济阳断陷盆地隐蔽油气藏勘探

JIYANG DUANXIAN PENDI YINBI YOUQICANG KANTAN

潘元林 张善文 肖焕钦 等著

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内 容 提 要

本书是胜利油区几十年来隐蔽油气藏勘探的总结，书中论述了隐蔽油气藏的地质基础和成藏基础，碎屑岩、碳酸盐岩、火成岩和其他类型等四大类隐蔽油气藏的分布规律，以及预测、评价、描述等勘探技术，并用典型实例说明各种主要勘探技术的综合应用及其效果。其中，碎屑岩隐蔽油气藏的重点是下第三系与各种扇体有关的油气藏，碳酸盐岩隐蔽油气藏的重点是下古生界碳酸盐岩潜山油气藏。从多方面对火成岩油气藏进行了研究，认识也达到一定的深度。其他类型隐蔽油气藏包括太古界变质岩潜山油气藏和下第三系泥岩裂缝油气藏。

本书可供石油地质科技人员、油气勘探工作者，以及有关大专院校师生参考。

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序

济阳坳陷是中国古克拉通第三系陆相裂谷盆地的典型代表。地质构造复杂、油气资源丰富、油气藏类型多种多样。40多年来，它为中国的石油工业做出了重大的贡献。这种贡献，不仅表现在已探明了占全国19%、占整个渤海湾盆地近50%的石油储量，已累计生产原油7.5×10^8t，占全国累计原油产量的19.7%，占整个渤海湾盆地累计原油产量的52%；而且更重要的是，在这里进行勘探开发的胜利油田不断创新，推进油气地质理论，不断发展勘探技术方法，积累了丰富的经验，推动了渤海湾盆地和全国同类盆地的油气勘探工作。

目前济阳坳陷仍待继续深入研究，仍有较大的资源潜力，非构造油气藏或地层—岩性圈闭油气藏（通称隐蔽油气藏）是一个重要领域，其数量众多，油气资源丰富。一般含油气盆地至少50%的油气储量蕴藏在隐蔽油气藏中。但是，由于其隐蔽性比较强，勘探的难度比较大，需要对油气分布规律有比较深入的认识，并具有相应的勘探技术，才能对隐蔽油气层进行有效的勘探。因此，大多数含油气盆地都是达到中等勘探程度以后，隐蔽油气藏才成为重点勘探对象。经过30年的勘探，进入20世纪90年代，济阳坳陷内构造油气藏的勘探程度已经较高，勘探难度越来越大。对隐蔽油气藏的成藏和分布规律已经基本掌握，也具备了资料和技术基础，胜利油田的勘探家们又不失时机地将勘探的主要对象转向岩性、地层和潜山圈闭等隐蔽性较强的油气藏，并进行了勘探新理论的探索和勘探新技术的开发研究，揭示了“断裂坡折带—低位扇”控制岩性油气藏群形成和分布的规律。在以往研究和实践的基础上，经过大量新技术的开发研究和实践，基本形成了各种隐蔽油气藏的勘探技术系列。理论探索、技术开发研究与勘探实践紧密结合，实现了隐蔽油气藏勘探的快速发展。近几年，每年探明的隐蔽油气藏石油储量已占年度总探明石油储量的60%以上，隐蔽油气藏成为新增石油储量的主要领域。

《济阳断陷盆地隐蔽油气藏勘探》一书，就是胜利油田现阶段关于隐蔽油气藏勘探的理论认识、配套技术方法和勘探实践经验的总结。它阐述了与隐蔽油气藏形成密切相关的盆地构造演化特征、盆地充填模式、异常压力单元封闭理论、“断裂坡折带—低位扇”控制砂岩体油气藏群的规律，总结了各种隐蔽油气藏成藏模式和分布规律，用配套的方法和实例介绍了部分隐蔽油气藏的基本认识及其勘探应用的主要技术、方法。该书的出版发行，将对加快我国同类油气盆地隐蔽油气藏勘探理论和勘探技术的发展和进一步深化老区的勘探起到积极的作用，对推动我国陆相断陷盆地油气勘探具有良好的作用。

胡见义

绪　言

自从20世纪60年代中期美国著名石油地质学家莱复生提出“隐蔽圈闭油气藏”概念以来，全世界隐蔽油气藏的勘探迅速发展，各种类型的隐蔽油气藏不断被发现，并且其中不乏以隐蔽油气藏为主的大型，甚至特大型油气田。隐蔽油气藏已成为所有石油地质家和勘探家研究和勘探的重要对象，增加油气储量的重要领域。尤其是中国东部的陆相断陷盆地，除了与同沉积断裂伴生的断层遮挡圈闭和少数滚动构造圈闭外，构造圈闭不甚发育，大量的是岩性、地层等各种隐蔽性圈闭。随着这些盆地资源勘探程度的不断提高，构造油气藏勘探的难度越来越大，隐蔽油气藏的勘探已引起了勘探界的广泛重视，并逐步上升为重点勘探领域。济阳坳陷经过30多年以构造油气藏为主要对象的勘探阶段后，于20世纪90年代初，在中国各含油气盆地率先进入以隐蔽油气藏为主要对象的勘探阶段，并且进展迅速、成果丰富，探明石油储量比例逐年增加并上升至主导地位，取得了经验，形成了一些理论认识和基本配套的勘探技术方法。为了系统总结现阶段关于济阳坳陷隐蔽油气藏成藏规律的认识和勘探技术，作为今后进一步研究及发展的基础和借鉴，也为类似盆地隐蔽油气藏的勘探提供一份比较系统的参考资料，我们编写了这部《济阳断陷盆地隐蔽油气藏勘探》。

