A new stochastic modeling method for the 3-D forecasting of IHS of point bar in meandering rivers*

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[Abstract] The paper designed and used a new stochastic modeling method for IHS of point bars in meandering rivers.Firstly,based on the hierarchy of fluvial deposits and guided by the hierarchical modeling, a model for the distribution of meandering rivers was established, and then using channel center lines, the curvature of a meandering river at different positions was calculated to determine the occurrence of each point bar; finally restricted by point bars, various parameters were forecasted by random sampling, such as the number of IHS, horizontal intervals of IHS, the dip angle and extended distance of an individual IHS,etc.,while the azimuth of IHS pointed strictly to the abandoned channel. A model for IHS of a real reservoir in Shengli oilfield of China was built using this method. The cross-validation gave an error of 24.5 percent ,which shows the method can be put into use for the enhancement of oil recovery.

Key words:point bar;IHS;modeling method;meandering river;Shengli oilfield

1.Introduction

The EOR now has been the most important question for the continental reservoir in east oilfields of China. The meandering river, as a main reservoir type, has very complex architectures due to the Inclined heterolithic stratification(IHS) in point bar. Some physical experiments and real reservoir performance monitoring show the remaining oil is mostly controlled by the IHS and concentrated on the upper area of the point bar(Jia H et al,2008;Bai Z et al,2009;Yan B et al,2008). The detail architectural analysis and modeling of IHS in point bar is an urgent task for the remaining oil redevelopment and EOR. As a basic work, the geological knowledge database of IHS has been explored and studied thoroughly by outcrops and modern sediments(Zhou W et al,2010;Zhang C,1989;Zhong J et al,2002;Ma S et al,2008a,2008b;Liu Z and Jiao Y,1996;Chen Q and Li Y,2005;Bridge,2006;Willis and Tang H,2010;Cao Y et al,1995;Deng M et al ,2008,Wang L et al ,2008,Zhou Y et al ,2009,Li Y and Wu S ,2008). The geometric parameters and its relationship of point bar and IHS have been studied. Furthermore, some quantitative functions

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of curvature ratio and the dimension of point bar, the position of point bar , the channel width/depth ratio and the dip of IHS have been summarized and constructed for the 3-dimensional model. However, the basic functions in geological knowledge database are not well integrated in 3-D forecasting. And now there are two methods for the forecasting of IHS. The first one is using Sequential Indicator simulation method to forecast the IHS, then revised the IHS geometry manually(Yue D et al,2007,2009;Wu S et al,2008); the other one is the Alluvsim method(Pyrcz,2009), which simulates the migration of the meandering river. The first one can give a reasonable result of a single point bar and its IHS, but loss of computer automation forecast and the uncertainty analysis; the second method gives a much more realistic process of the migration of meandering river, but its condition and real effect is under evaluation.

The paper proposes a new modeling method for the forecasting of the IHS in point bar. It considers the migration of the meandering river and gives the function to decide probability of the occurrence of point bar, the point bar position function is also given. Then ,the IHS frequency, dip and extended distance and areal geometry are analyzed under the constrain of the point bar. Finally, the meandering river model including point bars and IHS is built and a real reservoir model is constructed to examine and evaluate the validation of the new designed method.

2.An overview of the formation mechanisms of the point bar and IHS

The study on meandering river can go back to the 18th century, and its formation mechanisms is concluded as the process of erosion increasing convex concave(Fig.1). The formation of IHS is often connected to the one single flood. When the energy of flood decreases, the fine material such as muds will deposit on the point bar ,which forms the so-called IHS, a very important barrier in reservoir performance(Ma S and Yang Q,2000).

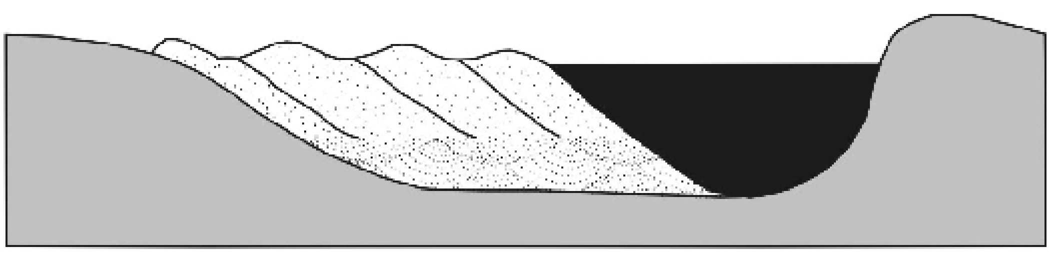

Fig.1 a sketch map of IHS in point bar

The IHS does not always exists for the scouring effect of the flood. Especially the lower part of the IHS will not be saved. As the upper part of the IHS can be seen in most outcrops and modern deposits , it only affect the flow of the upper parts, This phenomenon is called as the Semi-Communicated Sandbody

Model. For the complexities and importance on reservoir performance of the formation and preservation of IHS, Its forecasting is very difficult and urgent.

