

贾承造 主编：塔里木盆地石油地质与勘探丛书

(卷五)

TARIM BASIN

塔里木盆地 重点层系储盖层评价

朱筱敏 顾家裕 贾进华 等著

石油工业出版社
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内 容 提 要

本书在大量地震、地质、测井和钻井资料结合的基础上,对塔里木盆地寒武—奥陶系的生物礁的特征和分布规律及储集性能进行了研究分析,对重点层系东河砂岩段进行了详细的层序地层分析,探讨了东河砂岩的沉积环境、成岩作用及对油气的控制作用,建立了塔中和塔北东河砂岩不同的沉积模式;利用自生矿物、碳氧同位素和烃—水岩的相互作用分析了碎屑岩储层的发育和演化规律;从宏观和微观上对塔里木盆地的油气盖层进行了分析和评价;对从未涉及的处女地塔东南地区进行了初步的沉积相分析,建立了沉积模式。

本书可供从事石油地质、沉积储层研究的地质科研人员和大专院校师生参考。

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序

以“九五”期间勘探与研究成果为内容的《塔里木盆地石油地质与勘探丛书》一套十二卷即将面世，这是“九五”期间奋战在塔里木盆地这块热土上的全体石油地质工作者集体劳动的结晶，也是石油工业出版社同志们辛勤劳动的产物。它是塔里木盆地油气勘探史上重要的一环。丛书的出版，必将引起国内外石油界的广泛瞩目和浓厚的兴趣，我对丛书的出版表示热烈祝贺。

塔里木盆地的油气勘探从 20 世纪 50 年代算起已经有 50 多年了，其间因为种种原因，经历了“几上几下”的曲折历程，也积累了丰富的资料和经验教训。1989 年 4 月经国务院批准由中国石油天然气总公司组织了塔里木盆地石油会战，从而为在塔里木盆地大规模全面展开油气勘探迈出了扎实的历史性的步伐。与此同时国家也组织了相应的以塔里木盆地油气勘探为内容的“八五”和“九五”的重点攻关项目。

《塔里木盆地石油地质与勘探丛书》的内容，正是在广大石油工作者近 40 年野外和盆地周边地质调查和钻探、石油地球物理勘探局挺进大漠后连续苦干近 20 年所取得的丰硕资料，在“七五”和“八五”国家重点攻关研究工作的基础上，通过 5 年或更长时间的实践和研究所取得的成果，在此期间，对重点地区和重点层系进行了艰苦有效的研究和实践，应该说取得了令人满意的勘探成果，开创和深化了新的理论和认识，特别在复杂断裂构造带和碳酸盐岩中进行油气勘探，积累和丰富了大量储层描述和评价、地震采集和处理、测井、完井、试油等一系列理论、技术和工作方法。

“九五”期间，共发现或探明了 13 个大、中型油气田，27 个工业性含油气构造。发现和探明了大型整装的克拉 2 大气田，探明天然气地质储量 $2840 \times 10^8 \text{m}^3$ ，发现了库车坳陷的富天然气聚集带，为“西气东输”奠定了资源基础；继续探明了塔河一轮南大油田。近 5 年来新增油气地质储量 $5.905 \times 10^8 \text{t}$ （当量），其中石油地质储量 $1.908 \times 10^8 \text{t}$ ，天然气地质储量为 $3997 \times 10^8 \text{m}^3$ ，2000 年生产原油 $440 \times 10^4 \text{t}$ 。

通过“九五”期间勘探和研究，对库车前陆盆地石油地质的认识取得了重大进展，初步形成了库车大气区的石油地质理论基础；在古生代海相碳酸盐岩油气成藏规律研究、克拉通主力烃源岩评价、海相碳酸盐岩和碎屑岩储层发育机制及成藏期与成藏模式研究等方面，取得了新进展，丰富了海相石油地质理论，深化了对古老克拉通盆地海相油气分布规律的认识；对塔里木盆地石油地质的深入研究，明确了塔里木中、新生代盆地大地构造背景及包括塔里木盆地在内的特提斯北缘盆地群的油气地质特征；进一步总结和完善了塔里木盆地油气的富集成藏规律，评价优选出了一大批有利勘探区带和目标，明确了塔里木盆地油气勘探的战略发展方向，并形成了一系列油气勘探的技术和方法。

