

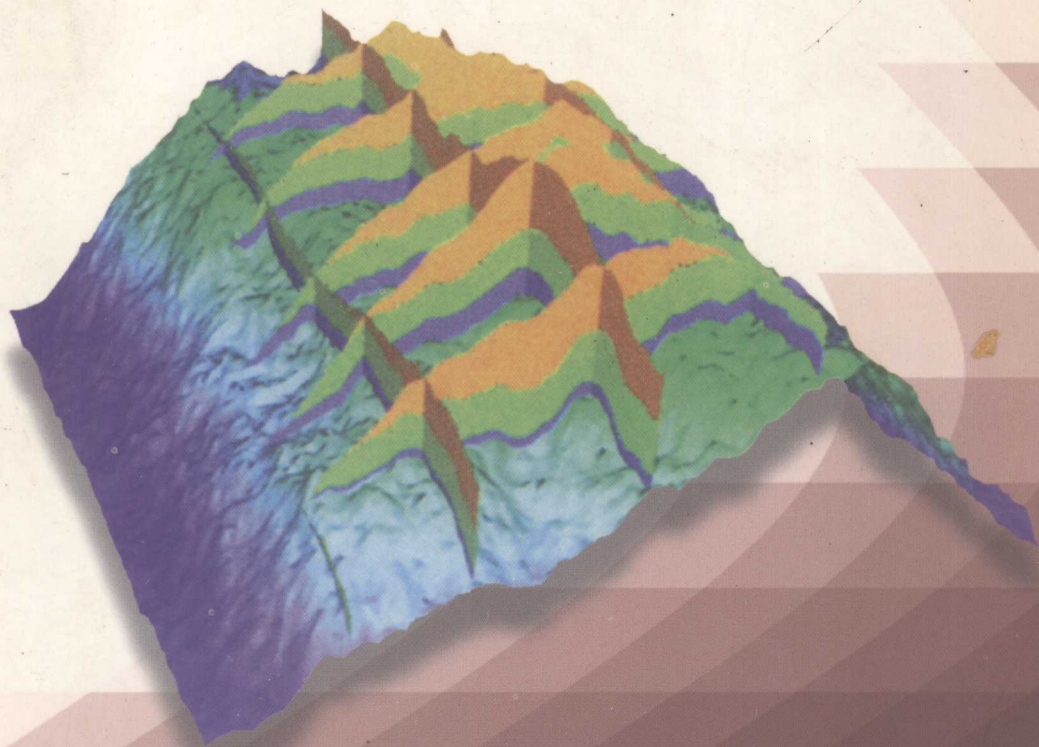
金之钧 张一伟 主编

油气成藏机理研究系列丛书·卷五

5

油气运移机理及物理模拟

曾溅辉 王 捷 等著



石油工业出版社
Petroleum Industry Press

油气成藏机理研究系列丛书·卷五

金之钧 张一伟 主编

油气运移机理及物理模拟

曾溅辉 王 捷 等著

石油工业出版社

内 容 提 要

本书为《油气成藏机理研究系列丛书》之卷五。全书共分七章,第一章论述了油气运聚成藏机理与油气运聚成藏模拟实验的研究现状与发展趋势,介绍油气运聚成藏物理模拟实验装置、设计与建造和功能;第二章为孔隙介质油气运移机理及物理模拟,主要探讨了界面力作用、浮力作用、压差驱动和热力作用下孔隙介质油气运移物理模拟实验结果以及油气运移机理;第三章着重讨论了孔隙介质含油、气饱和度增长的机理;第四章为裂隙介质油气运移成藏地质分析;第五章讨论了裂隙介质油气运移的物理模拟实验技术和方法,进行了裂隙介质油气运移的数值模拟,探讨了裂隙介质油气运移机理;第六章探讨了油气输导系统的类型和特征,阐述了均质和非均质(层间非均质和层内非均质)砂层输导系统油气运移机理及物理模拟;第七章介绍了断层输导系统油气运移模拟实验技术、方法以及模拟实验结果和应用,探讨了断层输导系统石油运移的影响机理及模拟实验。

本书适合于石油勘探及开发科研人员以及石油和地质院校相关专业的师生参考。

图书在版编目(CIP)数据

油气运移机理及物理模型/曾溅辉等著.

北京:石油工业出版社,2002.12

(油气成藏机理研究系列丛书;5/金之钧,张一伟主编)

ISBN 7-5021-4050-6

I. 油…

II. 曾…

III. 油气运移-物理模拟

IV. P618.130.1

中国版本图书馆 CIP 数据核字(2002)第 094617 号

石油工业出版社出版

(100011 北京安定门外安华里二区一号楼)

石油工业出版社印刷厂排版印刷

新华书店北京发行所发行

*

787×1092 毫米 16 开本 14.5 印张 365 千字 印 1—1500

2002 年 12 月北京第 1 版 2002 年 12 月北京第 1 次印刷

ISBN 7-5021-4050-6/TE.2892

定价:45.00 元

《油气成藏机理研究系列丛书》

编辑委员会

主 任 张一伟

副主任 金之钧 王 捷 潘元林

委 员 (按姓名笔画排列)

