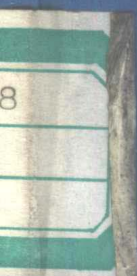


水文地球化学预报地震的 原理与方法

HYDROGEOCHEMICAL PRINCIPLES AND
METHODS IN EARTHQUAKE PREDICTION

教育科学出版社



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内 容 提 要

本书是二十年来我国水文地球化学预报地震的全面总结。作者通过整理,分析二十年中积累的大量实际资料,对我国水文地球化学预报地震的历史发展、基本原理、观测技术、资料分析、前兆特征、影响因素、异常机理以及对未来的展望进行了全面、系统的论述。书中既具有丰富的实践内容,又渗透着当代国内外的最新科研成果,可供地震预报、水文地质、地球化学等专业的科技人员以及大专院校有关专业的师生参考。

Synopsis

In this book research on earthquake prediction through the hydrogeochemistry approach in the past 20 years is summarized. Based on the analysis of the large amount of data accumulated in 20 years, the authors give an all round and systematic description of the historical development, basic principles, observation techniques, data analysis, precursory characteristics, influence factors, mechanism of precursors and future prospect of earthquake prediction through hydrogeochemistry. The book contains practical experience and recent results both in China and abroad. It might be a useful reference for scientists, technicians, students and teachers who are engaged in earthquake prediction, hydrogeology geochemistry etc.

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作者说明

自1966年邢台地震之后，我国开展了利用地下水化学组分变化预报地震的观测与研究。二十年来，在全国二十八个省、市、自治区建立了水文地球化学地震观测台网；开展了地震的水文地球化学正常动态及其影响因素、地震的前兆效应及其机理的理论研究；对水文地球化学地震观测点的环境条件、观测方法、测试技术、预报方法等技术问题和理论问题进行了有益的探索。所有这些工作，不仅取得了十分丰富的观测资料，在某些强震和中强震的预报中发挥了积极的作用，而且在前兆机理的实验研究方面取得了不少新的成果。

近些年来，水文地球化学方法作为探索地震前兆，预报地震的重要手段，已日益引起国内外科学界的重视，并被许多国家所采用。为了全面反映我国在水文地球化学预报地震方面取得的进展和成果，我们编著了本书。

本书共分Ⅶ章。第Ⅰ至Ⅳ章侧重介绍水文地球化学预报地震的基本原理、研究内容和研究方法；第Ⅴ章侧重介绍强震和中强震前后的水文地球化学异常、观测资料的分析处理和预报地震的方法；第Ⅵ章讨论了水文地球化学前兆机制及室内外实验研究的成果。第Ⅶ章对水文地球化学地震前兆探索的前景和方向进行了讨论。

本书第Ⅰ章、第Ⅴ章1、3、4、5、6、8节以及第Ⅶ章由张炜同志编写；第Ⅱ章、第Ⅳ章由王吉易同志编写；第Ⅲ章的1、2、3节由鄂秀满同志编写；第Ⅲ章的第4节由李正蒙同志编写；第Ⅴ章的2、7、8节由王长岭同志编写；第Ⅵ章由李宣瑚同志编写。全书由张炜同志主编。

在本书编写过程中，作者参阅和引用了许多从事这方面工作的同志的资料和成果，并得到各部门领导和许多同志的热情关怀与帮助。梅世蓉研究员为本书写了序言，《地震》编辑部对本书的编辑给予了大力支持。作者对热情帮助本书出版的单位和个人致以诚挚的谢意。

由于作者水平所限，错误和不当之处在所难免，恳望读者批评指正。

作者

一九八八年五月

Authors' words

Since the Xingtai earthquake of 1966, observation and research on changes in hydrogeochemical constituents for earthquake prediction have been carried out in China. For 20 years, hydrogeochemical observation networks have been established in 28 provinces, municipalities and autonomous regions; theoretical studies of the normal dynamic behaviors and their influence on precursors to earthquakes and their mechanisms have been made, the theoretical and technical problems of the observation environments, observation methods, calibration techniques and prediction approaches have been studied. The research work has not only accumulated abundant observation data and played positive roles in predicting some moderate or large earthquakes, but also led to some new achievements in experimental studies on the mechanisms of the precursors.

