油气地质学进展

主　编　刘树根　陆正元
副主编　赵永胜　李国蓉　徐国盛

四川科学技术出版社

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内 容 提 要

本书收集了1995年“油气藏地质及开发工程”国际学术研讨会(成都)部分学术论文。其内容涉及常规和非常规储层地质、储层模型、储层地球化学、储层流体、油气藏模拟、复杂油气藏勘探开发、盆地分析和石油应用地球物理等领域的研究现状和发展趋势,总体上反映了目前油气藏地质学研究方面达到的水平和取得的新进展。

本书可供从事油气田勘探、开发的地质科技人员及研究生、本科生参考。

油气地质学进展

主　　编　刘树根　陆正元
副 主 编　赵永胜　李国蓉　徐国盛
责任编辑　宋　齐　喻瑞卿
封面设计　卢奇勋
版面设计　杨璐璐
责任校对　苏晓宁
出版发行　四川科学技术出版社
　　　　　成都盐道街3号　邮编610012
开　　本　787×1092毫米 1/16
　　　　　印张 21.75　字数 557千
印　　刷　成都市保险公司印刷厂
版　　次　1996年8月成都第一版
印　　次　1996年8月第一次印刷
印　　数　1—1000册
定　　价　51.00元
ISBN 7-5364-3435-9/TE·11

前　言

由“油气藏地质及开发工程”国家重点实验室主办召开的“油气藏地质及开发工程”国际学术研讨会于1995年8月同时在成都理工学院和西南石油学院举行。本次研讨会由我国著名油气地质及开发工程专家罗蛰潭教授发起并亲自筹划，大会组委会由黄汲清、叶连俊、郭令智、童宪章、李德生、田在艺、刘宝珺、贺振华、罗平亚、罗蛰潭、李仕伦、John Tsung Fen Kuo，Kevin T. Biddle，H. J. Behr，Robert J. Weimer，Khalid Aziz，Norman C. Wardlaw，Walter J. Schmidt，Wuu-Liang Huang，Arthur E. Burford，Walter Vortisch，邱中健、石宝珩、赵复兴、包　茨、郭正吾、孙肇才、朱介寿、杨宝星、曾允孚、郝俊芳、施太和和马德坤等国内外知名学者组成。

在大会组委会精心组织和积极宣传下，尤其是大会执行主席美国哥伦比亚大学名誉教授John Tsung Fan Kuo博士将本次会议信息在国外一些重要油气藏地质及开发工程专业期刊上发布并直接与各大石油公司和研究部门联系，研讨会得到了国内外石油界的广泛关注和参与。来自国内外参会代表共222名，其中美国、加拿大、德国、奥地利、巴西和印度等国石油公司的专家和高等院校的教授26名，国内代表包括与会议主题有关的各高等院校、中国石油天然气总公司、中国海洋石油天然气总公司、中国地质矿产部和中国科学院等单位的专家和学者196名。

在短暂的3天会期里，从事油气藏地质及开发工程的专家、学者济济一堂。交流论文200余篇。为了扩大本次会议的影响，进一步促进学术交流，提高油气藏地质理论及其应用水平，大会组委会对与会者提交的论文进行了审阅，征得论文作者同意，将部分论文汇集成两部论文集：①《油气地质学进展》，由四川科学技术出版社出版发行；②《Reservoir Geology and Characteristics－The Tarim，Ordos and Sichuan Basins，China》，由英国皇家地质学会出版发行。

受大会组委会的委托，我们负责《油气地质学进展》的编辑工作。收入本书的会议学术论文56篇，内容十分广泛，涉及了许多当今油气地质学的热点和难点问题。论文分为五大部分，包括常规储层与储层模型、非常规储层地质、储层地球化学及储层流体、复杂油气藏及油气盆地分析和石油应用地球物理等。限于篇幅，我们对部分论文在保持论文主要观点和特色的基础上进行了较大的删改，由于时间仓促，未能反馈给有关作者，疏漏和贻误之处，敬请作者谅解。

最后，我们谨代表组委会和会议主办单位感谢所有参会者对本次会议的支持、积极参加和密切合作，使本次学术研讨会取得了圆满成功。我们还要感谢清绘图件、排字、印刷的同志们，正是有了他们的辛勤劳动和积极配合，本书才得以顺利出版。

编　者

1996年4月

目　录

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Reservoir Modelling in the Evaluation Phase

Qiu Yinan, Xiao Jingxiu, Wang Zhengbiao, Mu Longxin, Jia Ailin and Wen Jian

(Research Institute of Petroleum Exploration and Development, CNPC)

Abstract

The fact that a few data available, particularly the direct reservoir data from drilled wells for rservoir characterization and modeling is a vital problem in the evaluation phase of a hydrocarbon reservoir. The methodology of integration of reservoir geology, geophysics and engineering should be used. This paper aims to decribe the basic principles having to be followed for reservoir modeling in evaluation phase, and some case studies are also presented to demonstrate these principles.

