矿区地下水水文地球化学演化与识别

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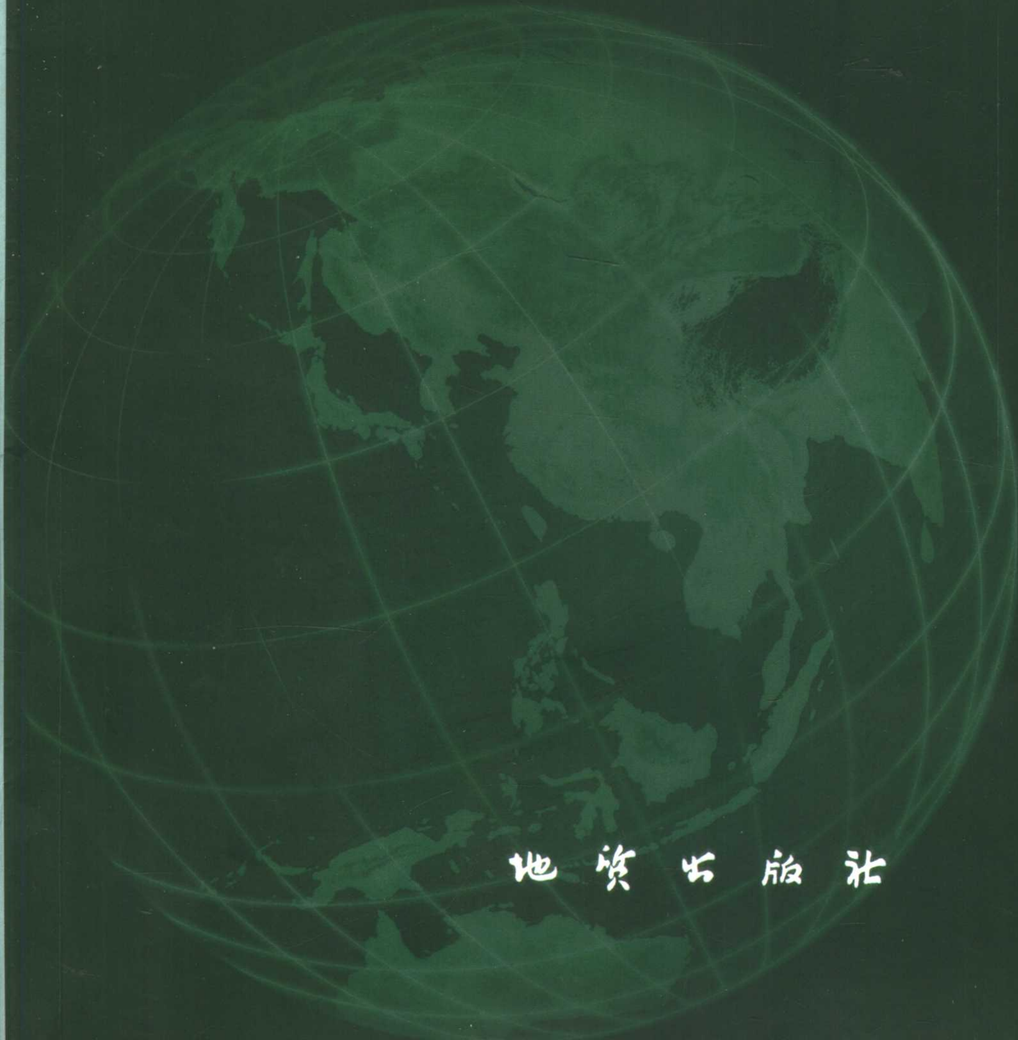

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·北　京·

内 容 提 要

在全面分析国内外煤矿水害事故识别技术的基础上，阐述了水文地球化学在煤矿防治水中的应用现状与发展趋势。通过在皖北矿区 30000 km^2 的范围内布置地下水取样点，定期采取 4 个主要突水含水层水样，测试地下水中常规离子、微量元素及环境同位素；探索了矿区内地下水的常规水化学、微量元素、环境同位素水文地球化学特征及其演化规律；建立了各突水含水层的多种识别模式，并在皖北矿区多个煤矿开展了成果的应用研究，取得了理想的应用效果。

