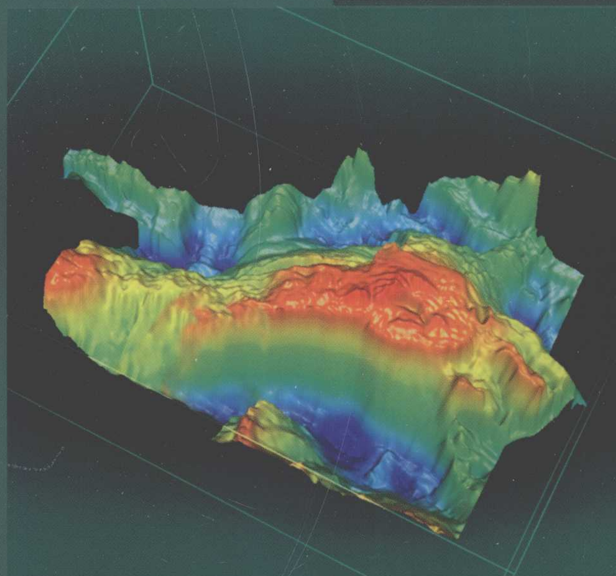

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序

随着油气勘探与开发的不断深化，潜山油气藏已成为国内外油气勘探的重要领域。

世界上最早发现潜山油气藏是在1909年，当时美国在勘探中新生界含油气层系时，在俄亥俄州中部辛辛那提隆起偶然发现了摩罗县潜山油气藏。其含油层系为上寒武统铜岭组裂缝溶洞发育、连通性好的白云岩，油井初期日产油21 t。有目的、有计划地钻探潜山油气藏，并获得成功的是1953年委内瑞拉马拉开波盆地发现的拉巴斯潜山油气藏，该油气藏储层为三叠系拉昆塔变质岩及火成岩，试采获日产620 t高产油流。目前，美国、委内瑞拉、阿尔及利亚、越南、俄罗斯、加拿大、利比亚、伊朗、巴西、摩洛哥、罗马尼亚等国都相继发现有潜山油气藏。

我国最早在1959年发现酒西盆地玉门鸭尔峡潜山油气藏，产层为志留系泉脑沟组浅变质千枚岩、板岩及变质砂岩，单井初产每日150 t。而大量潜山油气藏勘探始于1972年，渤海湾盆地济阳坳陷义和庄油田的沾11井在奥陶系灰岩油藏中获日产千吨油流。尔后1975年在冀中坳陷中元古界蓟县系雾迷山组白云岩中获单井日产1 000～3 000 t高产油流，发现了任丘潜山油田。此后国内迅速掀起潜山油气藏勘探热潮。20世纪70年代至今，我国已在冀中、济阳、辽河、黄骅、渤中、东濮、准噶尔、酒泉、二连、松辽、东海、北部湾、苏北等坳陷和盆地相继发现了数十个潜山油气田。

潜山油气藏形成条件与分布规律研究，是潜山油气藏勘探与开发的基本内容。《车镇凹陷潜山油气藏形成条件与分布规律》一书以车镇凹陷潜山油气藏形成为核心，以潜山多样性为主线，综合地质、地化、地震、测井、测试、分析化验等资料，应用油气地质学新理论、新方法，从潜山油气藏形成的静态地质要素和动态成藏过程分析入手，建立潜山油气成藏与富集模式，进而对潜山油气分布进行科学预测。

通览全书，主题明确、内容丰富、资料翔实、论据充分，既有理论又有实践，是科研与生产密切结合的硕果，是科研成果转换为经济效益和社会效益的典型。

本书有以下三个重要特点：

1. 潜山形成地质基础研究扎实。地层、沉积相是潜山组成的物质基础。论著对车镇凹陷结晶基底、沉积基底和沉积盖层的组成，古生界层序、沉积相及其演化进行了详细论述。构造特征及其演化是潜山形成的基本原因。论著将潜山的形成分为雏形、发育、定型、掩埋和成藏等阶段进行全过程分析，为潜山的组成与形成研究奠定了重要的地质基础。

2. 潜山油气藏形成基本条件研究既全面又重点突出。潜山油气藏形成是成藏要素和成藏动力学因素综合作用的结果。论著全面讨论了油气成藏的烃源、储集、封盖、圈闭条件，油气运聚机理，油气成藏史等，又重点突出了储层的储集空间、储集系统、裂缝特征及测井识别等储

