Pulsed electromagnetic techniques for non-destructively classifying rocks and rock sequences below the ground to help guide drilling programmes

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19th November 2024

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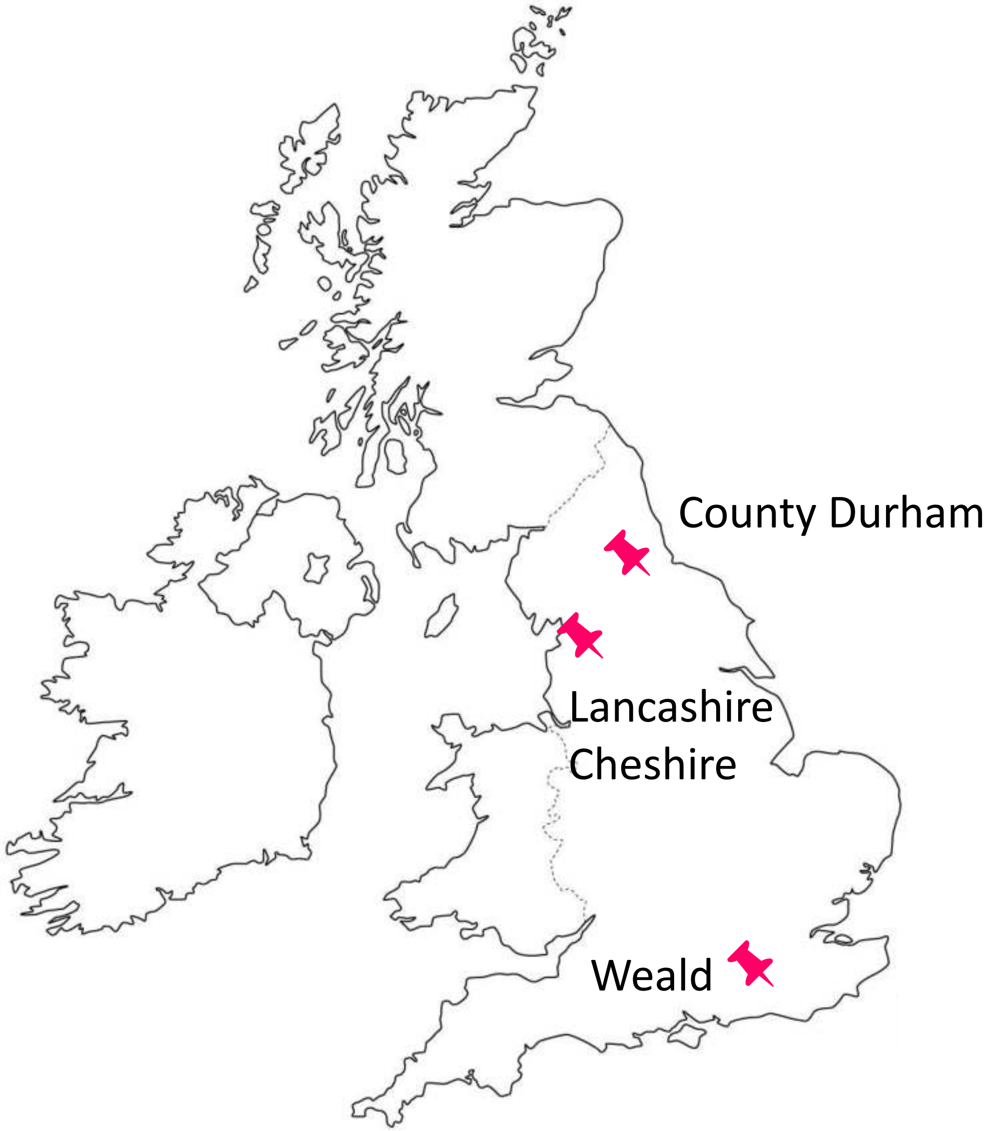


- Background & Motivation

The Problem

Trying to quantify subsurface rock, mineral, gas, fluid, density and temperature conditions for the exploration & production of natural resources is difficult because of the following reasons:

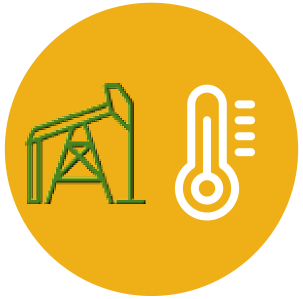
Subsurface fluids, porosity, permeability, minerals and temperature are very uncertain and difficult to read as they are dynamic and complex

The easiest way to read it accurately is through drilling which is very expensive & environmentally damaging

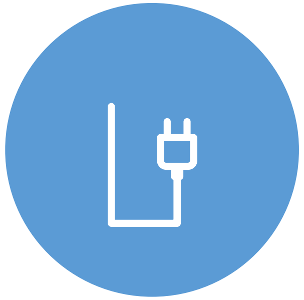
The Solution

Predrilling Virtual Logging®

Using pulsed electromagnetic ADR Technology, we can now **Digitally Drill** to virtually determine the existence of subsurface natural resources, temperature and fluids without the need for invasive drilling

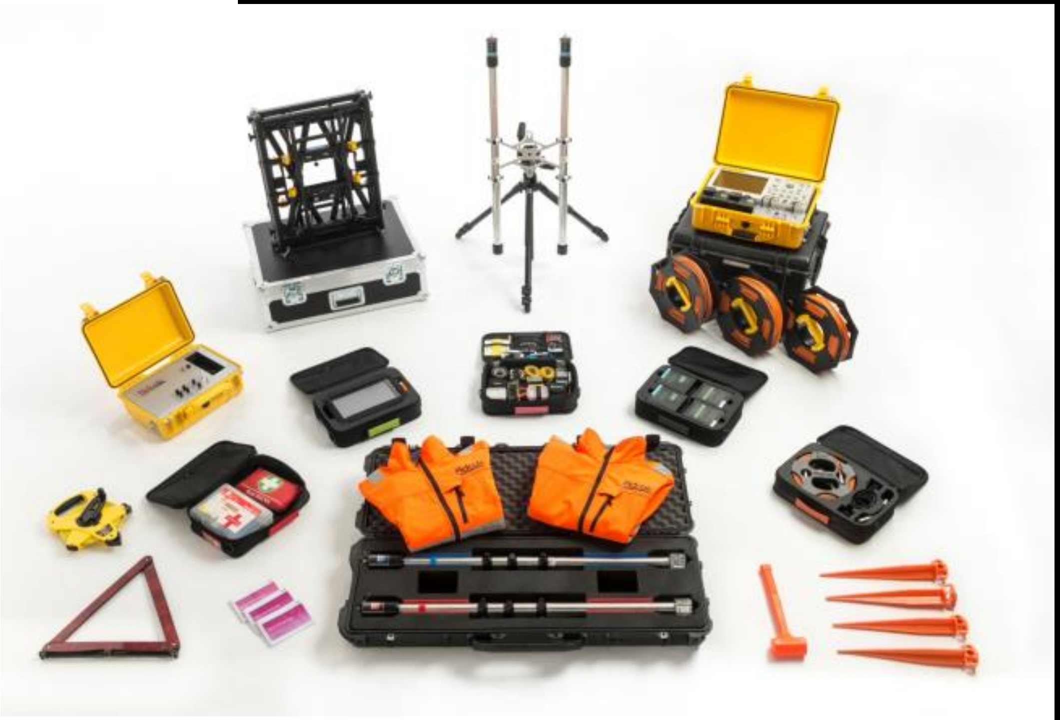


ADR allows the measurement of subsurface rock, mineral, fluid, temperature and gas conditions from the earth's surface, non-destructively

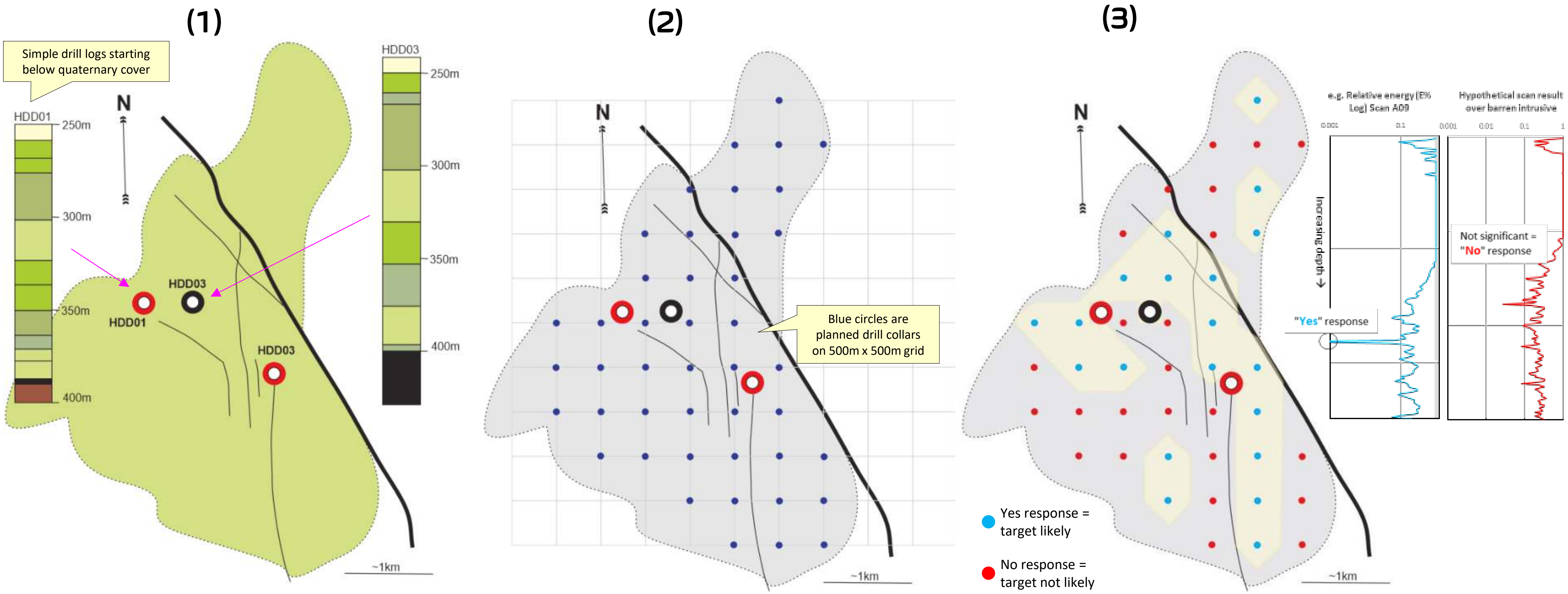


No need for extensive cable laying across fields compared to seismic & MT methods, as EM pulse is used

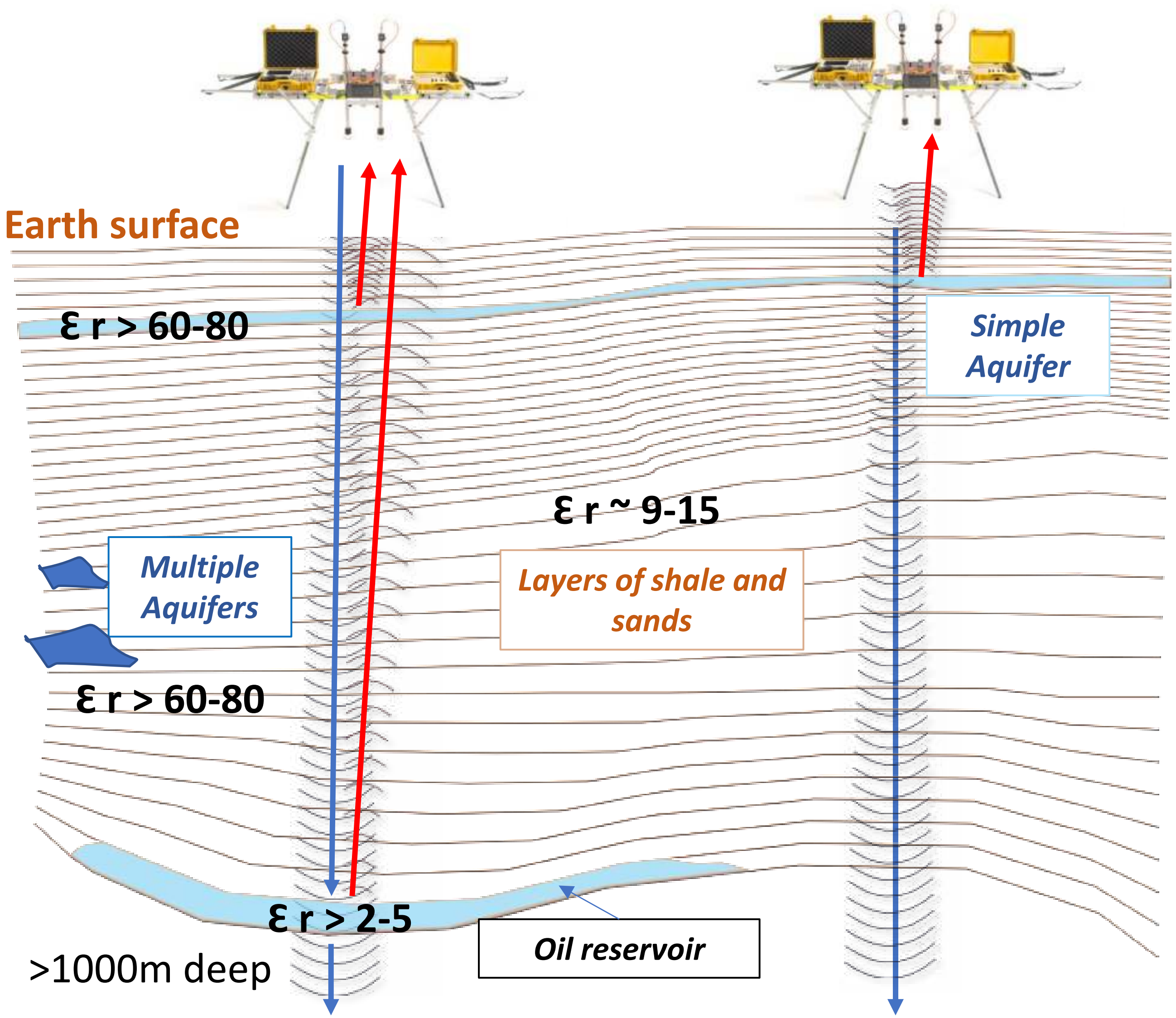
Our technology reduces the need for exploratory drilling and therefore reduces the expense and risks associated with it



Motivation: help guide pre-drilling delineation



How the technology works



- Transmits broadband pulses of radio waves between **1 to 70 MHz** into the ground.
- Detects the modulated reflections returned from the subsurface structures (backscatter).
- Measures dielectric permittivity (Ɛ r) and conductivity of material.
- Analyses spectral content of the returns to help classify materials (energy, frequency, phase).
- Time & frequency domain.
- Time ranges typically 20,000ns, 40,000ns & 100,000ns. This project used a 10,000ns range.
- High speed time domain sampling ~5GS/s
- Stack return signals for improved signal-to-noise 20,000, 100,000…..1million.

Forward model

- Maxwell equations coupled to ground model
- Ground model: permittivity, conductivity and polarization (*P*)
  - E electric field, σ conductivity, τ Debye relaxation time, ε_r relative permittivity
- Resulting system of partial differential equations:

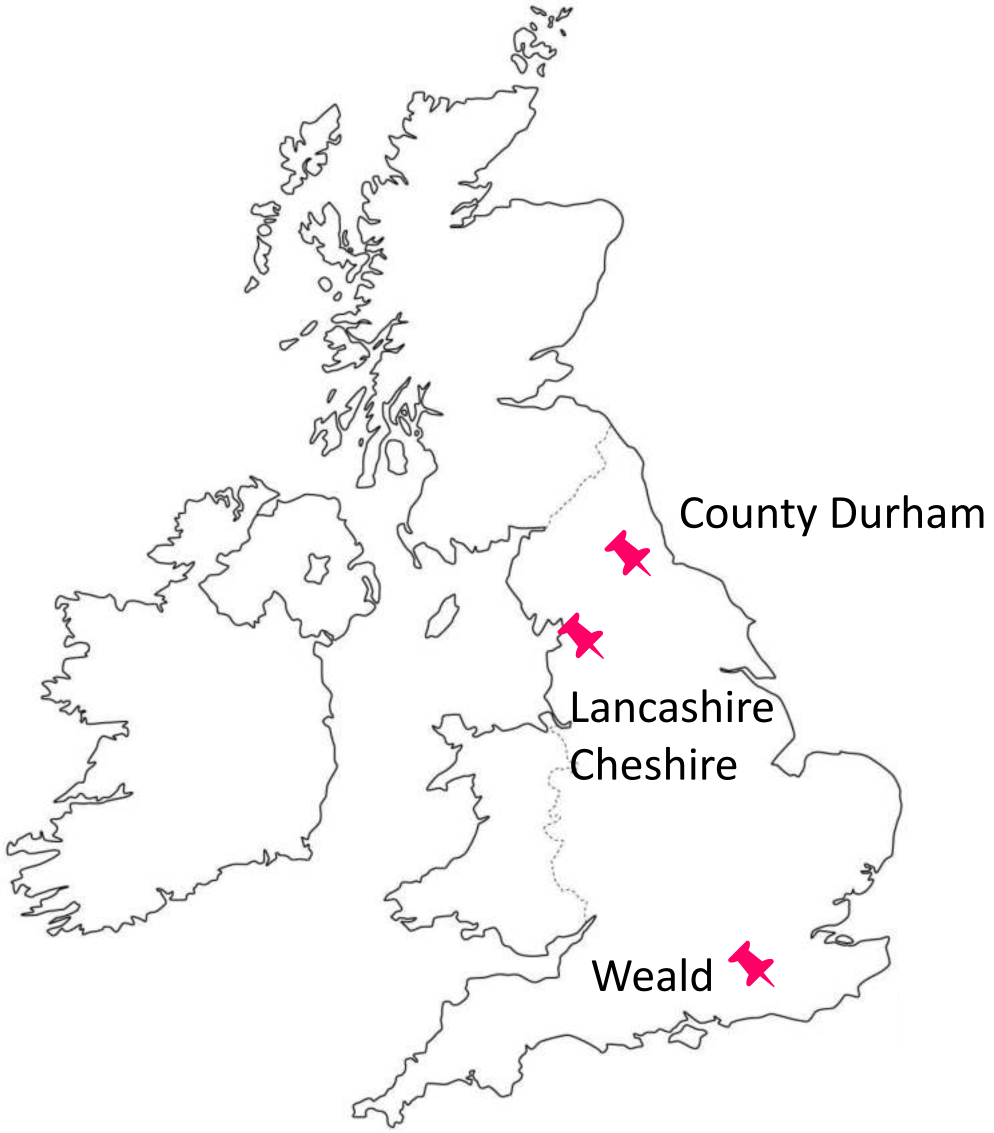
$$\epsilon_0 \frac{\partial^2 E(t,x)}{\partial t^2} + \sigma(x)\frac{\partial E(t,x)}{\partial t} + \frac{\partial^2 P(t,x)}{\partial t^2} - \frac{1}{\mu_0}\frac{\partial^2 E(t,x)}{\partial x^2} = 0, \qquad (1)$$

$$\tau(x)\frac{\partial P(t,x)}{\partial t} + P(t,x) = \epsilon_0(\epsilon_r(x) - 1))E(t,x). \qquad (2)$$

