中国煤层气资源

COALBED METHANE RESOURCES OF CHINA

中国煤田地质总局 著

China National Administration of Coal Geology

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《中国煤层气资源》编委会和编写人员名单

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序

煤层气作为一种资源量巨大的非常规性天然气资源，已经从研究逐渐走向开发利用。1996年，我考察了美国煤层气产量极高的圣胡安盆地ARCO公司辖区，有110口煤层气井，日产气660多万m^3，说明煤层气井可以相当高产。因此，世界上对煤层气研究日益加深，开发的地域日益扩大，煤层气在能源中的地位日益提高。近年来，煤层气亦受到我国政府和有关工业部门的高度重视，预示着我国煤层气工业在不久的将来定会有大的发展。煤层气资源的开发利用，对于充分利用这一宝贵的矿产资源、改善我国的能源结构、促进我国以煤为主的能源系统逐步向环境无害的可持续发展模式的转变并形成新的能源产业、从根本上防治瓦斯事故以改善煤矿安全生产条件，均具有战略性意义。

鉴于国家经济建设的上述需求，中国煤田地质总局和中国矿业大学基于我国40多年来丰富的煤田地质勘探成果和近10年来我国煤层气勘探开发试验所积累的大量资料，就原煤炭工业部计划项目“全国煤层气资源评价”进行深入研究，取得了我国煤层气地质界近年来的一项重大科研成果。该著作正是在该项目研究成果的基础上撰写而成的。其正式出版，不仅对于我国方兴未艾的煤层气资源勘探开发具有现实的指导作用并提供科学的依据，而且对于形成符合我国地质条件的煤层气地质理论具有重要的价值。

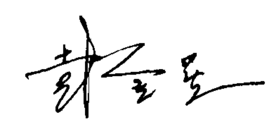
该书作者科学地揭示了我国煤层气资源的自然分布状况。获得甲烷含量4 m^3/t以上、埋藏2000 m以浅的全国煤层气资源总量14.34万亿m^3，包括远景资源量13.37万亿m^3，预测储量0.97万亿m^3。其中：含气量大于8 m^3/t的富甲烷煤层气资源量12.44万亿m^3，含气量介于4～8 m^3/t之间的含甲烷资源量1.90万亿m^3；埋藏深度小于1500 m的浅层煤层气资源量9.26万亿m^3，深度为1500～2000 m的较深层煤层气资源量5.08万亿m^3。作者创造性地建立起我国5大聚气区、30个聚气带、115个目标区的煤层气聚气区带的区划体系，进而从煤层含气性要素、资源级别、资源品级、埋藏深度、聚气区带规模等方面系统地探讨了我国煤层气资源的地域和层域分布特征，指出我国煤层气资源总量的90%以上赋存在华北聚气区和华南聚气区，科学地展示出我国富气目标区带的分布规律。这些研究成果，为清醒地认识我国煤层气资源状况、开展有利区带优选和进行勘探开发战略部署奠定了坚实的基础。

该书作者根据我国的地质条件，从煤层气成因、煤储层物性、构造作用、沉积作用、水文地质条件等角度深入系统地探讨了煤层气赋存和分布的地质控制规律，获得了多方面的发现和创新性认识。例如：建立起干燥煤样与平衡水煤样之间吸附特性的换算关系，就含水煤样朗格缪尔体积的演化规律得出了新的认识；从理论和实践上指出构造应力是影响我国煤储层渗透性的重要地质因素，首次总结出我国煤储层物性试井参数的分布规律，揭示出煤储层渗透率与煤层厚度和煤体结构之间的相互关系发现了煤岩显微组分组成对于煤储层吸附性具有的临界控制作用；指出我国地台基底型含煤盆地和地台与褶皱带过渡区含煤盆地具