现就本书涉及的几个重要概念、济阳坳陷隐蔽油气藏的勘探概况及本书编写的有关问题，作以下说明。

一、关于断陷盆地

陆相断陷盆地是中国重要的含油气盆地类型之一。“断陷盆地”这一名称已应用多年，但在有关含油气盆地分类的方案中，对其称谓并不一致。在叶连俊、孙枢（1980）的盆地分类中，似应是“同生断陷盆地”；李德生（1982）称之为“拉张型盆地”的“板内断陷、坳陷盆地”；按朱夏（1982，1983）的盆地分类，应为“拉张断陷盆地”或“断层走向滑移及其引起的拉张与断陷盆地”；胡见义等（1991）则命名为“克拉通内部衰亡裂谷盆地，也称断陷盆地”；田在艺等（1996）又称之为“大陆边缘裂谷盆地”等等。尽管它在各种分类方案中的称谓不同，但其主要涵义却极为相近。对于其成因的基本认识是：早期在某种地质作用下上地幔上拱，岩石圈隆起，产生拉张断裂、块体差异升降和翘倾，形成复式半地堑（箕状）或地堑式盆地，并伴有基性岩浆活动；晚期地幔物质冷却收缩，地壳区域性整体沉降，形成坳陷盆地；两种类型的盆地叠合在一起，构成断陷—坳陷复合盆地。在沉积上，此类盆地表现为下伏裂谷充填式沉积层序和上覆坳陷式沉积层序的有序组合。中国东部的陆相含油气盆地，基本都属于这种类型。但是，各盆地之间也有很大区别。按照一般的理解，如果一个断—坳复合盆地最主要的烃源层和含油气层系发育在断陷期，则称之为断陷盆地，例如渤海湾盆地等。济阳坳陷则是渤海湾盆地中的典型代表之一。反之，松辽盆地虽然也是断—坳复合盆地，但其主要断陷期是侏罗纪—早白垩世前期，而最主要的烃源层和含油气层系却发育在早白垩世后期—晚白垩世的坳陷期，因此绝大多数石油地质家都将它作为坳陷型盆地的代表，有的甚至称它为新克拉通沉陷复合盆地（胡见义等，1991）。

以渤海湾为代表的陆相断陷盆地，在裂陷主要发育期的早第三纪，表现为大量张性或张

扭性断裂的形成和发育，以及块体强烈的差异升降及翘倾，形成凸、凹（洼）相间，“群山环湖、湖中有山”的古地貌景观；各独立的次级盆地（凹、洼陷）都呈单断箕状结构或不对称地堑结构，面积都小于$1\times10^4km^2$；早第三纪沉积，具有多旋回、近物源、多物源、沉积类型多和沉积相变化大的特点，既是湖相烃源岩的主要发育期，其沉积地层又是盆地最主要的含油气层系；一个凹（洼）陷就是一个基本独立的油气生成、运移和聚集系统（含油气系统）；绝大部分油气藏的形成都与同沉积断裂有关。到晚第三纪，盆地内绝大部分断层都停止或基本停止活动，地壳活动性质转变为整体沉降，形成大型坳陷盆地，广泛发育河流相碎屑岩，基本不具备生烃条件，但可作为重要的储集层系。在济阳坳陷北部和渤海海域各凹陷，上第三系就是主要的含油气层系之一。

关于渤海湾盆地的形成和演化，自20世纪80年代以来，地幔上拱或地幔柱说占据主导地位，但也有越来越多的研究者注意到郯庐断裂带剪切运动的深刻影响。毫无疑义，郯庐断裂作为纵贯中国东部南北的深大断裂，它所产生的巨大剪切应力场，必然波及到邻近地区（如济阳、渤中、辽河等坳陷），并深刻影响它们的构造演化。20世纪90年代以来，关于济阳坳陷构造演化史的研究，也注意到了这一点，并进行了研究。研究认为，虽然不排除地幔上拱或地幔柱对渤海湾盆地形成、演化所起的作用，但郯庐断裂晚侏罗世以来大规模的剪切运动，对于济阳坳陷的演化和构造样式所起的控制作用，似乎更为重要。当然，仅就济阳坳陷讨论这个问题，肯定有某些局限性，但如果着眼整个渤海湾盆地，会更说明问题。比如，为什么渤海湾盆地在平面上呈北北东向拉长的“N”字形结构？为什么盆地的东界与郯庐断裂耦合在一起？为什么盆地的东部含油气特别丰富，而西部相对较差？我们认为，这可能都与郯庐断裂的活动密切相关，而单用地幔上拱或地幔柱很难做出令人满意的解释。本书第一篇第一章就是以这种认识为基础撰写的。之所以如此，并非标新立异，而是为了引起读者的关注和争论，进一步促进和深化对渤海湾盆地构造演化史的研究，从而更加深入、客观地认识渤海湾盆地的成盆、成烃、成藏规律，推动其油气勘探进一步向纵深发展。