In recent years, the hydrogeochemical method, as an important way to explore the precursors and to predict earthquakes, has stimulated increasing interest among scientists both in China and abroad, and has been used in many countries. We compiled this book with the aim of giving a detailed description of the advances and achievements in earthquake prediction through hydrogeochemical approach in China.

The book is divided into seven chapters. Chapter I to IV emphasize the basic principles, research content and methods in earthquake prediction through hydrogeochemical approach; Chapter V introduces anomalies in hydrogeochemistry before and after some moderate or large earthquakes, data processing and analysis and prediction methods; Chapter VI discusses the mechanisms of hydrogeochemical precursors and achievements of outdoor and laboratory experiments; Chapter VII discusses the prospect and trend of research on hydrogeochemical precursors.

Chapter I, Sections 1, 3, 4, 5, 6 and 8 of Chapter V and Chapter VII are written by Zhang Wei; Chapter II and IV are written by Wang Jiyi, Section 1 to 3 of Chapter III are written by E Xiuman; Section 4 of Chapter III is written by Li Zhengmeng; Sections 2, 7, 8 of Chapter V are written by Wang Changling; Chapter VI is written by Li Xuanhu. The whole book is edited by Prof. Zhang Wei.

During the preparation of the manuscript of this book the authors consulted or used data and results obtained by many colleagues. Prof Mei Shirong wrote the preface of this book. The editorial office of "Earthquake" gave full support for editing the book. The authors express their acknowledgements to the Publishing

House and individuals who gave their assistance in the preparation of this book.

Authors

May 1988

序 言

从地震学和断裂力学的现代概念出发,构造地震的震源是在剪切构造变形过程中积累的应力作用下,地壳岩石连续性的动态破裂。这个动态破裂的产生需要一个孕育过程。在此过程中,存在于地壳岩石中的微破裂的大小和数目逐渐增加,从而导致孕震区平均形变速度随着时间变化,并导致岩石弹性、电性、磁性等岩石物理性质的改变,引起各类物理前兆的出现。然而,地壳又是包含水、气的介质,伴随地壳中微裂隙的发展变化,必然会使充填在岩石孔隙和裂隙中的流体发生反应。这种反应表现为水文地球动力与水文地球化学效应。地下水的水位、压力或流量的变化属于水文地球动力前兆;地下水中的化学成分和气体成分的变化属于水文地球化学前兆。

苏联是世界上提出水文地球动力前兆与水文地球化学前兆最早的国家,但大规模开展此项研究是在1966年4月塔什干地震之后。这与我国开展水文地球化学前兆研究的起始时间差不多。我国先从邢台地震现场开始,然后逐渐扩展到天津、北京、山东、辽宁、山西、河南、内蒙、云南、四川、甘肃、陕西、宁夏、新疆、福建、广东、广西、湖南等省,积累了大量地质和水文地质条件不同的井(泉)的水化观测资料,为探索水化地震前兆打下了基础。由于我国的地震预报工作是在科学技术准备不足的情况下仓促上马的,在许多问题都不甚清楚的情况下开始各类前兆观测,盲目性很大,虽然积累了不少资料,也发展了一些预报方法,但是,由于信息与干扰处于“鱼目混珠”状态,限制了水文地球化学前兆在预报中作用的充分发挥。1983—1985年在国家地震局的统一组织下,开展了“地震前兆和预报方法的系统研究”,与此同时,在全国范围内开展了利用水文地球化学方法预报地震的全面清理工作,从地下水化学的观测技术、观测点的环境条件、水化地震观测中干扰因素的识别与排除方法、水化预报地震效能评价、水化地震前兆机理等方面进行了较深入的研究,取得了不少有价值的成果,为今后水化预报地震工作的深入发展奠定了良好的基础。

