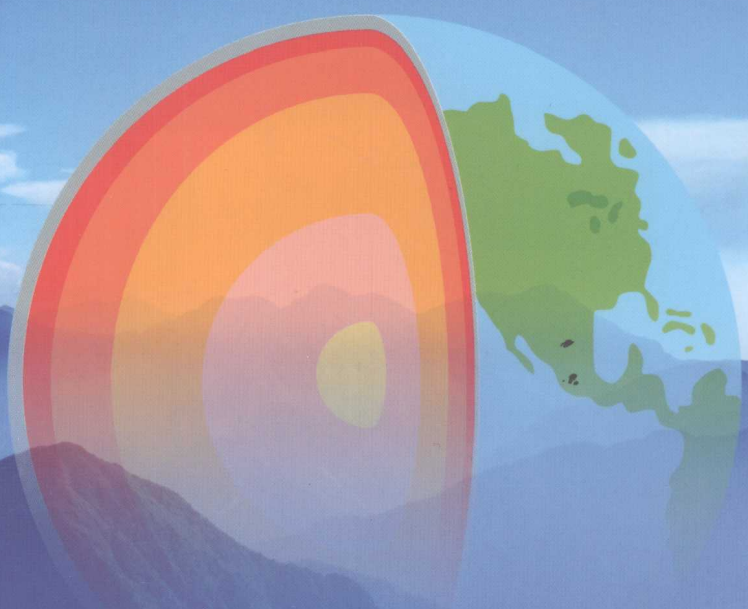
国家自然科学基金项目（40272088）
中国地质大调查项目（200110200038-1）资助

MANZHI GOUZAO YU ZIYUAN HUANJING

幔枝构造与资源环境

主　编：牛树银
副主编：孙爱群　王宝德　胡华斌



地质出版社

国家自然科学基金项目(40272088)
中国地质大调查项目 (200110200038－1) 资助成果

幔枝构造与资源环境

主　编　牛树银
副主编　孙爱群　王宝德　胡华斌

地质出版社
·北　京·

内 容 提 要

幔枝构造是地幔热柱多级演化的第三级构造单元。它一般由核部岩浆－变质杂岩、外围拆离滑脱层、上叠断陷火山－沉积盆地三个地质单元组成，一起构成相互关联的统一整体，是地幔热柱多级演化在地壳层次上的具体表现形式。它把地壳运动、成矿作用、地质环境、生态变化等看似孤立的、静止的地质事件与地球深部的核幔物质运动及其深部过程有机地联系起来，使地球科学研究更具科学性、系统性和预见性。

本书由以牛树银教授为主的研究群体在“十五”期间发表的论文中遴选22篇集结而成，侧重探讨了幔枝构造与陆内造山作用、成矿控矿作用、成矿物质来源、生态环境变化等几个重要论题。

本书可供广大地质学科技工作者及地矿类高等院校有关专业师生参考。

图书在版编目（CIP）数据

幔枝构造与资源环境／牛树银主编. —北京：地质出版社，2008.1

ISBN 978-7-116-05631-2

Ⅰ.幔… Ⅱ.牛… Ⅲ.地幔涌流－构造－研究 Ⅳ.P312

中国版本图书馆CIP数据核字（2008）第014109号

责任编辑：李莉等
责任校对：关风云
出版发行：地质出版社
社址邮编：北京海淀区学院路31号，100083
电　　话：(010)82324508（邮购部）；(010)82324567（编辑室）
网　　址：http：//www.gph.com.cn
电子邮箱：zbs@gph.com.cn
传　　真：(010)82310759
印　　刷：北京地大彩印厂
开　　本：787 mm×1092 mm 1/16
印　　张：20.25
字　　数：500千字
印　　数：1—500册
版　　次：2008年1月北京第1版·第1次印刷
定　　价：45.00元
书　　号：ISBN 978-7-116-05631-2

国家自然科学基金项目：
张宣幔枝构造的形成及成矿作用研究（40272088）
中国地质大调查项目：
冀北—太行山北段成矿规律和找矿方向综合研究（200110200038－1）
中国科学院知识创新工程：
华北东部中生代构造动力过程与时空耦合关系（KZCX1－07）