有良好的煤层气资源条件和开发前景，将我国煤层气赋气构造归纳为4类10型，认为燕山期构造运动和古地热场性质对我国东部晚古生代煤的煤层气生成保存条件具有深刻影响，揭示出我国煤级控气的阶段性特征并深入论证了其机理；创造性地将我国水文地质控气特征总结为水力运移逸散作用、水力封闭作用和水力封堵作用3种类型；认为我国上古生界浅层煤层气的解吸—扩散—运移效应十分显著，指出其根本原因在于煤层是一种“有机”储层，提出了这种效应越强烈则常规控气地质因素的重要性将会越显著的新观点。该书作者在煤层气控气地质因素方面的可贵探索，在我国煤层气地质选区中具有良好的应用前景，有力地推动了我国煤层气地质理论的深化和发展。

该书的一个显著特色，还在于突破了“综合评价标准”方法的传统思路和局限性，以新颖的技术思路和严谨的方法流程首次建立起“递阶优选＋定量排序”的我国煤层气有利区带优选理论和方法体系，为我国煤层气区带前景提供了一种科学性较强、可信性较高和可比性较大的统一评价和决策的工具。在该方法体系中，作者充分考虑到煤层气地质条件确定性和模糊性并存的双重属性，将几何、储层、盖层和资源4大因素14个要素予以量化，认为含气量、面积、资源丰度、渗透率和临储压力比5个要素是具有“一票否决”作用的关键要素，并将水文、构造、沉积等暂时难以量化的控气地质因素分析贯穿于优选的全过程，由此得出的全国煤层气有利区带优选成果是有科学依据的，必将为我国煤层气勘探开发战略部署和决策提供有力的技术支持。

我国煤层气地质背景复杂、类型多样，煤层气赋存和开采地质条件明显地不同于国外某些煤层气资源开发较为成功的国家和地区。该书是我国煤层气资源科学测评和地质理论系统研究的第一本学术专著，它科学地展示出我国煤层气资源开发利用道路曲折但前途光明的前景，也昭示出适合于中国地质条件的煤层气基础地质理论体系正在逐步形成，真乃可喜可贺！在该项研究成果正式出版之际，我衷心地期望我国煤层气工业在不久的将来会有新的突破，取得更大发展。

中国科学院院士 

一九九八年冬于北京

前　言

煤层气将会成为中国新的接替能源。煤层气的勘探开发对于我国国民经济的发展具有重要战略意义，它将改善我国的能源结构、促进我国以煤为主的能源系统逐步向环境无害的可持续发展模式转变，形成洁净能源新产业。同时，煤层气的开采还可从根本上防止煤矿瓦斯事故，改善煤矿安全生产条件，减少煤层甲烷排放导致的强烈温室效应，对全球大气环境的保护具有积极作用。

中国不仅是一个煤炭资源大国，煤层气资源也极为丰富。我国政府和有关工业部门高度关注煤层气的勘探开发，近年来成效斐然。但是，由于种种原因，投入与回报的比例仍不尽如人意。首先，煤层气资源量的计算依据尚不完善，致使对于资源量评价结果的可靠性难以把握，对全国煤层气资源总量及其分布的不均一性缺乏清醒的认识。第二，中国地质条件复杂，煤层气地质理论尚不成熟，对全国或煤层气主要赋存地区的煤层含气性、煤储层物性、控气地质特征等缺乏系统探讨和总结，煤层气选区评价标准和方法有待深入研究，这是以往某些煤层气勘探开发选区失当的重要原因。第三，煤储层不同于常规天然气储层，煤层气钻井、完井和排采技术不能完全移植常规天然气的有关技术，煤层气勘探开发中的有关工艺技术亟待改进。第四，煤层气开发经济评价有待进一步加强，以便有效地降低煤层气资源勘探开发的成本和风险性。

