Hydrogeochemical and water cycle features of groundwater at a western arid coal mine in the Ordos Jurassic coal province, China

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Abstract

Xiaojihan coal mine, located in the east of the Ordos basin, is typical of the regional hydrogeologic background and it commenced coal mining in 2014. To investigate water quality and water cycle features, 21 water samples were collected from underground aquifers for water quality tests, 14 samples for isotopes of D/^{18}O and T tests, and 6 samples for ^{14}C tests. The characteristics of the Jurassic aquifers are neutral pH, enriched in Na^{+}, high concentration of SO_4^{2-}, large TDS, and polluted with B and F. It was drawn that coal mining was inducing a much higher water connected zone than as expected and coal mining was dewatering and increasingly enlaring the depression cone in the Jurassic aquifers. It is urgent to limit the maxmum height of water interconnneted zone and control the further expansion of depression cone in the Jurassic aquifers.

Keywords: Hydrogeochemical, water cycle, the Ordos basin, China

Introduction

Nowadays, the Ordos Jurassic coal province of China is becoming the central bases of China coal industry(National Development and Reform commission 2016). Located in the arid western China, the Ordos basin is charactuerized as water scarce and ecologically fragile. The practical coal ming in the Ordos basin in the past decade encountered a series of challenges, including flowing sand catastrophes, unexpected coal-layer-aquifer water inrush, excessively large inflow drainage, super-thick overlying aquifers, etc. The disclosed mining hydrogeologic conditions are actually not as simple as it had been expected.

Xiaojihan coal mine, located in the east of the Ordos basin, is typical of the regional hydrogeologic background and commenced coal mining in 2014. Intially, the Xiaojihan cal mine had been viewed as hydrogeoligcal simple, but it was then classified as hydrogeologically medium complexity owing to a series of coal-fissure-aquifer water inrush. So far, it was frustrating the engineers again with a ceaselessly increasing mine water drainage. It is urgent to investigate the actual water cyle at the Xiaojihan coal mine. The purpose of this paper is to use hydrogeochemical methods to explore the signatures of groundwater and find the reasons for increasingly complicated hydrogeologic conditions at Xiaojihan coal mine.

Geologic settings

The main minerable coal beds at the coal mine lie in the upper part of the middle Jurassic Yan'an Formations (J2y), which are overlain by the middle Jurassic Zhiluo Formations (J2z) and An'ding Formations (J2a), the lower Cretaceous Luohe Formation (K1I) and the Quaternary sand deposits. As reported by the detailed coal exploration, the type of mining hydrogeologic coditions at the Xiaojihan cola mine was calssified as simple with a limited mine water inflow from the overlying Jurassic sandstone aquifers.

However, as the ealier mine coustruction engineerings, including the ventilation shaft, main roadways and first trial longwall face etc., were drawing near or passing through the J2y cola layer, there unexpectedly happened a seires of serious waterburst. The maximum inflow from the fissured coal-layer aquifer at that time was up to 800 m3/h and the Xiaojihan coal mine was then re-classified as hydrogeologically medium complexity with a potential risk of rare fissured-coal-layer aquifer water inrush.

Nowadays, as more longwall faces were excavated and the mining panel went further western and deeper, the toal mine water inflow didn't deceased as expected but dramatically rose up from about 700m3/h in 2013-2015 to 1200m3/h in 2018. The practitioners was confused where the extra inflow was running out, expecially warrying about whether the water-enriched K1l aquifers have hydraulic relationship with the underlying water-scarced Jurassic aquifers.

Methods

To investigate water quality and water cycle features, 21 water samples were collected from the underground aquifers for water quality tests, 14 samples for isotopes of D/^{18}O and T tests, and 6 samples for ^{14}C tests.

