Appendix G

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Drilling-Derived Rock Strength Can Simulate Upcoming Well Performance

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Abstract

A drilling simulator has been used during the past four years to improve the drilling performance in Western Canada. Rate of penetration improvement and subsequent cost and time reductions are the key elements for drilling these wells. A drilling simulator is required to generate the “Apparent Rock Strength Log” (ARSL) using available offset well data. The ARSL calculation is based on using inverted Rate of Penetration (ROP) models for different bit types, reported bit wear, lithological information and pore pressure in addition to the drilling parameters. The generated ARSL can be modified and correlated for different and new formation tops for planned wells.

The obtained ARSL logs for the wells in the same field have shown an acceptable overlay for the common lithologies using different bit runs and drilling parameters. Furthermore, it can be shown that the ROP match with the new simulated ROP in the same well applying another well's drilling parameters once their ARSL are adjusted. It has been shown that a typical cost reduction can be achieved for the planned wells utilizing the drilling simulator when previously drilled wells exist. The effect of using the combination of different bit runs and drilling parameters can also be explored through use of the simulator. In this paper, a study was conducted for two wells in an Albertan, Canada field to investigate the effect of using the bits used in a well to reduce cost and optimize the next well.

The ARSL logs of two wells were separately obtained and compared. The comparison between the new simulated ROP for the first well, using another well's drilling data, and the available ROP for the second well is also discussed. Final results are showing an acceptable match obtained for ROP values as well as for the corresponding drilling time and final bit wear status in each of the bit run sections. Utilizing the simulator in these type wells shows a significant cost and time reduction potential and can be helpful to apply in preplanning analysis for new wells to be drilled using previously utilized bit types and designs.

Introduction

The rig cost is a major part of an overall drilling cost. Rig cost depends on the drilling time used to rotate the bit, connections and tripping in or out of the well. The use of the drilling cost equation is useful in finding the better solutions of drilling optimization[1]. The calculation of cost per meter is done by the following conventional cost equation:

$$C_f = \frac{(t_r + t_t + t_c)C_r + t_r C_m + C_b}{\Delta D} \quad (1)$$

C_f is drilled cost per unit depth (\$/m), C_b is the bit cost (\$), C_m is downhole motor cost per unit time (\$/hr) and C_r is the fixed operating cost of the rig per unit time (\$/hr). In addition, t_r, t_t, t_c and ΔD represents bit rotating time, total tripping time, pipe connection time and depth drilled respectively[1]. According to the cost equation, the optimum drilling plan would reduce the drilling time by increasing rate of penetration and decreasing total tripping time.

Planning drilling with the highest rate, safe operations and lowest cost are the major objectives when drilling new wells. Drilling optimization techniques are of great importance when selecting the best combination of drilling parameters. Drilling optimization defines using the best combinations of equipment and techniques to complete drilling operations as quickly as possible in fulfillment with safety standards and environmental regulations.

The basic idea is to generate a pre-planned drilling plan for the new wells by comparing different drilling scenarios. Obtaining pre-drilled formation resistance prior to drilling wells in the same field can allow the operator to adjust drilling parameters to reduce the time and cost of the project. The ability to identify this optimum cost is the primary target of using the simulator. Offset data from previously drilled wells can be used in the drilling simulator, to generate the depth based rock drillability or Apparent Rock Strength Log (ARSL). Unlike the compressive rock strength, which is a static parameter measured in the lab, rock drillability is a dynamic parameter of the formation being drilled in the field.

The ARSL is a representation of the drilling resistance for different formations and is the main input for drilling simulation studies. The current application of the simulator was to generate the ARSL from drilling data from reference wells in an area then to optimize the drilling of a typical well in the area. This offset data was easily accessible, as it was measured and recorded at the rig site when the wells were drilled. Since the the drilling data is known, the rock strength can then be back calculated from ROP models in the simulator. The generated strength log for the reference wells can be either shrunk or stretched to match the formation tops in the new wells to be drilled. Once this unique strength log is generated for the new wells, this log can be used for drilling simulations in the simulator. These simulations can provide a practical method of studying several parameters such as different bit design, drilling operating parameters, formation properties and their effects on rate of penetration. The ARSL can also be used with pore pressure information to determine appropriate mud weight as well as pre-planning wellbore analysis.[2, 3 and 4]

