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Zaixing Jiang

# Sedimentary Dynamics of Windfield-Source-Basin System

New Concept for Interpretation  
and Prediction

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## Foreword I

A stable energy supply system is the material guarantee to realize the Chinese Dream. Currently, the second venture of the China oil and gas industry is ascending rapidly. In this context, the innovation of theory and method on sedimentology, which is a basic and important discipline, will potentially lead to new discoveries in oil and gas energy industries. In recent years, Prof. Zaixing Jiang has been working on sedimentary dynamics, and focusing on the impact of the windfield on subaqueous depositional environments. As an important supplement and improvement of the existing theories of sedimentology, it is expected to become a hot subject in the future sedimentology study. As a writer of the foreward to this book, I was fortunate to get the manuscript and read it through in advance and found the following innovative progresses:

- (1) The research on eolian sedimentology is becoming more and more mature, but the influence of wind on aqueous depositional environments and their responses to the depositional process is not well-understood at present. This book raises the concept of “windfield” from the traditional lakes, oceans and transition depositional environments, and emphasizes its interaction with the source and basin, as well as their dynamical control on most of the sedimentary systems, including the formation and distribution of clastic and carbonate rocks.
- (2) Quantitative study on sedimentology is considered as the basic direction during the sedimentology development, however, the quantitative study of paleowindfield, as described in the beginning of this book is rare in the previous research. The quantitative reconstruction methods on paleo-wind also fill the blank of atmospheric circulation in paleoclimatology.
- (3) Oil and gas exploration is an important battlefield for sedimentology application, and this book shows examples of windfield-source-basin system and its constraints and influences on the source, reservoir and cap rocks, as well as their combinations in petroliferous basin, providing a new perspective for petroleum geology evaluation.
- (4) The book is rich in content, including the results of modern outcrops study, such as the Qinghai Lake, and the deeply buried subsurface deposits, such as the thousands of meters deep deposits in the Shengli Oilfield, the Liaohe Oilfield and the Huabei Oilfield covering different types of sediments in Mesozoic-Cenozoic. Besides, geology, geophysics, hydrology, meteorology and other disciplines are intersected, representing the scientific connotation of “system”.

As Prof. Zaixing Jiang’s peer researcher, I have been paying attention to his academic achievements over years. He has been leading his team and devoting themselves into the study of sedimentology for decades and published abundant high-quality papers. This book represents the continuous, hard work and innovative results by his team and himself. I would like to recommend this book to every peer researcher on sedimentology and petroleum geology.

May 2016

Yongsheng Ma  
Academician of Chinese Academy of Engineering  
Sinopec Group

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## Foreword II

China is a country of great oil and natural gas production and consumption and has increasing demand for energy recently. Although oil and gas resources are relatively rich, it is still difficult to meet the needs of sustained and rapid development of the national economy, which leads to strong contradiction between the supply and demand of oil and gas. In addition, the major petroliferous basins in China are gradually entered into the high-level explored stage. The onshore oil and gas exploration is mainly targeted on the lithologic oil-gas reservoir, which is subtle and more difficult to explore. Especially for the mature oil and gas exploration area in the eastern basins, the oil and gas reservation and production are not stable and the new areas and new types of oil and gas reservoirs are hard to find. Facing the grim situation and increasingly complex exploration targets, how to expand new field of exploration, broaden new horizons of development of oil and gas, and make new breakthrough for newly discovered oil and gas exploration by further study on petroleum geology and new technical method, are not only major issues to the geologists and petroleum explorationists, but also challenges and opportunities to China's petroleum geology theory and exploration.

The new scientific findings are commonly from the first-hand information from the field work, and the new ideas of exploration are normally from the practice of oil production. It is the new scientific discoveries and new exploring ideas together that promotes the formation of new theories of petroleum geology and exploration, which guides the development of oil and gas exploration. During the long-term research on the sedimentology of petroliferous basins in eastern China, Prof. Zaixing Jiang and his team combine the natural phenomena of "winds spring-up water" with the sand body prediction technique. They proposed the concept of windfield-source-basin system sedimentary dynamics which is original, will guide explanations and distribution prediction of depositional systems.

