

地质力学的方法与实践

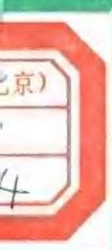
第四篇(下)

# 现今地壳运动问题

马宗晋 杜品仁 编著



地质出版社



国家自然科学基金联合资助

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### 第四篇（下）

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· 北京 ·

## 内 容 提 要

本书以李四光的地质力学理论和方法为指导,从全球角度论述了现今地壳运动问题。书中强调现今地壳运动主要是研究地壳和地球的微动态、微韵律和非平稳变化;并将全球现今还在活动的构造划分为环太平洋、大洋脊和北大陆三大构造系统,分别论述了它们的运动学和动力学特征;探讨了现今地壳运动的微动态变化和动力来源问题。本书可供从事地震地质、大地构造、地球动力学和灾害学研究的科研人员及大专院校师生参考。

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# 序

与地质力学密切相关的第一篇文章“地球表面形象变迁之主因”发表于1926年。构造型式和构造体系的概念是在本世纪20年代末期提出的(Lee, 1929)。结合中国大陆及东亚地区的地质实际,根据地球表面实际见到的不同型式的构造体系来论断地壳运动的,是1939年出版的《中国地质学》(英文版)一书。地质力学作为一门学科是1941年秋冬之际,李四光教授应厦门大学校长萨本栋教授之邀为该校数学力学和物理系(当时由于抗战该校迁至福建长汀)的同学讲演时提出的。之后,李先生开始写《地质力学之基础与方法》,并于1945年完稿。该书稿曾由重庆大学地质系油印,当时,在重庆的中国地质学会同仁还举行过多次学术报告会。该书于1947年春由中华书局正式出版。

1949年10月1日中华人民共和国成立后,为了适应国家经济建设需要,开展了大量地质工作,包括矿产勘探、工程地质、水文地质以及国家建设中出现的其他各种地质问题。地质力学在李四光教授亲自领导和参与下投入到国家建设洪流之中,与其他地质科学一样取得了迅速的进展。60年代初,内部出版了《地质力学概论》。1970年,内部刊印了《天文、地质、古生物资料摘要(初稿)》一书。上述两本书均由李先生亲自执笔。书中不少的地质实际资料是由各方面的地质工作者提供的。

李四光教授在他早年和晚年的著作中均曾提出过:地质力学的主要目的是研究地壳构造和地壳运动的规律,探索地球运动的起源;研究各种矿产在地壳中的分布规律以及现代地壳运动的程式,借以指导矿产资源预测以及地壳稳定性评价,防治可能发生的各种自然灾害。

李四光教授在其遗著中曾提示我们:研究地球科学,要从地球看宇宙,要以事物的生因、发展和系统联系的观点,从事实现象追寻本质的要求,来研究地壳运动所产生的各种地质现象发生、发展的规律。

从李四光教授1926年发表第一篇文章起至1971年4月底他逝世这45年间,他为地质力学学科的建立及应用,做了大量的实际工作,开辟了地壳运动研究的一条新途径,为发展地球科学作出了重要贡献。从李四光教授逝世到现在,许多地质工作者沿着他开拓的道路又进行了21年的工作。从1926年到现在这66年间,在国家经济建设和人类社会生活需要的各种自然资源的寻找以及与人类生存相关的各种自然灾害的斗争中,地质力学伴随其他地球科学做了大量的有益工作。《地质力学的方法与实践》丛书,就是这项工作的一种记录。今后,我们将把这项工作继续下去,为认识自然和改造自然作出新的贡献。

孙殿卿

1994年11月14日,北京

# PREFACE

The first paper closely related to geomechanics entitled the "Main Cause of the Changes of Superficial Features on the Earth" was published in 1926. As for the conception about the tectonic patterns and tectonic systems, it was put forth at the end of the twentieth century (Lee, 1929). It was in the book entitled the "Geology of China" (in English version) published in 1939 that the crustal movement had been proved by the author with the tectonic systems of different types actually found on the surface of the Earth, and in combination of the practical geological situation in the mainland of China and East Asia. Geomechanics as a branch of sciences was established in the autumn and winter time of 1941 by Prof. Li Siguang (J. S. Lee) during his lecturing for the students from the Department of Mathematics, Mechanics and Physics of the Xiamen University (moved to Changding City, Fujian Province owing to the anti-Japanese War) at the invitation of the Dean of the University. Later on Prof. J. S. Lee began to prepare the book on "The Basis of Geomechanics and Its Method", which was completed and was mimeographed by the Department of the Geology of the Chongqing University, Sichuan Province in 1945, and at the same time it was then once used as lectures for the colleagues of the Geological Society of China at Chongqing City. The particular monograph was officially published by the China Publishing House in the spring of 1947.