- Electromagnetic processing

Onshore

UK sites



Method (1) Calc Data Mix

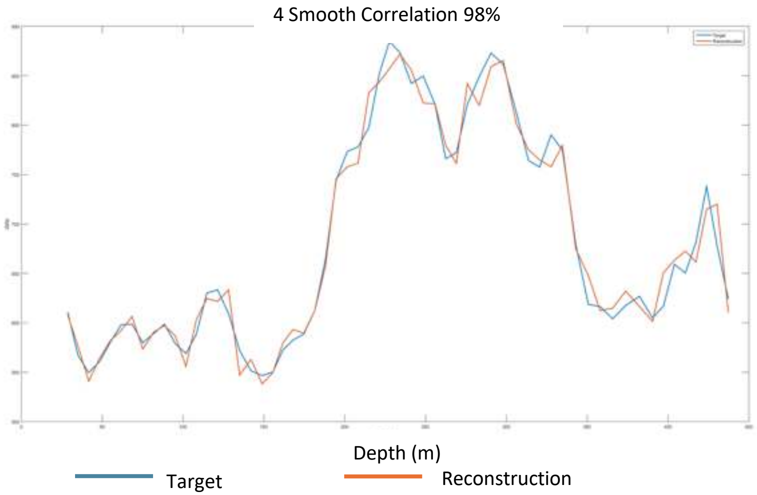
ADR Inputs

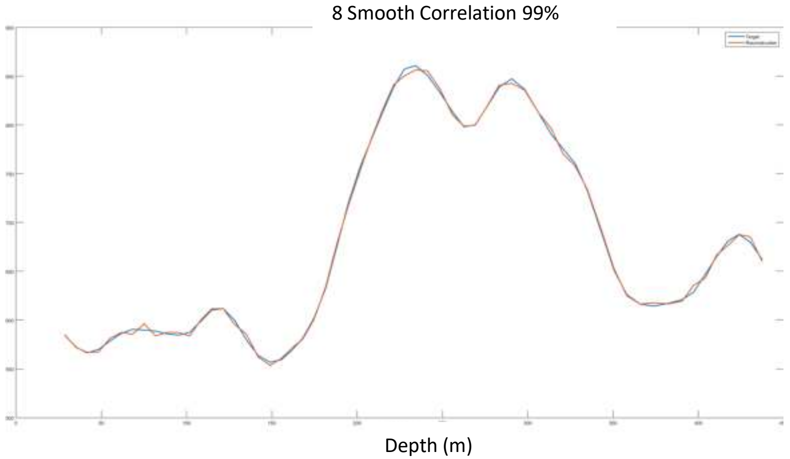
1) H#_(Drill_logName)Harmonics data.csv
2) H1(Drill_logName)_DCO-H1 Drill_logName_SII0 1.0-5.0MHz.csv
3) H#(Drill_logName)_DCO-H1 Drill_logName_SII0 5.0-10.0MHz.csv
4) H#(Drill_logName)_DCO-H1 Drill_logName_SII0 10.0-30.0MHz.csv
5) H#(Drill_logName)_DCO-H1 Drill_logName_SII0 30.0-60.0MHz.csv
6) H#(Drill_logName)_DCO-H1 Drill_logName_SII0 60.0-100.0MHz.csv
7) H#(Drill_logName)_DCO-H1 Drill_logName_SII0 100.0-120.0MHz.csv

Target File

1) H#_(Drill_logName)_Training Data.csv

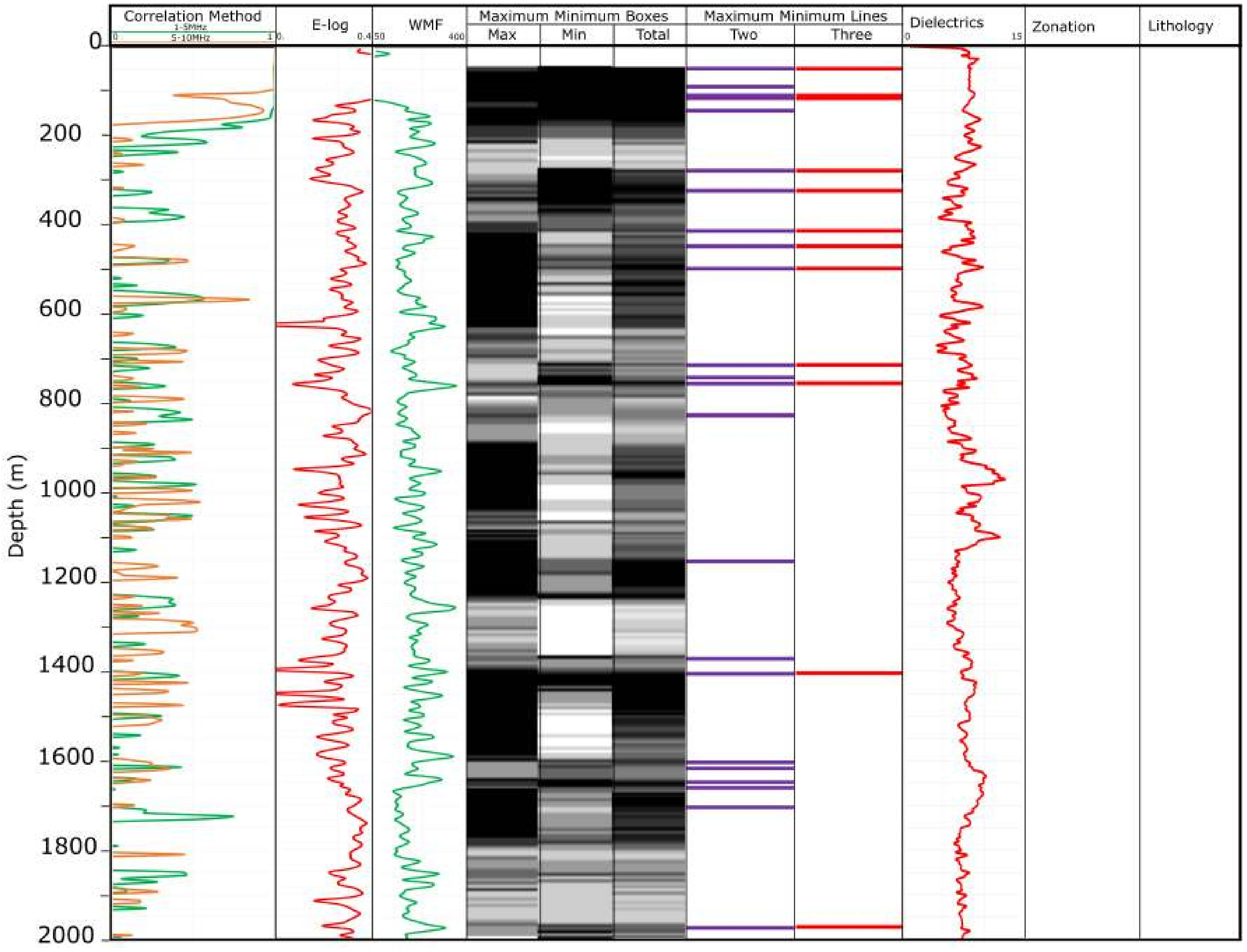
E-ADR	E-Gamma	E-Gamma 2	E-Max	E-Mean	E-Min	E-Range	E-SD	F-ADR	F-Gamma	F-Gamma
5.62E+02	-1.88E+03	-1.20E+02	1.93E+03	-2.42E+01	1.20E+02	-1.93E+03	1.22E+01	-2.34E+01	-2.99E+03	6.31E-01





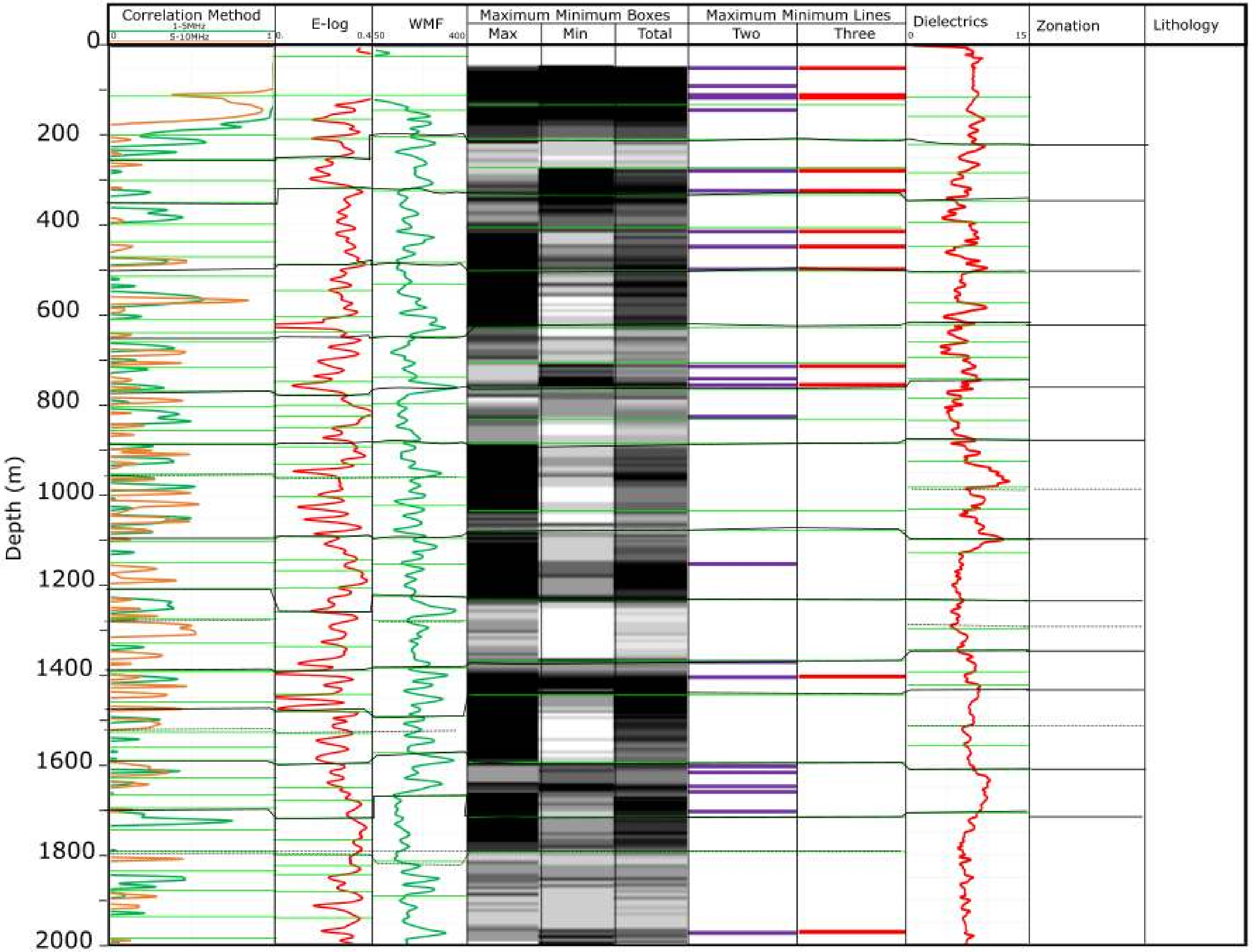
- ADR data (in orange) are imported alongside training data (in blue) outputting a matching graph as well as a coefficient that used for the Calc Data Mix tool. A correlation value is also included.
- Applied Smoothing window of 4 (best for small datasets e.g. Lancashire) and 8 (best for large datasets e.g. Weald)

Method (2) Zonation



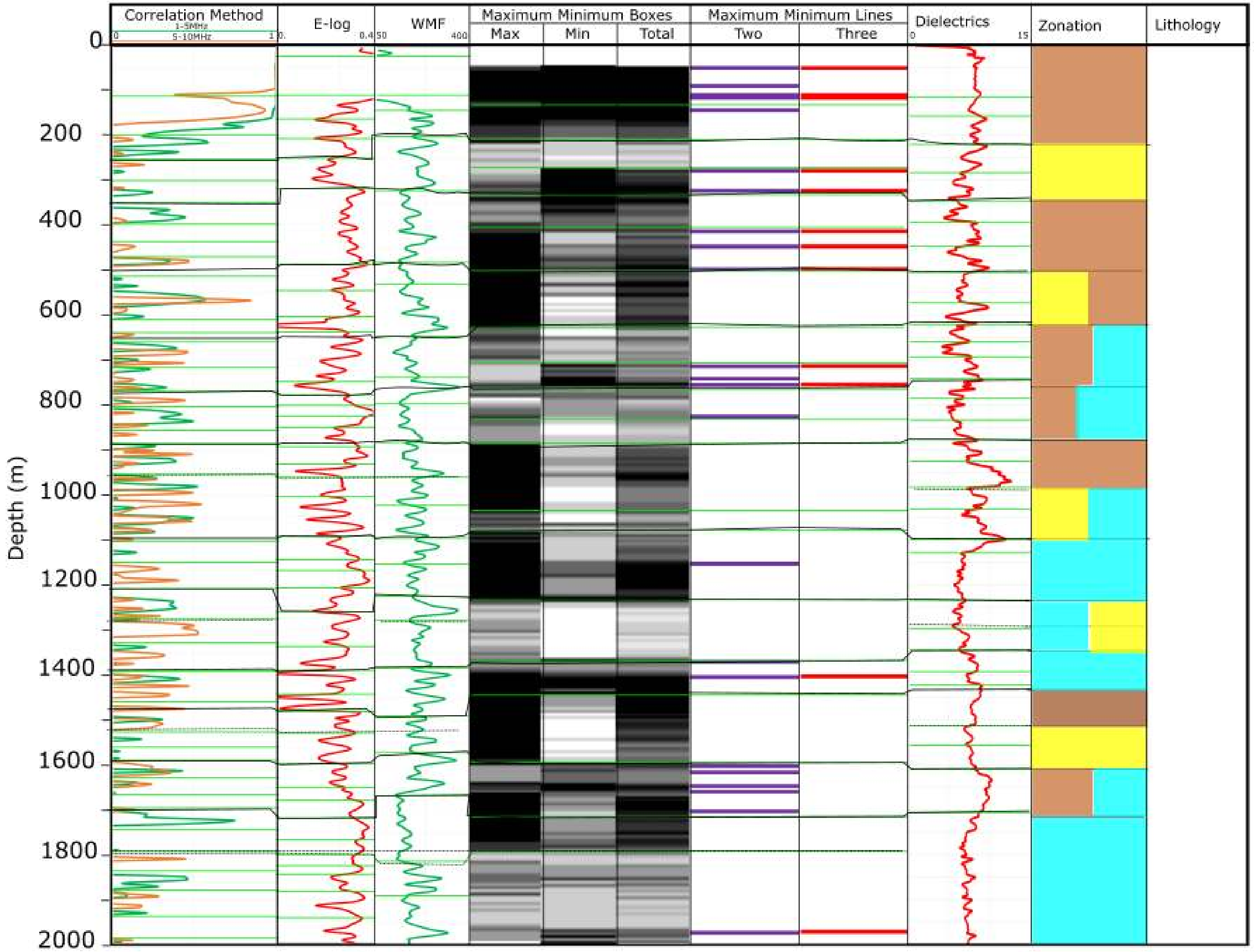
The first stage is to line up all data alongside each other and note down any features.

Method (2) Zonation



- These lines are then interpolated to a single depth.

Method (2) Zonation



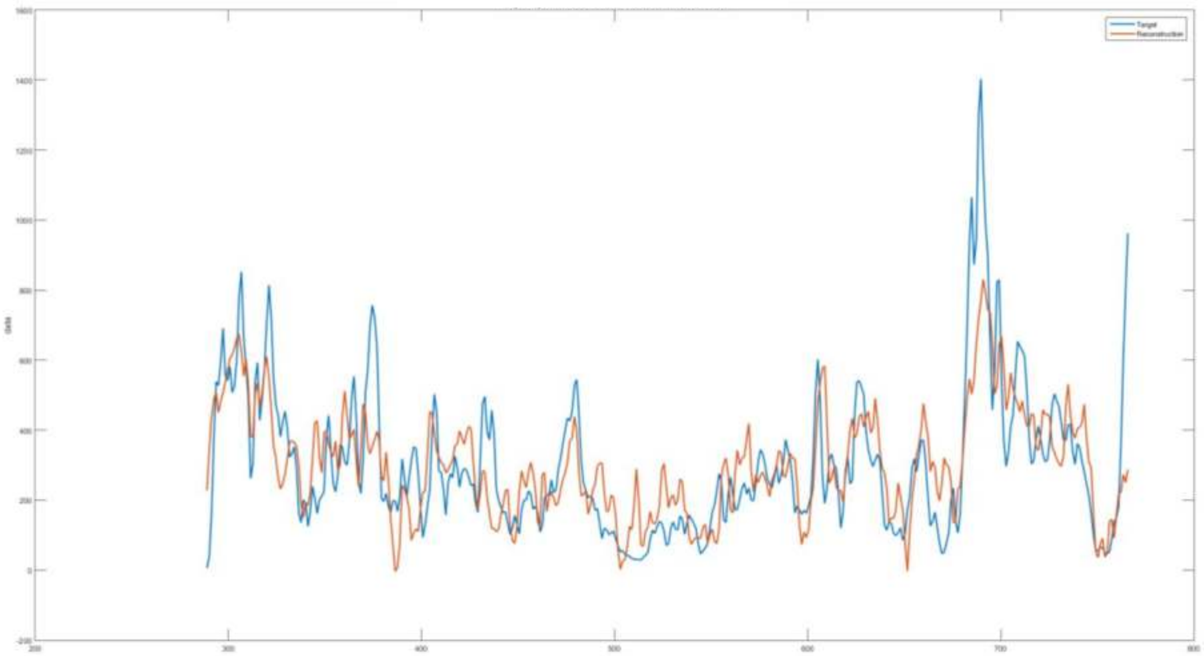
- Boundaries are identified and given colour codes dependant on possible lithologies.
- A database is also produced quantifying ADR values for different lithologies.

