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内 容 简 介

本书主要以渤海湾盆地东营凹陷和沾化凹陷为例，系统总结了含油气盆地的流体特征及其所指示的油气成藏的意义。全书在调研国内外盆地流体研究已有成果的基础上，根据中国东部渤海湾盆地和西部准噶尔盆地的油气勘探实践及相关研究成果，以盆地流体压力场、盆地流体化学场、盆地流体动力场三大核心内容为主线，通过不同盆地区域的流体压力场、流体地球化学分析，结合不同压力体系下有机质生烃、原油裂解成气模拟实验，阐述流体压力与油气成藏的关系；结合盆地区域构造、沉积环境及演化，从地层水矿化度、离子含量、离子比值参数、水型及原油物理性质等方面阐述不同沉积环境下盆地流体的地球化学场特征、水-岩作用及其指示的油气成藏的意义；通过研究不同盆地流体动力系统下流动型式的演化及流体势场的分布，论述流体动力场及其指示的优势油气运移方向和有利油气富集区的选择。全书资料丰富，内容翔实，将理论、方法与勘探实践相结合，丰富和发展了沉积盆地流体与油气成藏关系的认识。

本书可供从事油气勘探的科研工作者、技术管理人员及高等院校师生科研和教学时参考。

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总　　序

“211 工程”于 1995 年经国务院批准正式启动，是新中国成立以来由国家立项的高等教育领域规模最大、层次最高的工程，是国家面对世纪之交的国内、国际形势而作出的高等教育发展的重大决策。“211 工程”抓住学科建设、师资队伍建设等决定高校水平提升的核心内容，通过重点突破，带动高校整体发展，探索了一条高水平大学建设的成功之路。经过 17 年的实施建设，“211 工程”取得了显著成效，带动了我国高等教育整体教育质量、科学研究、管理水平和办学效益的提高，初步奠定了我国建设若干所具有世界先进水平的一流大学的基础。

1997 年，中国石油大学跻身“211 工程”重点建设高校行列，学校建设高水平大学面临着重大历史机遇。在“211 工程”的“九五”、“十五”、“十一五”三期建设过程中，学校始终围绕提升学校水平这个核心，以面向石油石化工业重大需求为使命，以实现国家油气资源创新平台重点突破为目标，以提升重点学科水平，打造学术领军人物和学术带头人，培养国际化、创新型人才为根本，坚持以优势带整体，以特色促水平，学校核心竞争力显著增强，办学水平和综合实力明显提高，为建设石油学科国际一流的高水平研究型大学打下良好的基础。经过“211 工程”建设，学校石油石化特色更加鲜明，学科优势更加突出，“优势学科创新平台”建设顺利，5 个国家重点学科、2 个国家重点（培育）学科处于国内领先、国际先进水平。根据 ESI（Essential Science Indicators，基本科学指标数据库）2012 年 3 月份更新的数据，我校工程学和化学两个学科首次进入 ESI 世界排名，体现了学校石油石化主干学科实力和水平的明显提升。高水平师资队伍建设取得了实质性进展，培养汇聚了两院院士、长江学者特聘教授、国家杰出青年科学基金获得者、国家“千人计划”及“百千万人才工程”入选者等一批高层次人才队伍，为学校未来发展提供了人才保证。科技创新能力大幅提升，高层次项目、高水平成果不断涌现，年到位科研经费突破 4 亿元，初步建立起石油特色鲜明的科技创新体系，成为国家科技创新体系的重要组成部分。创新人才的培养能力不断提高，开展“卓越工程师教育培养计划”和拔尖创新人才培育特区，积极探索国际化人才的培养，深化研究生培养机制改革，初步构建了与创新人才培养相适应的创新人才培养模式和研究生培养机制。公共服务支撑体系建设不断完善，建成了先进、高效、快捷的公共服务体系，学校办学的软硬件条件有显著改善，有力保障了教学、科研及管理水平的提升。

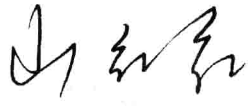
17 年来的“211 工程”建设轨迹成为学校发展的重要线索和标志。“211 工程”建设所取得的经验成为学校办学的宝贵财富。一是必须要坚持有所为、有所不为，通过强化特色、突出优势，率先从某几个学科领域突破，努力实现石油学科国际一流的发展目标；二是必须坚持滚动发展、整体提高，通过以重点带动整体，进一步扩大优势，协同发展，不断提高整体竞争力；三是必须坚持健全机制、搭建平台，通过完善“联合、开放、共享、竞争、流动”的学科运行机制和以项目为平台的各项建设机制，加强统筹规划，集中资源力量，整合