Since the founding of the People's Republic of China on October 1, 1949, in order to meet the need of the economic construction of the country vast amounts of geological work have been conducted, including prospecting for mineral resources, engineering geology, hydrogeology and various geological problems that have been occurred during the economic construction of the country. So geomechanics has been thrown into the mighty torrent of the economic construction of the country under the direct guidance of Prof. J. S. Lee himself and his personally taking part in the work, and as other branches of geological sciences, geomechanics in this way has also gained a rapid development. At the beginning of the 60's of this century the monograph: "An Introduction to Geomechanics" was published as a restricted publication, and in 1970 the monograph: "Astronomy, Geology and Palaeontology" (first draft) was also published as a restricted publication. All the above-mentioned monographs were written by Prof. J. S. Lee himself personally, by using a big amount of practical geological data provided by vast numbers of geological workers from various fields.

In his works published in his early and late years, Prof. J. S. Lee had repeatedly remarked that the major objective of geomechanics lies in the study of the regularity of crustal tectonics and crustal movement, in probing into the origin of the movement of the Earth, and in investigation on the regularity of distribution of various mineral resources in the earth crust, as well as on the mode of occurrence of the modern crustal movement, with the purpose of gui-

ding the prognostication of mineral resources and making the evaluation of the stability of the earth crust, thus preventing from the possible occurrence of these and those natural hazards.

In his posthumous works, Prof. J. S. Lee used to mention to the audience that in the study of geological sciences one must view the cosmos from the Earth and investigate the regularity of occurrence and development of various geological phenomena produced by the crustal movement from the viewpoint of the origin, development and systematic relations, and in accordance with the requirement of study on any matter by probing into the essence of things judging from the phenomena of the fact.

During the forty five years of his life, starting the publication of his first paper in 1926, and being ended with his death at the end of April in 1971, Prof. J. S. Lee had completed large amounts of practical work for the establishment and application of geomechanics as a branch of sciences, and had opened up a new approach to the study of the crustal movement, thus making a great contribution to the development of geological sciences. From the time of his passing away till the present, many geological workers have conducted great amounts of work for twenty one years along the path Prof. J. S. Lee had opened up. In the 66 years from 1926 till now, in the prospecting for natural resources needed for the economic construction of the country and social daily necessities of human beings, as well as in the struggle against various natural hazards that are closely related to the existence of human beings, together with other branches of sciences geomechanics has done a lot of useful things. The "Method and Practice of Geomechanics" series represents itself records of this kinds of work. In the future we will certainly keep taking this kind of records in order to make a new contribution to recognition and remaking of nature.

Sun Dianqing

November 14, 1994, in Beijing



# 引 言

地球科学界正热烈地通过各种不同的途径研究岩石圈和全球动力学。地质力学工作者也积极地按照自己多年来形成的途径,即将地质学、地球物理学、地球化学和力学等多种学科结合起来,通过对地壳地质构造和地壳运动的研究,以深化地球动力学和运动学的研究。

因为,地壳虽然是地球整体结构中极薄的一层,但她却记录和保存下了地球形成、发展、演化的踪迹;记录和保存下了地壳以外,诸如包围地球的大气层,围绕地球转动的月球,太阳系,以及其它各种星体对地壳发生的影响,宇宙微尘和陨星之类的的坠落等(星)球外事件的遗迹;记录和保存下了地壳以下,在高温高压条件下,地球各圈层物质的物理与化学变化和运动,以及由重力、日月潮汐作用和地球自转而产生的运动,都不可避免地要集中反映到地壳中来。

