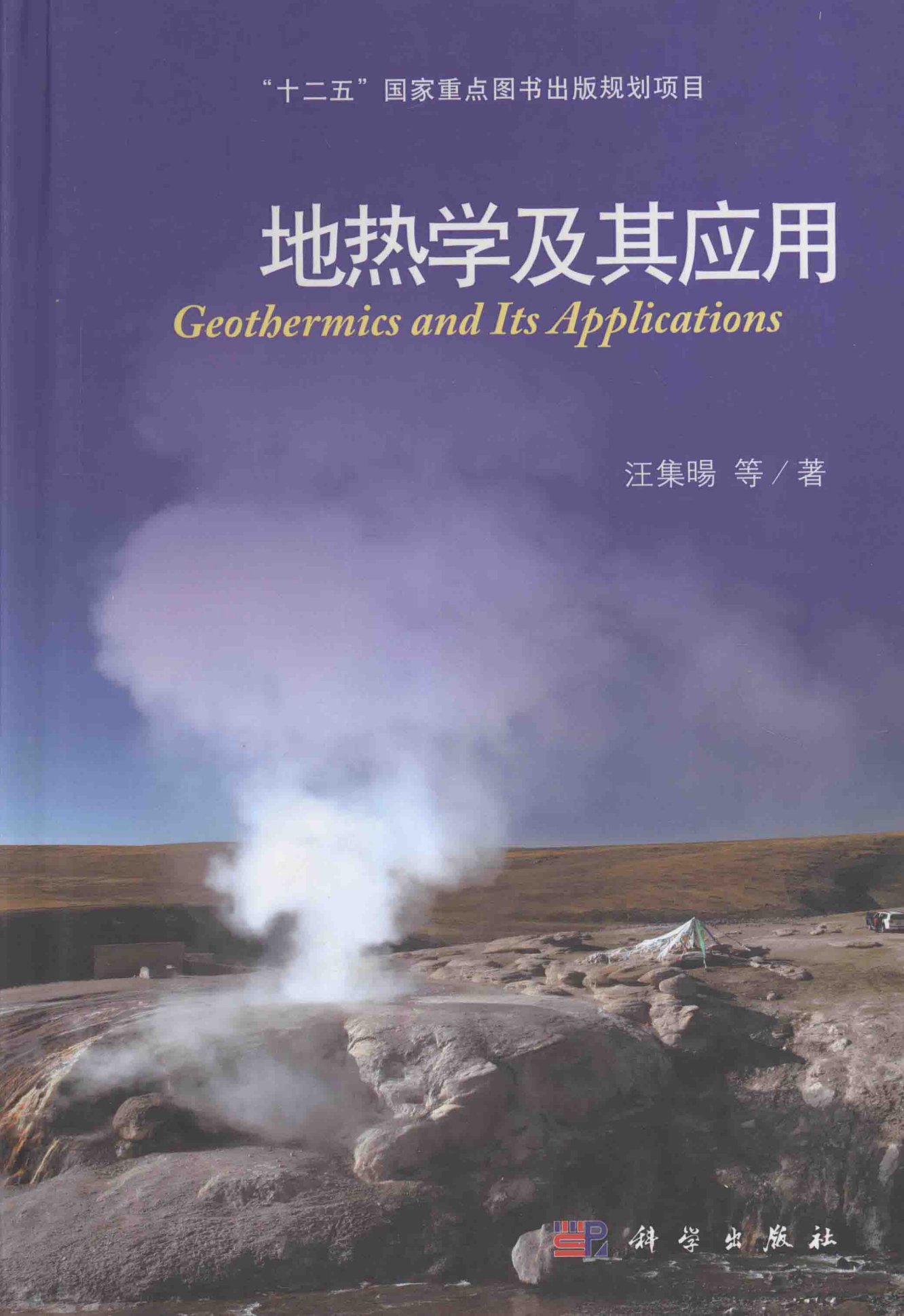
“十二五”国家重点图书出版规划项目

地热学及其应用

Geothermics and Its Applications

汪集暘 等／著



科学出版社

“十二五”国家重点图书出版规划项目

地热学及其应用

Geothermics and Its Applications

汪集暘 等／著

科学出版社
北京

内 容 简 介

本书是一部系统论述地热学理论及其实际应用的专著。全书分上、下两篇共11章，第1章全面介绍了地热学的学科定位与体系，回顾了其发展历程，展望了其未来趋势。第2章至第6章（上篇）是理论地热学部分，系统介绍地球内部热量的产生和传递、我国与全球大地热流分布、岩石圈热结构及其深部地球动力学含义等。第7章至第11章（下篇）是地热学应用部分，重点介绍地热学在地热资源开发利用、油气和天然气水合物资源勘探、矿山热害防治及全球变化研究等方面的应用。