王志章	王宜林	王 捷	方朝亮	石宝珩
关德范	张一伟	刘洛夫	陈章明	金之钧
邱楠生	吴胜和	吴元燕	罗治斌	庞雄奇
周家尧	周新源	袁明生	查 明	姜振学
傅诚德	蒋有录	曾溅辉	熊继辉	熊琦华
潘元林	蔡希源			

序 一

《油气成藏机理研究系列丛书》是原中国石油天然气总公司“九五”期间设立的重大基础研究项目“大、中型油气田成藏定量模式研究”的主要成果。回首六年前该项目立项的历史背景，今天读这部系列丛书，倍感它的重要价值。

20 世纪 90 年代初期，我国国民经济持续快速发展，出现了改革开放以来的经济发展高峰。1992 年，国民经济增长速度达到了 13%，随之石油供不应求的势头也日趋明显。中央领导十分关切石油，仅 1995 年，就先后有 5 位党和国家领导人深入塔里木盆地等石油单位考察，听取中国石油天然气总公司汇报，并作了许多重要指示。80 年代末至 90 年代初，全国石油勘探可采储量增长减缓，不能满足石油生产快速增长的需求，石油工业已经成为制约国民经济发展的“瓶颈”之一。要保持石油工业的持续稳定发展，必须解决好资源储量的接替问题。

但是，80 年代末以来，我国东部老油区资源探明率已达 30%~50%，寻找新的储量难度越来越大，而西部则面临着地面、地下条件复杂的情况，油气勘探面临多方面的挑战。作为油气勘探战线上的一名老兵，我深深体会到石油地质理论对油气勘探实践的指导意义。勘探要有新突破，首先要在理论和技术上有突破。一个新理论的诞生，往往会开辟一个新领域，并相应产生新的工艺技术，从而推动石油工业不断向前发展。因此，无论在全国油气勘探会议上，还是在塔里木盆地油气勘探开发技术座谈会上，我都曾多次强调开展基础理论研究的意义。在 1994 年中国石油天然气总公司油气勘探工作会议的总结报告中强调，要加强大区研究，从板块运动的历史去研究大区的地质结构和油气生成、运移、聚集的规律。在 1995 年举行的高级勘探专家座谈会上，又进一步提出新理论、新技术、新方法的重要性，指出油气勘探工作应着重发现新的领域、新的层系和新的油气藏类型，要求中国石油天然气总公司各职能部门规划好科研项目，积极组织落实，逐步形成符合深化勘探要求的勘探理论与技术。为此，设立“大、中型油气田成藏定量模式研究”项目。通过该项目的研究，形成一些指导我国油气勘探的新思路、新观点和新认识，同时培养一批勇于探索和注重实践的年轻学者。

该项目由石油大学（北京）牵头，组织了胜利油田、新疆油田等多家油田及院校有关研究力量，联合开展了油气生成、运移、聚集、保存与破坏的微观机理研究，以及盆地范围内油气分布规律研究，取得了许多重要的新认识和新进展，有效指导了各油田的油气勘探。在 2001 年 8 月，由中国石油天然气集团公司主持的成果鉴定中，包括石油勘探界、地质界五位院士在内组成的鉴定委员会，给予该项目成果“整体达到国际先进水平”的评价。由金之钧教授和张一伟教授主编完成的《油气成藏机理研究系列丛书》，正是在该项目研究基础上，经过一年多集体的共同努力，进一步总结、上升形成的，这套丛书具有以下几个方面的特点：

第一，实现了宏观与微观的结合。这套丛书包括了油气生成、运移、聚集、保存与破坏各个方面宏观与微观的研究，系统阐述了油气藏形成和分布各个环节的机理，探索了油气分布规律及主控因素，系统分析了中国含油气盆地同世界含油气盆地的差异性，得出的油气以

晚期成藏为主、近距离运移等结论，对于指导中国油气勘探发挥了重要作用。

第二，强调典型解剖与面上研究的结合。该丛书首先以准噶尔盆地和济阳坳陷为典型研究区，深入研究了控制油气运聚成藏的宏观控制因素，探讨了盆地的温度场、压力场（异常高压）和应力场对油气生成、运移、聚集和成藏过程的影响与作用，然后从典型区带的典型油气藏入手，通过典型解剖，深入剖析我国典型盆地、典型油气藏的形成条件、成藏力学作用、机理及成藏过程，最后通过地质研究和物理模拟，剖析油气生成、运移、聚集、保存与破坏的微观机理，为我国油气藏成藏机理研究提供了良好的范例。

第三，进行了物理模拟和数值模拟的结合。在地质研究基础上，通过物理模拟技术和方法，揭示油气生成、运移、聚集、保存与破坏的微观机理，取得了一系列新的认识，如氯化盐类在生烃过程上具有反催化作用，储集层孔渗级差（或非均质程度）为控制含油饱和度及油气运移优势通道的关键因素。在物理模拟的基础上，实现了从物理模拟到数值模拟的过渡，并开展了生排烃、油气运聚等方面的数值模拟。

第四，实现了定性与定量的结合。在地质分析和物理模拟、数值模拟的基础上，完善了各种油气分布的定量模式，建立了各种形式的油气排运量与主控因素之间的定量关系，并通过建立油气成藏体系，形成了油气运移量、聚集量和资源量的定量模式。