本书是系统反映我国水文地球化学前兆研究领域主要成果的专著。作者都是这个领域的专家。书中深入浅出地介绍了基本概念和基本原理;阐明了地震水文地球化学前兆产生的物理基础,检测地震前兆所必须的环境条件与合理的台网部署及现测技术;详细论述了各种干扰的来源、形态、作用与排除方法;提炼出强震与中强震水文地球化学前兆特征;评价了这些前兆在地震三要素预报中的作用与效能。书中包含了理论、方法、技术与经验,从实践到理论进行了系统阐述。这些内容对推进地震监测预报工作无疑具有重要的实用价值,对分析预报人员是一本带有“指南”性的好书,同时对促进地震水文地球化学——一门介于地震学、水文地球化学、水文地质学、地球化学间的边缘新学科——的发展具有一定的学术价值。书中包含的地震水化前兆时空强特征的解释要求增进对震源区的物理化学过程的了解。然而,迄今为止,许多有关震源孕育、发展的知识绝大部分来源于地球物理学,尤其是地震学,从水文地球化学方面提供的震源过程知识尚不多。作为岩石介质组成部分的水和气是反映岩石受力变形或破裂十分灵敏的组分。从岩层中流出的地下水,可以作为载体,将地下变化的信息传递到地表上来,为认识震源开辟一条新的途径。加里津曾指出:“地震是霎那间照亮地球内部的一盏明灯”,因为地震波不仅带来了地球内部构造,组成的信息,而且带来

了震源的信息。但地震波震过以后不久即消失，而地下水载来的信息可以持续较长的时间。地下水的干扰因素较多，只有在充分排除了各种非地震因素的干扰以后，通过研究地下水化学组分的变化，才可能获取地震前兆。对此，作者在书中反复强调，并且指出运用地球化学研究的原理，研究地震孕育过程中震源及外围地区地下岩层中各种化学组分的迁移变化规律、水-岩相互作用及水在地震孕育过程中的作用等重要问题，一旦这些问题取得进展时，人类对震源的孕育、发生过程的认识必将达到一个新的水平，并给地震预报带来新的远景。

梅世蓉

1988年4月1日于北京

Preface

According to the modern concepts in seismology and fracture mechanics, the source of a tectonic earthquake is the dynamic fracture zone of the continuous media of the crust in the process of tectonic deformation under the accumulated stress. There should be a process of preparation for this dynamic fracture. During this process the size and number of the micro cracks in the earth crust may gradually increase, therefore the average rate of crustal deformation in the seismogenic area may change with time and consequently the elastic, electric, magnetic and other physical properties of the rock also may change, and various kinds of physical precursors may appear. But the earth crust is a kind of media saturated with water and gases. With the development of micro cracks in the crust, there should be changes in the fluids that fill the cracks and pores within the rock. These changes are effects of dynamic geohydrology and hydrogeochemistry. The geohydrological precursors include anomalous changes in the water level, pressure and flow of the ground water, and the hydrogeochemical precursors include anomalous changes in the chemical and gaseous constituents in the ground water.

The Soviet Union is the first country in the world that reported the dynamic geohydrological precursors and hydrogeochemical precursors, but the research on these precursors has only been made since the Tashkent earthquake of April 1966. Almost at the same time China began its research on the hydrogeochemical precursors. In China the research work was first carried out in the Xingtai earthquake area and then gradually spread to Tianjing, Beijing, Shandong, Liaoning, Shanxi, Henan, Inner Mongolia, Yunnan, Sichuan, Gansu, Shaanxi, Ningxia, Xinjiang, Fujian, Guangdong, Guangxi, Hunan, and other provinces. Large amount of hydrogeochemistry observation data in geologically or hydrogeologically different wells (springs) have been accumulated. Thus a good foundation has been laid for the research on hydrogeochemical precursors. But earthquake prediction research in China was started in haste without sufficient scientific and technical preparation, and the observation began without clear understanding of many problems. Though a lot of data were accumulated and some prediction methods were developed, the role of hydrogeochemistry in earthquake prediction has been limited because useful information and contaminations are mixed in the data. From 1983 to 1985, organized by SSB, the "Systematic Research on Earthquake Precursors and Prediction" was carried out, at the same time an all round review of prediction methods through hydrogeochemistry approach was made, deepgoing researches on

the observation techniques, environments of observation posts, identification and elimination of contaminations in the observations, evaluation of the effectiveness of predictions, mechanisms of hydrogeochemical precursors were made and a lot of valuable results were achieved, a better foundation was laid for future development.

