

## Research Article

### Optimization and Application of Bit Selection Technology for Improving the Penetration Rate

Bing Hou, Mian Chen and Jianbo Yuan

State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum (Beijing), Beijing 102249, China

**Abstract:** Scientific selection of drill bits during drilling is a key technology to achieve high-speed drilling and reduce drilling costs. Based on the analysis of bit's working principles and its applicable conditions and in accordance with the well conditions of ultra-deep wells in Y area of Tarim Oilfield, this study has conducted mathematical statistics on a large number of actual drilling practices and detailed information of the drilling bits. As well, we studied the distribution of three-dimensional drillability in this area and optimized drilling parameters under neural network ROP model. Finally we put forth a set of comprehensive optimal selection techniques of bits that is applicable to Y Area. Field results show that the application of these comprehensive optimal selection techniques will enable a single well's penetration rate to increase by 30%, thus making a useful attempt to solve the deep well speed problems in Y Area.

**Keywords:** Comprehensive optimal selection, drillability, drilling bits, drilling parameters, neural network, ROP

#### INTRODUCTION

Bit is fundamental to borehole drilling. The rate of penetration depends primarily on whether the drill bits design and selection are reasonable. Large-scale application of PDC bits contributed greatly to raising drilling speed in Tarim Oilfield. By analyzing the application of PDC bits of this region in recent years, for example in year 2008, compared with the year 2004, we had witnessed an 11.69% increase of the average penetration rate, arriving at 4.3 m/h. As the drill bit design and selection techniques went mature, single well reduced the use of PDC drill bits with a reduction rate of 53.66% 2008 compared with the first three years. At the same time an increase in drilling depth of single bits greatly enhanced the penetration rate and shortened drilling cycle. In deep formations, however, the increase of the rate of penetration is experiencing a bottleneck which is closely related to the re-optimization of bits.

There are many factors affecting the rate of penetration in deep well. The factors which directly related to the drilling process can be divided into two types: one is the objective factors which can't be changed arbitrarily, such as geological conditions, rock properties and drilling depth; the other is bit type, mud property, drilling pressure and other drilling parameters which are adjustable variable selected by people. So the ROP equation is the basic model to predict penetration

rate and the main foundation of choosing the bits and optimizing the drilling parameters. Modeling ROP has been attempted since the 1960's, but the motor were not verified with laboratory data until the late 70's. The roller cone ROP modeling work performed by Amoco research developed the first two term model, which linked WOB, RPM, bit size and rock strength (Winters *et al.*, 1987). Two decades earlier had Galle and Woods made an attempt to perform optimization of WOB and RPM, with little or no practical implications however (Galle and Woods, 1960). This model is inadequate as discussed by Estes and Randall (1977). Bourgoyne and Young (1999) proposed to use eight functions to simulate the effect of most of important drilling variables (Bourgoyne *et al.*, 2003). A model of the drilling process for tri-cone bits called perfect-cleaning model was derived (Warren, 1987) and later modified by Hareland and Hoberock (1993). But the above ROP prediction models only have a better applicability on cone bit. Y structure lies in the 32<sup>nd</sup> Y Buried Hill Belt on the western part of Tabei Luntai uplift in Tarim Basin. Wells in this region are mainly deep and ultra-deep ones. Formation compaction and tectonic stress have very large impact on the drilling rate. This region is mainly using PDC bits. So utilizing the above ROP equations cannot optimize the drilling parameters and bit selection. Therefore it is crucial to consider various factors and create a new ROP model to propose a set of comprehensive optimal selection techniques of bit that is applicable to Y Area.

**Corresponding Author:** Mian Chen, State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum (Beijing), Beijing, China, Tel.: 010 8973 2165

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On the basis of large-scale application of PDC bits in the Y area in Tarim Oilfield, how to conduct a comprehensive optimal selection of bits and further improve the efficiency of bits seem to be especially important. This requires not only comprehensive consideration of the design and selection of bits, but also combination with comprehensive selection of the lithological features of the area, distribution of rock drillability and drilling parameters. This study has conducted mathematical statistics on a large number of actual drilling practices and detailed information, further it studied the reasons for the decline ROP and established the distribution of three-dimensional drillability in this area, optimized drilling parameters and effectively predicted the rate of penetration under neural network model and finally applied it in Y Area.

### METHODOLOGY

**Drillability analysis:** The impact of Y Area on the ROP mainly manifests itself in two aspects: firstly, the impact from formation compaction and tectonic stress; secondly, the impact from special lithostratigraphic. The two aspects both limit the increase of ROP; the second one brought especially some adverse effects on drilling engineering.