The book windfield-source-basin sedimentary dynamics points out that the depositional processes is closely related to the wind/climate, source, and basin system, thus involving controlling elements such as paleoclimate, paleo-provenance, palaeogeomorphy, and palaeo-water depth. The windfield and the associated paleoclimate control the internal sedimentary structures and textures of sediments; the provenance is the material basis; and the palaeogeomorphy and paleo-water depth significantly affect the distribution and scale of sedimentary bodies. These factors, with each one being constrained by the other, are changing constantly and interact with its counterparts to influence the depositional system. The windfield-source-basin system sedimentary dynamics research is aimed to explore how these factors control sedimentary processes.

At first, this book introduces the development of depositional system theory in the previous 100 years, focuses on the multi-controlling factors of depositional systems distribution, and suggests that the windfield is an important parameter in the concept of windfield-source-basin system sedimentary dynamics. This book also illustrates the composition elements of windfield-source-basin system sedimentary dynamics, and their influences on the sedimentary processes as well as the research methods. Under the guidance of this theory, authors take the modern depositional systems from Qinghai Lake and the ancient depositional systems from

Paleogene Bohai Bay Basin as cases study and establish modern and ancient models for windfield-source-basin system sedimentary dynamics.

The introduced new concept “windfield” by Prof. Zaixing Jiang promotes the study of sedimentology from traditionally “unitary facies mode” and “binary source-to-sink mode” into a new view of “ternary sedimentary dynamics mode”, involving wind, source, and basin elements. This improves the explanation on mechanism of depositional systems (including clastic and carbonate rocks) and the prediction on the distribution of unknown depositional systems (and reservoir). The research ideas windfield-source-basin system sedimentary dynamics not only improves the development of sedimentary facies, depositional system and source-to-sink system theory, but also enriches and expands the lacustrine sedimentology theory and fill the blank in this field. It is of great significance in sedimentology and paleo-climate study, and will provide a new theory and method for further exploration of sand body in mature petroliferous basin.

September 2016

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Petro-China Company

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## Foreword III

Since Charles Lyell inherited and developed “uniformitarianism” after James Hutton, the creed “the present is the key to the past” has influenced the geological science up to now, and also become the core basis of sedimentology. It is not difficult to find out that reports of flume experiments and modern sedimentary simulation is continuing without an end and a large volume of papers have been published on authoritative journal of sedimentology and petroleum geology. By observing the complex depositional processes, these two types of work complete the study of sedimentary dynamics and facies models and exert a far-reaching influence in the academic research. However, “the present is the key to the past” does not apply to every situation due to the lack of geological records and information of some ancient events in the modern deposits such as the Paleocene/Eocene boundary event, Cretaceous oceanic anoxic events and oceanic red beds and other major sedimentary geological. The objective existence of these strata provides a basis for continuously mining the boundary conditions that controls the complicated depositional processes. Hence, “the present is the key to the past” cannot express the ancient geological process completely, and “the combination of ancient and modern” is equally important as well.

Sedimentology was introduced from the west, whereby some concepts or theories, such as facies, facies model, sequence stratigraphy, sedimentary system and source to sink system, were of milestone meanings. They were developed by the western sedimentologists, and our domestic sedimentologists mostly just follow their work and use them as reference without breakthrough. Notably, this book, by taking China’s continental basins as the research objective and modern deposition from Qinghai Lake and ancient deposition from the Paleogene Bohai Bay Basin as case studies, combining ancient and modern, emphasizing wind as a control factor for depositional system as well as its interaction with the source and basin dynamic, on the basis of the traditional model and depositional system, proposes the “trinary system of windfield-source-basin system sedimentary dynamics”, which is applicable in lacustrine and marine sediments. The theory of this system is originated from China’s continental lake system and breaks the shackles of local facies model, depositional system and source to sink system, which is a promotion and innovation of China’s continental lake sedimentology. In addition, the paleowindfield is indispensable in paleoclimate study, but it is still weak. The framework of the windfield-source-basin system makes the reconstruction of paleowindfield possible. Using the theory of windfield-source-basin system sedimentary dynamics in petroliferous basin provides a new way to predict oil and gas reservoir.

The windfield- source-basin sedimentary dynamics is the crystallization of Prof. Zaixing Jiang and his team’s many years’ work. It sets a good example of sedimentology study for adhering to the methodology of “vertically step-down and laterally interactive cross disciplines”, which is representative and of potential replication. At the occasion of the book being published, I would extend congrats via this foreword!

