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THE COAL METAMORPHISM IN CHINA

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内 容 简 介

本书是在国家自然科学基金、地质矿产部行业基金、国家计委与地质矿产部专项资助的重点科研项目成果基础上精心著述而成，展示了中国煤变质研究领域的代表性成就。

书中深入阐述了中国煤变质主要类型及其地质成因、中国煤变质演化及其地质背景、中国煤变质规律及煤质煤类分布，对煤盆地构造—地热演化及影响方式、热源—介质—热场—煤变质作用时空配置关系、煤变质地球化学反应机理、煤变质热动力学机制等前沿课题和研究热点作了积极探讨，特别就中国煤的多阶段演化与多热源叠加变质作用进行了系统总结和理论概括。

本书可供煤、石油与天然气地质部门的教学、科研和生产科技人员、研究生、大学生以及从事地热、冶金、矿业、煤化工等专业工作者参考。

前　言

煤不仅是重要的能源，还是多种工业的原料。煤的加工利用方向取决于煤质差异。中国是个多聚煤期的国家，煤的储量丰富、煤类多种多样，但无论是储量还是煤类在地理分布上又都不均衡。为适应中国经济建设快速稳步发展的需要，充分发挥中国煤炭资源应有的作用，就不仅要求在勘查中增加煤的精查储量，在开采中增加煤炭产量，而且还需要从成因上研究煤类的形成和分布规律。鉴于煤变质在煤演化过程中是最后决定煤类的作用，因此加强煤变质研究，更有效地预测煤级及其地理分布，对指导煤炭资源的合理开发和综合利用是至关重要的。

“中国煤变质作用”是国家计委、地质矿产部专项资助的第三十届国际地质大会重点科研项目，前期工作还曾得到国家自然科学基金、地质矿产部地质行业基金的资助。本书正是在上述研究成果的基础上完成的，它既立足于对中国煤变质类型及其地质成因、中国煤变质演化及其地质背景、中国煤变质规律及煤质煤类分布等基本问题的深入细致研究，同时又对煤盆地构造—地热演化及影响方式、热源—介质—热场—煤变质作用的时间配置关系、煤变质地球化学反应机理、煤变质热动力学机制等前沿课题和研究热点作出积极探讨，阐述了多方面新认识，特别就中国煤的多阶段演化与多热源叠加变质作用进行了系统总结和理论概括。同时，也深化了对中国含油气盆地岩层有机质热演化特征及其生烃作用的认识，有助于揭示其中的特异规律。

总论部分以统计方法与地质分析相结合，将中国主要煤田（或矿区）的煤变质作用类型划分为深成变质作用（成岩作用）和异常热叠加变质作用两大类，从定性、定量不同角度反映出中国煤深成变质作用具有普遍性，多数煤田（或矿区）有不同程度的异常热叠加变质作用发生，其中区域岩浆热变质作用分布广泛，叠加效果显著。

第一章在论述深成变质作用中融合了盆地类型、盆地演化、盆地热史动态分析、煤变质数字化模拟等内容。从埋藏条件分析得出深成变质作用只是奠定了中国以低煤级为主的变质基础的结论；指出随着大地构造演化，古今地温状态在中国东、西部分别呈现增、减变化趋势；获得了壳幔作用不仅与构造沉降有关，还导致盆内地温分布不均匀性，以及在大型叠合盆地中，埋深增大和地幔隆升引发的热流增强是促成深成变质高煤级产生的双重原因这一新认识。

第二章根据岩浆性质、侵入规模、侵入方式、侵入深度以及盖层封闭条件，将煤的区域岩浆热变质作用进一步划分为浅成、中深成和深成岩浆热变质作用；详细描述了区域岩浆热变质煤的煤级分布、变质梯度、热变组分及矿化蚀变特征；按照变质带展布、岩浆区域活动规律及地球物理场状态互为验证的特点，从深大断裂活动、区域地壳结构与大地构造演化关系上，总结了中国煤的区域岩浆热变质作用地域分布规律。

第三章将煤的接触变质作用方式归结为两种效应：热影响——导致变质作用强烈进行；物质交换——熔浆与煤层及围岩交代产生催化反应效果。相对于高温低压过程，形成天然焦—热变煤系列；相对于高温高压（特别是应力作用）过程，产生石墨—热变煤系列。除对接触变质分带性、接触变质煤性质有深刻阐述外，还通过围岩蚀变及地温矿物变化研究取得了接