由此看来,如果其它研究地球动力学途径是科学的、有成效的,那么,地质力学以地壳为对象,通过对地壳地质构造、物质的运动和分布规律、地壳运动的起源和演化等的研究,由表及里、由浅及深、由局部到地球整体,深入地研究地球各圈层的组织构造、相互作用,地球的起源、演化和运动等一系列地球动力学和运动学问题,是不无道理的。

为此,地质力学工作者经过了长期的奋斗,在她自己的努力和各相关学科、广大科学工作者的支持下,做了大量的工作,取得了很多、很有意义的成果。经常地、及时地综合分析研究、总结这些成果,不仅对发展地质力学具有重要意义,对于发展地球科学,促进地质力学更好地为社会发展和国民经济建设服务,也不会没有意义的。地质矿产部和中国地质科学院将《地质力学的方法与实践》列为“八五”重要基础研究项目,在孙殿卿院士指导下予以实施。

早在60年代初,地质力学的创始人李四光教授就计划组织人力,编著一套《地质力学的方法与实践》丛书,总结地质力学研究和实践成果。为此,他亲自草拟大纲,并将他自己主持撰写的《地质力学概论》专著做为该丛书的第一篇。其后,他还提出了对《地质力学概论》进行修改的意见。

这次的综合研究和总结工作,就是实现李四光教授的遗愿,修订第一篇,编著四篇六本书和一幅全球构造图,即:

**第一篇** 地质力学概论 李四光著,孙殿卿、邓乃恭修订

**第二篇** 构造体系各论(中国典型构造体系分论) 王治顺等编著

**第三篇** 岩石力学与构造应力场分析 陈庆宣等编著

**第四篇** 地壳运动问题 高庆华等编著

现今地壳运动问题 马宗晋、杜品仁编著

**第五篇** 地质力学在区域地质调查和矿产资源勘查中的应用 刘迅等编著

地质力学在水文地质、工程地质和环境地质方面的应用 邹云惠等编著

全球构造体系纲要图 宁崇质等主编

《地质力学的方法与实践》既然是在广大地质力学工作者和有关学科科学工作者科学研究与实践应用成果基础上，经过综合分析研究、总结完成的一套丛书，无疑也是大家劳动成果的结晶。因此，除《地质力学概论》一书外，其它各篇册我们都用了“编著”一词，表示这一套书中还包含了他人的成果，并在此予以致谢。如果有什么疏漏和引用上的误解，也请予以批评指正。

《地质力学的方法与实践》编辑委员会



# INTRODUCTION

The geosciences circles have now been heartily investigating the lithosphere and global dynamics in different ways. Meanwhile, the geomechanic workers have also actively deepened their investigations on the dynamics and kinematics of the Earth in a way created by themselves in the passing years, namely by combining the geology, geophysics, geochemistry and mechanics with one another, and through the study of geological structures on the earth crust and crustal movement.

So although the earth crust tends to constitute only a thin layer in the whole texture of the Earth, yet it has recorded and preserved all the features formed in the course of origin, development and evolution of the Earth; the results of the influence from the atmosphere surrounding the Earth, the moon rotating around the Earth, solar system, and the other celestial bodies upon the earth crust; as well as the traces of the outer-space events, such as the fall of the cosmic dust and meteorites. Besides, in the earth crust there must have undoubtedly been recorded and preserved in a concentrated way all the expression, under high temperature and pressure, of physical and chemical changes and motion of matter in the litho-, hydro-, air-, and bio-spheres of the Earth.

In view of this, if the other approaches of the study of geodynamics are considered to be scientific and effective, then the geomechanics with the earth crust being as its target of research should also be valid and reasonable, since it keeps to the principle of going deep into the study of geodynamic and kinematic problems concerning the structure and texture of the litho-, hydro-, air-, and bio-spheres of the Earth, mutual actions of the later, as well as the origin, evolution and motion of the Earth in a way proceeding from the outside to the inside, from the simple to the profound, and from the part to the totality through the study of the geological structures of the earth crust, the motion and regularity of distribution of matter in the earth crust, and the origin and evolution of the crustal movement.