- Results

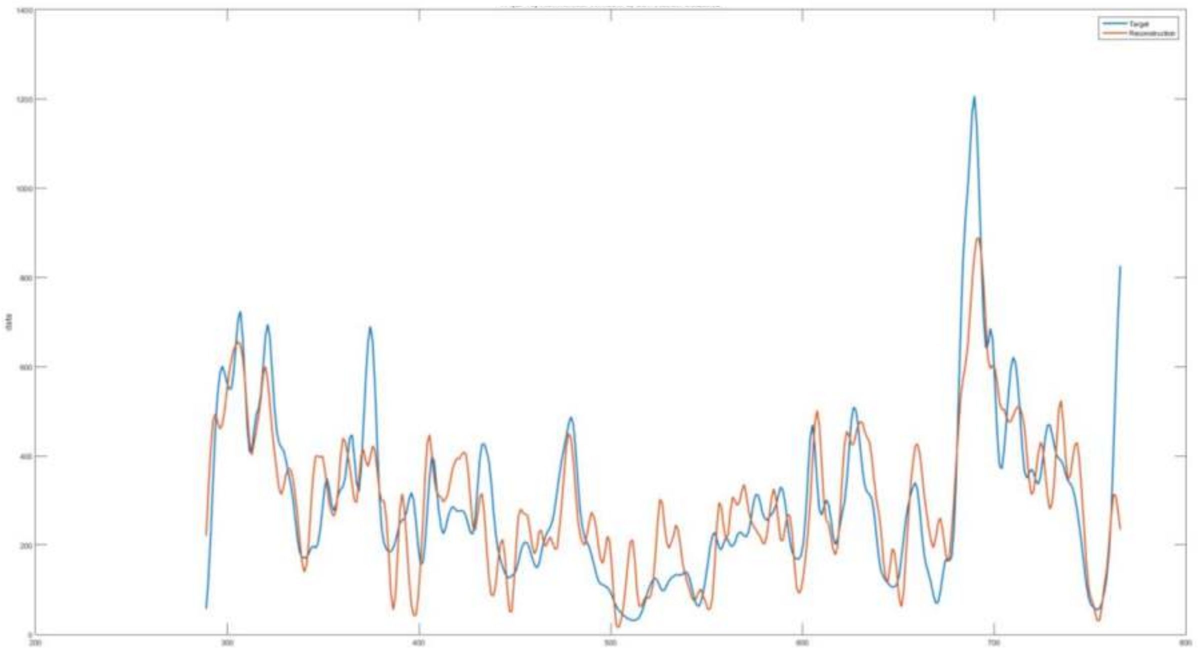
CalcData Mix

Durham LF10 Formation Resistivity

4 Smooth Correlation 73%



8 Smooth Correlation 82%

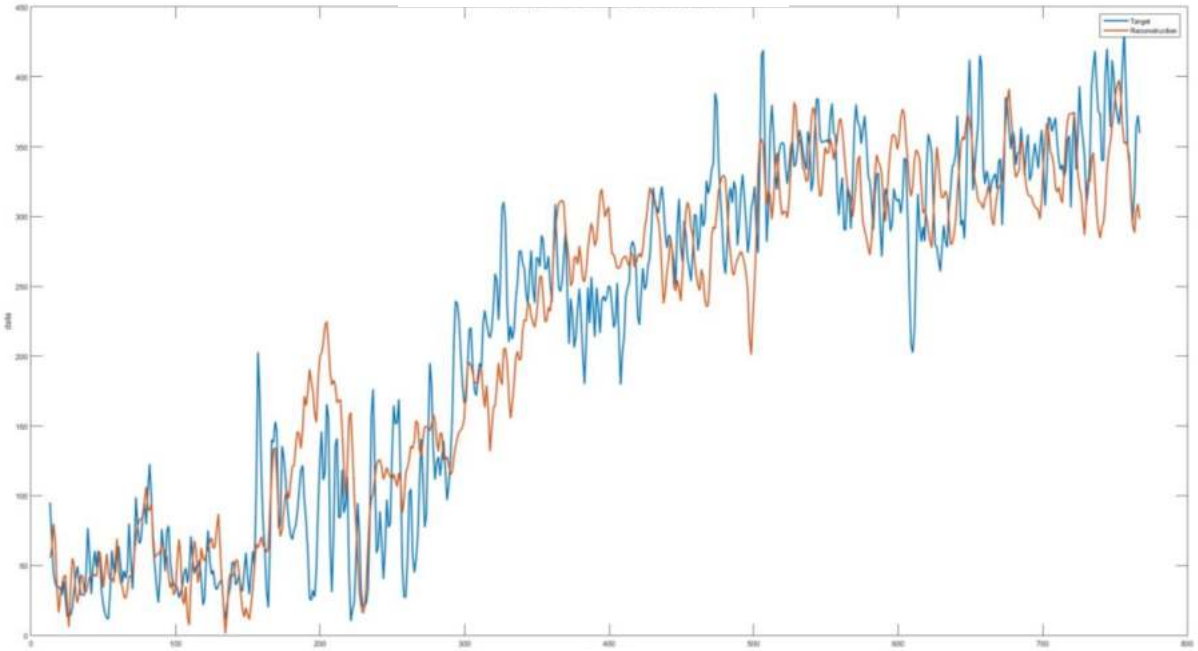


Target Reconstruction

- The CalcData Mix for Formation Resistivity at LF10 shows a correlation of 73% using a 4 Smooth & correlation of 82% for an 8 Smooth.
- This is a good result.

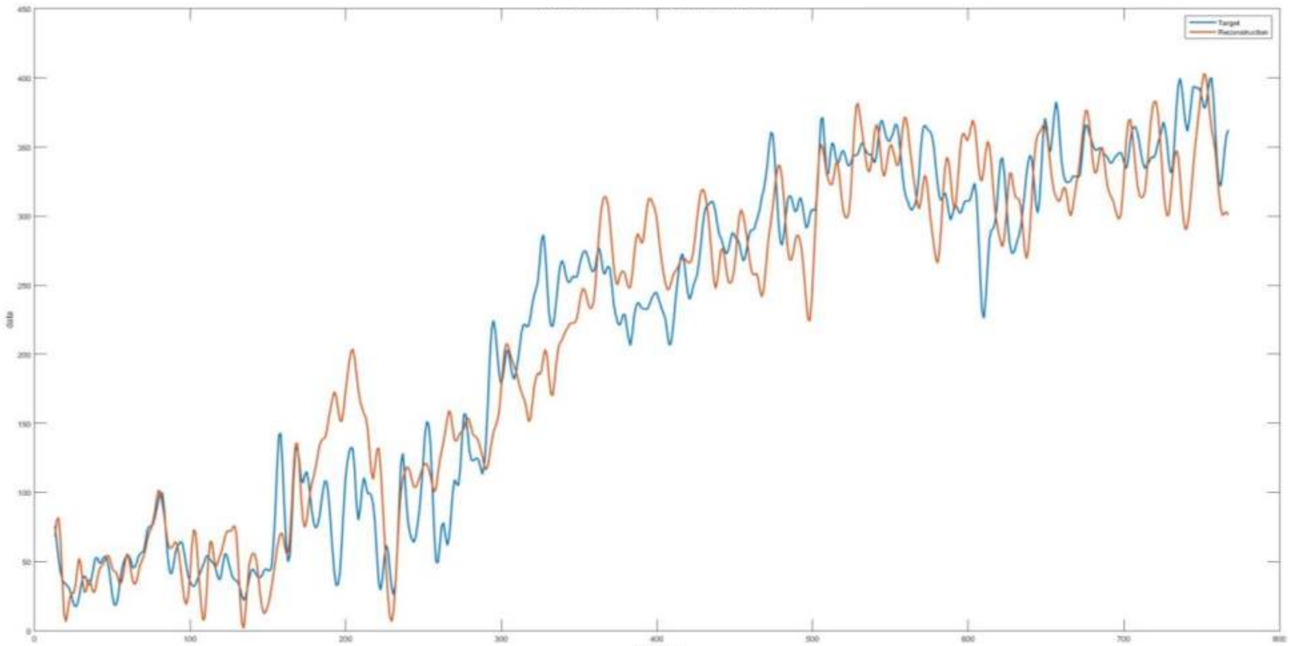
Durham LF10 Gamma Ray

4 Smooth Correlation 93%



Depth (m)

8 Smooth Correlation 95%



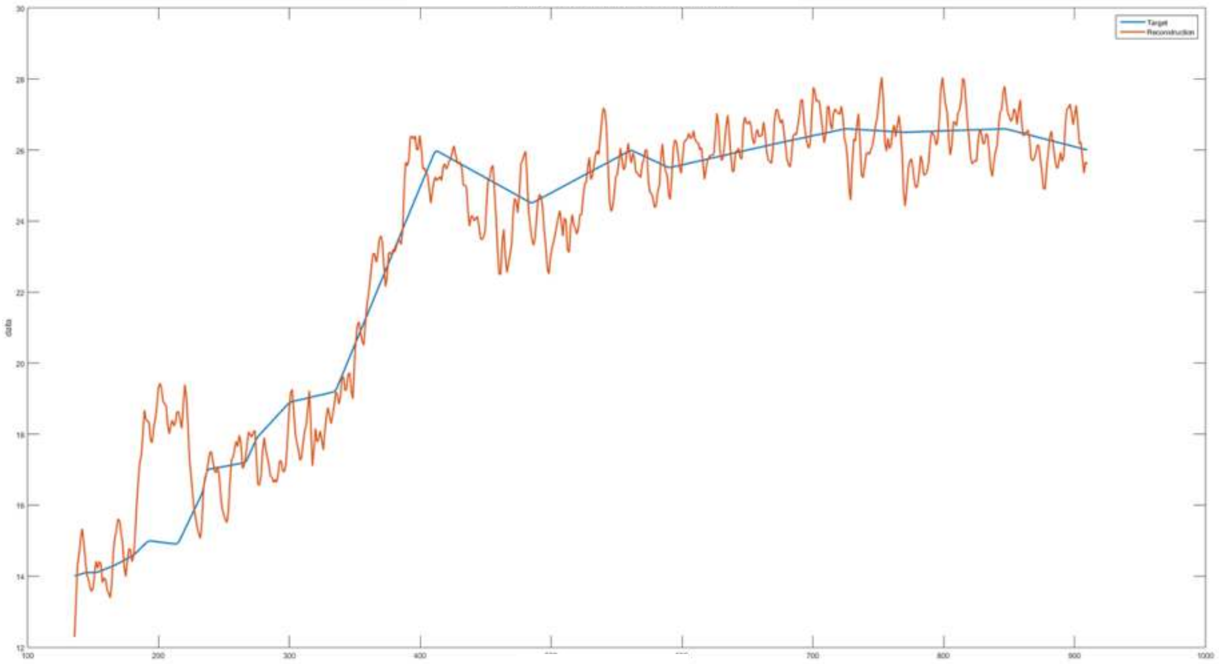
Depth (m)

Target   Reconstruction

- The CalcData Mix for Formation Resistivity at LF10 shows a correlation of 93% using a 4 Smooth & correlation of 95% for an 8 Smooth.
- This is a good result.

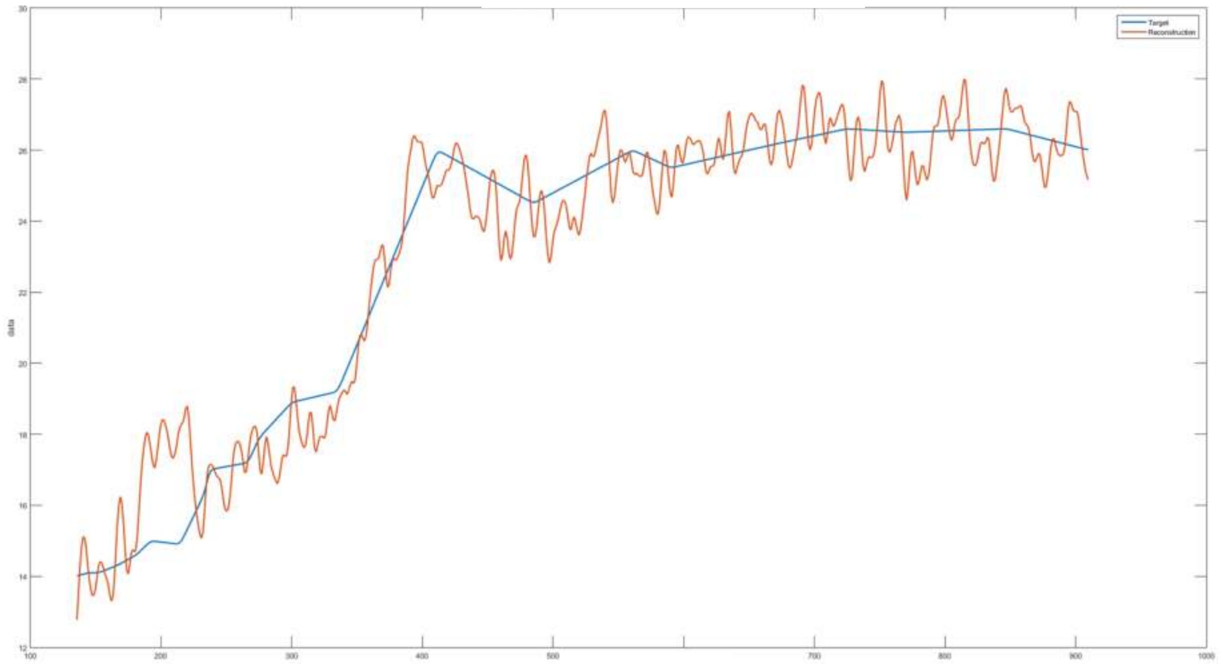
Durham LF10 Temperature

4 Smooth Correlation 96%



Depth (m)

8 Smooth Correlation 97%



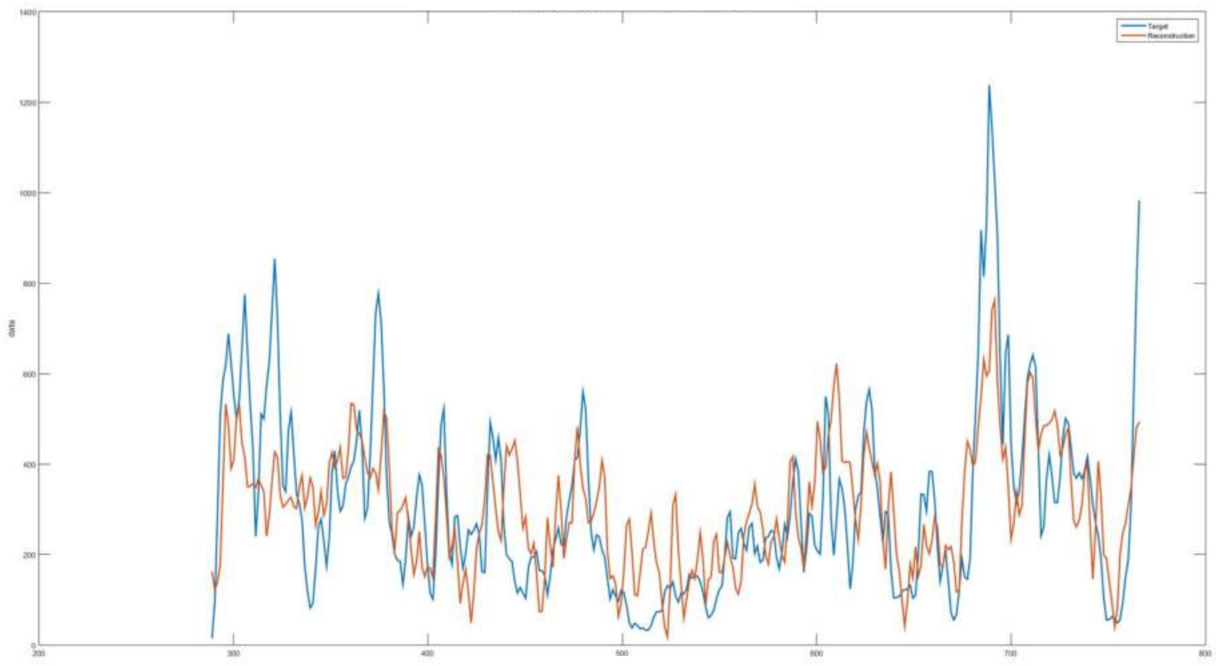
Depth (m)

Target Reconstruction

- The CalcData Mix for Temperature at LF10 shows a correlation of 95% using a 4 Smooth & correlation of 97% for an 8 Smooth.
- This is a good result.