幔枝构造与资源环境

编辑委员会

序

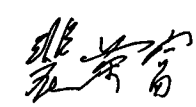
地幔热柱学说是继大陆漂移和板块构造之后新兴的全球构造理论，是对板（陆）内成矿认识的新发展。

以牛树银教授为首的研究群体通过多年来对地幔热柱构造学说的研究，结合国内成矿规律研究的具体实践，提出了幔枝构造与资源环境问题，并得到了国家自然科学基金和中国地质大调查项目的资助，本书是他们完成的研究成果的全面总结。

全书从地球圈层形成的不同结构及地幔热柱在垂向上产出的多级演化，阐述了华北东部地幔热柱—亚热柱—幔枝构造的形成及其与陆内造山耦合的动力学机制；探讨了在地球圈层中矿质受重力分异作用下沉和在地幔热柱发育区成矿元素反重力向上迁移的动力作用，提出了上升幔流－成矿物质深部来源、地幔柱－亚热柱－成矿物质反重力迁移通道和幔枝构造是控矿－成矿有利空间的认识，并对若干矿山深部和外围找矿作出预测；研究了大、中型金、银、多金属矿床的岩石学和矿物学、同位素地球化学、流体包裹体等特征，并提出成矿物质主要来自深源；论述了地球圈层动力作用形成地幔柱—亚热柱—幔枝构造的演化进程，较好地解决了中生代以来华北东部深部构造过程及其与形成盆－山构造的耦合机制，以及深部物质和有害元素上升对生态环境影响的问题。

总之，该书内容丰富，资料翔实，论证有据，特别是提出的在地球圈层动力作用下，垂向上形成地幔柱—地幔亚热柱—幔枝构造演化模式，不仅在理论认识上有创新，在找矿实践中也已取得实质性进展。预期该书出版后将会引起广大地学界对地幔热柱研究的关注，也会更广泛地活跃地学界讨论的气氛。

中国工程院院士



2007－08－07

前　言

地幔热柱是近年来提出的一种全新的大地构造理论，被认为是继大陆漂移、板块构造之后的第三次地学革命。地幔亚热柱、幔枝构造是地幔热柱多级演化的二、三级构造单元。华北东部盆岭区地幔亚热柱及冀东、张宣、阜平、小秦岭、鲁西等幔枝构造是地幔热柱多级演化研究的典型地区，亦是地幔亚热柱、幔枝构造研究的发源地，已引起越来越多地质学家的广泛关注和极大兴趣。

地球物质通过地幔热柱、地幔冷柱的对流，将地壳（岩石圈）与上、下地幔和外、内地核等地球内部的物质、能量、深部动力学过程以及地球表层的板块运动、陆内造山、成矿作用等有机地联系起来，成为解决诸如地壳运动、岩浆活动、地震作用、变质作用、成矿作用，甚至探索全球变化、环境变迁、生物演化等的主要地学理论。

这是因为在地球漫长的演化过程中，早期的混沌状态，在热力膨胀、引力收缩的统一支配下，地内物质开始分异，密度大、熔点低的铁、镍等物质呈熔融状态渗透过硅酸盐物质沉向地心成核，铁镁硅酸盐物质上浮形成地幔，地幔表层由于散热和挥发分的逃逸而冷却，并逐渐演化成岩石圈。这种密度分异和结构调整一直在进行着。

从另一角度来看，随着地球圈层结构的形成，地内温度逐渐提高，由于地球内外圈层存在着极大的温度差、压力差、黏度差、密度差，在整个地球广泛进行重力分异作用的同时，也必然会以地幔热柱、地幔冷柱的形式进行垂向的物质调整。一旦有部分自核幔边界超临界层高能量热物质流进入地幔热柱多级演化系统，它便会随地幔热柱多级演化向上运移，并伴有部分以气态形式迁移的金属元素直达幔枝构造，在有利的构造部位沉淀（积）成矿。以金为例：金元素的沸点为2807 ℃，很容易以气态形式迁移。中生代以来，由于强烈的地幔热柱活动，致使华北东部在形成盆－岭构造区的同时，也成为重要的成矿集中区。

