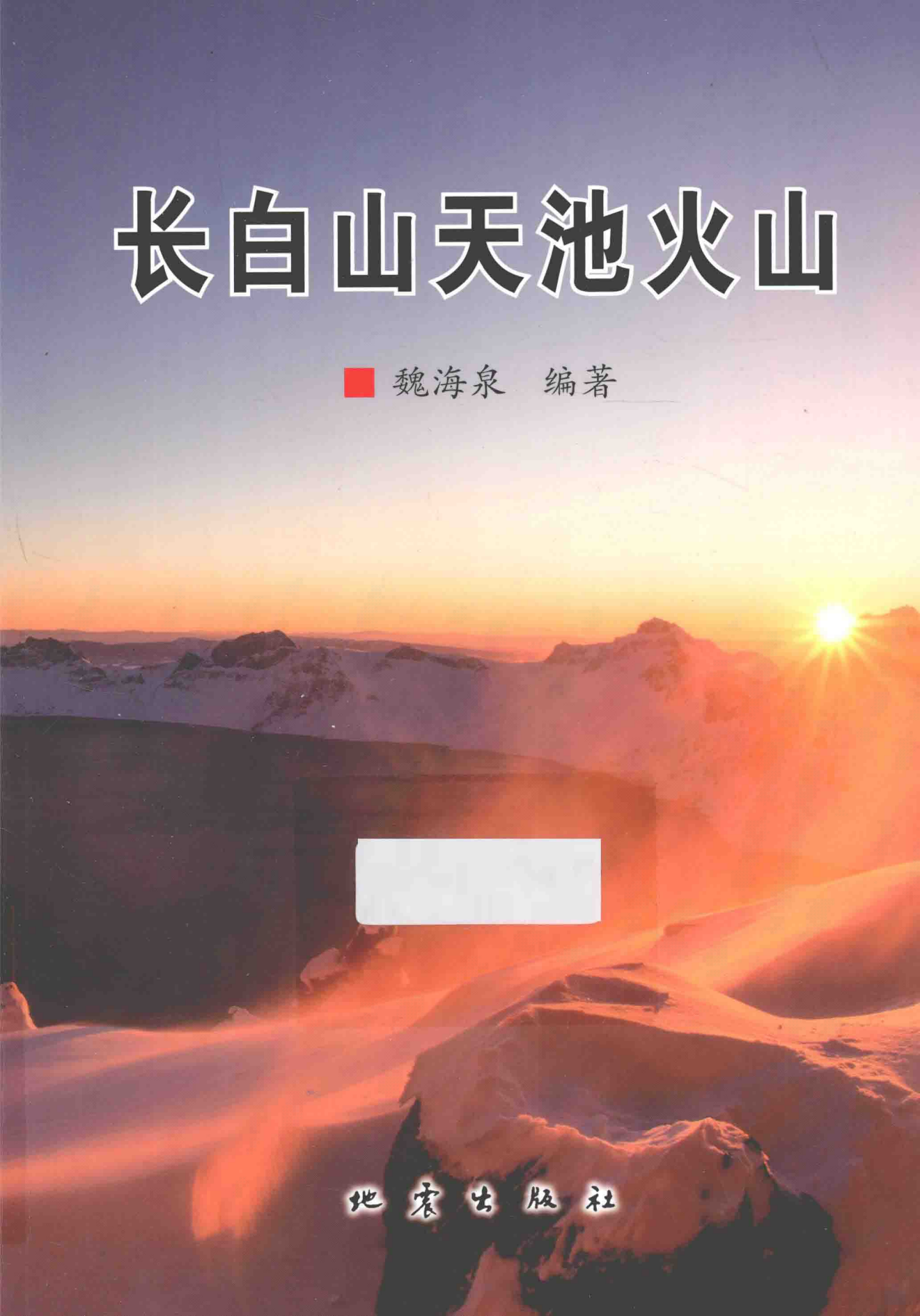
长白山天池火山

魏海泉　编著



地震出版社

长白山天池火山

魏海泉 编著

地震出版社

图书在版编目（CIP）数据

长白山天池火山 / 魏海泉编著. —北京：地震出版社，2014.8

ISBN 978-7-5028-4213-0

Ⅰ. ①长 … Ⅱ. ①魏 … Ⅲ. ①长白山－天池—火山—研究 Ⅳ. ① P317

中国版本图书馆 CIP 数据核字（2013）第 041499 号

地震版 XM2968

长白山天池火山

魏海泉 编著

责任编辑：樊 钰

责任校对：庞亚萍

出版发行：地震出版社

北京民族学院南路9号 邮编：100081

发行部：68423031 68467993 传真：88421706

门市部：68467991 传真：68467991

总编室：68462709 68423029 传真：68455221

http://www.dzpress.com.cn

经销：全国各地新华书店

印刷：北京地大天成印务有限公司

版（印）次：2014年8月第一版 2014年8月第一次印刷

开本：787 × 1092 1/16

字数：628千字

印张：29.5 插页：8

书号：ISBN 978-7-5028-4213-0/P (4901)

定价：110.00元

前　言

长白山天池火山曾经发生了近2000年以来世界上最大规模的两次喷发之一的爆破性喷发，这次千年大喷发的喷发物是众多火山学家近几十年来研究工作的重要对象。2002～2005年间，天池火山的不稳定性得到了很好的监测，由此也大大丰富了中国年轻火山的监测与研究资料，并且吸引了更多的科学关注与争论。