Generating Apparent Rock Strength Log (ARSL)

To generate an Apparent Rock Strength Log, offset drilling data was required from at least one well to create the necessary input files. All offset data are needed to perform quality control and has to be corrected in order to be appropriate for creating the ARSL. It was necessary to prepare three input files, including bit, drilling operating parameters and lithology data. For this paper, two wells were investigated, A and B, which where drilled in western Canada.

To generate the bit file for roller cone and PDC bits, the information such as bit size, depth in/out, bit wear in/out, number/size of nozzles were required. For roller cone bits, the IADC codes are essential to represent type, size and shape of cutters. For PDC bits, cutter specifications such as number/size of cutters, backrake/side rake angle, number of blades and junk slot area were needed. Tables 1 and 2 are showing bit information for two wells in more details.

When generating the drilling operating parameters file, it was required to have rate of penetration, rotary speed, flow rate, plastic viscosity, mud weight, mud type and drilling mode for each measured depth. This data was easily downloaded from available data hub, but it was necessary to perform quality control on each data set. Daily reports were used as references to ensure that the calibration and measurement errors were correctly identified. The last required file to run the simulator is the lithology file. To build the lithology file, the top depth and lithology of each formation is needed .The formation tops are reported in the well's stick diagrams and geology reports. The lithology details can usually be acquired from the project's geologist or generated from log properties.

Data quality control was done using an excel spreadsheet for each set of data. Table 3 shows the practical range for drilling parameters which was used as a basis for controlling the quality of the data. Quality controlling was done for each set of data versus measured depth. Some of these data points that were outside of the practical range could in some cases be related to the vibration of the measurement tools or background noises. Once these erroneous points were removed, the data is averaged over these points from last acceptable data point. This averaging process creates useable data for all formation intervals. As an example, Figure 1 shows the ROP values versus measured depth before and after quality controlling to generate the smoother and more accurate ARSL trend.

RPM data points obtained from the server only reflected the surface recorded values. Rotary speed generated by the mud motor needs to be added to the surface RPM before being inserted into the drill input file. To do this, the mud motor capacity factor needed to be multiplied by the flow rate to give the motor rotary speed. These factors can be seen in Table 4.

Another factor that needed to be adjusted was the effect of sliding on various drilling parameters. While drilling in sliding mode, the bit rotates only by motor RPM, which can cause the generated ARSL to be highly erratic. The recorded weight on bit can also be inaccurate during sliding, since the friction force between the drill pipe and wellbore will increase and result in a higher recorded weight on bit. For the sliding sections, it is recommended to use motor differential pressure correlations to get accurate WOB. Finally, the parameters such as plastic viscosity, mud density, mud type and drilling mode were also obtained from the toursheets and inserted into the drilling input file.

Results and Discussion

Once the quality controlled version of the data had been acquired, the rock strength could be generated using the drilling simulator for both wells A and B. The generated ARSL is shown beside the input drilling data, bit information and calculated bit wear versus measured depth for all the bit runs in the same plot.

The formation tops in well B were correlated with the corresponding formation depth in well A. This correlation resulted in an ARSL for each well with the same formation tops to make the interpretation easier. Well sketches and ARSL results for the entire wells are shown in Figures 2. The ARSL values generally overlaid in most of the well sections but there were some mismatches. These differences could be the results of the following,

- Inaccurate input lithology
- Lithology variation between two wells
- Improper calibration of measuring devices at the rig site
- Hole cleaning effects, especially in directional and horizontal sections
- Inaccurate input mud properties (i.e. plastic viscosity)
- Inaccurate bits and mud motor specifications
- Pore pressure variations, especially in directional and horizontal sections
- Inaccurate reported bit wear
- Using agitator only for well A to drill horizontal section