第五，体现了基础理论与实际应用的结合。丛书不仅就深盆地成藏机理、油气突发式成藏模式、储集层物性级差对含油气饱和度的影响等基础理论问题，提出了有价值的创新性观点，而且紧密结合我国油气勘探实践，对油气勘探战略选区进行了预测，对我国油气勘探提出了八条建议，具有重要意义。

丛书的出版，展示了我国油气成藏理论研究水平的提高，涌现了一批从事油气成藏理论研究的青年学术带头人 and 新秀，标志着我国油气成藏理论研究进入了一个较高的发展阶段和我国石油地质理论研究后继有人。该丛书的问世，不仅丰富了我国石油地质理论，同时也为我国油气勘探实践提供了理论指导，是从事石油地质研究和教学科研人员难得的教学科研参考书。

没有理论指导的实践是盲目的实践，没有实践检验的理论也往往是站不住脚的。我衷心地希望广大油气勘探管理者与决策者能够积极支持基础理论研究，自觉地使用先进理论指导实践，也希望广大理论研究者能够深入现场，在实践中检验理论，发展理论，把理论研究工作不断推向新水平。

王涛

二〇〇二年十二月二十六日

Foreword One

The Series of Books on Oil / Gas Accumulation Mechanisms are the major results of the project of “*Studies for Quantitative Models of Oil / Gas Accumulation in Medium- and Large-sized Fields in China*” which was funded by CNPC as one 9th Five-year Plan Key Project. Thinking of the background for the project six years ago and reading the series now, I can further feel its significance.

The early 1990s was one of the periods when Chinese economy experienced the fastest growth. In 1992, China's GDP recorded a growth of 13%. Because of the high growth rate, China's domestic petroleum supply could not meet demand. Thus leaders of central governments paid a greater attention to the Chinese petroleum industry. In 1995 alone, five senior state leaders successively inspected several oilfields and received oral presentations made by CNPC senior managers. Subsequently they gave important instructions. During the period from the late 1980s to the early 1990s, China experienced a downward trend in its annual domestic new reserves additions and the reserve additions could not keep pace with an increasing petroleum production. As a result, the petroleum supply became one of bottlenecks limiting the nation's economical development. In order to grow the Chinese petroleum industry at a steady and sustainable rate, we must find enough new reserves to replace the produced petroleum.

Since the late 1980s, 30 – 50% of the estimated total resources have been found in the mature petroliferous basins in eastern China and discovery of new reserves has become more and more difficult in this part of China. In western China, the harsh surface conditions and complex subsurface geology made the petroleum exploration very difficult and challenging. As a petroleum geologist with over 50 years experience, I can deeply appreciate the importance of petroleum geoscience theories in guiding petroleum exploration. Breakthroughs in petroleum exploration are largely attributed to breakthroughs in theories and technologies. Generally a new theory can open up a new exploration domain and advance relevant technologies. Therefore, I have emphasized the importance of fundamental theoretic research again and again at National Petroleum Exploration Conferences and Technology Symposium for the Petroleum Exploration and Development in the Tarim Basin. In my concluding presentation at the 1994 Petroleum Exploration Conference of CNPC, I also emphasized that we should enhance regional studies and investigations of geological structures and hydrocarbon generation, migration and accumulation within the plate tectonic framework. In the 1995 Exploration Symposium attended by senior explorationists, I further emphasized the importance of new theories, new technologies and new methodologies, and pointed out that we must pay a greater attention to explore oil/gas in new areas, new stratigraphic intervals and new plays. I demanded that the various departments of CNPC should layout the scientific projects and actively organize them so that we could develop new exploration theories and technologies that meet the demand of the petroleum exploration. The project of “*Studies for Quanti-*

tative Models of Oil /Gas Accumulation in Medium-and Large-sized Fields in China" is one of those funded by CNPC. Its aims are to obtain new thoughts, new viewpoints and new understandings, as well as to train a number of young scholars who like the challenge of oil/gas exploration.

The project was coordinated by University of Petroleum, Beijing and assisted by the Shengli Oil Administration, Xinjiang Oil Administration and other institutions. Project participants from these organizations studied the micro-mechanisms of hydrocarbon generation, migration, accumulation, preservation and destruction, as well as the oil/gas distribution in sedimentary basins. They have obtained many new important findings that can effectively guide the petroleum exploration. At the assessment meeting for this project presided by CNPC in August 2001, the evaluation committee, which include five academicians with expertise in the areas of exploration and geoscience, highly commended the achievements of this project, which are regarded as being advanced internationally. *The Series of Books on Oil /Gas Accumulation Mechanisms* are edited by Professors Jin Zhijun and Zhang Yiwei and the main contents of the series are largely derived from the results of the project. The book series have following characteristics:

Firstly, the series illustrate how macro studies are combined with micro investigations. They contain both macro-and micro-scaled studies of hydrocarbon generation, migration, accumulation, preservation and destruction. They also document the various mechanisms for hydrocarbon accumulation, characterize oil/gas distribution and the key factors controlling the distribution, and explain the differences between Chinese and foreign petroliferous basins. The series conclude that timing of oil/gas charging was late and migration distance was short, which provides helpful guidance for the Chinese petroleum exploration.

