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JIWA T.o.R: Estimation of Geothermal Top of Reservoir Uncertainties in the Exploration Drilling

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ABSTRACT

Understanding the uncertainties of geothermal T.o.R (Top of Reservoir) is crucial while designing drilling prognosis and managing drilling operation. In the exploration stage, the uncertainty of T.o.R is higher due to unavailable or minimal information from offset well. A probabilistic approach to estimate T.o.R uncertainties has been developed by incorporating geoscience and reservoir engineering best practices. The proposed technique is established in JIWA T.o.R, an analytic tool in JIWA System to allow a quick simulation and integration of M.T, thermal manifestations, and topography information of the well to be drilled. The embedded steam table and Monte Carlo simulator enables the results to be provided in a probabilistic manner, promoting better risk analysis in the exploration stage. It is intended that through the application of this technique, the exploration drilling risks (i.e., setting production casing depth) can be substantially minimized.

1. INTRODUCTION

Understanding the uncertainties of geothermal T.o.R (Top of Reservoir) is crucial while designing the drilling prognosis and managing drilling operation. One of the key decisions in drilling, setting the production casing depths, is largely dependent on the understanding of T.o.R. Production casing is required to set slightly (few tenths of meters) above the T.o.R. It should be not too shallow and not too deep to avoid poor cement job, permeability damage, low-temperature fluid infiltration, scaling, etc. In exploration well drilling, the risk associated with production casing depth is higher than development or make-up well drilling due to unavailable or minimal information from offset well. Before drilling the exploration well, subsurface scientists and engineers (geologist, geophysicist, geochemist, and reservoir engineer) usually rely on 3G survey data to estimate the T.o.R. However, uncertainties of the interpretation remained high until at least the T.o.R is determined directly from the PT survey of the first well.

In order to address this problem, AILIMA produces an analytic tool in JIWA System, namely JIWA T.o.R, which is aimed as a media for the subsurface scientists and engineers to collaboratively estimate the T.o.R elevation uncertainties of the well in the exploration drilling. Monte Carlo simulation has been embedded to enable the results provided in a probabilistic manner to better-promoting risks and opportunities analysis before drilling. Quick and easy reporting methods, with user-friendly and dynamic features also offered in JIWA T.o.R. A study case on how to estimate geothermal T.o.R elevation uncertainties of an exploration well is presented in this paper, as well as the comparison with the actual T.o.R after the well is drilled.

2. JIWA T.O.R

The methodology of JIWA T.o.R is shown in **Figure 1**, which will be elaborated in more detail as follows:

2.1 QA/QC, Processing, and Analysis of Data Input

QA/QC, processing, and analysis of JIWA T.o.R data input such as the ionic balance calculation, geothermometer interpretation, M.T inversion, constructing B.o.C map and cross-section, etc., is done separately by the user outside of this tool.

2.2 Input

The JIWA T.o.R input form is shown in **Figure 2**. The required input parameters are described as follows:

2.2.1 Case Name

Case name need to be specified by the user at the beginning of the simulation. The case name shall be unique to help the user identify and search the case they might be looking for in the future.

