

# Analysis of water and geothermal-well shallow drilling data via drilling software allows for rock drillability assessment and drill bit performance

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## ABSTRACT

Drilling maybe the most expensive part of an exploration campaign for production of minerals, geothermal fluids, water and hydrocarbons. Significant advances have been made on developing drilling bits and equipment as well as drilling techniques, with hydrocarbon exploitation industry leading the way but no such advances have been made on modeling rock-bit interaction. Some models have appeared for oil industry but with limited success, while no such models have been required for surface drilling, such as water or shallow geothermal well drilling, because drilling conditions are not so difficult. Water-well depths, however, have been increasing in recent years, and a closer look into drilling data is needed for choosing better drill bits and implementing optimum drilling conditions. An oil-well drilling simulator has thus been tested and used to simulate drilling data from two shallow water wells from USA and a geothermal well in Greece. The data is analyzed

with respect to the given lithology, drill bit and bit wear and drilling conditions (weight, torque, fluid flow). The results show that if we have access to drilling data from the region, such a tool could be very useful for planning new wells, for choosing the right drill bit and right drilling conditions, thus reducing costs in an exploration campaign.

## 1. INTRODUCTION

Drilling for oil, geothermal or water and mineral resources is the significant step to uncover subsurface resources, to determine their economic exploitation potential and to produce them. Drilling, however, can be very expensive. Hence, great effort has been devoted in the past to develop safe and optimum drilling practices to reduce the amount of time spent on drilling. At the same time, when planning for the next drilling campaign, it is very beneficial to have the ability to predict drilling rates, given the field conditions, so that a comprehensive

exploration and development plan is developed and implemented.

Several simulators have been developed in the past which allow prediction of drilling rates with one of them deserving particular attention as it has proved that it could simulate with fair degree of accuracy hydrocarbon well drilling. This is Payzone simulator, developed by Prof. Cooper of University of California at Berkley (Cooper et al., 1995, 1996) which has proven that it could perform well under given circumstances (Abouzeid and Cooper, 2003; Kelessidis and Dalamarinis, 2009). The particular simulator has a basic drill bit – rock interaction model and allows for a few adjustable parameters which enable fine tuning of the simulator with field data. Besides the capabilities, although not so advanced, which give a picture of the well drilled and present also the lithology and drill time log, the main feature is the prediction of drilling rate, using Eqn. (1),

$$ROP = (flow\_factor)(C)(RPM)(tooth\_length)(G) \quad (1)$$

where

$$G = 1 - \exp \left[ - \left( \frac{WOB}{UCS} \right)^{curv} * \left( \frac{12}{D^{2.5} (0.4 * tooth\_length)} \right) \right] \quad (2)$$

In the equations above, *RPM* is rotary speed, *tooth\_length* is the average length of the bit teeth, *UCS* is unconfined compressed stress of the rock, *D* is bit diameter, *WOB* is applied weight on bit; the following modifiable by the user constants are used: *C* is a constant; (*aggressivity*) is a formation and bit characteristic constant ranging between 20% and 100% and normally is given the value of 35%; (*curv*) is a formation – WOB interaction constant and it is usually given the value of 1.5; (*flow\_factor*) is a constant, ranging between 50% and 100% and defines the capability of the system to adequately clean the bit front by the cuttings. The above equation is similar in

predictions to the equation suggested by Teale (1965) where the specific energy was defined (Kelessidis and Dalamarinis, 2009).

Using the adjusted with field data Payzone simulator, a new campaign, in a similar field, or development drilling practice scenarios in the same field could be designed. The particular data needed is operational and formation data. The former include, weight on bit (WOB), rotation rate of the drill string (RPM), flow rate and fluid parameters, drill bit parameters like bit type, bit make, types of nozzles, and the bit record (depth in, depth out and wear condition at the end of bit cycle); the latter include, well geometry and formation parameters, like lithology and estimations of unconfined rock strength (UCS).

The particular simulator has not been tested, till today in drilling situations for geothermal wells and for the much shallower water-wells (Cooper, 2009). It is the intention of this paper to demonstrate the use of Payzone for geothermal drilling and water well drilling, to verify that it's capabilities are also well within the range of shallow drilling.