本书由国内长期从事地热研究的核心团队集体撰写，资料翔实、论据充分，反映出中国地热学理论及应用研究的最新进展，可供地球科学、环境科学、能源科学等领域的科研人员、大专院校师生及地矿、能源、环保等产业的工程技术人员参考。

图书在版编目(CIP)数据

地热学及其应用＝Geothermics and Its Applications/汪集暘等著. —北京：科学出版社，2015. 9

（“十二五”国家重点图书出版规划项目）

ISBN 978-7-03-045734-9

Ⅰ. ①地… Ⅱ. ①汪… Ⅲ. ①地热学-研究 Ⅳ. ①P314

中国版本图书馆CIP数据核字(2015)第223324号

责任编辑：耿建业 吴凡洁 刘翠娜 万群霞 / 责任校对：张怡君

责任印制：肖 兴 / 封面设计：黄华斌

科学出版社出版

北京东黄城根北街16号

邮政编码：100717

http://www.sciencep.com

中国科学院印刷厂 印刷

科学出版社发行 各地新华书店经销

*

2015年9月第 一 版 开本：787×1092 1/16

2015年9月第一次印刷 印张：36 1/4

字数：812 000

定价：258.00元

（如有印装质量问题，我社负责调换）

各章撰写人员

第一章　汪集暘
Wang Jiyang

第二章　张　健　许鹤华
Zhang Jian, Xu Hehua

第三章　胡圣标　黄少鹏
Hu Shengbiao, Huang Shaopeng

第四章　施小斌　杨小秋　石红才　郭兴伟
Shi Xiaobin, Yang Xiaoqiu, Shi Hongcai, Guo Xingwei

第五章　刘绍文　黄少鹏
Liu Shaowen, Huang Shaopeng

第六章　赵　平　何丽娟　刘绍文　孙占学
Zhao Ping, He Lijuan, Liu Shaowen, Sun Zhanxue

第七章　庞忠和　胡圣标　王社教　徐佩芬　王光杰　杨峰田
Pang Zhonghe, Hu Shengbiao, Wang Shejiao, Xu Peifen, Wang Guangjie, Yang Fengtian

第八章　邱楠生　胡圣标　何丽娟
Qiu Nanseng, Hu Shengbiao, He Lijuan

第九章　何丽娟　金春爽　张　毅
He Lijuan, Jin Chunshuang, Zhang Yi

第十章　庞忠和　孙占学　段忠丰
Pang Zhonghe, Sun Zhanxue, Duan Zhongfeng

第十一章　黄少鹏
Huang Shaopeng

序　一

今年春节过后的一天，汪集暘来到我办公室，说他们正在写一本有关地热学的书，要我为之作序。汪集暘1956年毕业于北京地质学院（中国地质大学前身）水文地质工程地质系，号称“黄浦一期”。我1952年北京大学物理系毕业后即在北京地质学院地球物理探矿教研室任教，我虽然没有直接教授过水文工程地质系的学生，但学生却尊称我为“教官”，现在看到他们的进步也就欣然接受作序的邀请。

大家知道，“地球物理”，严格来说应该是“固体地球物理”，包括“重、磁、电、震、热和放射性”等六大分支学科。但纵观地球物理在国内外的发展，地热学应该说是较为缓慢的一支。这倒不是因为地热学不重要，而主要是作为地热学的基础，大地热流值的观测需要借助钻孔，以致受限制较多。若从1939年英国剑桥大学Bullard教授在南非金矿钻孔中成功测试并获得第一批陆上大地热流数据算起，以具有实际观测数据为基础的“地热学”也只有短短75年的历史。