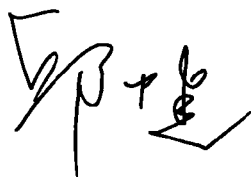
特别是库车前陆盆地创造性地运用断层相关褶皱理论，在库车前陆盆地褶皱—逆冲构造带建立了 10 种构造模型，并用于地震剖面精细构造解释和制图；应用煤成烃理论，深入分析和系统评价了库车前陆盆地三叠—侏罗系煤系地层烃源岩。提出库车前陆盆地发育分布广、厚度大、有机质丰度高、有机质类型以腐殖型为主、成熟度高的煤系地层烃源岩等，初步认识了库车大气区的石油地质特征。

针对山地地震勘探、高陡构造钻井、超高压气藏测试和评价、碳酸盐岩孔、洞、缝型储层的识别和预测及超深、低幅度薄层砂岩油藏勘探等一系列难题，加大了勘探技术攻关的力度，初步形成了五套油气勘探评价技术系列，基本满足了当前塔里木盆地油气勘探的需要。

这套丛书系统总结了“九五”及前人对塔里木盆地的勘探和研究工作，特点是总结了5年的勘探实践和认识。其中既有勘探的认识和基础研究成果，也有油气富集规律的总结和新技术、新方法的应用，内容十分丰富，对今后塔里木盆地乃至其它相似盆地的油气勘探有一定的借鉴意义。但我们认为，这些成果并不都是十分成熟、十全十美的，正相反，毕竟塔里木盆地情况十分复杂，勘探程度还比较低，许多难题还尚未解决，勘探的道路还很漫长，我们的认识虽有大的进步，但还有很多不清楚和不明白的环节和规律。可贵的是，塔里木盆地的石油地质工作者勇于实践，勇于探索，锲而不舍，不断进取，及时总结经验和教训，敢于把这些成果亮出来，接受实践的检验，在实践中深化认识。我相信，这套丛书的出版，定会丰富中国石油地质学的理论与实践，并对今后的勘探工作起到重要的指导作用。

随着塔里木盆地油气勘探不断深入并取得更大进展，人们的认识将会更加接近客观实际和事物的本来面目，通过继续不断地努力和探索，定会实现油气勘探的飞跃。到那时，中国石油工业的希望——塔里木盆地，将出现更多的克拉2和塔河一轮南型的大型油气田，进入新的油气储量增长的高峰期，塔里木盆地真正成为中国石油工业战略接替基地，我对此充满信心。

最后，我衷心希望丛书的出版能够起到“抛砖引玉”的作用，能够在一定程度上满足全国石油地质界关心和支持塔里木盆地找油事业的专家同仁的需要，并引起更多人的兴趣，从而参加到塔里木盆地油气勘探的接力赛的行列中来，共同投身到富有诱惑、充满挑战而又奥秘神奇的塔里木盆地这块热土中来。

A handwritten signature in black ink, appearing to read '尹建' (Yin Jian), written in a cursive style.

2003年6月

Preface

The 12-volume collection of *Petroleum Geology and Exploration of Tarim Basin*, the content of which is the exploration and research achievements during the "Ninth Five-Year Plan" period, will be published. This collection is the crystallization of all petroleum geologists ever fought in hot land of Tarim Basin during the "Ninth Five-Year Plan" period and the product of arduous work of comrades of Petroleum Industry Press. It is one important page of the hydrocarbon exploration history of Tarim Basin. After being published, this collection will undoubtedly be widely cared by domestic and foreign petroleum circles and bring them great interest. I hereby express my congratulation to the publishing of this collection.

Hydrocarbon exploration work in Tarim Basin started in 1950s and till now it has an over-50-year's history. In this course, the exploration personnel had suffered with many frustrations for various reasons but they also obtained rich materials, experiences and lessons. China National Petroleum Corporation, after approved by the State Council, organized a mass petroleum exploration campaign in April 1989, which was a firm and historic step for the large-scale overall hydrocarbon exploration in Tarim Basin. Meanwhile, the state also organized some "Eighth Five-year Plan" and "Ninth Five-Year Plan" brainstorm projects focusing on hydrocarbon exploration of Tarim Basin.