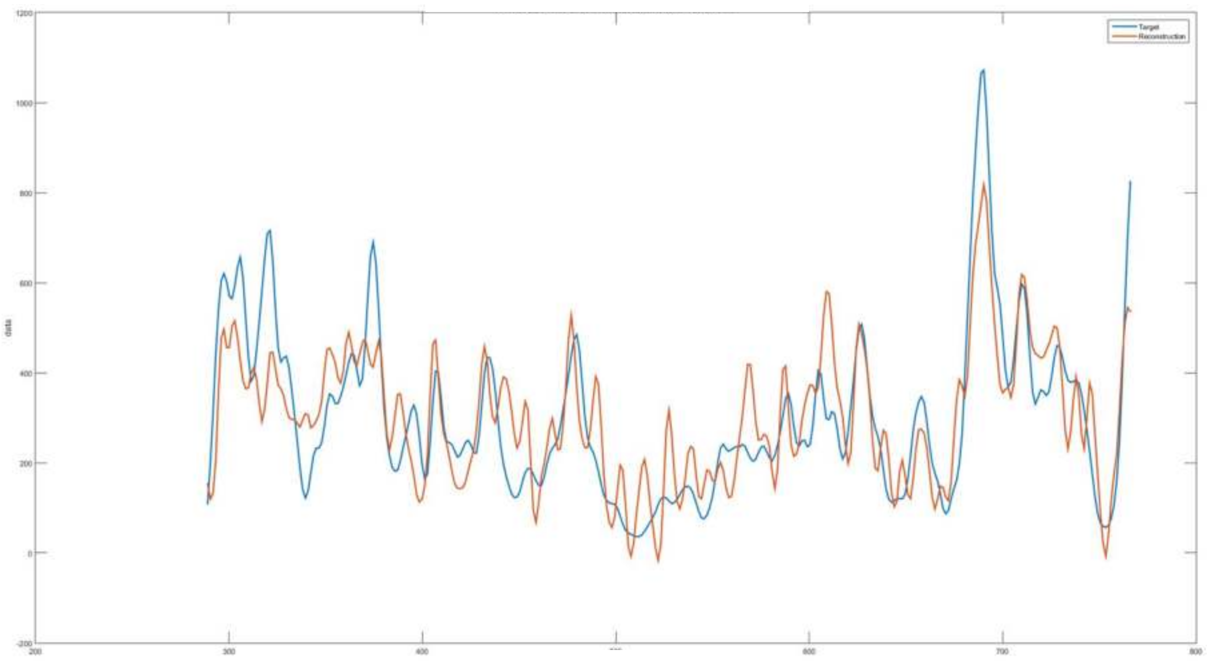
Durham LF03Pt4 Formation Resistivity

4 Smooth Correlation 67%



Depth (m)

8 Smooth Correlation 80%



Depth (m)

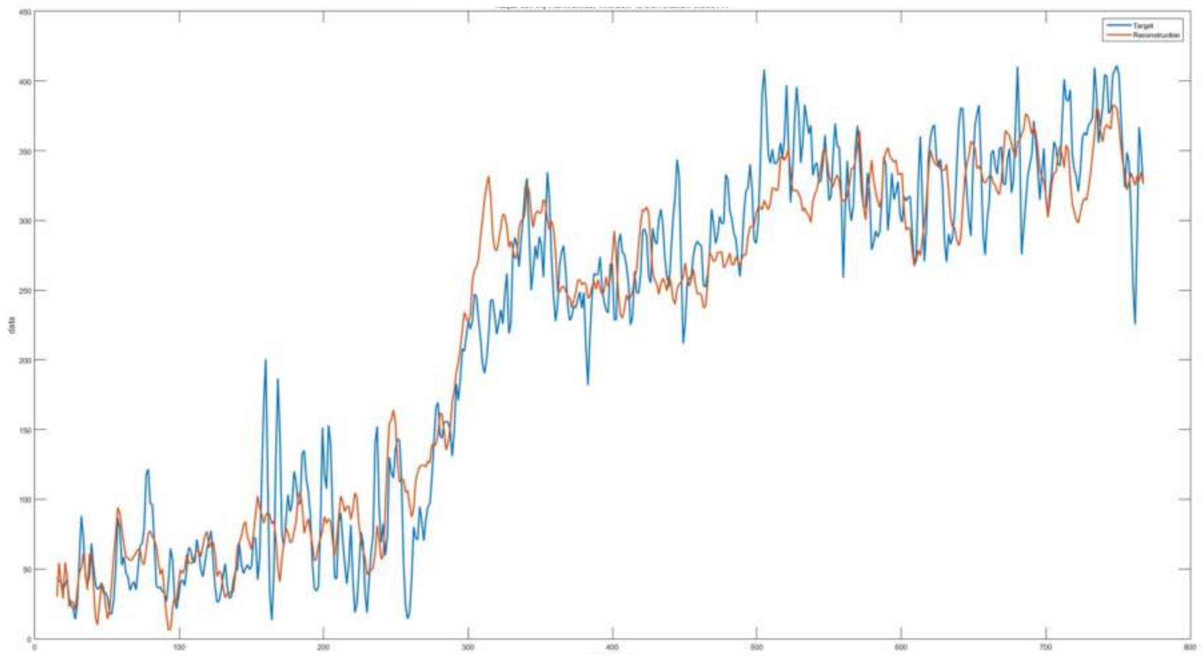
Target Reconstruction

- The CalcData Mix for Formation Resistivity at LF03Pt4 shows a correlation of 67% using a 4 Smooth & correlation of 80% for an 8 Smooth. This means that only the 8 Smooth shows strong correlation.

- This is an ok result.

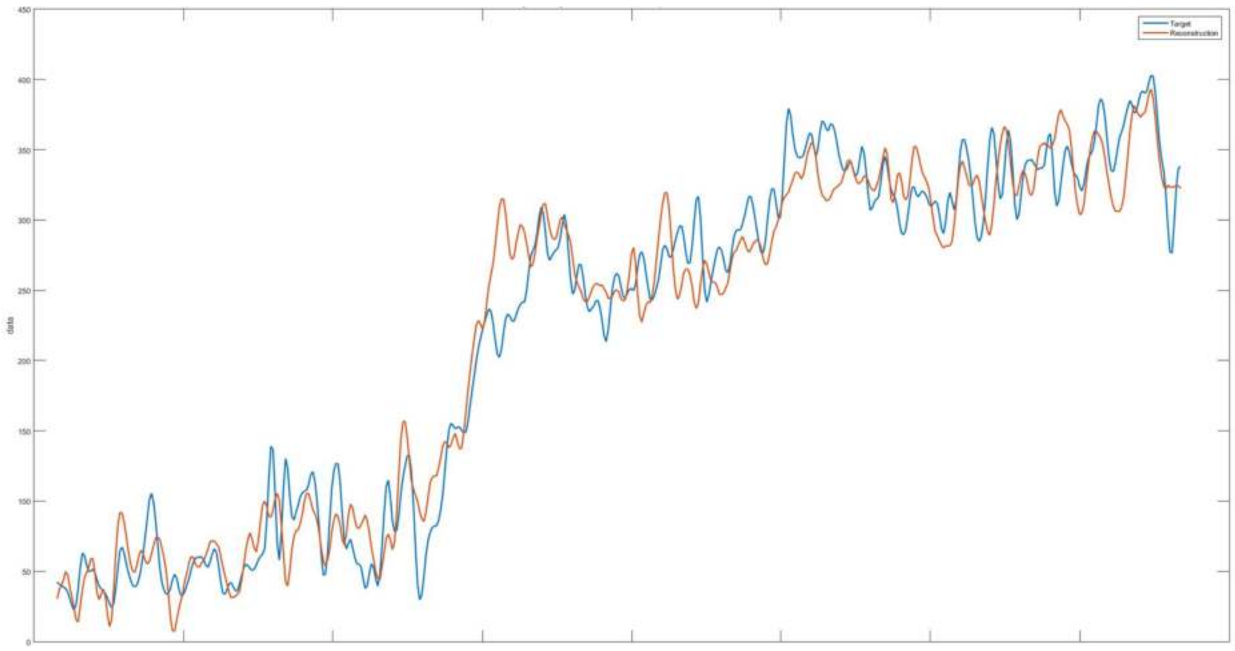
Durham LF03Pt4 Gamma Ray

4 Smooth Correlation 95%



Depth (m)

8 Smooth Correlation 97%



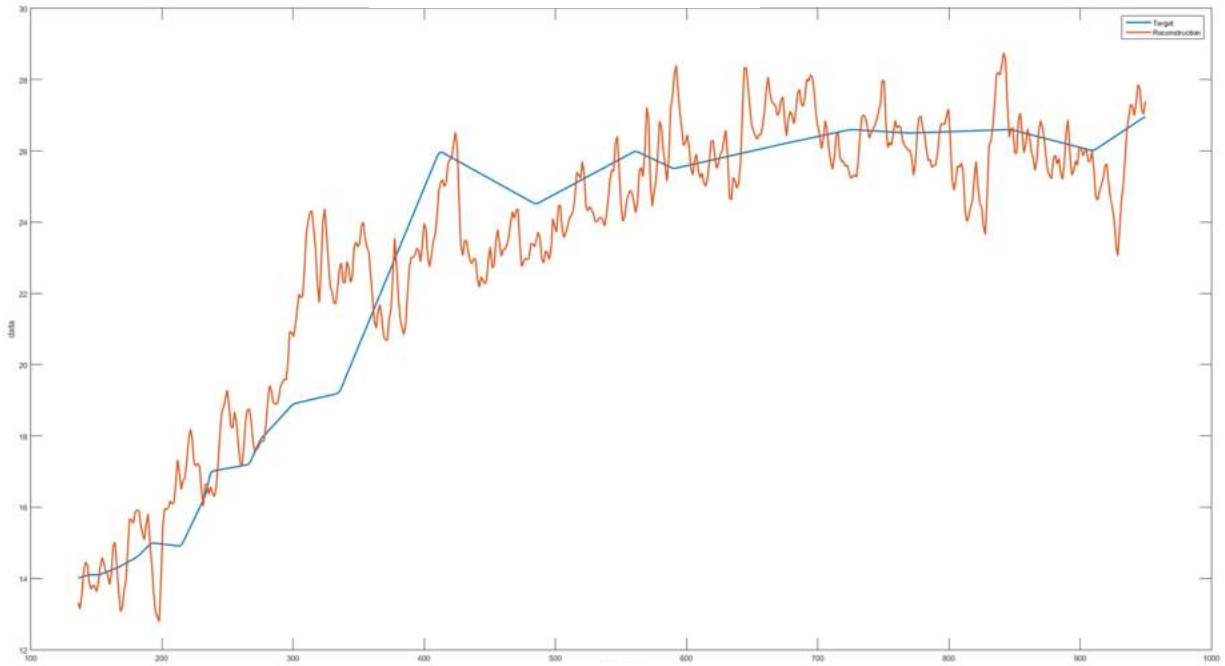
Depth (m)

Target   Reconstruction

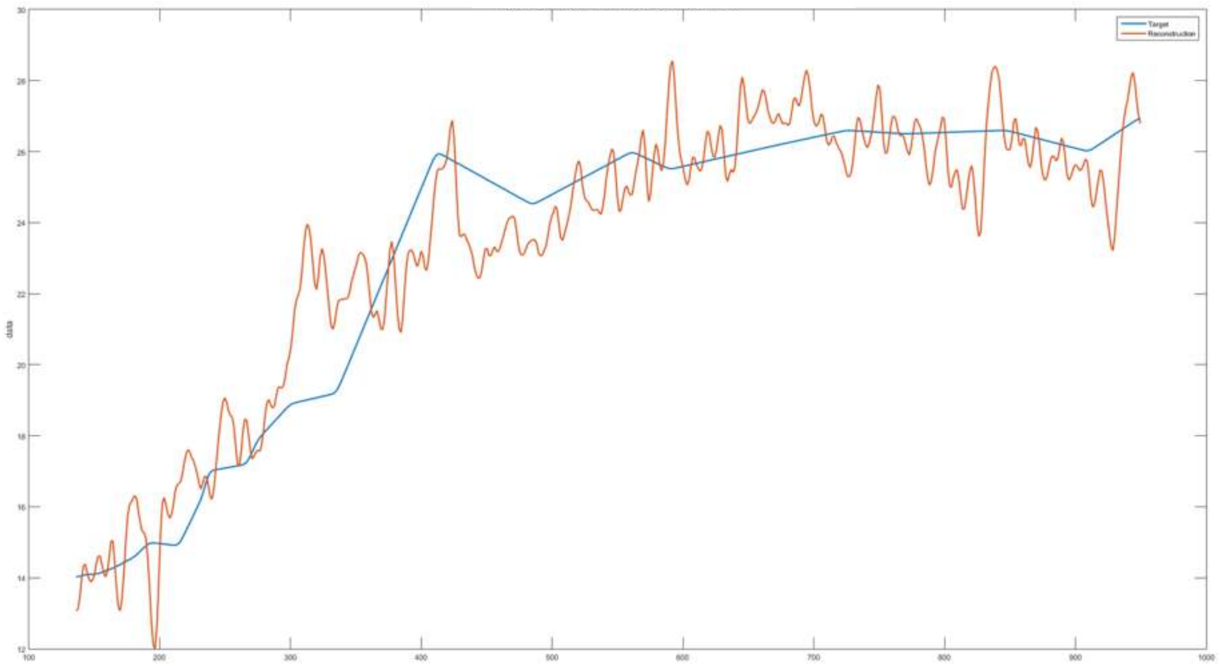
- The CalcData Mix for Gamma Ray at LF03Pt4 shows a correlation of 95% using a 4 Smooth & correlation of 97% for an 8 Smooth.
- This is a good result.

Durham LF03Pt4 Temperature

4 Smooth Correlation 93%



8 Smooth Correlation 94%



Depth (m)

Depth (m)

Target

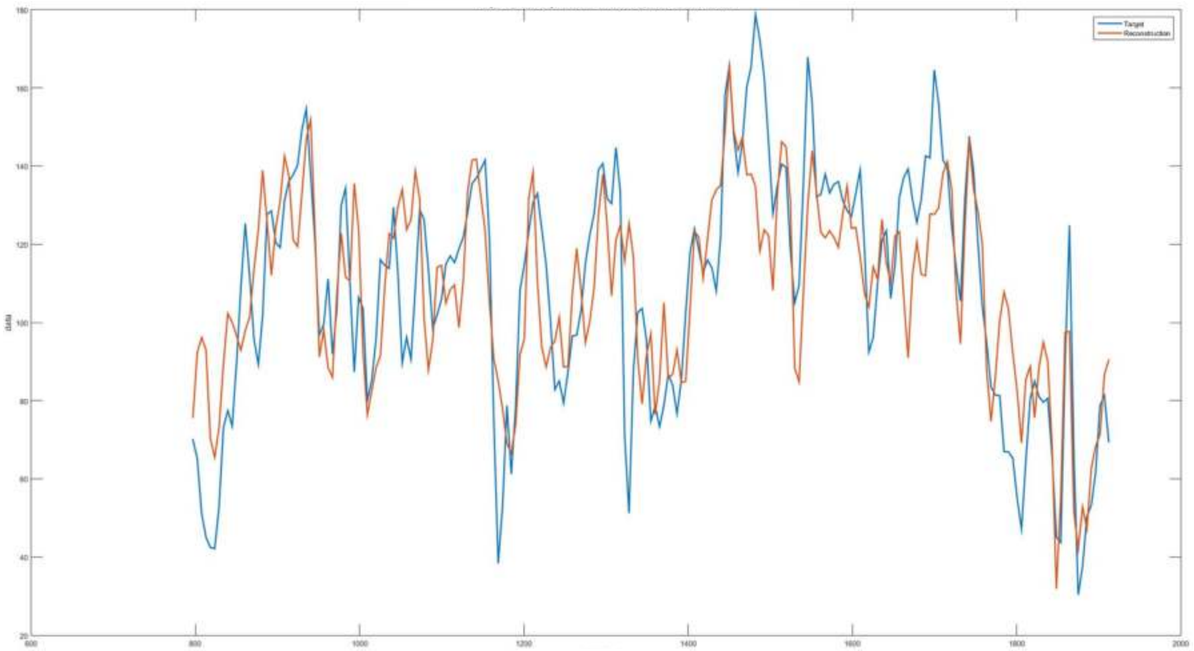
Reconstruction

- The CalcData Mix for Temperature at LF03Pt4 shows a correlation of 93% using a 4 Smooth & correlation of 94% for an 8 Smooth.

- This is a good result.

Cheshire - Ellesmere Port Gamma Ray

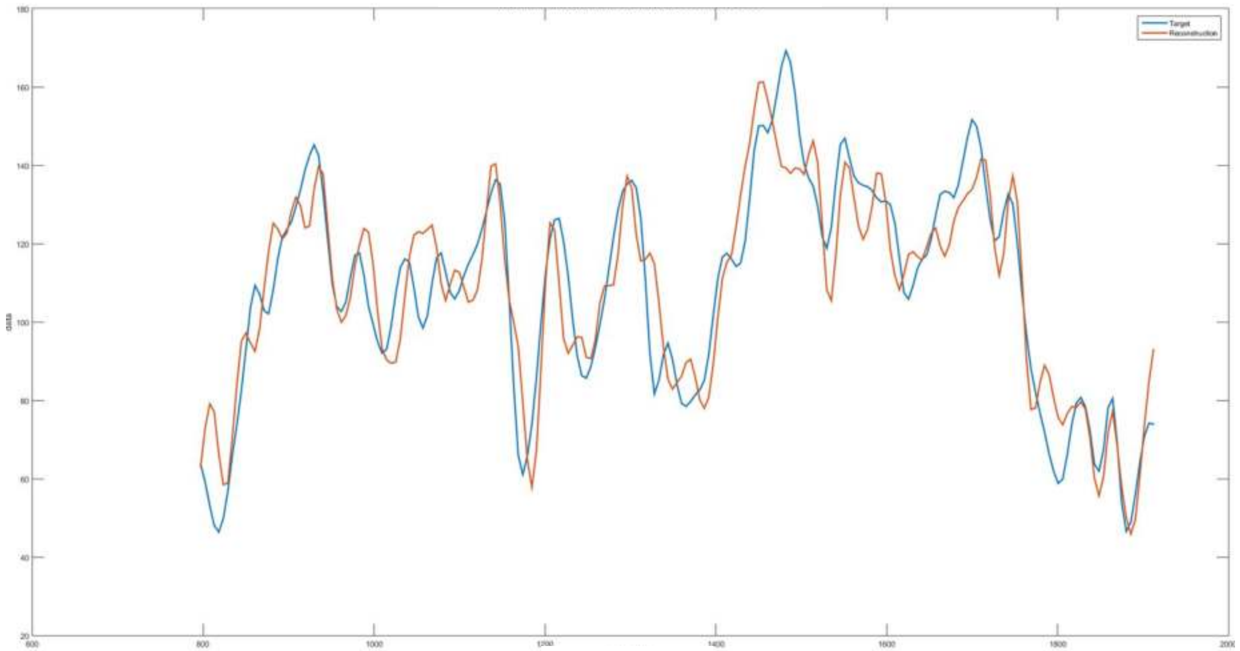
4 Smooth Correlation 77%



Depth (m)

Target Reconstruction

8 Smooth Correlation 91%



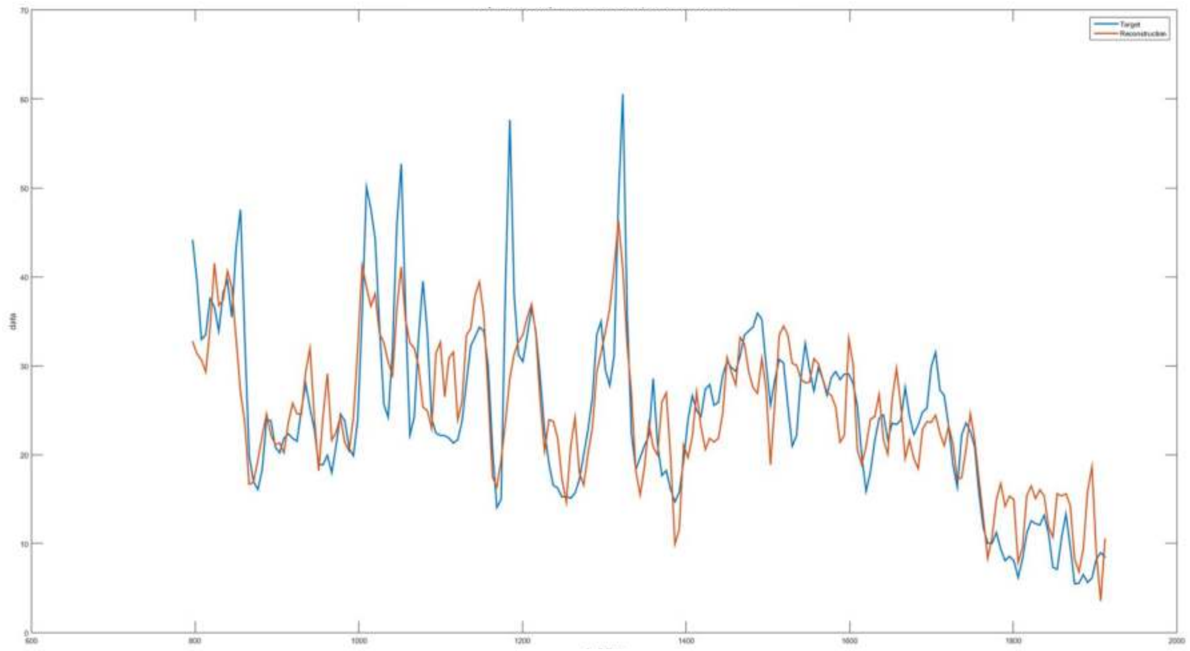
Depth (m)

- The CalcData Mix for Gamma Ray at Ellesmere Port shows a correlation of 77% using a 4 Smooth & correlation of 91% for an 8 Smooth.