Secondly, the series document the combination of detailed analyses with general studies. With the Junggar Basin and Jiyang Sub-basin as typical study areas, the series give detailed description of the macro-factors controlling hydrocarbon migration and accumulation, as well as discussion of the effects of temperature, pressure (abnormal high pressure) and stress fields on the processes of hydrocarbon generation, migration, and accumulation. With typical analyses of typical oil/gas reservoirs in typical plays, subsequently, the authors have analyzed the forming conditions, mechanics, mechanisms and processes of typical basins and oil/gas reservoirs. At the end, the book series document the micro-mechanisms of hydrocarbon generation, migration, accumulation, preservation and destruction obtained by geological analyses and physical simulations. The series set up a good example for studies of hydrocarbon accumulation mechanisms.

Thirdly, the series illustrate how physical simulations are combined with numerical simulations. Through physical simulations based on the geological analyses, the authors have obtained new findings about the micro-mechanisms of hydrocarbon generation, migration, accumulation, preservation and destruction. These include chlorite salts have anti-catalysis effects during hydrocarbon generation, the porosity and permeability difference (magnitude of heterogeneity) of reservoir rocks is the key factor controlling the oil saturation and preferential migration pathways. Thanks to the physical simulations, the authors have made it possible for the transition of physical simulation to numerical simulation. They have also developed the numerical simulations of hydro-

carbon generation, expulsion and accumulation.

Fourthly, the series document the combination of qualitative descriptions with quantitative studies. Based on the geological analyses, and physical and numerical simulations, the authors have perfected the quantitative models for various hydrocarbon distributions and established the quantitative relationships between the expelled, migrated amounts of hydrocarbons and key controlling factors. The authors have also established the quantitative models for the migrated and accumulated amounts of hydrocarbons and oil/gas resources with the petroleum accumulation system approach.

Fifthly, the series illustrate how basic theory research results can be combined with real applications. The authors have proposed valuable and innovative findings in several areas, including the accumulation mechanism of deep-basin gases, the bursting model of hydrocarbon accumulation and the controlling effects of reservoir heterogeneity on oil saturation. In addition, by taking the Chinese petroleum exploration reality into consideration, the authors have suggested the strategic regions for future petroleum exploration and raised eight pieces of significant advices for the future Chinese petroleum exploration.

Publication of the book series indicates the advancement of the theoretic studies on hydrocarbon accumulation. The fact that many young Chinese scientists have been engaging in the theoretic studies on hydrocarbon accumulation symbolizes that the theoretic studies on hydrocarbon accumulation have entered a new stage. We have trained enough capable young scientists to succeed the retiring scientists. The series not only enrich the petroleum geoscience theories, but also provide theoretic guidance for the future Chinese petroleum exploration. They are very important reference books for researchers engaging in the petroleum geological study and teaching.

The practice without the theoretic guidance is purposeless practice. The theory without being validated by practice is commonly untenable. I earnestly hope that the managers and decision makers of petroleum exploration can actively support the basic theoretic research and self-consciously use the advanced theories to guide exploration. On the other hand I highly recommend that the academic researchers also should get into the fields and validate and develop theories through practice, accordingly, accelerate the development of theoretic research.

Wang Tao

Former President of China National Petroleum Corporation

2002.12

序 二

自从石油工业产生以来,油气成藏机理研究一直是石油地质学研究的核心内容。例如早在19世纪怀特建立了“油气藏形成的背斜理论”,20世纪以来,许多学者发展了“油气藏形成的背斜理论”,相继产生了“非背斜构造油气藏”、“异常压力圈闭”、“水动力圈闭”、“天然气运聚动平衡”、“陆相成油理论”、“复式油气聚集带”等理论和认识,有效地指导了油气地质勘探,推动了石油地质学的发展。但是,由于石油和天然气为流体矿产,常处于运移流动状态,导致油气藏的形成过程非常复杂,并且它们因盆而异,随时间变化,研究难度大,从而使许多油气生成、运移、聚集、保存机理和规律等重大理论问题尚未解决,成为制约我国和世界油气勘探的“瓶颈”。

我国的含油气盆地多为陆相地层,块体小,相互之间的作用强,虽然油气资源比较丰富,但地质条件非常复杂,油气勘探的难度非常大。尤其是20世纪80年代以来,油气勘探形势越来越严峻,勘探难度日益加大,油气勘探的目标已从过去大型的、简单的油气藏转向规模较小的、隐蔽的和复杂的油气藏,因此,迫切需要开展油气成藏机理研究,建立新的油气成藏理论和模式,从而指导油气勘探。为此原中国石油天然气总公司在“九五”期间设立了重大应用基础研究项目“大、中型油气田成藏定量模式研究”,由石油大学(北京)牵头,组织全国有关院校和生产单位油气成藏的研究力量,联合攻关,开展油气生成、运移、聚集和保存与破坏的综合研究,取得了一大批重要的科研成果,并且有效地指导了胜利油田、新疆油田、吐哈油田等油田的油气勘探,总体达到国际先进水平。作为这一重大项目成果的评审委员会主任,我十分高兴地向国内外同行们推荐这项成果,并建议进一步总结上升,尽快公开出版。现在该项成果已由金之钧教授和张一伟教授主编完成,并以《油气成藏机理研究系列丛书》的形式出版,我认为该丛书基本代表了“九五”期间或近十几年来我国油气成藏机理研究的主要进展,展现了以下几个方面的创新性成果和认识。