人才队伍，优化各项建设环节和工作制度，保证各项工作的高效有序开展；四是必须坚持凝聚人才、形成合力，通过推进“211 工程”建设任务和学校各项事业发展，培养和凝聚大批优秀人才，锻炼形成一支甘于奉献、勇于创新的队伍，各学院、学科和各有关部门协调一致、团结合作，在全校形成强大合力，切实保证各项建设任务的顺利实施。这些经验是在学校“211 工程”建设的长期实践中形成的，今后必须要更好地继承和发扬，进一步推动高水平研究型大学的建设和发展。

为了更好地总结“211 工程”建设的成功经验，充分展示“211 工程”建设的丰富成果，学校自 2008 年开始设立专项资金，资助出版与“211 工程”建设有关的系列学术专著，专款资助我校优秀学者以科研成果为基础的优秀学术专著的出版，分门别类地介绍和展示学科建设、科技创新和人才培养等方面的成果和经验。相信这套丛书能够从不同的侧面、从多个角度和方向，进一步传承先进的科学研究成果和学术思想，展示我校“211 工程”建设的巨大成绩和发展思路，从而对扩大我校在社会上的影响，提高学校学术声誉，推进我校今后的“211 工程”建设有着重要而独特的贡献和作用。

最后，感谢广大学者为学校“211 工程”建设付出的辛勤劳动和巨大努力，感谢专著作者孜孜不倦地整理总结各项研究成果，为学术事业、为学校和师生留下宝贵的创新成果和学术精神。

中国石油大学(华东)校长



2012 年 9 月

序

沉积盆地中的地下流体包含地层水和油气等多种物质，他们共存于地下岩石空隙中。地层水作为油气运移、聚集的载体，其形成及运动规律与油气藏的形成、保存和破坏有十分密切的联系。因此，对我国陆相盆地从理论到实践进行系统地盆地流体与油气成藏作用研究，不仅具有重要的理论意义，而且对相关盆地的油气勘探具有积极的指导作用。

该书的作者以石油地质学为核心，以有机地球化学和无机地球化学理论为指导，以勘探实践中的大量钻井、试油和岩心测试资料为依据，以不同条件下的油气生成、原油充注与运聚等物理模拟实验和数值模拟技术为手段，以盆地流体压力场、流体化学场、流体动力场三大核心内容为主线，通过对中国东部渤海湾盆地和西部准噶尔盆地典型地区的油气勘探实践及相关研究成果的剖析，系统地研究和探讨了盆地流体的地质地球化学特征和油气成藏作用意义。

全书有如下几个方面值得大家关注。

（1）流体压力的分布、成因、预测及对油气生成与演化、油气运移与聚集的影响。通过对大量地质地球化学实测资料和模拟实验的分析，研究了典型陆相湖盆中流体压力的分布、成因及不同压力下有机质成烃特征；阐明压力对生烃动力学参数的定量影响，探讨分子生物标志物参数在高温阶段不同压力体系下的演化特征；分析异常高压对储集空间的影响及超压封隔层的封闭性能演化，阐明异常高压体系烃类流体的排放机制，剖析不同成藏动力学系统下的地球化学响应及油气聚集方式，指明了压力系统分布与油气分布的关系及超压流体的勘探意义。

（2）不同湖盆中地层水化学场响应、水-岩作用型式及油气成藏的意义。通过对准噶尔盆地和渤海湾盆地典型地区地层水化学的分析，阐明了盆地剖面水文地质分带和油气藏保存的意义，论述了水文地质旋回及其水化学场响应，对比研究了准封闭型强超压咸化湖盆、开放性局部超压型湖盆和低压湖盆的水化学场响应及其对油气成藏的意义，探讨了年轻地层和古老地层水化学场响应、水-岩作用与油气分布关系。

（3）盆地流体流动驱动机制、流动型式、流体势场及与油气成藏的意义。通过对准噶尔盆地和东营凹陷地下流体动力场的剖析，研究中国东部裂陷湖盆和西部前陆盆地中不同流体动力系统下流动型式、流体动力场的演化及其对油气成藏作用的意义，模拟地下油气运移动力学的路径和过程，在此基础上论述含油气盆地烃类流体运动的非均一性，阐述利用盆地流体场进行油气成藏有利目标区选择的综合研究方法和实践。