层非均质性研究和潜山油气成藏输导体系的类型、组合及分布的研究。

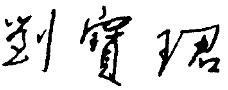
3. 应用含油气系统、成藏动力学理论进行潜山油气藏形成过程研究。论著把油气成藏的静态地质要素（烃源岩、储集岩、封盖岩）与动态作用要素（运移、输导、聚集、保存）整合为一体，对油气成藏事件及关键时刻进行深入分析，使潜山油气成藏理论与勘探实践紧密结合。

总之，李晓清博士等所著的《车镇凹陷潜山油气藏形成条件与分布规律》，是在应用现代沉积盆地、地球动力、石油地质与油气成藏等理论及沉积、构造、地球化学、地球物理等新技术、新方法，对车镇凹陷潜山油气藏形成条件与分布规律进行多学科综合、系统总结、深化认识、再次评价的基础上编写而成的。

该书不仅对车镇凹陷潜山油气藏的进一步勘探与开发具有重要指导意义，而且对济阳坳陷乃至渤海湾盆地的潜山油气藏勘探与开发都有着重要的参考与指导意义。该书的出版将在我国潜山油气藏研究领域新增一部具有理论和实践价值的重要文献。

值该书问世之际，特作序，以资祝贺。

中国科学院院士：



2006 年 4 月 7 日

Introduction

With the continuous deepening of oil and gas exploration and exploitation, buried hill reservoir has already become an important realm of petroleum exploration both in China and abroad.

The first buried hill reservoir in the world was found in 1909. A buried hill reservoir was accidentally found in the central Cincinnati, Ohio during exploring the Mesozoic-Cenozoic oil and gas bearing layers. The reservoir was composed of dolomites with well-developed fractures and caves as well as good connectivity in the upper Cambrian strata, and the well produced 21 tons of oil per day at its early stage. The first buried hill pool drilled successfully was the Labasi buried hill pool found in Maracaibo basin of Venezuela in 1953, where the reservoir was composed of Triassic metamorphic and igneous rocks. The daily oil production was 620 tons during the well testing. At present, a lot of buried hill reservoirs have been found in the United States, Venezuela, Algeria, Vietnam, Russia, Canada, Libya, Iran, Brazil, Morocco, Romania and many other countries.

The first buried hill reservoir in China was found in Jiuxi basin at Yumen (Ya'erxia reservoir), northwest of China. The oil-bearing layers were Silurian Quannaogou formation of metamorphic rocks: phyllites, slates and sandstones. There was 150-ton single well production at its early stage. An extensive exploration on buried hill reservoir in China began in 1972. For example, Zhan 11 of Yihezhuang oilfield in Jiyang depression, Bohai Bay basin produced thousand tons of oil per day in the Ordovician limestone reservoir. Later, Renqiu buried hill oilfield, with 1 000～3 000 tons of single well production per day, was found in the dolomites of Mesozoic-Proterozoic Jixian system (Wumishan formation) in Jizhong depression. Since then, buried hill reservoir exploration spread quickly in the whole country. So far, tens of buried hill oilfields have been found in Jizhong, Jiyang, Liaohe, Huanghua, Bozhong, Dongpu, Junggar, Jiuquan, Erlian, Songliao, Donghai, Beibuwan, Subei depressions and basins etc.

Study on the forming conditions and distribution regulation of buried hill reservoir is the fundamental content of buried hill reservoir exploration and exploitation. This book, *Forming conditions and distribution regulation of buried hill reservoirs in Chezhen sag*, with the buried hill reservoir formation in Chezhen sag as a core and the buried hill diversity as a chief line, has built models for buried hill oil and gas accumulation and enrichment from the beginning of analyzing the static geologic elements and dynamic pool-forming process of buried hill reservoir formation by use of geology, geochemistry, seismic, well logging, well testing, analyzing and testing data and new theories and methods of petroleum geology, in order to forecast the buried hill petroleum distribution scientifically.

With a definite topic, abundant contents, elaborated data and sufficient arguments, the whole book is a result of close combination of scientific research and practical production and a type from scientific research achievements to economical and social benefits.

Three important characteristics of this book are as follows:

1. The researches on geologic fundamentals of buried hill formation are well-knit. On one hand, stratigraphy and sedimentary facies are the physical fundamentals of buried hill components, while this book has discussed elaborately not only the components of crystallized basements, sedimentary basements and sedimentary covers but the Paleozoic sequence, sedimentary facies and their evolutions in Chezhen sag. On the other hand, structural characteristics and their evolution are the fundamental reasons for buried hill formation, it has analyzed the whole process of buried hill formation in several stages such as embryonic formation, development, shape, burial and pool-formation etc. , which provides important geologic fundamentals for buried hill components and formation.