October 2016

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## Preface

Sedimentary processes take place in preferable depositional environments or sedimentary basins and consequently result in the formation of sediments and sedimentary rocks. The formation and distribution of these sediments and sedimentary rocks is controlled by provenances, paleoclimate, and the sedimentary basins.

The concepts of lithofacies, sedimentary facies, facies model, and depositional system have been proposed to understand the distribution and genesis of depositional systems, and eliminate the prediction uncertainty on sand bodies.

The source-to-sink system theory combines sedimentary bodies in the basin with their sediment sources and transportation path in order to better understand the processes of how sedimentary bodies formed. It is well known that climate plays an important role in controlling the sedimentary processes, and there have been a large volume of literature published regarding the influence of temperature and humidity on the weathering of source rock and its production, and physical, chemical and even biological conditions in the basin, and their further influence on the sedimentary characteristics. However, with respect to the important component of climate, the research on how the windfield (including wind direction and wind power), influence the sedimentary processes is still not well-understood. Although the eolian research has become increasingly mature, the influence of wind on aqueous depositional environment and its sedimentary response is still the weak section in depositional process study. The first reason is that it relates to the cross field of Meteorology and Sedimentology; second, windfield is difficult to be recorded and to be identified in ancient strata resulting in the recovery difficulties in ancient windfield. A series of studies suggest that it is easier to form waves in windward area of shore and shallow sea (or lake) due to the wind blowing in the oceans and lakes. And these waves, affected by the topography during their propagation, are main factors controlling the formation of series of sand bars parallel or oblique to the shoreline. The geometry and size of these sand bars are related to waves and wind power. Therefore, through the identification and measurement of sand bars, paleo-wind direction and paleo-wind power can be quantitatively recovered, which further provides methods for paleowindfield reconstruction. In a sedimentary basin, though both controlled by the internal basin parameters and source condition, sediments distributed in the windward area significantly differs from those of leeward area. Most onshore and shallow water depositional systems themselves are influenced by the wave action, suggesting that the windfield is an important parameter controlling the deposition. These three factors work together and exert full control of the genesis and distribution of depositional systems. The above illustration shows how the windfield-source-basin system sedimentary dynamics is put forward. The core of the theory is to introduce windfield into sedimentation, and emphasizes its interaction with the source and basin dynamic. The “Trinary dimensional attribute” of windfield-source-basin system sedimentary dynamics is improved from traditional “single dimensional attribute” of sedimentary facies and sedimentary model and “binary dimensional attribute” of source to sink system. This makes the genetic explanation on depositional systems (including clastic and carbonate) more reasonable and the prediction of depositional system (or oil reservoir) in unknown areas more comprehensively and accurately. In addition, quantitative recovery

method proposed in this book fills up the blank in the area of quantitative recovery in the atmospheric circulation in deep time. Furthermore, the source, reservoir and cap rocks in the petroliferous basin are also constrained by the windfield-source-basin system sedimentary dynamics, which provides a new view for petroleum geological evaluation.