Key words: Reservoir modelling, Sandbody; Evaluation phase

0 Introduction

The evaluation phase is a very important transitional period from discovery to putting into development of a hydrocarbon reservoir, whose main tasks in this period include the development feasibility study , analysis of the hydrocarbon reservoir for commercial development the case putting in to development occurred, and the development strategy. However, a few data are available in this period, particularly the direct reservoir data from evaluation wells. Therefore, in the evaluation phase, how to make reservoir description and to build a resonable reservoir geological model, based on which the prediction of reservoir production performance and decision-making of development strategy are the most attractive point to the reservoir geologists. Especially in recent decades, exploration has been turned to frontier areas with harsh natural geographic and complex geologic conditions, and the drilling cost is rising sharply. A correctly geological evaluation of reservoir can be carried out with as few evaluation wells as possible, which had not only been a academic research problem, but also a very realistic problem in practice.

As a main oil production country in the world, China has reached a very high maturity in exploration and production of hydrocarbon in its East Part. Since late 80's, the exploration targets have been transfered to the three big basins in northwest desert, some oilfields have been discovered and put into production gradually. The evaluation and feasibility studies of all these oilfields were made with only few evaluation wells or even one discovery well. Experiences proved that in the evaluation phase through multi-discipline integration of geology, geophysics and engineering and adopting perfect research methodology to build the reservoir geological model with few wells, is not only possible but also very successful. Based on several successful case examples which we have practiced, this paper aims to describe the basic principles followed for reservoir modelling in the evaluation phase.

1 Sedimentary Environment Analysis

It had been a conventional procedure, that reservoir modeling must take the sedimentological analysis as its foundation especially in the evaluation phase, because it is impossible to establish the 3D distribution of the reservoir attributes directly when only sereval wells data are available. We must depend on the knowledge of the ancient or modern sedimentary analogues to infer the characteristics of the reservoir we studied. So it is the key point to identify the sedimentary environment of the reservoir deposited before selecting the analogue.

In our experience, we should identify the deposition environment as fine as possible. During the sedimentary analysis, it is best to catch the microfacies which will make more reliable for us to select their sedimentary analogues and to use their geological knowledge. Additionally, it is necessary to stress that more attention has to be paid to the process sedimentology, since there only have similar environmental deposits, have not two deposited bodies which may be absolutely the same. Through the analysis of process sedimentology and reestablishment of the palaeo-scale of the studied reservoir, we can build a more reliably quantitative geological model.

Tarim Basin Donghe No. 1 oilfield[3] was discovered in 1990, and development feasibility study was launched with only one discovery well available. The reservoir aged Carboniferous is composed of very thick and homogeneous fine grained sandstones which environmentally belongs to beach shoreface deposits. The thick sandstone has formed a massive hydrocarbon reservoir with a large bottom water body. However, there are some thin interbeds of argillacious siltstones and silty mudstones intercalated in the thick sandstone. It has been the key problem in geological modelling for such a bottom watered reservoir how to estimate thescale of these interbeds and their effect on the vertical permeability. Through very detailed core observation, these interbeds were defined as bottom set of small scale coastal bars deposited at shoreface environment. The thickness and width of the coastal bar were estimated according to the dip angle of the swash cross bedding and the overwash bedding and the thickness of the deposited rythm. The length of the bar were estimated based on the length/width ratio of ten ancient and modern coastal bar deposits. The scale of the bottomset interbeds were estimated

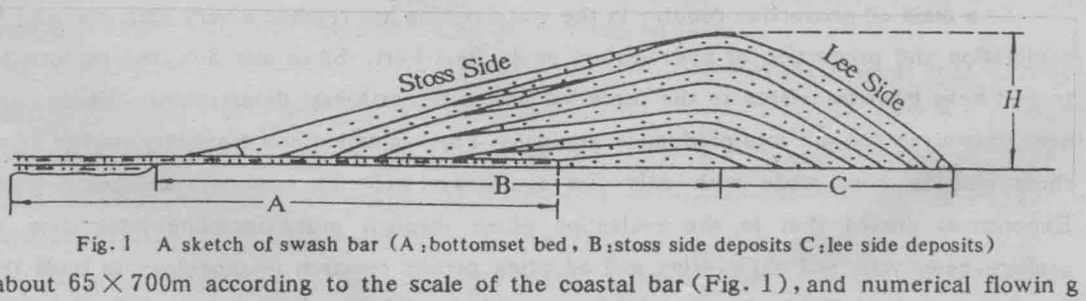

Fig. 1 A sketch of swash bar (A: bottomset bed, B: stoss side deposits C: lee side deposits)

about 65×700m according to the scale of the coastal bar (Fig. 1), and numerical flowin g simulation based on this geological model had predicted that the bottom water coning would not be the significant problem. Now, the oilfield has been putting into production for two years and the performance has proved the predicted reservoir model.