二、关于隐蔽油气藏

油气藏类型丰富多样，是中国陆相断陷盆地的典型特征之一。以渤海湾盆地为例，胡见义等（1991）将中国陆相盆地油气藏划分为四大类32种，其中22种油气藏，在渤海湾盆地有其代表；李德生（1997）将已发现的油气藏归纳为四类八种型式；此外还有其他的多种分类方案。不管哪种分类方案，就油气藏类型的数量而言，约三分之二都是岩性类、地层类及相关的复合型油气藏。实际上，已经发现的油气藏，尽管大多数断陷盆地内构造油气藏聚集了半数以上的油气储量，但岩性类、地层类及相关的复合型油气藏的数量却占大多数，并且其比例和新探明的石油储量正在以较快的速度增加。例如济阳坳陷，经过40年的勘探，发现的油气藏类型近20种，其中岩性类、地层类及复合型油气藏的数量占大多数，近几年新发现的油气藏，近70%是这几类油气藏，其中探明的石油储量占阶段总探明储量的50%以上。

虽然从莱复生提出隐蔽圈闭概念到目前已经30多年，在实践中也取得了令人瞩目的成果，但人们对隐蔽油气藏涵义的理解并不完全一致。多数学者认为，隐蔽油气藏近似于非构造油气藏。1983年，在江苏省无锡市召开的第一次全国隐蔽油气藏勘探学术讨论会上形成的共识是：隐蔽油气藏是指目前勘探技术手段尚不易认识和发现的油气藏。隐蔽油气藏是一相对的概念，不同时期、不同经济技术条件下，其涵义也有所不同，而与具体的油气藏类型

没有直接关系。1999 年，邱中建等在其所著《中国油气勘探》一书中，就将极复杂的小断块油气藏列入隐蔽油气藏范畴。我们认为，就勘探的难易程度而言，构造油气藏具有特定的空间形态和分布规律，不论是传统的勘探方法，还是现代的综合勘探技术和方法，它们都是比较容易发现的。虽然随盆地勘探程度的提高，构造油气藏勘探的难度相应地增加，但随着油气聚集分布规律认识的不断深化和综合勘探技术的应用，尤其是地球物理勘探技术及其勘探精度的不断提高，基本可以抵消勘探难度的增加。而岩性类、地层类及相关的复合型油气藏，则具有形成条件及其配置关系多样化、形状不规则、埋藏和分布的隐蔽性（胡见义等，1986），或储集层的极端复杂性等特点，并且除少数潜山油气藏（如任丘等）和复合油气藏（如渤南、双河等）规模较大外，中、小型油气藏占绝大多数，其发现的难度要比构造油气藏大得多。因此，多数学者通常也将它们统称为隐蔽油气藏。本书所说的隐蔽油气藏，就是按这种理解而界定的，它包括地层类、岩性类和相关的复合型油气藏，以及某些特殊类型的非构造油气藏。

不论是海相含油气盆地，还是陆相含油气盆地，隐蔽油气藏都占有极其重要的地位，其油气储量、产量都占很高的比例。据胡见义等（1986）的统计，20 世纪 80 年代中期，美国隐蔽油气藏的储量占其总储量的 42.7%，采油量占总产量的 44.8%；加拿大阿尔伯达盆地隐蔽油气藏储量占其总储量的比例更高达 65%。国外的大型海相盆地尚且如此，构造和沉积环境比海相盆地复杂得多的中国陆相断陷盆地，隐蔽油气藏的地位就更加重要，有的就是以隐蔽油气藏为主（如泌阳凹陷），有的则是随着勘探程度的提高，隐蔽油气藏的重要性逐步显现出来，并且各种隐蔽油气藏的数量和探明储量比例也呈现逐年增加的趋势（如济阳坳陷）。初步估算，中国东部各主要陆相断陷盆地，隐蔽油气藏的油气储量，至少可占盆地总储量的 50%左右，甚至更多。例如，到 2000 年底，渤海湾盆地的冀中坳陷，仅前元古界和下古生界潜山油气藏已探明的石油储量，就占其总探明石油储量的 60%以上，其累计产油量占坳陷总产油量的 70%以上；南襄盆地的泌阳凹陷，仅一个以构造—岩性油气藏为主的双河油田的储量，就占其总探明储量的 58%，其累计产油量占凹陷总产油量的 71%；济阳坳陷，隐蔽油气藏的探明石油储量已占总探明石油储量的约 30%，目前正以每年 6000×10^4～7000×10^4t 的速度增长。各种隐蔽油气藏，已成为中国东部各主要含油气盆地进一步挖掘油气资源潜力、增加油气储量的主要对象。

三、济阳坳陷隐蔽油气藏的勘探

对于一个具体盆地的勘探，总是首先勘探并发现大、中型构造油气藏，待主要的构造油气藏基本都发现后，勘探对象才逐步转向岩性和地层为主的各种隐蔽油气藏。对于隐蔽油气藏勘探，一般也会经历由不认识到认识，由不自觉到自觉的过程。虽然个别盆地最先发现的大油田也主要是隐蔽油气藏，但其最初仍然是按构造油气藏进行勘探的，如双河油田、渤南油田；或者是在勘探第三系构造油气藏时作为兼探目标而发现的，如任丘油田的潜山油藏。