- This is a good result.

Cheshire - Ellesmere Port Neutron Porosity

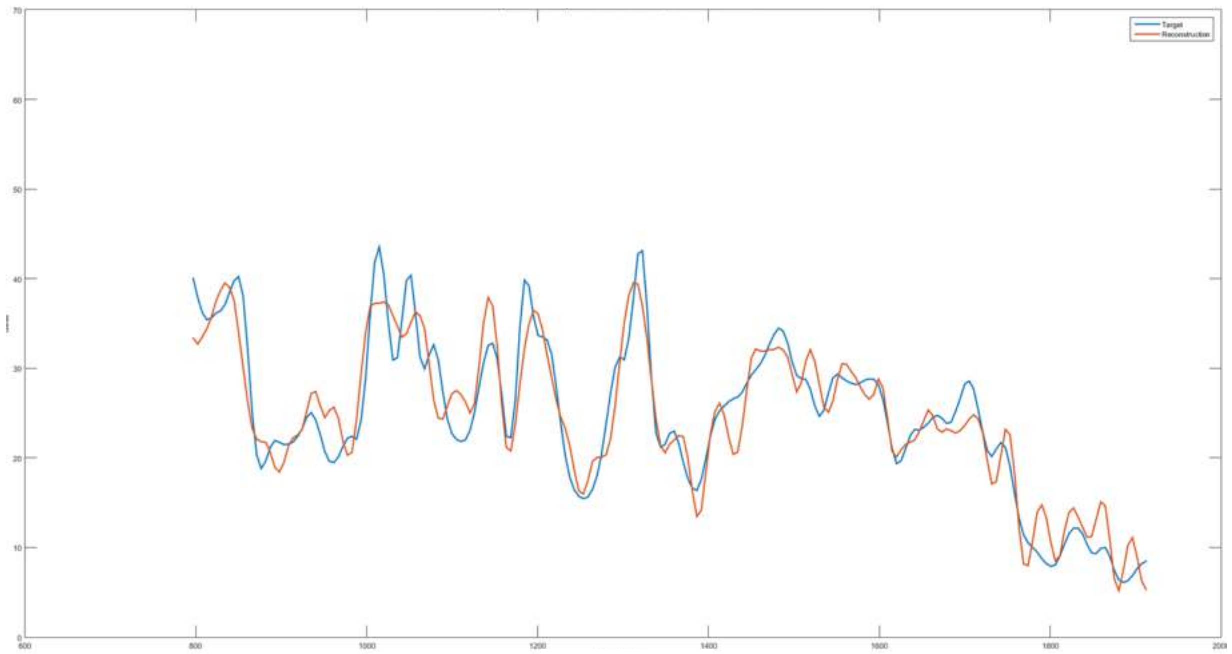
4 Smooth Correlation 81%



Depth (m)

Target Reconstruction

8 Smooth Correlation 94%



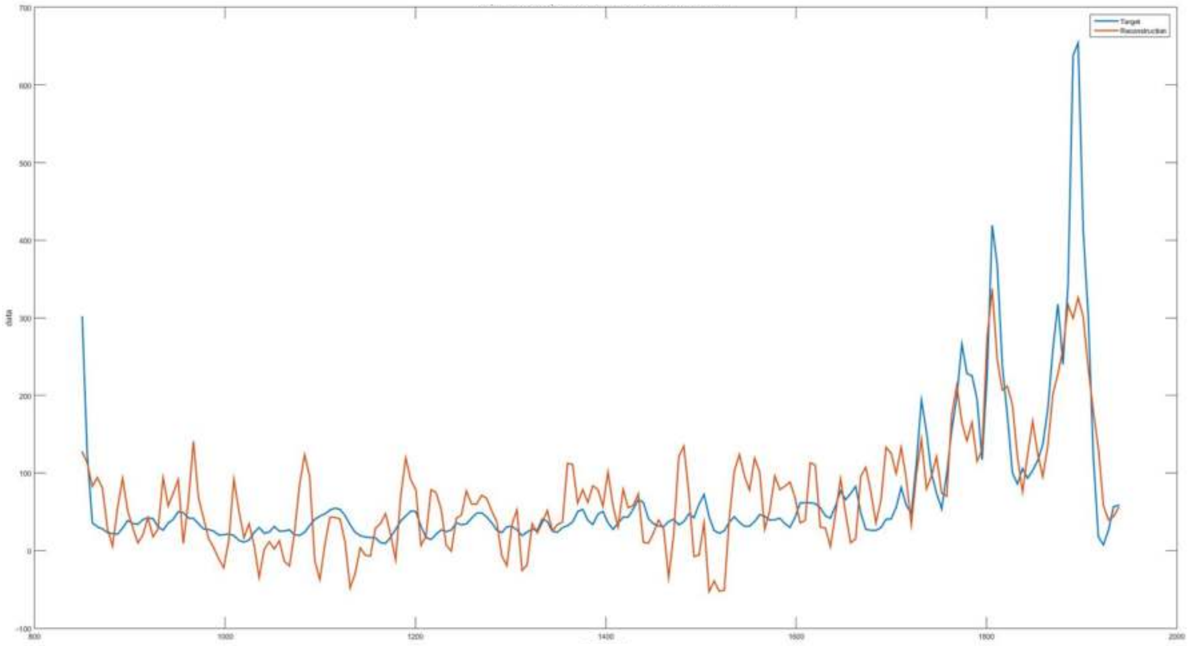
Depth (m)

- The CalcData Mix for Neutron Porosity at Ellesmere Port shows a correlation of 81% using a 4 Smooth & correlation of 94% for an 8 Smooth.

- This is a good result.

Cheshire - Ellesmere Port Resistivity

4 Smooth Correlation 78%

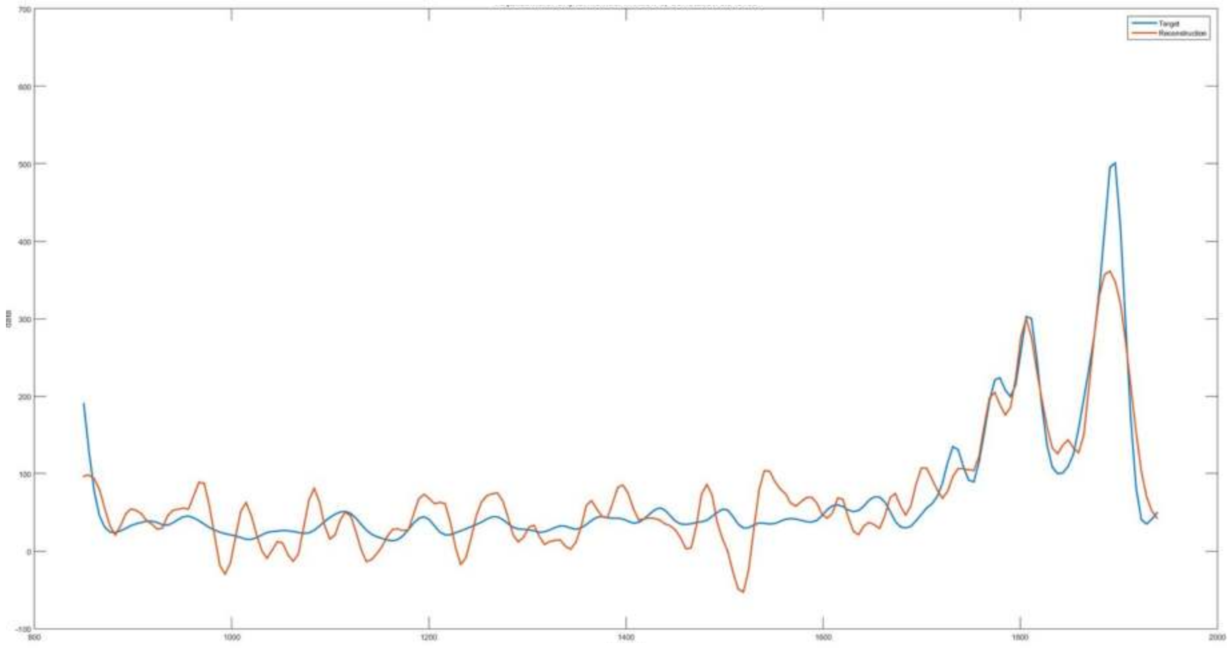


Depth (m)

Target

Reconstruction

8 Smooth Correlation 91%



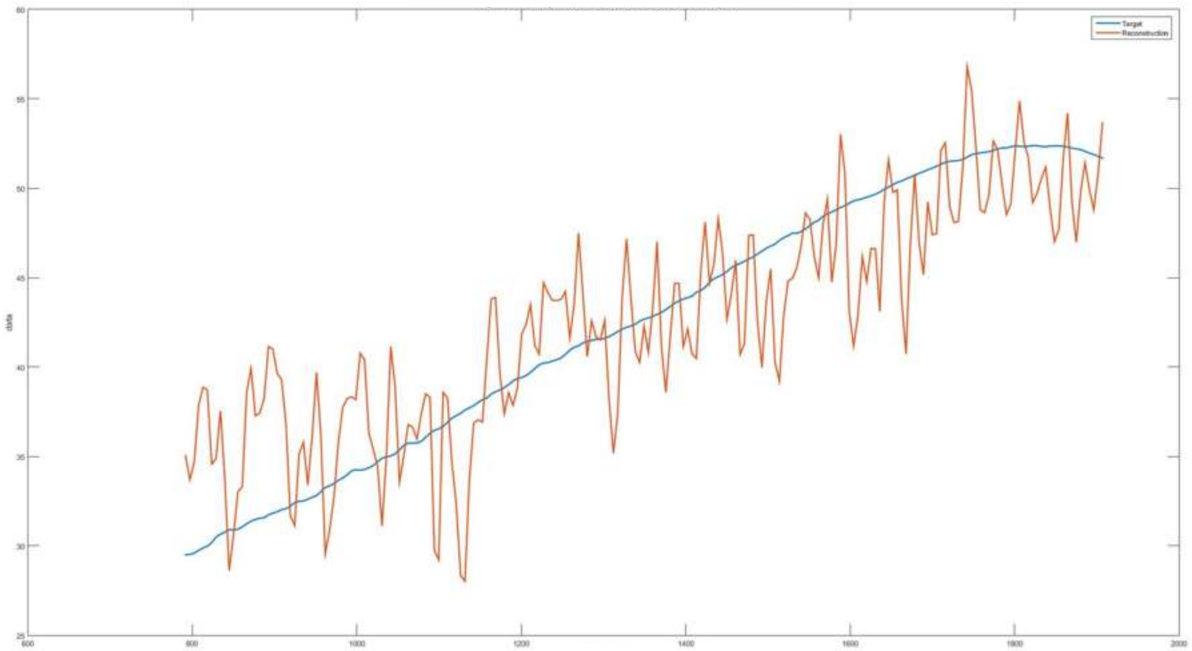
Depth (m)

- The CalcData Mix for Resistivity at Ellesmere Port shows a correlation of 78% using a 4 Smooth & correlation of 91% for an 8 Smooth.

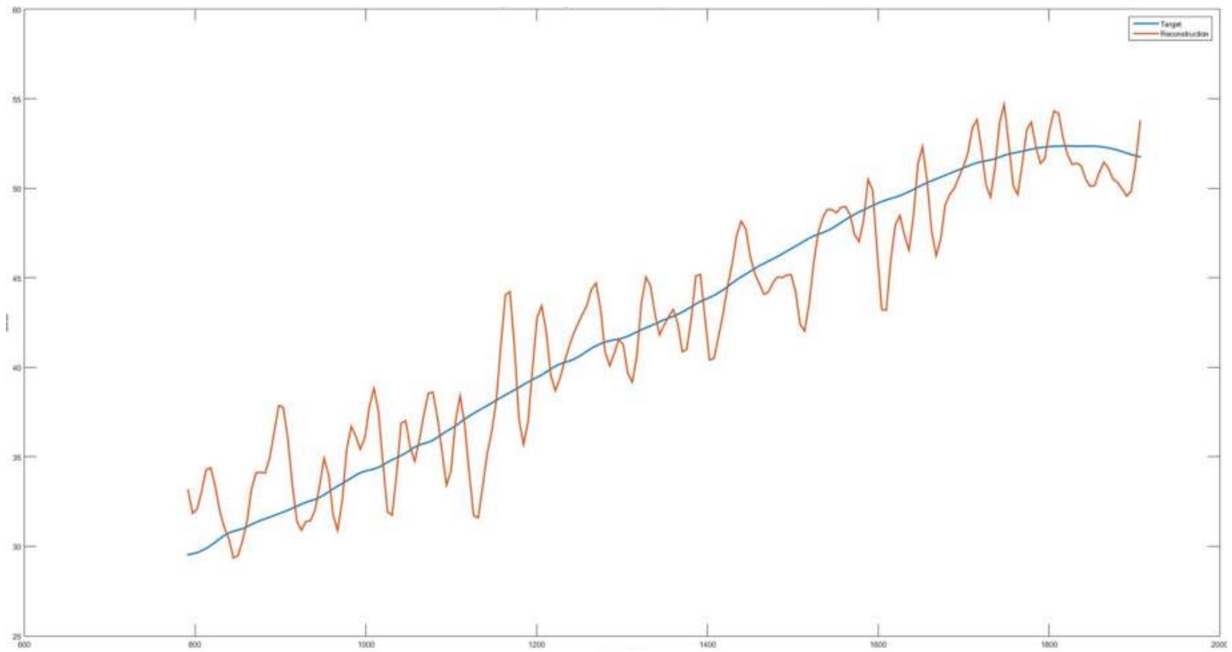
- This is a good result.

Cheshire - Ellesmere Port Temperature

4 Smooth Correlation 85%



8 Smooth Correlation 91%



Depth (m)

Depth (m)

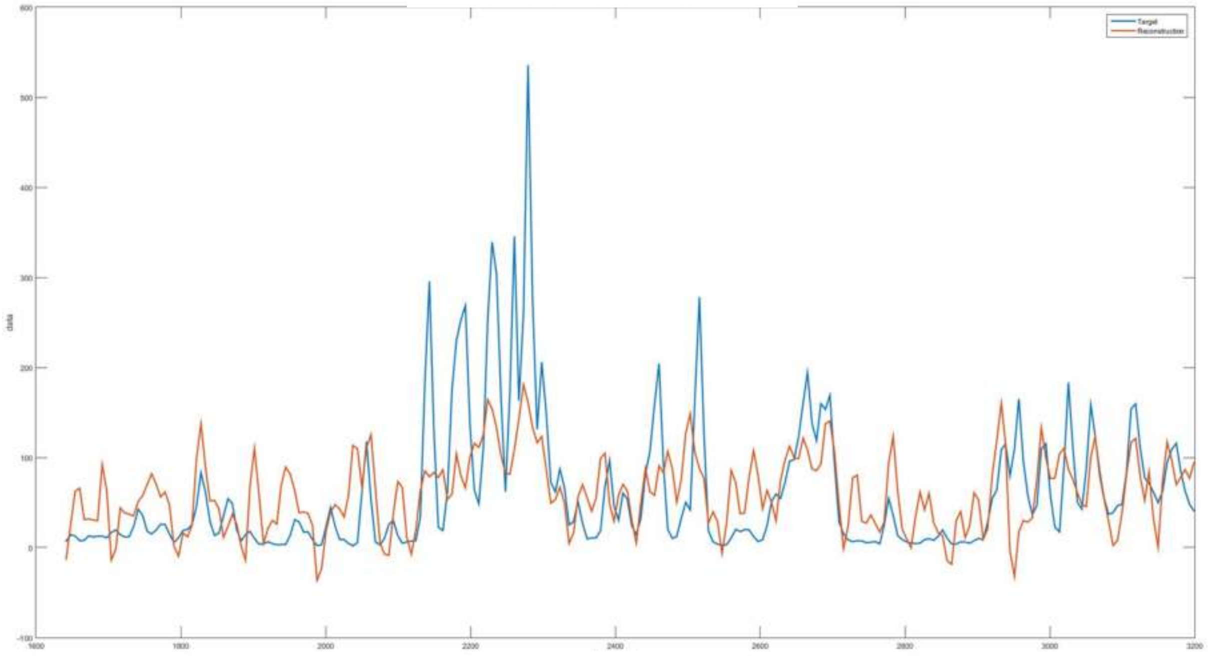
Target

Reconstruction

- The CalcData Mix for Temperature at Ellesmere shows a correlation of 85% using a 4 Smooth & correlation of 91% for an 8 Smooth.
- This is a good result.