2 Prototype Model

The stochastic modelling methods are often used during evaluation phase, and all the stochastic modelling methods rely on statistical properties of the space structure of reservoir attributes and are constrained by the geological knowledge. However, at the evaluation phase with few data control points spaced by several thousands meters, it is impossible to get the accurate statistical properties of attributes, particularily that of the lateral distribution. Some research workers had supposed that the lateral heterogenity of pemeability of a sandbody is similar to its vertical one[2], and proposed using the vertical statistical properties of the well to estimate the lateral distribuation of the same attribute. Horizontal drilling wells, however, have revealed that this opinion is not conformed to a number of deposited bodies (Fig. 2). The most

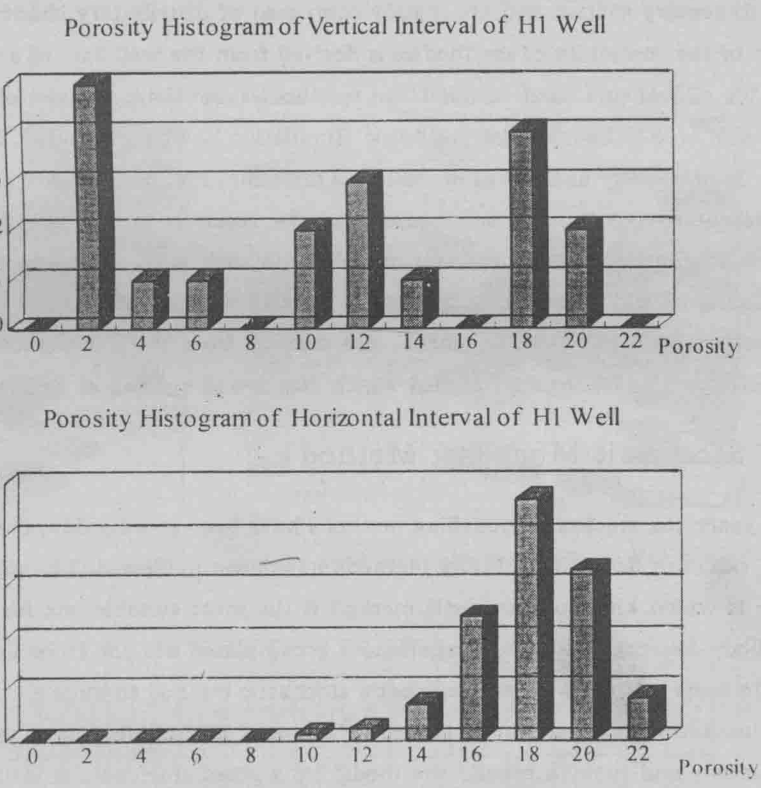

Fig. 2 Porosity histogram of a horizontal well in vertical (60m) and horizontal interval (500m)

effective method in our opinion is to seltect a sedimentary analoguous which had very dense data controlling points and had been detailed described. According to the principle of comparative sedimentology the sandbodies deposited at the similiar environment should have similiar heterogeneity, in which this analoguous sandbody can be observed as a prototype model for modelling the target sandbody. Statistical properties, such as variogram and Hurst exponent, and other geological knowledge such as width/thickness ratio and density of sandbodies from the prototype model can be used as reference and constrains during stochastic modelling the target sandbody to guarantee the simulated heterogeneity features in reality.

It will be best to select an outcrop analogue as the prototype model, which can be densily sampled for detailedly measuring the reservoir attributes. In this case, we can get the best prediction result. However, the outcrop knowledge accumulated are too little to meet the requirement for all types of environmental sandbodies. From our experience, the maturely developed oilfields which have well spacing in hundreds meters can be used as prototype models to predict the heterogeneities of analoguous reservoirs which are in evaluation phase generally drilled with well spacing in thousands meters. The predicted scale and accuracy are fine enough to meet the need of development feasibility study. Such prototype models that can be selected from maturely developed oilfields are more abundant than those from outcrops.

Yuejin No. 2 oilfield, located in Chaidamu basin with ten evaluation wells, are planed to put into development. Its neighboring Gaskule oilfield which had been developed some years ago is selected as a prototype model for reservoir modelling. The reservoirs of both fields belong to the same sedimentary system and are mainly composed of distributary channel sandbodies. The variogram of the continuity of sandbodies is derived from the well data of a pilot area from 350m to Gaskule oilfield and used to build the sandbodies, continuity model of Yuejin No. 2 oilfield by means of SIS (Sequential Indicator Simulation). The elongated orientations of sandbodies are determind by analysis of depositional direction. Fig. 3 has shown the distribution of several representative oil bearing sandbodies, and the result is satisfactory to development design. Fig. 4 is another example of resrvoir modelling in such way. The isoperm map of J_2S pay zone of Qiuling oilfield is simulated by Fractal algorithm with only several well drilled. Its statistical properties such as Hurst exponent, are dervied from the analaoguous sedimentary sandbody of neighbouring Shangshan oilfiled which was a well spacing of 300 meters.

3 Test of Stochastic Modelling Method

In recent years, the stochastic modelling methods have been speedly developed for the need of quantitative reservoir description. Many methods have been published. The problem facingto geologists now is which kinds of stochastic method is the most suitable one for modelling the specified sandbody heterogeneity. Our experiences accumulated are far from enough, and we would like to do some test work when we select a stochastic method to build a reservoir model.

