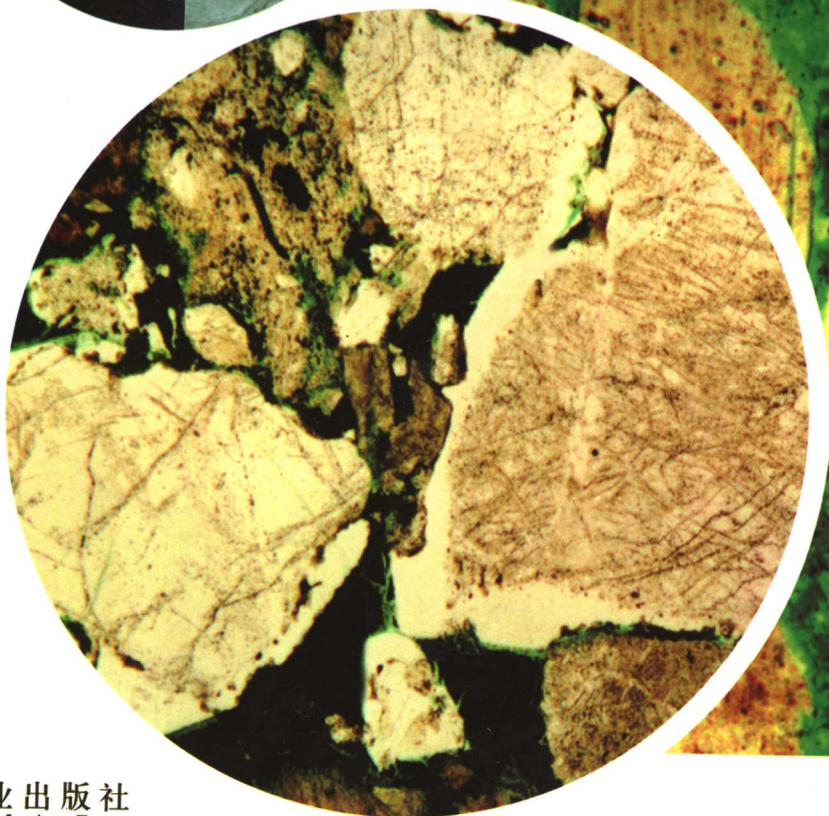
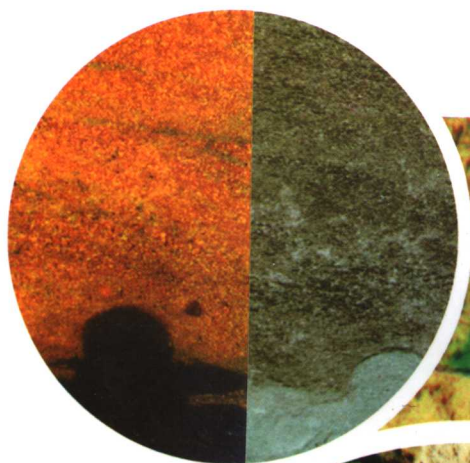


辽河拗陷

古近系碎屑岩储层

孟卫工 孙洪斌 著



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内 容 提 要

本书在概述辽河坳陷古近系的构造、沉积演化特点及碎屑岩储层总体特征的基础上,首先对储层的孔隙类型、孔隙演化及孔隙结构特征进行了阐述,然后从沉积作用和成岩作用两个方面重点分析了储层的特征及其演化特点,并提出了储层成岩作用的成岩模式;最后对储层中的粘土矿物、储层物性、储层非均质性、优质储层的成因及储层含油气性等进行了描述和分析。本书不但比较全面、系统、准确地反映辽河坳陷古近系碎屑岩储层特征,而且较好地反映了陆相箕状富油气凹陷储层的总体特征。

全书选用了 300 余幅清晰、精美、代表性较强的图版,包括:岩心照片、岩石薄片显微照片和岩石扫描电镜照片等,图文并茂,比较全面、系统、形象地反映了辽河坳陷古近系碎屑岩储层的特征。本书可供油气勘探开发地质研究人员和管理人员、科研院所研究人员及大专院校相关专业师生参考。