为此，以笔者二十多年开展天池火山研究的经历为基础，结合国内现有天池火山监测与研究的专题性工作成果，系统归纳形成了这篇代表天池火山现代火山学研究的部分主要进展的综合性成果的专著。本书共分七章，前四章系统阐述天池火山的历史，后三章则偏重天池火山的现状与未来。在天池火山的历史部分，首先给出了天池火山及邻近其他火山的构成与产出的地质背景，然后从化学与物理学角度分别对天池火山的喷发历史与过程作了详细介绍。对于天池火山的现状与未来，火山下方岩浆房与地热系统的综合判定与破火山口湖天池水体的泛滥过程，都被作为天池火山未来与火山灾害密切相关的基础资料作了系统整理与归纳。本书可用于研究生了解现代火山学研究内容，可用于天池火山周围公众减轻火山灾害工作时参考，也可以为人们进一步研究天池火山若干科学问题时参阅。不过，笔者想在这里强调的是，这最好是作为一本关于天池火山地质、火山结构与火山灾害的火山学参考书。

本书第一章首先介绍了天池火山及周围望天鹅火山、胞胎山火山等长白山区新生代火山的发育概况，然后系统描述了构成天池火山主体的玄武岩盾、粗面岩锥和伊格尼姆岩席的主要特征，文中对于天池火山地层学与火山样品最新的系统性定年研究成果也作了系统归纳。第二章着重介绍与天池火山构造背景制约有关的区域构造及火山细部构造与堆积相特征。与盖马高原玄武岩有关的长白山火山岩浆柱、北西向火山带及其北东侧的日本海－珲春深震带都是为了了解天池火山地质动力学背景而详细阐述的几个关键问题。天池破火山口内壁堆积层序、潜火山结构及不同类型喷发物空间堆积相的细部特征也放在本章详细叙述。第三章以天池火山化学特征为切入点，在天池火山熔岩盾和复合锥形成过程讨论的前提下，给出了笔者近年来采集与测试的系统性样品的测试结果与主要化学特征。岩浆演化机理的结晶分异作用和岩浆混合作用过程的讨论是按照天池火山不同喷发阶段系列产物的地质体为基本单元进行的。天池火山