“幔枝构造”是本课题组自主创新性提出的区域构造理论，它一般由核部岩浆－变质杂岩、外围拆离滑脱层、上叠断陷火山－沉积盆地三个地质单元组成，它们一起构成相互关联的统一整体。幔枝构造往往发育一套独特的断裂构造体系，也是幔枝构造成矿控矿的主要场所：幔枝核（轴）部构造主要

为脆韧性－韧脆性剪切带，或以叠加断裂构造为主。这主要与岩浆－变质杂岩形成环境有关，可分为轴部韧脆性剪切带、次级韧脆性剪切带、岩体环状及放射状断裂构造等；幔枝构造外围拆离滑脱层中往往发育几组断裂构造：主拆离滑脱带、次级拆离滑脱带、反向铲状断层及横张断裂等；在幔枝隆升过程中叠加在不同构造单元之上的断陷火山－沉积盆地及与次火山斑岩岩体、玢岩岩体等有关的次火山机构断裂体系。这些断裂构造往往成为晚期含矿流体活动的通道和储集场所，是有利的控矿构造空间。

项目组“十五”期间承担了中国地质调查局下达的“华北地台成矿规律和找矿方向综合研究”项目的二级课题：“冀北—太行山北段成矿规律和找矿方向综合研究（项目编号：200110200038－1）”。2003～2005年，项目组又获得了国家自然科学基金项目“张宣幔枝构造的形成及成矿作用研究”（项目编号：40272088）资助，同时，还承担了中国科学院知识创新工程“华北东部中生代构造动力过程与时空耦合关系（项目编号：KZCX1－07）”项目的部分研究任务，使项目组从更加宽泛的视角研究了华北东部地区中生代构造动力过程及其成矿作用，特别是通过解剖典型的张宣幔枝构造区取得了一系列新的研究进展。在国内外刊物上发表论文60余篇（其中三大检索论文17篇）、会议论文12篇。本文集收录了其中的22篇论文，旨在集中反映幔枝构造与陆内造山作用、幔枝构造及成矿控矿作用、幔枝构造与成矿物质来源、幔枝构造与生态环境变化等几个主要议题。

（1）从地球圈层结构的形成与地幔热柱多级演化这一对立统一矛盾的双方，阐述了华北东部地幔亚热柱——幔枝构造演化与陆内造山带的形成，探讨了华北东部一盆多山构造的耦合关系。并以张宣幔枝构造为例，研究了幔枝构造的几何学、运动学、动力学特征。

（2）从成矿物质的反重力迁移，探讨了金银等重元素在长期的重力分异作用下趋于沉向地核，而在局部地幔热柱多级演化过程中，又可以气态→气－液混合态→含矿流体的形式向上迁移。提出了上升幔流——成矿物质的深部来源、地幔热柱－亚热柱——成矿物质反重力迁移的通道、幔枝构造——成矿控矿的有利构造空间的系列认识。并据此开展了若干典型矿山深部、外围找矿预测，大幅度扩大了矿山储量，收到了很好的找矿效果。

（3）对研究区大部分大中型金银多金属矿山进行深入研究的同时，均采集了岩矿样品，除详细进行了光、薄片研究外，重点开展了硫、铅、碳、氢、氧、硅、氦、氩等同位素研究，以及含矿流体成分、包裹体测温等工作。研究表明，绝大多数金银多金属成矿物质主要来自深源，只是在地壳上部构造扩容带集聚成矿过程中混有少量天水。成矿控矿构造是诸多成矿因素中具有