第一,深化了五个方面的研究:①实现了压力、温度与应力三场耦合及其与油气成藏关系的研究,揭示了应力对油气运聚三个层次的影响;②针对中国含油气盆地的特殊性,提出了以油气聚集为核心的成藏体系概念,初步建立了研究方法,该方法在中国含油气盆地有着更广泛的适应性和针对性;③从微观模型到宏观“大庆长垣模型”的模拟,再到东营凹陷实地岩心的镜下观测,证实了优势通道的存在,并探讨了优势通道控油气机理及成藏模式;④进行了裂缝介质及非均质砂层的含油饱和度增长规律的研究,获得了一系列有意义的新认识;⑤在油藏解剖方面本项目在静态描述的基础上,加强了成藏过程受力机理方面的研究。

第二,在微观机理方面获得了5点新认识:①发现了氯化盐类在生烃过程中起反催化作用;②通过储集层非均质性对含油饱和度影响的研究,揭示了储集层孔渗级差是控制含油饱和度的最关键因素;③通过在油气储集层中发现沸腾包裹体,初步建立了“突发式”油气成藏模式;④分析了深盆地成藏动力学平衡与物质平衡两个关键问题,建立了两类方程;⑤以埋深、成岩、热史为主线,建立了不同成岩阶段的综合动力学模型。

第三,在以往对成藏定性描述的基础上,突出定量研究,进行了由地质概念模型向物理和数学模型的转化,初步获得了催化生烃、碳酸盐岩生排烃、孔隙介质与裂隙介质含油饱和

度增长等定量模型。

第四，在油气宏观分布规律研究方面，应用统计方法获得了油气大多为短距离运移、多期成藏、优质烃源岩双 0.5 边界的认识，并在此基础上对中国未来油气勘探理论研究与实践提出了有新意的八点建议。

上述创新性成果和认识一部分已在国内外刊物公开发表或正式出版，一部分已在准噶尔盆地、渤海湾盆地济阳坳陷和吐哈盆地等的油气勘探实践中得到应用，并取得了明显的经济效益。因此，我认为该套丛书的问世，展示了我国油气成藏机理的研究水平，标志着我国油气成藏机理研究已进入一个新的更高的发展阶段。它的出版不仅为石油地质研究人员介绍了油气成藏研究的方法，为油气勘探家提供了大、中型油气田的形成模式和勘探思路，同时也为从事石油地质教学的师生提供了很好的教学材料，是一套难得的教学和科研参考书。我相信该丛书的出版将推动我国油气成藏机理研究的深入发展，对我国油气勘探将产生重要的指导作用。为此，我很高兴地为该丛书作序，并郑重地推荐给各位读者。

中国工程院院士

彭光明
二〇〇二年十一月

Foreword Two

Since the birth of the modern petroleum industry, the studies on hydrocarbon accumulation mechanism are the core topics of petroleum geology at all times. In the 19th century, White had already established the “*anticline theory*”. Since the beginning of the 20th century, many scholars have developed the anticline theory and proposed a number of new theories, including “*non-anticline structural oil / gas traps*”, “*abnormal pressure trap*”, “*hydrodynamic trap*” and “*dynamic balance of natural gas dissipation and accumulation*”, “*theory of non-marine oil origin*” and “*complex oil accumulation fairway*”. The theories have effectively guided the petroleum exploration and accelerated the development of petroleum geology. As oil and natural gas are fluid deposits that can flow, however, the processes of hydrocarbon accumulation are very complicated. In addition, the accumulation processes vary with the different basins and geological times. It is very difficult to investigate them, Thus a number of questions related to the mechanisms and characteristics of hydrocarbon generation, migration, accumulation and preservation have not been fully tackled, which has become the bottleneck constraining worldwide petroleum exploration.

Most of Chinese petroliferous basins were filled with continental sediments. The blocks constituting the China continent are small in size and their interactions are intensive. Although China is rich in petroleum resources, its geological conditions are very complex and the petroleum exploration is very difficult. Since the 1980s, Chinese petroleum exploration has become more and more challenging and difficult as the exploration targets have shifted from large-sized, simple structural traps to smaller, complex subtle traps. Thus it is very necessary to intensify the studies of hydrocarbon accumulation mechanisms and establish new theories and models for hydrocarbon accumulation. Under these circumstances, China National Petroleum Corporation (CNPC) established the 9th Five-year Plan Project of “*Studies for Quantitative Models of Oil / Gas Accumulation in Medium-and Large-sized Fields in China*” coordinated by University of Petroleum, Beijing (UPB). UPB organized scientists, engineers and geologists from nationwide institutions to jointly carry out the project. These researchers have obtained many important results, which have effectively guided the petroleum exploration in the Jiyang Sub-basin, Junggar Basin and Tuha Basin. Most of their achievements have reached the internationally advanced level. As the chair of the evaluation committee for the project, I am glad to introduce the book series to domestic and overseas colleagues. I advised to publish the results as soon as possible. Professors Jin Zhijun and Zhang Yiwei have now accomplished the publication of “*The Series of Books on Oil / Gas Accumulation Mechanisms*”. I think the series generally reflect the major advancements in the studies of hydrocarbon accumulation mechanisms during the 9th Five-year Plan period or the past several decades. The series of books contain following new creative achievements and new understandings:

(1) The authors have deepened the theoretic research in five areas including: ① They have studied the interactions between the pressure, temperature and stress fields and the relationships between these fields and hydrocarbon accumulation. They concluded that the stress affects hydrocarbon migration and accumulation in three ways; ② Taking the special characteristics of Chinese petroliferous basins into considerations, the authors have established the concept of the petroleum accumulation system and illustrate how to use this new concept to investigate hydrocarbon accumulation. The methodology and approach of the petroleum accumulation system developed by these authors have broader applications and are more suitable to study the Chinese petroliferous basins; ③ The authors have validated the existence of preferential migration pathways by micro-scale modeling, simulation of the Daqing Changyuan Anticlined Belt and the optical microscope observations of cores from the Dongying Depression. In addition, they have also discussed the mechanisms and models for hydrocarbons to migrate and accumulate through the preferential pathways; ④ The authors have studied the features of the oil saturation increment in the fractured medium and in the heterogeneous sandy carrier bed and they have obtained new findings and understandings; ⑤ Based on the comprehensive description of oil/gas reservoirs, the authors have enhanced the studies about mechanisms of driving forces for petroleum accumulation.

(2) In the area of micro – scale mechanisms for hydrocarbon accumulation, five new findings have been obtained and they include: ① The authors have found that chloride salts have anti-catalysis effects during hydrocarbon generation; ② They have found that the porosity and permeability difference (magnitude of heterogeneity) is the most important factor controlling the oil saturation; ③ Based on the presence of the boiling fluid inclusions found in oil/gas reservoirs, the authors have established the bursting model for hydrocarbon accumulation; ④ Analyses of the dynamic balance of various forces and the material balance have led to the establishment of two types of equations for the accumulation of deep – basin gases; ⑤ The authors have set up the comprehensive dynamic models for different diagenetic stages based on analyses of the burial history, diagenesis and thermal history.

(3) Based on the qualitative depiction of hydrocarbon accumulation, they have given prominence to quantitative studies and converted geological conceptual models to physical and mathematical models. They have set up quantitative models for hydrocarbon generation by catalysis, hydrocarbon generation and expulsion by carbonate rocks and the oil saturation increment in the porous and fractured media.

(4) With regarding the oil/gas distribution, they have obtained new understandings. Analyses of statistical data indicate that the oil/gas migration distance is fairly short for the majority of fields. Accumulation of hydrocarbons proceeded during multiple episodes. High-quality source rocks characterized by TOC greater than 0.5% and R_o higher than 0.5% are required for oil/gas to accumulate in enough quantities to form a major field. They have also proposed eight pieces of advices about the theoretic research and the future Chinese petroleum exploration.

Parts of the above achievements have been published in domestic or international journals or monographs. The new findings and advices have been applied to the petroleum exploration in the Junggar Basin, Tuha Basin and Jiyang Sub-basin, which have yielded fruitful economic benefits.

Therefore, I think that the series of books reflect the level of studies on hydrocarbon accumulation mechanism. The publication of the book series symbolizes that the theoretic studies on hydrocarbon accumulation mechanisms have entered a new advanced stage. The series not only provide methodologies and models for studies of hydrocarbon accumulation in medium-and large-sized fields but also new play ideas for petroleum explorationists. In addition, they are a set of great reference books for teachers and students engaging in the petroleum geoscience teaching and research. I believe that the publication of the series will accelerate the studies of hydrocarbon accumulation mechanisms and guide the future Chinese petroleum exploration. Hereby, I am very glad to write this foreword and highly recommend the books to readers.

Zhai Guangming

Academician of Chinese Academy of Engineering

2002.11

前 言

发现油气藏是油气勘探的最终目标，而油气藏又是石油地质学研究的核心。研究油气藏形成过程、总结油气藏在时空的分布规律及主控因素，不但可以直接指导油气田勘探开发的实践活动，同时又是石油地质理论的核心问题。自石油工业产生以来，油气成藏机理研究得到了迅速的发展。早在 19 世纪建立了油气藏形成的“背斜理论”，20 世纪以来，相继产生了“非背斜构造理论”、“异常压力圈闭理论”、“水动力圈闭理论”、“天然气运聚动平衡理论”等，这些理论有效地指导和推动了油气地质勘探。另外，生烃化学动力学方程、流体势理论以及盆地古地温理论和分析化验技术，为近几年发展起来的盆地模拟技术和油气成藏研究打下了理论基础。我国石油地质工作者结合我国特定的大地构造环境，形成和发展了独具特色的陆相成油理论体系。这些理论有效地指导了我国和世界的油气勘探，丰富和完善了石油地质理论。但是，油气藏形成过程非常复杂，影响因素由宏观上的盆地变形至微观上的毛细管作用和分子扩散作用，涉及了生物作用、化学作用、物理作用和地质作用，它们均可因盆而异，并随时间变化，研究难度大，从而使许多油气生成、运移、聚集、保存机理和规律等重大理论问题尚未解决，成为制约我国和世界油气勘探的“瓶颈”。