鉴于上述现状，中国煤田地质总局积极开展了前期研究工作和勘探开发试验，40 余年来不仅在煤炭资源勘探中获得了大量煤层气、煤储层特征等方面的资料，而且近年来又开展了多项煤层气地质、煤层气勘探方法和开发工艺等方面的专项研究，在辽宁铁法、山西寿阳、山西霍东、山西西山、陕西韩城、河北峰峰、河南平顶山、安徽淮南、江西丰城、四川南桐等矿区进行了专门的煤层气勘探或开发试验工作。从 1993 年至 1998 年，中国煤田地质总局在全国部署施工煤层气参数井和生产试验井共计 25 口，并在铁法、韩城、寿阳等矿区成功地获得了工业性煤层气气流，积累了宝贵的勘探开发经验。在此基础上，中国煤田地质总局于 1995 年启动了“全国煤层气资源评价”研究项目，1997 年由原煤炭工业部列为部规划研究项目(编号 97－415)。该研究项目的目的，是通过对全国煤层气资源量、煤层含气性、煤储层特征、有利区带优选和有关控气地质因素的系统评价与研究，深入探讨和总结中国煤层气地质特征，为我国煤层气开发利用提供科学的决策依据，为创立中国煤层气地质学理论体系奠定基础。

“全国煤层气资源评价”研究项目起始于 1995 年 3 月，完成于 1998 年 8 月。第一阶段(1995 年)，由全国各省(区)煤田地质局进行省级煤层气资源评价，提交省(区)报告共计 26 份，报告主编如附表所列。第二阶段(1996～1998 年)，在中国煤田地质总局领导下，由中国煤田地质总局第一勘探局主持、中国矿业大学协作完成了“全国煤层气资源评价”研究项目。中国煤田地质总局副局长倪斌教授级高级工程师担任项目领导小组组长，淮南工业学院唐

修义教授、中国矿业大学刘焕杰教授担任研究顾问，第一勘探局叶建平高级工程师、中国矿业大学秦勇

研究前期各省(区)煤层气资源评价报告主编一览表

省 (区)	主 编	省 (区)	主 编
东北及内蒙古东部地区	李子俊	甘肃省	马 珂
黑龙江省及内蒙古东部	李子俊、王文化	青海省	王 嵩
辽宁省	林学雁	宁夏回族自治区	陈 元
吉林省	林学雁	贵州省	易同生
内蒙古自治区	刘建威	四川省	吴福祥
陕西省	李智学	云南省	杨复胜
山西省	王仲平	湖南省	刘登荣
河北省	李英超	湖北省	江振寅
河南省	盛建海	江西省	黄文涛
山东省	范士彦	广西壮族自治区	庞业旺
安徽省	叶诗忠	广东省	黄炳源
江苏省	傅雪海	浙江省	赵仲明
新疆维吾尔自治区	高志军	福建省	杨作霖

教授、中国煤田地质总局林大扬教授级高级工程师等 12 人组成研究小组。研究报告是在中国煤田地质总局各省局 1995 年底提交的分省报告基础上编制完成的，其背景资料以全国第三次煤田预测(1997)及有关科研报告为基础，同时参考了地矿、石油和煤炭系统其他兄弟单位的有关最新研究成果。本项目取得的研究成果主要包括三个方面：第一，《全国煤层气资源评价》研究报告；第二，中国煤层气资源图(1：200 万)；第三，全国煤层气资源数据库。

研究项目由国家煤炭工业局委托全国煤炭工业技术委员会组织最终鉴定。原煤炭工业部总工程师尚海涛教授级高级工程师任鉴定委员会主任委员，杨起院士和韩德馨院士任鉴定委员会副主任委员，戴金星院士、冯良处长、郝玉策教授级高工、彭苏萍教授、孙茂远研究员、张树明教授级高级工程师、杨锡禄教授级高级工程师、王双明教授级高级工程师、朱峰教授级高级工程师、顾谦隆教授级高级工程师等 10 名学者专家为鉴定委员会委员。鉴定委员会对研究成果给予了许多鼓励和高度评价，一致认为研究成果“总体上达到国际先进水平，部分成果处于国际领先水平”。本著作即是在该研究报告的基础上经过修订、深化和再创造编纂而成的。