For this reason, the geomechanical workers have conducted a great volume of work and have gained lots of meaningful results through their protracted struggle, and with their own effort and under the support of the interrelated branches of sciences and vast numbers of scientists. The frequent and timely comprehensive analysis and summation of these achievements and results are of great importance not only to the development of geomechanics, but also to the development of the whole geological sciences themselves and to promoting geomechanics to provide a better service for social development and national economic construction. With the support from the Ministry of Geology and Mineral Resources and the Chinese Academy of Geological Sciences, the publication of the "Method and Practice of Geomechanics" series has been placed in the "Eighth Five-Year Plan of the Development of Natural Sciences" as an important project of basic researches to be implemented under the guidance of Academician Sun Dianqing.

As early as at the beginning of the 60's of this century, Prof. J. S. Lee, the founder of geomechanics used to plan to organize labour power to compile a set of the "Method and Practice of Geomechanics" series, aiming at the summation of the achievements and results of the research and practice of application of geomechanics. For this purpose, Prof. J. S. Lee personally took a hand in drafting an outline for the particular series, and decided to take the monograph of his "An Introduction to Geomechanics" as the first volume of this series. Later on, Prof. J. S. Lee made comments on the revision of the monograph "An Introduction to Geomechanics".

The present comprehensive research and summation is exactly the implementation of the behests of Prof. J. S. Lee, modifying the first volume and compiling six books of four volumes and a sheet of Global Tectonic Map, namely:

Volume I, An Introduction to Geomechanics, by J. S. Lee, modified by Sun Dianqing and Deng Naigong;

Volume II, Separate Treatises on Tectonic Systems (Individual papers on typical tectonic systems of China, by Wang Zhishun and others);

Volume III, Analysis of Petromechanics and Stress Field of Tectonics, by Chen Qingxuan and others;

Volume IV, The Problems on Crustal Movement, by Gao Qinghua and other;  
The Problems on Recent Crustal Movement, by Ma Zongjin and Du Pinren;

Volume V, Application of Geomechanics in Regional Geological Survey and Prospecting for Mineral Resources, by Liu Xun and others;

Application of Geomechanics in Hydrogeology, Engineering Geology and Environmental Geology, by Shao Yunhui and others;

An Outline Map of Global Tectonic Systems, by Ning Chongzhi and others.

As the "Method and Practice of Geomechanics" series has been compiled on the basis of comprehensive analysis and summation of the results of research and practice conducted by vast numbers of geomechanical workers and scientists engaged in related branches of sciences, so it should undoubtedly be regarded as a crystallization of common effort of all the people concerned. Except for the monograph "An Introduction to Geomechanics", for all other volumes of the series we use the term "Compilation", to mean that in the particular series results of research by other people are included, which the authors beg to acknowledge hereby. So and comments on possible oversights any omissions and mistakes in quotations are welcomed.

**Editorial Board of "The Method and Practice of Geomechanics"**

# 前言

如果说，李四光先生所创立的地质力学是以力学的观点与方法来阐明他对地质构造现象的理解和工作的原理，那么，关于地壳运动问题的提出和讨论，就是他对全球构造的特征和形成过程的动力学分析。早在本世纪 20 年代他就提出了此问题，直至 50 年代他在北京地质学院讲学的时候，仍以“地壳运动问题”为题，足见他对这一问题的难度和复杂性的重视和始终如一的探索精神。为了纪念李四光先生诞辰一百周年而写的此书，用“地壳运动问题”为题，正是为了表明本书是以李先生的基本认识为基础继续对这一问题进行的探索。之所以要冠以“现今”两字，是为了点明本书的研究时域是从现今出发的，沿着“以今论古”的方式讨论地壳运动问题。