共存的碱性与亚碱性两个系列的岩石化学特征、连续性岩浆演化而非双峰式岩浆成分分布的岩浆演化过程对于理解天池火山深部岩浆作用过程机制提供了基础依据。矿物成分、微量元素与同位素资料指示的岩浆成因意义也与西太平洋俯冲带有着某种联系的地幔源区物质上涌地质动力学模型相符合。第四章关注的是与天池火山千年大喷发爆破性喷发产物相关的物理作用过程。文中首先介绍了天池火山千年大喷发不同成因类型堆积物的形成动力学特征，然后对天池火山岩浆房与火山通道系统的喷发物理过程作了系统的参数限定，其中对于天池火山岩浆房内不同岩浆的混合动力学过程还给出了初步的实验火山学模拟研究成果。

本书第五章重点阐述天池火山与岩浆房热系统有关的结构特征。本章首先从通用性岩浆房理论模型对天池火山之下现今可能的岩浆房结构与尺度做出判定，然后从地震学与温泉流体地球化学角度加以验证，以此作为天池火山未来可能的火山灾害性评估的依据。第六章通篇描述天池火山地表作用过程并以此作为评价未来火山灾害的基本依据。本章首先探讨的是天池火山喷发间歇期里火山表面随着时间持续的风化、剥蚀、碎屑搬运与堆积过程，初步限定了天池火山不同火山地貌区的时间演化序列与相关参数。无论是天池火山广为发育的不同期次火山泥石流，还是天池火山大规模火山滑坡体构造洼地及堆积物，本章内容都给出了较为详细的介绍。对于天池火山破火山口湖湖震及其火山表面碎屑物沿着二道白河搬运堆积的动力学机制在本章结尾部分也有较为明确的表述。第七章直接讨论的是天池火山灾害问题。针对天池火山喷发历史及现状，本章首先讨论了天池火山未来可能发生的各种主要火山灾害类型及空间影响范围与灾害强度，并且分别限定了“火”灾与“水”灾的致灾机理。在天池火山现今监测手段与部分监测结果表述的基础上，结合天池火山近几十年来展示的火山活动性状况，从岩浆补给速率的控制作用角度讨论了天池火山现今活动性及其成因机制。作为本章及本书的结尾，笔者强调的一个理念是人与火山共处。无论是人与自然的演化，还是文化与资源的保护及灾害减轻，21 世纪的天池火山都应作为和人类和睦共处的典范。

本书汇集了笔者 20 余年在天池火山从事野外地质调查和室内研究积累的主要资料，成书过程中也吸收了部分国内外同仁的研究成果。特别是注意吸取了历年来中国地震局火山研究项目取得的部分原始资料，虽说文中没有详细讨论，但是笔者真心希望读者能够从中理出一些您自己的思绪。如果说本书内容有着某种独特的有价值的内涵，那就是希望读者能够以自己的思路，细致把脉

天池火山的物理、化学过程，从而获取读者自己对天池火山的理解。无论是从深入的科学研究的角度，还是从减轻火山灾害的需求，笔者都愿意今后人们在有需要了解认知天池火山的意愿时，这本书能起到一个向导的作用。

众多科研团体与个人对本书的出版提供了直接或间接的帮助。特别要感谢的是金伯禄老师长期以来在共同研究工作中的指导和鼓励，您是我找到的珍爱天池火山的知音。感谢我的导师孙善平教授和李家振教授，是您们把我带进了火山物理学的大门。感谢刘若新教授，是您提供了我现在从事的系统性、专业性火山研究工作的机会。对于多年来中国地震局有关领导的支持和鼓励，我想特别致谢的有李明司长、吴建春司长、吴书贵司长、李克司长、王飞处长、刘桂平处长、田柳处长和北京市地震局吴卫民局长，各位领导的信任和鼓励是我多年来刻苦努力的动力。感谢地质研究所与研究室领导，多年来良好的研究工作环境使我能够更多地潜心整理，加深了对火山的理解。野外地质调查工作中，吉林省地震局、吉林省地矿局和天池火山观测站的有关领导和同事提供了大量的帮助，在此表示深深的感谢。本书成果包含了部分自然科学基金的研究成果（49102020、40172033、41172304），特别是1991年我首次申请的天池火山学研究的青年自然科学基金，为我建立天池火山认识的框架起到了关键作用。