An acceptable overlay obtained for the ARSL values for most of the formations are shown in Figure 2. When comparing the ARSL values, surface formation is showing higher values in well B compare to the well A which could be as a result of using re-tipped roller cone bit to drill the same formations. Since some formations are fairly thin, the measured drilling parameters might have been incorrectly recorded when referencing the top and bottom of the formations. Also, the ARSL values were almost doubled through some interval, which could be as a result of inaccurate selected bit specifications in well B as well as inaccurate WOB measurement while drilling in sliding mode.The formations were mainly located in horizontal sections and their ARSL comparison showed smaller values in well B. It is worth noting that the stress states are different while drilling a horizontal section compared to the same drilled depth in a vertical direction. Therefore, the entire wells trajectories were assumed as vertical while the actual trajectory was completely horizontal for the last two formations. Stress state differences, pore pressure depletion in horizontal direction and porosity variation could serve as the main reasons for the discrepancies when comparing the ARSL values for the formations in the horizontal section. Also, to drill horizontal section in well A, an agitator was used to better transfer weight to the bit.

The generated ARSLs of these two wells can be used for any further optimization for upcoming wells. The drilling simulator provides the possibility to do further optimization by applying different drilling operating parameters and drilling bit designs. Furthermore, it can be seen that the ROP match with the new simulated ROP in the same well applying another well's drilling parameters once the ARSLs are adjusted. The effect of using the combination of different bit runs and drilling parameters can also be explored through use of the simulator. For this purposes, the bits applied for drilling well B were used for the well A. The ARSL and drilling operating parameters were kept constant for the new simulated well A. Figure 3 shows the ROP comparison between well B and new simulated ROP for well A using the bits used for drilling well B. The New Simulated ROP of well A follows the ROP trend of drilled well B and acceptable match can be observed for the entire well.

The same results can be seen for drilling time of some of the bit run sections with having overlaid the ROP values. Comparison of bit wear trends are also shown in Figures 4 and 5 for the same bit run sections of new simulated well A with corresponding trends of well B. Since the ARSL and bit wear coefficient for both wells are similar, they match each other both in values and trends versus measuered depth with reasonable predictability.

Conclusion

- A commercially available drilling simulator was used to generate the ARSL values with available drilling data from offset wells.
- Drilling data obtained from the rig site via the online server needs to be quality controlled to eliminate the effect of erroneous readings and measurements.
- A smooth ARSL curve was obtained using treated drilling data for all sections of the wells.
- Encouraging matches between ARSL values were observed for the common formations between the wells.
- It is highly recommended to use ARSL values from multiple wells when optimizing wells to be drilled in the same area in order to make the calculations as accurate as possible.
- Using the drilling simulator makes it possible to investigate the feasibility of using a combination of bit types and drilling parameters in different drilling scenarios.
- Drilling optimization is very sensitive to the generated ARSL in terms of choosing different bit types, drilling parameters and bit pull depths.
- New simulated ROP values and drilling time were obtained for different bit run sections of one well utilizing the bits of the second well in the same area after their ARSLs were adjusted.
- Similar and fairly close trends were obtained for bit wear between corresponding bit run sections of two wells using the same bit wear coefficients.

References

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2) Hareland, G., Motahhari, H., Hayes, H., Qureshi, A.:" Increased Drilling Efficiency of Gas-Storage Wells Proven Using Drilling Simulator", paper No. 114798, presented at CIPC/SPE Gas Technology Symposium 2008 Joint Conference held in Calgary, Alberta, Canada, 16-19 Jun 2008.

3) Hareland, G., Nygaard, R.:" Drilling Simulation Versus Actual Performance in Western Canada", paper No.106570, Presented at SPE Rocky Mountain Oil and Gas Technology Symposium held in Denver, Colorado, USA, 16-18 April 2007.

4) G. Gjelstad, G. Hareland, K.N. Nikolaisen and R.K. Bratli; "The Method of Reducing Drilling Costs More than 50 Percent", SPE paper 47342, presented at SPE/ISRM Eurock held in Trondheim, Norway, 8-10 July, 1998.