In our opinion, the best test way is to scarify the data controlling points (well spacing) of the prototype model and then to rebuild the model by a given stochastic modelling method in various density of data points and to finally compare the modelling results to the original model. If the results are satisfactory, the stochastic modelling method can be accepted.

Shengli Chengdao oilfield is now at the evaluation phase, whose resevoir is composed of fluvial sandbodies of Fm. N_g Neogene. We take the neighboring Gudong oilfield which also has the fluvial deposits in same geologic period as the prototype model. The well spacing of the developed region had been reached up to 50 meters due to stacking of multi-producing zones. We scarified the well pattern gradually, and made the data controlling points spaced 300, 600 to 1000 meters respectively. The sandbody continuity models (Fig. 5) were produced by SIS, whose results have been shown that the reservoir model built at well spacing of 1000 meters

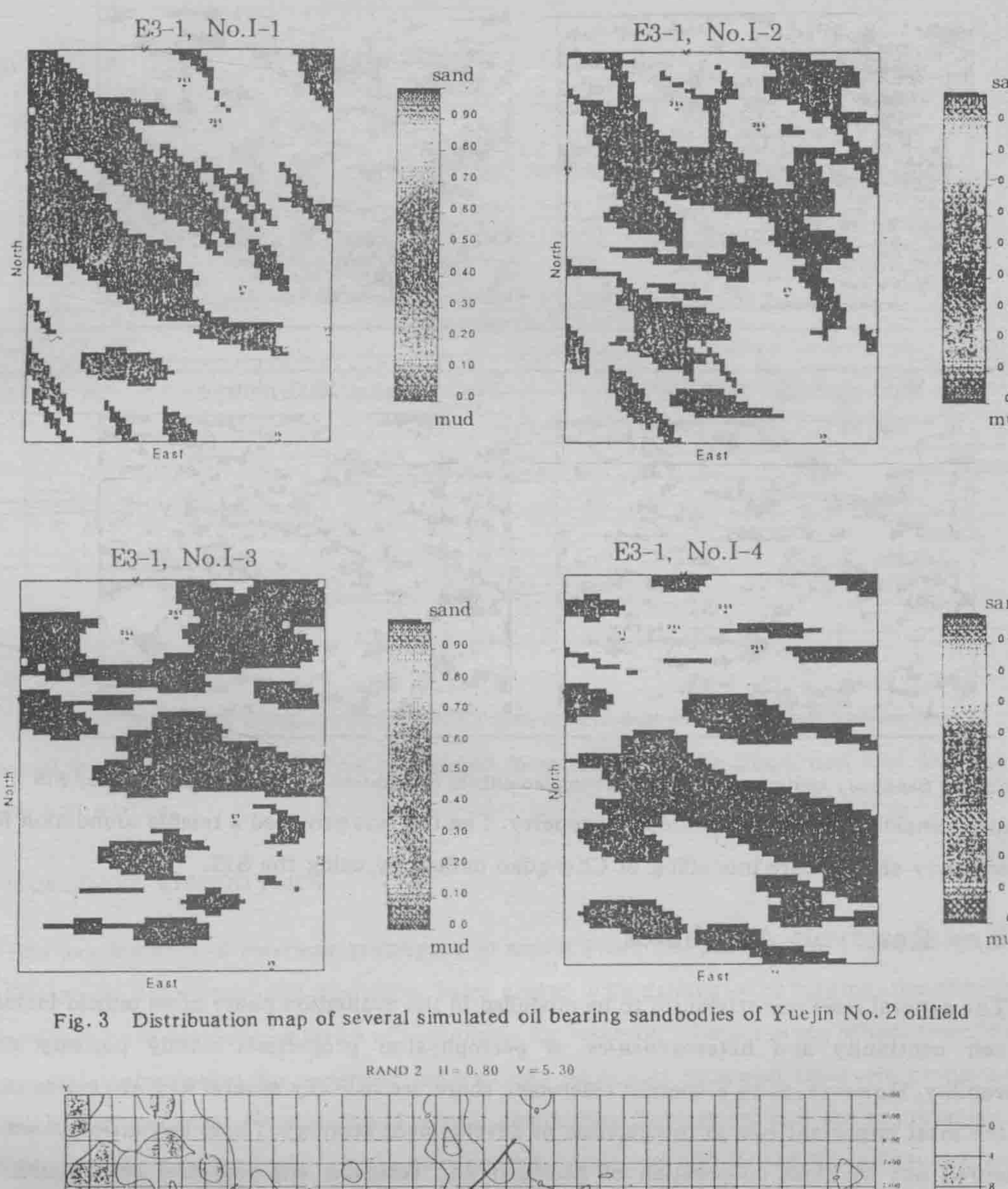

Fig. 3 Distribuation map of several simulated oil bearing sandbodies of Yuejin No. 2 oilfield