纵观全书，可以发现作者在理论与实践方面做了许多出色的工作，许多观点和认识具有新意，对盆地流体及油气成藏研究起推动作用，所提出的研究思路和方法不仅为我国陆相湖盆流体与油气成藏研究提供了范例，而且对相关盆地的油气勘探实践具有参考价值。

盆地流体与油气成藏作用研究涉及的时空范围广，控制因素复杂，要解决其中的某些问题需要具备多学科的理论知识和行之有效的方法。以往的研究和成果多只涉足某一方

面，该书作者对与盆地流体有关的压力场、水化学场与水动力场三个方面进行了综合研究，并把他们有效地结合在一起，进行了许多深入和有益的探索，所取得的成果非常值得肯定。

我向读者推荐此书，希望在盆地流体与油气成藏研究方面对读者有所启发或参考，同时也期望作者在此方面做更深入的研究，今后有更多、更好的成果问世。

中国科学院院士

2013年9月

前　　言

随着油气能源勘探的不断发展，尤其是非常规油气能源勘探的快速兴起，需要对油气成藏机理的认识和研究不断深入。沉积盆地中地下油气与地层水以不同的形式共存于地下岩石空隙中，地层水作为油气运移、聚集的载体，和油气之间存在物质成分交换，其形成及运动规律与油气藏的形成、保存和破坏有十分密切的联系。盆地中的地层水在三维空间内可以形成流体压力场、水化学场和水动力场，对油气的生成、运移、聚集都会产生重要作用。地层压力场反映了盆地中的沉积物，尤其是细粒烃源岩体的沉积过程和受压实程度、烃类的聚散平衡和封闭环境的开启、闭合等特点；地层水化学特性可以用于推断不同流体的混合程度和水-岩相互作用过程，水化学场分布则体现了盆地内能量场控制下的流体运移和聚集的物质效应；水动力场的研究可指示油气成藏的环境和水动力条件，具有十分重要的意义。由于天然气在深层多溶解于油或水中，因此把油气和地层水结合起来作为一个流体系统进行研究，可以更好地把握地下油气的形成与演化过程，更全面地反映地下油气的形成与分布规律，更深入地揭示地下油气成藏机理。鉴于盆地流体对研究油气成藏机理的重要性，国内外学者开展了大量的研究工作并已出版多部专著，国内的著作在盆地压力研究（马启富等，2000；王振峰和罗晓容等，2003；郝芳，2005；解习农等，2006）、地层水化学及动力场研究（蔡春芳，1997；焦大庆等，1998；康永尚和张一伟，1999；李贤庆等，2005；楼章华等，1998）等方面也展示了一系列重要成果。

尽管相关方面的研究已取得了长足的进展，但在盆地流体压力生烃动力学、不同盆地的流体化学场及考虑输导体系非均质性的油气成藏数值模拟等方面仍存在一些有待深入研究的科学问题。如在盆地流体压力生烃动力学方面，以郝芳（2005）为代表的国内外学者已经开展了大量的研究工作，取得了系统性的研究成果，但目前的研究多针对有机质热演化、有机质成油及有机质成气，在高温下原油裂解成气中，压力的影响及其对生烃作用抑制的定量认识等方面，还有待进一步研究。

因此，本书主要以与中国东部渤海湾盆地济阳拗陷相邻的、但盆地流体场截然不同的东营凹陷、沾化凹陷和惠民凹陷，以及中国西部准噶尔盆地西北缘和腹部作为研究对象，以大量地质、地球化学资料及相关模拟实验为基础，对陆相湖盆中流体压力的分布、成因、预测及其对油气生成与演化、油气运移与聚集的影响，不同湖盆中地层水化学场响应、水-岩作用型式及油气成藏意义，以及盆地流体驱动机制、流动型式、流体势场及其对油气成藏的意义三方面进行了系统研究和阐述。

本书的相关研究成果展现了对盆地流体的一些新认识。例如，在流体压力场及化学场方面，以东营凹陷和沾化凹陷为代表，通过对来自勘探实践的大量试油数据的分析，论述超压封隔层及超压封存箱的形成机制和其中的流体运动形式，剖析超压分布、超压控藏作用及超压封存箱的地质地球化学特征、生排烃特征及其中的油气运聚规律；对比研究陆相封闭性咸化湖盆和陆相开放性敞流湖盆中地层水的分布特征、水-岩作用及其与油气分