本书由叶建平、秦勇、林大扬任主编。各章节的执笔者分别如下：前言，林大扬、叶建平、秦勇；第一章，林大扬、张德民、叶建平、傅雪海、王子和；第二章，叶建平；第三章，唐书恒、林大扬；第四章，桑树勋；第五章，叶建平、傅学海；第六章，秦勇、王长海、张德民、王子和、叶建平；第七章，秦勇；第八章，叶建平、秦勇；英文目录和英文摘要，秦勇、傅雪海。全书由秦勇、叶建平负责统稿，叶建平最终定稿。唐修义教授、刘焕杰教授对研究工作予以了悉心指导，唐修义教授在每一个关键阶段均提出了具体意见，全面把关和审定。中国煤田地质总局原副局长梁继刚教授级高级工程师对书稿内容做了全面校核。中国煤田地质总局袁国泰处长、秦杰副

处长、左光国副处长、袁三畏高级工程师、黄凯芬处长和中国煤田地质总局第一勘探局林建法局长、史保生副总工程师、张春才处长等均提出了大量的建设性意见。中国煤田地质总局地质处、科技处和第一勘探局煤层气勘探开发研究所对于研究工作的顺利实施进行了卓有成效的领导、组织和协调。本著作既是中国煤田地质总局几十年来勘探研究成果的总结，也饱含着全国煤层气地质和煤田地质工作者的辛勤劳动，因而本书是集体智慧的结晶。

戴金星院士对于本项目研究工作十分关心，给予了许多鼓励和指导，并欣然为本书作序。研究工作还得到了中国煤田地质总局高洪烈高级工程师、程爱国高级工程师、宇新生高级工程师，山西煤田地质局许惠龙教授级高级工程师，中国煤田地质总局第一勘探局王留基高级工程师、刘昌勤高级工程师、陈春琳高级工程师、李素芬高级工程师、王洪林教授级高级工程师、李守乾高级工程师，安徽煤田地质局章云根高级工程师和焦作工学院资源与环境工程系等的支持和帮助。在此，谨向上述单位和专家学者表示衷心感谢。

本著作的出版是在中国煤田地质总局、中国煤田地质总局第一勘探局的直接领导、全力支持和热情关心下得以实施的，中国煤田地质总局倪斌副局长、袁国泰处长以及第一勘探局林建法局长、史保生副总工程师、张春才处长鼎力支持，为本书能尽早面世、奉献给广大读者发挥了积极的和关键的作用。东北煤田地质局曹立刚经理、陕西煤田地质局186队王兴总工程师、中国石油天然气集团总公司新区事业部煤层气项目经理部经理赵庆波教授级高级工程师等为本书提供了煤层气井的现场照片，在此一并表示感谢。

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主编谨识

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COALBED METHANE RESOURCES OF CHINA

ABSTRACT

The exploration and development of the coalbed methane (CBM) resources in China has remained to the assessing and testing stage for a long term. Thus, it is necessary that some aspects for coalbed methane geology in China, such as resources, geological controls and coal reservoirs, are farther studied, and the CBM developing technology suitable to the conditions of coal geology in China needs to be continually consummated still. Relying on the rich information of CBM content and coal geology from all the coal-bearing basins of China, accumulated by China National Administration of Coal Geology during past more than forty years, the research project "Assessment on Coalbed Methane Resources of China" was accomplished in the December, 1998, in combination with the valuable coal reservoir data recently obtained by the CBM well testing. The scientific book was written just on the basis of the main achievement of the project, value of which lies in showing systematically the distribution and its geological controls of the CBM resources in China for the first time.

Firstly, the distribution of the CBM resources in China has been scientifically revealed.

(1) Basing upon the data from the coal and CBM geology, which is most integrative, systematic and detailed by far, the quantity of the CBM resources over China was re-estimated. The total CBM resources of 14. 34 trillion $(14.34\times10^{13})m^3$ in the coal reservoirs with more than 4 m^3 per ton of methane content and less than 2000 m of burial depth was acquired. Therein, the prospective resources is 13. 37 trillion m^3 accounting for the 93. 24% of the total resources, and the expected reserves is 0. 97 trillion m^3 accounting for the 6. 76%. The resources in the coal reservoirs with methane content of more than 8 m^3 per ton is 12. 44 trillion m^3 accounting for the 86. 75% of the total resources, and the those with the methane content of 4 to 8 m^3 per ton is 1. 90 trillion m^3 accounting for the 13. 25%. The resources in the coal reservoirs with less than 1500 m of burial depth is 9. 26 trillion m^3 accounting for the 64. 58% and those with the 1500 m to 2000 m of burial depth is 5. 08 trillion m^3 accounting for the 35. 42%.