The content of the collection of *Petroleum Geology and Exploration of Tarim Basin* is full of the plentiful and substantial materials that have been obtained by a lot of petroleum workers through field geologic survey and drilling work around the basin in nearly 40 years and through continuous hard work for nearly 20 years after the Bureau of Geophysical Prospecting. This collection also contains the achievements that have been obtained through the practice and research for five years or more time based on the national key brainstorm research work during the "Seventh Five-year Plan" and "Eighth Five-year Plan" period; during this period, geologists had conducted hard but effective studies and practice on key regions and key series of strata. This course does obtain satisfying exploration achievements and initiate and deepen new theories and understandings. Especially, the hydrocarbon exploration work in complicated fracture zones and carbonate helps geologists in accumulating and enriching a series of theories, technologies and work methods such as large reservoir description and evaluation, seismic acquisition and processing, well logging, well completion and oil test and so forth.

During the "Ninth Five-Year Plan" period, 13 large/middle oilfields / gasfields and 27 gas/oil-bearing structures available for industrial application in total have been discovered or proven. The large self-contained Kela-2 Large Gasfield was discovered and proven during this period, the proven geological reserves of natural gases of which are $2,840 \times 10^8 \text{m}^3$, while the rich natural gas accumulation zone was discovered in Kuche Depression, which establishing the resource foundation for the "West-East Pipeline Project". Later, Tahe-Lunnan Large Oilfield was ascertained. In recent five years, $5.905 \times 10^8 \text{t}$ (equivalent weight) of geological reserves of oil and gas have been

ascertained, including $1.908 \times 10^8 \text{ t}$ of geological reserves of petroleum, $3,997 \times 10^8 \text{ m}^3$ of geological reserves of natural gas. In 2000, the production of crude oil reached $440 \times 10^4 \text{ t}$.

Through the exploration and research during the "Ninth Five-Year Plan" period, the understanding to petroleum geology of Kuche Foreland Basin has had an important breakthrough, and the theoretical foundation for petroleum geology has been preliminarily established for the large natural gas area in Kuche. In such aspects of research on Paleozoic marine carbonate hydrocarbon reservoir formation law, evaluation on major hydrocarbon source rock in Craton, research on development mechanism of marine carbonate and clastic reservoir, reservoir formation period and reservoir formation model and so on, some new progresses have been obtained, which has enriched the theory relating to marine petroleum geology, deepened the understanding on marine hydrocarbon distribution law of ancient cratonic basin. The deep research on petroleum geology of Tarim Basin ascertains the tectonic background of the Cenozoic basin of Tarim and the geological characteristics of hydrocarbon in basin groups in north edge of Tethys including Tarim Basin; it further concludes and perfects the occurrence and reservoir formation laws of hydrocarbons in Tarim Basin, evaluates and optimizes a large batch of favorable exploration areas, zones and destinations, determines the strategic development direction for hydrocarbon exploration of Tarim Basin and obtains a series of hydrocarbon exploration technologies and methods.

Especially, in Kuche foreland basin, geologists have innovatively applied the fault-related folding theory to establish 10 structure models in the fold-thrust structure zones of Kuche foreland basin and used it for interpretation and plotting of fine structures of seismic profile; the theory that states how coal is turned into hydrocarbon has been used to deeply analyze and systematically evaluate the hydrocarbon source rocks in the Triassic-Jurassic coal measure strata in Kuche foreland basin. It proposes the opinion that the coal measure strata hydrocarbon source rocks of wide distribution range, large thickness, high organic matter abundance, humus as main organic matter and high maturity are developing in Kuche foreland basin, while preliminarily understanding the petroleum geological characteristics of Kuche large gas area.

The brainstorm strength of exploration technologies is increased for a series of difficulties such as mountainous seismic exploration, drilling of high and steep structure, testing and evaluation on super-high pressure gas reservoir, recognition and prediction of carbonate hole, pore and seam-shaped reservoir, exploration of super-deep, low-amplitude thin sandstone oil reservoir, preliminarily establishing five sets of hydrocarbon exploration and evaluation technologies, which basically meet the current hydrocarbon exploration need of Tarim Basin.

