MIT EARTH RESOURCES LABORATORY
ANNUAL FOUNDING MEMBERS MEETING 2020

Earth Resources Laboratory

Data Driven Drilling and Rate of Penetration Optimization

Ammar Alali
PHD CANDIDATE, EAPS

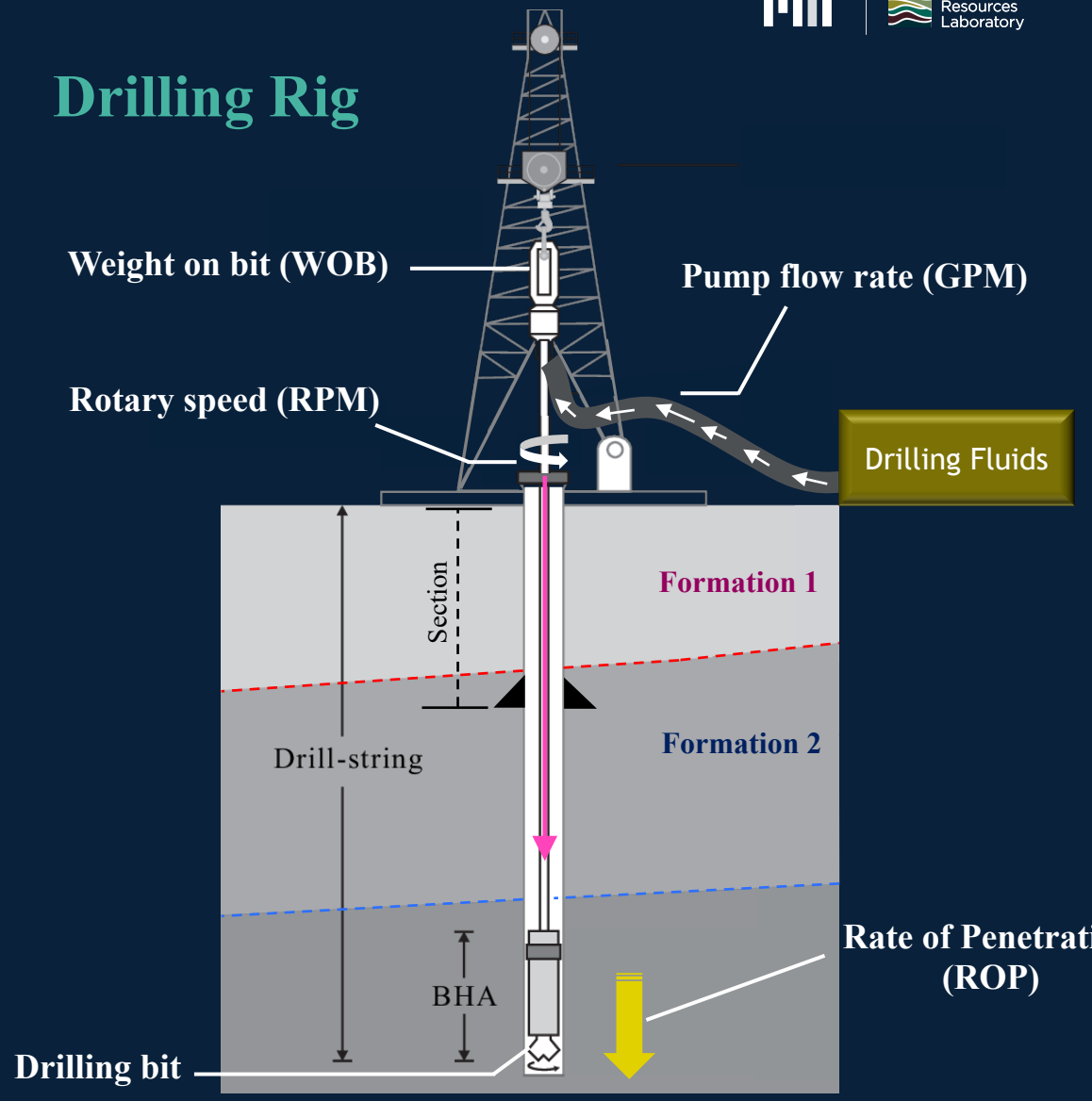
Earth Resources Laboratory

Background

Drilling

Rate of Penetration (ROP)

- Weight on bit (WOB)
- Rotary Speed (RPM)
- Pump flow rate (GPM)



ROP Optimization

The Rate of Penetration (ROP):

$$ROP = f(\omega_1 WOB, \omega_2 RPM, \omega_3 GPM).$$

ω_i : a weight given for each drilling parameter.

The optimum ROP is defined as the fastest ROP for a particular well, drilling through a particular formation, while minimizing drilling Non-Productive Time (NPT).

Motivation

No single system satisfactory predicts/optimize ROP globally

- Physics Approaches [*Bingham*, *Maurer*, *Teale*]:
  - Does not incorporate static and dynamic parameters.
  - Requires data we do not have, such as rock Uniaxial Compressive Strength (UCS).

- Data Based Approaches [*Moran*, *Alkatatny*, *Ahmed*] :
  - Previous work is done for one specific field/formation.

Objective

Need for a robust ROP optimization in real-time to recommend the controllable dynamic drilling parameters (WOB, RPM, GPM).

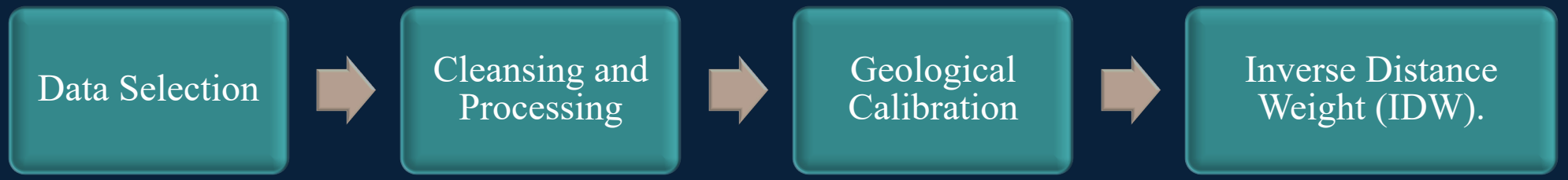
Earth Resources Laboratory

The Proposed Approach

The Proposed Approach

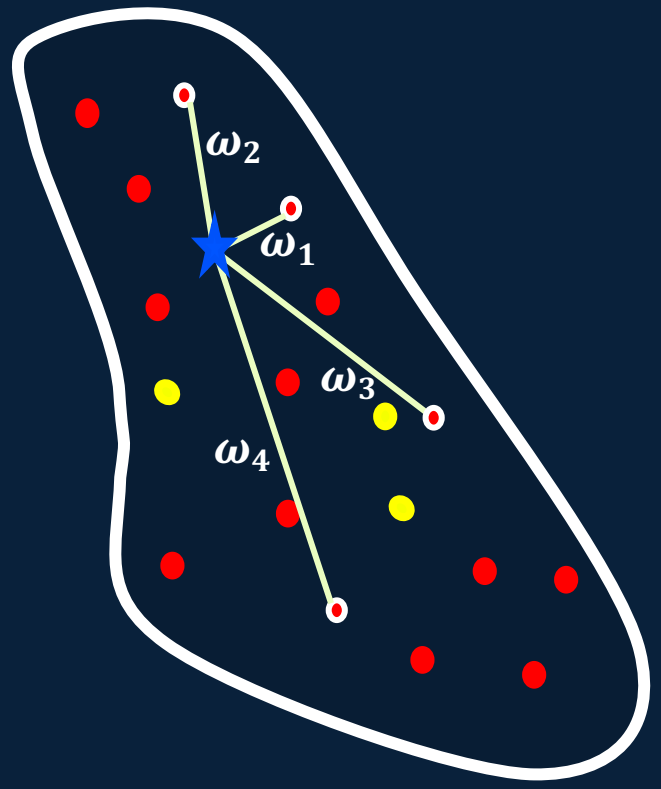
An integrated Two-phase data-driven rate of penetration optimization system.