布的关系，揭示咸化湖盆中异常类型地层水成因与成藏意义，以及不同类型地层水对沉积环境、油气保存的标示作用，阐明发育不同压力的陆相封闭性咸化湖盆和陆相开放性敞流湖盆中地层水化学场的差异及其对油气的不同指示，本书相关研究成果对油气聚集、分布的认识和油气勘探有重要帮助。再如在压力生烃动力学方面，借助东营凹陷的大量勘探实践数据建立地下流体的剩余压力及压力系数与有机质热演化参数镜质体反射率 R^{o} 之间的定量关系，开展压力抑制条件下的有机质生烃定量模拟实验，对不同压力体系下生烃动力学参数活化能及频率因子进行标定，获取超压抑制的校正系数；进行高温下原油裂解成气模拟实验，研究不同压力下有机质生烃特征、原油裂解成气过程中不同烃气和非烃气的产率，还进一步研究压力对生烃动力学参数的定量影响，并探讨正构烷烃、甾烷、萜烷、芳烃、金刚烷等分子生物标志物参数在高温阶段不同压力体系下的演化特征。通过大量的分析、对比和筛选，发现一些在不同体系下演化规律相似、具有较好一致性的分子生物标志物及参数，表明这些化合物具有相对较稳定的热演化规律，系统的开放性或压力的增大对其演化规律影响较小，这些参数具有作为高温演化阶段成熟度指标的潜力，该研究对盆地流体压力及分子生物标志物的研究都起推动作用。

本书在编写过程中，既侧重与盆地流体内容相关的理论与方法的论述，又进行了典型实例的精细剖析，努力将理论与实践相结合，尤其是把对盆地流体相关理论的认识与油气成藏作用相结合，以突出其应用价值和可参考性。例如，东营凹陷和沾化凹陷古近系的地层压力与生烃关系的研究显示出超压抑制热演化与生烃作用的差异性、层次性和门槛性；东营凹陷、沾化凹陷和惠民凹陷古近系的地层水化学场及其对油气成藏意义的研究表明，不同压力系统（强超压、超压、低压）下的水化学场响应和不同开放程度下的湖盆水化学场响应及水-岩作用、油气成藏意义的差异；分别以准噶尔盆地陆梁地区、准噶尔盆地西北缘克-百断裂带和渤海湾盆地廊固凹陷为例，阐述在水化学场特征基础上划分的水文地质旋回、不同构造部位和不同输导体系下的地层水化学响应，以及纵向水化学剖面的分带性和油气保存环境的判别，并以准噶尔盆地陆梁地区、克-百地区及东营凹陷为例，介绍水化学场的流动型式及演化。

盆地流体研究涉及多方面的地质因素，是一个复杂的地质问题。鉴于作者学术水平有限，有些盆地流体和油气成藏问题本书可能没有涉及，而涉及的有些问题可能尚未完全解决。期待同广大同仁进行广泛地交流和讨论，书中不当之处欢迎读者批评指正！

本书内容是作者多年研究成果的总结。为使本书内容具有从理论、方法到实践的系统性，相关内容引用了作者指导的研究生张守春、汪旭东、赵卫卫、罗凯声、张小莉、陈建平等的学位论文，还引用了作者课题组刘大勋、曲江秀等已发表和未公开发表的有关成果，同时还参考和引用了作者和其他学者的部分专著和文献。刘雯、甄园水、蒋文博、马遵敬、朱文慧、苏阳、江汝峰等参加了资料收集整理及图件清绘工作。本书的编写和出版得到国家自然科学基金（41272140、40802026）、山东省自然科学基金（ZR2011DM004）及中国石油大学（华东）“211”工程学术著作出版基金的资助，在此一并表示感谢！

作　者

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Basin Fluid and Hydrocarbon Accumulation (Abstract)

Based on a large number of geological, geochemical data and a number of related experiment simulation and numerical modeling, this book mainly discussed the subject about basin fluid and its significance to the oil and gas accumulation from many examples in petroliferous basin. These examples mainly included Dongying Sag, Zhanhua Sag and Huimin Sag in Jiyang depression of Bohai Bay Basin in eastern of China, and the northwestern margin and center part of Junggar Basin in the western of China. These examples have quite differences in fluid field and petroleum accumulation mechanisms, and so can be contrasted with each other for the research object. The book studied and expounded systematically that: ① the distribution, cause, forecast of formation pressure and its influence to the hydrocarbon generation and evolution, hydrocarbon migration and accumulation in the continental basin; ② formation water geochemical field response, water-rock interaction and their hydrocarbon accumulation significance in different lake basin; ③ driving mechanism of basin fluid flow, flow pattern, fluid potential field and their hydrocarbon accumulation significance .