## 2. METHODOLOGY AND DATA REDUCTION

### 2.1 Geothermal Well

Data for the simulated geothermal well were taken from the drilling report of well Milos-1, which was drilled in the island of Milos, Greece in the period November 1980 to March 1981 (Chlaboutakis, 2009). Two sections were simulated. The first one was in the non-producing formation, between 500 m and 814 m and has been simulated with 6 intervals. The lithologies with their UCS values, taken from Hoek et al. (1998), are shown in Table 1. The second interval is in the producing zone, between 1040 m and 1180 m, has been simulated with one section, with the characteristics shown also in Table 1. The values of UCS are very important for successful simulation. They were modified according to the degree of metamorphism of these rocks, based on the descriptions from the well report.

Thus, formations containing quartz, alvite, titanite, chlorite and having high degree of metamorphism were assumed to be on the high end of the UCS range for the particular formation. For example, schist has a range of UCS values between 30 to 60 MPa; for the interval 555 to 600 m, the rock is described as chloritic, calcitic schist with chlorite, hence, it has been given the UCS value of 53 MPa.

Table 1: Lithology description and UCS values

Interval (m)	Formation	UCS (MPa)
500-525	Mica Schists with epidote, quartz, albite. Low metamorphic grade	30
525-540	Calcitic schist with chlorite, epidote, titanite, . No metamorphism	35
540-555	Chloritic, talk, calcitic schist with albite. No metamorphism	40
555-600	Chloritic, calcitic schist with albite, quartz, quartzite veins. Low metamorphism	53
600-814	Mica schist, chloroschist with chlorite, epidote, calcite, titanite, graphite. High metamorphic grade.	56
1040-1080	Mica Schist, chloroschist with chlorite, epidote, calcite, titanite, graphite,pyrite, amphibole.Total metamorphosis.	60

Bit wear was also simulated in the production section to determine its effect on the rate of penetration. This was accomplished using the parameters *rock abrasivity* and *wear factor* in the metamorphic rocks so that it is similar to the wear indicated in the well report. Finally, the third adjustable factor *ROP\_factor* of the bit has been further modified to match real drilling data.

## 2.2 Water well

Water well data usually do not have complete bit records nor do they have good monitoring logs, as the relatively deeper geothermal wells and of course hydrocarbon wells do. Some water well reports do not even state the bit types they have been using. An extensive bibliographic search has been

performed to gather data with minimal required information in order to run the simulator. We have used two water wells with reports from USA. Nevada-1 well (Bechtel, 2005), with simulation of 0 to 760 m, with 25 lithology intervals consisting of various tuffs and breccia, simulated with UCS values between 15 and 50.0 MPa and 67.0 MPa respectively; and Nevada-2 well (Mace, 2009), with simulation of the section between 329 and 378 m, consisting of one limestone interval with UCS value of 60 MPa. In both wells, foam was used as drilling fluid, as is the usual practice in many areas for water-well drilling. The simulator does not simulate foam drilling; hence, the flow factor has been adjusted to one, thus assuming full cleaning capabilities of the drilling fluid. The intention was to see whether we can simulate the drilling parameters in water well drilling and not the flow parameters.

## 3. RESULTS – GEOTHERMAL WELL

The results of simulating the 500-814 m interval section of the Milos-1 geothermas well are shown in Figures 1 and 2. There were three 12 ¼-in. milled tooth drill bits used in the three intervals simulated, with drilling parameter values as: WOB ranging between 3-6 tons, RPM between 50 and 65 RPM and flow rate between 1800 and 2800 lpm. When simulating all three intervals with the real data, simulation is very good, with almost one to one correspondence, indicating the good approach of the simulator. When all significant drilling parameters (WOB, RPM, flow) are increased by a factor of 50%, then a decrease in drilling times is observed of approximately 170% for each interval.

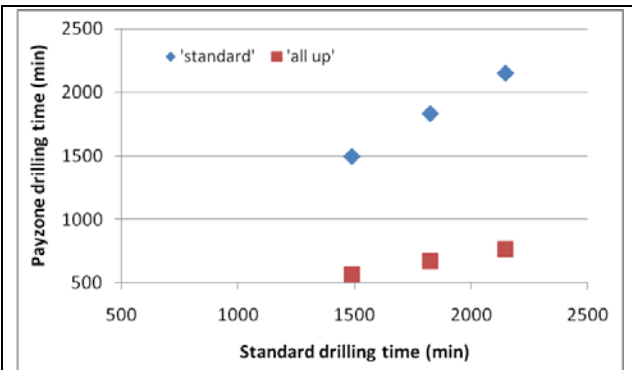


Figure 1. Simulation of interval 500-814 m, of real drilling conditions (standard) and of increasing all drilling parameters (RPM, WOB, FLOW) by 50% (all up).