**The impact form formation compaction and tectonic stress:** Formation compaction and tectonic stress have very large influence to the ROP. As the depth increase, the compaction of rock strata also ascends; the penetration rate is drastically reduced. The strata deposited under different environments and the differences in drillability are very large too. The differences express on the stratigraphic heterogeneity and gravel crushing hard when used the cone bit, making the ROP drastically lower than the sand-mudstone formation. The same on the Y Area, with the increase of the depth, the drillability of the rock is increased, so the ROP decline dramatically.

**The impact from special lithostratigraphic:** The complexity of the lithology has large influence to the ROP. In the Y Area, the drilling process of the Upper Tertiary system taupe gray mudstone caused serious crumbling. Crumbling frequently happened on the process of directional drilling, which caused some complex situations such as pump limp and sticking, then the bit teeth is damaged seriously; On the effect of high stress in the lower Tertiary System of the composite salt formation, sticking, casing collapsing, stratigraphic leakage and so on often happen. The limestone and dolomite grow from Cambrian and Silurian System are easily to cause the ground leakage, loss of drilling time is attributed to these complexities of these accidents, which also affected the ROP drastically. Figure 1 shows the effects of the ROP on three areas in different layers.

Analyzing the factors of restricting ROP in Y area, it can be concluded that drillability rate is a comprehensive reflection of the different rock's drillability and drilling technologies. Therefore drillability of Y area is great importance when considering the comprehensive selection techniques of bits (He and Zhu, 2006).

Propagation velocity of acoustic wave in the rock depends on the density of the rock, Young's modulus, Poisson ratio, shear strength, bulk modulus and other rock mechanical parameters. According to the logging data, the propagation velocity of acoustic wave is closely related to the formation lithology, rock structure and burial depth and the corresponding geological age. The propagation velocity of acoustic wave can also reflect the integrated physical parameters of the rock (Xiong *et al.*, 2009). Thus the relationship between acoustic interval transit time and the formation drillability parameter can be used to evaluate the formation drillability. We need logging data to determine the drillability of the Y Area. This study firstly sets the compressional wave slowness  $\Delta T_p$  as the independent variable, cone bit's drillability Level  $K_{dcone}$  as the dependent variable, chooses the best fitting curve through regression analysis under the exponential