近二三十年，国内外以“岩石圈动力学”或“地球动力学”所展开的全球构造研究，其对象的主体仍然是由地壳运动表现出来的，不过向海洋和深部大大扩展了。这也正是李先生所期望的。在大量获取新资料的同时而创立起来的“板块构造”观念和理论，的确对全球构造的总格局进行了一种新的概括，全面地影响了地质学向全球、向深部、向综合方向的巨大推进。但是直到现在，全球板块构造的规律性仍然没有能回答李四光先生早年所提出的一个地壳运动的基本问题——“为什么在某一地区，某一地质时期，按照一定的轮廓和规律，发生了沉降运动，而在同一时期，在某些地区和地带，又发生了某种形式的隆起运动？”（李四光，1973）。我以“取板块之精华，列立论之疑点”的态度对近二三十年为建立全球构造基本格局所依赖的基本事实进行了吞食与部分的咀嚼，并以地球坐标系的客观骨架为背景，探寻全球一级构造系统时空分布的必然性。至 80 年代后期，我们觉得已经可以把我们对全球三个一级构造系统的初步认识公之于众，以作为回答地壳运动的一个基本问题的尝试。

杜品仁同志用了两年多的时间整理我的有关论文，并补充收集了大量的资料与文献，编著成此书，在此对他创造性的合作表示谢意；并向鼓励我“终生为中国地学之开拓而奉献”的导师孙殿卿先生致以深深的敬意；向那些与我共同合作研究现今地壳运动的朋友们致敬。本项工作是在地质矿产部专项基金的支持与鼓励下完成的，同时也得到了国家自然科学基金的部分资助，在此一并致谢。

马 宗 晋

1994 年 12 月 10 日

# 目 录

第一章 绪论	(1)
1.1 现今地壳运动的定义、研究内容和研究意义	(1)
1.2 李四光的学术思想及其对现今地壳运动研究的指导作用	(2)
第二章 地球的构造系统和非对称性	(7)
2.1 地球的构造系统	(7)
2.2 地球的非对称性	(8)
2.3 板块构造及板块的相对和绝对运动	(11)
第三章 环太平洋构造系	(16)
3.1 定义和基本特征	(16)
3.2 板舌构造和板条构造	(19)
3.3 板舌变形的力学分析	(24)
3.4 东南太平洋区段	(29)
3.5 东北太平洋区段	(34)
3.6 西北太平洋区段	(35)
3.7 西南太平洋区段	(38)
第四章 大洋脊构造系统	(43)
4.1 定义和基本特征	(43)
4.2 洋脊的几何形态和构造分类	(46)
4.3 各大洋脊的基本特征	(50)
4.4 洋脊的分段、变格与跳位	(53)
第五章 大陆构造系	(56)
5.1 定义	(56)
5.2 基本特征	(57)
5.3 中蒙地震区	(61)
5.4 北美地震区	(70)
5.5 伊阿巴地震区和东地中海地震区	(80)
第六章 现今地壳运动的动态特征	(83)
6.1 地壳应力状态	(83)
6.2 地壳形变状态	(90)
6.3 地震韵律和地震迁移	(97)
6.4 地震活动与地球环境动力因子的关系	(109)
第七章 现今地壳运动的动力来源问题	(118)
7.1 概述	(118)
7.2 地球自转说	(119)
7.3 地球收缩说、地球膨胀说和地球脉动说	(124)

7. 4 地幔对流和其他地球内部物质运动假说 .....	(127)
7. 5 全球非对称对流模型 .....	(134)
7. 6 在上地幔分层基础上建立的构造热涌和地球自转模式 .....	(137)
7. 7 区域地球动力作用——中国大陆地震分区的动力因素讨论 .....	(138)
7. 8 结语：对地壳运动及其动力学研究的分析 .....	(139)
参考文献 .....	(143)
英文摘要 .....	(147)