Bit wear does not seem to be a factor when increasing drilling parameter values and in particular the WOB. We have attempted also an increase in the UCS value by 50%, which gave an increase in the drilling times, for all three intervals, around 50%.

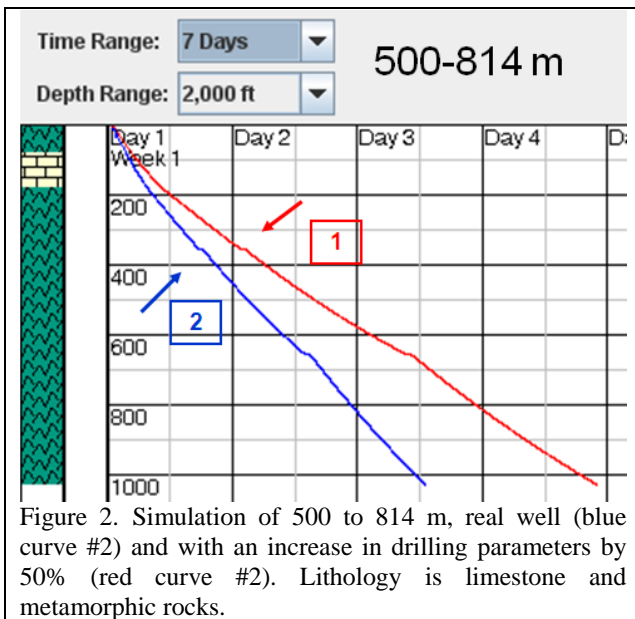


Figure 2. Simulation of 500 to 814 m, real well (blue curve #2) and with an increase in drilling parameters by 50% (red curve #2). Lithology is limestone and metamorphic rocks.

The results of simulation of drilling for the producing interval of 1040 to 1180 m is shown in Figures 3, 4 and 5. The six drill bits used were tricone milled tooth bits, 8 1/2-in. Drilling parameters were, 6 ton WOB, 40 to 60 RPM and 1600 to 2400 lpm flow rate. From Figure 3 we see that in the producing interval, real data has been well simulated. In fact there are six intervals, but in Figure 4, only 3 point are seen, because of the coincidence of values.

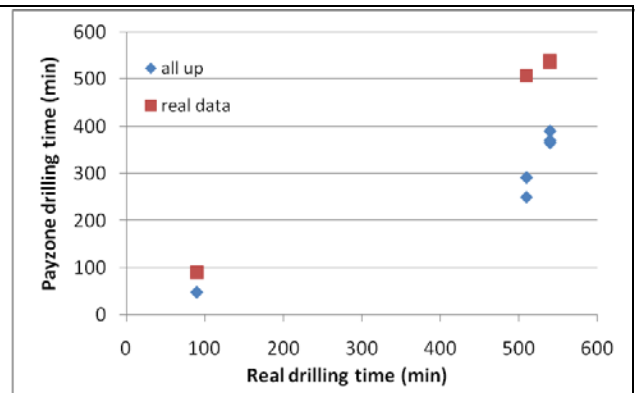


Figure 3. Simulation of interval 1040-1180 m, of real drilling conditions (real data) and of increasing drilling parameters (all up) as follows:  $RPM' = RPM + 20$ ,  $WOB' = 1.5 * WOB$ ,  $FLOW' = FLOW + 150 \text{ GPM}$

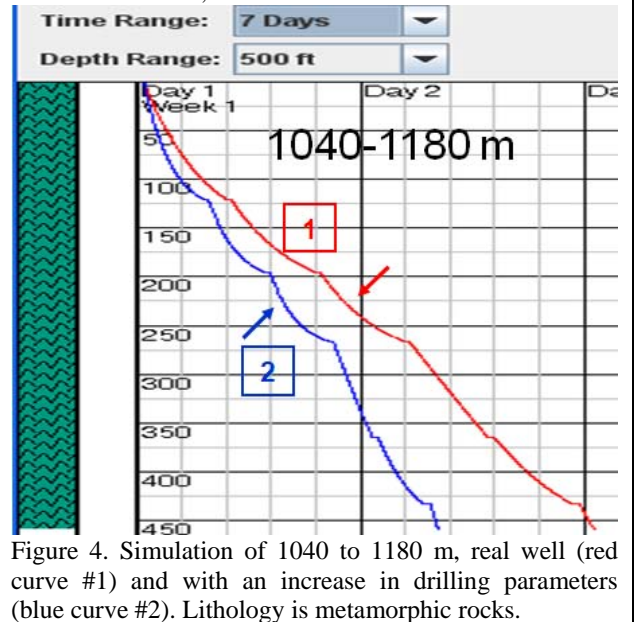


Figure 4. Simulation of 1040 to 1180 m, real well (red curve #1) and with an increase in drilling parameters (blue curve #2). Lithology is metamorphic rocks.

