal mining site can reach 2 hours; As the burial depth of coal seams increases during mining, the distance of atmospheric precipitation from the coal seam outcrop to the underground mining area increases, and the replenishment amount gradually decreases. The replenishment time of delayed precipitation also gradually increases. The Changxing Formation limestone is widely exposed near the coal seam outcrop in the Xinhua mining area of Jinsha County (Figure 3). This limestone can not only receive atmospheric precipitation as a reservoir, but also transport atmospheric precipitation deep into the mining area through channels such as dissolution gaps, caves, and fractures within the rock layers. In the original karst fissure state before being affected and destroyed by mining, the water supply to the underground mining area of the coal mine through the Changxing Formation limestone is relatively small, and the supply cycle is long; After damaging the integrity of the limestone in the shallow mine and completing mining, the water inflow in the deep mine significantly increased, and the time for atmospheric precipitation to supply to the underground was significantly reduced. For example, after the completion of mining in 2019 at the last 10508 working face (lower limit elevation 1115.3m) of the 5th coal seam in the northwest wing of Jinyuan Coal Mine, the mine began to retreat and close the pit. In the deep Guiyuan No.2 mine, the amount of water inflow has significantly increased, and the period of atmospheric precipitation recharge has been significantly shortened (Figure 6). The water inflow of the mine has increased from the normal inflow of 84m³/h before 2019 to 242m³/h in 2022. During the rainy season, the time interval between the peak water inflow in mines and the peak rainfall gradually decreases from about 10 months before 2019 to about 6 months in 2020. From 2021 to 2022, the peak water inflow in mines can be synchronized with the peak rainfall in the same month. From this, it can be analyzed that the secondary cracks generated after coal seam mining damage lead to the connection of primary cracks, dissolution cracks, and caves in the Changxing Formation limestone, and the unobstructed water storage and supply space in the goaf accelerate the speed and amount of atmospheric precipitation supply. Atmospheric precipitation has clearly become a source of replenishment for mine water.

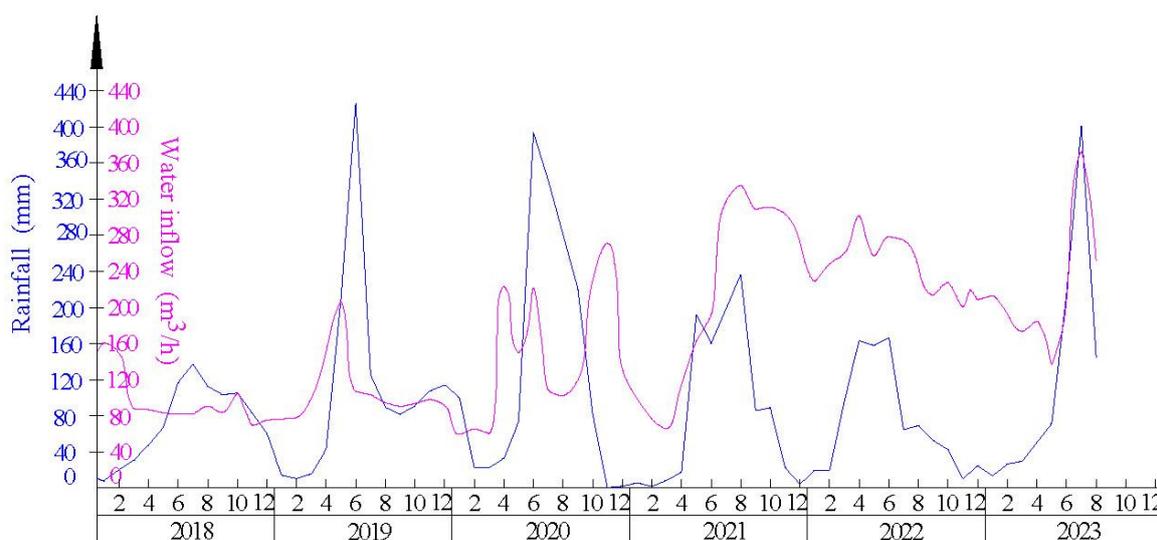


Figure 6. Curve of the relationship between water inflow and atmospheric precipitation in Guiyuan Coal Mine.