本书可供从事矿业工程教学、科研及工程技术人员阅读，也可供煤矿安全生产技术管理人员参考。

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前　　言

煤矿"水、火、瓦斯、煤尘、片帮"五大灾害中，水害位居其首。从国内外煤矿开采史看，水害事故伴随着煤炭资源开发的全过程。近年来我国水害影响日趋严重。就皖北矿区而言，近年来发生过多起重、特大型突水事故，其中发生淹井事故三起。1988 年 10 月，淮北矿业集团公司杨庄矿Ⅱ617 综采工作面发生底板奥灰突水，突水量 3153 m^3/h，淹没 4 个采区、49 km 巷道和 1 套综采设备，直接经济损失 1.5 亿元；1996 年 3 月，投产不久的皖北煤电集团公司任楼矿首采 7_222 工作面发生由隐伏导水陷落柱引起的特大型奥灰突水灾害，最大瞬时突水量达 34571 m^3/h，不到 10 小时，井下巷道全部被淹，造成 3.5 亿元的重大经济损失；2001 年 11 月，皖北煤电集团公司祁东矿首采工作面推进至距开切眼 42 m 时顶板再次来压，工作面发现有少量渗水，在不足一天的时间内水量持续增大至 1520 m^3/h，导致淹井，经济损失超过 1 亿元。

煤矿生产实践表明，水害的发生是多方面因素造成的，如矿井地质及构造条件、水文地质条件以及矿井开拓开采方式对地下水平衡条件的破坏等。近年来，众多专家学者和煤矿工程技术人员从不同角度广泛开展煤矿防治水研究，力图寻找水害预测预报的有效方法和途径，采取积极主动的防治水措施。

煤矿防治水工作有两个基本思路：一是被动防治，即在水害事故发生后，通过查明水源，提出治水方案并实施，进而恢复生产；二是主动防治，即通过对煤矿水文地质规律的认识以及对有关水文信息资料的分析研究，预测预报水害事故发生的可能性，最大限度地减小财产损失和人员伤亡。特别是煤矿可持续发展以及"以人为本"安全理念的进一步深入人心，使人们迫切希望寻找有效途径，提高水害识别的可靠性和准确度，煤矿水害防治真正做到变"被动"为"主动"。在这方面，国内外众多专家学者做出了积极的探索，提出了许多新的理论、方法和技术，探测水平也日益先进。尽管如此，重、特大型突水事故仍没有得到有效的遏制，特别是最近几年，重、特大型突水淹井事故频频发生，甚至连连发生重大人员伤亡事故，说明煤矿突水预测预报研究距离人们的期望相差甚远，现有的突水预测预报技术手段有待完善，特别是要在弄清地下水区域流场的水文地质特征基础上，寻求简便可行的预测预报方法，是理论界及煤矿生产现场共同关注的课题。

我们知道，所谓"突水"是指大量流水突发性地涌入矿坑，最大突水水量大于井下排水设备总排水能力而造成淹工作面、淹巷道、淹采区、淹井或人员伤亡的事故。凡是煤矿重大突水，在发生之前，总有一些预兆。从水量变化看，一般有"湿帮（'出汗'）→滴水→淋水→流水→突水"的量变到质变的过程。如果能够在突水预兆期内，哪怕是很短的时间内，通过捕捉水文信息分析发生突水的可能性，采取有效措施，最大限度地赢得时间减少人员伤亡和财产损失，是完全可以做到的。而要做到这一点，就必须要对整个矿区主要突水含水层的水文地质条件进行全面掌握。

突水预兆期内的水文信息包含很多内容，如水量、水温、水化学等。从这些水文信息

中分析水的来源，惟有水文地球化学才能发挥作用，这就是本书写作的基本出发点。从现有的水源识别方法来看，人们对常规水化学方法比较熟悉，常规水化学在煤矿突水水源判识中的应用也比较广泛。但是，随着煤矿开采过程中对地下水的疏排和矿区供水抽吸地下水，含水层地下水径流场的动态变化势必会导致水文地球化学场的变化，不同含水层地下水的混合以及越来越密切的水力联系，用常规水化学识别水源已经不能满足人们对突水水源预测预报的时效性和精确度更高的要求。而微量元素和环境同位素却能发挥独到的作用。

本书在全面分析国内外煤矿水害事故识别技术的基础上，阐述了水文地球化学在煤矿防治水中的应用现状与发展趋势。通过在皖北矿区开展的防治水理论及应用研究，以包括淮北矿业集团公司和皖北煤电集团公司在内的皖北矿区为研究基地，在该矿区 30000 km^2 的范围内布置取水样点，定期采取主要突水含水层水样，在对大量水样中离子或元素的测试与数据处理基础上，探讨了矿区内地下水的常规水化学、微量元素、环境同位素水文地球化学特征及其演化规律，建立了各突水含水层的多种识别模式。成果主要表现在以下几方面。