我国地学界前辈对地热研究十分重视。早在20世纪50年代，李四光教授就在他的地质力学研究所内组建起国内第一个地热研究组，并派人专门去苏联莫斯科大学留比莫娃教授处学地热。同时在京郊房山花岗岩体上打了一个500m深的钻孔测量地热，获得地温梯度数据。与此同时，中国科学院地质研究所张文佑所长在他的构造地质研究室内也组建起一个地热研究组，从事地热研究。但由于缺乏实测的岩石热导率参数，始终未能得到高质量的大地热流数据。直到70年代初，地热作为新能源和可再生能源的需求日益突出，李四光教授提出“向地球要热”的号召后，地热研究才真正“热”起来。汪集暘等也正是在这个时候开始了我国系统的地热研究，经过近10年的努力，他们一方面结合各项实际工作任务，利用自己组装的半导体测温仪进行大量的钻孔地温测量，取得一大批实测地温梯度数据。同时他们又狠抓实验室建设，先后研制成HY-1型和地热-Ⅱ型稳态和非稳态岩石热导仪，在测温钻孔中取样进行岩石热导率测定。经过严格筛选和评定，并按照“国际热流委员会（International Heat Flow Commission，IHFC）”制定的标准获取了一批高质量的大地热流数据，这批数据发表在1979年创刊的《地震学报》首卷首期上，并作为开篇文章刊出。这批数据不但填补了国内理论地热研究的空白，同时也得到了国际热流委员会的认可和高度重视，随后即收入《全球热流数据》汇编之中。这里面还有一段小插曲：本来这批数据和文章是放在傅老（承义）任主编的《地球物理学报》上的，傅老亲自修改了该文的英文摘要，使原来许多“Chinglish”的句子改为真正的“English”。该文后来被顾老（功叙）看到，非要将它放到顾老任主编的《地震学报》上去，从中也可看出我国地球物理学界两位泰斗级元老对地热学的重视和对非地球物理专业出身的后生的厚爱。

在以后三十多年的岁月中，汪集暘这支团队的研究工作取得了很大进展：第一，研究领域扩大了，从最初的大地热流测试到岩石圈结构、地壳上地幔热状态以至海、陆和全球热场的分析；第二，应用范围增多了，从地热资源的开发利用、矿山热害防治到含油气盆地

热体质、热历史，天然气水合物形成与分布的地热背景，以及利用钻孔测温资料反演过去几个世纪的气温变化，为全球变化与环境演变提供地热学证据；第三，研究方法、手段更强，除传统的地质、地球物理手段外，他们在20世纪80年代初已将有限元方法应用到地热研究之中。在含油气盆地热历史研究中，他们还改进和发展了Mckenzie在1978年提出的拉张盆地热演化模型，在最近承担的中国石油化工集团公司前瞻性研究项目“中国陆域海相沉积盆地热体制与油气资源”中还研发出了前陆盆地热演化模型，取得了很好的效果。可以毫不夸张地说，中国地热研究已跻身国际地热研究先进行列。而该书可以说是汪集暘这个团队耗时数十载、经历两代人研究工作的结晶，值得一读。

是为序。

2014年6月

Foreword One

Prof. Wang Jiyang is among the first carders of geoscientists educated in China, who graduated from the Department of Hydrogeology and Engineering Geology, Beijing Geological Institute (now China University of Geosciences) in 1956, where I used to teach geophysical explorations for mineral resources. I have been called tutor generally by the then students including those specialized in hydrology, among whom, Prof. Wang, even though I had not taught them classes. I am pleased to write this foreword because it is from one of the early members in our alumni.

As we all know that, geophysics, and that of the solid earth in particular, is composed of six subjects that address gravity, magnetism, electricity, heat and radiation of the earth jointly. As compared to other subjects, geothermics is relatively lagged behind in its progress. This is not because it is less important, but due to the fact that geothermal measurements require deep boreholes, which has somehow limited its growth. If we take the year 1939, when the first batch of terrestrial heat flow values were published by Prof. Bullard of Cambridge as the beginning of theoretical geothermics based on field measurements, it has existed only 75 years.