The CBM resources in China occur mainly in the North China CBM-province where the resources is 9. 55 trillion m^3, holding the 66. 60% of the total. The CBM resources in the South China CBM-province are 4. 13 trillion m^3, accounting for the 28. 80% of the total. In the Northeast China and Northwest China CBM-provinces, the resources are respectively 0. 42 trillion and 0. 24 trillion m^3, only accounting for the 2. 93% and 1. 61% of the total. As for

the administrational province, the resources in ascending order exist successively in Shanxi, Guizhou, Shaanxi, Gansu, Henan and so on.

(2) The CBM regionalism of China was scientifically made and the five provinces, including the 30 zones and 115 districts, were creatively distinguished. At the same time, the CBM resources and its abundance of all the CBM provinces, zones and districts were statistically computed in accordance to the reliability grades, quality grades and burial depth of the resources.

The nine types of the CBM zones over China were ascertained on the basis of the area and CBM resources abundance, including the 13 small-scale ones, the 9 middle-scale ones and the 7 large-scale ones. Similarly, the nine types of the CBM districts over China were also distinguished. As concerns the area, the 45 small-scale, 39 middle-scale and 31 large-scale CBM districts occur in China. As for the resources abundance, there are the 33 CBM-rich districts with more than 150 Mm^3 per square kilometer of abundance, the 49 CBM-bearing ones with 50 to 150 Mm^3 per square kilometer of abundance and the 33 CBM-poor ones with less than 50 Mm^3 per square kilometer of abundance. The CBM districts of China are generally characteristic of the more number, the much various area, the middle-scale abundance and the much scattered occurrence, and the middle- and large-scale ones as well as the CBM-bearing and -rich ones occur almost in the North China and western South China CBM-provinces.

Secondly, the distribution in space-time of the CBM-bearing characteristics of the coal reservoirs in China has been essentially found out.

(1) Through the systematical analysis to the regional, stratigraphic and burial distribution of CBM-bearing factors such as the CBM content, concentration, resources abundance and saturation, the occurrence in space-time of the CBM-bearing characteristics of the coal reservoirs in China has been essentially found out. This provides a scientific foundation for the CBM resources assessment and optimum seeking of potential zones and districts.

(2) In the North China CBM-province, the districts with similar CBM-bearing characteristics are naturally assembled into the CBM belts along latitude line, and the CBM-poor and -rich belts alternatively occur in region, for example, Daqingshan-Kailuan, Liulin-Yangquan-Jizhong, Hancheng-Jincheng-Anyang, western Henan-Huainan/Huaibei ones. This is also true along longitude line, and, for instance, the western Ordos, eastern Ordos, Qinshui, Taihangshan CBM-belts appear in turn form west toward east. In the Northeast China CBM-province, the CBM zones or districts, which are generally typical of the lower CBM content, lower CBM concentration, higher resources abundance and higher CBM saturation extend along NE or latitude strike. In the South China CBM-province where the zones and districts are commonly characteristic of the higher CBM content and saturation, there exist two CBM belts composed of the CBM-rich districts, i. e., the eastern Yunnan-weastern Guizhou-northern Guizhou-southern Sichuan belt with longitude strike and the central Hunan-central Jiangxi belt with northeastern strike. The Northwest China CBM-province, where the CBM-bearing

characteristics are closely related to the tectonic and magma activity, is high in CBM resources abundance but relatively low in CBM content and concentration.

Thirdly, the physical properties of the coal reservoirs in China have been systematically summarized and overall discussed.