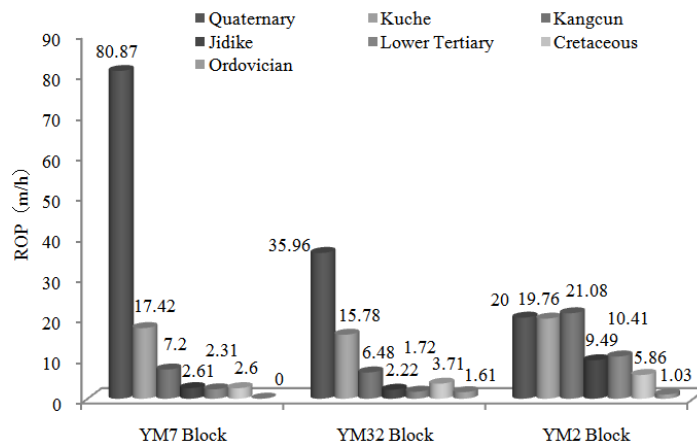


Fig. 1: The rate of penetration of different layers in YML block

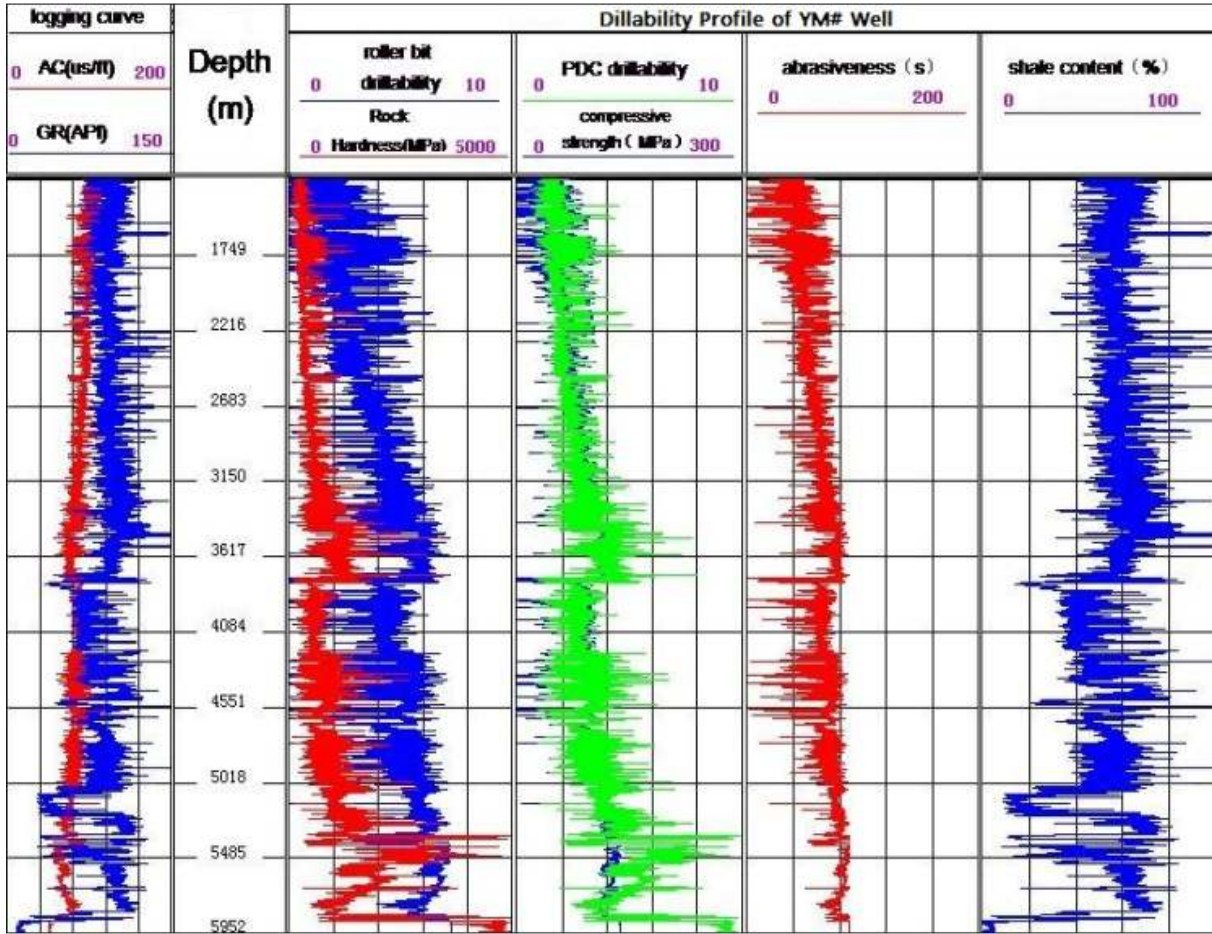


Fig. 2: Drillability profile of well YM#

model and then arrives at the calculation formula of drillability rate of the cone bits in Y Area:

$$K_{dcone} = 27.987e^{-0.022\Delta T_p} \quad (1)$$

PDC drill bits drillability rate calculation formula can be drawn in the same way:

$$K_{dpdc} = 51.167e^{-0.036\Delta T_p} \quad (2)$$

According to the calculation methods of drillability rate from formula 1 and 2, this study combines composite factors such as the hardness of the rock, compressive strength and abrasiveness, calculations are based on VB programming and sets up the single well drillability profile. Here is an example of Well YM #, as illustrated in Fig. 2.

In order to analyze the drillability of the area, further to guide the bits selection, the rock drillability profile of wells in those strata groups need to be established. We must first collect relevant engineering data of drilled wells in Y area, such as geological design of different wells, drilling design, history of drilling wells, logging data of different wells, seismic

data and formation information, etc. Let's take seven wells from Y 2<sup>nd</sup> block as examples. We calculate the formation stratified data and drillability rate and set up a three-dimensional model, inputs data and then arrive at the distribution graph of drillability in Y 2<sup>nd</sup> block as shown in Fig. 3. From Fig. 3 the following conclusions can be drawn:

- From Quaternary to Neogene System strata dominate sandstone and mudstone, with relatively good formation lithology and drillability. But at this stratum there are multiple sets of pressure system, in which bits are easy to get stuck; in particular Jidike formation is easy to suffer wall collapse and severe necking.
- From the Cretaceous, Jurassic into the Triassic, Silurian and Ordovician strata, the lithology becomes more complex with varied problems such as dense lithology, frequently interbedded sandstone and mudstone, widely different lithology both vertically and horizontally, serious deviation in high-steep structure, strong formation wearing resistance, inclined strata, poor drillability and a lot of fractured formation where leakage is very likely to happen. Therefore different conditions of each