作为本书成型的功不可没的国际友人、当代火山学鼻祖、已故“火山精灵”G. P. L. Walker教授的文章及对我的野外考察与研究能力的指导使我受益匪浅。国际火山学会前主席R. S. J. Sparks教授推荐的英国皇家学会的访问学者资助更使我切身体会了在国际当代一流火山学研究中心进修的快乐。已故知名华裔地质学家孙贤钵先生科学研究方法的指导也使我至今难忘，澳籍华裔学者张明老师20世纪80年代末带给我的《火山喷发物理作用》的综述性论文可以说为我开展系统的火山学研究开启了一盏明灯。

我也想把此书献给我的家人，我的父母教育我从小就要做到老实做人、认真做事，可以说这为我成年后选择减轻火山灾害为己任奠定了先天基础。我的爱人料理了家庭的绝大多数事务，这使我能够更专注于我所热爱的事业，希望你能从这本书——如果说这是一份唯一的礼物——里享受到一份快乐。我的孩子已经找到了他所喜欢的工作，以下16个字让我们共勉：顺天做事，诚实做人；完善自我，和谐他人。

最后特别需要说明的是本书文字初稿吸收了若干同仁的研究工作成果，在笔者最后统稿之前金伯禄老师仔细地阅读并修正了关键部分文稿。参加不同

章节初稿编写的同仁有：金伯禄、高玲、靳晋瑜、孙春强、刘强、陈晓雯、陈正全、杨清福、盘晓东、刘国明和刘永顺。本书研究内容主要汇集了中国地震局“九五”、“十五”、“十一五”火山研究项目的部分成果（95-11-03-02-01、2001BA601B06-01-4、2002DIA20009-20、8-27-7），出版经费得到了地震科学联合基金（506003）和地震行业专项（201208005）的资助。由于自己对天池火山的理解还不够深入，个人观点与章节文字等内容肯定还存在很多不完善之处。恳请对本书感兴趣的同仁不要拘泥于本书所写条条框框的限制，能够从中提炼出若干对您有用的信息，我将为自己在2010年完成的一件大事而兴奋不已。

魏海泉

2010. 11. 12

Preface

Tianchi Volcano produced one of the two largest explosive eruptions in the world during the past 2 thousand years. This powerful volcanic event (called the "Millennium Eruption") and its deposits have been the focus of many volcanological studies in recent decades. Moreover, the 2002-2005 volcanic unrest at Tianchi was well monitored by the Changbaishan Volcano Observatory established in 1999. Consequently, the greatly increased data now available have attracted much scientific attention, arguably making Tianchi the best-known of China's geologically young volcanoes.

This volume, composed of 7 chapters, synthesizes the results of recent volcanological and volcanic-monitoring studies of Tianchi, including my own geological research of this volcano over two decades. The first four chapters of the book summarize regional tectonic setting, geologic and volcanic features, and eruptive history of Tianchi and neighboring volcanoes. The remaining three chapters emphasize the present state of Tianchi, with particular focus on the caldera lake, the magmatic and geothermal systems beneath the volcano. Collectively, the integrated data on the volcano's eruptive history and current behavior provide the scientific basis to assess possible future eruptive activity and associated hazardous impacts. This book can serve as a comprehensive reference work for postgraduate students to understand the modern volcanological research and its applications, as well as for other scientists to pursue in depth specialized topics relevant to Tianchi Volcano. However, I also wish to stress that the information in this book could, and should, be used to best advantage by the emergency-management officials and the general public in the Tianchi region in the development of long-term programs to reduce risks from potential volcanic hazards. A more detailed summary of the contents of this volume is elaborated below.