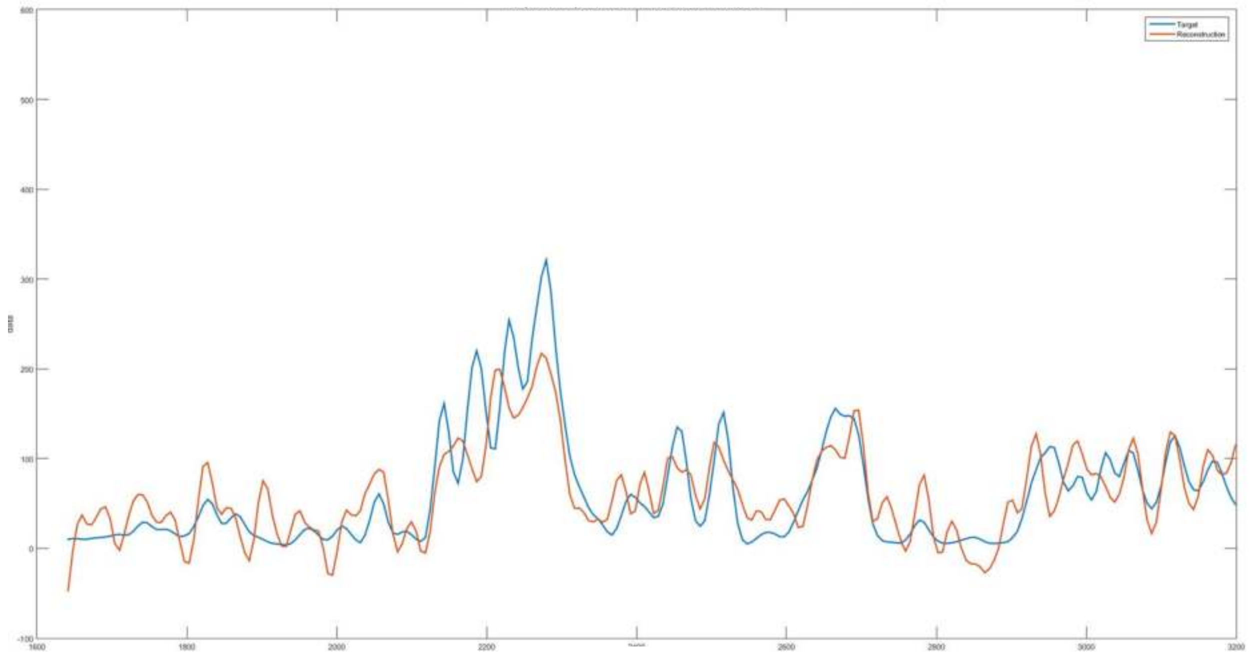
Lancashire - Becconsall Formation Resistivity

4 Smooth Correlation 57%



Depth (m)

8 Smooth Correlation 82%



Depth (m)

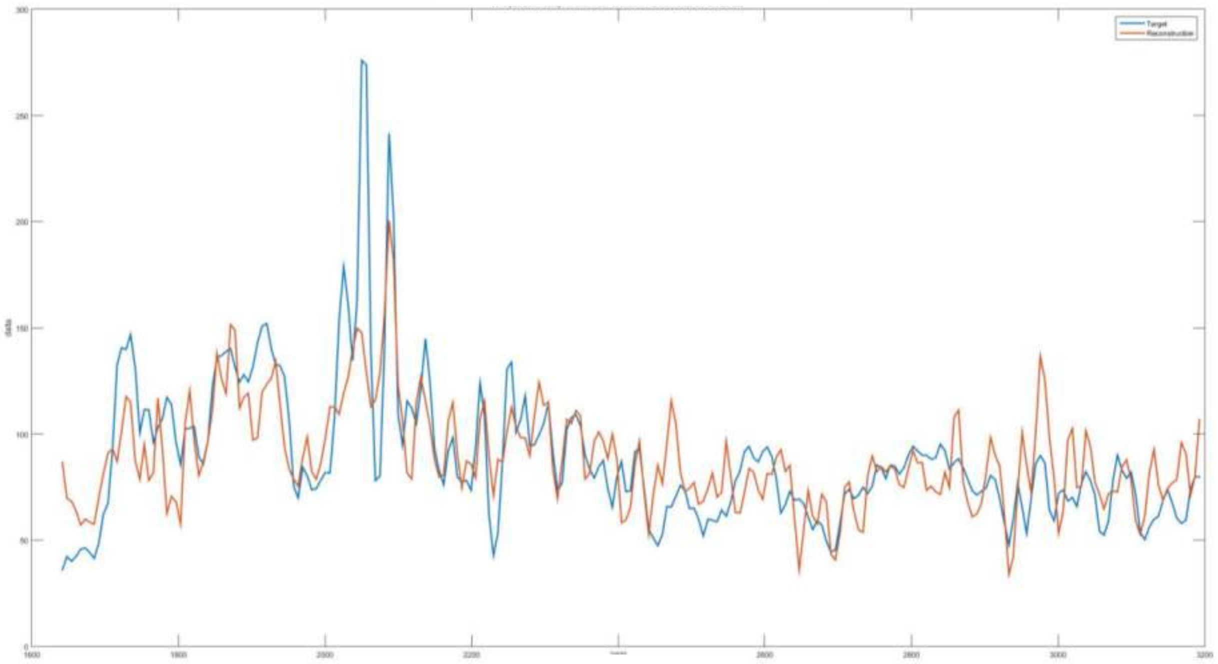
Target Reconstruction

- The CalcData Mix for Formation Resistvity at Becconsall shows a correlation of 57% using a 4 Smooth & correlation of 82% for an 8 Smooth.

- This is an ok result.

Lancashire - Becconsall Gamma Ray

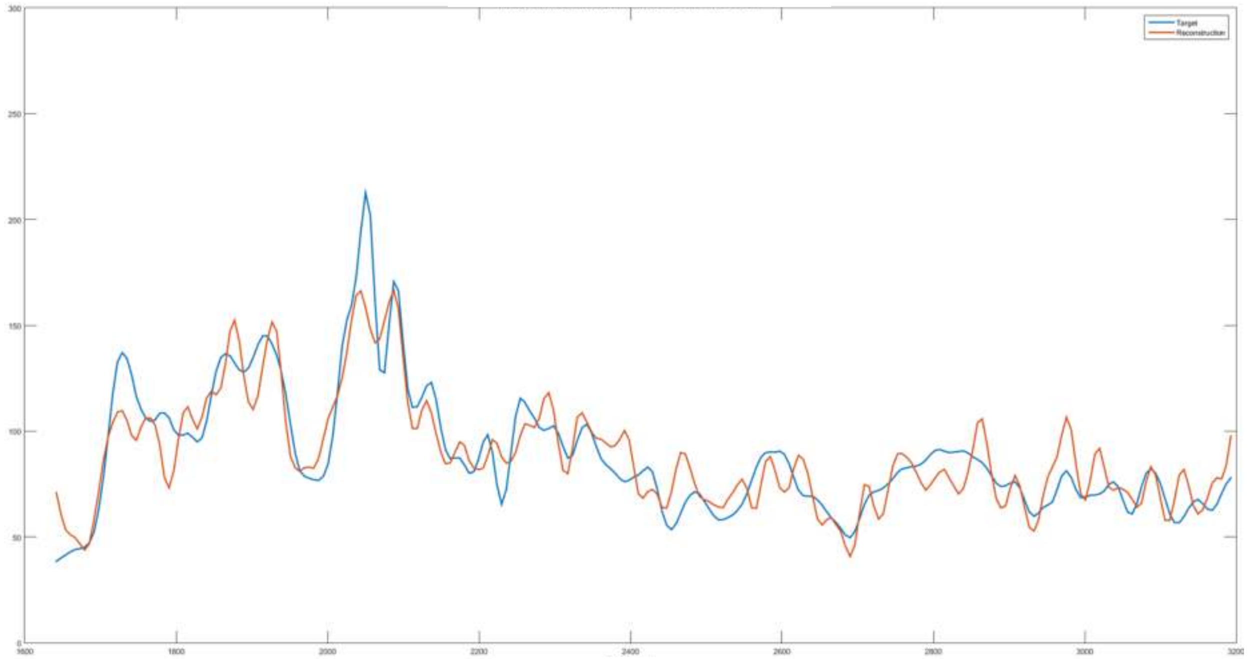
4 Smooth Correlation 72%



Depth (m)

Target Reconstruction

8 Smooth Correlation 89%



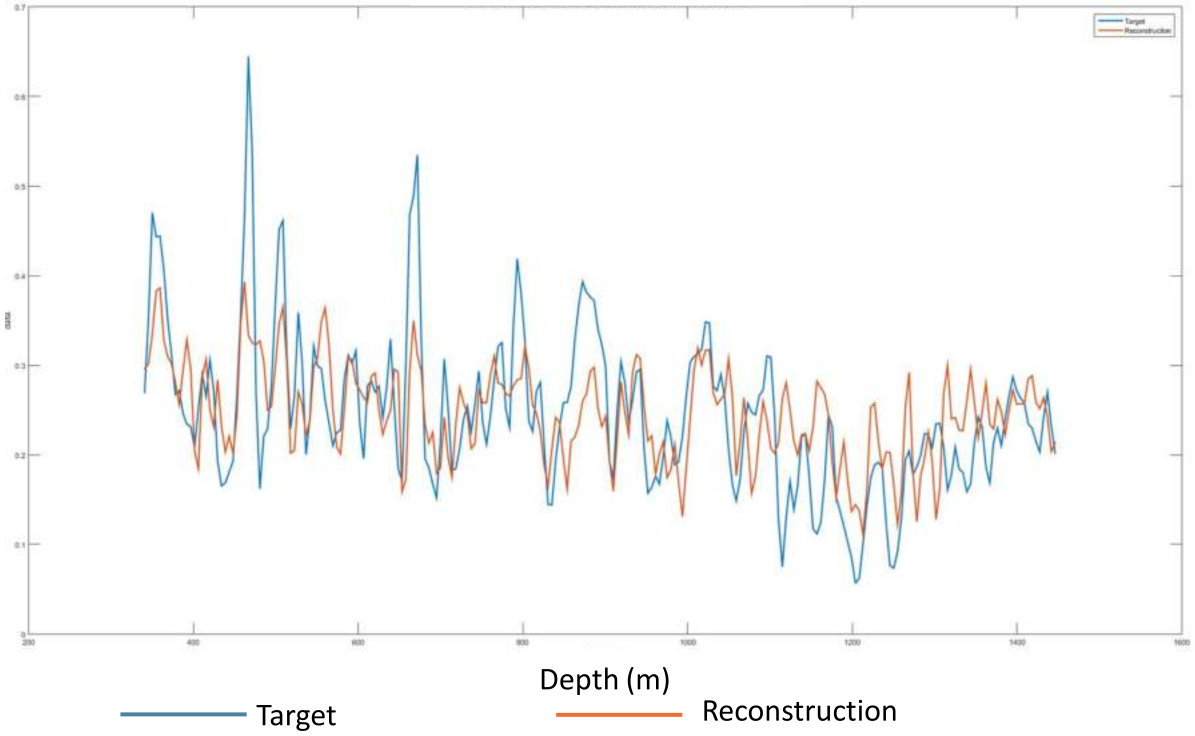
Depth (m)

- The CalcData Mix for Gamma Ray at Becconsall shows a correlation of 72% using a 4 Smooth & correlation of 89% for an 8 Smooth.

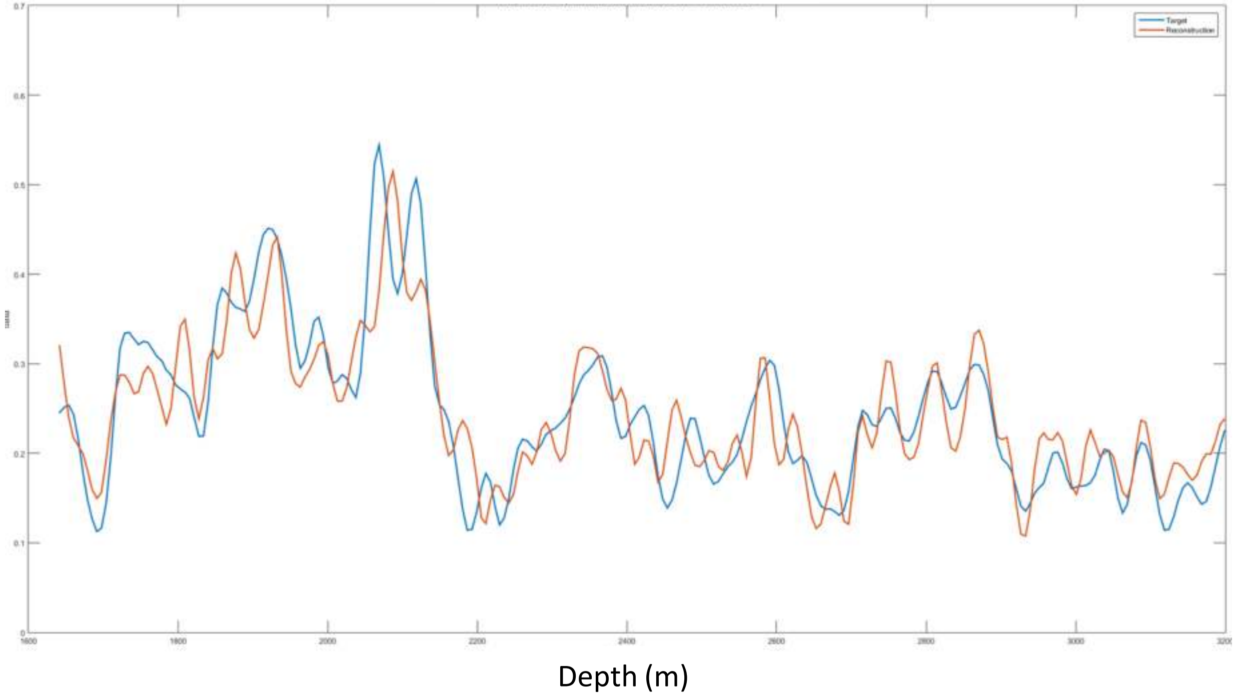
- This is a good result.

Lancashire - Becconsall Neutron Porosity

4 Smooth Correlation 66%



8 Smooth Correlation 87%

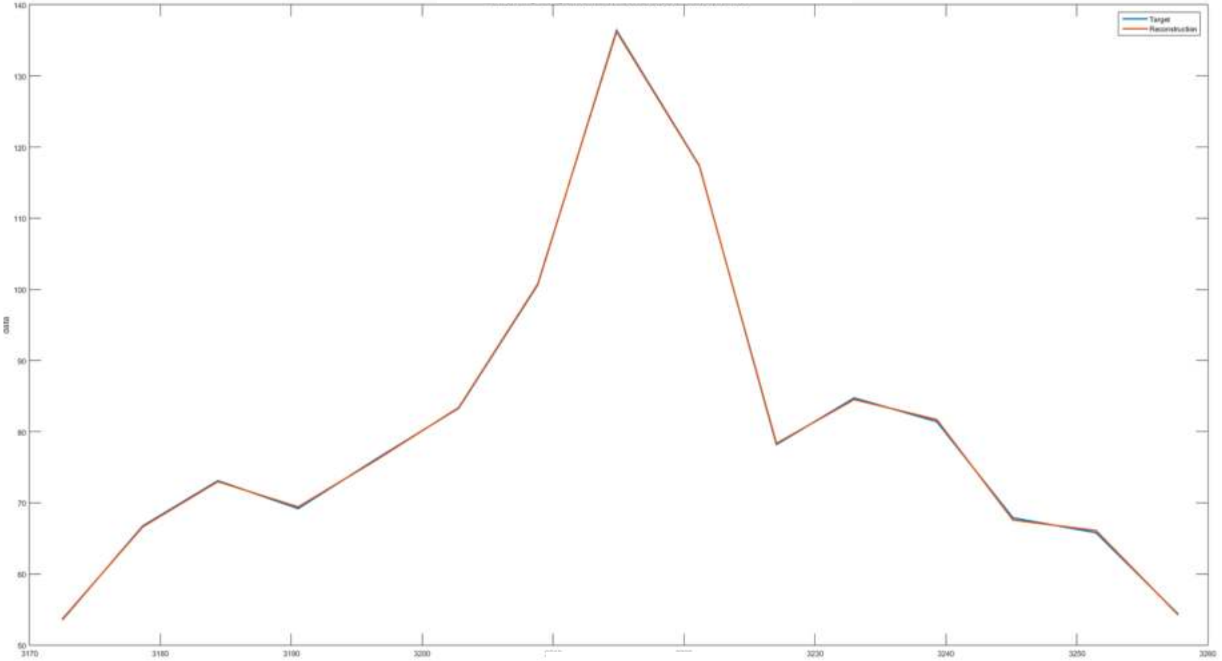


- The CalcData Mix for Neutron Porosity at Becconsall shows a correlation of 66% using a 4 Smooth & correlation of 87% for an 8 Smooth.

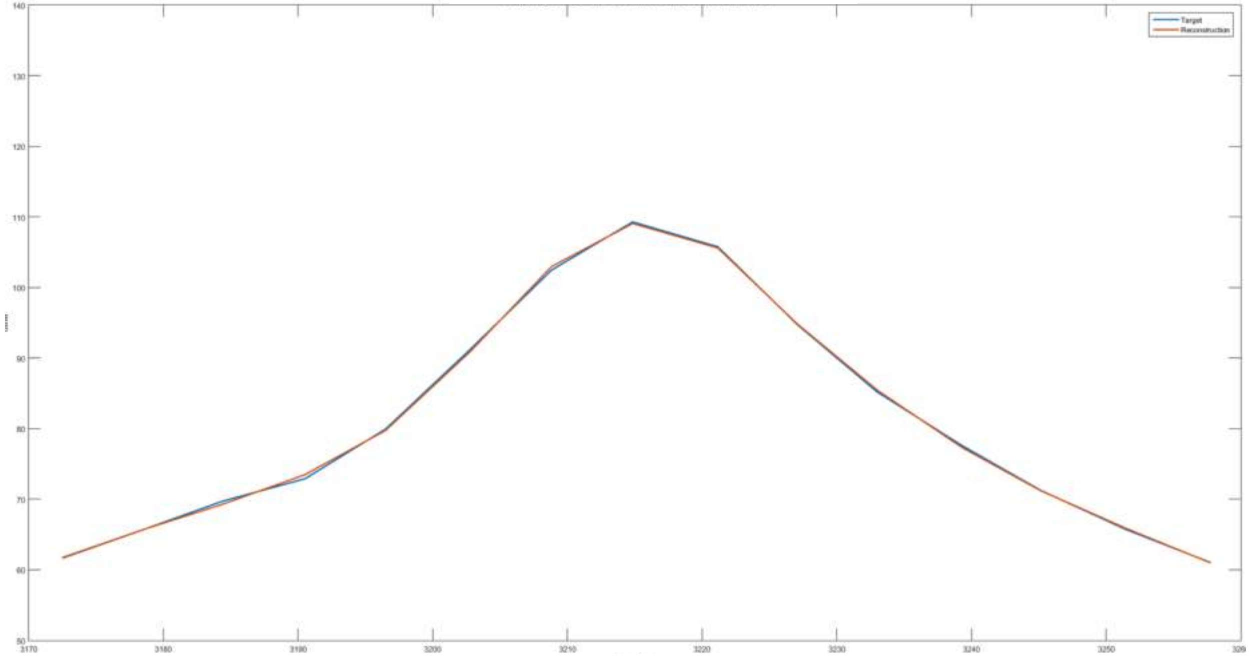
- This is an ok result.