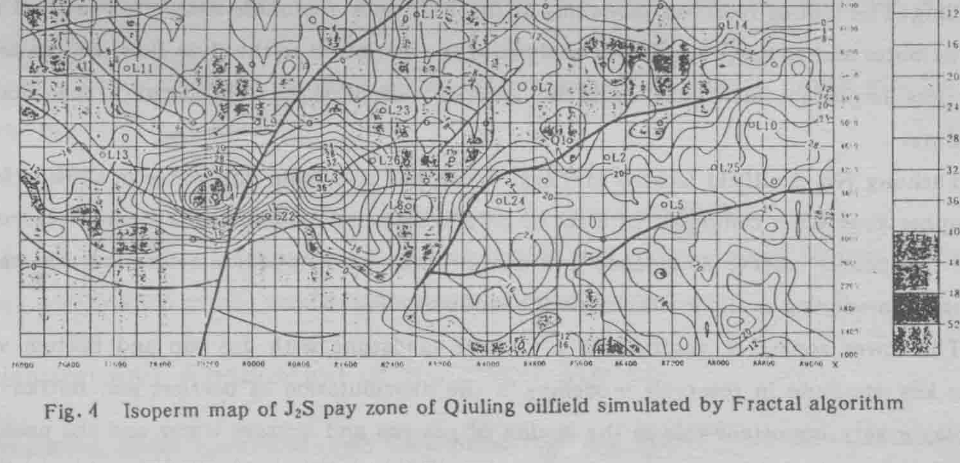

Fig. 4 Isoperm map of J_2S pay zone of Qiuling oilfield simulated by Fractal algorithm

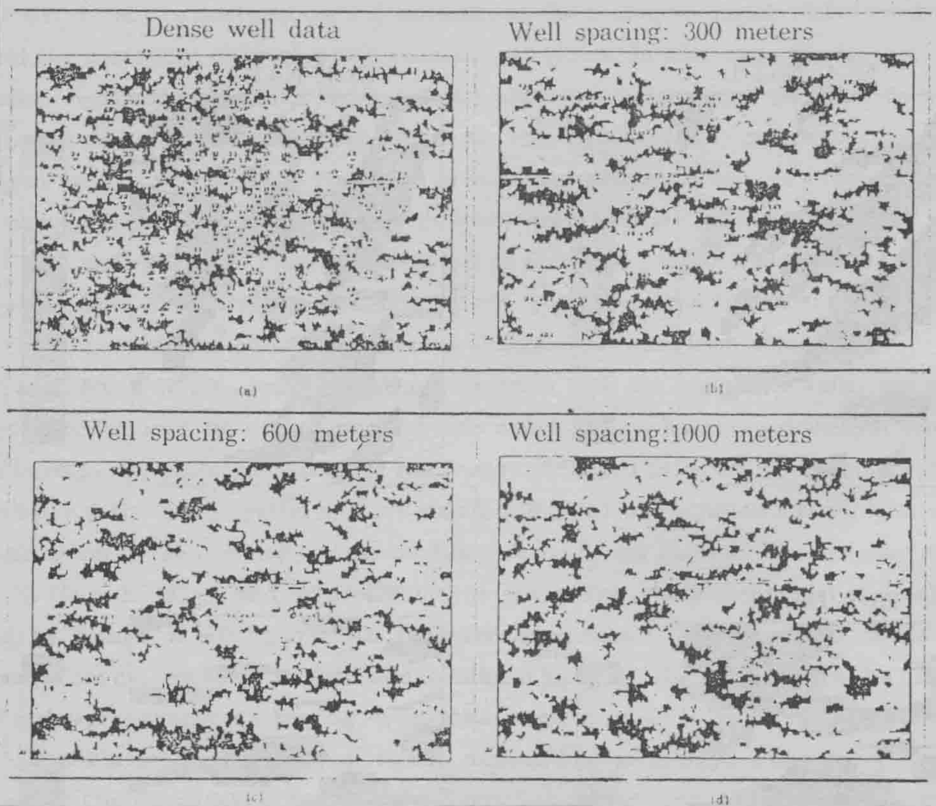

Fig. 5 Sandbody continuity models of Chengdao oilfield in different well spacing produced by SIS

basically remains the original continuity property. The test has provided a reiable foundation for the sandbody architecture modelling of Chengdao oilfield by using the SIS.

4 Key Reservoir Attributes

The general reservoir attributes to be modelled in the evaluation phase of an oilfield include reservoir ocntinuity and heterogeneities of petrophysical properties, mainly porosity and permeability. However, as to a specific reservoir, there are ususally several key attributes that play the most important role in the decision of development strategy. These key attibutes must be figured out by close cooperation of geologist and reservoir engineer and emphasized in modelling. The aim of reservoir modelling is firstly to seek reasonble simulation method of the key attributes and to make sensitivity analysis of the attributes to the fluid flow simulation. The other less important attributes could be ignored. All of these will simplify the modelling procedure.

Tazhong No. 4 oilfield located in Tarim basin has two main pay zones in Carboniferous. The upper zone CI is composed of a set of paralic deposits constituting a layered reservoir, of which the poorer reserve abundance and discontinuity of sandbodies determine that the key attibute in modelling is the architecture of sandbodies (Fig. 6).