Part 1 Formation fluid pressure and its significance to hydrocarbon accumulation

1. The distribution and main formation cause of overpressure in Dongying Sag and Zhanhua Sag

The overpressure in Dongying Sag and Zhanhua Sag was distributed in the large series of mud in the middle and lower part of Member 3 of Shahejie Formation (Es_3) and the Member 4 of Shahejie Formation (Es_4), and formed into binary structure: The above of the depth of 2000m in the Eogene System was normal compaction and normal pressured (low pressured) system, the below of the depth of 2000m in the Eogene System was uncompaction system. In the uncompaction system, the depth between 2000m and 2500m was the transitional zone, and the below of the depth of 2500m was overpressured system, which corresponding to the main source rocks.

The main source rocks, the Es_3 and Es_4 have the characteristics of quick and continuous deposition, large series of mud and shale, high heat flow and geothermal gradient, and high contents of organic matter, therefore has two-way supercharging effect of the compaction disequilibrium and hydrocarbon generation of which contribute to the abroad distribution of overpressure in the mature source rocks. There is overpressure developed above Es_3, and these overpressure is caused by overpressure transmission from the lower Es_3 and Es_4. Structural high part, fault zone and transition zone of atmospheric pressure and overpressure are the favorable zones for overpressure transmission.

2. Distribution, composition and formation of the sealing bed on the top of Paleogene overpressure compartment system in Dongying Sag

Pressure measurement and logging response analysis are two common methods used to study the top interface of overpressure (TIO) in Dongying Sag. The results show that the Paleogene TIO is mainly restricted within the thick mudstones in the middle part of Es_3 and corresponds to the interval between T4 and T6 reflecting interfaces in seismic sequences, which suggests the feature of strata controlled. The burial depth of this TIO ranges from 2. 4km to 2. 8km and shallows from the central to the margin. Sedimentary rocks below the TIO are composed of dark grey mudstone, calcareous mudstone and sandy mudstone. The horizontal distribution of TIO is partly controlled by lithology and deposition rate of underlying argillaceous rock, while tectonic uplift and denudation, faulting movement as well as salt diapirsm are the primary causes of the shallower TIO in certain areas.

The lithological composition of the overpressure seal is formed by a group of dark gray mudstone, calcareous mudstone and sandy mudstone, of which the average sand-clay ratio is 0. 092, the thickness is 500-900m and the maximal thickness of single mudstone is greater than 10 meters. Whole rock X-ray diffraction shows that the mudstones of the pressure seal contain large amounts of carbonate minerals and clay minerals. Mudstone diagenesis reaches the rapid transformation of the illitemontmorilloniteinterlayer minerals, and corresponds to the mass occurrence of carbonate minerals during the first and second stage. The overpressure seal could close surplus pressure greater than 14MPa, which had a close relation with high displacement pressure (average 5. 45MPa). Besides, thickness and the degree of diagenesis of the overpressure seal are important influencing factors for its sealing ability.

3. Geochemical self-organization process mechanisms of formation of over-pressured fluid compartment

The over-pressured systems form over-pressured fluid compartments (OPC) in vary levels, which control the hydrocarbon migration and accumulation. The geochemical characteristics of OPC demonstrated the geochemical self-organized course, and it included the phenomena of nucleus formation, growth, diffuse, convection, dissolution, deposition, and cementation under the state of non-equilibrium. These courses were controlled under the coupling of stress, temperature, chemistry and pressure field. The active heat fluid in the deep formation provided dynamical condition for the functions. The two series of seals was distributed at the depth of 2200m and 4000m, corresponding to the abnormal high content of Ca^{2+}. Two sets of regional sealing bed like the upper and lower tablet in the Bernard experiment, the minerals in the middle do fluid convection movement, and the result often lead to marginal minerals gathered nearby. The secondary pore zone formed in the turbidite sandstone body surrounded by mudstone is not only the important material source of the formation of the sealing bed, is also favorable for oil and gas accumulation. The sandstone in the margin of OPC, fault terrace zone in the outer edge of the lateral seal of contemporaneous fault consisting of underwater fan or shallow water beach, and the weathering crust and leached zone near unconformity surface are the important place of geochemical self-organization process.