In Figure 4 we see that we used six drill bits. Curve #2 is the simulation when increasing all drilling parameters, as shown in the caption. When introducing the increase of the WOB by 50%, of RPM by 20 RPM and of flow by 520 lpm, there is a reduction in drilling time for each interval, which ranges between 28 and 52%.

Comparison of bit wear condition, listed in well report, versus the bit wear condition from Payzone has indicated that bit wear was also well simulated. It is also evident from Figure 4 that increasing all parameters to the values indicated, additional bit wear is occurring, seen as the curved section of curve #2, which of course is not desirable. Thus, not only good

simulation of rate of penetration is needed, but also good simulation of the bit wear is necessary in order to fully model the process. Thus in real life situation, the driller would proceed to increase drilling parameters to lower values than the ones chosen in the example of Figure 4, for the first three intervals, where significant curvature is observed. In the last three intervals the values used were good because the curve is almost parallel to the original (curve #1).

The results of Figure 5 indicate that if UCS values were merely 50% higher than the one anticipated or used, in all six intervals, trying to simulate the uncertainty of the knowledge of this value (Kelessidis, 2009), drilling times may increase significantly, ranging between 26 to 150%. Furthermore, wear is very significant. This was not a problem in the real situation, and thus, one should know with better accuracy the UCS value for the given formations.

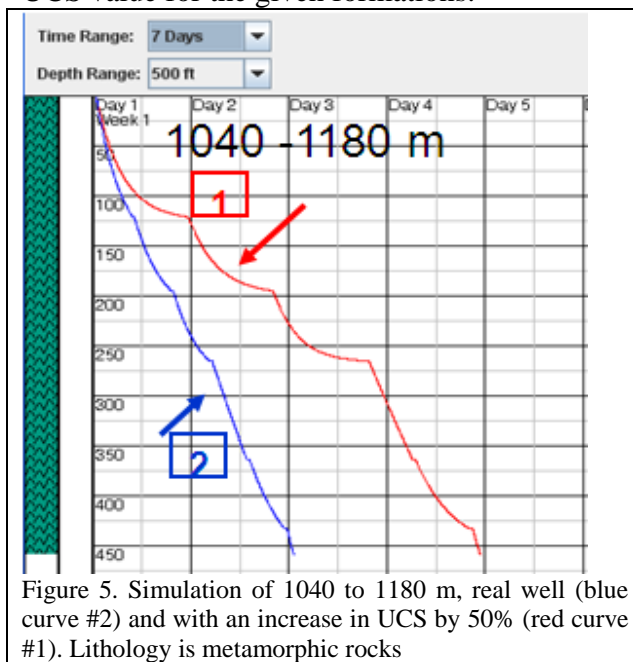


Figure 5. Simulation of 1040 to 1180 m, real well (blue curve #2) and with an increase in UCS by 50% (red curve #1). Lithology is metamorphic rocks

#### 4. RESULTS – WATER WELL

The drill time plot of the Nevada-1 well (Bechtel 2005) is shown in Figure 6. Four milled-tooth bits were used, two 17 1/2-in. in the first two sections up to 346 m and two 12 1/4-in. to the depth of 762 m.

In Figure 7, the comparison of real time with Payzone time versus depth is shown. The match is very good, of course using the adjustable parameters of the simulator. But this proves that, given the field data, the simulator can be tuned to reproduce them, and thus it can be used in the next design phase.

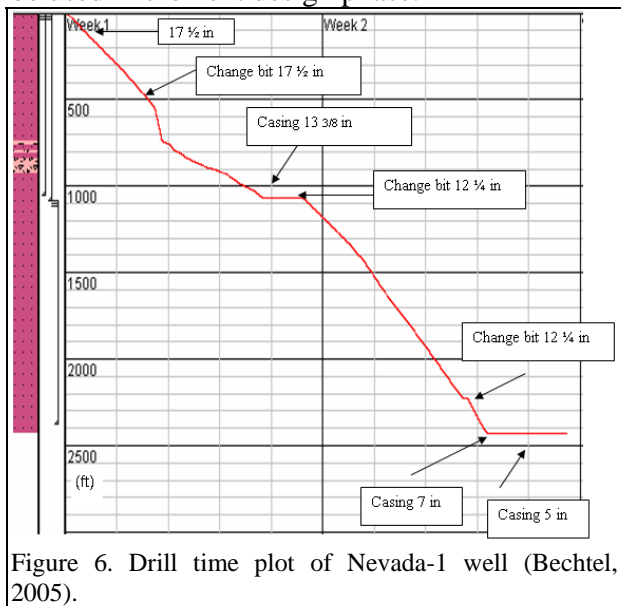


Figure 6. Drill time plot of Nevada-1 well (Bechtel, 2005).