The lower zone C Ⅲ reservoir is a massive sandstone with gas cap and bottom water, whose key attribute in reservoir modelling is the distributation of barriers and buffles which will play a very important role in the coning of gas cap and bottom water and the position of

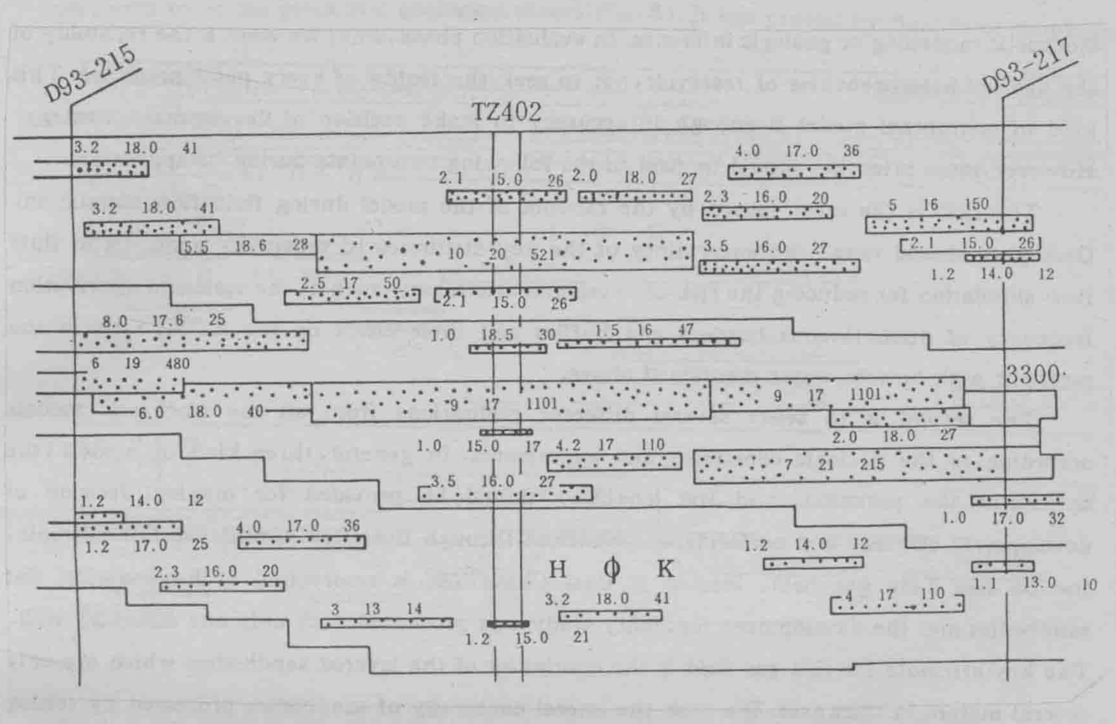

Fig. 6 Sandbodies architecture model of CI zone H: thickness ϕ: porosity K: permeability

horizontal wells. The focal point we considered in modelling is the dimension and density of barriers and buffles.

5 Reservoir Geophysics

The development of reservoir geophysics in recent years has provided an important means to the reservoir description and modelling. Inter grated with drilling, well logging, the reservoir geophysicists have developed a series of techniques for reservoir lateral tracing which provide an incomparable information for reservoir description, especially interwell reservoir prediction. Although the resolution of conventional seismic acquistition has not yet met the requirement of reservoir modelling, particularly for the continential clastic rocks in China, its inversion results are still of important reference and constrain to the stochastic reservoir modelling in the evaluation phase.

The reservoir geophysical results such as acoustic impedence, seislog profile etc. can be used in the following aspects:

5.1 To be some constrains of regional reservoir distribuation.

5.2 Served as an optimistic estimation to the reservoir lateral continuity.

5.3 After corrections of net/gross sand ratio by drilling well and of porosity by core analysis, the seismic information can be used as parameters of reserve estimation.

6 Selection and Application of Reservoir Models

Intergrating above mentioned, only conceptual reservoir model[4] can be established by stochastic modelling or geologic inference. In evaluation phase, what we want is the reliability of the general heterogeneities of reservoir, not to seek the reality of every point predicted. This kind of conceptual model is enough in accuracy to make decision of development strategy. However, more attention should be paid to the following two points during its application.

The first is the error caused by the random of the model during fluid flow simulation. Geologists should range the uncertainty of the key attributes to sensitivity anaIaysis in fluid flow simulation for reducing the risk of development strategy, such as the scale and distribution frequency of discontinuous barriers and buffles and their effect on the K_h/K_v ratio in the reservoir with bottom water mentioned above.