Lancashire - Grange Hill Gamma Ray

4 Smooth Correlation 99.9%



8 Smooth Correlation 99.9%

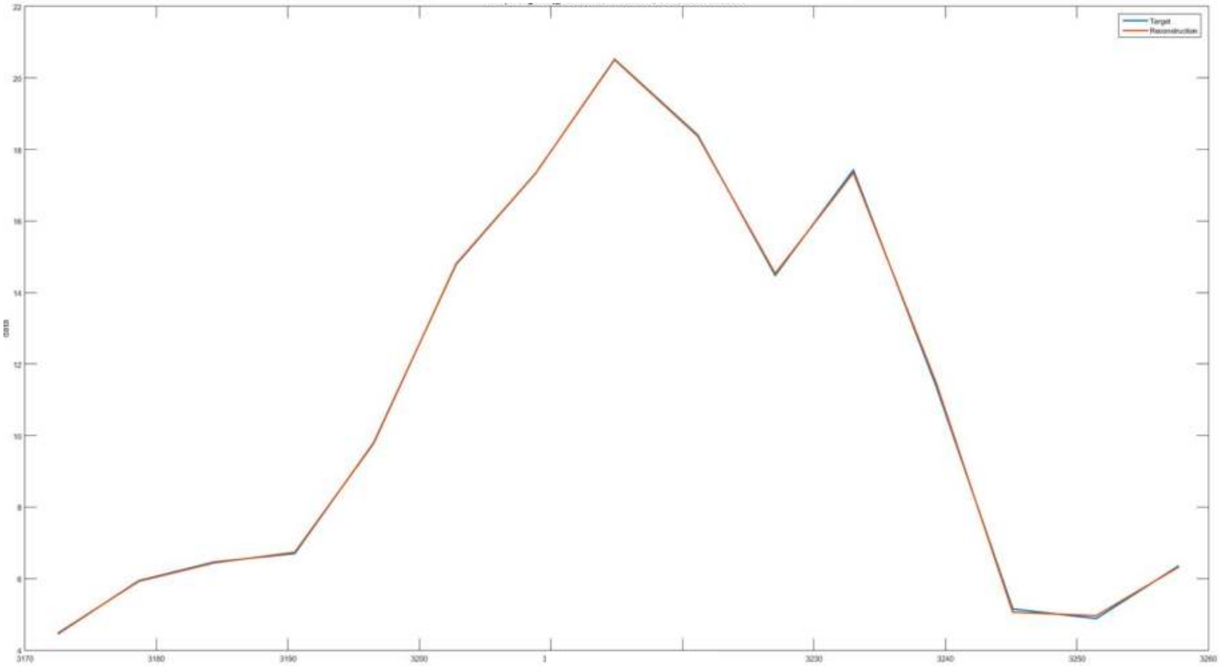


- The CalcData Mix for Gamma Ray at Grange Hill shows a correlation of 99.9% using a 4 Smooth & correlation of 99.9% for an 8 Smooth.

- This is a good result.

Lancashire - Grange Hill Neutron Porosity

4 Smooth Correlation 99.9%

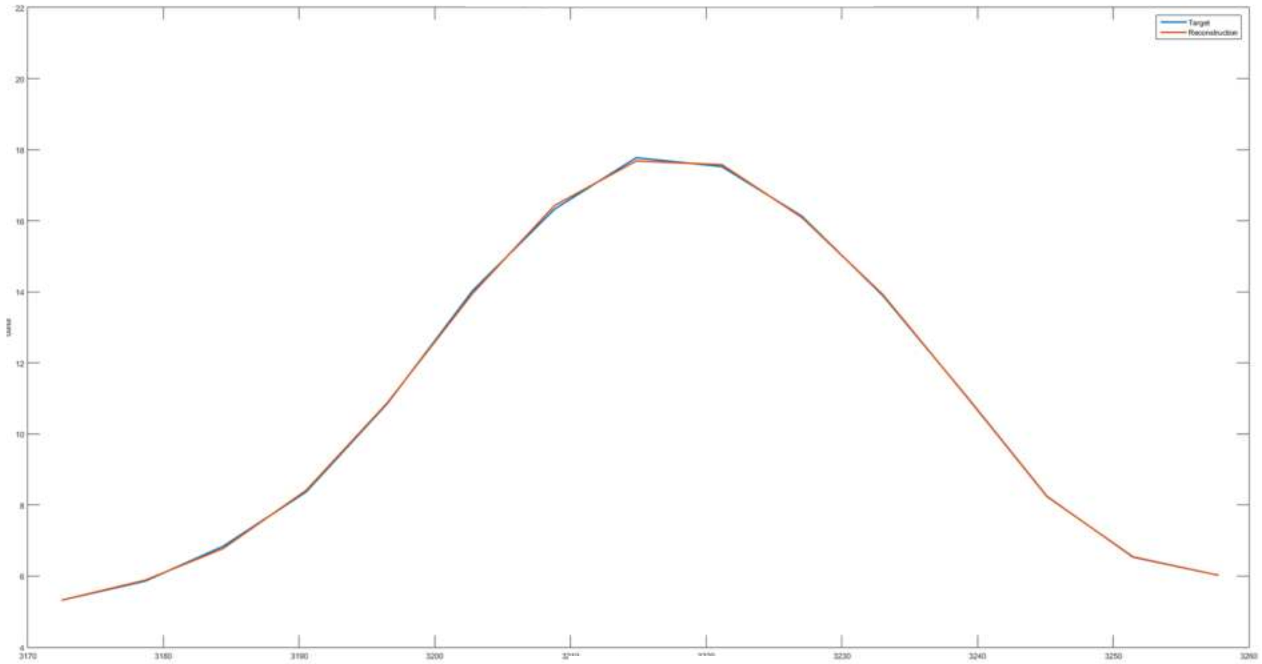


Depth (m)

Target

Reconstruction

8 Smooth Correlation 99.9%

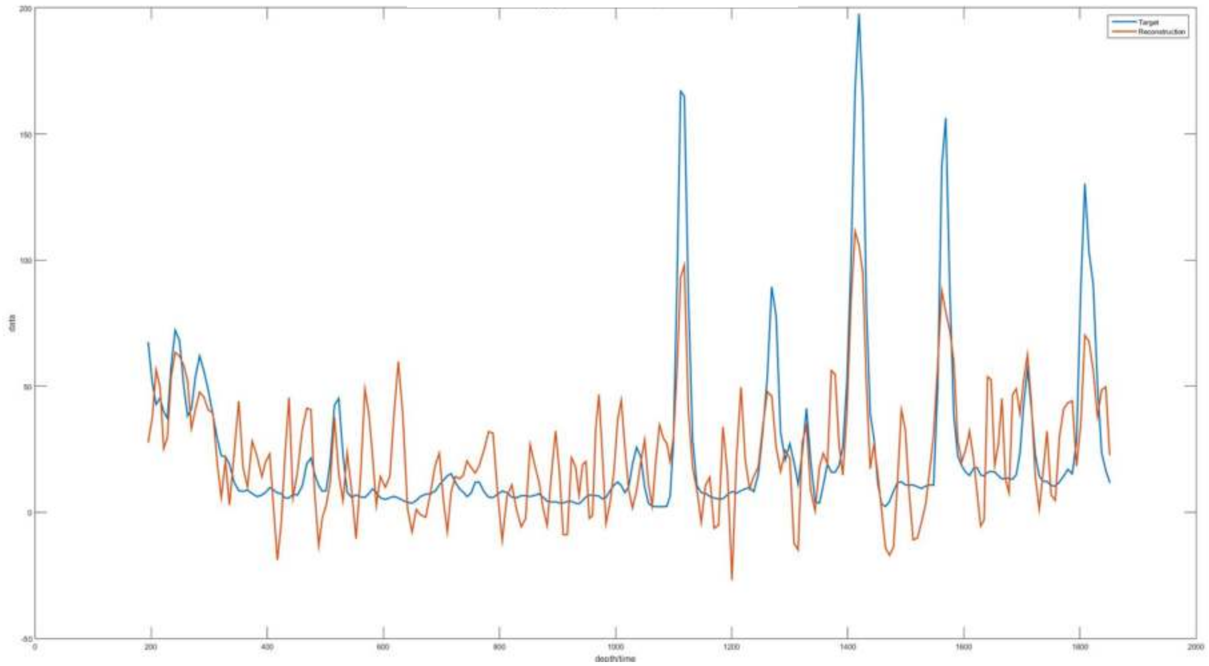


Depth (m)

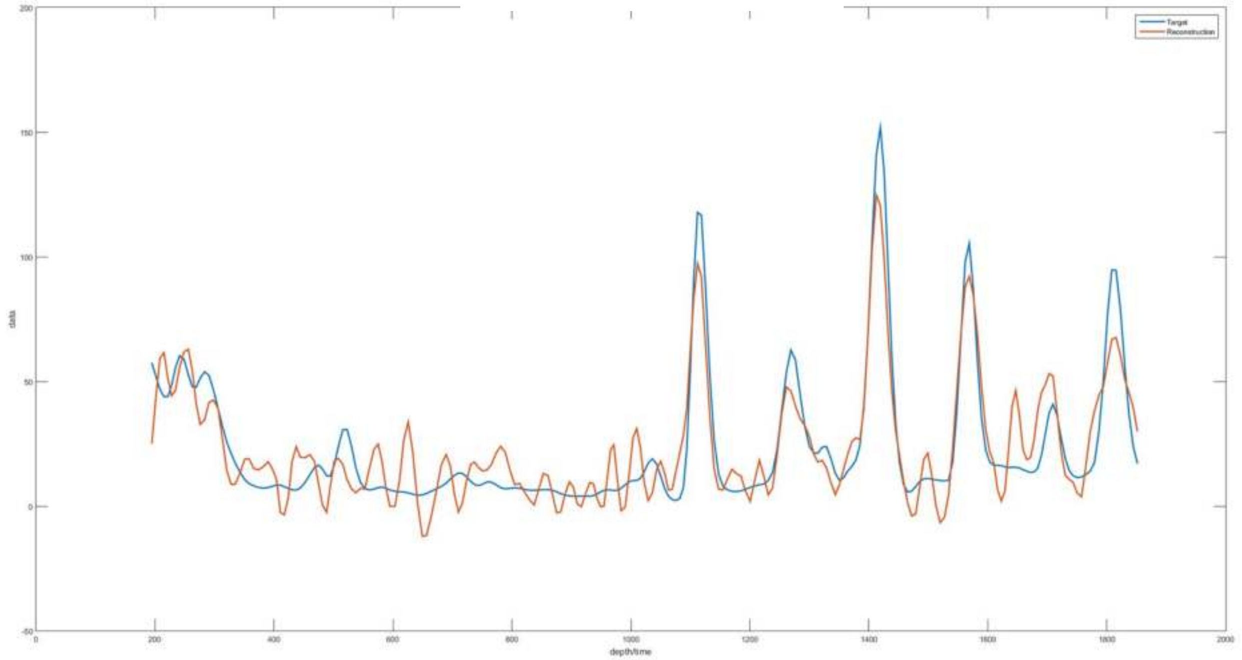
- The CalcData Mix for Neutron Porosity at Grange Hill shows a correlation of 99.9% using a 4 Smooth & correlation of 99.9% for an 8 Smooth.
- This is a good result.

Weald - Bletchingley 1 Deep Resistivity

4 Smooth Correlation 73%



8 Smooth Correlation 90%

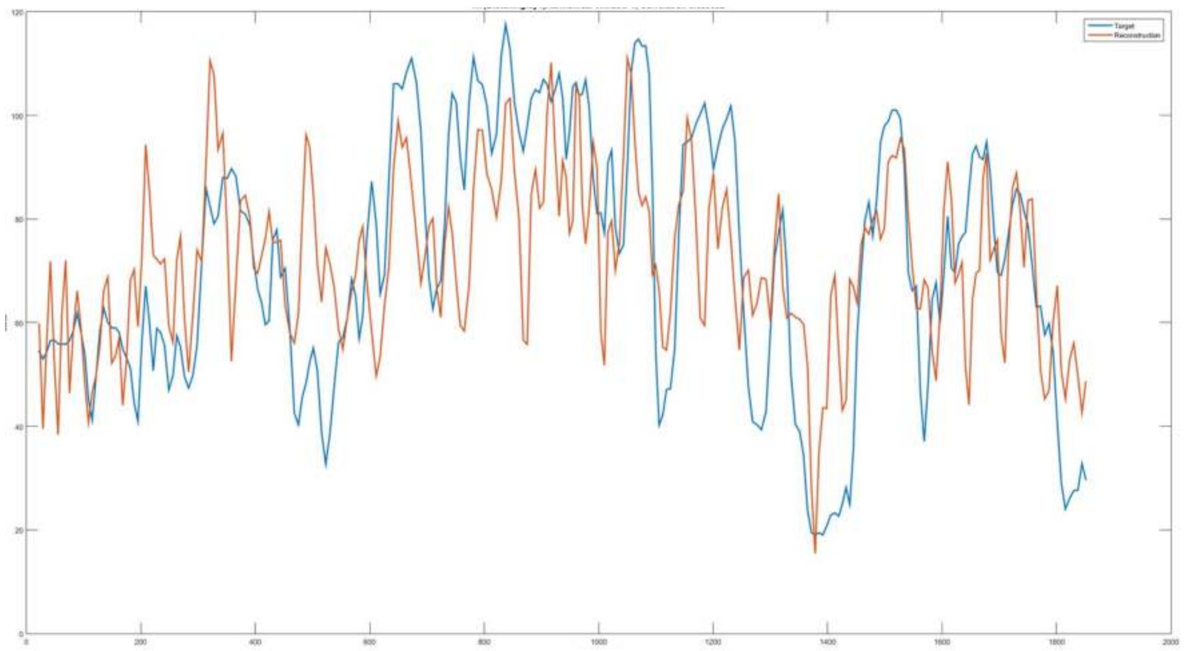


Target Reconstruction

- The CalcData Mix for Deep Resistivity at Bletchingley 1 shows a correlation of 73% using a 4 Smooth & correlation of 90% for an 8 Smooth.
- This is a good result.

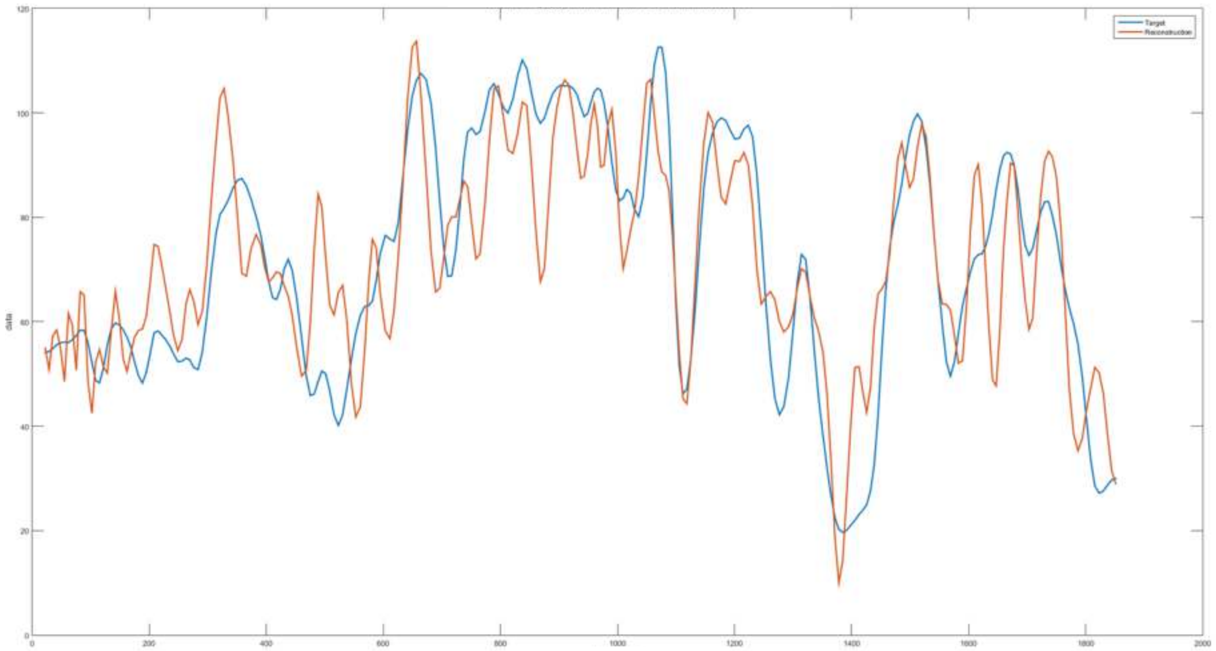
Weald - Bletchingley 1 Gamma Ray

4 Smooth Correlation 66%



Depth (m)

8 Smooth Correlation 83%



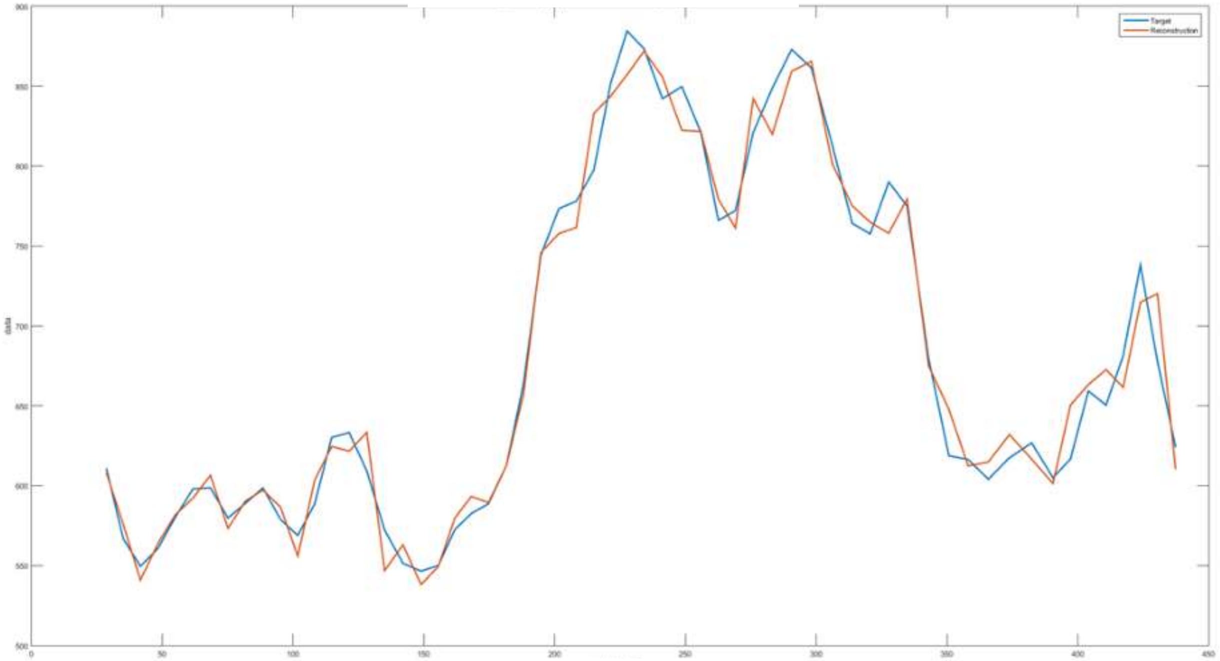
Depth (m)

Target Reconstruction

- The CalcData Mix for Gamma Ray at Bletchingley 1 shows a correlation of 66% using a 4 Smooth & correlation of 83% for an 8 Smooth.
- This is an ok result.