Phase One [Historical]: Geologically Driven and Historical Data Based



Phase Two [Real Time]: Automatic Drill-Off Test

The Proposed Approach



At 4,000 ft

Well 1:
WOB = 50 klb.
$\omega_1 = 1.6$

Well 2:
WOB = 52 klb.
$\omega_2 = 1.2$

Well 3:
WOB = 48 klb.
$\omega_3 = 0.8$

Well 4:
WOB = 45 klb.
$\omega_4 = 0.4$

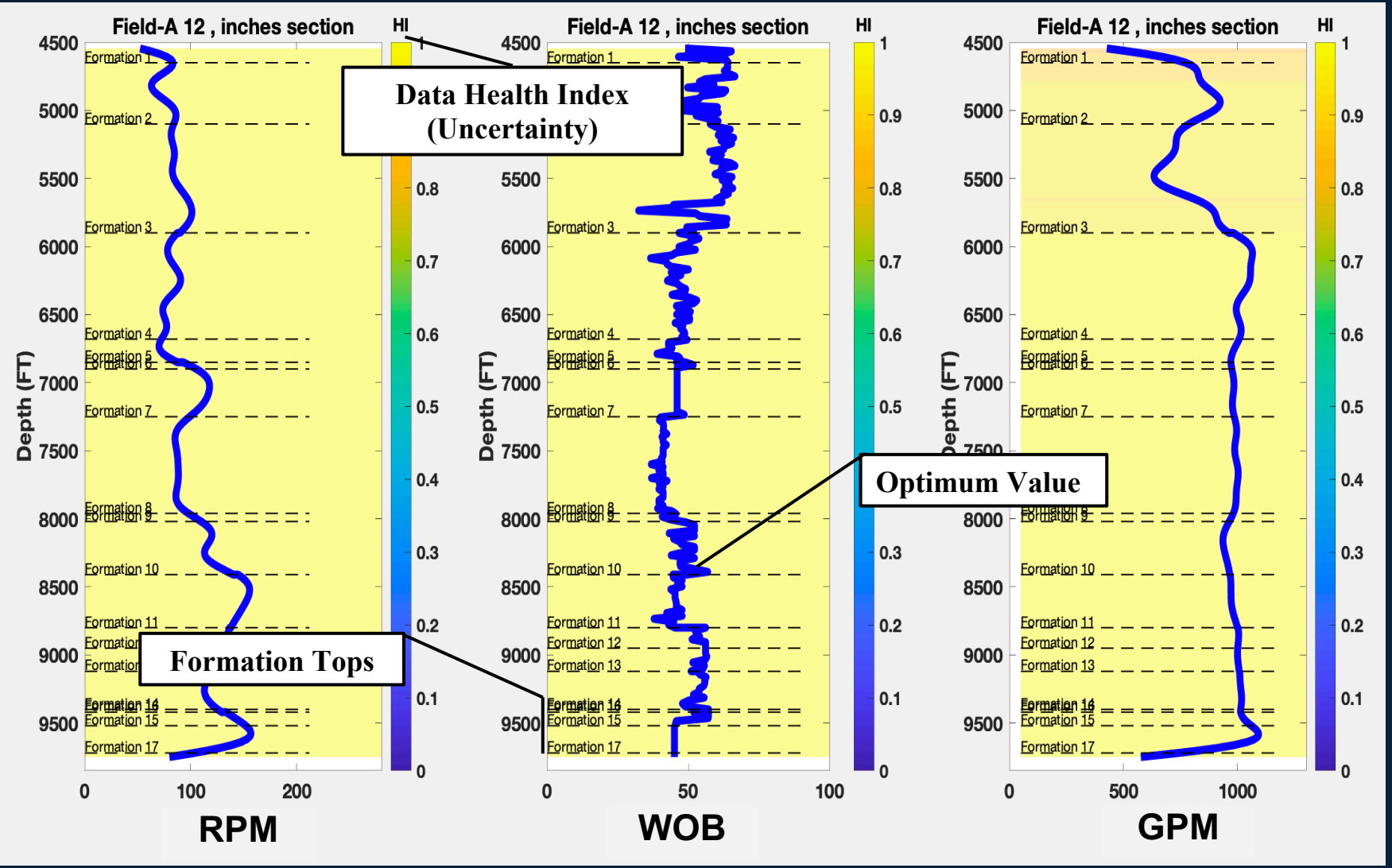
Output
WOB = 49.7 klb.

- Well with a drilling problem.
- Wells contributing to the model in this section, no NPT.
- Wells contributing to this depth step.
- w_i A weight for this well.