This is true even for the shallower water wells, hence, one can determine the effects of altering drilling parameters thus optimizing drilling practices.

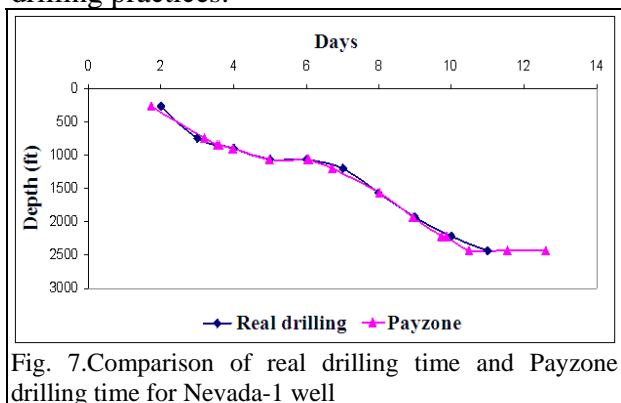
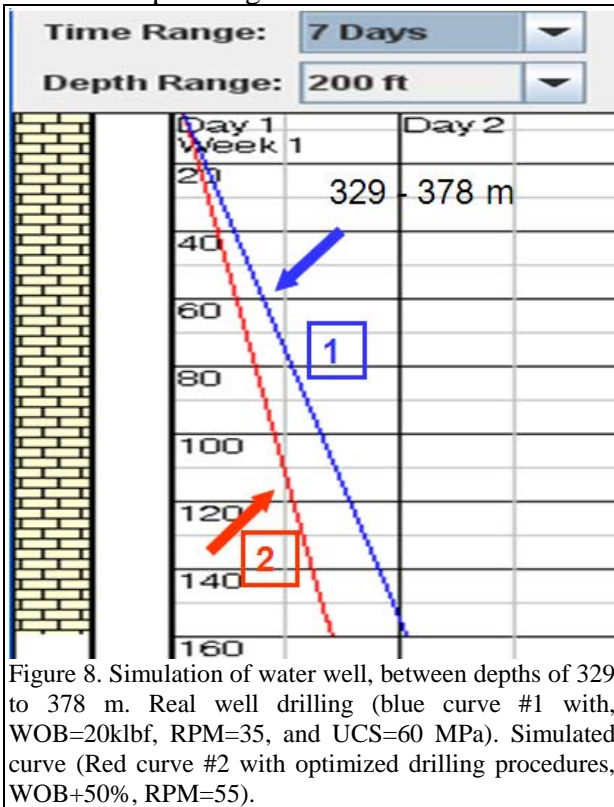


Fig. 7. Comparison of real drilling time and Payzone drilling time for Nevada-1 well

Such an attempt has been made with the second well, Nevada-2, with the results of real drilling data and Payzone simulated data with an increase in the parameters shown in Figure 8. One can see, as in the case of the geothermal well, shown above, but also for the case of hydrocarbon wells (Kelessidis and Dalamarinis, 2009), that increasing WOB and RPM has a

positive effect on the reduction of drilling times, thus proving that the simulator can be used for future well planning.



## 5. CONCLUSIONS

A hydrocarbon drilling simulator has been tried to test its capabilities for predicting drill times as well as bit wear for geothermal wells and much shallower water wells.

It was possible to fine tune the simulator for the geothermal well, using field data from Milos-1 well, drilled in 1980s. Tuning of the bit wear was also possible. Testing the effects of drilling parameters (WOB, RPM, flow rate) and of formation parameters (UCS) is possible with good degree of confidence thus providing an optimization tool.

Simulation of two much shallower water wells was also possible. Good matching of real data with simulator data has been achieved, without taking into account the effect of flow rate, because the wells have been drilled with foam. Optimization of drilling parameters is possible for water well drilling, as it has been

demonstrated with the simulation of Nevada-2 well.

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