Tables

Table 1: Bit information used for well A

No	Size(mm)	IADC	Jets (1/32”)	Depth out (m)	Distance Drilled (m)
1	349	115	3*22 20	399	399
2	349	115	3*20 18	443	44
3	222	NA	5*14	760	317
4	222	NA	5*15	1792	1032
5	222	537	3*16	2534	394
6	222	NA	4*12 4*14	2868	334
7	156	NA	3*16 3*12	2900	32
8	156	NA	3*18 3*12	3711	811

Table 2: Bit information used for well B

No	Size(mm)	IADC	Jets (1/32”)	Depth out (m)	Distance Drilled (m)
1	349	115	3*22	463	463
2	222	NA	7*11	1941	1478
3	222	NA	6*12	2220	279
4	222	537	3*18	2379	159
5	222	NA	4*12 4*15	2681	302
6	156	NA	3*18 3*12	3525	844

Table 3: Acceptable range for quality controlling of drilling parameters

No.	Drilling parameter	Acceptable Range
1	Rate of penetration, m/hr	1-150
2	Weight on the bit, 1000 kg	1-30
3	Rotary speed, rpm	<300
4	Flow rate, m^3/min	0.8 -2.7
5	Plastic viscosity, litre/sec	20<
6	Mud weight, kg/m^3	900<
7	Mud type	Oil based or Water based

Table 4: Pump specification for different hole sizes

No.	Hole section/Hole Size	Reveloution/m^3
1	Surface / 349 mm	44.88
2	Intermediate / 222mm	73.92
3	Main / 156mm	147.84

Figures

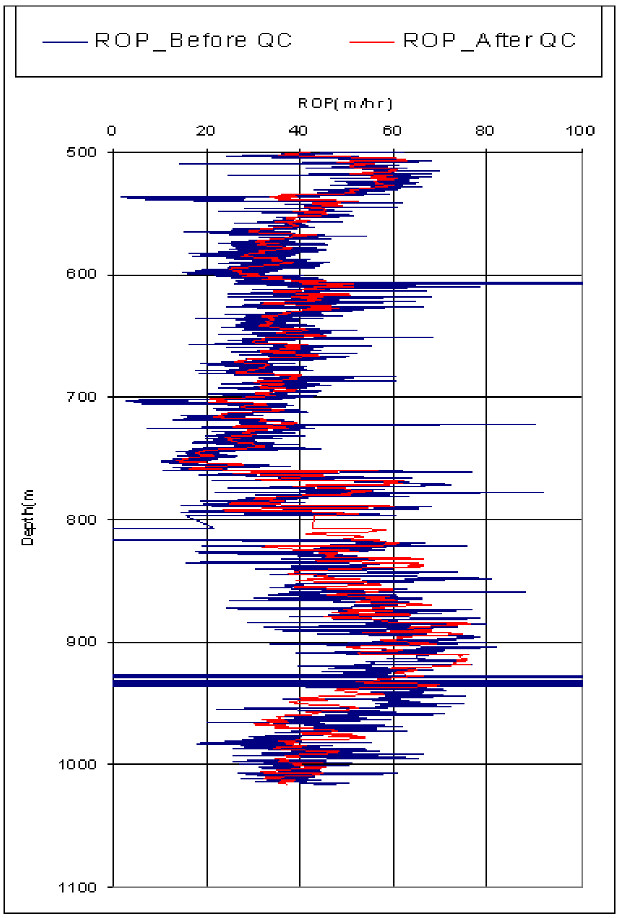

Figure1: Quality control on ROP data (Left: Before QC, Right: After QC)