4. Mechanism of Atmospheric Precipitation Replenishment Underground Stope

In the original state without mining damage, only some sections of the Changxing Formation limestone have developed dissolution cracks and caves, and the cracks are not developed. After atmospheric precipitation infiltration, the runoff is slow, and the recharge period for deep aquifers is long, and the recharge amount is small (Figure 7-1). The cation of karst water in the runoff retention area is mainly Ca^{2+} , otherwise Na^{+} is the main ion. After the completion of mining in the 5[#] and 9[#] coal seams, the shallow mines in the mining area have formed a large area of goaf and developed water conducting fracture zones, providing good storage space and water conducting channels for atmospheric precipitation to supply the mines. The water quality of the mine inflow is basically consistent with the surface water quality, with cation $\text{Na}^{+}(\text{K}^{+})$ being the main component. Before the closure of the shallow mine, atmospheric precipitation supplied the mining area smoothly through the water conducting fracture zone of the Changxing Formation limestone. Although the mine had a large amount of water inflow, there were no water inrush accidents in the mine. During this period, atmospheric precipitation and groundwater mainly supplied the shallow mine, with only a small portion supplying the deep mine with runoff (as shown in Figure 7-2). After the closure of the shallow mine, a large area of goaf and water conducting fracture zone accumulated water, with a large storage capacity and rapid replenishment. Before the closure of shallow mines, the goaf that has been fully mined in deep mines is filled with sediment carried by atmospheric precipitation. In addition, the rock in the goaf undergoes water immersion and mud expansion, resulting in a small amount of water inflow in the existing goaf (generally not exceeding $10\text{m}^3/\text{h}$). A large amount of water accumulation in the shallow goaf and water conducting fracture zone often occurs in the early stages of new mining operations in deep mines, where faults develop, where mining is slow, and during the cessation of mining (as shown in Figure 7-3).

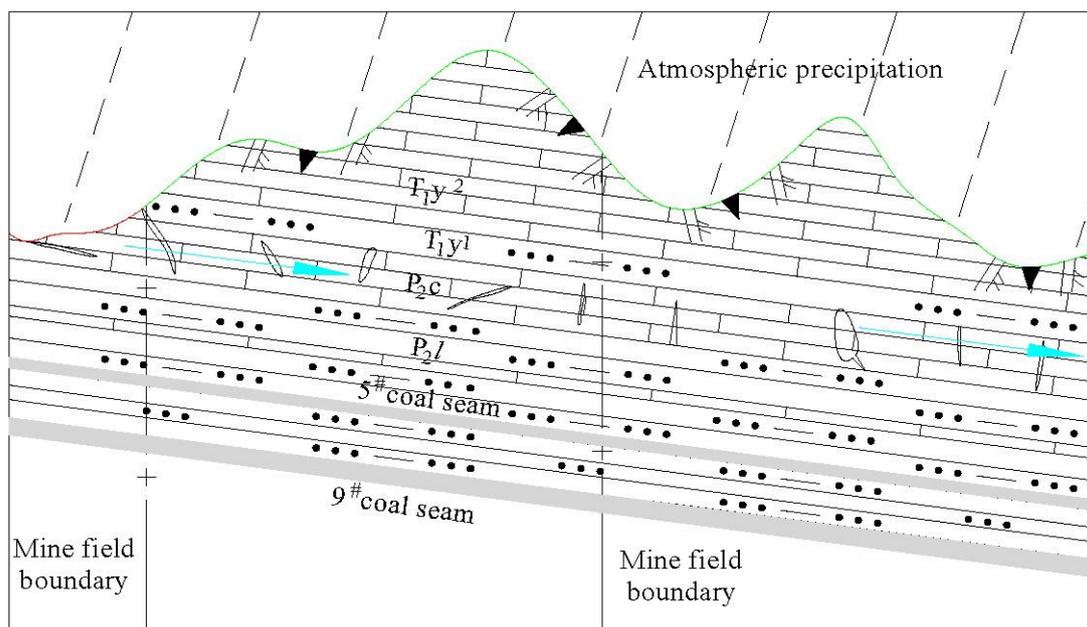


Figure 7-1. Water runoff map of the limestone in the Changxing Formation under the original occurrence state.