(1) The CBM absorption-desorption and its distribution of the coal reservoirs in China are particular in some degree. According to the now-available data, the absorption constant a value varies little among the CBM-provinces or \|districts, but evolves regularly with increasing coal rank. The a values of the dry coal samples with 0.5% to 1.1% or more than 3.5% maximum vitrinite reflectance ($R_{o,max}$) tend to reduce, but those with 1.1% to 3.5% $R_{o,max}$ rises with increasing coal rank. However, the a values corrected by inherent moisture enhances when the $R_{o,max}$ is less than 3.5% and reduce when the $R_{o,max}$ is more than 3.5%.

The absorption constant b values of the coals from the all South China CBM-districts, the most North China CBM-districts and some Northeast China CBM-districts are less than 0.25, and rise with increasing coal rank, reaching a maximum about in meagre coal. Those in the other North China districts and the most Northeast China districts are more than 0.25, and seem to be identically correlated with coal rank.

The CBM absorption ratio of the coals in China ranges from 22% to 65%, and is relatively low. The absorption time, commonly changing from a few hours to several days, is such short that the gas production peaks of the CBM wells might be attained in a shorter drainage period.

(2) The Langmuir volumes of the wet coal samples in China are notably correlated with those of the dry ones on the basis of the measured data. Accordingly, the relationship between the two can be expressed by an empirical equation through which the Langmuir volume measurements from the dry sample are possibly conversed into the wet data. The moisture content in coal influences largely the absorbing capability of the coals to methane and determines the acquisition of some key parameters such as CBM saturation in some degree. Thus, the empirical equation suitable to the absorbed property of the coal reservoirs in China provides a possibility for utilizing effectively a large number of the Langmuir volume measurements obtained previously from the dry samples, which might produce sufficiently a economic benefit in the assessment of the CBM-developed geological conditions.

(3) The data collected from the seventy-six seams of the twenty-three districts showed that the well-testing permeability of the coal reservoirs in China ranges from 0.002 md to 16.17 md, averaging 1.27 md. The mean permeability of the seven of the twenty-three districts is more than 1.0 md, that of the ten extends from 0.1 md to 1.0 md and that of the five is less than 0.1 md. Although there exists generally the geological setting of the low coal reservoir permeability in China, the cases with relatively high permeability are not absent, and occur commonly under the background of the low permeability in some districts. Accordingly, looking for the coal reservoirs or blocks with high permeability in the districts with the setting

of low permeability is a key to the strategic deployment of the CBM exploration and development in China.

According to the current data, the permeability of the coal reservoirs in China is regionally distributed in some regular patterns. The mean coal reservoir permeability of three CBM zones in the North China CBM-province, i. e. , eastern Ordos, Weibei and Qinshui ones, is much higher than that of the other zones in the province. In other words, the coal reservoir permeability in the western North China is overall higher than that in the eastern. The coal reservoir permeability in the Northeast China CBM-province is higher than that in the Northwest China CBM-province but lower than that in the North China CBM-province. This is an important reason why the current activity of the CBM development in China tends to be conducted in the western and middle North China, and indicates a quiet great progress in the investigation to coal reservoirs in china.

The permeability of the coal reservoirs in China is greatly influenced by the modern tectonic stress field, and is associated with the burial depth of coal reservoirs in some degree. The main stress differentia of modern crustal stress field is well correlated to the permeability, which could be used to predict the areas with highly permeable coal reservoirs.

(4) The pressure of the coal reservoirs in China is ordinarily low but high in some cases. According to the well-testing data from the sixty-four seams of the twenty-one districts, the pressure gradients vary from 2. 24 kPa/m to 17. 28 kPa/m. Therein, the 29 under-pressured coal reservoirs accounting for the 45% of total reservoir amounts, the 14 normally pressured those with the gradient of 9. 30 to 10. 30 kPa/m for the 22% of the total, the 17 highly pressured those for the 21% of the total and the 4 ultra-pressured those with the gradient of more than 14. 70 kPa/m for the 6% of the total are included.