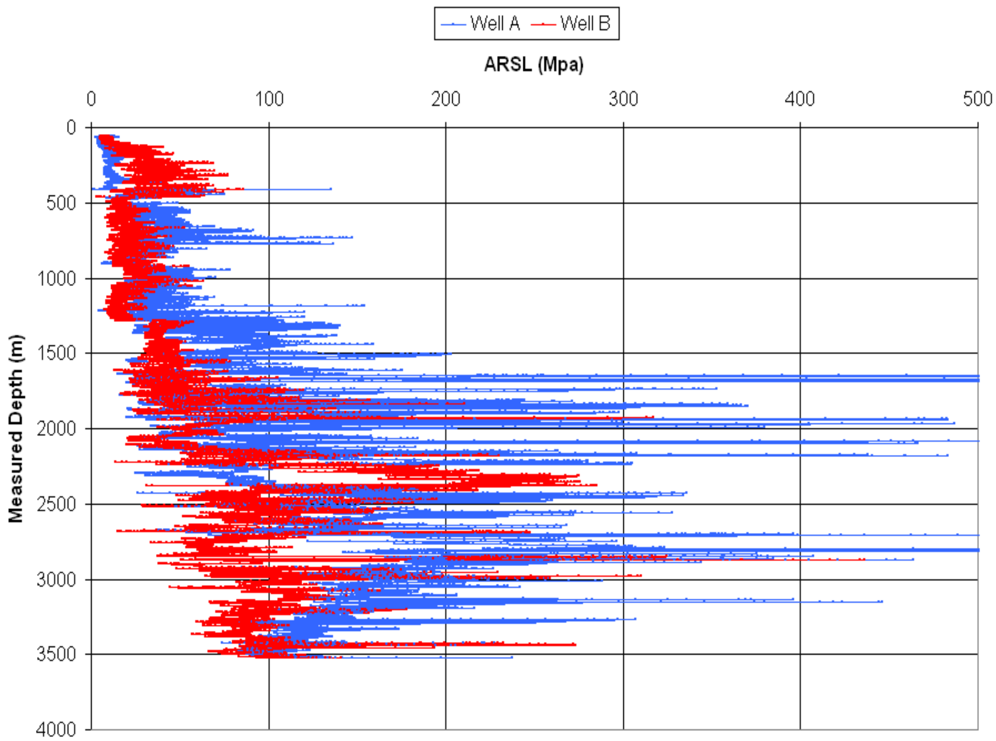

Figure 2: The comparison of generated ARSLs after formation tops match.

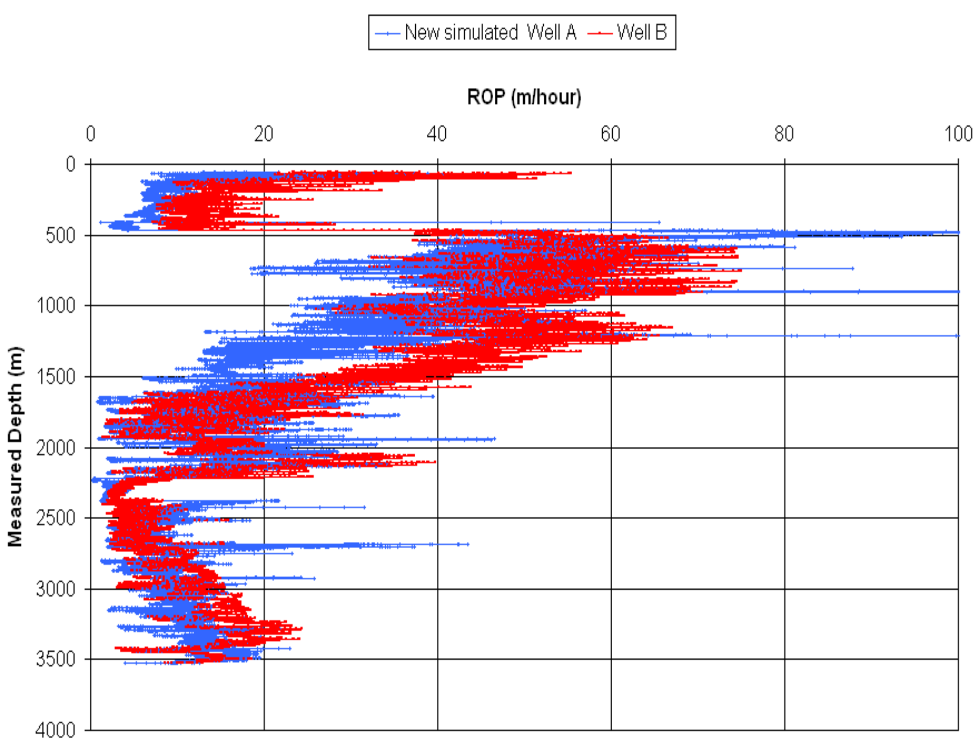

Figure 3: The comparison between new simulated ROP of well A and ROP of well B.