The second is to select several different realizations from all the stochastic models according to the geologic constrains and experiences. In general, three kind of models (the optimistic, the pesimistic and thė looklike) should be provided for making decision of development strategy and performance prediction through fluid flow simulation. For example, the Ba Jiao Ting gas field, located in East China Sea, is reservoired of Eogene tidal flat sandbodies and the development feasibility study was proceeded with only one discovery well. The key attribute for this gas field is the continuity of the layered sandbodies which are only several meters in thickness. We took the lateral continuity of sandbodies processed by seislog which has a vertical resolution of 30 meters as the optimistic geolgoical model ((Fig. 7). We

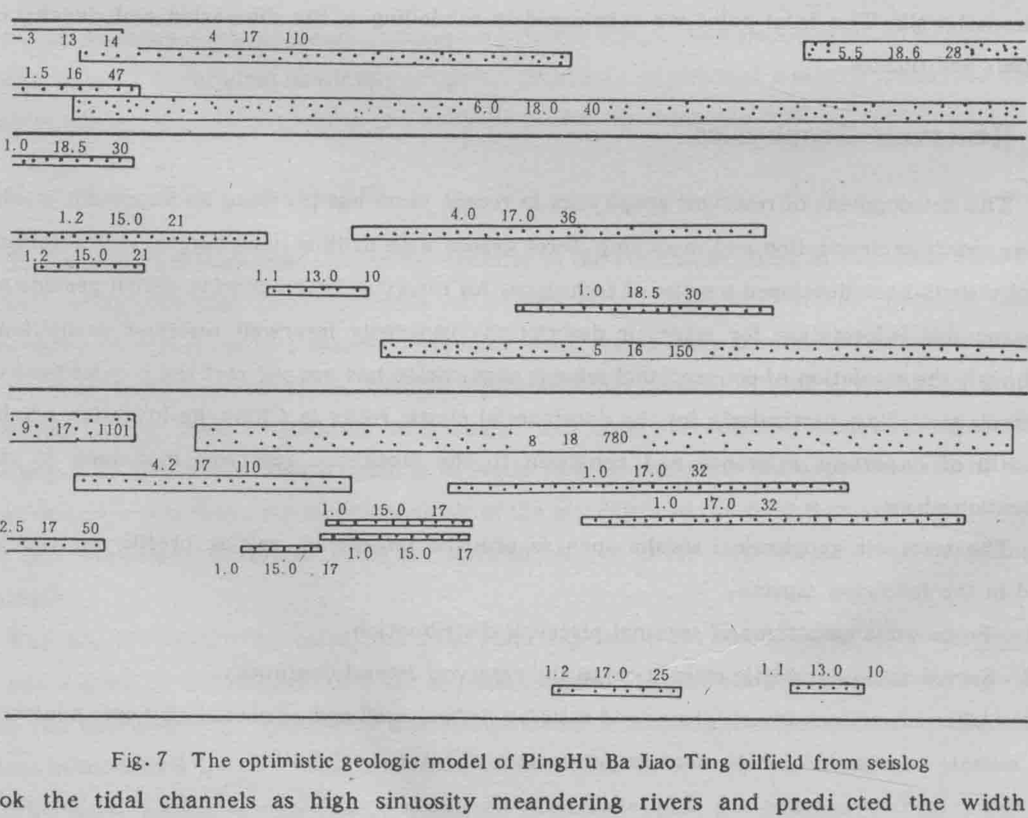

Fig. 7 The optimistic geologic model of PingHu Ba Jiao Ting oilfield from seislog

took the tidal channels as high sinuosity meandering rivers and predi cted the width of sandbody by width/thickness ratio from geolgical experiences, and the lateral connect was predicted by critical density value[1]. The continuity of sandbodies got by this method was considered to be the pesimistic geological model(Fig. 8). It has proved by fluid flow simulation