(5) The critical desorption pressure, recovery and saturation of the coalbed methane in the coal reservoirs of China are quietly low, which might be unfavorable of the CBM resources development. The critical desorption pressure range generally from 0. 5 MPa to 1. 74 MPa, with the maximum of 5. 98 MPa to 6. 51 MPa. The CBM desorption ratio varies from 6. 7% to 76. 5%, averaging 27%. The coal reservoirs in China are almost undersaturable, with the CBM saturation ranging from 15. 8% to 83. 3%, averaging 44%.

Fourthly, the investigation of the CBM-controlled geological conditions in China has been systematical made for first time.

(1) The relationship of the CBM accumulation to geotectonics and CBM-bearing structure was discussed. The authors suggested that the basement and geotectonic position of the coal-bearing basins are key to the CBM formation, accumulation and developmental potential. The potential of the CBM resources and its development might be well for the coal-bearing basins situated in the platform or the intermediate region between the platform and folded belt, relatively poor for those in the folded belts, and largely various for those located in the intermediate massifs. The CBM-bearing structures were summed up into the four types including the

eleven models, the distribution of these types or models in main CBM-accumulating zones or districts was investigated, and the geological controls of them to CBM accumulation were deduced.

(2) Based upon the analysis to the tectonic evolution and seam buried and heated history, the geological conditions of the CBM formation and accumulation in the different parts and coal-formed periods of China were discussed. The first CBM generation of the Upper Paleozoic coals in the North and South China occurred during the Hercynian to Indo-Sinian movement. The crustal inversion during the last Indo-Sinian to initial Yanshannian cycles leaded to bating the coal reservoir pressure, which caused the desorption and escape of the firstly generated CBM from the coal reservoirs. The Yanshannian movement brought about a important turn of the geological history in China, which controlled not only the modern framework of the coal rank distribution in the North and South China, but also the secondary CBM generation. The secondary coalification of the most Upper Paleozoic coals befell under the abnormally high geothermal field during the Late Yanshannian. The more intense the secondary coalification, the higher the coal rank, the more remarkable the secondary CBM generation. Moreover, the geothermal event derived from the magma activity during the Yanshannian might result in the geothermal metamorphism of some Mesozoic coals, which was favorable of the CBM generation.

(3) The relationship of the surrounding rock assemblies to their sealing capability was discussed in the light of the sedimentation. It was suggested that the surrounding rock assemblies in the delta and barrier coast systems might be well in the sealing capability to CBM, and those in the alluvial fan, shallow sea and open coast systems might be poor. Taking the South and North China as instances, the correlation of CBM content to sedimentary and surrounding rock assemblies was deduced, which is significant of the prediction of CBM content.

(4) It was found that the absorption constant a value does not vary gradually with increasing vitrinite content in coal reservoirs but becomes suddenly large at a critical content of the 55%. This correlation is independent of the coal ranks, exists not only in the CBM provinces but also in some given CBM districts. The differentia of the absorptivity among various macerals was regularly defined. The authors suggested that those might be mostly derived from two reasons, i. e. , the specific pore surface area related to the pore structure and the absorption potential of the macerals to methane. The a value of the macerals with high specific surface area and absorbed heat is certainly high, but that only with large specific surface area might be low sometimes and dependent of its absorbed heat still.

(5) The control of the thickness and structure-destroyed degree of the coal reservoir to its permeability was revealed according to the well-testing data from the 47 seams in the North China CBM-province. As for the structure-destroyed coal reservoirs, the well-testing permeability tends to be negatively correlated to the thickness. As concerns the coal reservoirs not destroyed by the paleo-structure stress fields, the well-testing permeability enhances generally with increasing the thickness when the permeability is less than 0. 5 md, but that reduces

instead when the permeability is more than 0. 5 md. Thus, the permeability of the structure-destroyed coal reservoirs might be greatly dependent of the thickness controlled comprehensively by sedimentation and subsequent structure. However, the permeability of the reservoirs without structure-destroyed coals and with the permeability of less than 0. 5 md might be collared in some degree by the natural fissures relative to sedimentation.