触变质低温、中温及高温反应数据，结合岩浆活动特点，较为全面地描述了接触变质过程。

第四章论证了煤的热液热水变质作用系来自地壳深部高温承压水和岩浆分异气液引起的异常地温场中煤的变质作用，主要发育于构造活动和深断裂发育区，断裂和透水层中热液热水循环、运移，呈现对流型热流体制特征，在热源性质、热导介质和输热方式上有其特点，表现为温度高、升温快、压力较低和有效作用时间短，煤级分布受对流热场控制，常出现煤级“上高下低”的反希尔特规律现象。

第五章从地热状态平衡与破坏的角度，通过理论推导与实例检验，建立了以沉降史模拟为基础的煤的深成变质和岩浆热变质动力学模型；以独创的平壁可变边界非稳态岩浆热场分析，采用变量替代和动态边界条件法来解决热源和热传导双重非稳态计算难题。揭示出煤的深成变质作用受控于地壳的地热结构、盆地沉降史及煤的埋藏史，并与盆地基底热流、沉降幅度及煤层埋深呈正相关；区域岩浆热变质作用受控于构造—岩浆作用史，与岩浆成岩温度和规模呈正相关，而与岩体定位深度及其与煤层的距离呈负相关。

第六章采用煤的大分子相和活性相“两相”结构观点并结合现代检测手段，系统考察了煤在变质过程中的结构转化及煤化作用机理，介绍了纳米技术应用于煤结构分析的成果；直观并定量地描述了大分子结构的芳香化、稠环化及三维空间上的有序发展；得出键合在煤的大分子结构上或以游离态存在的活性相组分，除呈现由重质组分向轻质组分转化的表观现象外，还经历多种地球化学变化的结论；对沥青化作用、产烃作用、焦化与石墨化过程给予了特别的关注。

第七章通过对大地构造特征、深部地质条件、地球物理场状态、煤盆地形成演化、构造变动、岩浆与热液热水活动等地质因素的综合分析，得出中国煤变质程度总体上自北而南、由西往东增高；异常热叠加变质作用的广泛性和叠加强度的差异性与太平洋板块向东亚大陆多次西向俯冲对中国大陆的影响自东向西减弱；印度板块北向推移对中国陆壳的影响自南而北减弱的构造背景一致等结论。总结出中国煤变质格局的形成是多阶段演化与多热源叠加变质的结果，而且多热源叠加变质作用包括在深成变质（成岩作用）的基础上叠加区域岩浆热变质、接触变质和热液热水变质中的一种或一种以上的煤变质作用。

本书涉及的多层平壁式非稳态热场模拟、对流型热体制中气液包裹体温压及成因分析、煤的纳米分析、喷金内标法煤结构参数的电子衍射定量等新技术方法的发展，不仅有效地促进了煤变质理论的深入探讨，也为古地热分析、沉积有机质演化、油气成因、煤及煤产品特性等相关课题的研究开辟了新的技术途径。

杨起主持了相关的研究与本书的编写，杨起、潘治贵、周春光、苏玉春执笔总论、第七章；吴冲龙、刘刚、罗映娟执笔第五章；汤达祯执笔第一章、第六章；康西栋执笔第二章；刘大锰、陈基娘执笔第三章；潘治贵执笔第四章。庄新国、潘伟尔、周江羽、梁雄兵、张琼岩等参加了部分研究工作。全书由杨起审改、编纂而成。

本书的出版得到地质矿产部科技司、国家科委国土局、国家自然科学基金委员会和中国地质大学领导的关心和支持。有关研究工作及基础资料曾得到国内地质矿产、煤炭行业众多兄弟单位的热情帮助。中国科学院戴金星院士、中国矿业大学金奎励教授、国家自然科学基金委员会田兴有研究员、地质矿产部勘查司尹善春高级工程师、煤炭科学技术信息研究所叶敦和研究员等，在研究和成书过程中提出了宝贵意见，在此深表感谢！

谨以此项成果，作为向第三十届国际地质大会的一份献礼！

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CONTENTS

THE COAL METAMORPHISM IN CHINA

(ABSTRACT)

This paper sums up the geologic characteristics of the predominant coal metamorphism types in China through the study of the heat source and its mode of operating on coal metamorphism.