2. The study on fundamental conditions of buried hill reservoir formation is both thorough and emphasis-stressed. As we know, buried hill reservoir formation is the comprehensive result of pool-forming elements and dynamic ones combined action. This book has thoroughly discussed the source rocks, reservoirs, seals, traps, mechanism of oil and gas migration and accumulation and history of the oil and gas accumulation etc. , meanwhile laid stress on the reservoir heterogeneity study of reservoir spaces, systems, fracture characteristics, well log identification and study on the types, combinations and distribution of buried hill hydrocarbon transport system.

3. Theories of petroleum system and pool-forming dynamics are applied to study the buried hill reservoir forming process. This book has integrated the static geologic elements of hydrocarbon accumulation such as source rocks, reservoir rocks and seal rocks with the dynamic ones such as migration, transportation, accumulation and preservation, and further analyzed the pool-forming events and critical moments, which makes the pool-forming theory and exploratory practice of buried hill reservoir combine closely.

All in all, *Forming conditions and distribution regulation of buried hill reservoirs in Chezhen sag* by doctor Li Xiaoqing and other people has been written on the basis of multi-subjects combination, systematical summarization, thorough recognition and reevaluation of the buried hill reservoir forming conditions and distribution regulation in Chezhen sag, by using theories of modern sedimentary basin, geodynamics, petroleum geology and hydrocarbon accumulation and new techniques and methods of sedimentation, structure, geochemistry, and geophysics etc.

This book has provided important meanings of guidance and reference for buried hill reservoir exploration and exploitation not only in Chezhen sag but also in Jiyang depression and even Bohai Bay basin. Thus it will become a new important document providing both theoretical and practical values in the buried hill reservoir realm in our country.

During the time of this book's born, I write the introduction in order to express my great congratulations.

Liu Baojun (Academician)
Chinese Academy of Sciences
2006. 4. 7

前　言

车镇凹陷为渤海湾盆地济阳坳陷北部的一个次级凹陷，行政区划属于山东省滨州市无棣和沾化县境内，面积约 2 390 km^2。地貌为黄河下游三角洲平原和滩海，东北方向濒临渤海。地势西南高东北低，整体低平，发育了徒骇河、秦口河、小米河、朱龙河、德惠新河等向东北汇入渤海的河流。交通便利，S237、S239、S320、S311 等公路横贯全区。

车镇凹陷是一个在古生代克拉通地台上发育起来的中新生代箕状断陷，自北向南由北部陡坡带、中部洼陷带和断阶带、南部缓坡带构成，洼陷带中被鼻状构造分隔开的车西、大王北、郭局子 3 个洼陷自西向东依次排列。

研究以车镇凹陷西部车西洼陷为主，其北部以埕南断层与埕子口凸起相接，西邻庆云凸起，南接无棣凸起和义和庄凸起，东部通过套尔河—车 3 鼻状构造与大王北、郭局子洼陷相连，东西长约 46 km，南北宽约 16～28 km，面积约 1 100 km^2。

近年来的勘探成果表明，基底岩系的中生界砂岩、古生界灰岩和前震旦系花岗片麻岩均可形成古潜山油气藏。古潜山油气藏勘探具有广阔的前景和巨大的潜力，但其成藏机理、油气藏类型相当复杂，勘探方法各不相同。总结古潜山油气藏形成条件与分布规律，探索古潜山油气藏勘探技术，对今后深化古潜山油气藏勘探与开发、争取新的突破和发现具有重要意义。

车镇凹陷西部勘探始于 20 世纪 60 年代初期，先后开展过重力、磁力、电法、地化、放射性及地震等勘探，经历了 5 次勘探会战。至 2003 年底，已发现了寒武—前震旦系、奥陶系、石炭—二叠系、古近系沙河街组沙四段至沙一段等多套含油层系，发现了套尔河、东风港及富台 3 个油田，探明储量约 8 000×10^4 t。据 2000 年资源评价资料，车镇凹陷资源量为 5.6×10^8 t，剩余资源量为 4.2×10^8 t，资源探明率仅 25%，远小于东营凹陷和沾化凹陷的 66.7%和 72.9%，表明车镇凹陷还有较大的资源潜力。

研究中着重应用了以下基础理论和先进技术：

1. 潜山构造特征及其形成过程研究：以区域地质学、构造地质学、地球物理学为原理，通过三维地震精细目标处理及解释，进行潜山构造演化史及构造样式特征研究，查明不同构造带潜山形成过程，落实潜山古地形、古构造和断裂系统，进而优选有利潜山勘探目标。

