深盆气成藏机理及分布预测

Accumulation and Distribution of Deep Basin Gas

张金川　金之钧　著
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内 容 提 要

本书结合作者近年来的科研成果，从成藏机理、地质特征、分布规律、勘探预测等方面对深盆气（根缘气）进行了系统论述。全书共分6章，第一章研究了深盆气藏概念及其基本特征，第二章论述了深盆气成藏机理，第三章分析了深盆气成藏地质条件及其变化规律，第四章讨论了深盆气分布预测的方法和技术，第五章预测了深盆气在我国的分布，第六章讨论了深盆气勘探的基本策略。

本书可供从事油气勘探、资源预测、决策管理等方面的科研人员以及大、中专院校相关专业的教师、研究生参考。

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序

深盆气是在较高勘探程度下所发现的一类新的机理气藏类型，在理论和实践上具有重要意义。目前已在全球发现了数十个深盆气藏发育的盆地，主要集中在勘探程度较高的北美洲，在南美洲、欧洲、亚洲、澳洲甚至非洲也陆续发现越来越多的深盆气。深盆气成藏机理研究是一项长期艰难的探索工程，国外的深盆气勘探研究经历了长期曲折的历程，但鉴于深盆气成藏机理特殊、资源量巨大、存在形式多样以及分布规律复杂等原因，对其成藏和分布进行研究具有越来越重要的科学意义和潜在的广阔应用前景。

加拿大和美国是深盆气勘探开发和理论研究的两个典型代表。到目前为止，对深盆气成藏理论解释的基本观点已多达十余种，对这一问题的不同理解直接产生了不同的深盆气成藏及分布认识。但无论如何，合理解释深盆气藏中普遍存在的气水倒置现象和深盆气藏的表现特征均是不可回避的基本问题。深盆气藏地质分布规律与常规气藏构成了优势互补，它通常存在于构造较低部位的致密储集层中，需要深入凹陷寻找甜点。因此，若能在大量勘探工作投入之前落实深盆气的存在并预测其分布有利区，将会使深盆气的勘探产生突飞猛进的效果。

中国复杂的石油地质特征，势必导致深盆气成藏比国外更复杂，有更多问题需要进一步研究。在我国，深盆气成藏理论分析和勘探应用研究起步不久，尚属于一个崭新的领域，目前仍处于百家争鸣阶段，在深盆气前景认识和评价方面还存在许多不同看法，在深盆气成藏标准的认识、模式特征的健全化、分布预测的合理化、勘探评价的系统化等方面还存在许多问题有待进一步探讨。

从深盆气概念的传入算起，我国的深盆气研究经历了风雨 20 余年。早期阶段是深盆气理论的引进和初期研究阶段，在 J.A.Masters 1980 年访问成都地质学院进行学术交流时，我国专家就指出了川西坳陷和鄂尔多斯盆地有存在深盆气的可能，但该阶段的深盆气研究主要是运用地质类比分析方法进行区域上的盆地预测，不同的研究者先后完成了调研报告或类比分析报告，从而开始了我国的深盆气研究；随着鄂尔多斯盆地上古生界的勘探进展和天然气研究的发展，国内连续组织召开了两届深盆气研讨会，深盆气研究在我国得到了实质性的发展，深盆气预测范围在我国也得到了迅速扩大。近期以来，深盆气研究在实验分析、理论研究以及勘探生产等方面都取得了很大的发展。

在我国开展深盆气研究是一项系统工程，前后涉及到了许多研究人员的艰辛劳动。本书作者自 1996 年以来在深盆气领域完成了大量探讨性工作，构成了我国深盆气研究的一个重要方面。在严肃的科学态度基础上，作者始终将研究所得结论的正确性与合理性作为惟一的标准，在深盆气成藏理论研究、实验分析以及应用实践方面的研究认识，已经得到了不同程度的认可。从这一意义来说，作者的研究已经对我国的深盆气研究产生了积极的推动作用。