决定意义的要素。

(4) 亚热柱－幔枝构造作为一种区域构造理论，它不仅较好地解决了中生代以来华北东部盆－岭构造区的深部过程及其盆－山耦合关系。而且由于亚热柱－幔枝构造间的物质流变与演化，使其直接控制着地热的形成与展布、控制构造能量的积累与释放（地震、火山喷发），甚至由于深部物质的上升，在把金银多金属等矿产抬升到近地表的同时，也把砷、氟、汞等有害元素带到近地表，并通过饮食等生态系统进入人体循环，导致某些元素超标致病。因此，随着人们生活水平的提高，应该注重生态环境的质量。

课题研究中得到了国土资源部、中国地质调查局、中国地质科学院、中国科学院地质与地球物理研究所、天津地质矿产研究所、河北省国土资源厅、石家庄经济学院、河北省地质矿产勘查开发局等单位有关领导和专家的热情指导。野外调研过中还得到了地矿、冶金、有色、武警黄金等部门地勘单位和矿山的友好协助和大力支持，在此一并深表衷心感谢。

作者还要特别感谢在项目研究中李廷栋、陈毓川、翟裕生、裴荣富、任纪舜等院士，张洪涛、叶天竺、毛景文、侯增谦、郝梓国、吕古贤、杜建国、于海峰、李俊建、毛德宝等研究员，郝东恒、张举刚、张建珍等教授以及王章俊编审所给予的热情指导和鼓励，同时感谢中国地质科学院地质研究所、矿产资源研究所等为课题测试了多种有关岩矿样品。

应该指出，虽然在室内、外研究的基础上，尽可能对调研资料进行初步归纳，对研究成果进行概括总结，但这仍是初步认识。加之前两年勘探经费投入不足，很多有利成矿区段或靶区未能进行及时验证，有些基本认识尚不够完善，敬请各位专家指正。

作　者

2007－06－16

Preface

Mantle plume is a new tectonic theory which is accepted by geologists in recent years. It is considered as the third geologic revolution after the continental drift and plate tectonics. Sub-mantle plume and mantle branch are the second and third-grade tectonic units during the multiple evolution of mantle plume. The sub-mantle plume in the east of north China basin-mountain area and the mantle branches in eastern Hebei, Zhangjiakou-Xuanhua, Fuping, Qinling Mountains and western Shandong are the typical areas for studying the multiple evolution of mantle plume. The study of sub-mantle plume and mantle branch was originated from these areas. More geologists have paid attention to these areas.

Through the convection of hot and cool mantle plumes, the material, energy and deep dynamic process in the crust (lithosphere), upper and lower mantle, outer and inner core within the Earth, and the plate tectonics, continental orogeny and metallogenesis on the Earth surface are connected with the movement of the Earth materials. This theory has become the dominant theory for scientists to study the crust movement, magmatism, earthquake, metamorphism, metallogenesis, even to explore the global movement, environment vicissitude and organism evolution.

During the endless evolution of the Earth, dominated by thermal expansion and gravitational attraction the chaos material of the early Earth began to differentiate. The melted and high density Fe and Ni penetrated silicate materials and sank to the central of the Earth and formed the core, and the Fe-Mg silicate materials floated up and formed the mantle. Because of the heat dispersing and volatile escaping, the surface of the mantle gradually evolved into lithosphere. The density differentiation and structure adjustment is successively developed.

Moreover, with the formation of layered structure and the increasing of temperature within the Earth, great differences between the layers are existed in temperature, pressure, viscidity and density. As the gravitational differentiation developed in the Earth, the materials would be vertically adjusted through the convection of hot and cool mantle plumes. Once the high-energy material, which comes from the super critical layer between the core and mantle, participates the multiple evolution system of mantle plume, it would move up with the multiple evolution of the mantle plume, and some gaseous metallic elements would move to the mantle branch and deposit as economic deposits in favorable structures. Take Au as an example, the boiling point of the Au is 2807 ℃, it is easy to move as gaseous state. Since the Mesozoic, intensive mantle plume evolution made the east of north China become a basin-mountain area and an important metallogenic concentration area.