2. 潜山储层研究：综合地质、测井、地震特征识别潜山储层。

潜山岩石类型及风化溶蚀作用分析：利用岩心观察、测量地质研究方法，对不同类型潜山的取心井进行细致描述，观察溶蚀发育段、溶蚀强度等，测量裂缝发育情况、裂缝类型及密度；利用储层测井特征研究方法，定量分析古潜山储层溶蚀及裂缝发育程度，建立古潜山储层溶蚀及裂缝发育成因模式。

潜山储层地震分析：以三维地震资料为基础，综合地质、测井、钻井等资料，从井出发，研究潜山不同层序的储集层分布规律及油气储集空间类型（溶洞、裂缝、孔隙等），建立储层与地震信息间的相关性，利用多种地震技术预测有利储层发育区；总结风化壳储层地质、地球物理特征及地震预测技术；总结潜山内幕储层特征描述方法，探讨不同潜山储层类型的有效地震描述技术。

3. 潜山油气藏类型与成藏模式研究：应用含油气系统、成藏动力学研究思路，在沉积、构造、储层特征研究基础上，通过潜山成因类型、油气藏形成条件、输导体系、油气富集控制因素的分析，建立车镇凹陷潜山油气成藏模式，指导潜山油气藏的综合评价与有利勘探目标优选。

4. 潜山油气藏分布规律及综合评价：潜山油气藏综合评价是一项油气藏地质特征与分布规律全面的定性、定量评价工作，是在油气藏勘探成果的基础上，对潜山圈闭要素、储层参数分布等进行研究，为油气藏的深化勘探与开发提供基础地质依据。通过潜山油气藏沉积特征、构造条件、储层分布、成藏模式、油气富集控制因素及潜山油气系统、成藏动力特征分析，对潜山油气藏勘探目标进行综合评价。

通过研究，在理论与实践方面取得以下重要成果：

1. 对车镇凹陷古生界地层、层序、沉积相、古地理进行了系统分析研究。将区内下古生界划分为2个二级层序，14个三级层序；上古生界划分为3个上升—下降完整旋回和2个不完整旋回。根据区内早古生代沉积相建立了研究区早古生代沉积模式。

2. 车西地区前古近纪构造运动复杂，经历了多次强烈构造运动，其形成和发展可分为4个阶段。太古代、元古代：结晶基底形成与抬升剥蚀阶段；古生代：稳定克拉通阶段；中生代：三叠纪褶皱隆升与潜山雏形形成，侏罗—白垩纪断块抬升与潜山发育阶段；新生代：古近纪断陷发育与古潜山定型，新近纪坳陷发育、整体掩埋与潜山成藏阶段。

3. 车西洼陷断裂系统由前古近系和古近系2个断裂系统组成。前者以燕山期北东向断层为主，切割印支期北西向断层，如埕南断层、埕南二台阶断层、车西断层等；后者以喜山期同沉积断层为主。断层与油气关系十分密切。车西洼陷构造样式亦分为前古近系和古近系2个系统。前者以陡坡带-滑动断阶潜山构造样式和缓坡带-反向翘倾断块潜山构造样式为主；后者的构造样式为陡坡带-板式构造样式、洼陷带-浊积扇岩性体构造样式和缓坡带-盆倾断层构造样式。

4. 车西洼陷潜山储集体类型主要有风化壳型和潜山内幕型。前者在整个车西洼陷广泛发育，主要发育于下古生界潜山顶部，纵向发育厚度一般为0～150 m左右；后者主要发育于车西北带潜山的二台阶断层上升盘，发育层位为冶里-亮甲山组和凤山组。

5. 对潜山储层的形成机制进行了探讨，认为岩溶作用是下古生界储层发育的首要成因机制，岩性和断裂作用决定潜山内幕储层的形成与发育。在总结车西洼陷潜山储层发育特征的基础上，建立了车西洼陷储层发育模式。该模式为寻找车西洼陷有效储层提供了方向。

6. 提出“测井地质特征单元”概念，把具有相似测井地质特征的地层段称为“测井地质特征单元”，简称“测井元”。以成像测井和常规测井曲线形态、数值特征为主，建立了典型测井元识别标准。进一步利用测井信息分析总结了本区3种典型潜山类型（残丘山、褶皱山、断块山）的储集空间发育规律。明确了影响储层发育的3大主控因素，即岩性、构造和岩溶作用。

7. 对车西洼陷下古生界碳酸盐岩储层裂缝进行了系统研究。研究认为，车西洼陷潜山油藏储层裂缝发育层位主要为奥陶系冶里-亮甲山组、八陡组，其次为寒武系凤山组和太古界片