4. The evolution of organic matter and hydrocarbon under abnormal pressure

4.1 The evolution of organic matter and hydrocarbon under abnormal pressure in the profile of Dongying Sag and Zhanhua Sag

The distribution rule of thermal maturity indicators including vitrinite reflectance (R^o), main carbon, contents of normal alkanes, $\sum C_{21^-}/\sum C_{22^+}$, $(C_{21}+C_{22})/(C_{28}+C_{29})$, Pr/nC_{17}, Ph/nC_{18} and Pr/Ph in the OPC was investigated in the Dongying Sag. The inhibition effects of pressure on the evolution of organic matter and hydrocarbon has a threshold. The obvious inhibition on the thermal evolution of organic matter by the over pressure in Dongying Sag was connected with the continued overpressure in Dongying sag and late good preservation condition, and this is reflected by the contrast with Zhanhua Sag, whose paleogene system also developed overpressure, but because of the relatively small pressure coefficient, its thermal maturity parameter R^o does not appear negative anomaly, implying the thermal evolution of the hydrocarbon source rock is not obviously affected.

Overpressure shows affects obviously the distribution of the thermal maturity indicator R^o in 2400-3400m in Dongying Sag, so correlation analysis was made on the maximum residual stress, pressure coefficient and the corresponding R^o anomaly (R^o predicted-measured values) within the depth range. According to analysis, the relation between surplus pressure (pressure coefficient) and R^o outliers are: $y=-5\times10^{-7}x_1^4+6\times10^{-5}x_1^3-0.0023x_1^2+0.044x_1-0.0836(R^2=0.9823)$

$$y=-1.0345x^4+7.9969x^3-23.996x^2+29.238x-13.67(R^2=0.9865)$$

y is R^o outliers, the x_1 is residual stress (MPa), x_2 is pressure coefficient.

4.2 An experimental simulation study on the hydrocarbon quantity generated under pressure suppression

Hydrocarbon generation is influenced by geologic settings such as temperature, pressure and etc. The process can be described in chemical kinetic models. Open-system and closed-system simulation experiments were used to study the kinetic characteristics of 4 kinds of main source rocks in the Dongying Sag and Zhuahu Sag. Vertical pressures equivalent to underground strata were taken into account in closed-system experiments Some conclusions were made on the basis of the comparative analysis of the experiments. Pressure suppresses the hydrocarbon generation on different extents according to different source rocks and different evolutionary stages. The higher the hydrocarbon generation potential of parent materials, the evolutionary degree or formation pressure, the more evident the suppression of hydrocarbon generation. The kinetic parameters of hydrocarbon generation of the source rocks related to pressure were accordingly determined.

4. 3 Hydrocarbon generation mechanism of deep source rocks based on the comparison of experimental simulations in open-system and closed-systems

In order to study the characteristics of hydrocarbon generation at different maturity stages of source rocks in the Dongying Sag, experimental simulations of hydrocarbon generation and expulsion in a closed-system and an open-system at rising temperatures were performed by using source rock samples from Es_4. Their yields and reciprocal transformation of compositions were compared. The samples were acquired from the upper Es_4 in the well Guan-07 in the southern slope of the Dongying Sag. Their TOC content occurs at the main peak of the frequency distribution from the TOC statistics of this set of source rocks, and thus is representative. The following conclusions were obtained. The products of direct kerogen degradation are mainly heavy oil and gaseous hydrocarbons, while light hydrocarbons mainly comes from the secondary cracking of heavy oil; Light oil can be largely expelled immediately after they are generated by source rocks, and thus it is difficult to crack the light oil into gas under existing kinetic conditions; The appearance of macromolecular heavy oil from source rocks marks the beginning of hydrocarbon generation, while the appearance of light oil from further degradation of the heavy oil marks the initiation of hydrocarbon expulsion. The experimental results can be used to explain the origins of condensate oil and gas in the Dongying Sag.

4. 4 Oil cracking into gas under different pressure: Simulation of oil in the paleogene reservoirs in the Dongying Sag, Bohai Bay Basin, eastern China

The evolution of oil cracking products and the effect of pressure on the yield and kinetic of gas generation during oil cracking was investigated by comparative laboratory simulation experiments under different pressured system. The low matured oil sample was from Shahejie Formation in Paleogene of Dongying Sag. Setting an initial experimental temperature of 300℃, the temperature was increased to 650℃ at a heating rate of 30℃/h and 100℃/h. The products were tested every 50℃ starting at 300℃, and a pressure of 20MPa was achieved using a water column. The results show that high pressure inhibits or delays oil-gas cracking as well as retards the initial cracking of oil. The threshold of oil cracking temperature and the activation energy of $C_{1\text{-}5}$ hydrocarbon gases also increase under high pressure. High pressure and high temperature inhibit the conversion of heavy hydrocarbon gases $C_{2\text{-}5}$ to methane during the secondary cracking stage. In addition, high pressure retards N_2, H_2, and CO generation during oil-gas cracking. Water may increase the yield of total cracked gas, heavy hydrocarbon gases $C_{2\text{-}5}$, and CO_2 in high pressure water environments. Simulation results show that CO_2 and heavy hydrocarbon gases $C_{2\text{-}5}$ have similar yield during oil-gas cracking, thereby denoting the close relation of the formation mechanisms of CO_2 and heavy hydrocarbon gases $C_{2\text{-}5}$. Total average activation energy of gas formation and hydrocarbon gases $C_{1\text{-}5}$ during oil-gas cracking was promoted under 20MPa compared to 0. 1MPa, showing the effects of pressure on the kinetic of oil-gas cracking process.