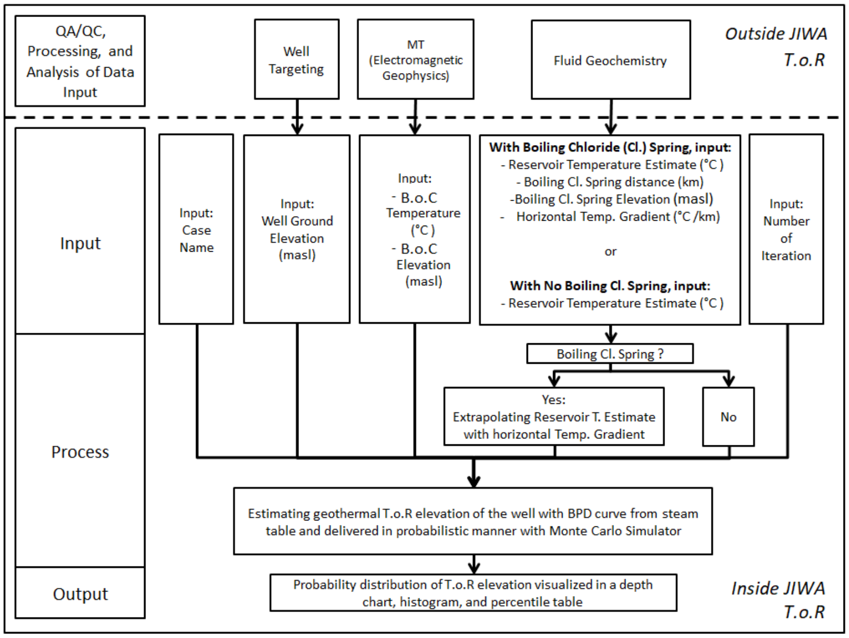


Figure 1: JIWA T.o.R Workflow.

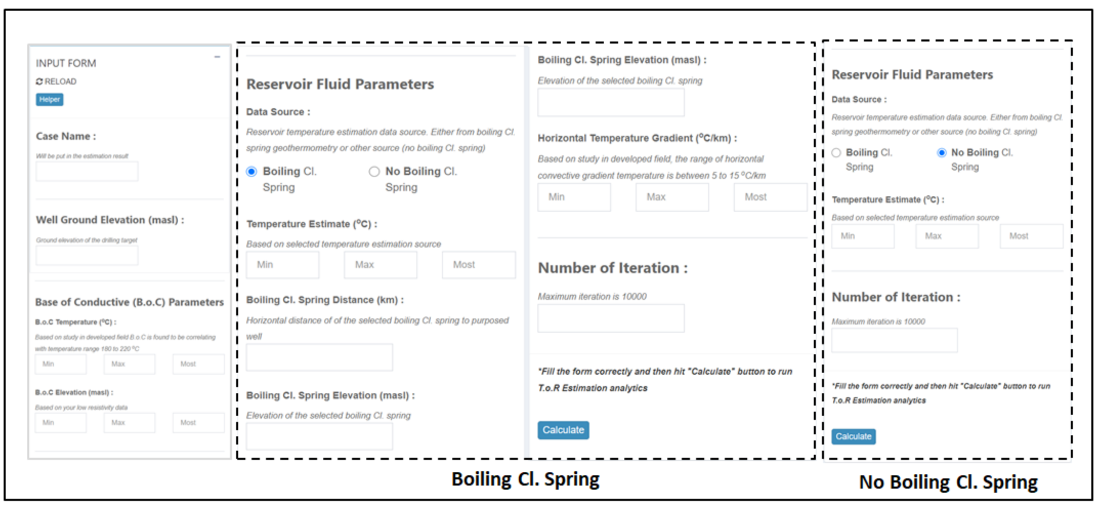


Figure 2: Form of Data Input in JIWA T.o.R.

2.2.2 Well Ground Elevation

Ground elevation of the well to be drilled is required to visualize the results. As shown in **Figure 5**, the rig is placed at the well ground elevation inserted by the user.

2.2.3 Base of Conductive (B.o.C) Parameters

There are two data inputs associated with B.o.C, including B.o.C Elevation (m asl) and B.o.C Temperature (°C). Base of conductive (B.o.C) is the base of low permeability zone, representing the base of cap rock, located over and adjacent to the geothermal reservoir. In volcano – hosted hydrothermal system models, cap rock is predominantly by smectite and interlayered illite-smectite, formed by the circulating hydrothermal fluids at depths. Smectite clay itself has a high cation exchange capacity (CEC), so that rock contained in them is likely to have a low electrical resistivity, usually less than 10Ω.m (Ussher et al., 2000). Based on a study from developed fields of andesitic volcanic arc - geothermal system by Dyaksa et al. (2016), B.o.C is found to be correlating with the temperature of 180-220°C. A similar range of temperature is also stated by Anderson et al. (2000) and Gunderson et al. (2000). Thus, these principles are practically used to map the geophysical resistivity value, usually with the magnetotellurics (M.T) method, in order to delineate the potential geothermal resources in the exploration phase, including the interpretation of B.o.C to predict the T.o.R before exploration drilling.