Earth Resources Laboratory

Validation

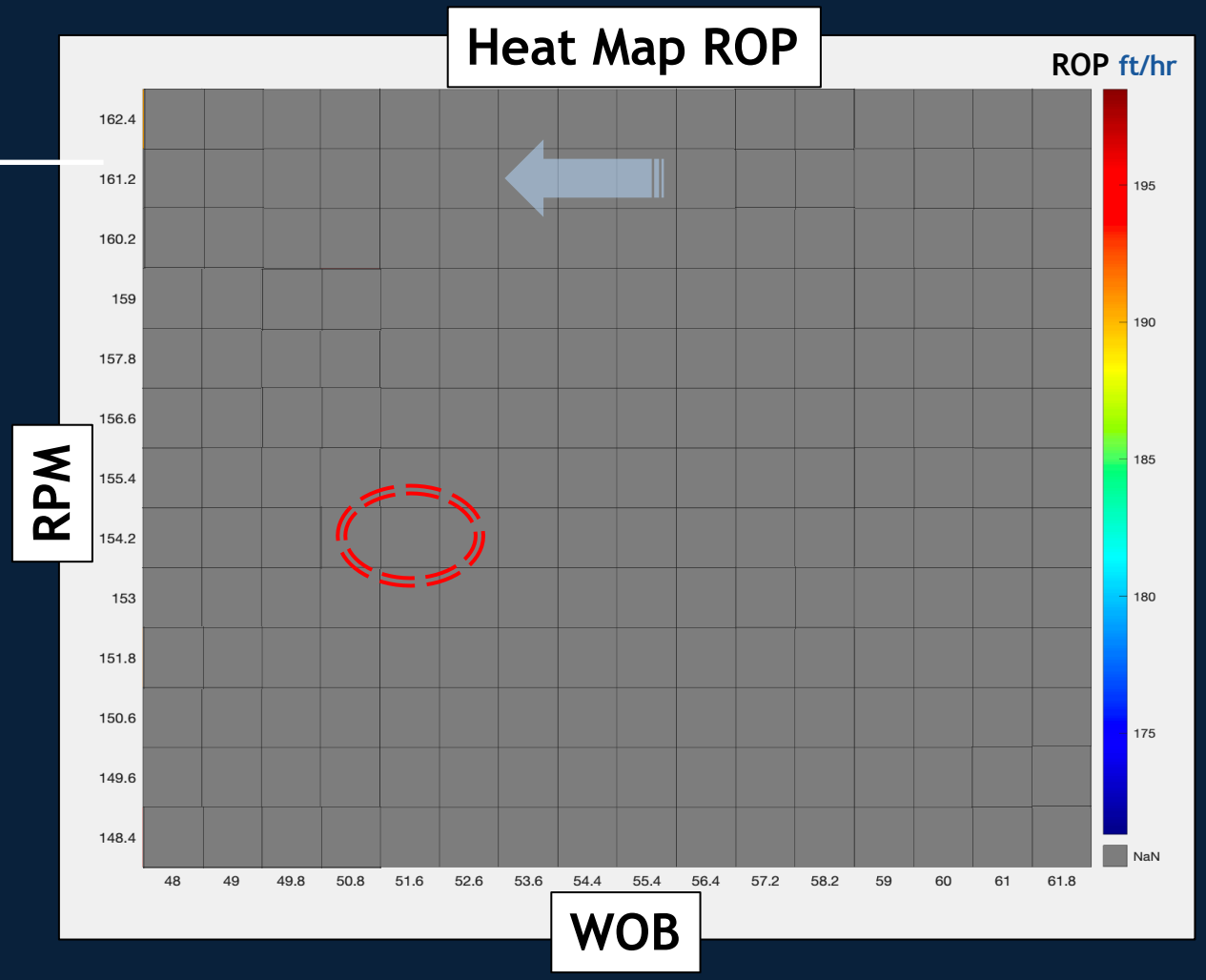
Phase One Model



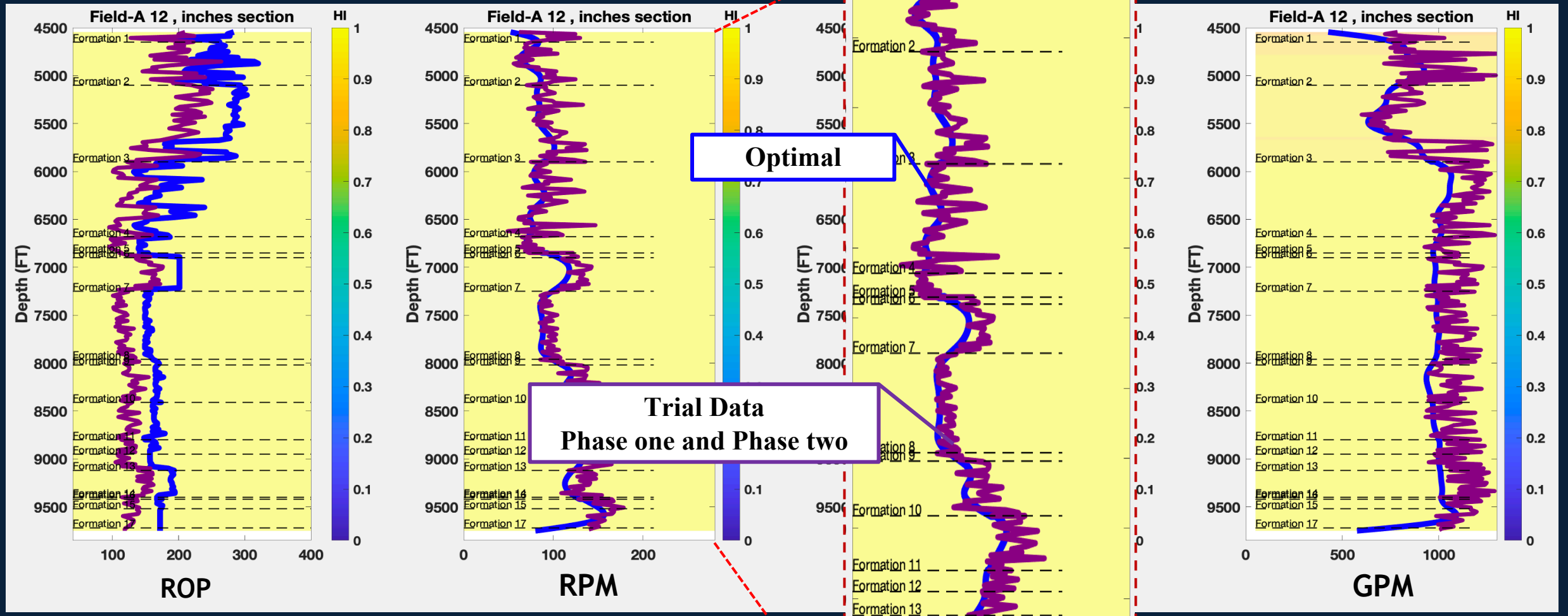
Phase Two Update

Jump/adjustment of phase one recommendation as we entered a new geological formation.

A visual of the automated drill-off test window, that illustrate the different pairs of WOB and RPM with the resulted ROP



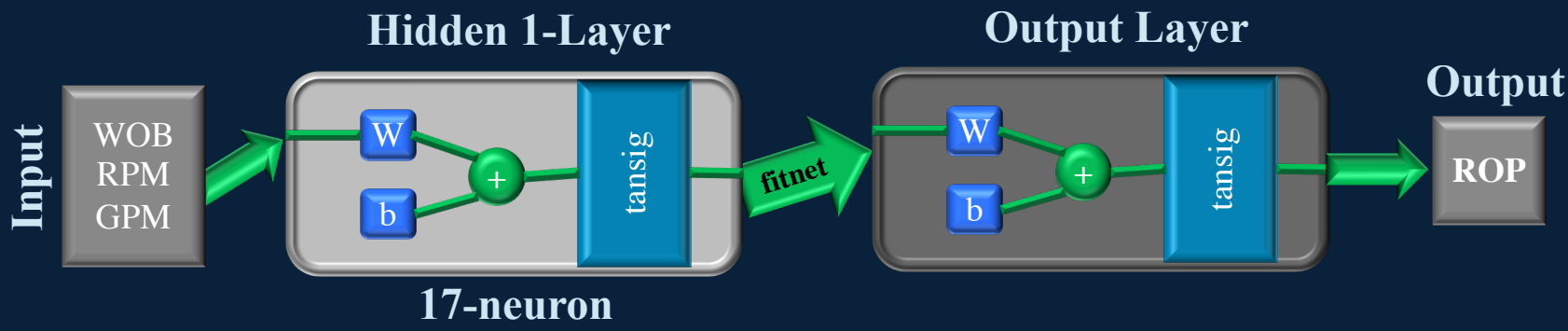
Results


Field-A 12 , inches section
Depth (FT)
ROP
RPM
GPM
HI
Optimal
Trial Data
Phase one and Phase two
Formation 1
Formation 2
Formation 3
Formation 4
Formation 5
Formation 6
Formation 7
Formation 8
Formation 9
Formation 10
Formation 11
Formation 12
Formation 13
Formation 14
Formation 15
Formation 16
Formation 17