Mantle branch structure is a creative regional tectonic theory which was conceptualized by the authors of this research group. It generally includes three associated geological units which are core magmatic-metamorphic complex, surrounding detachment zone and overloaded volcano-sedi-

mentation faulting basin. Mantle branch usually develops a series of unique faults, and they are the major mineralization places for mantle branch structure. The core (axis) of the mantle branch develops brittle-ductile/ductile-brittle shearing zones, or superposed faults. This can be contributed to the circumstance for the formation of magmatic-metamorphic core complex. The fracture system includes core ductile-brittle shearing zone, secondary ductile-brittle shearing zone and ring or radiated faults within intrusions. The surrounding detachment zone of the mantle branch develops several groups of faults, which include dominant detachment zone, secondary detachment zone, reverse listric faults and cross extension faults. During the uplifting of the mantle branch, the volcano-sedimentation fault basin and the fault system in subvolcanic system related with subvolcanic porphyritc intrusions were superposed on different tectonic units. All above faults are the channels or concentration places for later hydrothermal fluids, and they are the favorable structures for mineralization.

During the "Tenth Five-year Plan", the project group undertook the project of "The Comprehensive Study on the Metallogenesis and Ore Prospecting in North Hebei and North Taihang Mountains" (200110200038 - 1), which is a part of the project "The Comprehensive Study on the Metallogenesis and Ore Prospecting in North China Platform" sponsored by China Bureau of Geological Survey. During 2003 ~ 2005, we got financial support from NSFC for the project of "Study on the Formation and Metallogenesis of Zhangjiakou-Xuanhua Mantle Branch Structure (40272088)". At the same time, the project group made some study on the project of "The Dynamic Process and Time-space Coupling of Mesozoic Structures in the East of North China (KZCX1 - 07)" sponsored by CAS. All these studies helped the project group make more understandings on the dynamic process and metallogenesis of Mesozoic structures in the east of north China. By dissecting the Zhangjiakou-Xuanhua mantle branch structure, much progress has been made by the group. More than 60 papers authored by the group members have been published in different publications both at home and abroad, and 12 papers were published on conference contributions (among them, 17 papers were included in SCI, EI, CA) . This publication includes 22 of these papers. The purpose of this contribution is to reflect the continental orogeny, metallogenesis, source of metallogenic material and environment related with mantle branch structure from following aspects:

(1) Viewed from the counterparts of layered structure and multiple mantle plume evolution of the Earth, the evolution of sub mantle plume-mantle branch and the formation of continental orogeny in the east of north China are elaborated, and the coupling relation between basin and mountain is discussed for this area. Taking the Zhangjiakou-Xuanhua mantle branch as an example, the geometry, kinematics and dynamics of the mantle branch structure are studied.

(2) On the basis of anti-gravity movement theory of metallogenetic material, it is considered that heavy elements such as Au and Ag tend to sink to the core during gravity differentiation. However, during the process of multiple evolution of mantle plume, they can move up as gaseous state→gas-liquid→hydrothermal fluid. It is proposed that the upwelling mantle flow is the source for metallogenetic material, the mantle plume or sub-mantle plume is the channel for metalloge-

netic material to move up against the gravity, the mantle branch structure is the favorable place for mineralization. Based on this theory, some ore prospecting were made in the deep and surrounding of typical mines, the ore reservation was enlarged, and the prospecting is effective.

(3) When we made study on most Au, Ag and polymetallic deposits, the studies are focused on isotope analysis of S, Pb, C, H, O, Si, He, Ar, and the chemistry and temperature of gas-liquid inclusions except for physical study on thin sections. Study indicates that most Au, Ag and polymetallic materials came from the deep, only has small amount of meteoric water was mixed in the ore-forming process in upper crust structural extension zones. Metallogenetic structure is an essential one among metallogenetic factors.

(4) As a regional tectonic theory, the sub-mantle plume and mantle branch structure can be used to explain the deep process and basin-mountain coupling in the east of north China since the Mesozoic. The material convection and deep process of sub-mantle plume and mantle branch dominant the formation and distribution of geothermal flow, the accumulation and release of the stress energy (earthquake and volcanic activity). Moreover, because of the uplifting of deep material, while the Au, Ag and polymetallic resources were elevated to the surface, noxious elements such as As, F and Hg are also brought to the surface and came into the ecosystem and human body, which could result in some diseases. So, for improving the living standard, more attention should be paid to the quality of environment.