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序

辽河拗陷是我国，乃至世界著名的陆相富油气拗陷。拗陷内地质条件十分复杂，被地质人员形象地称为“石油地质的大观园”。

辽河油田投入油气勘探 40 年来，几代地质科研人员根据油气勘探开发工作的需要，开展了一系列的石油地质研究工作，对地下地质特征有了比较深入的认识，并取得了许多较高水平的研究成果，对辽河油田油气增产和稳产起到了重要的保障和促进作用；同时，也积累了丰富的资料和经验。

以本书作者为代表的沉积学界的优秀年轻学者们，多年来孜孜不倦地从事着油气储层方面的研究，再不断地将这些研究成果及时地应用到油气勘探与开发工作中，并取得了显著的效果。辽河油田所有的重大勘探发现都包含有储层研究的贡献。研究成果也多次获得奖励，并多次在专业期刊和学术会议上发表。

从本书内容可以看出，作者不但工作认真、刻苦，在观察和研究了大量的岩心资料和岩石薄片资料的基础上，掌握了丰富、翔实的第一手资料；而且在此方面还具有较强的理论基础和实际工作经验。

经过精心编写的这部专著，将碎屑岩储层的宏观和微观特征相结合，将沉积作用和成岩作用对储层的控制作用相结合，将研究工作与生产实际相结合，较系统地反映了辽河拗陷古近系碎屑岩储层特征，更是较好地反映了我国陆相箕状富油气凹陷储层的总体特征，在整个渤海湾地区，乃至我国东部地区具有一定的代表性。书中精选出的精美图片，同样具有较强的代表性和系统性。

对于目前我国许多已经进入精细勘探阶段的油田，对于岩性油气藏勘探越来越重要的陆相盆地，尤其是储层研究在油气勘探开发中的作用越来越突出的今天，作者编写本书具有十分重要的历史意义和现实意义。我愿意将本书推荐给广大石油战线的同行们，以及相关行业人士。相信集广大科研人员研究成果于一身的这本专著的出版，必将会对从事油气勘探与开发研究工作的人员具有重要的参考价值，对你们工作也将具有较大的帮助。

王承达

2007. 4. 2

Preface

Liaohe Depression is a famous continental petroleum – rich depression in China, even in the whole world. It is called by geological workers as “The Grand Garden of Petroleum Geology” for its complicated geological conditions.

Since Liaohe Oilfield was put into oil and gas exploration 40 years ago, generations of geological researchers have conducted a series of petroleum geology researches to fulfill the requirement of oil and gas exploration. By doing this, they had better understanding of the geological characteristics underground and gained a lot of research results, which played an important role in keeping a stable output as well in increasing the output. What’s more, they accumulated rich research data and experience.

Young scholars in sedimentology, taking the author for an example, have been working hard being engaged in researches on oil and gas reservoirs. Then they apply timely what they have achieved to the practical exploration and development for oil and gas, and obtain good research and application results. The contribution of reservoir research can be found in all the important discoveries in Liaohe Oilfield. Their research results have won many prizes and many have been published in professional journals and academic conferences.

We can easily see from the book that the author works hard and carefully. They acquire rich and accurate information based on carrying out a great deal of observation and researches of rock core and core sections. Besides, they master abundant relative theories and hands – on experience.

Integrating macro with micro features of clastic reservoirs, sedimentation with diagenesis, research with practice, this painstakingly compiled book systematically reflects the characteristics of Paleogene clastic reservoirs in Liaohe Depression and the general features of continental dustpan – like petroleum – rich depression. It could be regarded as a representative work in Bohai Bay area, even in the whole east part of China. The pictures carefully selected in the book also have strong representative and systematic functions.

For the oilfields under fine exploration, the continental basins are more and more important for the exploration of lithologic oil & gas reservoirs, especially when the research of reservoir is playing a more and more important role in the exploration for oil and gas at present. So the writing of the book is of great historic and practical significance. I would like to recommend the book to petroleum workers and people work in relevant areas. I believe the publication of the book, which combines the efforts of many researchers, will be of great value to the researchers engaged in exploration and development for oil and gas, and will also be helpful to your work.