(6) The hydrogeological conditions effect markedly the CBM migration and accumulation. In this book, three hydrogeological CBM-controlled patterns were suggested, i. e. , the hydraulic migration-escape, the hydraulic sealing and the hydraulic jam. Specially, the hydraulic migration-escape, which was propounded by the authors in this book for first time, leads to the CBM escape and is unfavorable of the CBM accumulation. This pattern is characteristic of the productive aquifer, strong runoff and well hydraulic connectivity between the aquifer and coal reservoir, that is to say, the CBM resources in the areas with strong runoff are commonly poor. Conversely, the hydraulic sealing or jam is favorable of the CBM accumulation.

(7) The CBM accumulation in the Upper Paleozoic coal reservoirs of China was distinctly influenced by the CBM desorption-diffusion-migration effect since the coal reservoir is a kind of organic reservoir in which the equilibrium of the CBM absorption to desorption is strictly controlled by the pressure derived from the overlay strata. The CBM escape or re-accumulation is dependent of the equilibrium. Thereby, the much deeply the coal reservoirs were buried, the much weakly the CBM occurrence was controlled by the conventional gas-controlled factors such as structure. Conversely, the importance of the conventional gas-controlled factors would be emphasized. In the districts with the bituminous coal or anthracite reservoirs, the lighter the stable carbon isotope of coalbed methane, the more remarkable the CBM migration effect, the closer the sealing conditions for the CBM accumulation to those for the normal natural gas. For this reason, a close attention should be paid to the distribution of the stable carbon isotopes of the coalbed gases when the optimum seeking for the potential CBM-accumulating zones or districts is made.

Fifthly, the methodology for the optimum seeking of the potential CBM-accumulating zones and districts has been instituted.

(1) Abided by the dialectical thought from geological investigation (qualitative) through quantitative ordering (quantitative) to geological analysis (re-qualitative), a quantitatively assessing method, called as "risk probability plus Analytic Hierarchy Process", was put forward, and the methodology, named as "Key Factor Progressive Optimum Seeking", was established by the authors for first time. Following those, the potential CBM zones and districts in China were evaluated and sorted through the comprehensive analysis to the four quantitative factors including geometry, reservoir, cap rock and resources, taking account of the key elements such as CBM content, area, resources abundance, reservoir permeability and critical desorption pressure to reservoir pressure ratio, and referring to the qualitative factors

such as hydrogeology, structure, sedimentation and paleo-geothermal history. The methodology surmounts the limitation of the traditional methodology called as "comprehensive assessing standard", is more operational and comparative, and provides a new thought for the optimum seeking of the CBM zones and districts in China.

(2) Based upon the current data and cognizance, the potentials of the 29 CBM zones except for Taiwan could be concluded respectively into three levels, i. e. , very favorable, favorable and rather favorable ones which were further classified into the 3 pattern including the 8 types. The potential of the large-scale and CBM-rich Qinshui zone is very favorable. The potentials of the large-scale and CBM-rich eastern Yunnan-western Guizhou and eastern Ordos zones, the middle-scale and CBM-rich Xuzhou-Lianghuai and eastern Taihangshan zones are favorable. Those of the nine zones such as the large-scale and CBM-bearing Weibei are rather favorable, and those of the other zones such as the large-scale and CBM-rich southern Sichuan-northern Guizhou might be unfavorable.

(3) The 115 CBM districts over China were divided into two categories with or without the CBM well-testing data, the former was called as the confirmed ones and the latter as the unconfirmed ones. According to the evaluated area and CBM resources abundance, these districts were further classified into the 3 pattern including the 9 types. Based upon those, the CBM potentials of the districts were evaluated in accordance with the now-available data. In the confirmed category, the potentials of the large-scale and CBM-rich Yangquan-Shouyang, Jincheng and Hancheng districts are very favorable, those of the large-scale and CBM-rich Liulin-Sanjiao and Huaibei districts and the middle-scale and CBM-rich Anyang-Hebi district are favorable, and those of the eight districts such as the little-scale and CBM-bearing Tiefa and middle-scale and CBM-bearing Pingdingshan are rather favorable. As for the unconfirmed category, the potentials of the three CBM districts such as the large-scale and CBM-rich Liupanshui might be favorable.

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