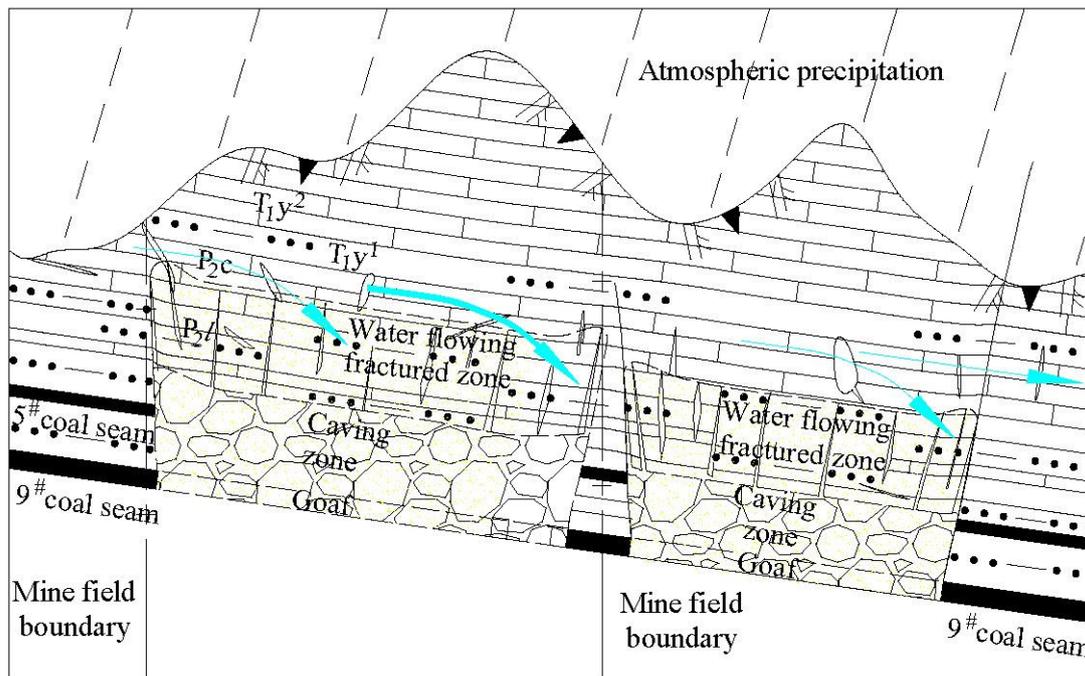


Figure 7-2. Atmospheric precipitation-groundwater recharge before the closure of shallow mines.

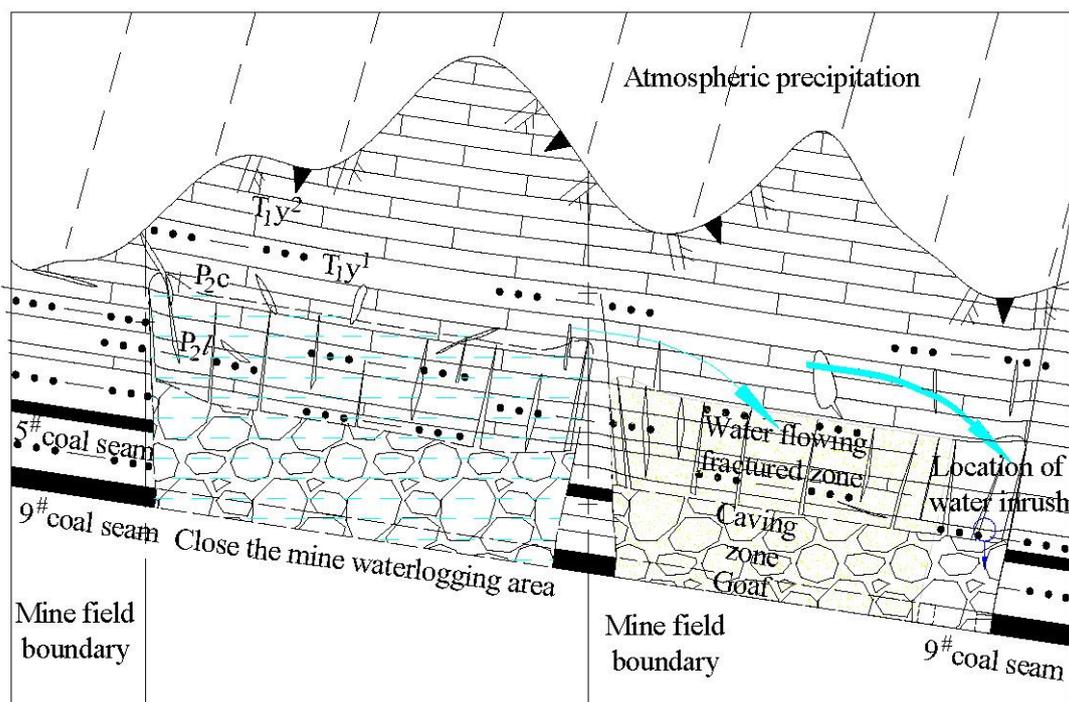


Figure 7-3. Atmospheric precipitation groundwater recharge map after the closure of shallow mines.

5. Conclusions

1) The weak rich (conductive) water bearing layer of the Changxing Formation limestone is connected to the original dissolution gaps and caves through cracks generated under mining damage conditions, making the Changxing Formation limestone a smooth water conducting channel and a huge water storage space for atmospheric precipitation to supply deep mines.

2) There is a hydrochemical connection between surface water, Changxing Formation limestone aquifer water, and mine inflow water. The water quality types of mine water and surface water are consistent, and the original Changxing Formation limestone water is an transitional type of the two.

3) After being damaged by mining, the huge damage range and water storage space of the Changxing Formation limestone not only shorten the distance of atmospheric precipitation supplying the mining area, but also increase the intensity of atmospheric precipitation supplying the mining area. Atmospheric precipitation is the main source of water inrush in existing mines.

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