# Contents

<b>Chapter 1 Introduction</b>	(1)
1. 1 Definition of contemporary crustal movement, research scope, and its significance	(1)
1. 2 Li Siguang 's scientific idea and its guiding role in research of recent crustal movement	(2)
<b>Chapter 2 Tectonic systems and asymmetries on the Earth</b>	(7)
2. 1 Tectonic systems on the Earth	(7)
2. 2 The asymmetries on the Earth	(8)
2. 3 Plate tectonics and relative and absolute motions of plates	(11)
<b>Chapter 3 Circum-Pacific tectonic system</b>	(16)
3. 1 Definition and basic characteristics	(16)
3. 2 Structure of plate tongue (slab) and plate lath	(19)
3. 3 Mechanical analysis of plate tongue deformation	(24)
3. 4 The southeastern Circum-Pacific segment	(29)
3. 5 The northeastern Circum-Pacific segment	(34)
3. 6 The northwestern Circum-Pacific segment	(35)
3. 7 The southwestern Circum-Pacific segment	(38)
<b>Chapter 4 Ocean ridge tectonic system</b>	(43)
4. 1 Definition and basic characteristics	(43)
4. 2 Geometry and tectonic classification of the ocean ridges	(46)
4. 3 Basic characteristics of the ocean ridges	(50)
4. 4 Segmentation, pattern change, and location jump	(53)
<b>Chapter 5 Tectonic system on the continents</b>	(56)
5. 1 Definition	(56)
5. 2 Basic characteristics	(57)
5. 3 China-Mongol seismic region	(61)
5. 4 North America seismic region	(70)
5. 5 Iran-Afghanistan-Pakistan and Eastern Mediterranean seismic regions	(80)
<b>Chapter 6 Dynamic characteristics of recent crustal movement</b>	(83)
6. 1 State of crustal stress	(83)
6. 2 State of crustal deformation	(90)
6. 3 Seismic rhythmicity and migration of earthquakes	(97)
6. 4 Relation of seismicity to geoenvironmental dynamic factors	(109)
<b>Chapter 7 Problem on the dynamic force source for recent crustal movement</b>	(118)
7. 1 An outline	(118)
7. 2 Hypothesis on the Earth's rotation	(119)

7. 3	Hypotheses on the Earth contraction, the Earth expansion, and the Earth pulsation .....	(124)
7. 4	Hypotheses of mantle convection, mass movement in the Earth's interior, and others .....	(127)
7. 5	Model of global asymmetric convection .....	(134)
7. 6	Model of tectonic heat upwelling and Earth's rotation constructed on the basis of the layering upper mantle .....	(137)
7. 7	Regional geodynamic process: discussion on the dynamic factors for seismic regionalization of the China continent .....	(138)
7. 8	Conclusions: analysis of the crustal movement and its dynamics .....	(139)
<b>References</b>	.....	(143)
<b>Summary</b>	.....	(147)



# 第一章 绪 论

## 1.1 现今地壳运动的定义、研究内容和研究意义

### 1.1.1 定义

地壳运动是李四光先生开创的地质力学的第一主题，他希望通过地质力学方法为解决地壳运动总问题开辟一条道路。在 50 年代，地壳运动实质就是指“大地构造运动”最基本的表现，而在李四光先生介绍地球的地球物理剖面时，将地壳作为岩石圈层的代表。尽管李先生在展开地壳运动的研究时一直追溯到了显生宙早期的“海水进退规程”，但他强调研究晚近时期的地壳运动，并以那些现今可见的构造要素来构筑他的构造体系。这是一种可靠的可以直接观察与论证的工作途径。

基于上述理解，结合 60 年代以来“地壳运动”主题向“岩石圈动力学”或“地球动力学”的发展，笔者在 1989 年正式提出“现今地球动力学”这一概念，并指出（马宗晋，1989）：地球动力学按其研究内容的特点和时间属性，原则上可分为现今地球动力学和历史地球动力学。前者以现今可见、可测和可直接进行正反演的现象、场和暂态信息为对象，进行全球尺度构造几何学的概括，探求全球构造要素整体的时空协调运动规律，进而给出统一的动力学解释。后者则以现今可得的各类遗迹或残迹为对象，进行全球尺度古地理演变史的推断和地球演化史的理论分析，并探求与之协调的运动学规律，最终完成全球构造演化全过程的再造。

在上述说明中，没有划定“现今”与“历史”的明确断代界限，因为它们本来只是说明认识巨大历史事物的两个方向：“由古论今”和“由今及古”，而不是历史的“断代”。因为随着研究问题的特点和空间尺度的变化，“由今及古”可以达到的历史长度是不同的。例如研究地震现象，由现代仪器测量的地震到历史记载的地震，再到地表变动所留下的遗迹，目前至多可能追溯到几万年前；而如果研究全球的地壳运动，从大洋底可以连续追溯的运动遗迹，则可达到中生代晚期或中期，再向前就是间断性的残迹了。大陆的地壳运动可以连续追溯的历史大概也只能到达中生代。看来，中生代燕山运动的前后确是全球性构造变革的一个重大阶段。难怪李先生特别强调研究“晚近”时期的重要意义，这也正是现今地球动力学或现今地壳运动目前主要的研究时域。