Model Generated

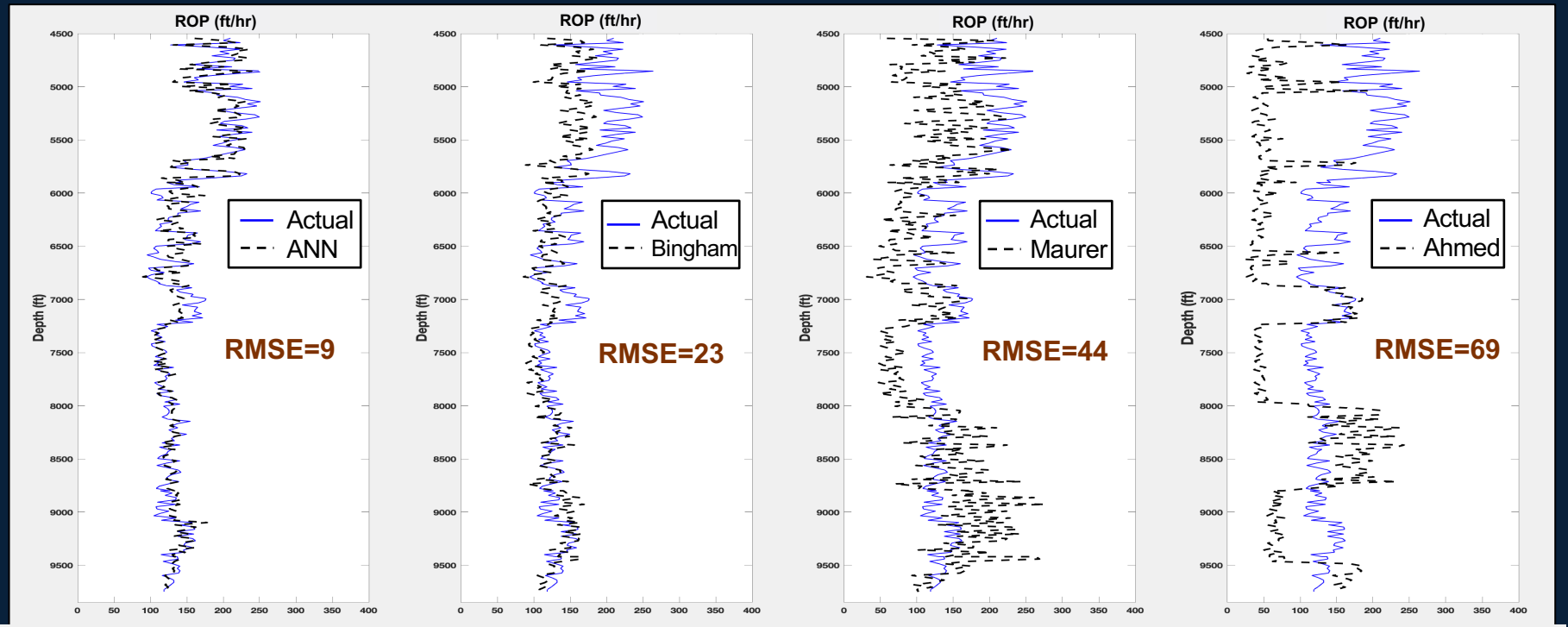
A new relationship was derived from the ANN model using the biases and weights of neurons-connections among the input, hidden and output layers. The new ROP correlation is shown in the following Equation:

$$ROP_n = \left[\sum_{i=1}^{N} W_{2i}\left(2/\left(1+e^{-2\left(W_{1i,1}WOB+W_{1i,2}RPM+W_{1i,3}GPM+b_{1i}\right)}\right)-1\right)\right] + b_2$$