In the book's first chapter, the development and history of Holocene volcanism in Changbaishan area—involving Tianchi, Wangtiane, and Baotaishan Volcanoes—are introduced first. Then the main features of the basaltic shield, trachyte cone, and ignimbrite sheet are described in detail, including the latest systematic geochronometric and stratigraphic studies on Tianchi Volcano. Chapter two deals mainly with the regional tectonics related to Tianchi Volcano and some specific features of the volcano's structures and depositional facies, such as the Changbaishan magma prism, NW-trending volcanic belt, and the deep earthquake zone of Hunchun-Sea of Japan. All of these features are related to the basaltic volcanism on the Gaima Plateau, and are described in detail for the reader to understand the geologic and dynamic setting of Tianchi Volcano. The depositional sequences of the inner

caldera, subvolcanics, and smaller-scale variations in facies of different types of eruptions are considered. Chapter 3 describes the geochemical variations observed in Tianchi's eruptive products. Within the context of the evolution from shield-building activity to construction of the composite-cone, I present the latest analytical data on systematically collected samples, as well as a detailed discussion of differentiation and magma -mixing processes that characterize of the individual depositional series. For Tianchi Volcano there exists two series of co-existing alkaline and sub-alkaline magma, and it is the "contemporaneous", but not "bi-modal", evolutionary trends of these two magma series that provide constraints in understanding of deep magmatic processes beneath Tianchi Volcano. The magmatic genesis inferred from mineral compositions, trace element and isotopic data accords also with a dynamical model of upwelling mantle material, which may be related to the subduction of the western Pacific plate. Chapter 4 focuses on the physical processes related to the powerful explosive Millennium Eruption of Tianchi Volcano. This chapter contains the first published inferences of the depositional dynamics of the emplacement of various genetic types of the deposits from the Millennium Eruption, providing qualitative systematic parameters for the physical processes operating within the magma chamber and conduit system of Tianchi Volcano. At the end of the chapter, the results of a preliminary simulation experiment of the operative subsurface dynamic processes involving different magmas beneath Tianchi are presented.

Chapter 5 of this book mainly elaborates the structural and thermal characteristics of Tianchi's magma chamber and hydrothermal system. Here I first propose a general theoretical model of a magma body and enveloping hydrothermal system of an assumed size and configuration. Then I validate the model using seismological data and the geochemistry of the spring fluids. This model serves as a basis for assessing the volcanic hazards from possible future eruptions at the volcano, which is the focus of the next chapters of 6 and 7. The entire contents of chapter 6 describe potential hazardous surface processes at Tianchi. The processes of weathering, erosion, transportation, and deposition of fragments on the surface during the intermittent periods of eruption are first discussed. Then the timing and local, differing relief for the known lahars around Tianchi are discussed. By the end of this chapter, the consequences of a seiche originating in the caldera lake and the possible overflow processes along the Erdao river are considered.

Chapter 7 directly addresses the problems of potential volcanic hazards posed by Tianchi Volcano. Within the context of the eruptive history and present state of Tianchi, this chapter starts with the consideration of the main types of possible volcanic hazards, the impact areas and intensities of these hazards, treating the mechanisms of the "fire" and "water" hazards separately. After a preliminary description of the volcano-monitoring networks and past events of Tianchi Volcano, combined with volcano unrest in recent

decades, I discuss the present state and mechanism of the volcanic activity based on a constant rate model of magma replenishment. By the end of this chapter, I conclude that man should coexist with volcanoes. Regardless of the evolution of nature and mankind, or of the preservation of the culture and resources, or of reducing risk from volcanic hazards, I hope that Tianchi Volcano will get along with humankind in the 21 Century.

Some of the data and ideas contained in this book have their origin in the field and laboratory studies that I myself have conducted at Tianchi Volcano for the last two decades. However, in the process of composing this book, I have incorporated the contributions and ideas of many scientific colleagues, both abroad and at home. Moreover, it should be noted that the book includes important new data obtained from the continuing volcanological study projects, supported by the China Earthquake Administration (CEA). Although not explicitly mentioned in the book, I hope that readers of this volume will gain their own particular insights and interpretations from the information presented, to refine our understanding of the physical and chemical processes that govern Tianchi Volcano. Thus, for both spurring further scientific research or the development of strategies to reduce volcano risk, it is my wish that this book can be used as a "guide" by involved scientists, government officials, and the general public at risk.