This book consists of seven chapters. Chapter 1, written by Zaixing Jiang, Junhui Wang and Qing Li, points out the changing of the attention of the sedimentological community in the recent 100 years and the focus of sedimentology gradually shifted from the initial establishment of scientific facies models and explaining depositional environment to explain factors controlling the depositional processes. These control factors include climate, tectonic, source etc, whereby the windfield is considered as an important climate parameters and should be paid more attention as it widely influences the depositional system. Therefore, the genesis and distribution of depositional systems can be summarized as a combined effect of wind, source and basin and the windfield-source-basin system sedimentary dynamics is based on the combination of these factors. Chapter 2 (written by Zaixing Jiang and Junhui Wang) elaborates each element (wind direction, wind power, provenance, topography, water depth etc.) of windfield-source-basin sedimentary dynamic and their effects on the depositional processes. The interaction between various elements and their corresponded deposition are also analyzed. This chapter summarizes and puts forward the recovery method of various elements; improves the trinary sedimentary dynamics system comprehensively considering windfield, source and basin; and sets a classification scheme of depositional systems based on the windfield-source-basin system depositional dynamics. In Chap. 3 (written by Ji Chen and Zaixing Jiang), a modern example of windfield-source-basin system sedimentary dynamics is studied and the related depositional model is established, whereby the modern example is from the Qinghai Lake, by comparison of the leeward with abundant sediment supply and the windward system of relatively less sediment inputs. The leeward system in proximity to source area, consists of alluvial fan, fan delta, rivers and delta. The windward system with weak provenance includes eolian dune, beach barrier, lagoon, littoral and beak-shaped estuary. These modern deposits provide examples for understanding the concept of windfield-source-basin system sedimentary dynamics. Chapter 4 (written by Junhui Wang, Zaixing Jiang and Yuanfu Zhang), conducts the sequence stratigraphy and depositional system study on the fourth Member of Shahejie formation of the Paleogene in Dongying Sag. Based on the core, well log and seismic data, the research ideas and methods apply windfield-source-basin system sedimentary dynamics to recover the paleo-waterdepth, paleogeomorphology, paleoprovenance and paleowindfield. A comprehensive research on the depositional system, their genesis and controlling factors and the model of windfield-source-basin system sedimentary dynamics are presented in this chapter. The middle Eocene evidence of ancient East Asia monsoon is found and its control on sedimentary system is discussed as well for the first time. Chapter 5 (written by Xiabin Wang, Yuanfu Zhang and Zaixing Jiang) illustrates the sedimentary characteristics, genesis types and control factors in the fourth Member of Shahejie Formation of the Paleogene in Liaohe Basin. The beach bar in west Liaohe depression sand body was mainly developed in the early lowstand systems tract and transgressive systems tract. According to the sedimentary genesis, including depositional processes and sediment source, the beach bar can be subdivided into five categories: delta laterally modified, delta front modified, bedrock modified, delta submerg modified and storm modified. The distribution of beach-bar sand body is mainly controlled by the trinary system: wind, source and basin. Chapters 6 and 7 give examples of coarse clastic rocks formed under the background basin of weak wind but large sediment supply. Chapter 6 (written by Hui Liu and Zaixing Jiang) focuses on Daxing conglomerate from Paleogene in Langgu Sag. By detailed core observation and description, reconstruction of palaeoprovenance and paleotopography, three genetic models of the Daxing conglomerate are established, namely fault-trough gravity flow, nearshore subaqueous fan of debris flow and nearshore subaqueous fan of mudslide. The reservoir quality is related to such genesis models. Chapter 7 (written by Lijing Zheng and Zaixing Jiang) elaborates the research on sedimentary characteristics of dense carbonate breccia deposits, tectonic activity, provenance and basin of the

third Member of Shahejie Formation in the Paleogene in Shulu Sag. The conglomerate is divided into two categories: the fan delta conglomerates formed by the interaction of alluvial fan and lakes, and slump fan conglomerates and seismites triggered by earthquake. The reservoir quality of the conglomerate beds with different genesis and different oil-bearing property are discussed in this chapter. The whole manuscript is chiefly edited by Finally Zaixing Jiang.