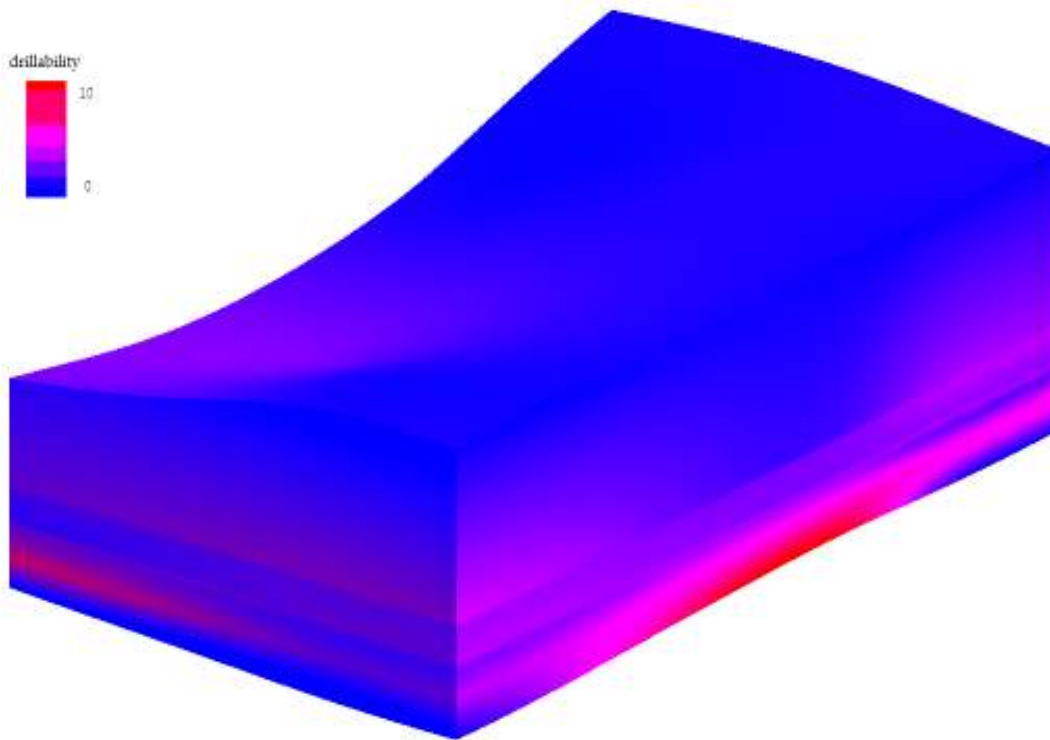


Fig. 3: Three-dimensional drillability distribution figure of YML 2<sup>nd</sup> block

layer in this block must be taken into consideration of the selection of bits.

**ROP prediction and drilling parameter selection:**

According to the field data, there are many ways to improve drilling penetration rate thereby reducing the cost of drilling. One way is that, by careful selection of some drilling parameters to complement each other's advantage, exploit their technological advantages, in the end and achieve a maximal penetration rate. Therefore we need to carry out the bit selection that combined with drilling parameters optimization after comprehensive analysis of the block drillability. There are many ROP prediction models, among which the Bourgoyne and Young's model and the modified Warren's model have comparatively better applicability (Mahmood and Mohammadreza, 2007). Based on what information is being focused on or what information is available, the models can be discriminated. Bourgoyne and Young model focuses more on drilling parameters such as WOB and rotary speed, while Warren's model is substantially based on rock strength information (Bilgesu *et al.*, 1997). Therefore, application of Warren's model is recommended when a high quality and reliable rock strength data is available and usage of Bourgoyne and Young's model is suggested when effect of drilling parameters is more important. However, the sources of these methods are limited in drilling process and laboratory, they affect the accuracy of the results and the workload is also big. Moreover,

the above models are not very ideal for PDC bits. According to the deficiency of the two mentioned models in some cases, the implication of neural network fitting method can be examined for the prediction of ROP. For this purpose, neural Network Fitting Tool (NFT) of MATLAB programming software has been used. Using this toolbox, the influence of more parameters can be taken into account for development of a model. So it can make up for deficiencies of existing methods and improve the prediction accuracy.