麻岩；储层裂缝几何参数（长度、角度）与单井产量密切相关，裂缝长、角度陡则单井产量高；研究区潜山储层裂缝成因主要为2种，即构造成因与非构造成因，其中构造成因裂缝在区域上具有一致的方向性和规律性，区内主要的有效裂缝类型为高角度缝，在富台油田、套尔河油田广泛分布。此外还对车西洼陷下古生界潜山储层裂缝系统的成因机制和裂缝发育程度进行了岩石力学测试和数值模拟预测。

8. 通过对烃源岩的评价，认为车西洼陷沙三中、下亚段和沙一段烃源岩是优质烃源岩。沙三下亚段烃源岩在东营中期进入生烃门限，馆陶早期进入大量生排烃阶段；沙三中亚段烃源岩在馆陶末期进入生烃门限，明化镇中期进入大量生排烃阶段；沙一段烃源岩在平原初期进入低熟生烃门限，目前尚未完成低熟演化阶段。油源对比表明沙三中、下亚段是车西地区的主要烃源岩，尚未发现明确的沙一段来源的油气。

9. 车西洼陷发育有沙三段与沙一段—东营下亚段2套分布稳定的区域性盖层，它们对其下油气的聚集成藏起到有效的封盖作用。沙一段—东营下亚段盖层的有效封盖使得车西洼陷在沙一段以上的储层中至今未见有利油气显示；整体来看2套盖层尖灭线以外的油气成藏封盖条件不好；洼陷西部盖层稳定，目前油气发现较少，如有有利的圈闭将会有所突破。烃源岩、储集层与盖层在空间上形成自生自储、下生上储、上生下储、新生古储4种生储盖配置关系、8种生储盖组合。

10. 砂体、断层、不整合面在空间上的相互组合构成了车西地区复杂多样的输导体系，平面上发育有砂体-断层输导区、断层-不整合输导区、砂体-不整合输导区以及不整合输导区4个油气输导区。在二台阶潜山带油气主要通过车57东、车古25东2条油源断层向潜山供油，缓坡带油气则通过由沙四上输导层、曹家庄断阶带、不整合面组成的复合输导体系运移，最终通过不整合面向潜山供油。

11. 根据构造、储集层、成藏规律研究成果，对潜山构造带进行油气藏的综合评价。应用TrapDES 2.1圈闭评价软件对车西洼陷已钻含油圈闭、已钻不含油圈闭以及解释圈闭共17个圈闭的成藏条件进行了综合评价，通过研究提供钻探井位5口，其中风险井1口（车古54潜山圈闭）、预探井4口（车61、车古28、车古4以及车古55南潜山圈闭），总计预测含油面积20.5 km^2，预测资源量1 732.3×10^4 t。

本专著是胜利油田东胜石油集团公司地质勘探研究人员在胜利油田众多油气勘探家们数十年艰苦奋斗、勇于实践、发现和研究车镇凹陷潜山油气藏的基础上，承前启后、不断总结的成果。

本专著是在“车镇凹陷潜山油气成藏规律与勘探目标”项目研究基础之上，应用近年来油气藏形成新理论，结合最近车西潜山勘探实践编写而成的。它是胜利油田东胜石油集团公司和中国石油大学（华东）、胜利油田地质科学研究院、胜利油田物探科学研究院等单位科技人员共同劳动的结晶。

参加研究工作的有胜利油田东胜石油集团公司李晓清、陈东、赵玉华、王登稳、梁书义、车京虎、李茹、黄伟、李传民，中国石油大学（华东）林承焰、董春梅、谭丽娟、朱永峰、王海涛，胜利油田物探科学研究院苏朝光、王军、牟敏、罗霞、王楠，胜利油田地质科学研究院林会喜、石砥石、巩建强、孙怡、毕彩芹，以及国土资源部成都地质矿产研究所丘东洲等。

全书共分六篇十五章，各章编写分工如下：

前言：李晓清、丘东洲；第一、第二章：李晓清、陈东、丘东洲；第三章：丘东洲；第四章：牟敏；

第五章：林承焰；第六章：车京虎、李茹、梁书义、巩建强；第七、第八章：朱永峰、赵玉华；第九、第十、第十一章：林承焰、朱永峰；第十二、第十三章：李晓清、林承焰、王登稳、黄伟、李传民；第十四章：陈东、王登稳、牟敏；第十五章：林承焰；结论与认识：李晓清、丘东洲。全文最后由丘东洲、车京虎统篇定稿。

专著在编写过程中，得到了胜利油田东胜石油集团公司领导刘晓明、王学春、曹钧合等的关心和支持，同时得到了中国石油大学（华东）地球与资源信息学院、胜利油田物探科学研究院、胜利油田地质科学研究院领导的支持和帮助。