Pioneers of geosciences in China have always emphasized the significance of geothermics. As early as 1950s, Prof. Li Siguang (J. G. Lee) formed the first geothermal research group in China within the Institute of Geomechanics, Chinese Academy of Geological Sciences. He also sent young scholars to study geothermics with Prof. Lubimova in the former USSR. In the mean time, they drilled a borehole of 500m deep, in the granite body in Fangshan of suburban Beijing, to measure down-hole temperature. About the same time, Prof. Zhang Wenyou, then director of Institute of Geology, Chinese Academy of Sciences, also established a geothermal research group within the Division of Structural Geology in his institute. However, no heat flow values could be obtained due to the lack of thermal conductivity measurements on rock samples. Geothermal study was not a hot topic until the beginning of 1970s, when geothermal energy was emphasized as one kind of renewable energy resources and Prof. Li timely launched "Heat from the Earth"campaign. It was from that time that Prof. Wang Jiyang and his colleagues began to carry out geothermal studies in a comprehensive manner. After efforts of about a decade, they obtained a large amount of down-hole temperature measurements through various geological and mining projects in the country. In the mean time, they focused on laboratory construction and established thermal conductivity measurement apparatuses including HY-Ⅰ, Geothermal-Ⅱ types that could measure

thermal conductivity in steady or non-steady state. They measured thermal conductivity of cores from boreholes with down-hole temperature data. After careful screening and assessment according to the standard procedures set up by the International Heat Flow Commission (IHFC), they obtained the first set of terrestrial heat flow values in China and published them in the first issue of *Acta Seismologica Sinica*. The publication of this batch of heat flow data has not only marked the birth of theoretical geothermal science in China, but also informed the international geothermal community of its existence. Consequently they were later on included in the Global Heat Flow Compilation by IHFC.

There is a story to tell about this batch of heat flow data. The paper was first submitted to the *Chinese Journal of Geophysics* and Prof. Fu Chenyi, the then editor-chief of the journal had already commented it and corrected the non standard expressions-Chinglish in its English abstract. Prof. Gu Gongxu, founding editor of the Chinese *Acta Seismologica Sinica*, realizing the existence of this manuscript, insisted on publishing its in "his" journal! It is quite obvious that the two top-level geophysicists in China both paid special attention to geothermics and both offered fair treatment of research work of young people from a non-geophysical background.

I am pleased to note that Prof. Wang Jiyang and his team of geothermal researchers have made remarkable progress in the past 30 years. Firstly, the scope of research has been expanded to include thermal structure of lithosphere, thermal regime of the crust and upper mantle, and further to the inter-comparison of continental versus oceanic geotemperature fields in global scale. Secondly, the applications of geothermics have been broadened to include not only geothermal resources and geothermal hazards in deep coal mines, but also oil and gases as well as paleo-global change. Thirdly, methodologies have been improved from conventional geological and geophysical ones to include finite element modeling (back in the 1980s). In basin research, they revised the thermal evolution model of pull-apart basins first proposed by Mckenzie in 1978. More recently, they have established a thermal evolution model that is applicable to foreland basins. It is no doubt that Prof. Wang and his team have become one of the leading research groups in the international geothermal community nowadays. This book in front of you is composed of highlights of key geothermal research achievements of two generations of geothermal scientists in China in the past several decades. It is worthy to read this book timely.

June, 2014

序　二

“地热学”是地学中的一门基础学科，又具有很强的应用性。我国地学界老前辈，无论是地质界的李四光、黄汲清、张文佑、涂光炽、李春煜、叶连俊、刘东生、马杏垣、陈国达等院士前辈，以及地球物理学界的顾功叙、傅承义等院士前辈，都曾大力提倡和推动地热学在我国的发展。早在20世纪50年代，李四光先生在他的地质力学所内组建起我国第一个地热研究组，并派人去苏联专门学习理论地热。张文佑教授在60年代初亦在中国科学院地质研究所构造地质研究室中设有地热组。他认为“重力”和“热力”是地球生成、发展、演化的基本动力。随着70年代初国际石油危机的出现，新能源和可再生能源的开发利用已成为一股世界潮流。地热是地球的“本土”能源，具有很大的优越性，因此世界各国对开发利用地热资源十分重视，我国李四光教授也大力提倡开发利用地热资源。汪集暘等也就是在此时开始了我国系统的地热研究工作，并于1978年在中国科学院地质研究所内正式成立了地热研究室，该室主要研究全球与区域地温场、大地热流、地壳-上地幔热状态、岩石圈热结构以至地球热状态、热历史等地热基础理论。同时研究地热资源形成条件、分布规律，矿区深部地温预测与矿山热害防治、含油气沉积盆地热历史、热演化、天然气水合物形成与分布的地热背景以及地热与全球变化等诸多实际应用问题。经过近四十年的努力，汪集暘和他所在的研究集体在上述各方面都取得了不少创新性的成果，呈现在读者面前的这本专著，可以说是该团队两代人在地热研究上的结晶。