Figure 4 represents a simple drawing of the architecture of the network which has been made to predict rate of penetration. This model is mainly constituted of three three-tier networks: an input layer, one hidden layer and an output layer. As the figure indicates, eight numbers of parameters have been chosen to feed as the inputs to the model and the ROP as the output would result. The input parameters include vertical depth, drillability rate, weight on bit, rotary speed, mud weight, pump capacity, pump pressure and hydraulic jet speed. The hidden layer transfer function selected for tansig function. Using the available data, a network has been constructed for ROP prediction. The provided data has been divided into 3 parts which have been used for training, validation and testing of the resulted network, respectively. 60% of the data has been used for training, 20% for validation and 20% for testing. Figure 5 illustrates the three steps of

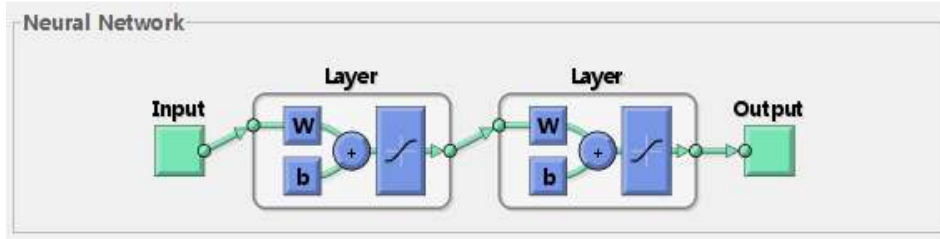


Fig. 4: The architecture of the network developed for ROP prediction

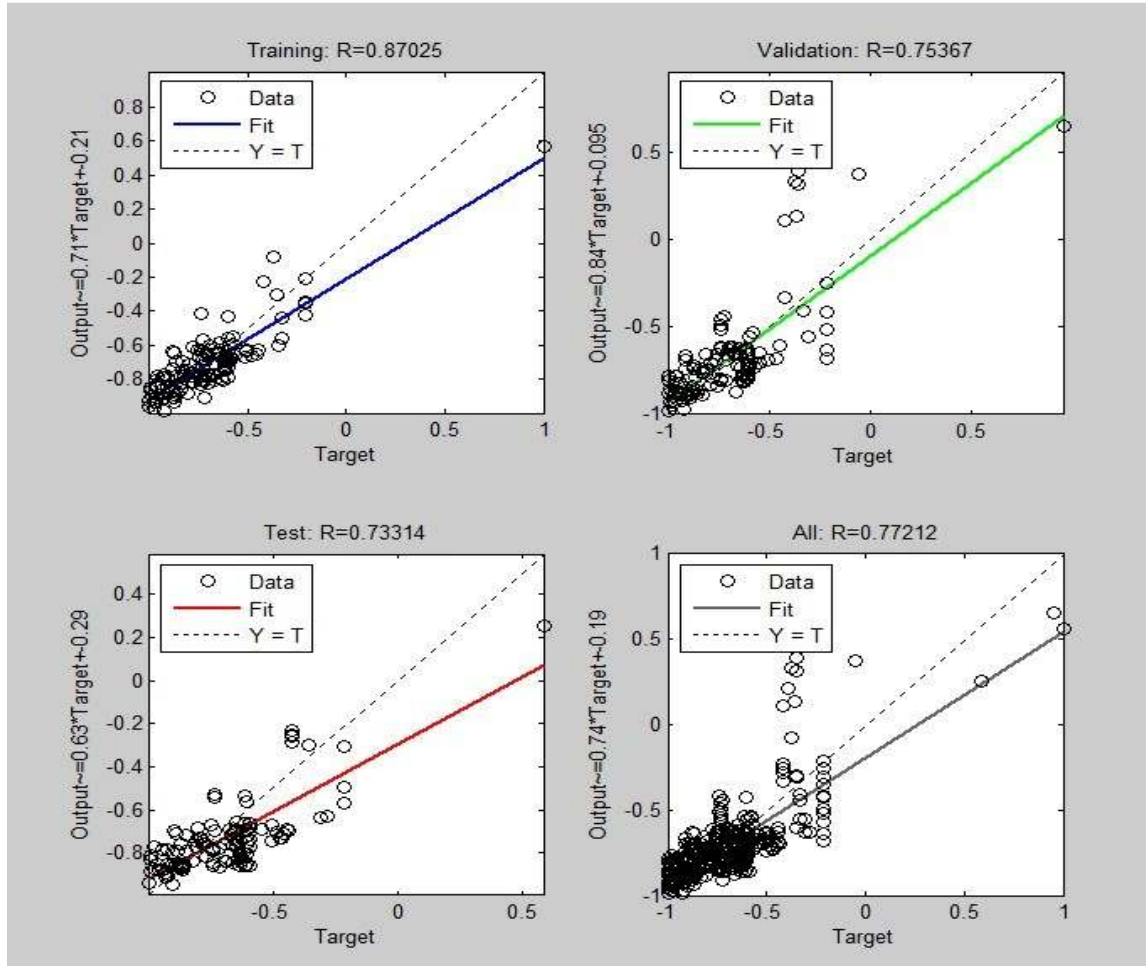


Fig. 5: Generation of the neural network for prediction of ROP using neural network fitting