This book embodies the author and his team's researches and achievements of more than 10 years. They are funded by the following: the National Science and Technology Major Projects "Large Oil and Gas Fields and Coal-bed Methane Development"; "11th Five-Year" the China National Key Research Project (Oil and Gas Exploration on New Reservoir Geology and Evaluation of Oil and Gas, 2009ZX05009G002); "12th Five-Year" the China National Key Research Project (Oil and Gas Exploration on New Reservoir Geology and Evaluation 2011ZX05009G002); "13th Five-Year" the China National Key Research Project (Genesis of Terrestrial Deep-Water Reservoir and New Methods for Geological Evaluation 2017ZX05009-002), the National Natural Science Foundations (Lake Sedimentary Simulation Based on Beach-bar Deposition 41102089, Lacustrine Beach-bar Sand Geological Quantitative Prediction 41572029, Quantitative characterization of paleowind field based on beach-bar deposits – take the Eocene Dongying Depression, Bohai Bay Basin as an example 41702104); Shengli Oilfield of Sinopec Group Huabei Oilfield of Petro-China Limited Company and Liaohe Oilfield of Petro-China Company, Oil and Gas Sedimentary Geology Innovation Team of Ministry of Education. Significant in-depth guidance was given from academicians Chengzao Jia, Yongsheng Ma, Yuzhu Kang, Deli Gao, Tingdong Li, Chengshan Wang, Shufeng Yang, Suping Peng, Meifeng Cai and Wenzhi Zhao. Important supports, discussions and advices were given by professor-level senior engineers Shanwen Zhang, Guoqi Song, Yongshi Wang and Huimin Liu from the Shengli Oilfield; professor-level senior engineer Xianzheng Zhao from Dagang Oilfield; professor-level senior engineers Yiming Zhang and Ruifeng Zhang from Huabei Oilfield; professor-level senior engineers Weigong Meng, Zhenyan Chen and Junfeng Shan from Liaohe Oilfield; Prof. R. Steel and C. Fulthorpe from the University of Texas at Austin; Prof. E. Gierlowski-Kordesch from Ohio University; Prof. D. Nummedal from Colorado School of Mines; Dr. H. Lu from Shell oil company; Prof. R. Koch from Nuremberg University in Germany; Prof. Hongwen Deng from China University of Geosciences (Beijing), Prof. Longwei Qiu from China University of Petroleum have given many comments for improving the results as peers. Dongmei Luo and Wenmao Xu. Their help is greatly appreciated! A number of doctors and masters involved in the study have made an important contribution to the formation of the results. They are: Weili Yang, Xingpeng Peng, Yaming Liu, Guobin Li, Jijun Tian, Guiju Chen, Shu'an Xiang, Li'an Liu, Guiting Yuan, Ning Zheng, Shenglan Wang, Lanzhi Qin, Wei Zhao, Lei Feng, Weiling Li, Haowei Zhou, Xiaojie Wei, Shuai Yuan, Weiwei Gao, Junjie Li, Xiaowei Sun, Xiangxin Kong, Haipeng Li, Wenmao Xu, Shan Song, Chao Liu etc.

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Beijing, China  
May 2016

Zaixing Jiang

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# Contents

<b>1</b>	<b>The Emergence of Windfield-Source-Basin Dynamics</b> . . . . .	1
1.1	Depositional System Advances . . . . .	1
1.2	The Influence of Windfield on Depositional System . . . . .	5
1.2.1	Influence of Windfield on Clastic Depositional System . . . . .	5
1.2.2	Effect of the Wind on Carbonate Depositional System . . . . .	12
1.3	Multiple Control of the Genesis and Distribution of Depositional Systems . . . . .	20
1.4	Research Significance . . . . .	22
1.4.1	Significance in Sedimentology . . . . .	22
1.4.2	Significance in Paleoclimate . . . . .	23
1.4.3	Significance in Hydrocarbon . . . . .	23
	References . . . . .	25
<b>2</b>	<b>Elements and Research Methods of Sedimentary Dynamics of Windfield-Source-Basin System</b> . . . . .	29
2.1	Windfield . . . . .	29
2.1.1	The Generation of Wind and Three Kinds of Windfield . . . . .	29
2.1.2	The Influence of the Wind . . . . .	31
2.1.3	Wind Waves . . . . .	33
2.1.4	Distribution of Beach Bar Sand Bodies Under the Influence of Wind Force . . . . .	36
2.1.5	Research Methodology of Paleo-Windfield—The Recovery of Paleo-Wind Direction . . . . .	41
2.1.6	Paleo-Windfield Research Method—Paleo-Wind Strength Recovery . . . . .	42
2.2	Source . . . . .	46
2.2.1	Formation of Sediment Source . . . . .	46
2.2.2	Control of Source on Sedimentation . . . . .	46
2.2.3	Source Analytical Method . . . . .	47
2.3	Basin . . . . .	54
2.3.1	Basic Characteristics of the Basin . . . . .	55
2.3.2	The Influence of Paleogeomorphology on Sedimentation and Its Research Method . . . . .	57
2.3.3	Influence of Paleo-water Depth on Sediment Deposition and Its Research Method . . . . .	63
2.3.4	Influence of Tectonic Activity on Sedimentation . . . . .	67
2.4	Windfield-Source-Basin Dynamics . . . . .	69
2.4.1	Interactions Between the Elements of the Windfield-Source-Basin System . . . . .	69
2.4.2	Classification of the Windfield-Source-Basin System . . . . .	71
	References . . . . .	73