济阳坳陷的隐蔽油气藏勘探，走过了比较曲折的道路。1961 年 4 月，东营凹陷中央带东营背斜构造上的华 8 井，在上第三系馆陶组构造油气藏获得工业油流，是胜利油区发现的标志。1962 年 9 月，在构造北翼钻探的营 2 井，本意是勘探馆陶组和下第三系沙河街组构造油气藏，但结果与原来的设想大相径庭。原设计目的未达到，却意外地钻遇沙三中亚段的超压岩性油气藏，15mm 油嘴日产油 555t，为当时全国最高产的油井。而后，相继部署钻探的营 4、营 6、营 9、营 10、营 11 等井，也都钻遇了沙三中亚段的岩性油气藏。由于各含油

砂体互不连通，油层厚度、产能、压力各不相同，埋藏深度也差别较大，在盆地勘探的初期，很难掌握其发育和分布规律。因此，当1964年在相邻的胜利村背斜坨7井沙三上亚段构造油气藏试油获得日产361t的高产油流后，勘探重点立即转向盆地最主要的含油气层系——沙二段和沙三上亚段的构造油气藏，很快探明了济阳坳陷最大的油田——胜坨油田，并相继又发现和探明了东辛、永安镇、滨南、纯化、孤岛等一批以构造抽气藏为主的大、中型油田。其间，虽然也在东营和沾化凹陷先后发现了以沙三段浊积岩隐蔽油气藏为主的渤南、梁家楼、五号桩、牛庄等油田，但究其勘探过程，它们最初都是按构造油气藏进行勘探，或由构造油气藏扩大勘探而发现的。此外，作为兼探目标也发现了一些小型隐蔽油气藏，如王庄潜山油气藏和东营凹陷中央带的一些岩性油气藏等。到20世纪90年代初，济阳坳陷内的大、中型构造油气藏基本都已被发现，大部分比较容易发现的小型构造（断块）油气藏也已被发现，构造油气藏的勘探难度越来越大，新发现的构造油气藏规模越来越小，数量和储量也越来越少，而隐蔽油气藏却显示了巨大的勘探潜力，并逐步上升为主要勘探对象。以五年为一个统计单元，仅前中新统隐蔽油气藏探明石油储量占阶段总探明石油储量的百分比，即由1985—1990年的20%左右上升到1995—2000年的60%左右。

回顾济阳坳陷40年的油气勘探史，可以发现，理论认识的提高和勘探技术的进步，是发展岩性油气藏为主的隐蔽油气藏勘探的重要保证。

1962—1975年，以构造油气藏为主要勘探目标，对岩性油气藏缺乏理论性认识，加上勘探技术落后，不知道到哪里去找，也不知道怎样去找，虽然也发现了一些岩性油气藏，但其发现可遇而不可求，具有极大的偶然性。1976—1985年，浊积理论的引进和应用，从理论上解决了一部分岩性油气藏的成藏规律性认识问题，知道了应该到哪里去寻找它们。因此，在继续勘探构造油气藏的同时，开始有意识地兼顾岩性、地层油气藏的勘探，但囿于勘探技术的落后，其勘探发展的步伐比较缓慢，仅发现了五号桩油田的桩52—桩74、单家寺、牛庄及现河庄等地区的一些岩性或地层—岩性油气藏，并且对由多个小型岩性油气藏组成的牛庄油田，也只能按含油砂体叠合连片的办法计算储量。1985—1990年的油藏描述技术攻关研究，为后来隐蔽油气藏勘探的快速发展提供了技术储备。20世纪80年代后期以来，大批三维地震资料的采集和应用，以及地质建模、模式识别、测井约束反演、储层预测、测井新技术、油气层保护和改造等多项勘探新技术的相继形成和配套，尤其是下第三系层序地层的研究，揭示了砂、砾岩隐蔽油气藏群受“断裂坡折带—低位扇”控制的成藏规律，既解决了到哪里找，又解决了如何找的问题，促进了隐蔽油气藏勘探的快速发展。近十多年，逐步形成了隐蔽油气藏勘探的高潮，在东营凹陷北部陡坡带、博兴洼陷、沾化凹陷的埕南断裂带、渤南洼陷—孤北斜坡带、孤岛西部斜坡、埕岛油田东北坡、车西洼陷南坡等地区，都发现了大批岩性、地层油气藏，以岩性油气藏为主的东营凹陷郝家—史南地区、牛庄油田和沾化的五号桩油田进一步扩大，临邑洼陷、车西洼陷北坡的隐蔽油气藏勘探相继取得突破，新发现隐蔽油气藏的数量逐年增加。近几年，每年探明的一亿多吨石油储量中，隐蔽油气藏储量比例高达60%～70%。隐蔽油气藏已成为济阳坳陷增加油气储量的主要领域。

四、关于本书的编写

本书的重点是各种隐蔽油气藏的分布规律，以及预测、评价、描述等勘探技术，并用典型实例说明各种主要勘探技术的综合应用及其效果。因此，对与成藏有关的基础部分作简化处理。地质基础只写了与隐蔽油气藏关系密切的盆地构造特征和充填模式两部分内容，成藏