3. Methodology

The formation mechanisms of the point bar and IHS reveals a hierarchical architecture in meandering river. That is, the point bar is belong to the meandering river,and the IHS is belong to the point bar. Due to the hierarchy, the modeling method can be divided into three parts.First, the meandering river is modeled; then, the point bar and the abandoned channel in the simulated meandering river is forecasted; finally, the IHS in point bar is simulated.

3.1 The meandering river forecasting method

Due to the simple geometry of the meandering river, the object-based method is the prior choice. The theory is rather simple ,first generate the channel center line, then assign the profile of the channel along the center line. Different method of the generation of center line forms different simulation algorithms for meandering river forecasting. In the paper, the Gaussian function method is adopt, that is , the Fluvsim (Deutsch,1996;Yin Y et al,2006) is used to construct the meandering river.

In Fluvsim, when the channel center line is simulated by Gaussian function, the curvature ratio of the channel is calculated for the determination of the convex and concave side of the channel. Then, the profile geometry of the meandering river is simulated by the relative position of the maximum depth.The detail description of this method can be referred to the references.the mathematical function for the channel sides is as follow.

$$a(y)=\begin{cases}\frac{1}{2}(1-\frac{|C_v(y)|}{C_v^l}) & C_v(y)<0\\ \frac{1}{2}(1+\frac{|C_v(y)|}{C_v^l}) & C_v(y)>0\\ \frac{1}{2} & C_v(y)=0\end{cases} \quad (1)$$

In the formula, $C_v(y)$ is the curvature ratio of the center line. C_v^l is the maximum curvature ration.If $a(y)$ is greater than 0.5，the concave side is the right; If $a(y)$ is less than 0.5, the concave side is the left.

In Fluvsim, only the channel model is built and the curvature ratio of channel and the side data are not saved. However, the curvature ratio is and the side data are very important information to the distribution of point bar and IHS. The sign shift of $C_v(y)$ determines the semi-bow of the channel, which implied the occurrence of the point bar. the side data determine the position of the point bar and the dip of the IHS. So the new designed method extract and preserve the curvature ratio of channel and the side data for the next point bar and IHS simulation.

3.2 The point bar forecasting method

The generation of point bar is due to the channel migration. When channel migrates, the channel curvature ratio increases .So the probability of the occurrence of point bar can be characterized by the channel curvature ratio. In fact, the curvature ratio is one main factor of the classification of the meandering river .when the curvature is greater than 1.5(He Y and Wang W,2006), then the channel is a meandering river. Some modern meandering river deposits and physical simulation show that the occurrence of point bar under the condition of the curvature ratio is equal to 1.013(Zhang C,Liu Z,and Shi D,2000). From the GooglEarth software, the modern meandering river deposits show the definite occurrence of point bar when the curvature ratio is greater than 1.7. According to the above analysis, a probability function of the occurrence of point bar is designed as follow.

$$p(pb) = \begin{cases} 0 & |C\ (y)| < 1.013 \\ \frac{|C(y)| - 1.013}{1.7 - 1.013}) & 1.013 < |C\ (y)| < 1.7 \\ 1 & |C\ (y)| > 1.7 \end{cases} \qquad (2)$$

$p(pb)$ is the probability of the occurrence of point bar. during the simulation of point bar, $p(pb)$ is first calculated and a Monte Carlo sample is implement to determine whether a point bar exist.

The 3-D geometry of the point bar is very complex for its arc shape in plane and concave shape in profile and the shape characterization is not implement directly. Howerver, considering the channel migration and the point bar generation, the 3-D geometry of point bar can be depicted by the associated abandoned channel(Fig.2) ,which geometry is the same to the meandering river.