However, according to Cumming (2016), various cap rock and/or even clay-bearing sediment can exist in a geothermal environment. These conditions are complicating the resistivity interpretation to determine the B.o.C elevation, including its correlation with particular isotherm. For example, the reservoir top in Ngatamariki field is overlain by interlayered clay with higher resistivity value, instead of the 1 to 7 Ω.m with 150ºC base of conductive temperature (Boseley et al., 2010). A similar case also happens in Muara Laboh and Rantau Dedap, where the moderate to high resistivity mixed-layer clay zone is located below the more conductive smectite clay (Dyaksa et al., 2016). Another scenario that we could encounter is the relict of a high-temperature zone with low permeability and temperature adjacent to the interpreted cap rock.

In order to address the uncertainties as mentioned above, the B.o.C elevation and temperature, along with other data input (section 2.2.4), are honored in this probabilistic evaluation. Therefore, data input in JIWA T.o.R is in the form of statistical distribution, i.e., rectangular (min and max) or triangular (min, max, and most likely) (see subsection 2.2.3). As an option, fix or non – probabilistic input is also available by fill the data in the “min” input box (**Figure 2**).

2.2.4 Reservoir Fluid Parameters

There are two options to input the reservoir temperature estimate (°C), i.e. from boiling chloride (Cl.) spring that provide the most reliable result (Nicholson, 1993), or no – boiling Cl. spring. Several additional inputs are needed for boiling Cl. Spring, i.e., boiling Cl. spring distance from the well (km), boiling Cl. spring elevation (masl), and horizontal temperature gradient (°C/km). As well as the B.o.C, the reservoir temperatures estimate uncertainty is also honored with a probabilistic approach.

2.2.5 Number of Iteration

Number of iteration is the number that the simulation will be repeated. According to Driels and Shin (2004), for 1% error and 95% confidence level in Monte Carlo Simulation, the number iteration required is 7,120. Meanwhile, JIWA T.o.R provided a maximum of 10,000 iterations.

2.3 Process

There are two essential principles of the processing work in this tool, i.e., the BPD curve and Monte Carlo Simulation. Additional extrapolation will be done for the reservoir temperature estimate from boiling Cl. spring. Explanation of each aspect as follows:

2.3.1 Horizontal Temperature Gradient

The horizontal temperature gradient is considered for liquid geothermometers that is quickly equilibrated, such as silica geothermometers, as quartz that mostly controlled dissolved silica in the ascending fluid is deposited very quickly in response to the temperature changes when the temperature at depths are greater than 225°C (Fournier, 1973). The temperature estimate data is spatially extrapolated to the well location by the gradient input before the T.o.R elevation is estimated with the BPD curve. Based on the author’s experience in developed fields, a range of horizontal temperature gradients between 5 – 15ºC/km can be assumed.

2.3.2 Boiling-point-to-depth (BPD)

Boiling-point-to-depth (BPD) curve based on the steam table is used to extrapolate T.o.R elevation from BOC elevation in respect to the temperature, illustrated in **Figure 3**. According to Grant and Bixley (2011), the BPD model can give a good estimation of the reservoir initial state condition.