基础部分只写了成烃、油气运移和成藏、油气藏分类概述等内容。

虽然隐蔽油气藏包括了岩性、地层和复合型等三类多种油气藏类型，但是，如果严格按油气藏类型编写，既不便于认识某些类型油气藏之间的成因联系，又不便于把握其成藏和分布的规律，并且还不可避免地造成文字的重复。比如一个陡坡砂砾岩扇体群，其中可能形成透镜状、岩性上倾尖灭、物性封堵、断层—岩性、地层超覆等几种类型的油气藏，如果严格按油气藏类型，势必将其分成几部分，难以把握其成藏和分布的总体规律，涉及砂砾岩扇体部分的认识和勘探技术，也必然会多次重复。实际上，一个扇体群中的各种油气藏类型通常相互交叉叠置在一起，勘探阶段既无必要也很难将它们区分开，一般都将一个扇体群作为一个目标进行研究和勘探。因此，本书采取了按储集体类型编写的方式，分为碎屑岩、碳酸盐岩、火成岩和其他类型等四大类隐蔽油气藏分篇编写。其中碎屑岩隐蔽油气藏的重点是下第三系与各种扇体有关的油气藏，碳酸盐岩隐蔽油气藏的重点是下古生界碳酸盐岩潜山油气藏。火成岩油气藏，虽然胜利油区在近几年仅发现三处，其类型也有所不同，但都从多方面进行了研究，认识也达到一定的深度，因此所着笔墨也较多。其他类型隐蔽油气藏包括太古界变质岩潜山油气藏和下第三系泥岩裂缝油气藏，前者的发现不太多，后者虽然已发现不少出油点，但还没有探明一个油气藏，因此，对这两种油气藏只作简单的介绍。其中的泥岩裂缝油气藏，是以李琦博士来胜利油区博士后工作站的研究成果为基础编写的。

全书由潘元林、张善文、肖焕钦等确定写作提纲并组织编写。具体编写工作由集体分工完成。各篇章的主要编写人员分别是：绪言——潘元林；第一篇：第一章——宗国洪，第二章——邱以钢、潘元林；第二篇：第三章——张林晔、刘庆、孔祥星，第四章——王宁，第五章——肖焕钦；第三篇：第六和第七章——王居峰，第八章——陈宝宁、王宁、潘元林，第九章——肖焕钦、刘书会、邱以钢，第十章——肖焕钦、王化爱、郭玉新；第四篇：第十一章——王永诗、李开勐、张秀芝，第十二章——王永诗、李开勐、马立弛、潘元林，第十三章——王永诗、姜素华、史建忠，第十四章——王永诗、林会喜、王居峰；第五篇：第十五章——谢忠怀、刘惠民，第十六章——刘惠民、韩荣花，第十七章——刘惠民、韩荣花、潘元林，第十八章——刘惠民；第六篇：第十九章——张善文、王永诗、林会喜，第二十章——张善文、王永诗、张家霞。全书由潘元林统稿和定稿。

《油气地质与采收率》期刊前常务副主编付瑾平高级工程师，以及朱宗浩高级工程师协助进行了统稿和文字加工；还有许建华等同志为书稿清样、校对，编写目录和参考文献，在此谨致以衷心的感谢！

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我们参与本书写作的人员，多年来主要从事油田现场勘探研究和实践，理论水平有限，对隐蔽油气藏概念的理解、其成藏和分布规律的认识，肯定会有某些局限性，甚至不足之处，有些勘探技术也还有待进一步改进和完善。读者在阅读和使用本书时，一旦发现问题，请不吝赐教，向我们提出批评和改进意见。我们也愿意就某些问题与读者进行探讨，共同提高。

Introduction

Since A. I. Leverson, the famous American petroleum geologist, put forward the concept of "subtle trap" in the mid－1960s, the exploration of subtle reservoir has developed rapidly in the world. All kinds of subtle reservoirs were discovered continuously, including many large and super subtle reservoirs. The subtle traps have been the important potential targets by which geologists and explorationists to study for reserve increasing. In the terrestrial faulted basins of East China, the structural traps were not sufficiently developed, except for the fault－screened traps associated with synsedimentary fault and a few rollover structural traps, there are lots of subtle traps such as lithologic and stratigraphic traps. As the degree of exploration rises in these basins, it is very difficult to find structural hydrocarbon reservoir continuously, so the subtle reservoir has aroused general concern, and become important potential targets. Over 30－year structural reservoir exploration, the subtle traps in Jiyang Depression were main exploration object firstly in China, in early 1990s. As the exploration of subtle reservoir developed rapidly, the plentiful results have been achieved, the proven reserves have been increasing year by year, and the relative theory and technologies have been formed. To sum up knowledge about the subtle reservoir's characteristics and exploration technologies in Jiyang Depression for the basis of further study and development, also for the systematic exploring reference of similar basins, we write the book Exploration of Subtle Reservoir in Jiyang Faulted Basin.

The following statements are given to several important terms in the book, the exploration activities of Subtle Reservoir in Jiyang Depression as well as some issues about the book.

1. Faulted basin

The terrestrial faulted basin is one of the dominant types of petroliferous basins in China. The term of "faulted basin" has been used for many years, but its name was not same in the different basin classifications, such as "synrift basin" (Ye Lianjun, Sunshu, 1980), "intraplate faulting and downwarping basin" in "tensional basin" (Li Desheng, 1982); "tensional faulted basin" or "fault strike sliding as well as corresponding tensional and faulted basin" (Zhuxia, 1982, 1983), "interior cratonic faulted basin, or faulted basin" (Hu Jianyi, 1991), "continent－marginal faulted basin" (Tian Zaiyi, 1996) and so on. The main meaning of above names is basically same. The common knowledge about its genesis is: In early, the upper mantle upwarp and lithosphere uplift caused by some kind of geologic function resulted in tensional faulting, moving differentially up and down, and upwarping, to form multiple half grabens (half graben) or graben basin, simultaneously there was basic magma movement. In late, Earth crust regionally fell due to the mantle materials cooled and shrank, to develop to depression basin. While above two types of basins overlapped to develop rift－depression basin. This kind of basin is featured by regular depositional sequences with underlying rift－filling sedimentary sequences and overlying depression sedimentary sequences. Almost all of the continental petroliferous basins in East China belong