the network generation and their fitness values. As it can be seen, the correlation factor value for the tested data is 0.733. This value indicates that the reliable results can be obtained for estimation of ROP in the future drillings since it has been tested using 20% of the data.

This study uses the lower strata from the Cretaceous to Ordovician in the Y 2<sup>nd</sup> block as an example to get the drilling parameters appropriate to PDC drill bits under neural network model (Table 1). This provides a reliable reference and basis for follow-up drilling parameters design in Y area.

### COMPREHENSIVE OPTIMAL SELECTION OF BIT

According to the statistics of the bit data in Y block, we employ the principles of mathematical statistics, data analysis and statistics to compare different types of drill bits used in the same layer so as to optimize the drill bits, determine the effect interval of different drill bits and evaluate its employ effect of the used bits (Li and Bian, 2006). In addition, we need to comprehensively analyze the whole block's drillability distribution, geological structure and other factors.

Table 1: Recommended drilling parameters for PDC bits in YM 2<sup>nd</sup> block (4000-5800)

Depth (m)	4000	4200	4400	4600	4800	5000	5200	5400	5600	5800
Formation	K1bs	K1kp	J	T	S	S	S	O	O	O
WOB (lb)	8	10	10	8	10	11	10	11	9	6
Rotational speed (rpm)	40	50	50	40	50	50	40	50	40	40
Mud density (pcf)	74	76	76	78	79	79	79	80	80	70
Pump capacity (L/sec)	1700	1700	1600	1600	1700	1700	1800	1600	1600	1000
Pump pressure (MPa)	190	190	190	190	190	190	190	190	190	200
Jet speed (m/sec)	24	24	24	24	24	24	24	24	36	24
ROP (m/h)	26	20	4	3	8	6	5	1	4	1

Table 2: Recommended drill bits in YML 2<sup>nd</sup> block

Section	Well profile	Code	Type	Companies
12 1/4"		HAT127/MP2G	Roller bit	SHANGHAI/ KINGDREAM
8 1/2"		HAT127	Roller bit	KINGDREAM
		MS1955SS	PDC	BEST
		MS1952 (3) SS	PDC	BEST
5 7/8"		FS2563BG	PDC	DBS
		GP13467	PDC	CHUANSHI
		M1365D/M1354MSS	PDC	BEST