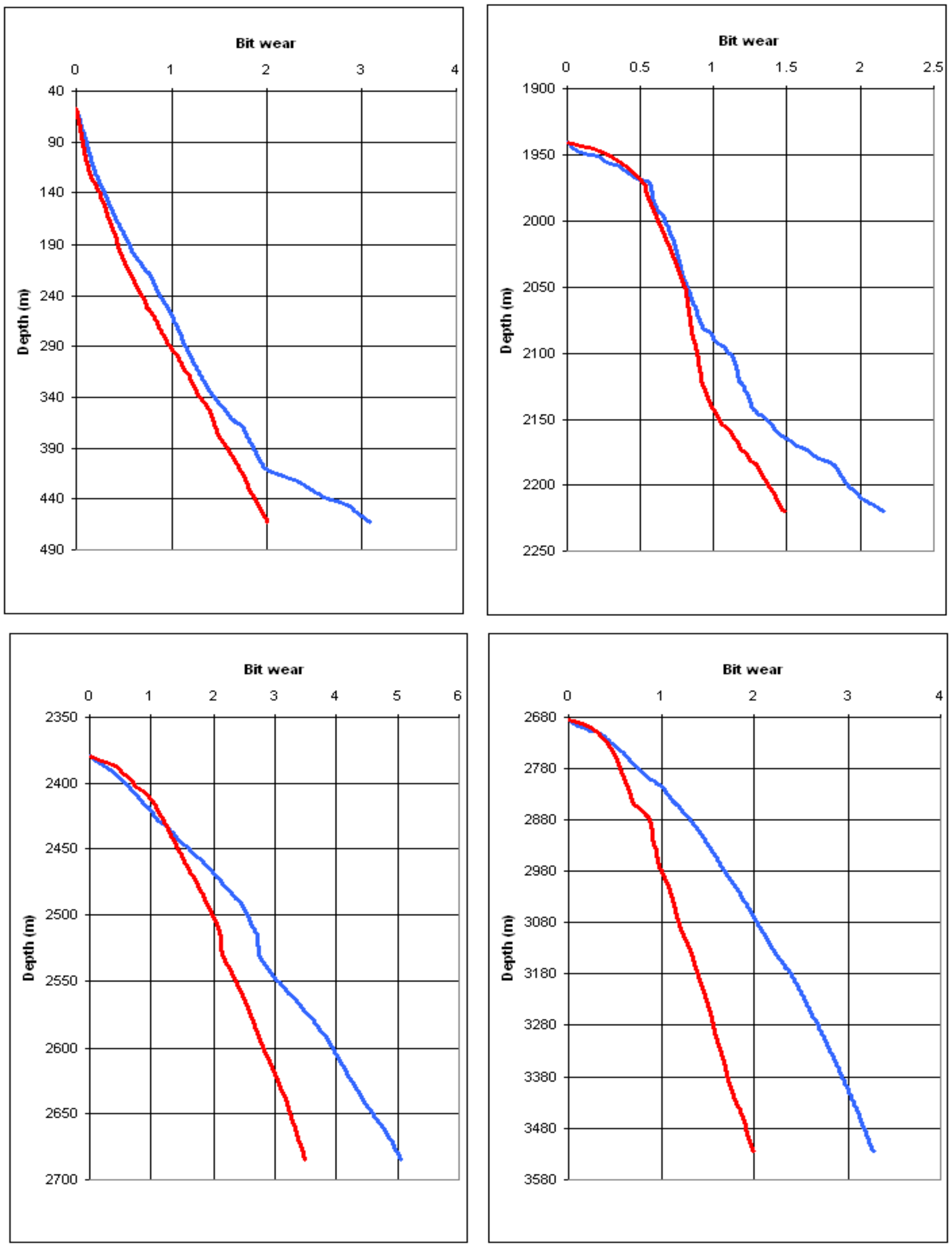

Figure 4: The comparison of bit wears between new simulated well A (blue) and well B (red).