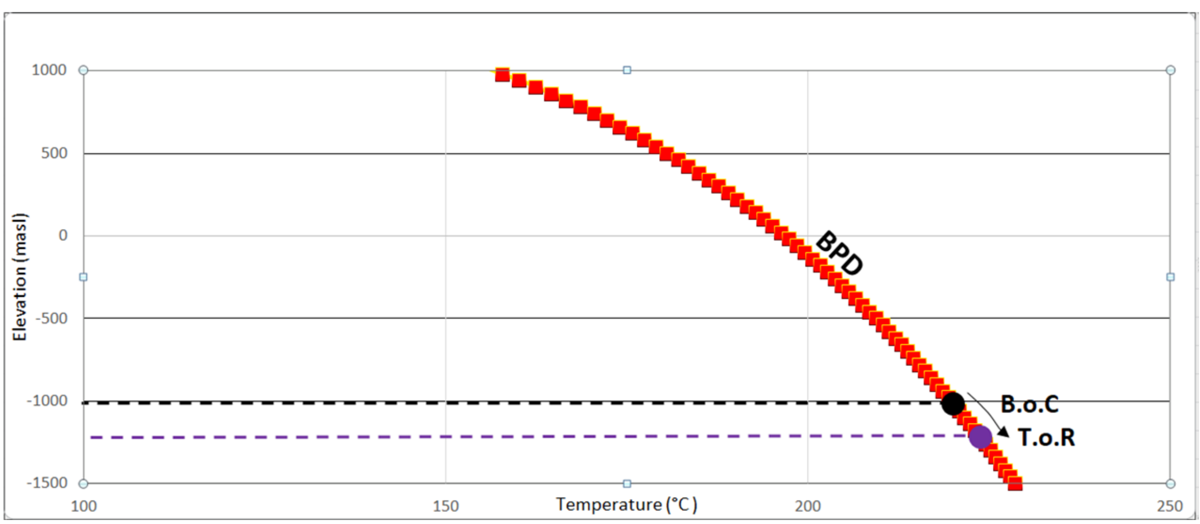


Figure 3: BPD Principles to Predict the Geothermal T.o.R elevation.

2.3.3 Monte Carlo Simulation

Monte Carlo Simulation is a simulation that relies on repeated random sampling on probability distributions and statistical analysis (Raychaudhuri, 2008). This method is beneficial to the experiments for which the specific results are not known in advance. There are so many probability distributions, such as rectangular, triangular, normal, lognormal, etc. Rectangular and triangular distributions are provided in JIWA T.o.R.

2.4 Output

The probability distribution of T.o.R elevation is provided in JIWA T.o.R visualized in a chart, histogram, and percentile table, with the terminology of P1 (1st percentile), P10 (10th percentile), P20 (20th percentile), and until P99 (99th percentile) based on the input value. The lower percentile indicates the more conservative estimation that could potentially leave too many opportunities, while the higher percentile could give over-estimates. User-friendly features to support prompt reporting are also available for the user.

3. CASE STUDY

This section shows the application of JIWA T.o.R prior to the exploration drilling based on a real exploration case in Muara Laboh Field, South Solok Selatan, West Sumatra. The data input and actual T.o.R information is obtained from Stimac et al. (2019) and Wisnandary and Alamsyah (2012).

Muara Laboh field is a liquid-dominated, fractured controlled – geothermal reservoir that lies within a right stepover of the GSF in an area of Quaternary volcanism. Based on 1D of 3D inversions of a magnetotelluric survey, the low resistivity anomaly (≤10 Ω.m) is interpreted to be correlating with the base of hydrothermal smectite clay. The results of geochemistry survey and analysis of Muara Laboh thermal features interpreted the springs located at the south and, in particular, the Sapan Malulong (SM), as the main outflow of the system. The quartz, Na-K-Ca, and Na-K-Ca-Mg geothermometers of the boiling chloride spring SM show 192 and 202°C temperature, respectively. Exploration drilling is conducted with six deviated wells, i.e., A1, B1, C1, E1, H1, H2. In this paper, well A1 is used as a demonstration on how to estimate T.o.R elevation prior to drilling. Data input to estimate the T.o.R is shown in **Figure 4**.