目前我国的油气勘探形势越来越严峻，勘探难度日益加大，勘探目标已由过去大型的、简单的油气藏转向规模较小的和隐蔽的、复杂的油气藏，因此迫切需要开展油气成藏机理的基础理论研究，改变过去的定性推测研究方法，将典型油气藏形成过程分析与油气成藏过程的物理模拟和数值模拟相结合，进行油气成藏机理的定量研究，建立油气成藏定量模式，从而推动石油地质理论的发展，指导当前的油气勘探与开发。为此原中国石油天然气总公司设立了“九五”重大应用基础研究项目“大、中型油气田成藏定量模式研究”，由石油大学（北京）牵头，在全国范围内组织有关专业人员联合攻关，并适当组织国际合作与交流，开展油气运移、聚集及成藏模式的定量研究。这对于完善我国陆相油气成藏理论体系，丰富石油地质理论，指导油气勘探，并为油气勘探及开发提供新思路，发展新技术、新方法，造就一批从事油气藏研究的高层次的、跨世纪的人材，具有十分重要的理论意义和实际意义。

“大、中型油气田成藏定量模式研究”项目于 1995 年 11 月由原中国石油天然气总公司批准立项，1996 年 8 月项目设计获得通过并正式启动，1997 年 3 月确定为总公司“九五”十个重大研究项目之一，1999 年转为中国石油天然气股份公司管理。该项目为油气成藏的重大基础理论研究项目，其主要目的是充分发挥高等院校基础理论研究的优势，在盆地油气藏形成与分布及其主控因素和典型区带油气成藏研究基础上，集中研究油气的生成、排出、运移、聚集和保存与破坏机理。该项目下设 7 个二级课题、24 个三级专题，其主要研究内容分别为：

1. 油气藏类型、特点、分布规律及主要控制因素研究 (01)；
2. 典型区带油气藏解剖 (02)；
3. 油气生成和排烃的定量模型 (03)；
4. 油气成藏过程的动力学机制及定量模型 (04)；
5. 油气藏的保存与破坏研究 (05)；

6. 流场流体特征及其相互作用机理研究 (06);
7. 大、中型油气田成藏定量模式的综合研究 (07)。

该项目从典型盆地油气藏类型、特点、分布规律和主控因素,以及典型区带实际油气藏解剖分析出发,采用系统的、动态的和定量的研究方法,综合考虑油气的生成、运移、聚集、保存和破坏的全过程,将油气成藏典型实例分析与物理模拟和数值模拟相结合,以油气成藏动力学研究为核心,建立大、中型油气成藏定量模式。

经过五年多的研究,在大量文献调研、样品分析、模拟实验的基础上,该项目获得了一些有特色的和创新性的成果。

1. 基本完成了两项基础性建设成果即成藏物理模拟实验室建设和数据库建设。结合石油大学(北京)“211工程”建设,进行了一系列油气成藏模拟实验装置的研制、改造和实验室的建设,主要有:①研制了三套油气运移和聚集模拟实验装置。第一套为二维高温低压模拟实验装置,第二套为多功能岩心流动模拟实验装置,第三套为一维油气生成、排烃、运移和聚集模拟实验装置,在此基础上,建成了油气成藏机理模拟实验室,并成为教育部重点实验室。②完成有关油气藏保存与破坏的模拟实验装置三套,其中可控温、控压的天然气扩散系数测定装置两套,砂岩—泥岩断层的泥岩涂抹模拟实验装置一套。③组装和改装了三套孔隙介质油气运移模拟实验装置,即油水接口置换模拟实验装置、油气运移微观模拟实验装置及油气运移宏观模拟实验装置。初步建立了“中国油气藏基础数据库”的基本框架,并收集和整理了包括41个大油田、42个大、中型气田及其相关的盆地和区带地质和石油地质基础资料。该数据库具有下列特点:①基于GIS(地理信息系统)技术的数据库管理框架,使其适于各种数据库平台及各种与地质、地理相关的数据库应用。②独特的应用方法模块设计,使数据库系统不仅用于数据查询,也可用于数据处理,为石油地质综合研究提供了一种新的手段。③图形绘制功能与多媒体输出功能设计,使系统服务于科学研究全过程,人们利用数据库进行研究工作,并将研究成果反馈给数据库,使数据库不断完善、更新和扩充。

2. 发展和完善了三项研究方法和技术。

1) 初步建立了一套油气成藏机理物理模拟实验方法:①干酪根催化生烃模拟实验方法;②孔隙和裂隙介质以及输导砂层油气运移和含油饱和度增长的模拟实验方法;③单一油相和油/水两相连续(稳态)或幕式(非稳态)充注条件下,断层输导系统油的运移和聚集模拟实验方法;④考虑裂解压力因素的原油裂解成气的模拟实验方法;⑤油样的菌解模拟实验方法;⑥断层涂抹层发育特征模拟实验方法。