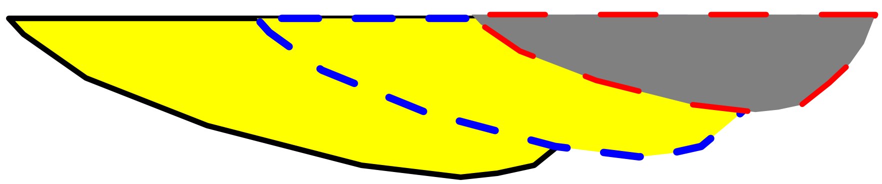

Fig.2 the profiles of the configuration of point bar and abandoned channel

(yellow:point bar,gray:abandoned channel)

The position of the point bar is rather simple for it always deposit in the convex side, which is revealed by the $a(y)$。The abandoned channel is on the concave side.

When the probability of the occurrence , shape and position of point bar are determined, the point bar model will be forecast accurately under the constrain of meandering river model.

3.3The IHS forecasting method

The IHS is also related to the migration of channel and positioned in point bar. it is crescent-shaped in plane and concave in profile. The crescent shape can be determined by the migration boundary of channel and the concave shape can be determined by the abandoned channel boundary in profile, similar to the Alluvsim method.

The extended distance of the IHS is very different and its determination is rather difficult. A triangle distribution function is proposed.

$$f(x)=\begin{cases}\dfrac{(x-a)^2}{(b-a)(c-a)} & a\le x\le c\\ 1-\dfrac{(b-x)^2}{(b-a)(b-c)} & c<x\le b\end{cases} \qquad (3)$$

a is the minimum distance , b is the maximum distance, c is the mode. x is the simulated distance.

The frequency and interval distance of IHS are another parameters must be considered。Like the parameter of extended distance, two triangle distribution functions are proposed.

The dip inclination is directly determined by $a(y)$, that is, the dip inclination is point to the concave side of the meandering river.

As the parameters for the characterization of the IHS are determined, the IHS can be simulated under the constrain of point bar.Fig.3 is an unconditional model including point bar, abandoned channel and IHS。 The fine architectures in meandering river are well reproduced, which shows the new designed method can be used for constructing fine reservoir model of meandering river. A real reservoir model is built by the new method.

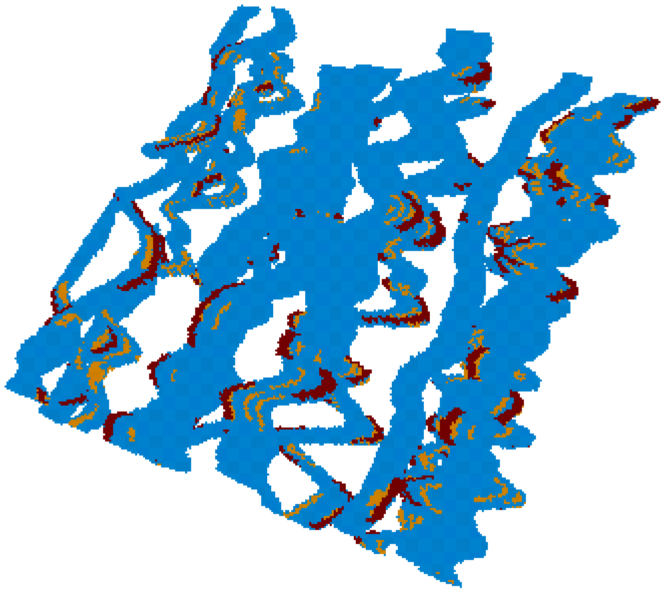

Fig.3 the 3-D model of the IHS of point bar in meandering river(blue: channel,red:abandoned channel,yellow IHS)

4. Case study

The study area is located in Shengli oilfield of Sinopec, Shangdong Province, China. There are 94 wells and the average well distance is about 70 meters. The basic geologic research shows it is a typical meandering river reservoir and can be recognized four architecture types: point bar ,abandoned channel ,IHS and floodplain. Some modeling parameters are extracted by detail reservoir architectural element analysis and empirical functions(Table 1). The IHS model is then simulated by the new method(Fig.4,Fig.5). The simulated model reveals the details in meandering river very well. The channel is sinuous and consists of the point bar and abandoned channel. The IHS is located in the point bar and has a crescent shape in plane and concave shape in profile. A cross-validation is implement. The result shows there are an error of 24.5 percent in 5 newly drilled wells, which proves the model has a comparable precision.