Jia Chengzao

April 2nd, 2007

前 言

辽河拗陷位于辽宁省中南部的辽河下游平原,其北、东、西三面环山,南面延入辽东湾水域。这里鱼、虾、贝、蟹等养殖业发达,苇海无边,稻米飘香,是名副其实的鱼米之乡。这里交通还十分便利,沈山、沈大、沟海铁路,京沈、沈大、盘海营高速公路穿梭其间。中国著名的辽河油田,及其总部所在地盘锦市就坐落在这丰庶之地。

辽河油田是我国第三大油田,原油年产量最高在1995年达到 $1552 \times 10^4 \text{t}$,目前基本稳定在 $1200 \times 10^4 \text{t}$,绝大部分的原油产自于辽河拗陷古近系碎屑岩油气藏。辽河拗陷的油气储层主要是古近系碎屑岩,同时,还有部分太古宇变质岩、元古宇碳酸盐岩、石英岩、中生界火山岩、碎屑岩及古近系火山岩和碳酸盐岩。

随着油气勘探开发工作的不断深入,人们越来越认识到了储层研究的重要性,尤其是近几年岩性油气藏勘探工作越来越受到重视,加强储层研究,尤其是碎屑岩储层研究的意义就显得更加重大。碎屑岩储层研究不仅与油气勘探和合理的油气开发密切相关,而且对探索和认识油气藏的形成与分布规律、丰富和发展石油地质理论具有十分重要的意义。

以薛书浩、邱云贞、金万连、阎火、李应暹等为代表的沉积储层研究前辈,在辽河油田投入勘探之初就开展了扎实的沉积相及储层研究工作,并积累了丰富的研究成果。辽河拗陷投入油气勘探开发40年来,随着油气勘探开发工作的不断深入,人们对油气储层的认识在不断加深,尤其是近10多年来,研究人员在继续开展宏观储层研究的同时,加大了微观储层研究的力度,先后取得了几十项较高水平的研究成果,并获多项科技进步奖。其中,研究成果《辽河拗陷古近系储层综合评价》于1995年获得了石油天然气总公司科技进步三等奖,出版了《辽河拗陷古近系储层沉积构造图册》和《辽河拗陷变质岩及火山岩储层图册》等专著,发表了多篇学术论文,多次获得“全国沉积学与岩相古地理学学术讨论会”优秀论文奖,对油气的勘探与开发起到了重要的促进作用。随着各级领导的不断重视,研究力量的不断加强,研究投入的不断增加,研究手段、实验测试手段和方法的不断改进与完善,储层研究工作得到了很大促进,碎屑岩储层研究工作得到了长足的发展,并积累了丰富的研究资料、研究成果和研究经验。这些都为本书的编写打下了坚实的理论基础和实践基础。

本书是以1993年完成的成果《辽河拗陷古近系碎屑岩储层图册》为基础,并结合了1992年完成的成果《辽南地区东营组砂岩成岩作用及其对储层物性的影响》、1994年完成的成果《辽河拗陷东部凹陷古近系砂岩成岩作用研究》、1996年完成的成果《辽河盆地深层石油地质综合研究》、1997年完成的成果《辽河盆地古近系区域储层评价研究》、1998年完成的成果《辽河滩海地区石油地质综合研究及勘探目标评价》、1999年完成的成果《海南一月东复式油气聚集带成藏条件及油气富集规律研究》、2000年完成的成果《辽东湾北部滩海油气地质》等,同时,借鉴和吸收了多年来其他科研人员的部分储层研究成果编著而成。

全书共分九章,其中:第一、第二章概述辽河拗陷的构造—沉积背景和储层总体特征,第三、四章较详细地分析了古近系碎屑岩储层的孔隙类型、孔隙演化及孔隙结构特征,第五、六章采用宏观与微观相结合,以微观为主的方法,对沉积作用和成岩作用之下的碎屑岩储层的形成条件、储集性能及演化特点进行了重点阐述,第七、八章简述了储层中的粘土矿

物、储层物性及储层非均质性，第九章分析了优质储层的成因及储层的含油气特点，并浅析了油气勘探潜力。

读者可以透过本书，对辽河拗陷古近系碎屑岩储层有一个比较系统、全面的认识。书中精选出的图片，以岩石薄片和铸体薄片显微镜下照片为主，并结合了岩心照片、阴极发光照片、扫描电镜照片和岩石荧光照片等，具有较强的代表性和系统性。

本书是集体智慧和劳动成果的结晶，是辽河油田碎屑岩储层研究成果的一个缩影。其在一定程度上反映了辽河油田碎屑岩储层研究的现状；不但比较全面、系统、准确地反映辽河拗陷古近系碎屑岩储层特征，而且较好地反映了陆相箕状富油气凹陷储层的总体特征，在整个渤海湾地区具有一定的代表性。