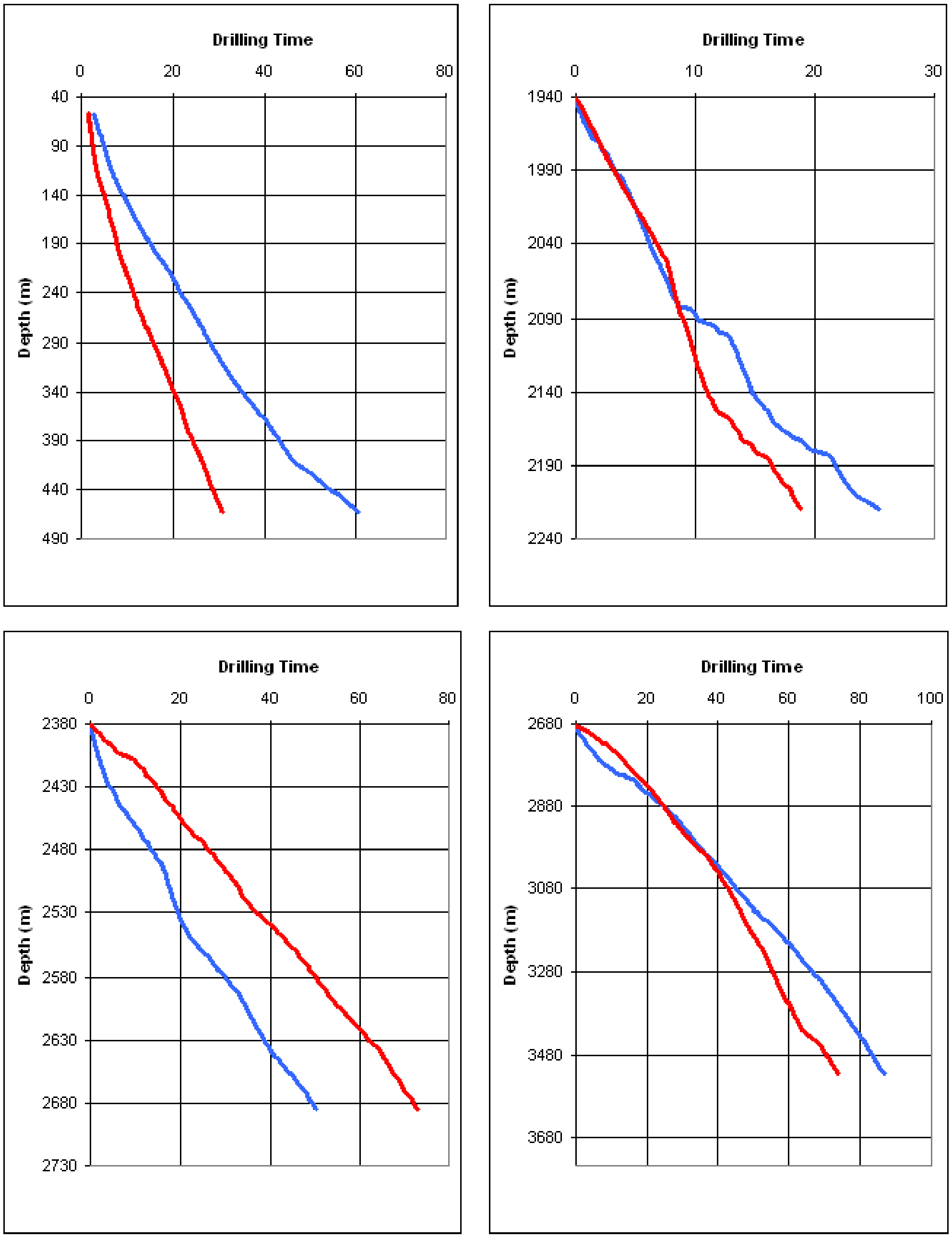

Figure 5: The comparison of drilling time of each bit between new simulated well A(blue) and well B (red).