This collection systematically concludes the exploration and research work that was carried during the "Ninth Five-Year Plan" period and by predecessors. Especially, it concludes the exploration practice and understandings obtained in past five years, including the understandings to existing exploration and basic research achievements and also including the conclusions of hydrocarbon occurrence law and application of new technologies and methods. Its contents are very rich and have a certain guiding significance to the future hydrocarbon exploration in Tarim Basin and other similar basin. However, we do not think that these achievements are very mature and perfect. On the

contrary, as the situations of Tarim Basin are very complicated, its exploration degree is relatively low, there are many difficulties unsolved and the exploration road is still very long, in our understandings there still are many unclear links and laws although there is a large progress. It is notable that the petroleum geologists in Tarim Basin are brave in practice and probing into new fields, they can work with perseverance for greater progress, and they are always summarizing experiences and taking lessons from practice, and they are brave to inspect their achievements in practice so as to deepen their understandings in practice. I believe that this collection will undoubtedly enrich the theories and practice of China's petroleum geology and play an important guidance role to the future exploration work.

As the hydrocarbon exploration in Tarim Basin has been continuously deepened and more progress has been obtained, our understandings will be closer to the reality and the original appearance of things. Through continuous efforts and exploration, our hydrocarbon exploration will undoubtedly have a forward leap. Till then, the hope of China's petroleum industry--Tarim Basin will produce more large oilfields and gasfields like Kela-2# and Tahe-Lunnan and get into a new peak stage of hydrocarbon reservoir, and Tarim Basin will really become the strategic base of China's petroleum industry. I am confident in this.

Finally, I sincerely hope that the publishing of this collection can play the role that offers a few commonplace remarks by way of introduction so that others may come up with valuable opinions, can in a certain degree meet the need of those experts in the national petroleum geology field who concerns with and support the petroleum exploration work in Tarim Basin, and can intrigue more people, so that there are more people to throw themselves into the hydrocarbon exploration relay race of Tarim Basin and to step into the charming and mystic Tarim Basin full of challenges.

Qiu Zhongjian

June 2003

前 言

储层研究既是含油气盆地基础性石油地质工作,也是一种可直接为生产服务的应用研究,是进行有效的石油勘探和开发不可缺少的研究工作。本书以沉积学作为储层研究的基础,对塔里木盆地重点层系的储层进行了解剖和分析,力图从中找出塔里木盆地重点层系储层的一般特性和分布规律,以有助于油气勘探的进一步深入。研究认为塔里木盆地中晚奥陶世是生物礁的主要发育期,台地边缘是生物礁发育的最佳场所,特别是在塔中Ⅰ号断裂带西侧的中上奥陶统中发育的礁体,规模大,礁核累积厚度达74m,延续长100km以上;Ⅰ号断裂带处于台地的边缘相带,广泛发育高能粒屑滩,而且断裂所派生的各种裂缝及伴随而形成的埋藏溶蚀孔洞所组成的缝洞系统,构成了最有利的、储渗条件好的储集相带。

塔里木盆地塔北和塔中地区重点层系东河砂岩的沉积环境是有差异的;而且孔隙发育演化也存在较大的不同。塔中地区主要是以溶蚀的次生孔为主,而塔北地区以原生孔和次生孔混合发育为特征,反映了成岩过程的差异性。

中、新生界碎屑岩成岩环境分析表明,上侏罗统以上地层主要处于碱性成岩环境,而上侏罗统以下地层主要处于酸性成岩环境。成岩环境的不同对孔隙的形成和演化具有重要影响作用;次生孔隙的形成主要与干酪根成熟时释放的酸性流体有关,烃类的蚀变产生的有机酸能促进长石和岩屑的溶解,但烃类的侵位具有选择性且不能阻止石英的加大。

同时本书中介绍了利用成像测井、时频分析、地层倾角测井及常规测井的信息进行沉积学分析的方法,并解释了沉积相和古流向;应用LOGES系统全面计算了不同地区泥岩的封盖参数,建立了实测排替压力值与声波测井资料的关系式;利用灰色系统理论开发和改进神经网络解释模型并对储盖层进行了评价,在实际应用中收到了良好的效果。