to this type. However, there are also some differences among these basins. According to general understanding, in a fault – depression basin, if the main source – rock beds and hydrocarbon – bearing strata formed in faulting period, it is called faulted basin, such as Jiyang Depression in Bohai Bay Basin. Otherwise, Songliao is also a faulted – depression basin, but its main faulting period was Jurassic – pre Cretaceous, the main source – rock beds and hydrocarbon – bearing strata formed in late period of early Cretaceous – late Cretaceous depression period, so the most petroleum geologists think it is a representative of depression basin. Someone call it new Craton depressed basin (Hu Jianyi, 1991).

In terrestrial rift basin, such as Bohai Bay basin, a large amount of tensional or transtensional faults developed in early Tertiary, and moved up and down strongly as well as upwarping. It is appeared to the kame – and – kettle palaeogeomorphic landscape looked like "mountains around the lakes and mountains in the lakes". Early Tertiary was main development period of lake facies source rock. Each independent secondary basin (sag) has the structures of single fault half graben or asymmetric graben, covering an area less than $1 \times 10^4 km^2$. The sedimentary formations in this period were characterized by polycycle, proximal deposit, more sources and types, complex environments and sedimentary facies. Every sag could be an independent system of generation, migration and accumulation of oil and gas (Petroleum System). Most of reservoirs were related to synsedimentary faulting. By late Tertiary, most of faults stopped moving, the large depression basins were formed as the mass settlement of earth shell. The fluvial facies clastic rock was widely developed. They had not conditions for hydrocarbon generation, but could be important reservoir. In the north of Jiyang Depression and sags in Bohai Sea, Neogene system was one of the main oil and gas bearing strata.

About the generation and evolution of Bohai Bay Basin, since 1980s, the theory of mantle upwarp has occupied a dominant position. But more and more people pay attention to strong influence of shear movement of Tanlu Faulted Belt, across north to south in East China, its huge shear stress certainly influenced nearby regions (for example, Jiyang depression, Bozhong depression, Liaohe depression). It also deeply influenced their structural evolution. The results studied on the structural evolution history in Jiyang Depression show that, although not to eliminate effect on generation and evolution of Bohai Bay Basin mantle by upwarp or mantle plume, it seems more important that the effect large shear movements of Tanlu Fault Belt on evolution and structural style of Jiyang Depression. Of course, there is some limitation on discussing the issue only for Jiyang depression, it should be much clear for the whole Bohai Bay Basin. For example, why the structure of Bohai Bay Basin is in the form of "N" on plane? Why the east boundary of Bohai Bay Basin put together with Tanlu Fault Zone? Why the east of Bohai Gulf Basin has abundant oil and gas, and the west has no? We think these were related to movement of Tanlu Fault Belt, and the theory of mantle upwarp or mantle plume could not explain these questions. The first chapter in this book is written on the basis of this knowledge. We hope the points can arouse general concern and contention, further promote reach on structural evolution history of Bohai Bay Basin, so that, we can understand Bohai Bay Basin deeply and correctly, and make much further exploration.

2. Subtle reservoir

Many diversified reservoir types are one of typical characteristics of China terrestrial faulted basin. Reservoirs in China basins were classified as 32 types within four classes by Hu Jianyi *et al*. (1991), and there are 22 types of these in Bohai gulf basin. Discovered reservoirs were summarized into eight types within four classes by Li Desheng (1997), and other various classification as well. For the numbers of reservoir type, about two thirds of these are lithologic, stratigraphic or complex reservoirs. In the most rift basins, although the hydrocarbon reserves of discovered structural reservoirs exceed more than 50 percent, most of the reservoirs belong to lithologic, stratigraphic and complex reservoirs, and their numbers and proved petroleum reserves have been increasing rapidly. The 40 – year exploration in Jiyang Depression indicates most of the nearly 20 kinds of discovered reservoirs belong to lithologic, stratigraphic and combined reservoirs, and the 70% recently discovered reservoirs belong to these reservoirs, of which the proved petroleum reserves exceed more than 50 percent of the total proved reserves in the period.

The concept of "subtle trap" was first proposed by A. I. Levorson 30 years ago, but people had different understanding on the subtle reservoir. They feel that subtle reservoir is similar to nontectonic reservoir. In 1983, the first National exploration Technology Conference on Subtle Reservoir Exploration was held in Wuxi city of Jiangsu Province. Many people agreed that subtle reservoir was referred to a reservoir that could not be easily discovered by existing exploration technologies. The concept of subtle reservoir is relative, without reference to types of reservoir. Its meaning varies with different contexts under different economic and technical conditions in different periods. In the book of China Hydrocarbon Exploration written by Qiu Zhongjian *et al*. (1999), the extremely complex small fault reservoir was referred to in the category of subtle reservoir. For the exploration, we think that structural reservoir has specified space shape and distribution characteristics, and it can be easily discovered by either conventional or modern comprehensive exploration technology. The exploration difficulties of structural reservoir increased appropriately as the degree of exploration rose. However, the increase could be eliminated by deepening cognition for hydrocarbon accumulation distribution characteristics and application of comprehensive exploration technologies, especially the improvement of geophysical exploration technologies and surveying accuracy. The lithologic, stratigraphic and complex reservoirs have the characteristics of diversified generating conditions and distribution relations, non – regular shape, concealment (Hu Jianyi, *et al*., 1986), and extreme complexity of reservoir. Most of them are small and medium reservoirs except for a few buried hill reservoirs (such as RenQiu etc.) and complex reservoirs (such as Bohai, Shuanghe etc.). Hence they are also commonly referred to as subtle reservoirs. Subtle reservoir mentioned in this book, which are stipulated in accordance with this understanding, include lithologic, stratigraphic, complex reservoirs and some of special nontectoric reservoirs.