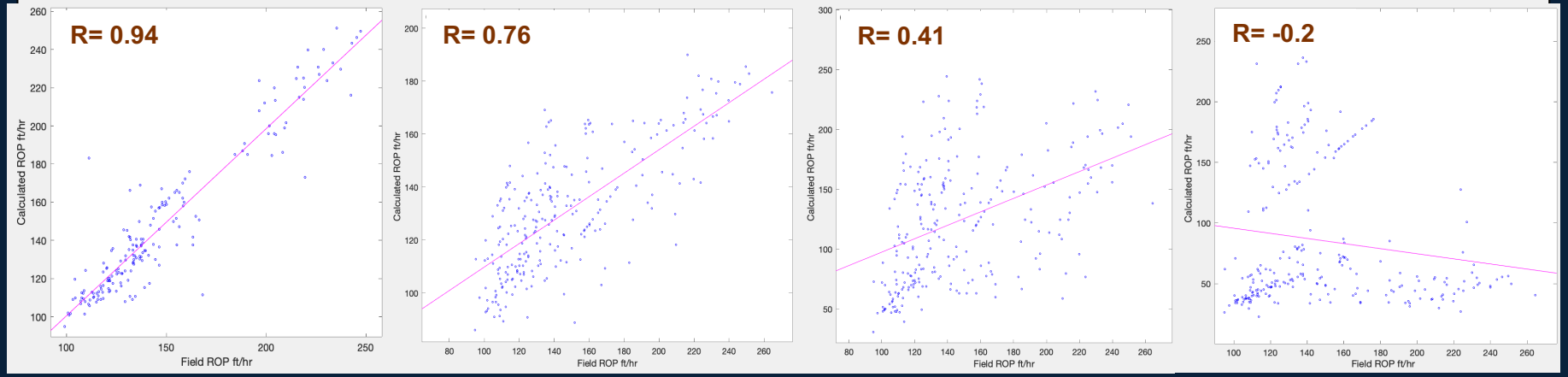


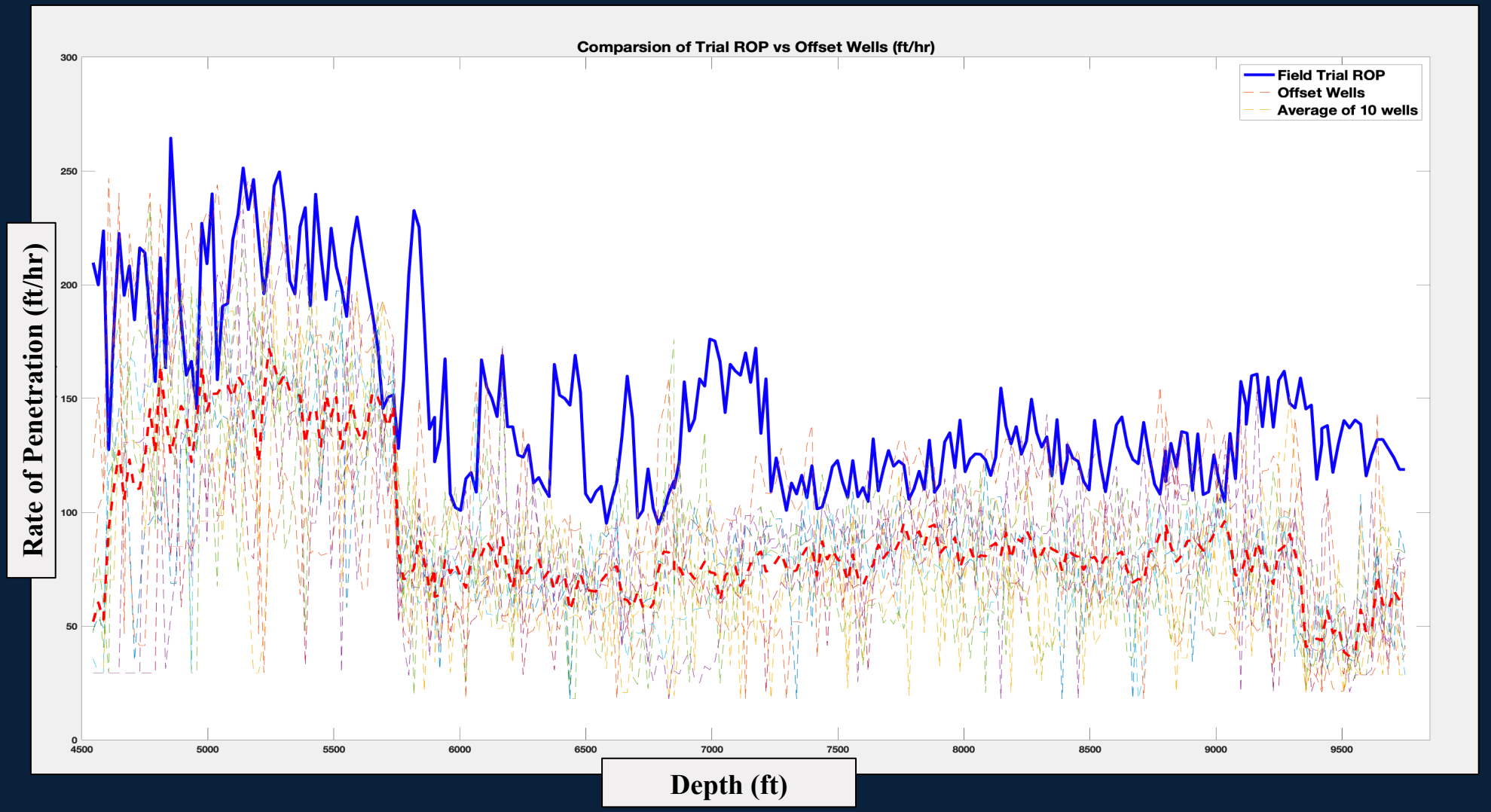
Comparison with Other Models

Actual ROP vs Predicted ROP



Correlation Coefficient





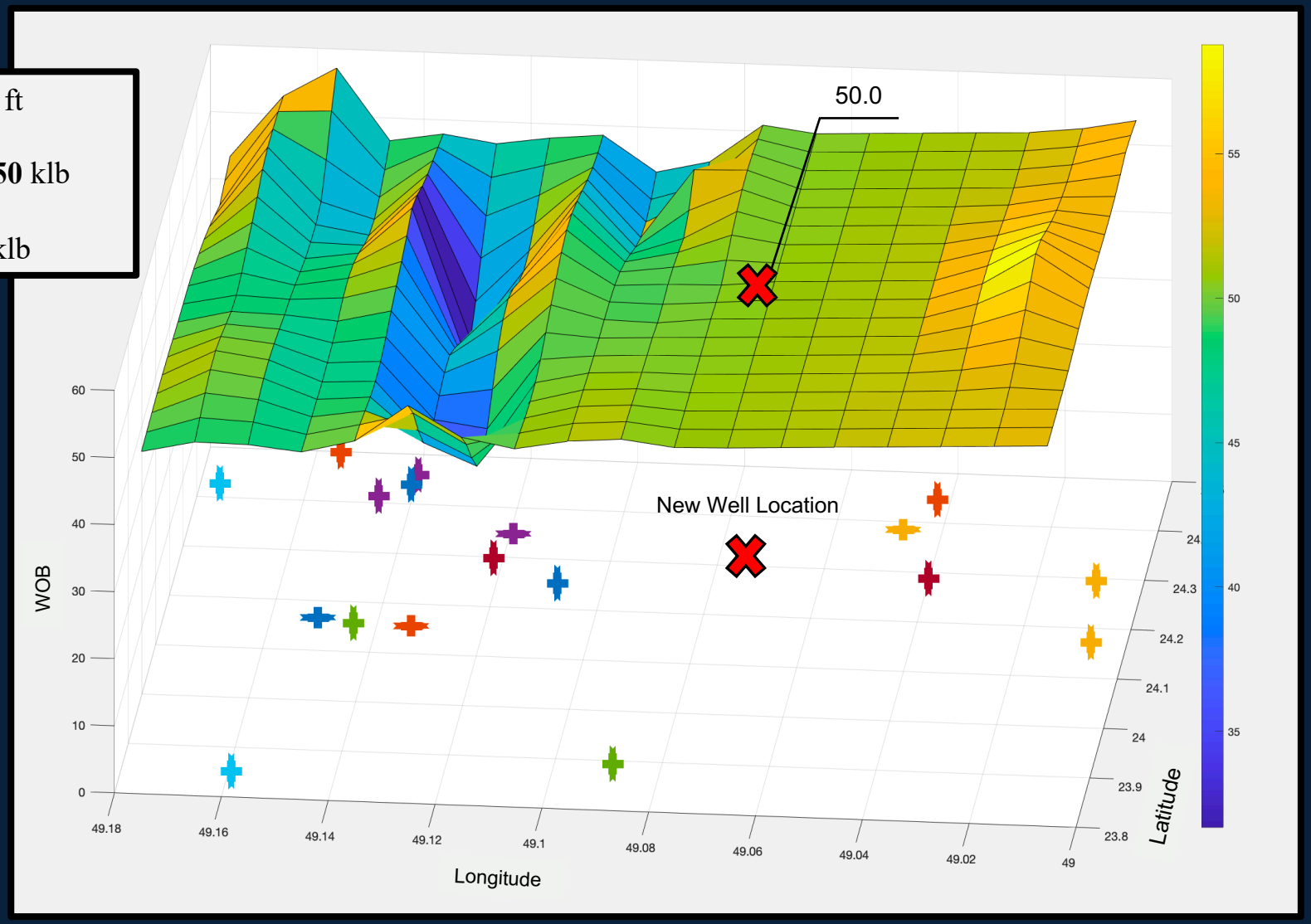
25% Higher ROP Achieved, compared with the top 10 offset wells.