（1）测试矿区各含水层地下水的常规水化学组分及部分水化学综合指标（Ca^{2+}、Mg^{2+}、K^+、Na^+、SO_4^{2-}、Cl^-、HCO_3^-，pH 值、总溶解固体、电导率、总硬度），分析了这些常规水化学组分的分布特征，采用总溶解固体的分布规律，模拟了皖北矿区各含水层水质浓度梯度场，探索了各含水层地下水的水循环特征，研究了各含水层地下水的补给、径流和排泄条件。根据岩溶水中 Ca^{2+} 水化学平衡特征，对该矿区的太灰和奥灰地下水水循环特征作了系统的研究。应用系统聚类逐步判别分析方法，对常规水化学指标进行水源判别分析，建立了矿区主要突水含水层的常规水化学识别模式。

（2）根据地下水中的微量元素（Ag、Al、As、Ba、Cd、Ce、Co、Cr、Cu、La、Mn、Mo、Ni、Pr、Sb、Se、Sr、Ti、V、Zn、Pb、F、Li、Sn）测试资料，获得了矿区内微量元素水文地球化学的基本特征，得出了地下水中微量元素与它们在地壳岩石中丰度之间的关系，以及微量元素与常规水化学组分之间的相关关系。通过微量元素之间的相关性、微量元素与常规离子的相关性及微量元素在地理空间上的分布剖面，确定了矿区地下水的特征微量元素（As、Ba、Co、Cr、Cu、Se、V）。根据矿区四含、太灰与奥灰地下水中多个微量元素的含量，应用主成分分析法，得出了矿区主要突水含水层地下水的微量元素成因模式。在此基础上，根据地下水中的特征微量元素和常规离子的含量，建立了由常规离子修正的微量元素 Bayes 多类线性判别模型，取得了较理想的判别效果。

（3）找出了皖北矿区各含水层氢氧稳定同位素（D、^{18}O）和放射性同位素（T）组成的不同特征，以此分析了含水层之间不同程度的水力联系，初步确定了各含水层在矿区内的补给区、径流区、排泄区。计算出矿区内各含水层的平均补给标高（四含和煤系水不超过 30 m、太灰与奥灰水均大于 130 m）和补给温度（四个含水层的大气降水补给温度均在 5℃左右）。

（4）根据四含水、煤系水、太灰水、奥灰水的氢氧稳定同位素组成特征，阐明了各含水层地下水混合模式和成因模式的各自特点。分析得出了 δ 值与 pH 值、总溶解固体（TDS）、电导率（ρ）、常规离子的相关关系，以及 T 含量与常规水化学指标的关系，运用多元线性回归模型，提出了矿区地下水环境同位素水源识别模式。建立的一系列环境同位素水源识别模式都具有接近于 1 的复相关系数，识别效果显著。

以上研究成果，通过在皖北矿区多个煤矿的实际应用，取得了理想的应用效果。其中在淮北矿业集团公司芦岭矿的应用中，已安全开采810采区煤炭240万t，创产值7亿元，实现利润4亿元。目前正在解放该采区9煤层（150万t储量）。整个810采区8、9煤层的开采，可使整个芦岭矿延长服务年限2.4年，使该矿西部井延长服务年限5年之多，经济效益和社会效益巨大。

本书共十章，第一、二、三、十章由桂和荣执笔；第四、五、六、七章由桂和荣、陈陆望执笔；第八、九章由陈陆望、桂和荣执笔。全书由桂和荣统稿。

限于研究水平和条件，书中难免存在错误和不足，恳请读者提出批评指正。

Foreword

Water gushing disaster is one of the five most dangerous kinds of coalmine disaster. According to the mining history accidents of coalmine, water gushing takes place in the whole process of mining, and water gushing has a trend of being more and more serious in recent years. Taking Wanbei mining district as an example, a lot of great or catastrophic water gushing cases have occurred in the past a few years, three of which led to the disaster of mine being drowned. For example, in the October of 1988, an accident of bursting water from the Ordovician System aquifer took place in the Ⅱ617 working face of synthesis mechanization of the Yangzhuang coalmine, which belongs to Mine Group Company of Huaibei, the bursting water yield was about 3153 m^3/h, and led to four working sections, tunnel of 49000 m and a set of equipment of synthesis mechanization mining being immersed totally as results of this serious disaster, the direct economic loss up to 150 million yuan (RMB). In the March of 1996, a catastrophic water gushing from the Ordovician System aquifer caused by karst collapse occurred in $7_2 22$ working face of Renlou coalmine in the Group Company of Coal and Electricity of Wanbei, which was put into use before long, in its first mining. The maximum of the instantaneous bursting water yield reached 34571 m^3/h, roads in the mine were flooded in less than 10 hours. The accident led to a significant economic loss of 350 million yuan (RMB). Besides, in November, 2001, a second sudden pressure came when the working face of Qidong coalmine of the Group Company of Coal and electricity of Wanbei advanced to what had a distance of 42 m to the starting cut. In the beginning, just a small amount of water appeared in the working face, however, the amount kept rising to 1520 m^3/h in not more than one-day time, leading to the mine being drowned in the end and more than 100-million -yuan economic loss.