Table 1 the input parameters for the modeling method

parameter	minimum value	average value	maximum value
channel orientation(degree)	-10	0	10
channel amplitude(meter)	40	60	120
channel wavelength(meter)	200	400	800
channel thickness(meter)	2	4	6
channel width/thick	20	40	100
abandoned channelthick/channel thick	0.2	0.4	0.8
abandoned channelwidth/channel width	0.1	0.15	0.2
dip of IHS (degree)	2	10	20
extended distance of IHS(meter)	30	40	60
horizontal invertals of IHS(meter)	20	40	80
frenquency of IHS(number)	1	4	10
horizontallength of IHS(meter)	100	150	400

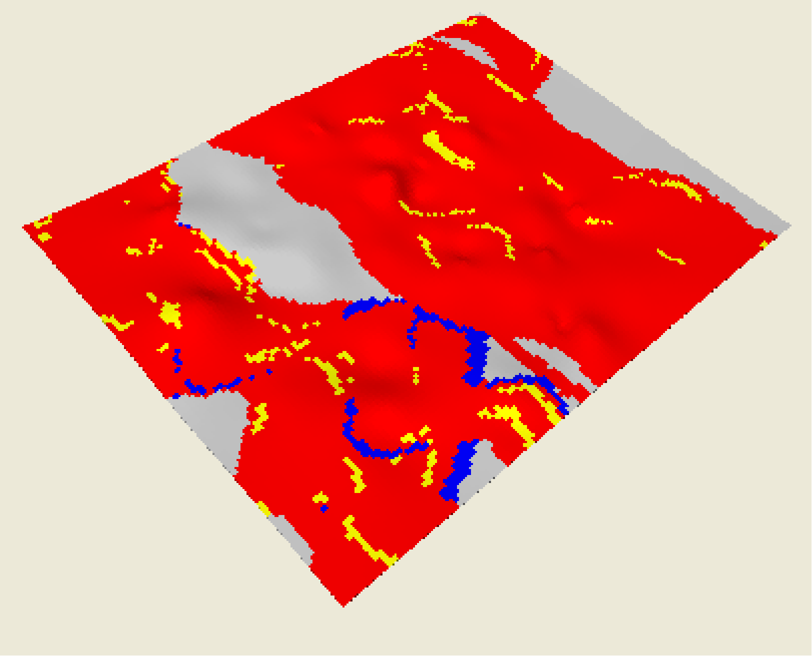

Fig.4 the areal map of the IHS model of point bar in meandering river of the oilfield (red:channel,yellow:IHS,blue:abandoned channel,gray:backgrounds)

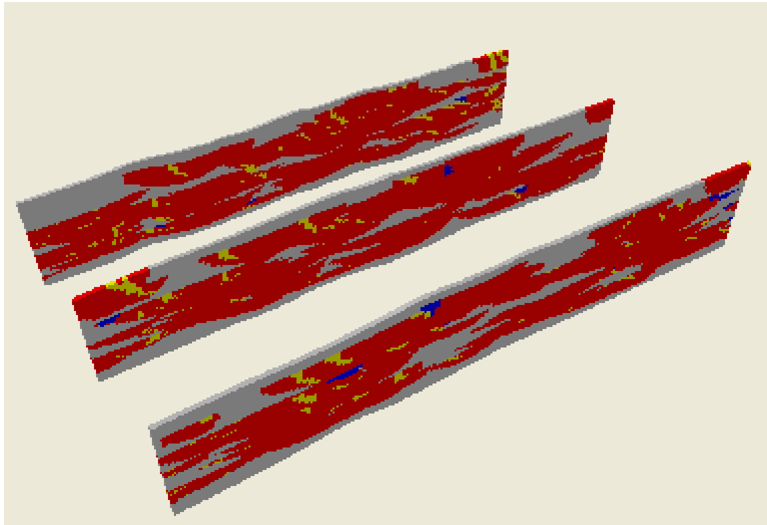

Fig .5 the profile map of the IHS model of point bar in meandering river of the oilfield
(red:channel,yellow:IHS,blue:abandoned channel,gray:backgrounds)

5. A primary conclusion

The paper has designed a new IHS and point bar modeling method for the meandering river reservoir. A case study shows that it can build the real reservoir model well, which shows the new method has much more advancement. However, the work must be studied thoroughly. The parameters of the IHS and point bar must be extracted and summarized by many outcrops, modern sediments and dense-drilled well area analysis. That is, A detail geological knowledge database should be constructed for the simulation. Another problem is the channel avulsion and channel rebirth, which are common in channel but not considered in the new methods. Finally the new method is an object-based algorithm and the conditioning has to be improved by further study.

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