该书重点从实验分析、理论研究和盆地预测等方面对深盆气的成藏分布机理和勘探技术方法进行了系统论述，提出了深盆气成藏的系统思路和勘探预测的系统方法，其中不乏创新性的观点和结论认识，是我国深盆气研究的一部力著，故推荐大家一读，并将受益匪浅。

中国科学院院士

2003 年 12 月

Preface

Deep basin gasis a type of gas accumulation with new mechanism discovered at high exploration degree. The gas is of great significance both in theory and practice. Dozens of basins bearing deep basin gas have been currently found worldwide, which are concentrated in North America where the exploration degree is relatively high. More and more deep basin gas is found in South America, Europe, Asia, Australia and even Africa, too. The study of the deep basin gas accumulation is a long – term and difficult project, which has been substantiated abroad. Researching the accumulation and distribution for deep basin gas has become more and more important in terms of science and has a broad prospect for application owing to the special accumulation mechanism, the magnitude of resources, the variety of existing forms and the complexity of distribution law.

Canada and United States are two countries in which deep basin gas or basin – centered gas accumulations have been successfully developed. Up to now, there are more than 10 opinions to illustrate the accumulation mechanism of this kind of gas, each of which will bring particular explanation and different application for the predication of deep basin gas accumulation. However, it is a non – avoided problem for the general phenomenon of water over gas to be reasonably interpreted and represented characteristics of deep basin gas to be expatiated. Most deep basin gas and conventional gas accumulations distribute respectively in the deep basin and shallow basin to consummate the geological distribution law of natural gas. Occurred within the tight sand reservoirs, exploration for deep basin gas accumulation should turn into deeper part of depression in search for sweet points. Therefore, it will save a great deal of time and money to predict timely and accurately the favorable distribution of deep basin gas accumulations before confirmation of its existence by drilling exploration many wells.

Compared to the basins abroad, complicated petroleum geological characteristics in China basins will inevitably cause more complicated issues concerning deep basin gas accumulation, which need to be brought under further studies. Since the theoretical analysis and exploration application on deep basin gas started not long ago in China, it is still a new field open to various opinions and disputes over the assessment of the deep basin gas prospects. There are still a lot of issues to be further settled of deep basin gas accumulations on standards for distinguishing identification, perfection for model characteristics, reasonability for distribution prediction, and systematization for exploration assessment.

Deep basin gas in China has experienced two decades since the conception was introduced into the

country. The early stage marks introduction of the deep basin gas conception and preliminary study in this discipline. When J. A. Masters visited Chengdu Geological Institute for academic exchanges in 1980, China experts initially came up with the possibility that deep basin gas might exist in Western Sichuan and Ordos Basins. Studies at this stage were featured with geological analogical analysis for prediction of regional basins, when the different researchers completed investigation or analogical analysis reports and started China's deep basin gas study. With the progress in Upper Palaeozoic exploration in Ordos Basin and the further breakthrough on natural gas in China, two conventions have been hold in China making the substantial progress in the country's deep basin gas studies. With the rapidly enlarged scope of predicted deep basin gas in China, deep basin gas accumulations have been seen significant development in experiment, exploration, production, and theoretical study in recent years.

The authors of this book have done a large quantity of research work in the deep basin gas field, which is an important part of China's deep basin gas studies. The deep basin gas study is a systematic project in China involving hardworking of many researchers. Based on the scientific attitude, the authors have always taken the correctness and reasonability of the conclusions drawn from their studies as the sole standards. The research results they have achieved in the theoretical study of deep basin gas accumulation, experimental analysis and application practice have been accepted at different levels. Therefore, their works have actively promoted the deep basin gas study in China.

Focusing on experimental analysis, theoretical study and geological prediction, this book elaborates systematically the accumulation mechanism, distribution laws and exploration methods for deep basin gas accumulations. Compared to other studies both at home and abroad, the book also comes up with a series of creative principles and techniques for exploration and prediction of deep basin gas accumulations. That is the reason why I recommend this valuable book focusing on China's deep basin gas study and I am convinced that readers will be much benefited.