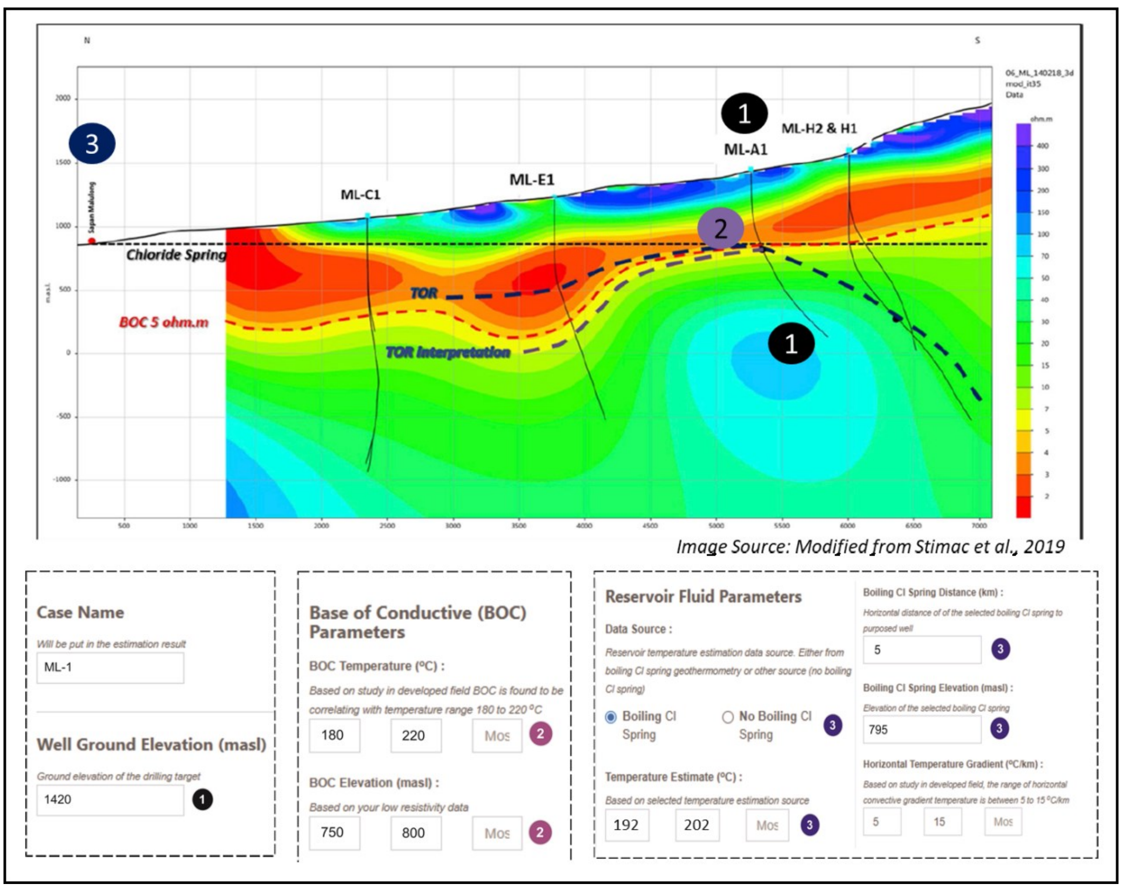


Figure 4: ML-A1 of Muara Laboh Data Input in JIWA T.o.R compared with the M.T Profile and SM Chloride Spring.

The estimation result of well A1 T.o.R uncertainties with JIWA T.o.R is about ± 100 m, in a range of ± 695 to 795 masl (**Figure 5 – 7**). Compared with the actual T.o.R, it correlated with the 50th percentile (**Figure 8)**. Until recently, the well A1 is used as one of the production wells in the Muara Laboh 80 MWe of dual flash capacity.