Subtle reservoir with more hydrocarbon reserves and oil productions occupied very important position in either marine or continental petroliferous basins. According to the statistics by Hu Jianyi, *et al*., in the mid – 1980s, the reserves and oil production of subtle reservoirs were respectively 42.7 percent and 44.8 percent of total reserves and production in America; The re-

serves of subtle reservoir in Albert basin were up to 65 percent of total reserves in Canada. In China, oil and gas bearing basins are mainly complex terrestrial rift basins, some of them rely mainly on subtle reservoirs (such as Biyang depression), and others also have many subtle reservoirs, of which their numbers and reserves are raising year by year. It is estimated that the hydrocarbon reserves of subtle reservoir at least can account for 50 percent and more of total reserves in the major terrestrial rift basins. For example, by the end of 2000 year, the proved oil reserves and the accumulative oil production of Neoprotozoic and lower Cambrian buried hill reservoir had respectively accounted for more than 60 percent and more than 70 percent of total proved reserves and oil production in Jizhong depression of Bohai Gulf Basin; In Biyang sag of Nanxiang Basin, only the reserves and the oil production of Shanghe oil field which is mainly structural – lithologic reservoir respectively accounted for 58 percent and 70 percent of total reserves and oil production; The proved oil reserves of subtle reservoir in Jiyang depression made up 30 percent of total proved reserves, and were increasing at the rate of $6000\times10^4-7000\times10^4$t per year. At present, various subtle reservoirs have been the major potential targets of petroliferous basins in the east of China.

3. Exploration of subtle reservoir in Jiyang depression

In a depression, it is common that the medium or large structural reservoirs are first discovered, and then the main object is averted to subtle traps which are mainly lithologic and stratigraphic reservoirs. The exploration of the subtle reservoirs is often accompanied by the progresses of knowledge and consciousness. But there are some exceptional examples, such as Shuanghe oilfield and Bonan oilfield, that the subtle reservoir was first discovered during exploring structural oilfield; And Renqiu buried hill oilfield was found as a sub – object during the exploration of Tertiary structural sandstone oilfields.

The path of exploring subtle reservoirs in Jiyang Depression is tortuous. In April 1962, well Hua – 8 had commercial flow from Guantao formation (Neogene system) on the central uplift belt of Dongying anticline in Dongying sag, it is the first discovery well in Shengli oilfield. In September 1962, well Ying – 2 was drilled on the north limb of the same structure, in order to explore the structure of Guantao formation and Shahejie formation(Eogene system), but the results was widely divergent. Instead of finding structural oilfields, a supper – high pressure lithologic oil pool in middle – Shahejie sub – member was found occasionally. This well was tested at an oil flow of 555t per day by 15mm bean, and became the highest production one in China at that time. The subseqent wells, Ying – 4, Ying – 6, Ying – 10, Ying – 11 were drilled, and encountered the same reservoir. But there were so diffrents of sands connection and thickness, oil rates, as well as reservoir pressure and depth in these wells, that it was difficult to study the distribution of the reservoir. As a result, after well Tuo – 7 lied on Shenglicun anticline got a production of 361t per day in up – Es3 member, the main objective of exploration was turned to Es2 member and up – Es3 member, which is the main structural reservoir of Shengli oilfield. The largest oilfield – – Shengtuo and a number of medium to large size structural oilfields were dicoved from then on, such as Dongxin , Yonganzhen , Binnan, Chunhua, Gudao oilfields etc.

Athough some subtle oilfields were found at the same time, such as Bonan, Liangjialou,

Wuhaozhuang, Niuzhuang oilfields, they were originally explored as structural trap. There were also some small – size oilfields proved as accessories, such as Wangzhuang and some small oilfields on the center uplift of Dongying sag. In 1990s, almost all of the medium to large size oilfields and most of the small size simple structures had been proved, so it was more and more difficult to find such oilfield, and the reserves of structural oilfields were less and less. On the contrary, the subtle oilfields show more potentiality, and became to the main object of the exploration. Using 5 years as a statistical unit, the reserves of subtle oilfields were about 20% of the proved reserves from 1985 to 1990, but the percentage went up to 60% from 1995 to 2000.

The 40 – year exploring history of Shengli oilfield shows that, it is important to enhance the level of theory of the subtle reservoirs, the raise of the theoretical level and the improvement of technology are the guarantee of the development of exploration.

From 1962 to 1975, the main exploration targets were structural oilfields, because technology and theory about subtle reservoirs was underdeveloped, we did not know how to do, only there were a few occasional discoveries, but ends and means were not definite. From 1976 to 1985, because of introduction and application of the turbidite theory, we partially found a way out of the difficulty and consciously sought some lithologic and stratigraphic reservoirs. Due to the limitation of the exploration technology, only some small oilfields were proved, including Wuhaozhuang, Sanjiashi, Niuzhuang, and Xianhe oilfields. Reserves of the pools were calculated only by the accumulated thickness of net pay.