Dai Jinxing

Academician of China's Academy of Sciences

December 2003

前　言

自1976年在加拿大西部的阿尔伯达盆地发现艾尔姆华士巨型深盆气田以及1979年J.A. Masters提出深盆气藏概念以来，它作为一种特殊的非常规气藏类型在中国受到了日益广泛地重视。深盆气藏以地质储量巨大为基本特色，目前已在北美的非常规气藏(依次为深盆气、煤层气、页岩气和水溶气等)产、储量构成中占据着最重要的地位。

天然气的广泛应用正在改变着能源消费结构，而越来越多的深盆气发现正在成为油气勘探接替的重要领域。深盆气是一种具有普遍意义的气藏类型，是致密砂岩气的主要表现形式，是高勘探程度条件下对油气成藏赋存规律的重新认识。Spencer(1989)，B. E. Law和C. W. Spencer(1993)认为，致密砂岩气藏(深盆气藏)几乎存在于所有的含油气区；R. C. Surdam(1999)在AAPG年会(San Antonio)上发言认为，盆地中心气(深盆气)是现今世界上最热点的勘探类型(K. Shirley，1999)，它的顶界面表现为区域地震速度的反转面(该面在美国一般为2100～2800m，在阿尔伯达盆地为1000m或更浅)。他指出，现今为止所发现的天然气中大约90%为常规圈闭气，但将来所发现的油气很可能有90%为深盆气；基于深盆气藏与常规气藏之间的机理过渡关系研究，作者(2001)在理论上也指出了深盆气藏的存在具有普遍意义；B. E. Law(2002)又进一步指出，深盆气目前已经成为油气勘探的热点。

在世界范围内，目前已发现了越来越多的深盆气藏，除了美国和加拿大西部地区盆地以外，国外目前又在更广泛的地区内发现或认证了深盆气藏的存在。到目前为止，已在勘探程度较高的美洲、欧洲、亚洲等地区发现了大量深盆气。按Law(2002)资料统计，全球已发现或推测发育深盆气的盆地有70个，其中，北美34个、欧洲20个、亚太9个、南美2个、南亚2个、中东1个、非洲2个。实际上，这一数据仍在不断增加。在我国，许多盆地，尤其是中西部地区盆地具有良好的深盆气发育潜力，目前已在鄂尔多斯、吐哈、四川等盆地中找到了深盆气发育的大量证据，在塔里木、准噶尔、柴达木、沁水、楚雄、松辽、南华北、苏北以及焉耆等盆地中预测了深盆气的发育。

理论和技术的不断发展为我国深盆气的勘探实践带来了新的契机，深盆气勘探预测研究对迎来我国天然气新的储量增长高峰具有积极意义。我国的油气勘探在20世纪，尤其是20世纪下半叶以来取得了辉煌的成就，但由于需求的不断增加，现今的油气勘探发展仍然面临着社会经济建设高速发展的巨大压力。我国目前的油气勘探形势和存在问题主要是勘探程度普遍较低，后备储量发展不均衡，亟须找到新的能源接替领域，摆在我们面前的基本问题是在保证稳产基础上增加储量发现率，找到高丰度、大规模的油气田。

自从J.A. Masters发表西加拿大深盆气圈闭(1979)一文以来，我国的相关研究也陆续展开。

在深盆气研究工作的早期，主要通过与阿尔伯达盆地地质条件的类比，指出了四川盆地和鄂尔多斯盆地可能存在深盆气藏。但由于深盆气的成藏机理和成藏条件尚不清晰明了，因此深盆气评价预测主要使用地质条件类比方法，进一步的预测评价和勘探应用受到了很大制约。在深盆气理论研究方面，一直存在着不同的观点认识，多种成藏机理解释百花齐放；在深盆气应用研究中，一直存在着两种基本看法，一种认为中国盆地不存在深盆气成藏的特殊地质条件，另一种则认为中国盆地致密砂岩普遍发育，深盆气普遍存在。后期经我国多方专家的共同努力，分别在鄂尔多斯、四川、吐哈等盆地针对深盆气藏特点完成了大量工作，取得了重要成果和认识。但如何评价并发现更多的深盆气藏、进一步扩大深盆气勘探领域并将巨额的深盆气资源量合理有效地转化为产出量仍然是一件需要投入精力进行研究的问题，首先需要从理论上解决深盆气的成藏机理问题。