This is a professional book that presents systematically the main achievements in the researches on the hydrogeochemical precursors in China. The authors are experts in this field. In this book, the basic concepts and principles are explained in depth but in simple terms. The physical basis for the occurrence of hydrogeochemical precursors, the necessary environments for the detection of the precursors, the reasonable layout of the observation networks and observation techniques are discussed. The origin, pattern, effects and elimination of contaminations are described. The characteristics of hydrogeochemical precursors to moderate and large earthquakes are summarized. The role and effectiveness of these precursors in earthquake prediction are evaluated. The book covers theories, methods, techniques and experience, and give a systematic presentation of both practice and theory. All these contents undoubtedly are of great practical value to promote the work of monitoring and predicting earthquakes. This worthy book may be used as a guide book by people who work on the analysis and prediction. It is also of academic value in promoting the development of seismo-hydrogeochemistry - a new frontier discipline between seismology, hydrogeochemistry, hydrogeology and geochemistry. The explanation of the temporal and spatial characteristics of hydrogeochemical precursors demands new understanding on the physical and chemical process in the focal region. However, until now the understanding on the seismogeny and development in the focal region has mainly come from geophysics, and especially from seismology, but very little from hydrogeochemistry. As constituent parts of the rock, water and gases are quite sensitive to the deformation and fracture of the rock. The water that flows out from the rock may serve as a carrier that brings information on the underground variations to the earth surface. Therefore it is a new approach to understand the earthquake source. Galitzin once said "The earthquake is a lamp that illuminates the earth's interior instantly", because the seismic waves not only carry information of the structure and composition of the earth's interior, but also carry information from the earthquake source. However the seismic waves disappear quickly, but the information carried by the ground water may last for a relatively long duration. But there are many contaminations in the ground water, the precursors to earthquakes can be obtained only when contaminations are sufficiently eliminated

and the variations in the chemical constituents in the ground water are studied. Therefore the authors have repeatedly pointed out in this book that as soon as progress in important problems, such as the application of the principles of hydrogeochemistry, the migration and variation of the chemical constituents within and outside the focal region during the seismogenic process, the interaction between water and rock and the role of water in the seismogenic process etc., has been made, man's knowledge on the seismogeny and occurrence of earthquakes will reach a new level, and new prospect will open for earthquake prediction.

Mei Shirong

April 1 1988 in Beijing

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第 I 章 地震水文地球化学前兆研究概述

地震预报问题是当今地球科学中尚未解决的科学难题。地震的频繁发生及其给人类带来的巨大灾难,使解决地震预报问题成为人类的迫切需要。本世纪初,一些科学家就已提出了进行地震预报的设想,但是限于科学发展水平,所采用的测试仪器没有足够的精确度和灵敏度,所以直到50—60年代,在地震前兆探索方面并未取得明显进展。本世纪60年代,地震进入了一个新的活跃期,国内外相继发生了一系列破坏性地震,一大批科学家投入了地震预报的探索工作。目前,地震预报的实用化研究已经被列为重要的研究课题。解决地震预报的关键在于寻找出地震的前兆现象,并研究这些现象与地震发生的时间、地点和震级之间的关系。

近年来,随着地震前兆研究的进展,水文地球化学方法作为探索地震前兆的重要手段已在中国、苏联、日本、美国等世界许多国家开展起来并建立了大批地下水化学观测点,对地下水中的常量组分、微量组分、气体组分、同位素组分以及其它物理参数进行着观测与研究,探讨其与地震发生之间的关系。经过各国地震工作者的努力,已获得许多宝贵的资料。

第 1 节 地震水文地球化学的研究简史和现状

在我国,地震预报中的水文地球化学方法是在地震监测预报的实践中诞生和发展起来的。1966年3月,邢台发生了7.2级地震,震后的现场调查发现,强震前曾出现过大量的地下水翻花、冒泡和水味苦甜变化等宏观现象。结合地震史料中关于大震前地下水水质变化的众多资料,人们提出了利用地下水中气体—化学组分变化探索地震前兆的设想。

邢台地震后,根据周恩来总理提出的“深入现场调查,抓住邢台不放”,“总结经验,找出规律”的指示,中国科学院地球化学研究所于1968年5月、地质部水文地质工程地质研究所于1968年7月,先后在邢台地区对地下水中的氡浓度、氯、钙、镁等离子成分的含量以及地下水中的气体总量进行测量,积累了邢台余震水化组分变化的科学资料,获得了水化组分变化与地震关系的初步认识。

1973年3月,河北省的河间发生了6.3级地震,于是在河北及京津地区进一步加强了地震水文地球化学观测工作。1968年7—8月,又在天津、河北、北京等地选择了一批条件较好的井孔,并在天津地区专门为地震观测打了三口自流深井,避开了开采层,减少了人为干扰,加强地震监测工作。至1968年7月18日渤海7.4级强震前,在华北北部已初步形成了地下水化学观测台网,取得了渤海7.4级强震的水化观测资料。