从当今正在蓬勃兴起的地球系统科学角度看，可以说地热学既“链接圈层”，又“穿越时空”。众所周知，从20世纪80年代开始，国际地学界逐步意识到必须将地球作为一个整体，将大气圈、水圈、生物圈、岩石圈以至深部核幔作为一个系统联系起来加以研究，才能解决地学的诸多重大理论问题以及解决诸如全球变化、全球碳循环等诸多实际问题。地球系统科学的核心是将地球各圈层加以“链接”，观察其相互作用和影响。而在时间尺度上可从现今扩展到地球形成早期乃至整个太阳系类地行星形成时期，即所谓“穿越”时空。地热学由于其研究对象的广泛性和解决实际应用问题的现实性，同地球系统科学两大核心研究内容紧密相连。举例来说，该专著基础篇既谈到地球内热的起源、演化，又涉及地球内部的热传递，并与其他类地行星诸如月球、水星、金星、火星的内热进行了比较。既阐述地壳、上地幔热状态，又剖析岩石圈热结构以至产生于核-幔边界的地幔热柱等。应用篇含油气盆地地热研究主要谈的是古地温、沉积盆地热历史和热演化，也讨论了利用地温资料反演气候变化。总之，该专著的研究内容和方法体现了地球系统科学理论，这在国内外地学研究中均不多见。

我同汪集暘院士从中国科学院原地址研究所时期就是老同事，作为当时的所领导，同时也见证了地热研究室的成立与发展。而今我欣喜地看到，当时由不同专业（构造地质、岩矿、水文工程地质……）组建起来的这支所谓“热一代”团队，在完成自身工作的同时，已培养出一批在我国从事理论和应用地热研究的“热二代”。正如“前言”中所说，该专著主

要由“热二代”撰写完成，这说明我国的地热事业正欣欣向荣，后继有人。

这部凝聚两代地热人成果的专著将在 2015 年出版问世，届时恰逢汪集暘院士 80 大寿之年。汪集暘院士是著名地热学家，他致力于科学发展和服务国家社会经济建设并作出卓越成就，我谨借此机会向他表示衷心祝福！

孙枢

2014 年 6 月

Foreword Two

Geothermics is a fundamental science but finds many areas of applications in the mean time. Well known geoscientists in China have always promoted the development of geothermics. In the 1950s, the first geothermal research group was established in the Institute of Geomechanics by Prof. Li Siguang(J. G. Lee), who also sent scholars to study geothermics in the former USSR. Prof. Zhang Wenyou formed a geothermal research group in his division of Structural Geology at the Institute of Geology, Chinese Academy of Sciences, back in the 1960s. He considered that "gravity" and "heat" are the basic driving forces for the development and evolution of the Earth. During the global oil crisis in the early 1970's it was a booming worldwide to develop new and renewable energy resources including geotherm. It is obvious that geothermal energy is an indigenous energy resource with many advantages. It is emphasized by most national governments. Late Prof. Li Siguang was a strong promoter of geothermal energy. Prof. Wang Jiyang and his colleagues began to study geothermal energy and formed a Geothermal Research Division at the Institute of Geology in 1978. The division focused its efforts on basic research on geo-temperature fields at the global and regional scales, terrestrial heat flow measurements, thermal regime of crust-upper mantle, thermal structure of the lithosphere as well as the thermal regime and thermal history of the Earth. In the mean time, it has engaged in applied research on various practical subjects such as geothermal resources exploration, geo-temperature field and geothermal hazards prevention in deep coal mines, thermal history and evolution of oil and gas basins, geothermal background for methane hydrates, paleo-climate reconstruction from borehole temperature. With the efforts of nearly 40 years, Prof. Wang and his team have made a series of achievements and the book in front of us, summaries the key results of research by two generations of geothermal scientists in China.