The continent of China, situated at the southeastern part of the Eurasian plate, is bounded on the north, east and southwest by the Siberian, Pacific and Indian plates respectively. The geotectonic framework of China has become highly complicated owing to superimposition and reworking by multiperiodic tectonism. Mesozoic tectonisms, especially the Yanshanian orogeny, had exerted a crucial influence on the evolution of coal metamorphism and the formation of zonation of medium-high rank coals in China. On the basis of a series of characteristics, such as geotectonics, coal-forming periods, geomorphology and the distribution of coal ranks, three coal metamorphism regions have been recognized.

1 MAJOR COAL METAMORPHIC TYPES IN CHINA

There are four predominant types of coal metamorphism in China, i. e. geothermal metamorphism, telemagmatic metamorphism, contact metamorphism and hydrothermal metamorphism.

1.1 GEOTHERMAL METAMORPHISM OF COAL

During the late Paleozoic, the North China and the Yangtze platforms appeared mainly as grand-scaled rolling depressions which constitute then the main coal accumulating areas. In East China widespread Triassic deposits play an important role in the preservation of the Paleozoic coal measures. By upper Triassic the sedimentation region of North China obviously shrank towards the west, while in South China narrow subsiding belts and large undulating depressions occupied seperately the east and the west. During early Yanshanian, there developed steadily younger coal accumulating depressions or superimposed basins on previous intracratonic basins or basins formed on the basis of fault blocks. Some of the enormous depressions composed mainly of Triassic and Jurassic sequences could be developed in a long period, such as the Ordos basin and the Sichuan basin. From the late Yanshanian to the Himalayan stages, the coal-bearing regions in West China were dismembered and surrounded by folded mountains, whereas most of the coal measures in East China were close to the surface as a result of veneer denudation, hence geothermal metamorphism appeared to reach a "standstill".

The central parts of the large Mesozoic and Cenozoic depressions such as the Songliao, the Qaidam and the Tarim basins, still remain in the state of crustal thinning, meanwhile the Moho uplift and the geothermal gradient increasing from the margin to the center.

The present pattern of isogeothermal contour in the Sichuan basin is similar to the shape of the basin contour. The basement within the basin is stable, and the Moho depth in Nanchong and Neijiang is less than 39km; outwardly, crustal thickness increases. The distribution of coal rank within the basin is obviously concordant with the Moho depth.

The Ordos basin is a huge Mesozoic depression. Along the line joining Changwu-Tongchuan-Hancheng the total thickness of the Triassic is about 3000m in the southern part of the basin. In the subsidence center along the western border fault the Jurassic system reached a maximum thickness of almost 3000m and the Cretaceous system also exceeded 1000m. At the northeastern margin the fitting data of the paleoheatflow changed approximately from 1.6HFU to 1.0 HFU from the Cambrian to the present. During the Triassic at the southeastern and the southern parts of the basin the paleoheatflow conspicuously enhanced to 2.18 — 2.39 HFU with the increasing subsiding amplitude. Obviously the Triassic geotemperature was higher than pre-and post-Triassic.

Through geothermal metamorphism, the Paleozoic coals in general reached only a low to medium rank bituminous, mainly low rank stage while the Mesozoic coals evolved to low rank bituminous stage, and the Tertiary coals mainly remained unmetamorphosed. The unevenly spatial distribution of paleogeotemperature and the chronological variation in paleogeothermal field during the geological time also controlled to a certain degree the evolution of the geothermal metamorphism in China.

1.2 TELEMAGMATIC METAMORPHISM OF COAL

Based on the magmatic characters, intrusive scale, intruding depth and horizon, and the confining conditions of the sedimentary cover of coal seams, telemagmatic metamorphism is divisible into three subtypes, i.e. hypabyssal, Mesogenetic and plutonic telemagmatic metamorphism. Zoning of metamorphic coal well marked in the area where telemagmatic metamorphism occurs, and the closer to intrusive rock, the higher the coal rank is. Coal metamorphic gradient caused by telemagmatic metamorphism is higher than that caused by geothermal metamorphism, and usually more than $0.1R_{o,max}\%/100m$. Generally, the occurrence of vesicles, spherules and mosaic texture in coal results from abnormally high temperature effect. Wall-rock alterations usually took place in areas affected by telemagmatic metamorphism.

It is the Mesozoic and Cenozoic magmatic activities, especially igneous intrusions during Yanshanian stage, that had exerted important influence on coal metamorphism in China, forming a series of medium-high rank coals. The Yanshanian magmatic activities are characterized by their great intensity, wide sphere of influence, polycyclicity, and their better development in the south and east parts than in the north and west parts, in other