在此对以上单位和个人，以及本书所引用的参考文献的作者一并表示衷心感谢。

特别诚挚感谢中国科学院刘宝珺院士在百忙中审阅本书并为之作序。

潜山地质构造复杂，勘探难度大，勘探技术也有待改善和完善。书中认识尚有局限和不当之处，恳请读者赐教。

李晓清

2006 年 4 月

Preface

With its northeast close to Bohai Sea, Chezhen sag, which belongs to Wudi and Zhanhua county of Binzhou city, Shandong province and covers an area of about 2 390 km^2, is a subsidiary sag in the north of Jiyang depression, Bohai Bay basin. The research area is part of the coast plain in the lower reach of Yellow River. The area is low and flat, but is a little bit higher in the southwest and lower in the northeast. Several short rivers, for example, Tuhai River, Qinkou River, Xiaomi River, Zhulong River and Dehuixin River, converge here and extend towards the northeast into Bohai Sea. The traffic is convenient with several roads such as S237, S239, S320 and S311 across the total area.

Chezhen sag is a Mesozoic-Cenozoic half-graben sag developed on the Paleozoic craton, which, from north to south, is composed of northern steep slope zone, central subsidence zone and fault step zone, and southern gentle slope zone. In the central subsidence zone, there are three sub-sags, Chexi, North Dawang and Guojuzi, separated by nose structures, from west to east.

The study focuses on Chexi sub-sag, the west part of Chezhen sag. The area is adjacent to the north of Chengzikou uplift by Chengnan fault, bordering Qingyun uplift in the west, close to Wudi uplift and Yihezhuang uplift in the south, and connecting North Dawang and Guojuzi sub-sags through Tao'erhe—Che3 nose structure in the east. The study area is about 1 100 km^2, about 46 km in length from west to east and 16 to 28 km in breadth from north to south.

Recent exploration results show that the Mesozoic sandstone, Paleozoic limestone and even Pre-sinian granite gneiss of basement rocks could be probable buried hill reservoirs. With the broad prospects and huge exploration potentials, buried hill reservoirs are very complicated in hydrocarbon accumulation mechanism. Different reservoir types require different exploration methods. Therefore, to summarize formation conditions and distribution regularities of buried hill reservoirs and to improve the exploratory technology are of great significance in the buried hill hydrocarbon exploration and exploitation.

Exploration with gravity, magnetic, electric, geochemical, radioactive and seismic methods in the west of Chezhen sag began in the early 1960s. Till now five exploration campaigns have been conducted in this area. By the end of 2003, various oil-bearing layers, including Pre-sinian—Cambrian, Ordovician, Carboniferous—Permian, Es_4 to Es_1 of Shahejie formation in Paleogene; and Tao'erhe, Dongfenggang and Futai oilfields, with about 80 million tons of proved reserves, have already been found. According to the resource assessment conducted in 2000, Chezhen sag has 560 million tons of reserves, with 420 million of remaining reserves and only 25% of proved resource rate, far less than that of Dongying sag (66.7%) and that of Zhanhua sag (72.9%), indicating that there is still great resource potential in Chezhen sag.

The following fundamental theories and new technology have been primarily applied:

1. A study on the buried hill structures and their forming processes: According to regional geology, structural geology and geophysics, by means of 3-D seismic precise target processing and interpretation, some researches on the buried hill tectonic evolution and structure styles have been done, the buried hill forming processes of different structural zone have been found out, the paleotopography, paleostructure and fracture systems have been made certain, and the favorable buried hill exploration targets have been optimized.

2. Buried hill reservoir research: Buried hill reservoirs have been identified in accordance with geologic, well logging and seismic characteristics.

Analysis of buried hill rocks types and their weathering/denudation: Make a quantitative analysis of the buried hill reservoir denudation and fracture-developing degree through core observation and geological measurement methods, and establish its geological model.

Seismic analysis of buried hill reservoir: Based on 3-D seismic data, a study on the reservoir distribution regularity and hydrocarbon reservoir spaces (such as caves, fractures, pores etc.) has been conducted, establishing the correlation between reservoir and seismic information, and finally predict favorable reservoir zone by a variety of seismic techniques. Reservoirs' geologic and geophysical characteristics and seismic prediction techniques of the weathering crust have been summarized, as well as the descriptive methods of buried hill interior reservoir characteristics, and the effective seismic descriptive techniques of different buried hill reservoirs have been probed into.

3. Buried hill reservoir types and hydrocarbon accumulation models: On the basis of sedimentation, structures and reservoir characteristics, the petroleum system and dynamics of hydrocarbon accumulation have been analyzed, hydrocarbon accumulation models of buried hill reservoir in Chezhen sag have been established, and the buried hill types, reservoir forming conditions, conducting system and control factors of hydrocarbon enrichment have been discussed, so as to improve the comprehensive evaluation of buried hill reservoir and optimization of favorable exploration target.