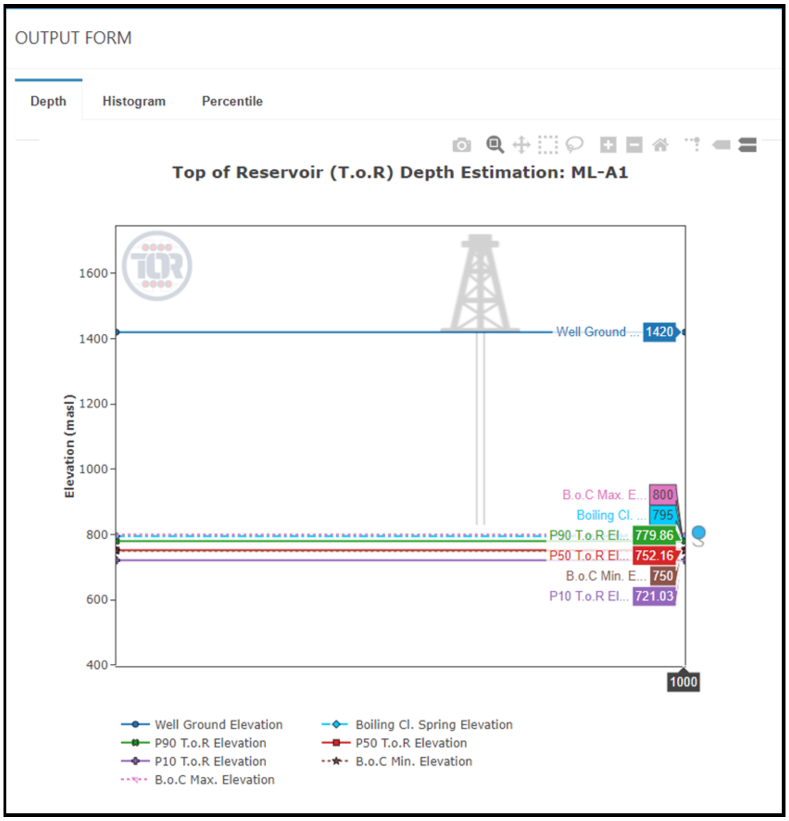


Figure 5: Elevation chart of ML-A1 T.o.R Uncertainties compared to the B.o.C elevation, Boiling Cl. Spring elevation, and the ML-A1 ground elevation.

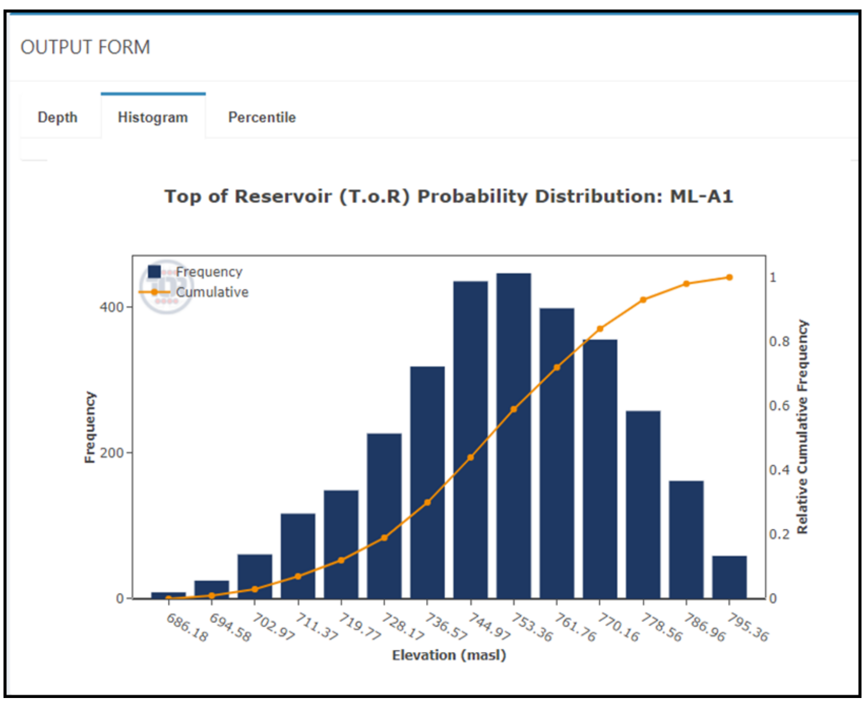
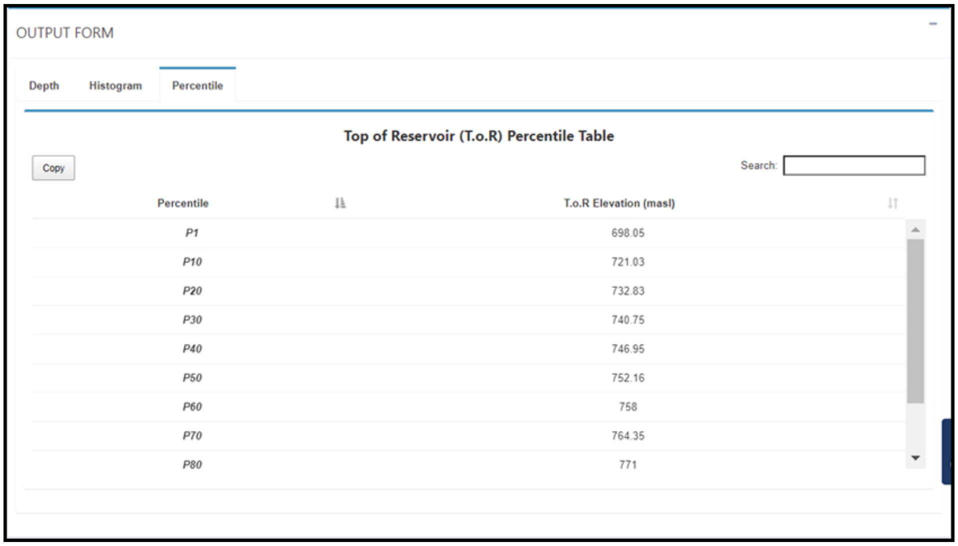