1970年1月5日,云南通海发生了7.7级地震。震后,云南地震工作队在通海地区开展了余震的地下水化学观测,取得了地下水中氡含量、水电阻、水温、流量的观测资料,讨论了上述观测项目变化与4.0级以上余震之间的关系。

1971年5月在河北省正定县召开了第一次全国水文地球化学地震预报经验交流会。会议根据渤海7.4级地震及其它4级左右地震的水文地球化学前兆（氡浓度、水电导、氟离子、亚硝酸根离子的变化），特别是震前地下水中氡含量的变化，认为水文地球化学方法是地震预报的一种有希望的方法。会上还提出了布设水化观测台网、努力提高观测精度、识别和排除干扰、深入震区进行研究以及发展新领域和新方法探索等问题。此次会议之后，我国地震预报的水文地球化学方法引起了广泛重视，并在全国其它地区也逐渐发展起来了。至1973年，山东、辽宁、山西、河南、内蒙古、云南、四川、甘肃、陕西、宁夏、新疆、福建、湖南等地震活动性强弱不同的省（自治区）先后建立了一批水化观测点，积累了地质和水文地质条件不同的井（泉）的水化地震观测资料，为探索水化地震前兆打下了初步的基础。

1973年在河北省石家庄市召开了第二次全国地震水化专业会议，对几年来的水化地震监测工作进行了交流。会议着重总结了选择水化观测点的环境条件；总结了提高观测质量、改善测试方法和观测室条件等问题；制定了《水氡观测技术规范（初稿）》；对观测条件差的井（泉）进行了调整，淘汰了一大批大口民用井和变化无规律的井（泉）；提出了地震水化观测点的选点原则，特别强调要注意构造条件和水文地质条件等问题，从而使水化观测资料的可信度有了较明显的提高。

1973年之后，在吉林、黑龙江、江苏、上海、浙江、安徽、江西、湖北、广西、青海等省（市）又建立了一批水化观测点，这样，在我国基本形成了以华北、西南多震区为重点的全国水化地震观测台网。

1973年2月四川炉霍发生了7.9级强烈地震。1974年5月，云南昭通—永善发生了7.1级地震。在这两次强震前再次在个别点上观测到了水氡大幅度的临震突跳现象。1975年2月，辽宁海城发生7.3级地震，震前在辽宁省的较多的观测点上观测到了水氡测值的趋势性异常和临震突发性异常，海城地震前地下水中化学组分的突出变化为海城地震的成功预报提供了重要依据。1976年5月，云南龙陵发生7.4级地震。1976年8月，四川松潘发生7.2级地震。在这两次强震的预报中，地下水中氡浓度的变化也发挥了积极的作用。

1976年7月，河北唐山发生了7.8级强震。这次地震发生在水化地震观测工作开展较早、台网密度较大的地区，震前虽观测到了较多的异常现象，但预报中震级估计过低，更未作出临震预报。这一惨痛教训使我们清醒地认识到，利用地下水化学组分变化预报地震是一项十分艰巨、复杂的科研课题，要找到确定性的水化地震前兆指标，还需要坚持不懈地付出艰辛的努力。

1966至1976年的十一年间，我国大陆连续发生多次七级以上强震。在经历了海城、龙陵、松潘等地震的成功预报和唐山地震预报失败之后，1978年6月在广州召开了第三次全国地震水文地球化学专业会议。会议对1973年以来发生的海城、龙陵、唐山、松潘、盐源、巴音木仁等几次六级以上强震进行了总结；研究讨论了强震的水化前兆特征，水化预报地震的方法、观测技术、测试仪器的研制；水化地震前兆机理等方面的科研成果；对水化地震前兆探索方面存在的问题以及今后研究内容和方向进行了广泛讨论。会议认为，今后应在水化地震短临前兆信息的研究、干扰因素的识别和排除、水化正常动态的研究、水化测试仪器的改进与提高等方面开展深入的工作。会后编印了《地震地球化学论文集》。

1978年以后，我国大陆地震活动进入相对平静时段，客观情况使我们有可能对一系列复杂的现象和问题进行系统的总结和研究。1977年，国家地震局组织了地震水文地球化学攻关