Many people, organizations, and institutions have directly or indirectly contributed to the production of this book. First and foremost, I want to express my huge appreciation to Prof. Jin Bolu for his endless inspiration, enthusiastic support, and critical help during our collaborative studies of Tianchi Volcano. I am greatly indebted to my supervisors, Professors Sun Shanping and Li Jiazhen, for their invaluable tutoring me in my academic work, and beginning my volcanological training. Prof. Liu Ruoxin was instrumental in furthering my volcanological experience by providing me opportunities for systematic and professional work on the volcanoes of China. My grateful acknowledgements also go to the leaders in CEA for their support and encouragement over the years, particularly to the directors Li Ming, Wu Jianchun, Wu Shugui, Li Ke and Wu Weimin, and to the section chiefs Wang Fei, Chen Feng, Liu Guiping and Tian Liu. Without the steadfast trust and confidence placed in me by the CEA, conducting my research on Tianchi would have been much more difficult, perhaps impossible. I also sincerely thank the staff and my colleagues of the Institute of Geology of CEA for providing the cooperative and stimulating work environment under which I have been transforming scientific ideas into published research results. Thanks also go to my colleagues and friends of the Jilin Earthquake Administration, Geological Bureau of Jilin, and Tianchi Volcano Observatory for providing much appreciated assistance during my field work on the volcano.

Some notable colleagues and friends have made indirect but most important contributions to this book. I am particularly indebted to the late Prof. G. P. L. Walker—Great Britain's

internationally renowned volcanologist ("guru")—who tutored me in the field methods of mapping volcanic deposits and interpretations of their mode of emplacement. Also highly influential in shaping my volcanological experience was Prof. R. S. J. Sparks (University of Bristol), who secured me a visiting scholarship from the Royal Society, which enabled me to conduct volcanological work in a productive environment in a most excellent research center. I also gained much from interactions with two Chinese colleagues: the late famous Chinese geologist, Shenshu Sun, with whom I shared many unforgettable memories in doing science; and Prof. Ming Zhang, who in the late 1980s introduced me to a review paper "physical processes of volcanic eruption," which placed me on the road to volcanological research.

I also wish to express deep thanks to members of my family. When I was a child, my parents taught me to be honest and to do everything in earnest; their teachings have guided me well in pursuing my career and advocation to reducing risks from volcanic hazards. My wife, Ms. Zhu Shuyue, who has assumed most of the responsibilities and doing most of the work in running our household, has made it possible for me to focus heavily on my career. I dedicate this book to Zhu Shuyue for her unwavering support, help, and patience over the years. My son, who got his interesting employment, has been highly supportive and understanding while I worked on the book.

Finally, I wish to acknowledge the assistance of a number of colleagues that directly contributed to the publication of this volume. In particular, Prof. Jin Bolu read carefully and modified some of the key content of the relevant chapters, materially improving their presentation and clarity. Other colleagues who made specific contributions to various chapters of the book are listed below with thanks: Gao Ling, Jin Jinyu, Sun Chunqiang, Liu Qiang, Chen Xiaowen, Chen Zhengquan, Yang Qingfu, Pan Xiaodong, Liu Guoming and Liu Yongshun. I deeply appreciate all of these contributions. The contents of this book include some data and results of state volcanic research projects supported by CEA (95-11-03-02-01, 2001BA601B06-01-4, 2002DIA20009-20, 8-27-7) and from the Natural Science Foundation of China (49102020, 40172033, 41172304). Funding for actual publication came from the Union Foundation of CEA (506003). I am particularly grateful for the first financial support I received from NSFC in 1991, which allowed me to clearly frame the course of my subsequent and continuing research to the present. In closing, I want to emphasize that, while this volume highlights important advances in our understanding of the past and current activity of Tianchi Volcano, much remains to be learned. Nonetheless, this book, updated from a manuscript mostly completed by 2010, marks an important step forward.

Wei Haiquan

2010.11.12

目　录