Results

Characteristics of water quality of the semi-cemented Jurassic aquifers at the Xiaojihan coal mine: (1) Neutral pH; The average pH of groundwater in the J_2a, J_2z and J_2y aquifers was 7.5-7.7, obviously less than that in the K1l aquifer of 8.3; (2) Enriched in Na^+; The Na+concentration in the the J_2a, J_2z and J_2y aquifers was up to 330 ~ 550 mg/L, much higher than that in the overlying K_1*l* aquifers of 31mg/L; (3) High concentration of SO_4^{2-}; The concentration of SO_4^{2-} in the J_2a, J_2z and J_2y ground water was excessively rise up to 1000 ≈ 2800mg/L, accounting for 95% of its anions in meq and 60-70% of the TDS in mg/L; In comparison, the concentration of SO_4^{2-} in the K_1*l* aquifer was only 18mg/L; (4) Large TDS; The TDS of groundwater in the J_2a-J_2y aquifers was high up to 1600-4300mg/L, whereas that in the K_1*l* aquifers was no more than 350mg/L; (5) Scarce in Fe^{2+}, Mn^{2+}, H_2S and NH_4^+, indicating an hydrogeologically oxygenic status in the J_2a-y aquifers; (6) Uniform and narrowly ranged water type (Figure 1); The water samples in the J_2a, J_2z and J_2y aquifers fell into the water types of Na-Ca-SO4, Ca-Na-SO4, and Na-Ca-SO4 repectively, distinctively different from the water type of Ca-Na-Mg-HCO3 in the K_1*l* aquifer and that of Ca-Mg-HCO3 in the Q4 aquifer; (7) Apart from Na+ and SO_4^{2-} pollution, the water in the J_2a, J_2z and J_2y aquifers was also with F (maximum of 1.77mg/L) and B maximum of 1.23mg/L) pollution.

D/^{18}O signature of 21 groundwater samples: (1) The δD of groundwater samples from the J_2a , J_2y, and J_2y sandstone aquifers averaged -81‰, -83.5‰, and -84.5‰ respectively, and the δ^{18}O of them averaged -10.28‰, -10.72 ‰ and -10.78‰; (2) the D/^{18}O plot of these water samples from the J_2a , J_2y, and J_2y aquifers was $\delta D_{v\text{-}SMOW} = 7.80 \cdot \delta^{18}O_{v\text{-}SMOW} + 0.12$ with R^2=0.98, which was almost parallel with and beneath the local precipitation line; (3) The water samples from the J_2a to the J_2y

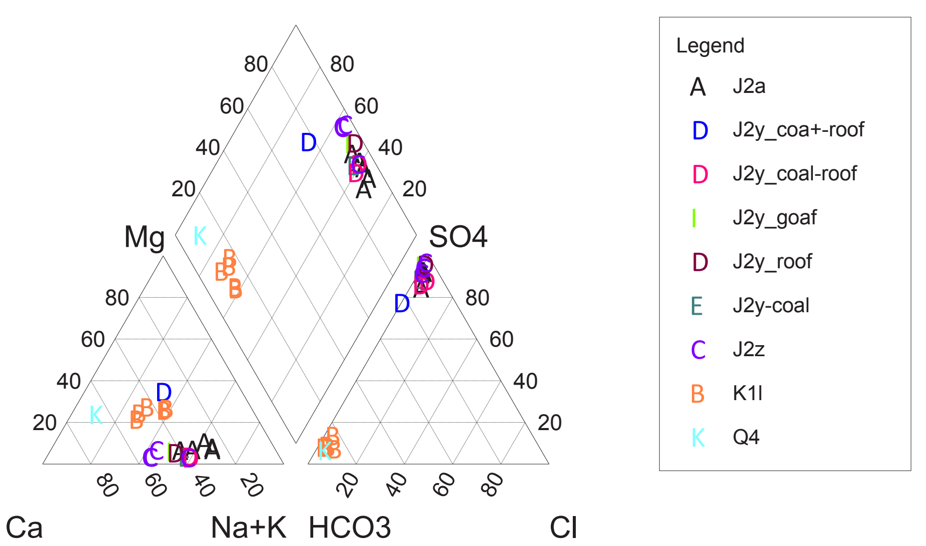

Figure 1 Piper plot of the wate samples from the Xiaojihan coal mine.