In the years of 1985 to 1990, the study of tackling key problem of depicting the reservoirs provided the technology to enhance the pace of the exploration of subtle reservoirs.

After the late 1980s, the reservoir discription technology created favouable conditions for the rapid development of subtle reservoir exploration. Using large quantities of 3D seismic data and a series of new technologies including geology modeling, model identification, logging constraint inversion, reservoir prospecting, new technology of logging, reservoir protection etc., we studied specially the sequences of lower Tertiary, and understood that the developed and distributed characteristics of subtle reservoir was controlled by slope breaks and lower fans, so we knew how to seek and where is in the subtle reservoirs. In the recent ten years, many subtle reservoirs have been proved in many places, such as north slop of Dongying sag, Boxing sag, Chengnan faults zone of Zhanhua sag, Bonan sag – – Gubei slop, the north slop of Gudao lift, east slop of Chengdao lift, the south slop of Chexi sag etc., Haojia – Shinan region, Niuzhuang and Wuhaozhuang oilfields, known as subtle reservoirs, enlarged the area of oilfield, and there are some breakthroughs in Linyi sag, the north slope of Chexi sag. The reserves of subtle oilfields were about 50% – 70% of newly increased reserves every year recently. Now, subtle oilfields have become the main exploration goal in Shengli oilfield.

4. about the book

The book emphasizes the distribution characteristics of subtle reservoir and the technology of prospecting, evaluating, and depicting with typical examples. The basic theory about oil accumulation was simplified, only including two aspects of the geologic theory: the structural features and the filling model closely related to subtle reservoirs. There are also some contents about hy-

drocarbon generation, migration, and accumulation, as well as classification of reservoir.

Although subtle reservoir can be classified into three types: lithologic, stratigraphic and composite reservoir, if the book had been written by this classification, it is difficult to make out the relationship of some reservoirs and to know the distribution of the reservoirs. For example, a series of sand－conglomerate fans may form a sand－conglomerate lens reservoir, or a onlap pinching reservoir, or a fault－lithologic reservoir, and so on. According to above classification, it must be divided into several sections, so that it is difficult to know its distribution characteristics wholly. The description for the understanding and technology of sand－conglomerate fans would be repeated. Actually, various types of reservoirs of a fan group are often juxtaposed, which are difficult and need not to be distinguished during exploration phase. So we often study it as an exploration goal. In view of this, this book describes four types of subtle reservoirs in four chapters, which includes clastic reservoir, carbonate reservoir, igneous rock reservoir, and others. Of them, we focus on the clastic reservoir of the lower tertiary relating to various fans, and the carbonate buried reservoir of the lower Paleozoic. To the igneous rock reservoir, although we have found three in Shengli oil area in recent years, which have different types, we have studied them in detail. So this section is the focal point. Others include metamorphic rock buried reservoir, which is not common in Shengli Oilfield, and the mudstone fractural reservoirs of lower Tertiary, which have been found many oil pools with none proved. So we introduced these two types simply. The content of fractured mudstone reservoir is according to the achievements of Dr. Liqi, who does research work in postdoctoral stop of Shengli.

The book framework is determined and the writing organized by Pan Yuanlin, Zhang Shanwen and Xiao Huanqin. The authors of the sections and chapters is list below: Introduction by Pan Yuanlin; Section 1: Chapter 1 by Zhong Guohong; Chapter 2 by Qiu Yigang and Pan Yuanlin; Section 2: Chapter 3 by Zhang Linye, Liu Qing and Kong Xiangxing; Chapter 4 by Wang Ning; Chapter 5 by Xiao Huanqin; Section 3: Chapter 6 and 7 by Wang Jufeng; Chapter 8 by Cehn Baoning, Wang Ning and Pan Yuanlin; Chapter 9 by Xiao Huanqin, Liu Shuhui and Qiu Yigang, Chapter 10 by Xiao Huanqin, Wang Huaai and Guo Yuxin; Section 4: Chapter 11 by Wang Yongshi, Li Kaimeng and Zhang Xiuzhi, Chapter 12 by Wang Yongshi, Li Kaimeng, Ma Lici and Pan Yanlin; Chapter 13 by Wang Yongshi, Jiang Suhua and Shi Jianzhong; Chapter 14 by Wang Yongshi, Lin Huixi and Wang Jufeng; Section 5: Chapter 15 by Xie Zhonghuai and Liu Huimin; Chapter 16 by Liu Huimin and Han Ronghua; Chapter 17 by Liu Huimin, Han Ronghua and Pan Yuanlin; Chapter 18 by Liu Huimin; Section 6: Chapter 19 by Zhang Shanwen, Wang Yongshi and Lin Huixi; Chapter 20 by Zhang Shanwen, Wang Yongshi and Zhang Jiazhen. The book finalized by Pan Yuanlin.

Acknoledgement should be given to Mr. Hu Jianyi, an academician of Academy of Engineering and a well－known petroleum scientist, composed the preface.

The authors of the book are mainly engaged in practice of exploration, and have a limited theory level on subtle reservoirs and their distribution, and the technology of exploration keeps on improving, if you find some problems in the book, please inform us. We are willing to discuss some issues in the book with you.

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