我们的深盆气研究工作开始于1996年，先后完成了“吐哈盆地台北凹陷深盆气成藏条件研究及有利勘探区带预测”、“台北凹陷深盆气有利勘探目标选择等”一系列相关的研究任务。在1999年之后，陆续申请并接受了中国博士后科学基金（中博基[2000]23：侧重于成藏模式及勘探评估研究）、中国石油天然气集团公司石油中青年创新基金（Cx 2000－2：王志欣、张金川，侧重于实验分析、评价研究）以及国家自然科学基金（40172052，40272062，40472073，侧重于成藏机理研究）的资助，并与国家“十五”攻关项目（2001BA605A05－01－04，侧重于川西坳陷研究）合作，研究工作进一步系统化，研究深度逐渐加大。从1998年开始，我们针对深盆气成藏机理先后展开了探讨性实验研究，其中包括两相流微观运动实验、气水卡断—连续运移的模型实验、气水倒置条件实验、深盆气藏异常压力演化实验、三维仿真模拟实验等，在此基础上提出了典型深盆气成藏的活塞式运移原理。2001年以来又对深盆气成藏机理进行补充实验，形成了深盆气成藏机理解释的系统认识。为了进一步确认实验结果的可重复性和实验分析的可靠性，我们又不断对部分实验进行了验证分析，进一步的实验研究目前仍在进行中。

在资料分析和实验研究基础上，从1997年开始逐渐形成了深盆气成藏理论的系统认识（如深盆气成藏动力平衡方程、活塞式成藏模型等），1999年构建了本书框架；2000年，与吐哈油田合作完成“台北凹陷深盆气有利勘探目标选择”研究任务并于2001—2002年取得了良好的生产效果，理论认识和研究方法得到进一步成熟。通过进一步的实验分析和理论研究，本书书稿定型（书中所列参考文献截至2002年，并在随后的研究中，我们逐渐使用“根缘气”术语来代替“深盆气”概念）。由于深盆气的成藏机理与分布规律研究尚有许多争议问题有待进一步探究，为求认识结论的真实可靠，在2003—2004年间，我们又对书中的部分结论和认识进行了多次斟酌。几经反复酝酿，最终决定在近期将书稿正式出版。值得欣慰的是，虽然本书的出版时间较晚，但部分成果认识已经或正在得到不同程度地认可和验证。

书中以历年的研究成果为基础，以国家自然科学基金资助项目研究成果为主线，对深盆气以及与深盆气相关的实验分析、理论研究、应用实践等方面成果做了压缩总结和系统分析。以《深盆气成藏机理及分布预测》奉献读者，期望抛砖引玉并对深盆气成藏机理和我国的深盆气勘探预测研究

做出力所能及的贡献。书中所用资料、基本观点和认识结论均截止于2002年底，对其中一些反映前期情况的统计数据已根据现状资料进行了修正，对某些非紧密有关的资料和数据也做了大量删减。由于深盆气研究仍在进行，一些观点认识也将会不断得到修正和充实，这还有待于今后工作的进一步努力。

依据深盆气研究的系统性，本书在内容上共分六章：第一章以北美发育的深盆气为地质模型，研究讨论了深盆气概念；第二章从微观过程原理讨论了深盆气从初次运移直到封闭保存各主要过程的基本特点，运用动力分析原理和渗流力学原理研究了深盆气的成藏过程；第三章讨论了深盆气成藏条件及其变化特征；第四章系统地总结研究了深盆气藏的预测方法和勘探技术；第五章对我国的深盆气发育进行了区域性预测，以吐哈盆地为例进行了解剖研究；第六章对深盆气勘探的方法、原理和技术进行了系统分析。