Thank You

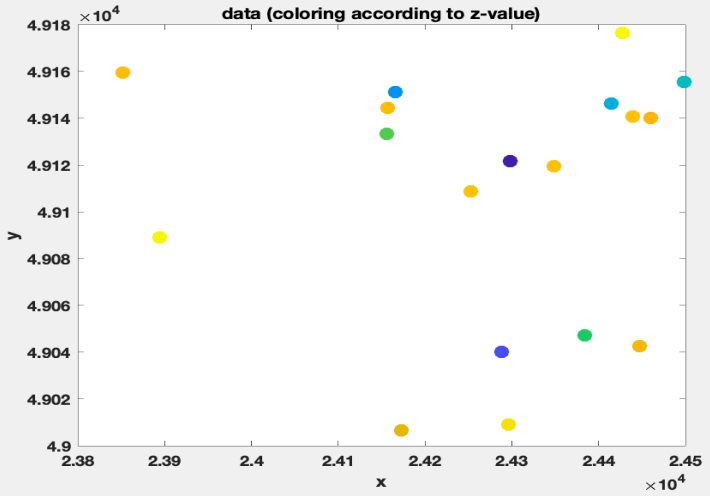
Depth (ft): 5551 ft

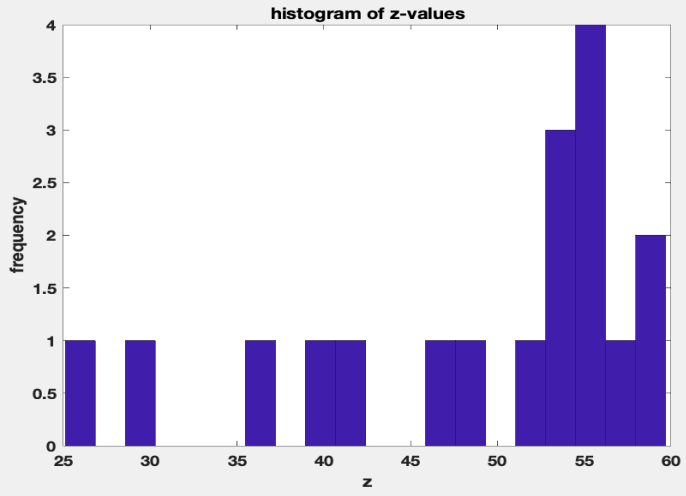
WOB Kriging: 50 klb

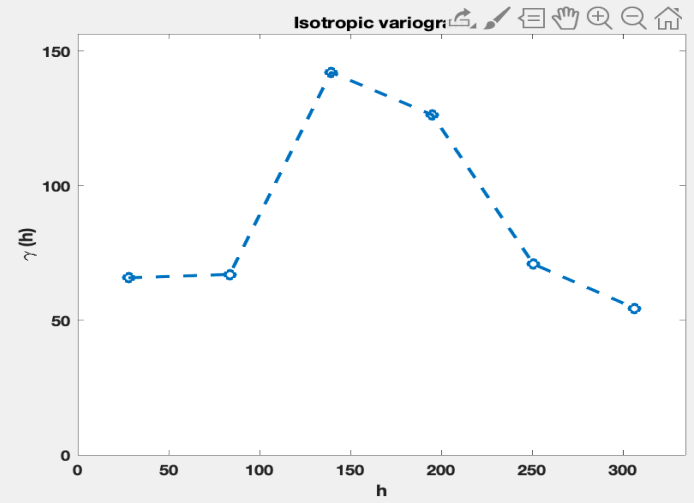
WOB IDW: 58 klb

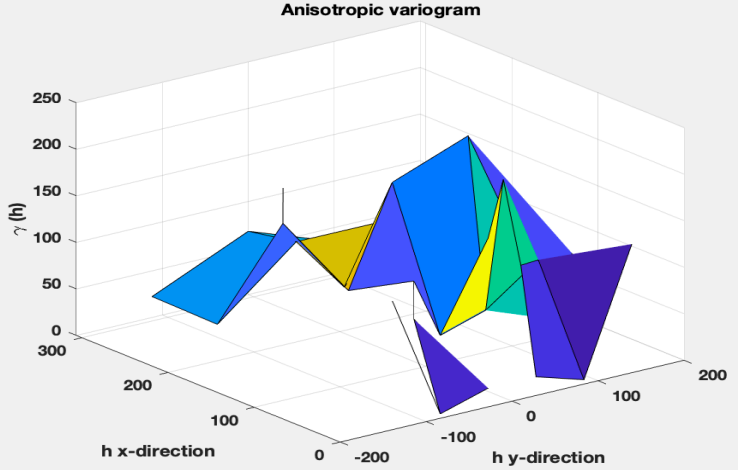


WOB at Depth (ft): 5551 ft
WOB IDW: 58 klb

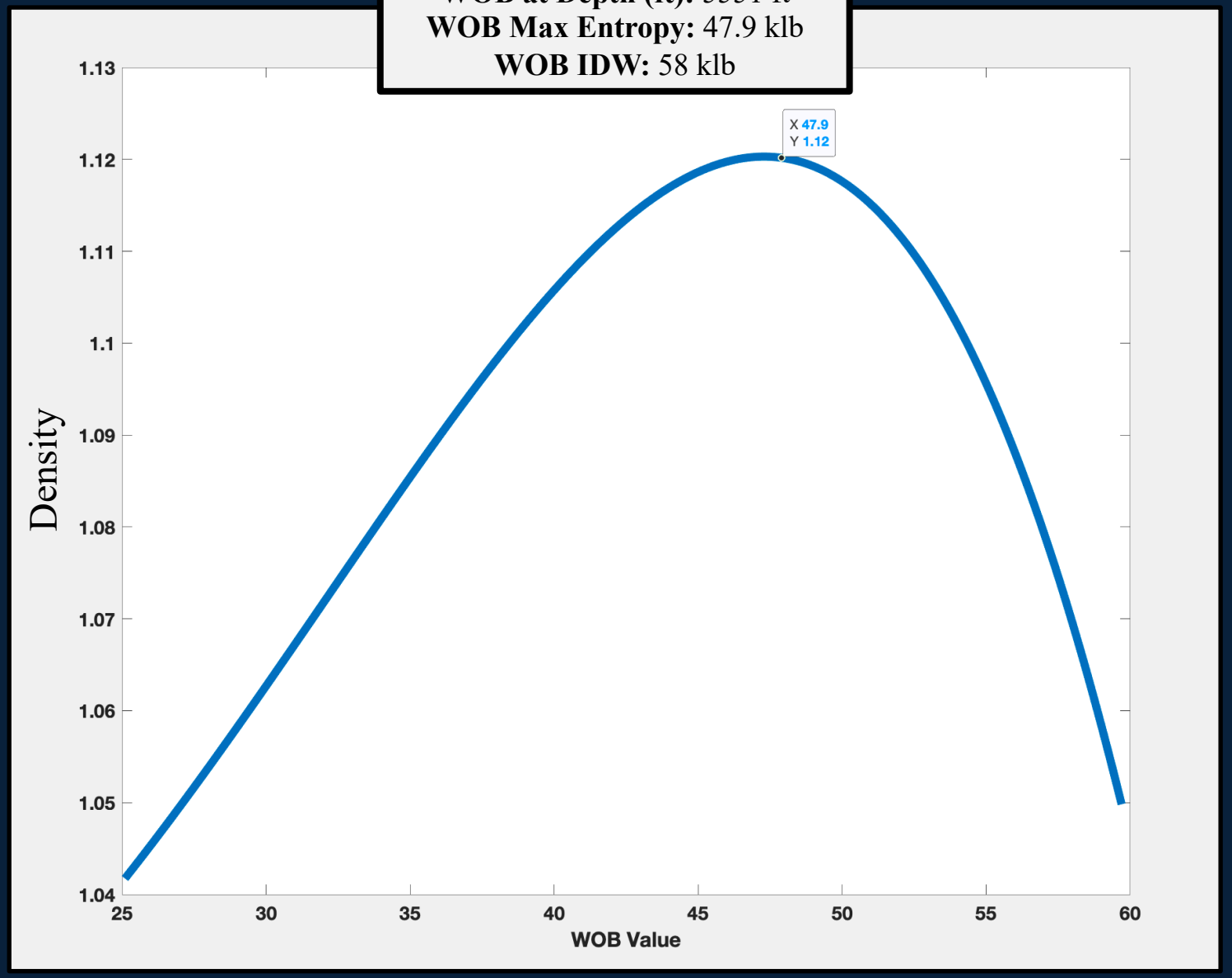






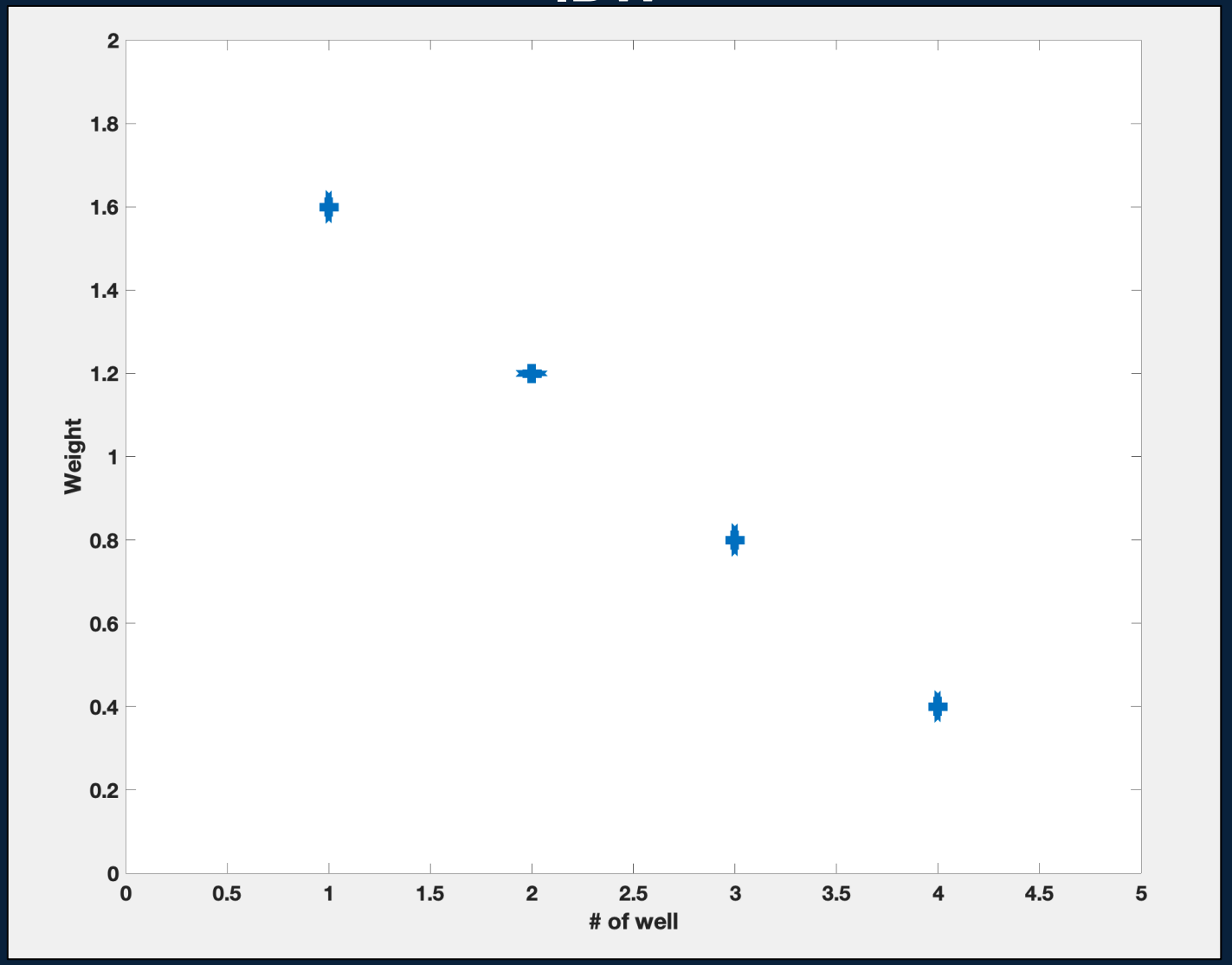


WOB at Depth (ft): 5551 ft
WOB Max Entropy: 47.9 klb
WOB IDW: 58 klb



IDW

$$\frac{\sum_{i=1}^{n=4} w_i}{n} = 1$$

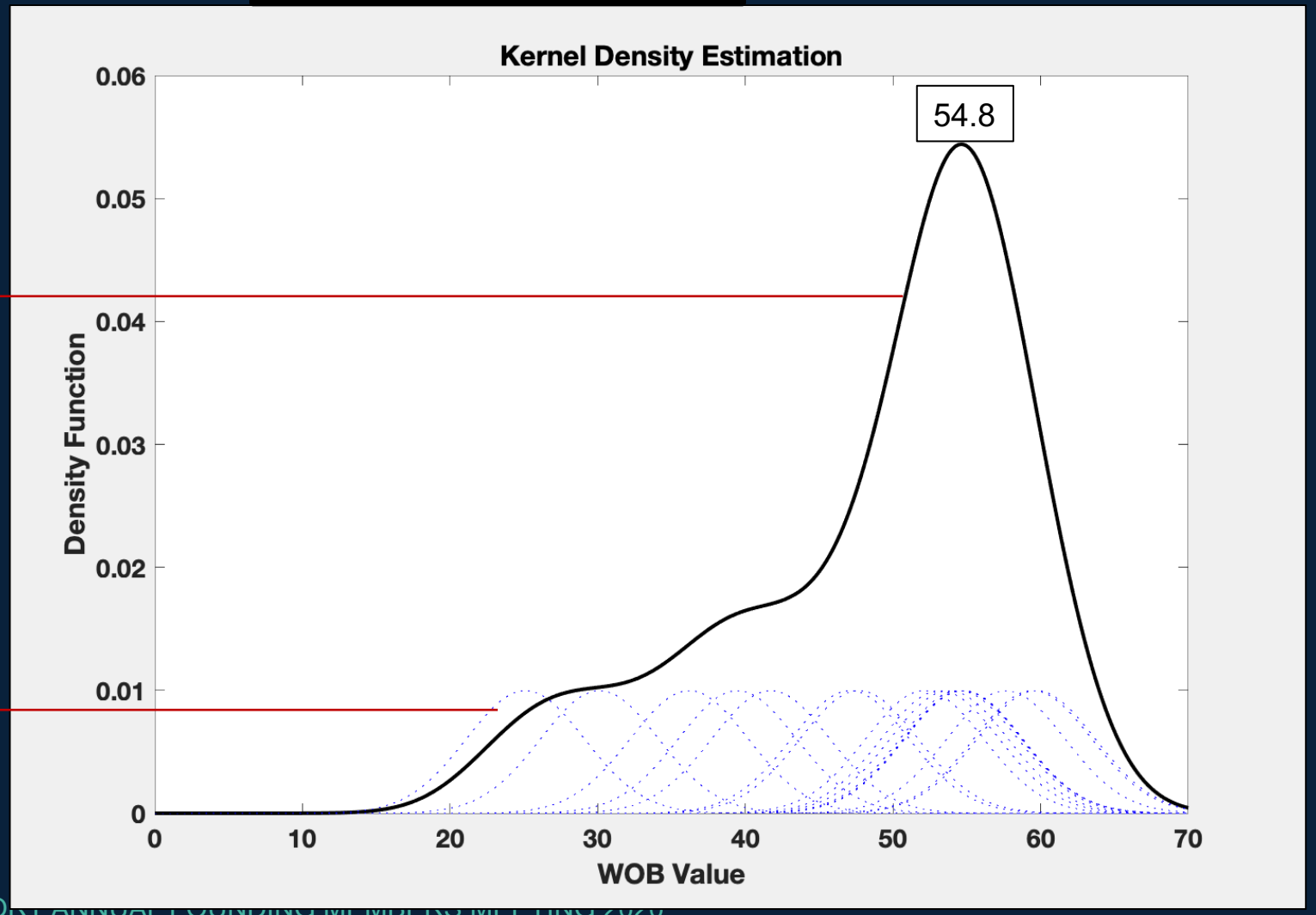


WOB at Depth (ft): 5551 ft

Normal Kernel (the normal kernel is often used, which means $K(x) = \phi(x)$, where ϕ is the standard normal density function.)