为什么要在地壳运动中划分出现今地壳运动呢？因为随着人类文明和科学技术的高度发展，人类已用仪器记录并积累了地壳运动的大量资料，而且这类资料还将与日俱增。通过现今地壳运动资料各时间序列的分析研究，可深入认识地壳和整个地球的微动态变化规律和过程。这是任何只能反映地壳或地球的平稳变化或平均行为的长期资料所不能替代的。

人类目前面对着资源紧缺、环境恶化和灾害加剧三大问题，现今地壳运动的微动态研究，也将给上述三大问题的理论研究和实用研究注入新的生机。为了解自然灾害强度和频

度随时间的变化,需要调查几千乃至几万年的地壳微动态变化。为了解自然环境的变迁、地壳升降、大气组成和温度的变化,若以中国大陆区青藏高原的升起和东部平原的下沉为例,可能至少要上溯到几百万年的始新世;而为了了解矿产资源的形成规律,则可能要上溯到1亿年左右的中生代晚期。我国80%的矿产和石油资源就是在这一重要时期形成的。近年来,成矿理论研究中,以构造地球化学观念为代表的研究方法的兴起,要求打破平稳成矿的观念,而补之以构造微动态的成矿机理;环境研究中,陆地表面和海洋与大气的演变及考虑日地系统中突变因素与突变行为,也需要现今地壳运动“微动态”研究的支持。至于自然灾害的形成,它们本身就是自然因子短时间尺度“微动态”变异所决定的。所以,无论从时间上,还是从运动机理上,都表明这些重大问题对现今地壳运动研究的需求。

总之,现今地壳运动研究,主要是为了研究地壳和地球的微动态、微韵律和非平稳变化,并由此建立非平稳的地壳运动模型,给以初步的微动力学分析。笔者希望现今地壳运动的研究能成为地球科学的一个新的生长点。

### 1. 1. 2 现今地壳运动的研究内容和研究意义

笔者认为现今地壳运动的研究应包括下述诸方面:

(1) 现今地壳运动的观测,即通过水准测量、形变测量、倾斜测量、重力测量、地磁测量、地震观测、火山活动观测和空间大地测量等各种手段取得现今地壳运动的信息;

(2) 对现今地壳运动资料进行单项的和综合的分析,得出现今地壳运动的时、空变化规律,从时间上分出不同尺度的变化,如对地震活动而言,分出地震期、地震幕、地震阶、地震丛等;从空间上探讨不同构造尺度,如全球级、区域级、地区级等的活动规律;

(3) 现今地壳运动的应用研究,即运用现今地壳运动资料为探查矿产、改善环境和减轻灾害服务;

(4) 现今地壳运动的理论研究,诸如研究现今地壳运动的分类、现今地壳运动与地球深部或地表运动的关系、现今地壳运动的动力学分析等。

可见,现今地壳运动涉及的面很广,是多种学科的边缘领域,需要多种学科的协调与配合。对现今地壳运动的研究也各有侧重,或侧重于大地测量,或侧重于地球物理,或侧重于地质等。本书从笔者的专业,即从地震地质角度提出了对现今地壳运动问题的一些认识,还不是对现今地壳运动的全面系统研究。

当代科学技术的高度发展,使大区域和全球的地壳运动实时观测成为可能,也使测量持续时间仅为微秒级的运动变得容易。开展现今地壳运动的研究,能从广阔的空间范围和微小的时间尺度两个方面增进我们对地壳运动的认识。现今地壳运动还是地球深部物质运动的一种反映,研究现今地壳运动是了解地球深部运动的一个窗口。

## 1. 2 李四光的学术思想及其对现今地壳运动研究的指导作用

李四光教授作为本世纪中国地球科学家的一位杰出代表,其学术思想自成体系,独创一派。深入研究、继承并发扬其学术思想,不仅对中国地球科学的发展是必要的、重要的,而且对世界地球科学的发展,对东、西方地球科学思想的交流,都将作出有益的贡献。