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RESEARCH PAPER

Application of multi-point geostatistics in deep-water turbidity channel simulation: A case study of Plutonio oilfield in Angola

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Abstract: In order to simulate the deep water channel distribution of the Oligocene O73 sand layers in the Plutonio oilfield in Angola of west Africa. Based on the shallow high frequency seismic data, the morphology and quantitative scale of shallow channel were studied. By analogy, this study was used as guidance for the scale statistics of single deep channel sandstone, and a three dimensional quantitative training image was created. On this basis, the deep water channel distribution was simulated using multi-point geo-statistics Snesim algorithm and tested by real drilling. The results show that the width and depth of shallow single channel are in linear correlation, while the tortuosity is negatively correlated with the slope gradient exponentially. The average depth of single channel sandstone was 13 meters and the average width was 162 meters. It is concluded that the deep water channel distribution simulation results consist with well data obtained through high resolution gradient impedance inversion, extraction of shallow channel geologic body as 3-D quantitative training image and simulation using Snesim algorithm. The spatial morphology and size of different channels are constrained by the quantitative characteristics of training image, and can reproduce geometric characteristics and spatial structure of deep water channels and levees.

Key words: deep-water sedimentation; turbidity channel; multi-point geo-statistics; shallow-water sedimentation; three-dimensional training image; Oligocene; Lower Congo-Congo Fan Basin

Introduction

Multi-point geostatistics is one of the popular directions in geostatistics study, capable of describing spatial architecture and geometry. Its application difficulty mainly lies in gaining the training image. Previously, based on dense well network data[1–5], training images were obtained by acquiring morphologies of various microfacies to get 2-Dimensional training image by interpolation and extrapolation model fitting of single wells. With high dependence on geologists' speculation, the training images obtained by this method have relatively large uncertainty. Offshore drilling features high drilling cost, high well density, and difficult control of single sand body scale (single channel). Furthermore, turbidity channels are characterized by frequent migration and swing in the course of deposition, and complex superimposition between single channels, making it very hard to describe the frequently varying sedimentary process with 2-D training images, hence 3-D training images are needed to characterize spatial configuration. Based on the high frequency seismic data of shallow channel deposits, we use multi-attribute analysis and inversion to clearly describe the shallow channel configuration, which is a critical source of 3-D training images by analogy. In this study, firstly, O73 sand layers in Plutonio oilfield, located in Angola of West Africa have been taken as an example to demonstrate the feasibility of using shallow channel to guide the study of deep channel targets; secondly, the plane form and swing of single channels have been delineated through analyzing high frequency seismic data of shallow channels, quantitative relationship between width, depth and tortuosity have been counted, and quantitative three-dimensional training images conforming to sedimentary patterns have been created; lastly, micro facies in the study area has been simulated with multi-point geostatistics in the hope to provide a geologic basis for the development adjustment of this area.

1. Geological background

Plutonio oilfield is located in the south of Congo Basin, middle-lower part of the continental slope, West Africa (Fig. 1)

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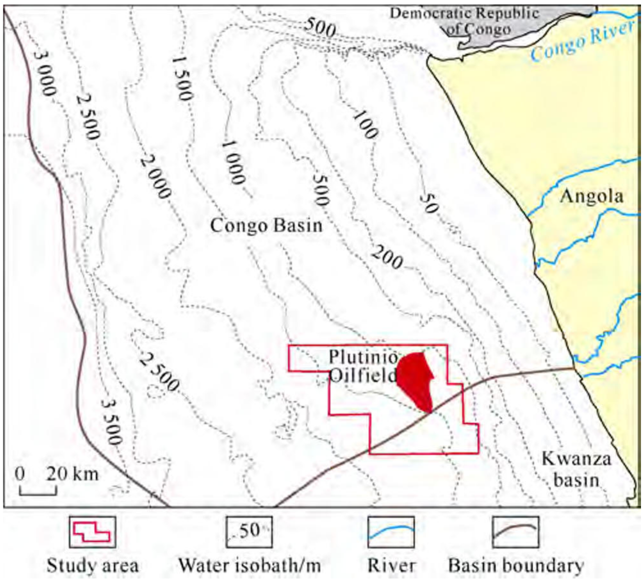