4. 5 Geochemical evolution during the cracking of crude oil into gas under different pressure systems

The two comparative simulation experiments showed the geochemical evolution during the cracking of crude oil into gas. Before the oil was cracked into gas, some components, including macromolecular n-alkanes, were cracked into medium or small sized n-alkanes. The secondary oil cracking of heavy hydrocarbon gases of $C_{2\text{-}5}$ to methane mainly occurred between 550℃ and 650℃, and the parameters $\ln(C_1/C_2)$ and $\ln(C_1/C_3)$, as well as the dry coefficients increased. Compared with the normal pressure system, high-carbon n-alkanes and other compounds in the 20MPa pressure system were reserved. Furthermore, the parameters $\sum C_{21}^{-}/\sum C_{22}^{+}$, $\ln(C_1/C_2)$, and $\ln(C_1/C_3)$, as well as the dry coefficients, decreased within the main temperature range. During secondary oil cracking (550℃ to 600℃), the Ph/nC_{18} and Pr/nC_{17} decreased. High pressure influenced the evolution of the biomarkers Ts and Tm, C_{31} homohopane, C_{29} sterane, adamantine, and their related maturity parameters to different extents during oil cracking under different temperature ranges.

5. The mechanism of oil and gas migration and accumulation in the abnormal high pressure system

5. 1 The effect of overpressure on the reservoir and sealing bed

The influence of overpressure on the oil and gas migration and accumulation in the overpressure system reflect on the fluid emission from hydrocarbon source, preservation and improvement of reservoir space, evolution of the sealing ability of cap rock on hydrocarbon fluid, and the pattern of over-pressured hydrocarbon fluid accumulation.

The influence of abnormal high pressure in reservoir is mainly manifested in three aspects: One is the protection of original reservoir space, the second is the improvement of reservoir space by the secondary porosity, and the third is to induce the generation of cracks.

The sealing mechanism of cap rock mainly included physical sealing (also known as capillary pressure sealing), overpressure sealing and hydrocarbon concentration sealing. The compaction disequilibrium and transformation of clay mineral dehydration of the sealing bed in the OPC of Dongying Sag make itself has certain residual stress, and the mudstone also have ability of hydrocarbon generation, thus the seal has capillary pressure sealing, overpressure sealing and hydrocarbon concentration sealing.

5.2 The episodic hydrocarbon expulsion in the over-pressured systems in Dongying Sag

The over-pressured systems compartments could be divided into three parts according to the geochemistry characteristics: The edge of compartment (seal), which hold up the hydrocarbon migration to outside; the favorable release zone for hydrocarbon, in which over pressure was released in some degree and hydrocarbon was expelled mostly; the stagnant zone for hydrocarbon, in which the over pressure remains and the hydrocarbon is stagnant relatively.

The long-term development of overpressure and accumulation results in the episodic hydrocarbon expulsion which is an important manner of hydrocarbon expulsion in Dongying Sag. According to the mechanisms and modes of episodic hydrocarbon expulsion in the over-pressured systems in Dongying Sag, the episodic hydrocarbon expulsion can be classified as "tectonic episode" and "pressure episode". The mechanism of "tectonic episode" is the destruction came from tectonic movement outside and the path of hydrocarbon-expulsion is fault surface. The mechanism of "pressure episode" is the accumulation and release of over-energy inside of the overpressured systems and the path is fissure. Through episodic hydrocarbon expulsion the efficiency of hydrocarbon expulsion was higher than others. The characteristics of high energy, quick migration and accumulation make it very significant in the petroleum exploration.