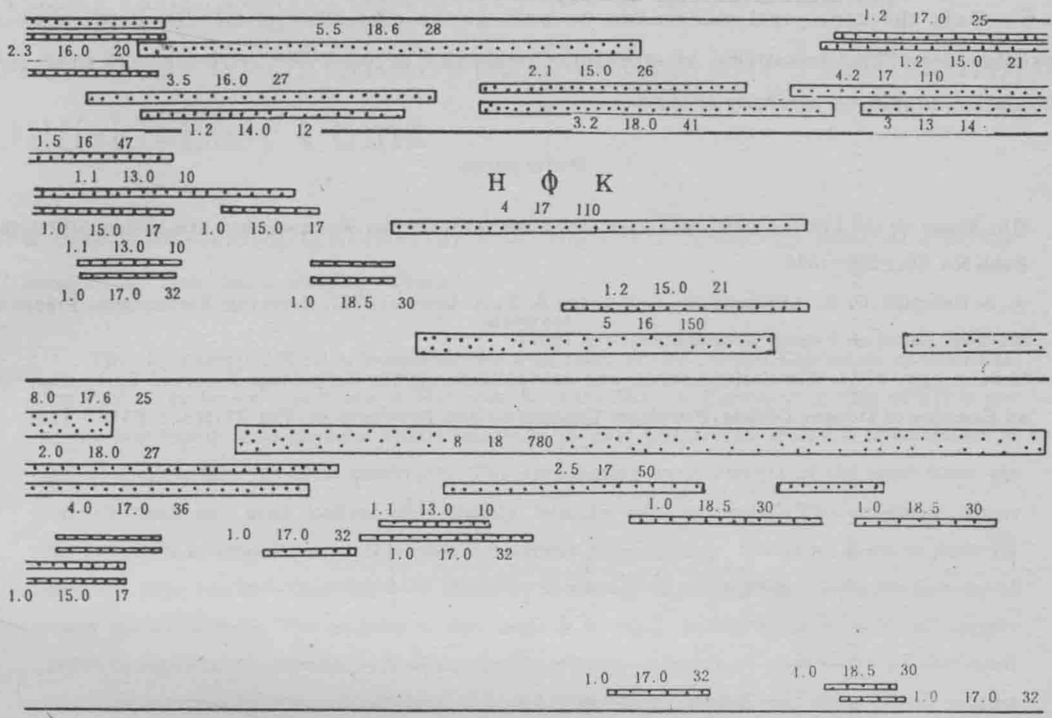

Fig. 8 The persimistic geologic model of PingHu Ba Jiao Ting oilfield from geologic experience
H: thickness Φ: porosity K: permeability

that the gas field belongs to economically marginal one. Even the optimistic geologic model is economically margined.

7 Conclusions

The basic principles, which should to be followed for reservoir modelling in the early evaluation phase are as follows:

7.1 Analysis of sedimentary environment is the foundation of resevior modelling. Not only the microenvironment has to be identified, but the process sedimentology must be carefully reconstructed.

7.2 A sedmimentary analogue having very finely grided data controlled should be properly selected to serve as a prototype model. Outcrop analogues are the best selection, however, the reservoir analogues having been densely derilled in the maturely developed area can also be considered as candidate.

7.3 The key attributes of reservoir, which influences on decision of development strategy, should be found out.

7.4 The geostatistical methods used for conditional simulation have to be properly examined on the prototype model.

7.5 The reservoir seismic inversion is a very important tool for reservoir characterization and modelling in evaluation phase, whose results can be taken as an important reference and constrain for modeling.

7. 6 Only the conceptual models can be built in the evaluation phase due to the lack of available data. The sensitivity of stochastic properties of reservoir attributes on fluid flow simulation should be carefully studied.

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Reservoir Heterogeneity of Fan-delta in Member Ⅲ of Shahejie Formation Huzhuangji Oilfield, East China

Wu Shenghe, Xiong Qihua, Liu Yuhong, Wu Xinsong and Ji Fahua

(University of Petroleum, Beijing, China)

Abstract

The Huzhuangji Oilfield is located on the west ramp of the Dongpu Depression of the Bohai Bay Basin. The fan-delta reservoir of Memeber Ⅲ of the Shahejie Formation in this oilfield is one of the few highly heterogeneous clastic reservoirs in East China. The reservoir is composed of littoral-shallow lake fan-delta sandstones. The sedimentary environments of the sandstones are unstable, and the sand bodies vary quickly laterally and vertically. The reservoir shows characteristics of large interbed difference in reservoir property, large lateral variation in reservoir property, large microheterogeneity, poor efficiency of waterdrive development, and rapid increase of water cut in oil wells. The purpose of this paper is to apply various methods and techniques, including core analysis, quantiative imaging analysis of pores, mercury injection analysis, experiment of oil displacement by water, experiment of reservoir sensitivity, digital processing of well logging data, geostatistics and stochastic modeling, to characterize systematically the reservoir heterogeneity of this area and its influence on waterdrive development of oilfield from different aspects, and to summarize the heterogeneity model of the fan-delta reservoir of this area.

Key words: Reservor heterogeneity; Geostatistics; Reservoir stochastic modeling; pore network; Huzhuangji Oilfield

0 Introduction

The fan-delta is a genetic type of highly heterogeneous reservoirs. Due to large difference in reservoir property of sand bodies of various microfacies as well as its rapid vertical and lateral variation, interbed and lateral heterogeneity is very large. At the same time, reservoir intrabed and pore heterogeneity is also very severe. During waterdrive development, oil recovery from such reservoirs is commonly low, and water cut increases rapidly. Thus the efficiency of waterdrive development is affected.

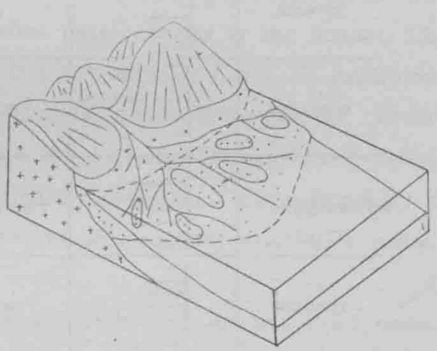

Fig. 1 Dpositional model of fan-delta in Block 12

The Member Ⅲ of the Shahejie Formation in Hu Block 12 of the Huzhuangji Oilfield is a typical highly heterogeneous fan-delta reservoir. It is situated on the west slope of the Dongpu Depression of the Bohai Bay Basin, and is the fan-delta depositional system developed on a gently-inclined bottom (Fig. 1). In the oilfield, only the fan-delta front and pro-fan-delta are preseved. The