2) 发展和完善了适合中国多旋回含油气盆地的油气运移成藏史分析理论方法——盆地流体历史分析方法,并在烃类流体注入和储集层成岩作用之间关系、烃类流体—水—岩石之间相互作用关系方面进行了探索,深化了流体历史分析理论。同时,应用流体历史分析的方法,对油气成藏期次和模式提出了新的认识和证据。

3) 建立了油气藏解剖工作方法和规范标准。

3. 深化了4个方面的理论研究。①前期主要研究压力与油气成藏的关系,本项目实现了压力、温度与应力三场耦合及其与油气成藏关系研究,揭示了应力对油气运聚三个层次的影响。第一层次:应力是油气运移的直接驱动力;第二层次:应力作用形成油气运移的通道和影响油气运移通道的有效性;第三层次:应力促使岩层变形和变位,引起流体势场的变化。②基于一次成藏的含油气盆地建立起来的含油气系统分析方法,在多期成藏的盆地应用受到很大的限制。针对我国含油气盆地的石油地质特征,初步建立了成藏体系的概念及其研

究方法,提出了油气成藏体系的“源一位分类方案”和油气成藏体系的划分原则,比含油气系统有着更广泛的适应性。③前人提出了油气运移“优势通道”的概念,一些学者也曾在常温常压下应用玻璃管实验进行了实验论证。本次研究从微观模型到宏观“大庆长垣模型”的模拟,再到东营凹陷实际岩心的镜下观测,证实了优势通道的存在,并探讨了优势通道控油气机理及成藏模式。④前人研究了均质孔隙介质中含油饱和度的增长规律,本项目进行了裂缝介质及非均质砂层的含油饱和度增长规律的研究,获得了一系列有意义的新认识。

4. 对成藏微观机理获得了5个方面的新发现和新认识。①通过大量催化热模拟实验发现氯化盐类在生烃过程中具有反催化作用,即在氯化盐类作用下有机质总生烃量下降、反应速度降低,该结果在国内外文献中尚未见报道。②本次研究注重储集层非均质性对含油饱和度的影响,通过地质分析和实验研究了非均质性砂层的含油气饱和度增长规律,揭示了储集层孔渗级差(或非均质性程度)是控制油气饱和度的最关键因素。大量统计资料表明,无论是天然气还是稠油、稀油,当储集层的非均质程度足够高时,油气是不能成藏的,应用储集层渗透率级差来描述储集层非均质性时,天然气、稀油和稠油成藏的最大边界条件是900、300和150。③以往研究认为油气在流体势的作用下均匀缓慢的聚集成藏或是幕式成藏,本次研究通过在油气储集层中发现沸腾包裹体,并结合典型油气藏解剖及盆地构造活动规律与油气藏特点,初步建立了“突发式”油气成藏模式,即在断裂、褶皱等构造运动作用下,油气成藏过程可以在短时间内完成。④以往在深盆地成藏研究方面主要注重成藏条件和成藏特征的描述,本次研究分析了成藏动力学平衡与物质平衡两个关键问题,从天然气在孔隙介质运移动力和阻力的受力情况分析入手,揭示了毛细管阻力与浮力的平衡及毛细管阻力与膨胀力的平衡,并建立了描述深盆地成藏形成充分必要条件的力学平衡与物质平衡方程。⑤对于排烃动力学以往学者做过讨论,但其认识往往停留在单因素、单力学机理的分析上。本次研究以埋深、成岩、热史为主线,初步提出了在不同成岩阶段油气排烃的综合动力学模型,第一阶段为压实作用和扩散作用,第二阶段为多动力多相态排烃阶段,第三阶段为高温裂解气膨胀排气阶段。

5. 在油气宏观分布规律方面获得了6个方面的重要认识。

1) 通过统计分析获得形成大、中型油气田烃源岩条件的双0.5边界:即有机质丰度(TOC)大于0.5%,镜质组反射率(R_o)大于0.5%,其高峰为 $TOC = 2.0\%$, $R_o = 1.0\%$ 。就烃源岩而言,煤系地层比国外的比例大,而碳酸盐岩烃源岩比例小。

2) 中国大、中型油气田形成的油气运移距离一般小于40km,油比气具有更短的运移距离。

3) 中国大、中型油气田多数为晚期成藏,油主要为中、新生代成藏,气主要为新生代成藏。

4) 油气成藏体系范围内能否形成大、中型油气田的关键因素是油气资源的丰度。

5) 中国大、中型油气田储、盖层岩性大多以碎屑岩为主,细砂岩和粉砂岩储集层占整个储集层的70%,碳酸盐岩储集层及膏盐类盖层较国外少。中国85%的储量集中分布在500~2500m的深度范围内。

6) 中国大地构造发展演化的特殊性决定了中国油气分布的差异性。中国油多气少,储量油气比为10:1,资源量为10:4,而世界的油气比为10:7;中国以陆相油为主,国外以海相油为主;其根本原因是中国三大板块之间的多小陆板块且不稳定,含油气盆地具有“多动症”,保存条件较国外差。中、新生代以来中国主要为陆相沉积,国外含油气盆地多为海相沉