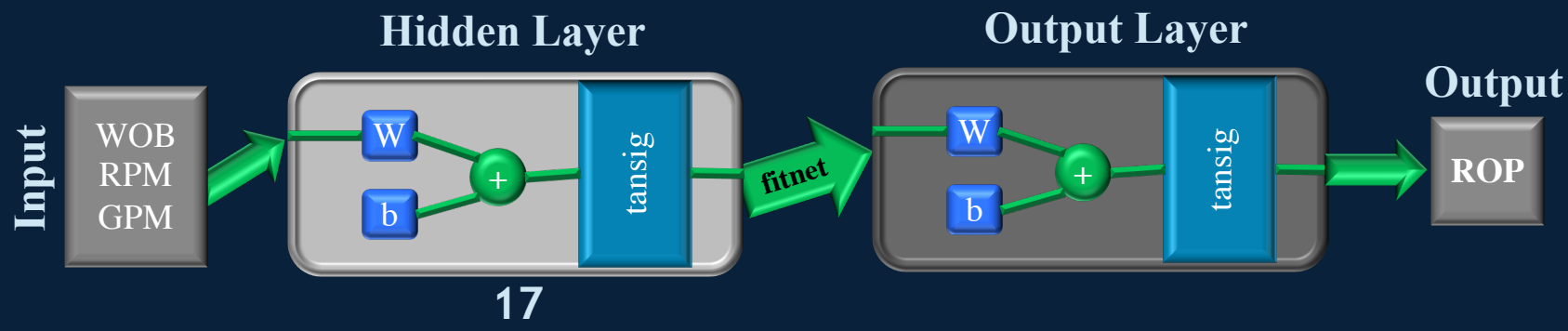
Smoothing=4

Normal distribution
Sigma=3



❖ ANN Method Development

Data distribution	65 / 35	70 / 30	75 / 25	80 / 20	85 / 15				
# of Neurons	20 - 0	20 - 10	10 - 10	10 - 20	15 - 10	15 - 10	17 - 0	18 - 0	
Training functions	trainlm	trainbr	trainbfg	traingd	traingdm	trainb	trainoss	trains	
Transfer functions	tansig	hardlims	poslin	radbas	compet	purelin	softmax	tirbas	netinv
Network functions	fitnet	feedforwardnet		cascadeforwardnet					



- HIGHT ROP AT WHICH CUTTINGS ARE BEING GENERATED TOO FAST TO BE CLEANED FROM THE ANNULUS;