aquifers were gradually and linearly depleted in D and ^{18}O, indicating that they might have a common origin and were experiencing a continuous hydrogeologic evolution; (4) Between the D/^{18}O line of the J_2a -J_2y aquifers and the local precipitation line, the (δD, $\delta^{18}O$) values of the K1l aquirer water and Q4 auqifer water separately distributed in small groups; Thereby, it help us to infer the J_2a -J_2y aquifers have no direct hydraulic relationship with the K1l and Q4 aquifers.

Tritium dating of 21 groundwaer samples: (1) the ^3H of groundwater either in the J_2a-J_2y aquifers or in the K_1l aquifers are less than 3TU, reflecting an innate ^3H feature; (2) In contrast, the ^3H in the Q_4 groundwater was much higher up to 30.8 TU, thereby indicating that the groundwater in the J_2a-J_2y and K_1l aquifers was not been affected by the anthropogenic activities in 1950s and had had a longer residence time.

Groundwater dating by ^{14}C of the six water samples: (1) the ^{14}C values of groundwater in the J_2a, J_2z and J_2y aqufers were 79.15%mod, 27.24% mod and 25.11% mod respectively, correspondint to their residence time of 1.93ka, 10.75ka and 11.42ka in turn. From shallow to deep, the groundwater is getting older. (2) In comparison, the 14C of the overlying K1l aquifer water was 26.08 % mod with an estimated age of 11.11ka. (3) At the same time, one water sample collected from an underground inrush site showed a fairly young age, which corresponded with its water quality features of less TDS, SO_4^{2-}, etc.

Analysis

Occurrence of ground water in the middle Jurassic sandstone aquifers: (1) From the distinctive signature of wate quality, it was inferred that the main geochemical reactions would include plagioclase weathering, carbonate rock weathering, gypsum dissolution, cation exchange, etc.; (2) High concentration of SO_4^{2-} was derived from a large amount of gypsum cement material in the Jurassic clastic formations; Enrichment in Na+ would be attributed to the textures of slightly weathered plagioclase grains; (3) The Jurassic interplate lake sedimentary environment was arid and oxygenic, primarily predominating the hydrogeochemical occurrence in the basin.

Water cycle features of the ground water at the Xiaojihan coal mine: (1) The J_2a, J_2z and J_2y formations stored more paleo-water, had a common/similar water origin, and had no direct hydraulic relationship; (2) The Jurassic aquifers actually stored much more amount of water than as expected; Though all the aquifers of the Jurassic had only very weak hydraulic connection, current coal mining was drastically dewatering the storage in the lower J_2z and J_2y aquifers, or even draining the upper J_2a aquifers as well; (3) From the hydrogechemical evidence, the K_1l aquifers have no direct hydraulic connection with the underlying Jurassic formations.

Being hard and fissured made the Jurassic coal layer the rather preferential water reservoir even than coarse sandsone. As Mining, muh higher water connected zone was unexpectedly induced. More naturally inact aquifers got involved in the anthropogenically mining drainage. The depression cone of drainage aquifers was still unpredictably expanding.

Conclusions

The characteristics of the Jurassic aquifers are neutral pH, enriched in Na^+, high concentration of SO_4^{2-}, large TDS, and polluted with B, F and Mn^{2+}. The hydrogeochemical reactions mainly include plagioclase weathering, carbonate rock weathering, gypsum dissolution, cation exchange, etc. It is the arid, oxygenic, and interpolate-lake sedimentary environment that was basically predominating the hydrogeochemical occurrence in the basin. Coal mining was inducing a much higher water connected zone than as expected, and coal mining was drastically enlarging the depression cone in the Jurassic aquifers. For the purpose of mining safety, it is urgent to limit the maxmum height of water interconnneted zone and control the enlarging depression cone in the Jurassic aquifers.

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