4. Buried hill reservoir distribution regularity and comprehensive evaluation: Buried hill reservoir evaluation is a qualitative and quantitative work in geologic characteristics and distribution regularity, which studies the buried hill trap elements, reservoir parameters etc., on the basis of hydrocarbon exploration results and ultimately provides fundamental geologic criteria for further exploration and exploitation. Comprehensive assessment on the explora-

tion target of buried hill reservoir is carried out by analyzing its sedimentary characteristics, structural conditions, reservoir distribution and hydrocarbon accumulation pattern, hydrocarbon accumulation controlling factors, buried hill petroleum system and dynamic characteristics of hydrocarbon accumulation.

Through the study, significant results both in theory and practice have been achieved as follows:

1. Systematic analysis of the Paleozoic stratigraphy, sequence, sedimentary facies and paleogeography in Chezhen sag has been carried out. In this area, the lower Paleozoic is divided into two second-order sequences and fourteen third-order sequences, while the upper Paleozoic is divided into three complete uplift-subsidence cycles and two incomplete ones. The early Paleozoic sedimentary models of the study area have been established according to its sedimentary facies.

2. Before Paleogene, Chexi area underwent a number of strong tectonic movements, being rather complicated. Its formation and development can be classified into the four following stages. Archaeozoic and Proterozoic Era: Basement-forming, uplifting and eroding stage; Paleozoic Era: Keeping stable craton; Mesozoic Era: Folding and uplifting and forming the buried hill in the Triassic, fault block uplifting and developing the buried hill during Jurassic and Cretaceous periods; Cenozoic Era: Fault subsiding and shaping the buried hill in Paleogene, the depression formed in Neogene, and the buried hill hydrocarbon accumulated.

3. Two fracture systems, Pre-paleogene and Paleogene, make up the fracture systems in Chexi sub-sag. The former is mainly northeast fault system formed in Yanshan stage, cutting the northwest faults in the Indo-China stage, such as Chengnan fault, Chengnan Ertaijie fault, Chexi fault etc. The latter is chiefly composed of fault system formed in Himalayan stage. And there is a close relationship between the faults and hydrocarbon. The tectonic styles of Chexi sub-sag also include the same two systems mentioned above.

4. The buried hill reservoir types in Chexi area are primarily weathering crust and buried hill internal pool. The weathering crust one, mainly on the top of lower Paleozoic buried hill with a vertical thickness of about 0～150 meters, could be found in almost the total Chexi area while the other, buried hill internal pool type, mainly exists in the lower Ordovician Yeli-Liangjiashan formation and the upper Cambrian Fengshan formation, the up thrown block of Ertaijie fault in buried hill, north of Chexi.

5. Through studying the forming mechanism of buried hill reservoir, it is believed that karstification is the primary cause, which has lead to the lower Paleozoic reservoir formation, and also, lithology and faulting can decide the formation and development of buried hill internal pool reservoir. Based on the buried hill reservoir characteristics of Chexi area, the reservoir development model of Chexi area have been established to provide guidance for looking for effective reservoir in Chexi area.

6. The concept of well-logging geological characteristics unit has been introduced. A well-logging unit is used for the stratigraphic members with similar well-logging geological

characteristics. Typical well-logging unit identification standard has been established according to the shape and numerical characteristics of microresistivity scanner log and conventional log curves. Reservoir space development regulations of three typical buried hill types (remained mound hill, fold hill, fault block hill) have been summarized according to well-logging information analysis, and three chief controlling factors, lithology, structure and karstification, which affect the reservoir development, have been identified.

7. A systematic research is done on the lower Paleozoic carbonate reservoir fractures in Chexi area. The fractures mainly exist in the Ordovician Yeli-Liangjiashan formation and Badou formation, some in the upper Cambrian Fengshan formation and fewer in Archaeozoic beds. Geometry parameters (length, orientation) of the reservoir fractures are closely related to single well production, commonly high single well production coincide with long and steep fractures. There are two types of buried hill reservoir fracture origins in our study area: Tectonic and non-tectonic. Tectonic fractures are in the same direction and distribution rule in the whole area. Such fractures are often steep and mainly distributed in Futai and Tao'erhe oilfields. In addition, rock mechanics testing and numerical simulation prediction have been carried out on the genetic mechanism and fracture-developed degree of lower Paleozoic buried hill reservoir fracture system in Chexi area.