- HIGH WOB THAT WILL GENERATE EXCESSIVE TORQUE FOR THE TOP DRIVE;
- HIGH WOB THAT WILL GENERATE EXCESSIVE TORQUE FOR THE DRILL PIPE; AND
- HIGH RPM THAT CAUSES EXCESSIVE VIBRATION OF THE DERRICK.
- HIGHT GPM THAT WILL INDUCE LOSSES.

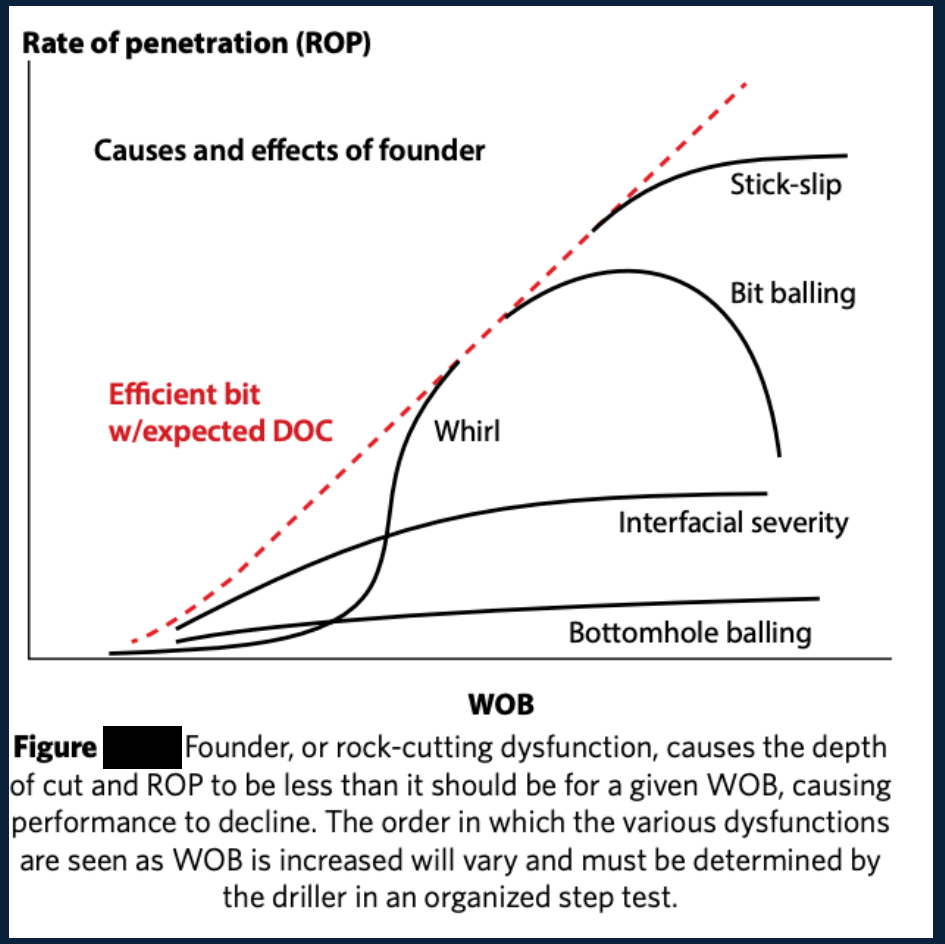


Figure [redacted] Founder, or rock-cutting dysfunction, causes the depth of cut and ROP to be less than it should be for a given WOB, causing performance to decline. The order in which the various dysfunctions are seen as WOB is increased will vary and must be determined by the driller in an organized step test.

https://www.iadc.org/