Fig. 1. Location of the study area.

with a water depth from 1 000 to 1 500 meters, where the main oil-bearing layer is Oligocene O73 sand layers. Comprehensive core analysis shows O73 is typical deep water turbidity channel deposits. Channel and natural levee are major micro facies developed here, and channel sands, main reservoirs, forming high porosity and high permeability lithologic-structural reservoirs with bottom water. Tectonic deformation in this area is intense due to the influence of salt diapirism in late stage. Thirty wells have been drilled in Plutonio since it was put into production in 2007, and the average well space is 600–800 meters, hard to cover the single sand scope. After over eight years of intensive production, producing wells have reached an average water cut of 40%, some wells with water cut as high as 90% have been shut down. However, the recovery percent of recoverable reserves is only 30%, with sustantial amount of remaining oil left. Currently, Plutonio is in the 3rd stage of well location optimization, to tap the remaining oil, detailed reservoir distribution must be figured out.

There also deposits a set of turbidity channel sand in the shallow zone of the study area (Pliocene), which, unaffected by salt activities, well-preserved in structure, has high seismic resolution (with dominant frequency of 60Hz). Shallow channel is an important source to construct, and can be of good guidance for deep water channel model, when the shallow channel and deep channel are highly similar in sedimentary backgrounds. Shallow channel analogy has some unique advantages compared with other prototype models[6–7] (outcrop, modern sediments and dense pattern data): (1) reliable data accuracy (high-density offshore collection and high-resolution data processing); (2) large project area to ensure the investigation of entire sedimentary architecture; (3) characteristics of sedimentary structure can be described from plane, profile and 3-D perspectives; (4) sufficient quantitative samples can be provided. Drawing on the shallow high frequency seismic (dominant frequency 60Hz) data, turbidity channel characteristics have been studied quantitatively via seismic reflection analysis, inversion and multi-attribute analysis. In this study, we have drawn an analogy between the sedimentary features of shallow and deep channels in the study area: in terms of geographic location, both lie in deep water zone in Angola, West Africa; in terms of regional structure, both are located in the transition area between compression and extension structure; sedimentary sources are both from north-east Congo River, deposition setting being typical deep water turbidity sedimentary environment in overall regression background; in terms of basin background, both are passive continental margin basin (lower-Congo-Congo Basin), sharing the same sedimentary facies of river-sea fan turbidity type; and both are in depositional landform of the middle-lower continental slope (where high sinuosity channels develop). Thus it can be seen that there are similarities between shallow and deep channels, and it is possible to employ shallowly-buried channel morphology (width, depth, sinuosity and curve length of channel) to guide the simulation of O73 sedimentary microfacies.

2. Quantitative study of turbidity channels

Acquiring quantitative training images that can reflect real geology is the key and basis of multi-point geostatistics. Firstly, based on the shallow seismic data analysis, morphology, scale distribution and quantitative relations of parameters of the turbidity channels were obtained; secondly, the empirical formula of shallow channel was used to guide the analysis of deep channel sand scale through quantitative analogy, and the scale of shallow and deep channel sands were compared to provide reference on sand scale changing coefficient in multi-point simulation process; lastly, 3-D turbidity channel target geologic bodies were extracted from shallow high frequency seismic inversion data to establish quantitative 3-D training image of deep turbidity channel.

2.1. Shallow (Pliocene) channel morphology

Single channels are the basic genetic unit in the formation of channel system[8–9]. Single channels migrate laterally and vertically, forming complex channel systems of various scales. 3-D training image must not only reflect quantitative geometry of single genetic units, but also quantitative combination pattern of various genetic units, and structural features of reservoir in different evolution stages. Study on single channel morphology and evolution helps to get a better understanding of the formation of complex channel systems, thus to lower the development risks effectively. But, as a single channel is a small unit, it is difficult to control channel interface with relatively sparse well pattern. Therefore, we analyzed channel migration pattern from the aspects of profile and plane based on structure analysis of shallow high frequency seismic reflection.

Single channels are one-time genetic unit with sand thick-

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