参加本书工作的还有：刘敏、李应暹、徐秉鳌、黄毅、魏喜、陶永春等。

工作中得到了辽河油田的王玉龙高级工程师、谭时勇高级工程师、牛仲仁高级工程师，石油大学的朱筱敏教授，以及辽河油田勘探开发研究院地质实验室和开发实验室等的大力支持和帮助。尤其是王玉龙高工认真、耐心的指导，对作者工作成绩的取得起到了很大的作用，在此表示最真挚的谢意！

希望本书的出版能够给尊敬的读者提供一份参考资料，尤其在岩性油气藏勘探工作中，能够发挥一定的指导作用，那将会使笔者感到无比欣慰！

由于资料所限，本书对埋深超过 4000m 储层的认识有待深入研究；同时，由于编者的水平有限，错误和不当之处敬请广大读者批评指正！

作 者

2007 年 2 月

Foreword

Located at the downstream plain of Liaohe River in the mid – south of Liaoning Province, Liaohe Depression is surrounded by mountains to the north, east and west, with Liaodong Bay lying to the south. This is a land of milk and honey thanks to the developed aquaculture industry, endless reed and rice fields. Besides, the transportation is convenient with several railways and expressways shuttle to and fro here, such as Shenyang – Shanhaiguan, Shenyang – Dalian, and Goubangzi – Haicheng railways, Beijing – Shenyang, Shenyang – Dalian, and Panjin – Haicheng – Yingkou expressways. Panjin City, where the headquarter of famous Liaohe Oilfield is located, is also in this rich and flourishing place.

Liaohe Oilfield is the third largest one in China, with its maximum annual crude production being 1552×10^4 t in 1995. At present, the relatively stable output is 1200×10^4 t each year. Most of the crude comes from the paleogene clastic oil & gas reservoirs of Liaohe Depression, while some are from Archean metamorphic rocks, Proterozoic carbonate rocks, quartz rocks, Mesozoic volcanic rocks, clastic rock, Paleogene volcanic rocks and carbonate rocks.

The more exploration people do to hydrocarbon reservoirs, the more they realize how important it is to research them. In particular, people in recent years pay more and more attention to the exploration of lithologic reservoirs. Therefore, the research on reservoirs, especially the clastic reservoirs, becomes more and more important. Clastic reservoirs not only affect the exploration and development of hydrocarbon reservoirs, but also help to find out the rules of how hydrocarbon reservoirs are generated and distributed. What's more, it is of great importance to rich and develop geological theories.

Since the very beginning of exploring Liaohe Oilfield, some senior and respectable sedimentary reservoir experts like Xue Shuhao, Qiu Yunzhen, Jin Wanlian, Yan Huo, and Li Yingxian have conducted research on sedimentary reservoirs carefully and have achieved a lot. So hydrocarbon reservoirs have become more and more familiar to us in the past 40 years of exploration. Especially in recent 10 years, researchers have laid more emphasis on micro – research while continuing macro – research. They have obtained dozens of high – level achievements and won several Awards for Science and Technology Advancement. Among them, *Comprehensive Evaluation on Paleogene in Liaohe Depression* won the third prize in 1995 awarded by CNPC. They also published books like *Album of Paleogene Sedimentary in Liaohe Depression* and *Album of Metamorphic and Volcanic Reservoirs in Liaohe Depression*. Besides, many of their academic essays won prizes at the “National Conference on Sedimentology and Lithofacies Paleogeography” which contributed a lot to the exploration and development for oil and gas. With more attention from the leaders, more people are joining in, more funds is given, more improvement in research means, test ways and methods, the research has gained great progress, and the study of clastic reservoirs has advanced a lot. Those rich research information, research results and research experience lay a solid theoretical and practical foundation for this book.

The book, based on the *Album of the Paleogene Clastic Reservoirs in Liaohe Depression* (1993), combines the results of *The Diagenesis of Sandstones of Dongying Formation in The South Liaoning Area and Its Effect on Reservoirs* (1992), *Study on the Diagenesis of Paleogene Sandstone*

Reservoirs in Liaohe Depression (1994), *Comprehensive Study of the Deep Petroleum Geology of Liaohe Basin (1996)*, *Evaluation on the Paleogene Regional Reservoir in Liaohe Basin (1997)*, *Comprehensive Study of Petroleum Geology and Evaluation on Targets of Exploration in Liaohe Beach Area (1998)*, *Research on the Forming Conditions of Multiple Oil – Gas Accumulation Belt and the Accumulated Law in Hainan – Yuedong Area (1999)*, *Petroleum Geology of the Beach Area North of Liaodong Bay (2000)* etc.. The book also absorbs and benefits from other researchers' research achievements in the past years.