The practice of mining shows that different kinds of factors decide whether the water gushing happens or not. For example, the geography characteristics of the coalmine, the conditions of both the structure and the hydrogeology, as well as the constructions what opening-out and mining way to the condition of groundwater balance affect the happening of water gushing. In recent years, numerous experts and mine scholars have begun to do some research in the area of preventing and curing the water gushing disaster from different angles extensively, striving to not only look for efficient ways to forecast but also take active measures to prevent water gushing.

The work of preventing water gushing in coalmine has two basic thoughts. One is passive prevention, which means to find out the source of water just after the water gushing occurs, put forward and carry out a practical plan to regulate the water; the other is positive prevention, which means by the comprehensive understanding of the mine hydrogeological laws and the analysis of the hydrogeological information related to forecasting the possibility of the water gushing happening to help to reduce the economic loss and human injuries and deaths. When the ideas of sustainable development in coalmine and "making people the center" are accepted extensively, people are eager to find effective ways to improve the reliability of the water gushing identification, and wish that the prevention against water gushing can be more positive than passive. On this aspect, a lot of experts and scholars have made positive researches and put forward new theory, means and technology, making the ability of exploring keep developing at the same time. Nevertheless, great or catastrophic water gushing disasters haven't been kept within limits effectively, especially in the past a few years, great or catastrophic water gushing disasters happened from time to time, what was worse, great human injuries and deaths took place very often. It means the researches into forecasting the water gushing in coalmine haven't reached people's expectation, and available measures remain to be developed. On the basis of making clear the hydrogeological characteristics of the regional seepage area of groundwater to look for convenient and practical ways is what both the theory circle and coalmine site focus on.

As we know, the so-called "water gushing" refers to a great quantity of water gush into mine abruptly, and the maximum bursting water yield is larger than the total ability of the drainage equipment in the underground mine and finally leads to flooding working faces, roads , working sections and whole underground mine and human injuries and deaths. Any great water gushing in coalmine, before happening, always has some omens. Judging by the range of the water amount, there's always a progress of "road wall moisten→dripping water→drenching water→running water →water gushing" . If taking effective measures through catching the possibility got by the analysis from the hydrogeological message within the period of omen, even in a rather short time, and winning time to reduce human injuries and deaths as well as economic loss are absolutely possible. However, to complete the job, it is a must to master the hydrogeological condition of the aquifers of water gushing in the whole coalmine area.

The hydrogeological information in the period of omen contains much comment such as water amount, water temperature and water chemistry and so on. Only hydrogeochemistry works when analyzing the water sources by studying the hydrogeological information. It's also the basic point of this book. Among the available ways to identify water sources, people are much familiar with the ways of routine hydrochemistry which has a extensive function when identifying the water sources of coalmine water gushing. However, with the mining process, dewater and pump groundwater for water supply from aquifers, the dynamic change of the groundwater seepage area will certainly lead to the variation of the hydrogeochemical area and mixed groundwater from different aquifers and strengthening hydraulic relationship, the identifying ways of routine hydrochemistry can't satisfy people's request in timeliness and precision of the forecast of the water gushing sources. For this, trace elements and environmental isotopes have an original effect.

The authors expound the present situation and developing trend of hydrogeochemistry on the basis of a comprehensive analysis of water disaster identifying technology. Through the regulating water theory and application research in Wanbei mining district, including the research base containing the Mine Group Company of Huaibei and the Group Company of Coal and Electricity of

Wanbei. The authors arrange water sample points in an area of 30000 km^2 of this coalmine, using specially made instrument applied for groundwater sampling from deep hole to get samples timely. After having examined large amount of ions in the samples and dealt with the data, the authors inquire into the hydrogeochemical characteristics and their evolutional laws of routine hydrochemistry, trace elements and environmental isotopes in the underground water in the coalmine, and build kinds of identifying models of each aquifer of water gushing. The achievements mainly express in the following aspects:

(1) The author tested the routine hydrochemistry elements (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}, SO_4^{2-}, Cl^{-}, HCO_3^{-}、pH、total dissolved solid、conductance ratio and total hardness) of the water of each aquifer underground water, analyzed the distributing characteristics of the routine hydrochemistry elements, adopted the distributing rules about the total dissolved solid, simulated each aquifer water quality concentration gradient field in the mining area of North Anhui, explored the water circulation characteristics of each aquifer underground water and studied the conditions of the recharge, runoff, drainage and stagnant of each aquifer underground water. According to the hydrochemical balance characteristics of the Ca^{2+} in the Karstic water, the systematical research was done in the water circulation characteristics of underground water in Taiyuan limestone aquifer and Ordovician limestone aquifer in the mining area. By progressively applying the system cluster analysis method to the sources of water discriminating analysis for routine hydrochemistry indexes, the routine hydrochemistry genesis models of the main water invasion aquifer in the mining area were developed.

(2) According to the tested data about trace elements (Ag, Al, As, Ba, Cd, Ce, Co, Cr, Cu, La, Mn, Mo, Ni, Pr, Sb, Se, Sr, Ti, V, Zn, Pb, F, Li, Sn) in the underground water, the hydrogeochemistry elementary characteristics of the trace elements in the mining area were acquired, the relationships between the trace elements in the underground water and their abundant degrees in the lithosphere rock were educed, and the relationships between trace elements and routine components were educed, too. According to the relativity among the trace elements, the relativity between trace elements and routine ions, and their distributing sections in the geographical space, the characteristics of the trace elements (As, Ba, Co, Cu, Se, V) of the underground water in the mining area are determined. According to the content of many trace elements in the forth aquifer, Taiyuan limestone aquifer and Ordovician limestone aquifer by adopting the main composition analysis method, the genesis models of the trace elements in the underground water of the main water invasion aquifers in the mining area of North Anhui were acquired. On this base, according to the content of the typical trace elements and routine ions in the underground water, the trace elements Bayes multiple liner discriminating models which revised by routine ions are developed to obtain ideal discriminating results.

(3) The different composing characteristics of the oxygen and hydrogen stable isotopes (D, ^{18}O) and the radioactive isotope (T) in each aquifer were found out in the mining area in North Anhui, and the different degrees of hydraulic relations were analyzed for each aquifer. The recharge area, runoff area, stagnant area and drainage area of each aquifer were determined prima-

rily in the mining area. The average replenishment elevations (the water in the forth aquifer and the coal measures do not exceeds 30 m while the water in both Taiyuan limestone aquifer and Ordovician limestone aquifer exceeds 130 m) and supplying temperatures were determined (the atmospheric precipitation supplying temperatures of the four aquifers are all around 5℃) of each aquifer in the mining area.

(4) According to the composing characteristics of the oxygen and hydrogen stable isotopes in the forth aquifer, coal measures, Taiyuan limestone aquifer and Ordovician limestone aquifer, the paper clarifies the characteristics of the mixed models and the genesis models of the underground water in each aquifer. The relationships between the value of δ and pH, the value of δ an the total dissolved solid, the value of δ and the conductance ratio, the value of δ and the routine ions, the content of T and the routine hydrochemistry index of the underground water in the mining area of North Anhui were obtained. By applying the multiple liner regression model, the author brought forward the underground water environment isotope hydrochemistry genesis model in the mining area. A series of the environment isotope hydrogeochemistry genesis models which had the multiple correlation coefficient close to 1 were developed, and obtained the distinct results.

Achievements above have got ideal effects after being applied into practice in several coalmines in Wanbei mining district. Among these examples of application, Luling coalmine of the Mine Group Company of Huaibei has mined 810 working section safely, producing coal 2, 400, 000 t, having a production of 700 million yuan (RMB) and a profit of 400 million yuan (RMB). At present, the coalmine is mining 9 coal-bed in this working section, which has a reserve of 1, 500, 000 t coal. Mining the whole of 8 & 9 coal-beds of 810 working section can help the Luling coalmine postpone serving years by 2. 4 years, and make the west of coalmine postpone serving years as long as 5 years, the economic and social benefits are numerous.

This book falls into ten chapters. The first, second, third and tenth chapters are written by Gui Herong; the forth, fifth, sixth and seventh chapters by Gui Herong and Chen Luwang; the eighth and ninth chapters by Chen Luwang and Gui Herong. The whole of the book is edited by Gui Herong.

Owing to the limitation of the authors' academic proficiency, some of the achievements maybe have mistakes and shortages. We are in sincere hope for advice and corrections from experts and readers alike.

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