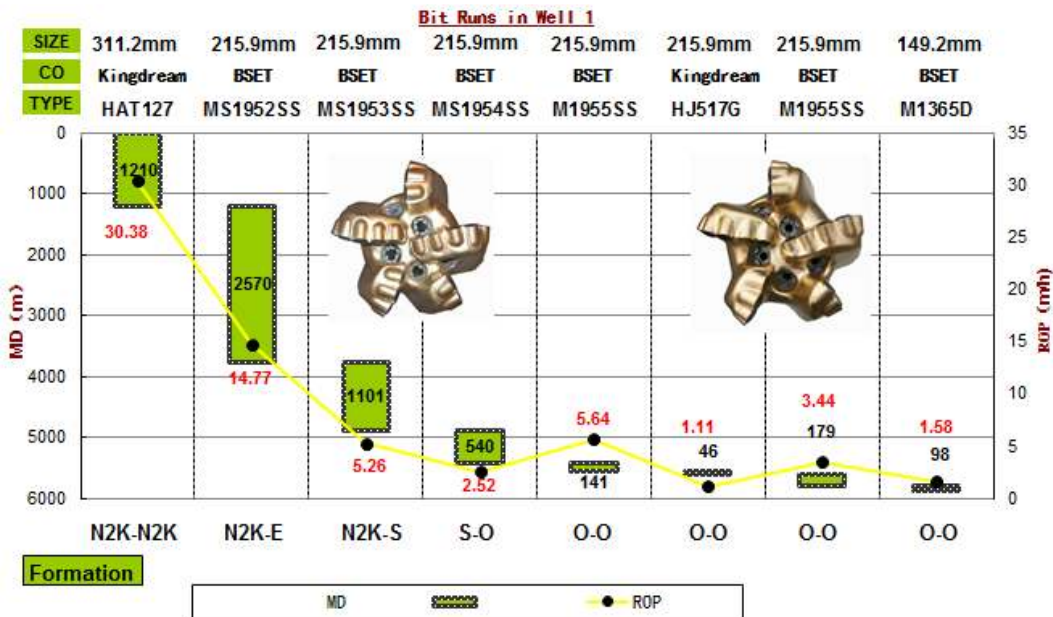


Fig. 6: The bits run in well 1

Take the Y 2<sup>nd</sup> block as an example, from Quaternary to Neogene, the major lithology are sand and shale, featuring relatively good drillability, therefore bits of the steel style with a large spiral blade wing and large displacement flow design should be selected for drilling. When it comes to the Triassic, Cretaceous, Silurian, Cambrian and Ordovician, considering the lithology complexity and the poor drillability, we should select the PDC bits with higher diamond content, greater impact resistance and longer life. In addition, this kind of PDC bits has no-moving parts, is able to withstand high speed and can be used in conjunction with downhole drill motor. These technical performance and advantages will help to achieve high economic and technical indicators in hard formations. Lastly, taking into account of factors such as the cost of

the bits, we obtain optimal drill bit types for Y 2<sup>nd</sup> block as shown in Table 2.

**Field application:** Based on integrated optimization technology, drill bits and drilling parameters were carried out in the Y 2<sup>nd</sup> block of the Well 1 and Well 2 for field applications. These two wells are located in the Tabei uplift Y low Y N.O 2 anticline zone, which belong to the development wells. Integrated bit optimization techniques, the bits type and footage of the two wells are shown in Fig. 6 and 7.

In the design of drilling parameters, using the recommended parameters of the prediction model, combined with the actual ground conditions and the drill bits, compared to 4000-5600 m well section, ROP of Well 1 and Well 2 tally with the parameters of