The book contains 9 chapters. Chapter 1 and 2 outline the structural and sedimentary backgrounds and the overall reservoir characteristics of Liaohe Depression. Chapter 3 and 4 make a full analysis of different pore types of Paleogene clastic reservoirs and their evolution as well as structural characteristics. Chapter 5 and 6, though mainly focusing on micro – research, combine the macro – research with the micro – research and explain the forming conditions, reservoir properties and evolution characteristics of clastic reservoirs under the effect of sedimentation and diagenesis. Chapter 7 and 8 briefly describes the clay minerals, reservoir properties and reservoir heterogeneity. And the last chapter, Chapter 9 analyzes the genesis of high – quality reservoirs and their oil – gas – bearing characteristics, and briefly indicates the potential of exploration for oil and gas.

The book provides readers with a thorough and comprehensive understanding of Paleogene clastic reservoirs in Liaohe Depression. The pictures selected in the book are mainly about rock section and casting body slice taken under a microscope, together with some pictures about rock core, cathodoluminescence images, scanning electron micrograph photos and rock fluorescent photos, which are highly typical and systematic.

The book is a crystallization of collective wisdom and hard work, an epitome of the research results of clastic reservoirs in Liaohe Oilfield. It reflects to some extent the present situation of clastic reservoir research in Liaohe Oilfield. It not merely depicts completely and exactly the characteristics of Paleogene clastic reservoirs in Liaohe Depression, but also manifests the general features of continental dustpan – like petroleum – rich sags. To sum up, it may be regarded as a representative work in the whole Bohai Bay area.

The book benefits from the work of Liu Min, Li Yingxian, Xu Bingao, Huang Yi, Wei Xi, Tao Yongchun, et al.

I would like to acknowledge senior engineers Wang Yulong, Yan Shiyong and Niu Zhongren of Liaohe Oilfield and Professor Zhu Xiaomin of China University of Petroleum for their generous help. My gratitude is also to the Geology Research Lab and Development Lab of Exploration and Exploitation of Liaohe Oilfield. I cannot fully express my thanks to senior engineer Wang Yulong for his conscientious and patience which contributes greatly to the book.

I wish that the book could provide all the readers a kind of reference, especially in the exploration of lithologic hydrocarbon reservoirs. I will be gratified if the book can be of any help.

I should point out that due to limitations of information, reservoirs more than 4000 meters deep need more complete study. At the same time, there are of course not without error and oversights. I sincerely hope that readers can kindly share any comments and suggestions.

The authors
February, 2007

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第一章 地质背景

辽河坳陷是一个古近纪以来形成的大陆裂谷背景下的断陷—坳陷型盆地，面积约15906km²（陆上部分12400km²，滩海部分3506km²）。

第一节 构造背景

辽河坳陷的大地构造位置在华北地台的东北隅，是辽冀台向斜的一部分。其东连辽东台背斜，西接燕山台褶带，北靠内蒙地轴东缘，南临渤海。其是渤海湾含油气区的重要组成部分（图1-1）。