<b>3 Modern Sedimentary System and Windfield-Source-Basin System</b>	
<b>Dynamics of Qinghai Lake</b> . . . . .	79
3.1 Geographical and Geological Background . . . . .	79
3.1.1 Geographical Location . . . . .	79
3.1.2 Climate of Qinghai Lake . . . . .	81
3.1.3 Hydrology of Qinghai Lake . . . . .	82
3.1.4 Stratigraphy of Qinghai Lake Basin . . . . .	83
3.1.5 Structural Features and Evolution of Qinghai Lake Basin . . . . .	85
3.2 Modern Sedimentary System of Qinghai Lake . . . . .	86
3.2.1 The Riyue/Bison Mountain–Daotanghe River–Barrier Island Depositional System . . . . .	87
3.2.2 Qinghai Nanshan–Alluvial Fan–Fan Delta/Coast Depositional System . . . . .	96
3.3 The Distribution of Modern Depositional System and Windfield-Source-Basin Dynamic Model of Qinghai Lake . . . . .	110
3.3.1 The Distribution Characteristics of Modern Depositional System . . . . .	110
3.3.2 Main Controlling Factors of the Modern Depositional System of Qinghai Lake . . . . .	111
3.3.3 Application of the Windfield-Source-Basin Model . . . . .	116
References . . . . .	119
<b>4 Paleogene Sedimentary System and Sedimentary Dynamics of Windfield-Source-Basin System in the Dongying Sag</b> . . . . .	121
4.1 Geology of the Dongying Sag . . . . .	121
4.1.1 Tectonic Setting . . . . .	121
4.1.2 Stratigraphic Sequence . . . . .	121
4.1.3 Characteristics of Tectonic Evolution . . . . .	121
4.2 Sequence Stratigraphic Division of Upper Sha-4 Submember in the Dongying Sag . . . . .	125
4.2.1 Identification of Sequence Boundaries (SBs) . . . . .	125
4.2.2 Division of Sequence in the Typical Wells . . . . .	131
4.2.3 Division of Sequence Stratigraphy . . . . .	150
4.3 Sedimentary Facies of Upper Sha-4 Submember in the Dongying Sag . . . . .	152
4.3.1 Fan-delta . . . . .	152
4.3.2 Subaqueous Gravity Flow Deposits . . . . .	154
4.3.3 Delta . . . . .	156
4.3.4 Clastic Beach Bar . . . . .	157
4.3.5 Carbonate Beach Bar . . . . .	160
4.3.6 Storm Deposits . . . . .	162
4.3.7 Fine Grain Deposits (Semi-Deep Lake-Deep Lake) . . . . .	165
4.3.8 Framework of Sedimentary System . . . . .	166
4.4 Dynamics of Windfield-Source-Basin System in Upper Sha-4 Submember . . . . .	173
4.4.1 Reconstruction of Paleo-Water Depth . . . . .	173
4.4.2 Reconstruction of Paleo-Geomorphology . . . . .	177
4.4.3 Analysis of Paleo-Provenance . . . . .	178
4.4.4 Reconstruction of Paleowind Force . . . . .	182
4.4.5 Paleo-Windfield and Sedimentary Environment . . . . .	192
4.4.6 Analysis of Factors Controlling Distribution of Beach Bar Sandbodies . . . . .	196
4.4.7 Division of Windfield-Source-Basin System . . . . .	199