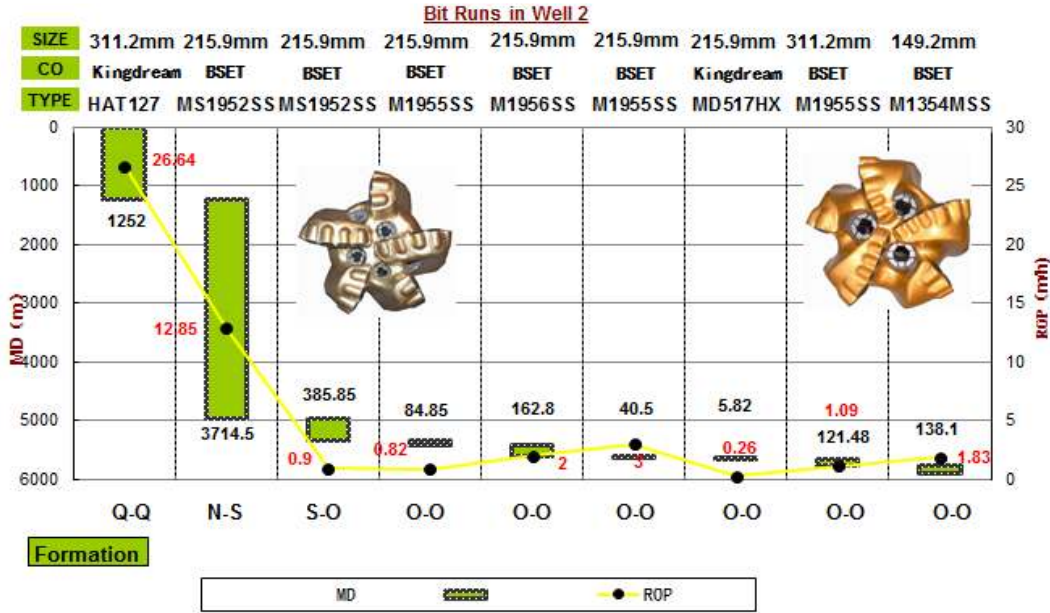


Fig. 7: The bits run in well 2

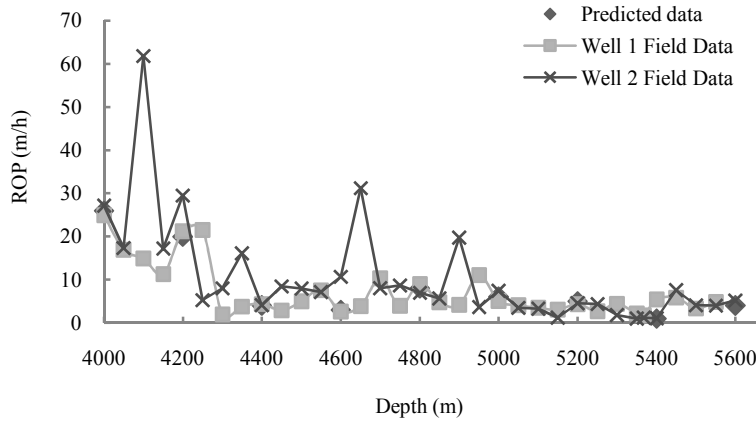


Fig. 8: Neural network predicted and field data of well 1 and well 2

Table 3: YML 2<sup>nd</sup> block comparison of the experimental well and comparative well (average) parameters

Section			ROP (m/h)	Comparison (%)	ROP (day/100 m)	Comparison (%)
12 1/4"	Test well	Well 1	35.294	17.94	0.701	-0.25
	Test well	Well 2	27.671	-7.54	0.543	22.32
	Offset well	Average	29.930		0.700	
8 1/2"	Test well	Well 1	6.327	15.84	1.355279	32.55
	Test well	Well 2	6.006	9.95	1.454114	27.63
	Offset well	Average	5.460		2.000	
5 7/8"	Test well	Well 1	1.815	50.39	7.526	57.22
	Test well	Well 2	1.829	51.58	8.448	51.98
	Offset well	Average	1.210		17.600	

neural network ROP model predicted, the specific comparison results are shown in Fig. 8.

Review of the field applications of the recent completion of the Well 1 and Well 2, during the drilling process we should choose the bit model rationally, according to the actual drilling drillability, optimize of drilling parameters, safely and fast complete the drilling tasks. In the second open (8 1/2 "or 9 1/2") hole section, the rate of penetration increased by 15.84 and 9.95%, in

third open (6 1/4 "or 5 7/8") hole section, it increased by 50.39 and 51.58% respectively as shown in Table 3.

Overall, the bits have been put in full use and achieved considerable footage and good benefits. Especially in the Well 2 sec open section, model MS1952SS of 8 1/2 "PDC bit drilling through the hole section 1252-5352 m, with footage of 4100 m and reciprocating time: 440 h, achieving an average penetration rate of 9.32 m/h. This is a result of

reasonable bit selection and BHA with appropriate technical parameters. Therefore, the comprehensive optimal bit selection technique for Y area has a good application value and is worth promoting.

## CONCLUSION

Based on the discussion presented here, the following conclusions are reached:

- The special bit selection centered on PDC bits significantly improves the deep well drilling efficiency of the Y area and reduces downhole drill bit accidents; but the bit selection needs further improvement on ROP and bit life in deep highly abrasive formations.
- With the help of logging data and core analysis we can establish rock drillability prediction model, obtain point by point the value of the rock drillability of a single well and the drillability profile of the rock layer and then draw a distribution plot of three-dimensional drillability which provides basis for comprehensive selection of new wells and forecast of the rate of penetration.
- The comprehensive bits selection must take different conditions of each layer into account. In strata of Kuche and Kangcun group exist several sets of pressure systems, easily cause sticking; Jidike Formation in particular is easy to have wall collapse and severe necking; The evaporate beds in the Lower Tertiary are prone to get stuck in the upper strata and have leakage problems in the lower strata; Cretaceous, Ordovician, Silurian and Cambrian exist a large number of fractured formations, easy to leak. In addition, there are problems such as serious deviation in high-steep structure, formation with strong wearing resistance and poor drillability. These factors should not be ignored in optimization of the bit.
- By neural network ROP Prediction model, we can obtain the optimized drilling parameters of PDC bit. Compared with the ROP predicted by the model and the real data of field application, the error is relatively small. Therefore, the model has a high application value, providing a reliable reference for drilling parameter design of the followed-up drilling in Y area.
- Bit selection requires not only consideration of the drill bit design and selection of type, but also the formation lithology, the distribution of the rock drillability and the drilling parameters. A new well in the field application of the Y 2<sup>nd</sup> block shows

that this set of bit comprehensive optimization techniques in Y is more accurate and scientific than other bit selection techniques, since it perfectly matches the actual use of the block and has strong application value.

## ACKNOWLEDGMENT

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### List of symbols:

$\Delta T_p$  : Compressional wave slowness

$K_{dcone}$  : Drillability of Cone Bits

$K_{dpdc}$  : Drillability of PDC

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