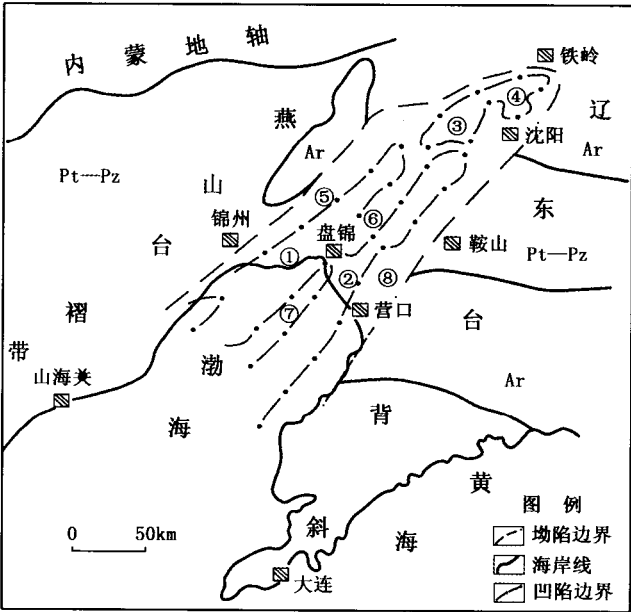


图 1-1 辽河坳陷大地构造位置及构造区划图
①西部凹陷；②东部凹陷；③大民屯凹陷；④沈北凹陷；
⑤西部凸起；⑥中央凸起；⑦中央低凸起；⑧东部凸起

辽河坳陷是叠置在中生界盆地之上的新生代含油气坳陷（图1-2）。其基底结构较复杂，可分为前中生界和中生界两个构造层。前中生界构造层由太古宇、中上元古界和古生界构成。其中，太古宇主要是混合花岗岩和花岗片麻岩；中上元古界为碳酸盐岩、石英岩和板岩等；古生界主要为灰岩、页岩和砂岩等。中生界分布范围广，主要为火山岩和碎屑岩。坳陷周边地区为古老的山地，以太古宇、中上元古界及中生界为主。

坳陷盖层为新生界，是巨厚的砂泥岩沉积。其中以古近系最为发育。其最大厚度在西部凹陷的清水洼陷和东部凹陷滩海地区的盖州滩洼陷，沉积都在9000m以上。

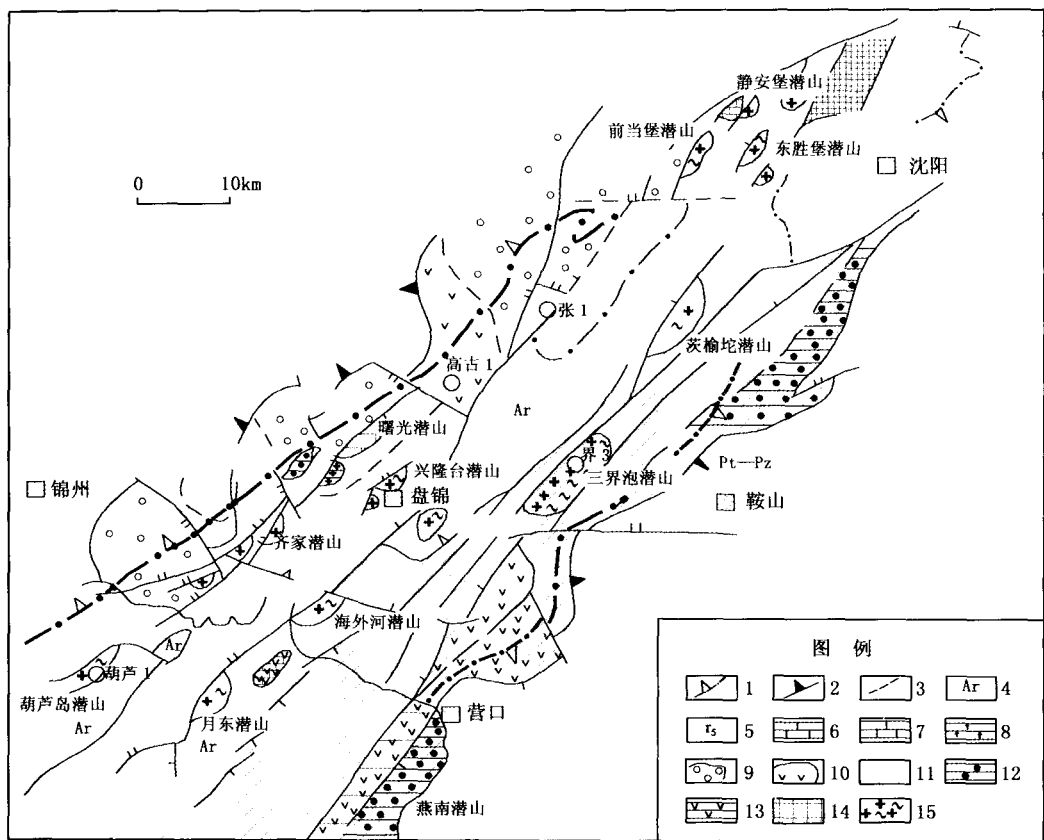


图 1-2 辽河拗陷前古近纪基底岩性图

1—古近系缺失线；2—侏罗系缺失线；3—地质界线；4—太古宇；5—燕山期花岗岩；6—元古宇石英岩；7—元古宇（古生界）灰岩；8—元古宇灰质白云岩；9—中生界沙海组砾岩；10—中生界义县组火山岩；11—中生界梨树沟组暗色泥岩；12—中生界小岭组火山岩；13—中生界小东沟组火山岩；14—中生界土城子组火山岩夹煤层；15—太古宇花岗岩