Figure 6: Histogram of ML-A1 T.o.R Probability Distribution.



OUTPUT FORM

Depth | Histogram | Percentile

Top of Reservoir (T.o.R) Percentile Table

Copy

Search:

Percentile	T.o.R Elevation (masl)
P1	698.05
P10	721.03
P20	732.83
P30	740.75
P40	746.95
P50	752.16
P60	758
P70	764.35
P80	771

Figure 7: ML-A1 T.o.R Percentile Table.

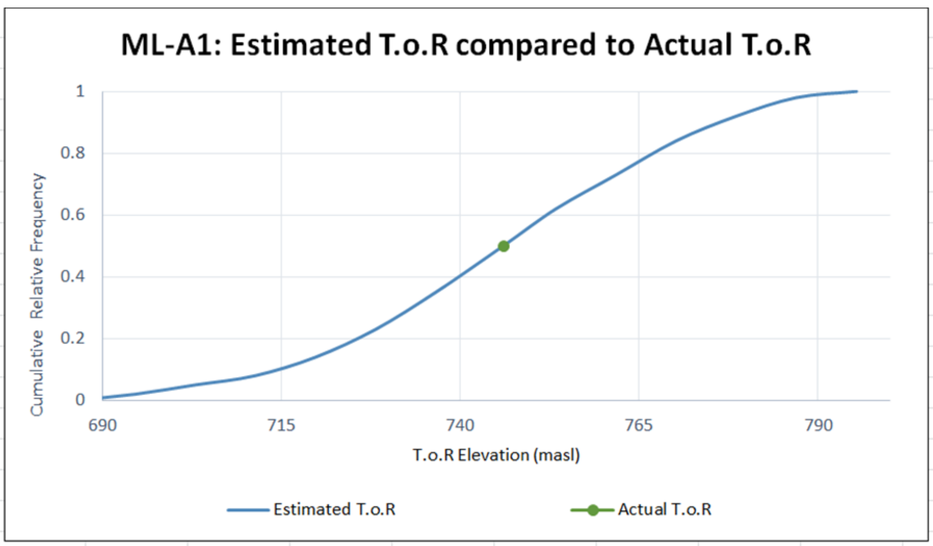


Figure 8: Estimated T.o.R compared with the actual T.o.R of ML-A1

4. CONCLUSION

JIWA T.o.R has been developed by AILIMA to promote collaborative work between subsurface scientists and engineers to perform geothermal T.o.R elevation assessment prior to drilling. As the T.o.R elevation in the exploration phase can be highly uncertain, the probabilistic approach offered through JIWA T.o.R simulation promoting better risk analysis.

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