4.5	Significance of Research on Windfield-Source-Basin System and Prospect of Its Application . . . . .	202
4.5.1	Significance of Paleo-Climate . . . . .	202
4.5.2	Significance for Petroleum Geology . . . . .	202
	References . . . . .	204
<b>5</b>	<b>Depositional Systems and Windfield-Source-Basin System Dynamics of the West Sag, Liaohe Depression, Bohai Bay Basin . . . . .</b>	<b>207</b>
5.1	Geologic Setting . . . . .	207
5.1.1	Tectonic Divisions. . . . .	207
5.1.2	Strata Characteristics . . . . .	207
5.2	Sequence Stratigraphy Framework . . . . .	207
5.2.1	Recognition of Sequence Boundaries . . . . .	207
5.2.2	The Establishment of Sequence Stratigraphy Framework by Combination of Wells and Seismic Data . . . . .	213
5.3	Sedimentary Systems and “Windfield-Source-Basin System” Depositional Dynamics. . . . .	213
5.3.1	Sedimentary Facies . . . . .	216
5.3.2	Depositional Model of Beach-Bar Deposits in the West Sag, Liaohe Depression. . . . .	224
5.3.3	Windfield-Source-Basin System in the Upper Es <sub>4</sub> West Sag, Liaohe Depression. . . . .	227
5.4	Detailed Study of Beach-Bar Deposits . . . . .	229
5.4.1	High-Resolution Stratigraphy Framework . . . . .	229
5.4.2	Sedimentary Systems of Beach-Bar in the Shubei Area . . . . .	229
5.5	Controlling Factors for the Distribution of Beach-Bar Deposits . . . . .	231
5.5.1	Reconstruction of Paleo-Geomorphology . . . . .	231
5.5.2	Reconstruction of Paleo-Water Depth. . . . .	234
5.5.3	Reconstruction of Paleo-Source . . . . .	235
5.5.4	Reconstruction of Paleo-Windfield. . . . .	238
5.5.5	Controlling Effect of Windfield-Source-Basin System on Beach-Bar Deposition . . . . .	240
	References . . . . .	243
<b>6</b>	<b>The Sedimentary Characteristics of Paleogene Conglomerates and Their Sedimentary Dynamics in Source-to-Sink System in the Langgu Sag . . . . .</b>	<b>245</b>
6.1	Geologic Background. . . . .	245
6.2	Sedimentary Characteristics of the Conglomerate Body. . . . .	246
6.2.1	Rock Type . . . . .	248
6.2.2	Texture Characteristics. . . . .	248
6.2.3	Sedimentary Structures. . . . .	248
6.2.4	Gravel Compositions . . . . .	251
6.2.5	Interstitial Components . . . . .	256
6.2.6	Mudstone Between Conglomerates . . . . .	259
6.3	Palaeogeomorphology Restoration . . . . .	259
6.3.1	Residual Topography of Highs . . . . .	259
6.3.2	Morphology of the Basin Controlling Fault. . . . .	259
6.3.3	Basin Paleomorphology . . . . .	260
6.3.4	Paleomorphology Models . . . . .	263

6.4	Paleo-Provenance Restoration . . . . .	264
6.4.1	Residual Strata . . . . .	264
6.4.2	Distribution of Gravel Components in Conglomerate . . . . .	264
6.4.3	The Paleogeologic Evolution of the Daxing High . . . . .	266
6.5	Source-Basin and Sedimentary Model. . . . .	270
6.5.1	Fault-Trough Gravity Flow . . . . .	270
6.5.2	Debris Flow Nearshore Subaqueous Fan. . . . .	270
6.5.3	Mudslides Nearshore Subaqueous Fan . . . . .	271
6.5.4	Distribution Characteristics of the Conglomerate . . . . .	272
6.6	Reservoir and Oil-Gas . . . . .	272
6.6.1	Controls of Gravels on Reservoir . . . . .	272
6.6.2	Controls of Conglomerate Genetic Types on Hydrocarbons . . . . .	276
	References . . . . .	278
<b>7</b>	<b>A Source-to-Sink Study of the Paleogene Shulu Sag: Characteristics and Depositional Dynamics of Its Deposits. . . . .</b>	<b>281</b>
7.1	Geological Background . . . . .	281
7.1.1	Overview . . . . .	281
7.1.2	Regional Tectonic Features. . . . .	281
7.1.3	Basin Evolution . . . . .	283
7.1.4	Stratigraphy . . . . .	285
7.1.5	Sequence Stratigraphy of the Lower E <sub>s3</sub> Submember . . . . .	285
7.2	Sedimentary Characteristics of the Lower E <sub>s3</sub> Submember . . . . .	285
7.2.1	Rock Classification Scheme . . . . .	285
7.2.2	Gravel Composition. . . . .	290
7.2.3	Well Log Identification . . . . .	292
7.2.4	Lithology Distribution . . . . .	295
7.3	The Impact of Tectonic Activity on Sedimentation. . . . .	296
7.3.1	Types and Characteristics of Seismites . . . . .	296
7.3.2	Seismites Sequence . . . . .	309
7.3.3	Criterion of Seismites . . . . .	310
7.4	Provenance and Depositional Processes of the Calcirudites . . . . .	312
7.4.1	Depositional Environments and Facies Models of the Calcirudites . . . . .	314
7.4.2	Distribution of the Calcirudites . . . . .	319
7.4.3	Relationship Between Two Types of Calcirudites . . . . .	323
	References . . . . .	325