第二节 构造演化

中生代晚期至第三纪晚期，辽河拗陷经历了拱张（隆升）、裂陷和拗陷 3 个构造演化阶段，相应地形成了侏罗系—白垩系、古近系（房身泡组，沙河街组四段、三段、二段、一段和东营组三段、二段、一段）和新近系—第四系 3 个构造层。

古近纪进一步可以细分：沙四期为初陷期、沙三期为深陷期、沙一二期为扩张期、东营期为再陷（拗陷）期。

古近纪的裂陷阶段是辽河拗陷发生断陷、断块运动最活跃的时期。其主干断裂主要为北东向。断裂活动将该期的拗陷分割为 4 个凹陷（西部凹陷、东部凹陷、大民屯凹陷和沈北凹陷，其中沈北凹陷此次未做描述）和 4 个凸起（西部凸起、中央凸起、中央低凸起和东部凸起，其中的中央凸起和中央低凸起之间以一个小的鞍部相隔）（图 1-1）。同时，也将每个凹陷切割出了若干个大小不等的断块，形成了凹陷内部高低起伏、垒堑相间的格局。如

横切凹陷的地质解释剖面所示（图 1-3），从而使古近纪的辽河拗陷呈现箕状断陷盆地的特征。

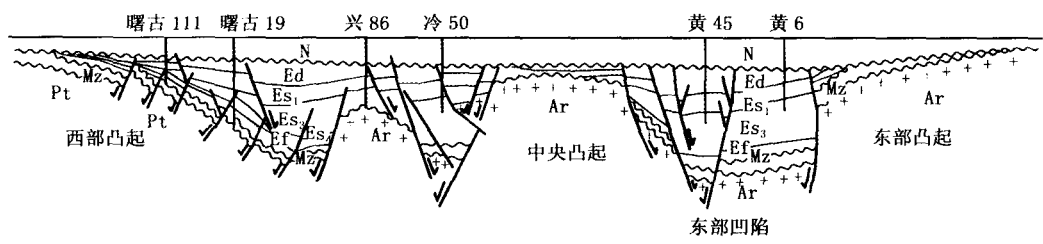


图 1-3 辽河拗陷地质解释剖面图

辽河拗陷内的断裂活动既控制了拗陷内构造的形成与演化，同时，也控制了拗陷内古近纪的沉积。

第三节 沉积模式

构造作用对沉积作用的控制辽河拗陷，主要是通过断裂及由此形成的不同坡度的斜坡来实现的。

辽河拗陷在其发育过程中正断层十分发育。由拗陷边缘向拗陷中心节节下掉的正断层切割基底，依次形成了多个台阶，塑造了高山低谷的地形，形成了断陷型盆地特有的沉积模式（图 1-4）。