Much helps have been got from the Ministry of Land and Resources, Bureau of China Geological Survey, China Academy of Geoscience, Institute of Geology and Geophysics, CAS, Tianjin Institute of Geology and Mineral Resources, Hebei Department of Land and Resources, Shijiazhuang University of Economics, Hebei Bureau of Geology and Mineral Resource Exploration. During field works, we also got helps from organizations in geology, metallurgy, nonferrous metals, armed police. We express our acknowledgements to them.

Special thanks are paid to academicians Li Tingdong, Chen Yuchuan, Zai Yusheng, Pei Rongfu, Ren Jishun, and Professors Zhang Hongtao, Ye Tianzhu, Yu Haifeng, Hao Zhiguo, Lu Guxian, Du Jianguo, Zhang Jianzhen et al. for their advises and encouragement. We also thank to Institute of Geology and Institute of Mineral Resources in China Academy of Geoscience for their testing work on rock and ore samples.

Although we have made much progress based on data studying and achievements summary through field and laboratory works, these are only preliminary understandings. Because the shortage of exploration investment in past decade, many favorable target area are not verified, some basic understandings are imperfect. Any criticisms are welcome.

Author

2007 – 02 – 16

目　　次

Contents

Mantle branch structure and eco-environmental changing

幔枝构造与陆内造山作用

幔壳运动与地幔热柱多级演化

牛树银[1]，王宝德[1]，孙爱群[1]，李红阳[1]，侯泉林[2]

（1. 石家庄经济学院地质调查研究院，河北 石家庄 050031；
2. 中国科学院地质地球物理研究所，北京 100101）

摘要：地球是重力分异和热力对流的对立统一体。重力分异使地内重元素下沉、轻元素上浮，并分划成壳－幔－核结构圈层。核幔间巨大的温度差、压力差、黏度差和速度差的存在，导致源于“超临界层”的热物质流呈柱状上涌，形成地幔热柱多级演化。由于地球圈层结构及其圈层间的差异，分别在670 km，100 km深处，即核－幔界面上和岩石圈底部形成地幔亚热柱和幔枝构造。地幔热柱、地幔冷柱共同驱动幔壳运动，并控制着板块运动，形成复杂的大陆（大洋）动力学系统。这种动力学模式越来越得到地球物理学的证实。

关键词：地幔热柱；幔枝构造；幔壳运动；地球动力学

地球是物质的，物质是运动的，因而物质运动的规律是人类不懈探索的前沿课题。当今，随着科学技术的发展，人类已能“上天、入地、下海、登极”，亦能通过高精度地球物理探测，从多角度、多视野来认识、研究地球及其物质运动。

1 层圈结构与核幔运动

地球在其漫长的演化过程中，不仅始终进行着物质分异作用，而且存在着垂向物质运动。

1.1 层圈结构的形成

地球（太阳系，甚至银河系）演化的研究，目前仍属探索领域。但是，不管是宇宙大爆炸理论，还是星际物质聚集理论，都认为地球物质的初始状态是比较均匀的。在其46亿年的漫长演化过程中，在引力（重力）收缩和热力膨胀的统一作用支配下，地内物质开始对流。随着温度的升高，密度大、熔点低的铁镍呈熔融状态渗透过硅酸盐物质沉向地心，并逐渐形成地核。铁镁硅酸盐物质上浮形成地幔。地幔的表层，由于散热及挥发分的逃逸而慢慢冷却，并逐渐演化为以铝硅酸盐物质为主的固体地壳，便形成了核、幔、壳

基金项目：国家自然科学基金（40272088），中国科学院知识创新项目“KZCX1－07”和中国地质调查局（200110200038）资助。

本文曾发表于《矿产资源·地质环境·经济管理——石家庄经济学院五十周年校庆论文选集》，2003。