8. It is found that good source rocks are mainly in the middle section of Es_3, the lower Es_3 and Es_1 by evaluation of the source rocks. The lower Es_3 source rocks evolved into the hydrocarbon-generating period in the middle of Dongying stage, and large volume of hydrocarbons generation and expulsion period in the early Guantao stage. Correspondingly, source rocks of the middle section of Es_3 evolved into the similar periods in the late Guantao stage and middle Minghuazhen stage respectively. As to the Es_1 ones, they entered the low mature generating period in the early Pingyuan stage, and so far still haven't completed the low mature evolution stage. Oil-source correlation shows that, in Chexi area, source rocks of the middle and lower sections of Es_3 are the primary source rocks, and no oil or gas being originated from Es_1 member.

9. In Chexi sub-sag, there are two sets of regional cap rocks, Es_3 member and Es_1—lower Dongying sub-member, beneath which hydrocarbon accumulation and pool formation are sealed effectively. In light of the effective sealing of lower Es_1—Dongying cap rocks, favorable oil and gas showing has still not been found in reservoirs above the Es_1 member, Chexi sub-sag. In the whole area, there are not good hydrocarbon accumulation and seal conditions in the places lack of the two sets of cap rocks. Although there are stable cap rocks in the west sub-sag, only a few hydrocarbon discoveries have been confirmed by now. This means that some favorable traps might be found in the future. The source rock, reservoir and cap rocks have formed four types of relations in space: Self-generating and self-preserving, lower-generating and upper-preserving, upper-generating and lower-preserving, and new bed-generating and old bed-preserving, forming eight different assemblages.

10. The complex and various transportation system of Chexi area are formed because of

the spacial combinations of sand bodies, faults and unconformities. There are four types of hydrocarbon transport zones: sand body-fault zone, fault-unconformity zone, sand body-unconformity zone and unconformity transport zone. In the Ertaijie buried hill zone, oil and gas are mainly transported through two oil-source faults, East Che57 and East Chegu25, to the buried hill area; and in the gentle slope zone, this is achieved through the compound transportation system composed of the upper Es_4 transport layers, Caojiazhuang step fault belt and unconformity; and eventually the oil is transported to the buried hill area through the unconformity.

11. Reservoir comprehensive evaluation has been done on the buried hill structural belt according to the study on the structure, reservoir and hydrocarbon accumulation. By applying TrapDES 2.1 trap evaluation software, the comprehensive evaluation on hydrocarbon accumulation conditions of seventeen traps, including drilled oil-bearing traps, drilled non-oil-bearing traps and explained traps in Chexi sub-sag have been completed. And eventually five exploratory well locations encompassing one risk well (Chegu54 buried hill trap) and four exploratory wells (Che61, Chegu28, Chegu4 and South Chegu55 buried hill traps), with a predictive oil-bearing area of 20.5 km^2 and 17.323×10^6 t of predictive resources, have been suggested.

This book is an achievement summarized by the geological exploration researchers of Dongsheng Petroleum Corporation, Shengli Oilfield. Large numbers of petroleum exploration experts have discovered and studied buried hill reservoirs in Chezhen sag with their hard struggle and bold practice for many decades.

Based on the study of buried hill hydrocarbon accumulation regularity and exploration target, it is completed by applying latest reservoir formation theories in recent years and combining with recent Chexi buried hill exploration practice. Thus this book is the common efforts of all the scientific and technological researchers from Dongsheng Petroleum Corporation, Shengli Oilfield, China University of Petroleum (East China), Shengli Oilfield Geological Science Institute, and Shengli Oilfield Geophysical Research Institute and so on.

The researchers include Li Xiaoqing, Chen Dong, Zhao Yuhua, Wang Dengwen, Liang Shuyi, Che Jinghu, Li Ru, Huang Wei and Li Chuanmin from Dongsheng Petroleum Corporation, Shengli Oilfield; Lin Chengyan, Dong Chunmei, Tan Lijuan, Zhu Yongfeng and Wang Haitao from China University of Petroleum (East China); Su Zhaoguang, Wang Jun, Mu Min, Luo Xia and Wang Nan from Shengli Oilfield Geophysical Research Institute; Lin Huixi, Shi Dishi, Gong Jianqiang, Sun Yi and Bi Caiqin from Shengli Oilfield Geological Science Institute; and Qiu Dongzhou from Chengdu Institute of Geology and Mineral Resources, Ministry of Land and Resources and so on.

This book is classified into six parts with fifteen chapters, each part and chapter is finished as follows:

Preface by Li Xiaoqing, Qiu Dongzhou; Chapter 1 and 2 by Li Xiaoqing, Chen Dong and Qiu Dongzhou; Chapter 3 by Qiu Dongzhou; Chapter 4 by Mu Min; Chapter 5 by Lin