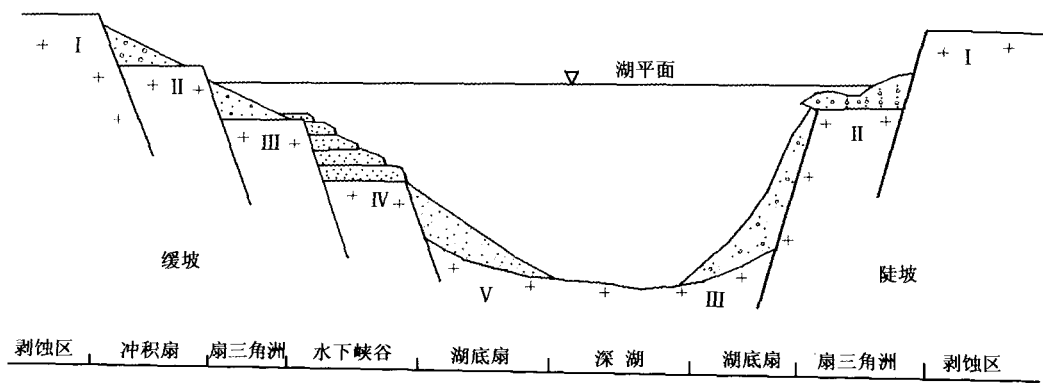


图 1-4 辽河拗陷古近纪沉积模式图

该模式控制了古近系砂体的沉积类型和砂体展布特征，并使形成的沉积物具有了近物源、短流程、快速沉积、粗碎屑含量高和砂岩成熟度低等特点。

一、缓坡型沉积模式

在缓坡型沉积模式中，凹陷基底被 4 条正断层切割，在相对缓坡上，形成了 5 个台阶，湖水面在第 III 个台阶之上。其中：第 I 台阶为剥蚀区，即沉积物源区；第 II 台阶为冲积扇相发育区，向湖中心方向可以发育泛滥平原相（河流相）；第 III 台阶为浅水环境，发育扇三角洲相或辫状河三角洲相和浅湖相，向湖中心方向可以发育重力流沉积，即水下峡谷沉积，处

于向半深湖过渡部位；第Ⅳ台阶处于半深湖—深湖环境，主要发育近物源的粗粒碎屑流沉积；再向前则处于深湖环境，发育远端层状浊流和深湖泥沉积。

二、陡坡型沉积模式

陡坡型沉积模式中的地形较缓坡型明显变陡，高差加大，前两条断层合并发育为一条，后两条断层也合并发育为一条，即凹陷基底被两条正断层切割，在相对陡坡上，形成3个台阶，湖水面在第Ⅱ台阶之上。其中，第Ⅰ台阶为剥蚀区，局部残留有冲积扇相；第Ⅱ台阶主要为扇三角洲相，缺乏河流相，冲积扇相发育范围也很小；再向前为扇三角洲前缘相转换成的碎屑流沉积，相当于缓坡型中的第Ⅲ、Ⅳ台阶的沉积，向湖中心方向为浊流和深湖相的泥岩沉积。

在上述两种沉积模式中，进入半深湖—深湖的碎屑流沉积物受湖底地形的限制，扇体形态都不明显，总体上沿轴向由北向南展布。

第四节 沉积演化

在构造控制之下，依据古近纪构造运动的差异性，辽河拗陷的沉积演化可划分为3个旋回、4个时期（图1-5），每一个旋回的沉积作用都各具特色。

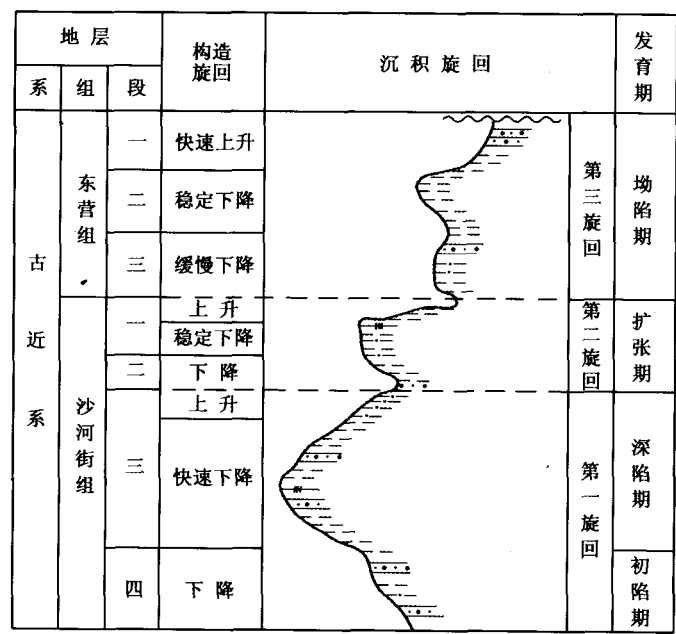


图 1-5 辽河拗陷古近纪沉积演化示意图

一、第一沉积旋回

该旋回为始新世沙四初陷期和沙三深陷期。该期的构造活动和沉积作用都十分强烈；其沉积速率最大（表1-1），主要发育浅湖—半深湖—深湖环境下的扇三角洲相和湖底扇相，以冲积扇—扇三角洲—湖底扇沉积体系为代表。