5.3 Physical simulation on hydrocarbon accumulation of lithologic reservoirs by episodic hydrocarbon charging

As the hot spot and emphasis of petroleum exploration, lithologic reservoir is the main type of subtle reservoirs for increasing reserves in continental rifted basin, but there are many differences of cognition in the aspect of migration process and hydrocarbon mechanism. According to the hydrocarbon accumulation characteristics of lithologic reservoirs in continental rifted basin, the physical simulation on hydrocarbon accumulation process was carried out, and the accumulation mechanism of lithologic reservoirs was studied. The result shows that lithologic reservoirs have differences in accumulation process, accumulation characteristics and accumulation efficiency under different conditions. The episodic accumulation has high accumulation efficiency and high speed characteristics. Hydrocarbon source conditions, charging patterns, pressure, faults, sand bodies properties are the main controlling factors of lithologic reservoir accumulation. Among these conditions, fault connected migration pathway is the critical factor of lithologic reservoir forming.

5.4 The mechanism of oil and gas gathering

With the exception of the stagnant fluid dynamics system, there are two kinds of fluid dynamics system in Dongying Sag: Normal-pressured opening fluid dynamics system and OPC fluid dynamics system, which results in two accumulation dynamic mechanisms: One was self-sourced and sealed dynamic mechanism, another was outward-sourced and opened mechanism, and the former provided the oil-gas source and drive for hydrocarbon accumulation. OPC is moving and changing at all times, so all the geological behaviors should be investigated by historical and developmental eye.

Faults and rupture were important pathway for episodic hydrocarbon expulsion, so the sandstone-body communicated by faults and conformation-anticlines were favorable prospects for exploration, and the sand lens reservoirs around over-pressured source rocks were latent targets for the exploration of subtle trap reservoirs.

5.5 The distribution patterns of oil and gas in overpressure system

5.5.1 Distribution of gas in profile

The episodic hydrocarbon expulsion and hydrocarbon charging determines the special oil and gas distribution, and oil and gas distribution rule is closely related to formation pressure distribution. This pattern of hydrocarbon charging from OPC transports hydrocarbon with higher gas-oil ratio into the shallow traps. As temperature, pressure drop, the hydrocarbon fluid gradually differentiate, thus making the oil dissolved gas gradually separated from the oil and gas abundance increases from deep to shallow, even pure gas reservoir formed in shallow, to form appeared in turn from top to bottom " high saturated pure gas reservoir", " saturated hydrocarbon reservoirs" and "low saturated hydrocarbon reservoirs".

5.5.2 Distribution of gas in plane

The present annular plane distribution patterns of natural gas in Dongying Sag, which to a certain extent, can also be related to the influence of the formation pressure. From the central to the edge of sag, Paleogene, Neogene gas accumulated in four ring belts, and the inner ring belt is the native gas accumulation zone within deep overpressure compartment. Shallow pure gas reservoir is located in the outer ring between the concave and convex, mainly in the Neogene Guantao Member and Mhuazhen Memebr outside of over-pressured compartment. They are mostly small sandstone lens gas reservoirs, and their formation is the result of differentiation of the oil and gas migration along fault and the lateral stratigraphic unconformity surface in the basin.

5.5.3 Distribution of deep cracked-gas system

Abundant of information about geochemistry indexs on hydrocarbon generation, gas compositions and formational pressure were analyzed, The results showed: the lower part of Es_3, Es_4 and Member 2 of Kongdian Formation formed composite natural-gas systems; the gas formed in the middle and late of time of deposition of Minghuazhen Formation and has characteristics of accumulation in late time. The over-pressured system in Paleogene System was classified into two sub-over-pressured systems by the salt and gypsum rock in the middle part of Es_4, and accordingly, the composite natural gas accumulation systems formed by gas accumulation system over salt and below salt. Every kind of fan body formed by sand or conglomerate and secondary pores were the main reservoir rocks body and the reservoir rock type. The mud and oil shale of deep-lake faces in the middle and lower part of Es_3, the dark mud interspersed by calcium-mud in the upper part of Es_3 and large set of salt and gypsum rocks in the middle part of Es_4 formed into high-quality sealing rock in region, which was the favorable conditions for natural gas preservation combined with inactive structure movement in the area. There were faulted-gas reservoirs, structure-lithological gas reservoirs, and lithological gas reservoirs formed by every kind fan-body in the area, and the latter should be the main targets for the gas exploration in the deep of Paleogene System in Dongying Sag in the future.

Part 2 Formation water geochemical field and hydrocarbon accumulation

6. The composition and evolution of formation water field in basin

6.1 Formation water type, main composition and chemical parameters

Formation water in sedimentary basin is the comprehensive reflection of the hydrological geology, fluid flow and rock interaction, the fluid flow and mixing effect in the process of basin evolution, and the process is closely related with the formation of