Viewed from the emerging earth system science, geothermics not only links spheres, but also connects time and space. It is well-known that, since the 1980s, the international geo-scientific community realized that it is necessary to study the earth as an integral system, including atmosphere, hydrosphere, biosphere, lithosphere and even the mantle and core. Only in this way, key geo-scientific issues like global climate change, global carbon cycle can be resolved. The key of earth system science is to collectively consider the different spheres of the earth and to observe interactions among them. With respect to time scale, it is necessary to expand the study from present day processes to early stages of earth, or further to the origin and evolution of planets in the

whole solar system. It is so-called "connecting time and space". Geothermics is closely related to the two key scientific issues of earth system science, due to its extensive scope of research and practical nature of applications. Taking this book as an example, it deals not only with the origin and evolution of the Earth's heat, but also covers heat transfer in the Earth's interior, with a comparison of it with other planets such as Mercury, Venus and Mars. It discusses not only the thermal regime of the crust and upper mantle, but also the thermal structure of the lithosphere, including mantle plume originated from the boundary between the core and the mantle. In the application aspects, it has not only a good coverage of paleo-geotemperature, thermal history and evolution of sedimentary basins, but also includes reconstruction of paleo-climate using geotemperature data. The scope and approaches of this book reflect the concepts of earth systems science, which is not so common in international geo-scientific studies.

I have been a colleague of Prof. Wang for many years. As former director of the Institute of Geology, Chinese Academy of Sciences, I witnessed the birth and growth of the Geothermal Research Division. Today they have not only achieved scientific results, but also educated the second generation of geothermal researchers. As is indicated in the preface, the book chapters have been written mainly by the second generation of geothermal researchers, which shows a very positive sign of continuation of geothermal research in this country.

On the occasion of the publication of this book, I would like to congratulate Prof. Wang on his eightieth birthday. Prof. Wang is a famous geothermal scientist, who has made outstanding contributions not only to the pure-science geothermal research, but also to the economic development of our country through applied research in geothermics.

June, 2014

前　言

很早就想写一本有关地热学方面的书。这是因为：第一，地热学在地球科学中既是一门基础学科，又是一门交叉学科，它涵盖地质、地球物理、地球化学诸多学科领域。第二，纵观国内外，迄今为止尚没有一本既清晰阐述理论地热学的研究方向、研究内容、研究方法、研究手段，又将地热学的应用部分集中起来进行展示的专著。从所见到并已出版的文献来看，要么过于简单，许多问题未阐述清楚，以至国内地热界出现将“温度”等同于“热量”的基本概念错误！要么过于零碎、烦琐，写得太啰嗦，书中引用的实例也大多为“洋货”，不接“中国地气”。第三，随着整个地球科学的发展和国民经济需求的增长，地热学的研究内容和对象也在不断更新、变化、扩展。譬如应用地热学中，过去矿山和油田地热是两大块，随着能源和环境问题日益突出，新能源和可再生能源的开发、利用正受到国际能源界和各国政府的高度重视，作为地球“本土”能源的地热资源的开发利用也不例外，正在飞速发展。又如，作为“21 世纪新型能源”的甲烷天然气水合物的探寻、勘查，也离不开温度和压力两个基本参数，因此以天然气水合物为对象的地热研究也就应运而生。理论地热学方面，随着地球系统科学的兴起和不断成熟，最近国际科学理事会（International Council for Science，ICSU）制订出“未来地球”计划，旨在联合各国科学家共同面对并更好地解决人类当前所面临的资源、能源、灾害、环境问题，这里更是有许多理论地热学方面的问题需要解决。

正因为如此，撰写一本地热学专著的想法近年来就更强烈了。但是由于种种原因，上述想法始终未能实现。直到两三年前，20 世纪 50 年代毕业的师兄、师姐先后步入“80 后”阶段，有不少弟子为他们办了 80 大寿，于是我的“热二代”弟子也纷纷提出要为我作 80 大寿的想法。经过再三思考，我跟他们说：80 大寿就不作了，但我们能否写一本地热学方面的专著，一方面将我们这个研究集体两代人的研究成果进行集中总结和展示；另一方面也算实现了我的上述心愿。同时，我还跟我的弟子约定，这本专著以“热二代”为主来写，我只写“前言”和“绪论”。因此本专著也可当做是对我 80 大寿的庆贺和一件珍贵的礼物。经过我这么一说和解释，他们也都同意并欣然接受。于是我们一次次开会讨论，不断修改书名和各章、节编写大纲，最后决定定名为“地热学及其应用”。这里需要加以说明的是，我的弟子目前可以说都是国内地热界的中坚力量，有的还是国际地热学界的领军人物，平时他们的工作都很忙，但他们还是抽出大量的时间和精力来完成这本专著，令我十分感动。