本书的撰写完成始终得到了张一伟教授、郑浚茂教授、贾承造院士、戴金星院士和王涛博士等的支持和指导，得到了石油大学(北京)盆地与油藏研究中心庞雄奇、曾溅辉、汤良杰、陈崇和、姜振学、王志欣、王洪玉等人的支持，得到了不同深盆气课题组成员以及袁明生、钱基、张世焕、张代生、宋岩、罗晓容、赵应成、钱凯、戚厚发、贾红育、蔡忠贤、张永贵等教授专家的支持与帮助，许多研究生也提供了有益的帮助。

作为一种新的机理类型，深盆气(根缘气)研究仍然存在许多争论。同时也由于时间仓促，水平有限，文中错误在所难免，恳请读者批评指正。

作者2002年于北京

(出版前修改)

Foreword

As a special unconventional type of gas accumulation, deep basin gas has drawn more and more extensive attention in China since the giant deep basin gas fields were found in Alberta Basin in Western Canada 1976 and J. A. Master came up with the conception of deep basin gas 1979. Characterized with magnitude of geological reserves, deep basin gas currently takes the most important position in the unconventional gas production and reserves in North America, following the order as deep basin gas, coal – bed methane, shale gas and water – dissolved gas.

Wide application of natural gas is changing the energy consumption structures. With more and more deep basin gas discovered, it is becoming an important field for oil and gas exploration. As a new kind of gas accumulation discovered under high exploration degree, deep basin gas is the main form for gas accumulation in tight reservoirs existing universally in the world. In the opinions of C. W. Spencer (1989), B.E. Law and Spencer (1993), tight sand gas , or basin – centered gas / deep basin gas exists nearly in all of oil and gas areas in the world. R.C. Surdam deemed 1999 at San Antonio that basin – centered gas is one of the hottest targets for exploration in the present – day world (K. Shirley, 1999). The top interfaces of this kind of gas accumulations represent as a regionally inverted seismic interface, which is generally 2100 – 2800m in the western basins in USA and about 1000m in Alberta Basin in Canada. He pointed out that about 90 percent of natural gas so far found was normally trapped types, but 90 percent of oil and gas to be found in the future will likely to be deep basin gas. Based on the cognizing of the mechanically transitional relations between deep basin gas accumulation and conventional ones, we pointed theoretically out that the existence of deep basin gas accumulations are of extensive significance in 2001. B. E. Law (2002) further pointed out that basin – centered gas or deep basin gas has currently become the focus of oil and gas exploration. More and more deep basin gas accumulations have been presently discovered worldwide. They are confirmed to exist in more extensive regions worldwide in addition to the basins in North America such as Europe and Asia where the exploration degrees are relatively high. Based on the statistical data by B. E. Law (2002), a total of 70 basins in the world are found or predicted to occur this kind of gas accumulation, of which 34 basins are located in North America, 20 in Europe, 9 in Asia – Pacific, 2 in South America, 2 in South Asia, 1 in the Middle East, and 2 in Africa. Actually, these figures are still on the rise. In China, many basins have great potentials for deep basin gas accumulation, especially the basins in Middle and Western China. A great deal of

evidences for deep basin gas accumulations have been found in Ordos Basin, Turpan – Hami Basin, Sichuan Basin and so on. In addition, Tarim Basin, Junggar Basin, Qaidam Basin, Qinshui Basin, Chuxiong Basin, Songliao Basin, Bohai Bay Basin, Southern North China Basin, Subei Basin, and Yanqi Basin have also been predicted to exist deep basin gas accumulations.

Theoretical and technological development provides new opportunities for deep basin gas exploration in China. The prediction of deep basin gas is of great significance to China's reserve peak of natural gas. Remarkable achievements in China's hydrocarbon exploration have been made in the 20th century, especilly the second half of the past century. However, the current oil and gas exploration and development is still confronting with a huge pressure of the rapid social and economic development with the demand growing steadily. The current situation and main issues in China's oil and gas exploration are relatively low exploration degree in extensive areas and imbalanced development of the newly found reserves. It is of great urgency to find the new substitute energy field. The basic tasks facing us are to increase the discovery rate of reserves and find high – abundance and large – scale oil and gas fields on the conditions to keep the production stable.