本书是在国家“九五”科技攻关课题《塔里木盆地沉积储层特征》(96-111-01-02)的研究报告基础上经综合加工而成的,本书是该课题全体科研人员潜心研究的成果和创造性劳动的结晶,成功属于集体。该书具体编写人员分工如下:第一章陈景山、谭秀成、王振宇等;第二章朱筱敏、赵澄林、钟大康等;第三章张国栋、叶英、沈忠悦等;第四章王建国等;第五章顾家裕、贾进华、梅博文、蔡春芳等;第六章陈章明、李国平、石强等;第七章管守锐、王贵文、宋子奇、赵良武等,最后朱筱敏、顾家裕和贾进华对本书进行了统编和整理以及修订工作。本书收集和使用了大量前人研究成果以及地震、测井、钻井、地质资料,在此表示深切的感谢。

作者

2003年6月

Foreword

Reservoir study is both basic petroleum geological work for oil and gas basins and application study for direct service for production. It is the inalienable part of the research work for exploration and development. Basing the reservoir study on sedimentology, this book makes analysis of the reservoirs of the key stratum series in Tarim Basin in an attempt to find the common characteristics and the distribution law of the key stratum series in the basin for further promotion of oil and gas exploration. Based on the results of the study, Middle and Late Ordovician is the main development period for bioherm while the periphery of platform is the best place for development of bioherm. The Middle and Upper Ordovician bioherm developed west of Tazhong-1 fractural belt, in particular, is large in scale with an accumulated thickness of 74 meters and an extended length of more than 100 kilometers. Tazhong-1 fractural belt is located in the periphery of the platform with extensive development of high-energy grain beach. The variety of seams derived from the faults and the associated seam and cavity system composed of buried dissolved pores provide the most favorable reservoir belts with good storage and permeable conditions.

The difference exists in the sedimentary environment of Donghe sandstone, the key stratum series in the areas of Tazhong and Tabei in Tarim Basin. In addition, great difference also exists in porous development and evolution. Tazhong area is concentrated on the dissolution secondary pores while Tabei area is characterized with the mixed development of primary and secondary pores, reflecting the differential of the diagenetic process.

The analysis of Mesozoic and Cenozoic clastic diagenetic environment shows the strata above Upper Jurassic are mainly located in alkali diagenetic environment while the strata below Upper Jurassic are mainly located in acidic diagenetic environment. The difference of diagenetic environment bears important influence on the porous formation and development. The secondary pores are related mainly to the acidic fluids released when kerogen is mature. The organic acid produced from hydrocarbon alteration can promote dissolution of feldspar and debris, but the hydrocarbon emplacement has the selective property and cannot stop the growth of quartz.

Meanwhile, this book also briefs about the methods for sedimentary analysis by using imaging logging, time-frequency analysis, stratigraphic dip logging and conventional logging information and explains the sedimentary facies and the ancient flow direction. The LOGES system is used to calculate the sealing parameters of mudstone in different regions while the relation formula between the real-testing discharging pressure value and acoustic logging data is established. The gray system theory is used to develop and improve the neural network interpretation model and makes assessment of the reservoir

caprock. The desirable results have been achieved in application.

This book is written on the basis of the research report of "Characteristics of Sedimentary Reservoirs in Tarim Basin" (96-111-01-02) – one of the scientific research projects in the country's "Ninth Five-Year Plan". This book is the teamwork of all the research workers involved in the project. The writers of this book are as follows: Chen Jingshan, Tan Xiucheng and Wang Zhenyu for the first chapter, Zhu Xiaomin, Zhao Chenglin and Zhong Dakang for the second chapter, Zhang Guodong, Ye Ying and Shen Zhongyue for the third chapter, Wang Jianguo and others for the fourth chapter, Gu Jiayu, Jia Jinhua, Mei Bowen and Cai Chunfang for the fifth chapter, Chen Zhangming, Li Guoping and Shi Qiang for the sixth chapter, Guan Shourui, Wang Guiwen, Song Ziqi and Zhao Liangwu for the seventh chapter. Finally, Zhu Xiaomin, Gu Jiayu and Jia Jinhua make unified examination, compilation and revision of the book. This book uses a large quantity of the research results achieved by the predecessors and the related seismic, logging, drilling and geological data. Gratitude is extended to those predecessors.

Authors

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