本专著分上、下两篇共计 11 章，上篇基础篇为理论地热学，从热传导基本概念说起，直到地球内热、海陆大地热流、全球热场分布和岩石圈热结构，基本涵盖了理论地热学的全部内容。下篇应用篇为应用地热学，包括资源地热学、含油气盆地地热学、矿山地热学、全球变化地热学和天然气水合物地热学五大部分。其实这五个部分每一个都可成为一本专著，但限于篇幅和本书目的，只能择其最精华之点在此展示一下。前面已经说过，“热二

代”现在都是教授、博导，同时又承担着各项国家任务并战斗在科研第一线，因此他们所撰写的各章内容应该能反映地热学当今研究的前沿和热点问题。另外要再说明的一点是，各章之间有些内容不免有些重复，有些词条如“大地热流”的定义也许在不同章节中多处给出，但基本概念只有一个，不会出错！

作为本书第一作者，本应负责全书统稿，但限于时间和精力，我只做到了通读全部书稿，并提出修改意见，然后各章作者自行修改完成，最后相互传阅、校核，以期书稿精益求精，少出差错。

最后，我还想借此机会向刘光鼎、孙枢两位院士表示深切的感谢。前者是我大学时的老师和原中国科学院地球物理研究所所长，后者是我的学长和原中国科学院地质研究所的老领导，他们为本书作“序”既是对本书的肯定，同时也为本书增色不少。

本来应该到此为止，但有一点不得不做以下说明：即我的名字中的“暘”字，有的参考文献中写成“旸”，“旸”乃是“暘”的简写，为尊重原文，两者皆保留，特此说明并请读者见谅！

汪集暘

2014 年 5 月

Preface

It is my strong desire to write a monograph on Geothermics for many years. This is because that: firstly, it is understood that geothermis is not only a basic discipline in geosciences, but also an intersected one in geosciences. Secondly, there is no such a monograph neither at home nor abroad so far describing not only theoretical part of geothermics but also applied ones. From the existed monograph on geothermics it is obvious that the content seems to be either over-simplified, or over-loaded. Furthermore, the basic definition sometimes is not clearly given. For instance, they could not distinguish the term "heat" and "temperature". And hence, the term "geo-temperature energy" appeared in Chinese literature instead of "geothermal energy". In fact, "heat" is energy but "temperature", only a measure of heat energy. Thirdly, with the development of science and technology, the content of geothermics is changing with time too. For example, the geothermal studies for methane gas hydrate are a newly emerged discipline in applied geothermics. And many new subjects in theoretical geothermics are appeared with the rapid development of "Earth System" and "Future Earth" sciences.

I was born in 1935 and next year, I would step into 80 years old. According to Chinese tradition, there should be a celebration for this big event. However, owing to the situation nowadays, I told to my exPhD students that it is not necessary to hold such a formal celebration ceremony and instead of that, we would write a book to memorize it. All my exPhD students agreed to and supported my idea and started to work on this monograph entitled "Geothermics with Its Application" early this year.

The Monograph is divided into two sections with 11 chapters in total. The first section with 5 chapters is devoted to theoretical geothermis and the second section, applied geothermics. In the first section, the basic conception of internal heat of the Earth and the definition of the heat transfer were given (Chapter 2), followed by terrestrial heat flow in continental area of China (Chapter 3) and in marine area (Chapter 4). Chapter 5 is given to global heat flow and Chapter 6, thermal structure of the lithosphere. In the second section, geothermal resources were conducted (Chapter 7), and geothermics of oil-gas bearing basins (Chapter 8), geothermics of methane gas hydrates (Chapter 9), geothermics of mining areas (Chapter 10) plus geothermics of global change (Chapter 11) were described respectively.

It must be pointed out that the most authors of the monograph are my exPhD students and/or former post-doctorates. At present, they are the core members in geothermal community both at home and abroad and carrying out various key R&D projects

in geothermics. It is no doubt that the results of their scientific activity are included in each chapter and the authors are responsible for the contents.

Finally, I would like to thank to Profs. Liu Guangding and Sun Shu, both of them generously gave their preface to this monograph.

Wang Jiyang

May, 2014 in Beijing

目　录

上篇　基　础　篇