The related study has been brought under way in China since J.A. Masters published his article on deep basin gas in Western Canada 1979. The early studies on deep basin gas in China were based the possible existence and geology analogy with Alberta Basin in the basins of Sichuan and Ordos. However, the main method for assessment on deep basin gas prediction is analogy of the geological conditions because the deep basin gas accumulation mechanism and conditions remain unclear, seriously impairing the further assessment on prediction and exploration application. Theoretically, the different opinions always exist in the deep basin gas study. There are always two basic opinions in the study of deep basin gas application in China, one of which is that China's basins have no favorably geological conditions for deep basin gas to accumulate and the other is that there is extensive development of tight sand reservoirs in China's basins with extensive existence of deep basin gas accumulations. Having made joint efforts to complete a large quantity of work focused on the deep basin gas reservoir characteristics in Ordos Basin, Sichuan Basin and Turpan – Hami Basin, Chinese experts made a great deal of important achievements later. However, it is necessary to make greater efforts for assessment and discovering more gas accumulations, further expansion of the deep basin gas exploration field, and reasonable and effective conversion of abundant deep basin gas resources into production. First and foremost, it is necessary to theoretically clarify deep basin gas and its accumulation mechanism.

Our works on deep basin gas accumulation started from 1996. During the year from 1999 to 2003, we applied for and received the support from China Postdoctoral Science Foundation, Innovation Foundation of CNPC and National Natural Science Foundations of China. In addition, we cooperated with

the nation's 10th Five – Year Plan to systemize and expand our research work. Starting from 1998, we conducted the experiments on the deep basin gas accumulation mechanism, including the microcosmic experiments on two – phase flow, gas – water disconnected and continuous migration model, water over gas conditions, abnormal pressure evolvement of deep basin gas, and 3D realistic model. The principle for piston – style migration and typical accumulation of deep basin gas is proposed on the basis of those experiments. The supplementary experiments on deep basin gas accumulation mechanism were made later in 2001, shaping the system of knowledge to interpret the accumulation mechanism for deep basin gas. To confirm the repeatability of the experimental results and the reliability of experimental analysis, we made analysis to confirm the experiment results later. Further experimental studies are still under way.

A system of knowledge about the deep basin gas accumulation theory has been gradually shaped on the basis of data analysis and experimental studies since 1997. In the year 1999, the framework of this book was established. The Project *Selection of Favorable Targets for Deep basin Gas Exploration in Taibei Depression* was finished in 2000 with the desirable production results achieved between 2001 and 2002, making the theoretical knowledge and study methods further matured. This book is shaped through the efforts for further experimental analysis and theoretical studies in 2002. However, many disputes concerning the deep basin gas accumulation mechanism and distribution laws remain and need to be brought under further studies. To ensure the reliability of the conclusions, we repeatedly discussed some of the conclusions and knowledge in the book from the year 2003 to 2004 and finally decided to publish this book recently.

Based on the study results achieved in the past years and the support from the research projects supported by the National Natural Science Foundation, this book systematically summarized and analyzed the results achieved from experimental analyses, theoretical studies and application practices related to deep basin gas. We provide readers with *Accumulation and Distribution of Deep Basin Gas* in the attempt to make contributions to the studies on accumulation mechanism and exploration prediction of deep basin gas in China. The deadline for the data, basic conceptions and conclusions in this book is the end of 2002.

According to the systematic deep basin gas study, this book is divided into six chapters. The first chapter discussed the conception and geological models of deep basin gas. Based on the micro process studies on general characters of deep basin gas from initial migration to preservation, the second chapter discussed the gas accumulation process by using dynamic analysis principle. The third chapter discussed the geological conditions and variation characteristics for deep basin gas accumulations. The fourth chapter systematically summarized and studied the prediction methods and exploration technologies for deep basin gas. Taking Turpan – Hami Basin as an illustrating example, the fifth chapter predicted the

regional distribution of deep – basin gas accumulations in China. The sixth chapter systematically analyzed the methods, technologies and strategies for deep basin gas exploration.

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目　录