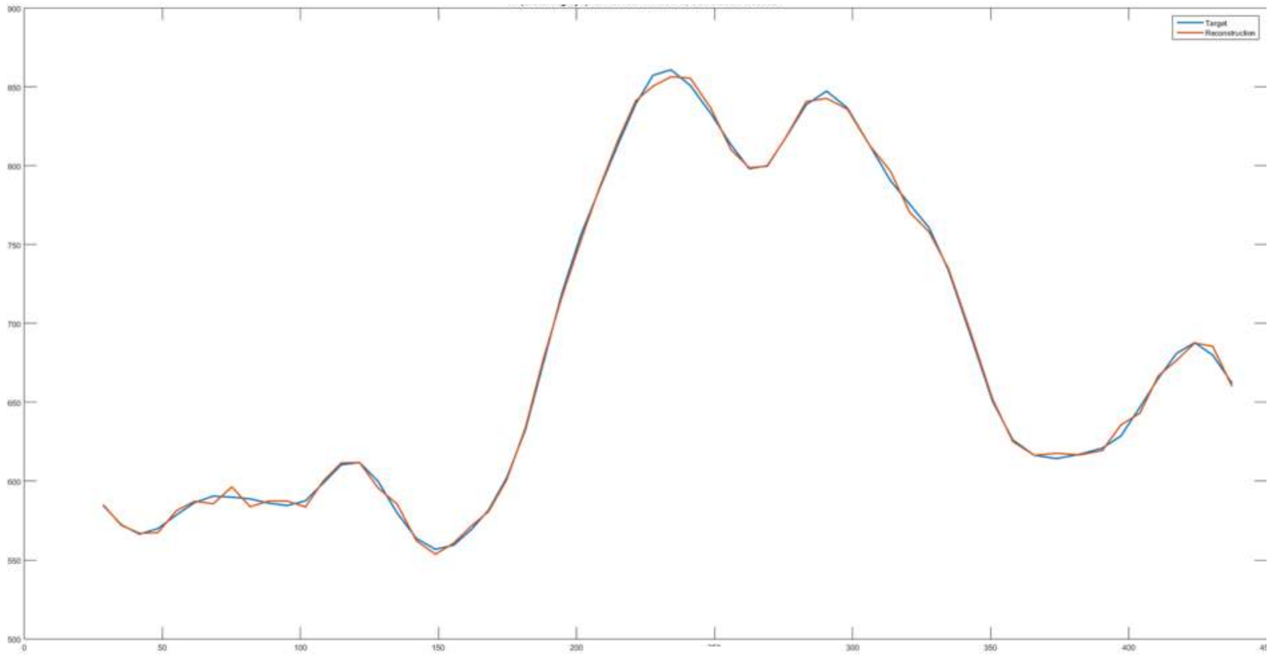
Weald - Bletchingley 1 Neutron Porosity

4 Smooth Correlation 98%



Depth (m)

8 Smooth Correlation 99%



Depth (m)

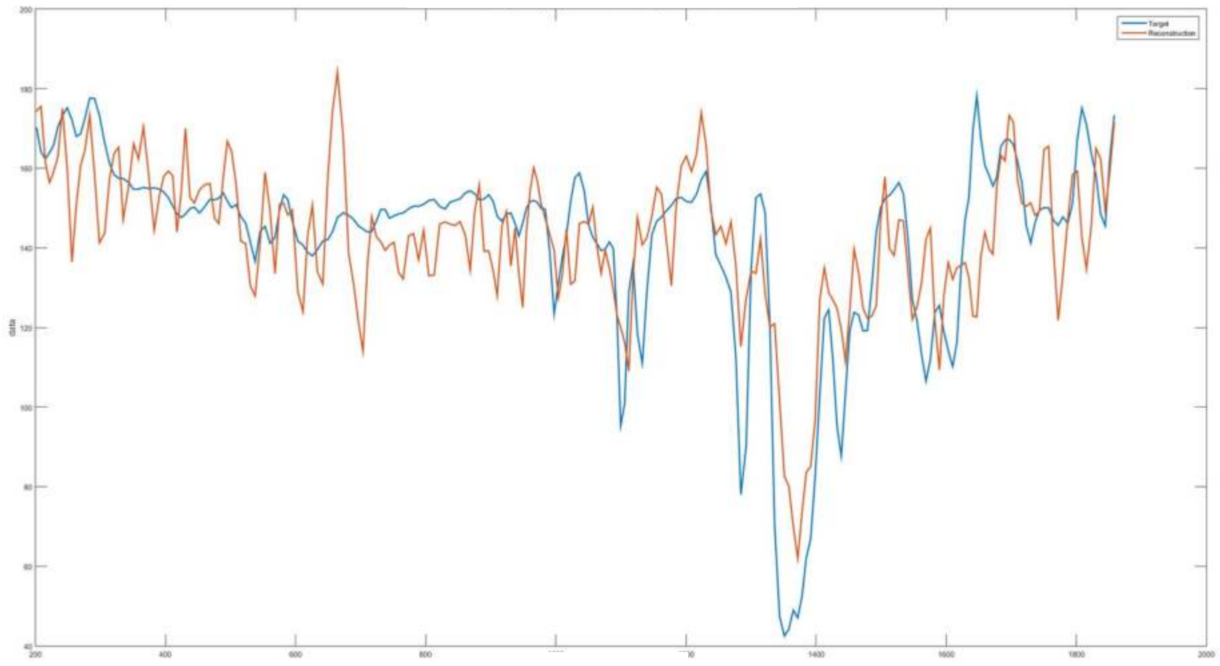
Target   Reconstruction

- The CalcData Mix for Neutron Porosity at Bletchingley 1 shows a correlation of 98% using a 4 Smooth & correlation of 99% for an 8 Smooth.

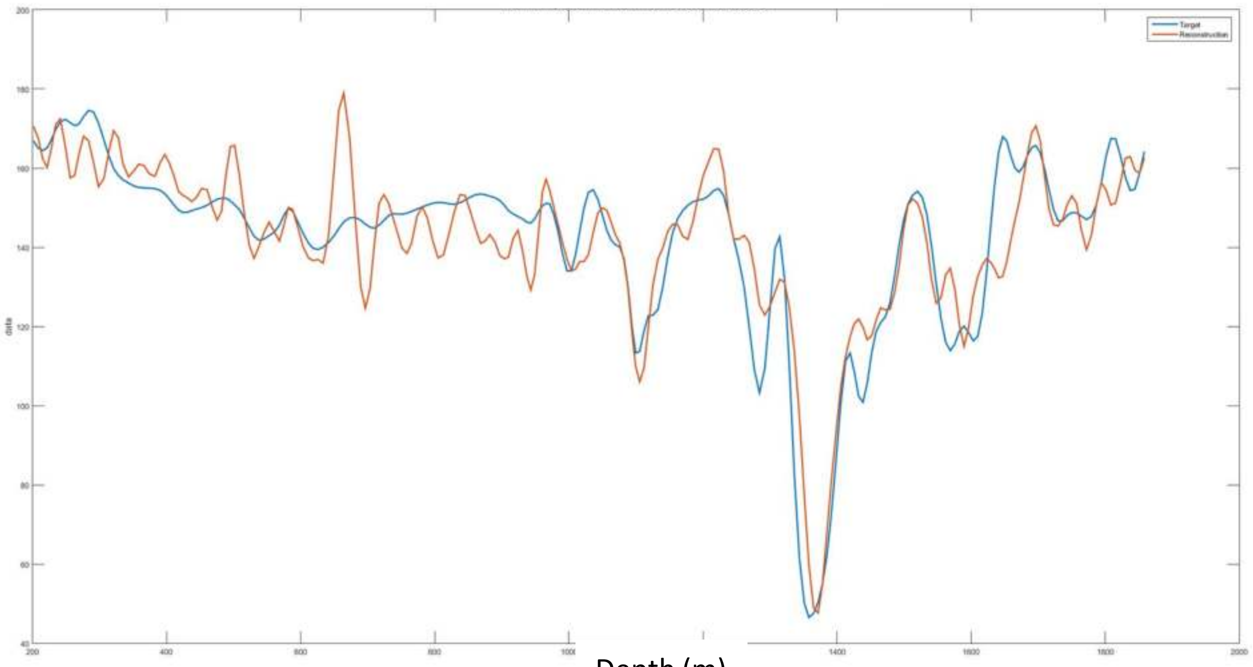
- This is a good result.

Weald - Bletchingley 1 Spontaneous Potential

4 Smooth Correlation 77%



8 Smooth Correlation 90%



Depth (m)

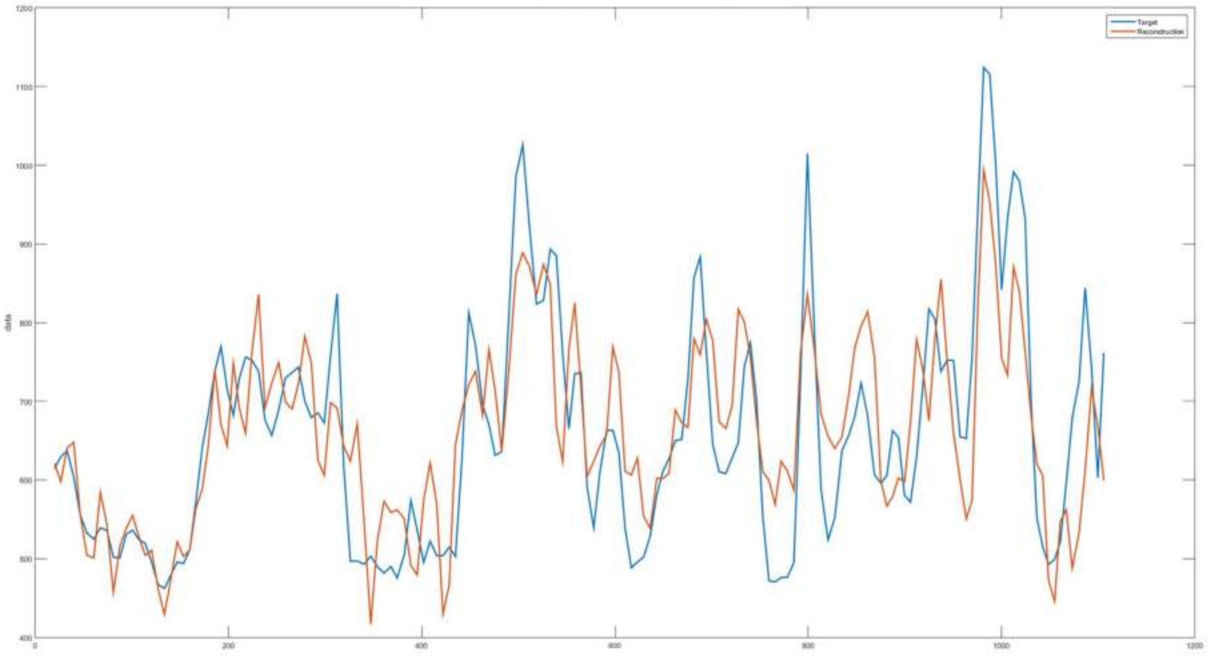
Target Reconstruction

- The CalcData Mix for Spontaneous Potential at Bletchingley 1 shows a correlation of 77% using a 4 Smooth & correlation of 90% for an 8 Smooth.

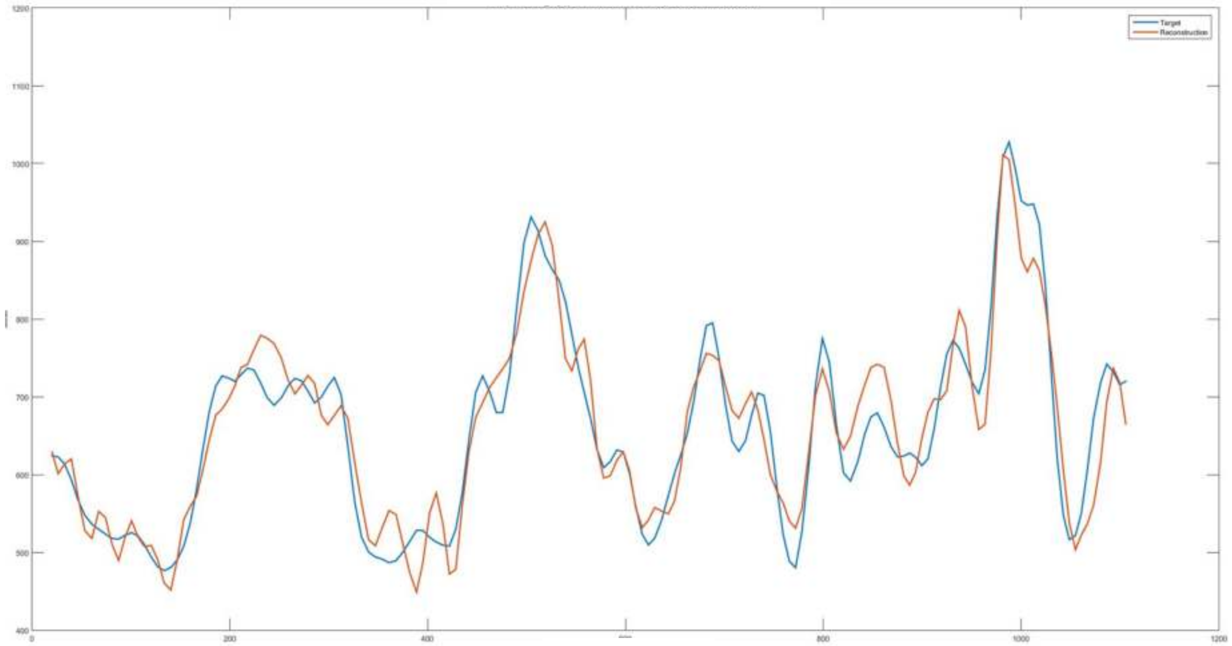
- This is a good result.

Weald - Bletchingley 2 Neutron Porosity

4 Smooth Correlation 79%



8 Smooth Correlation 97%



Depth (m)

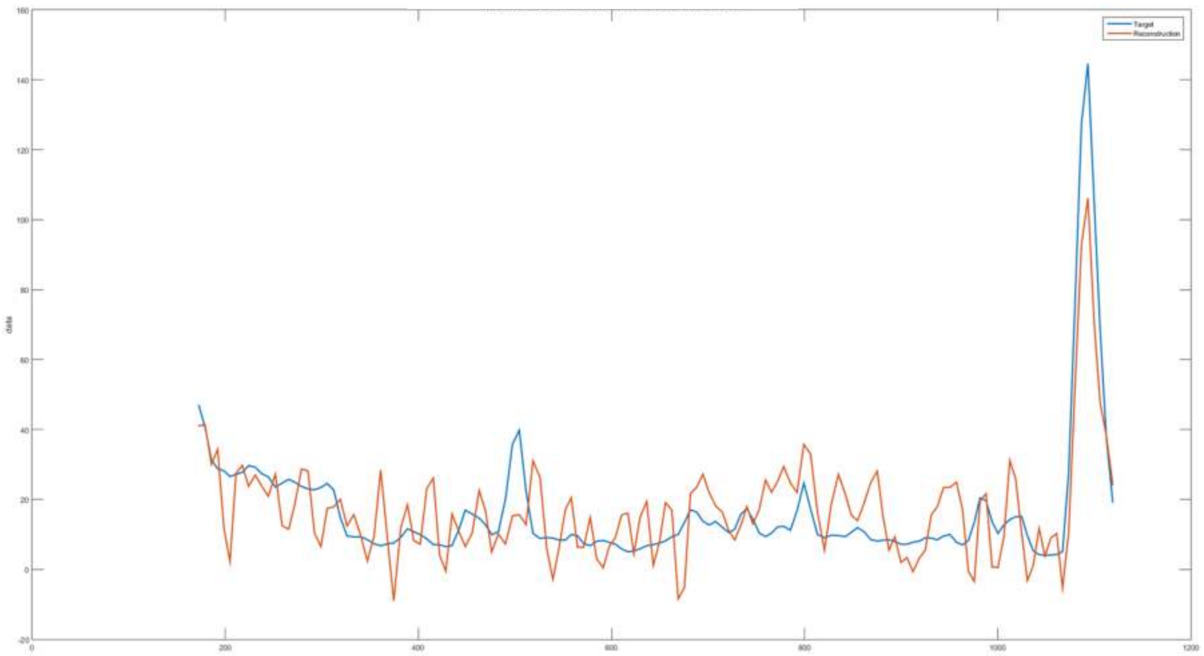
Target Reconstruction

- The CalcData Mix for Neutron Porosity at Bletchingley 2 shows a correlation of 79% using a 4 Smooth & correlation of 97% for an 8 Smooth.

- This is a good result.

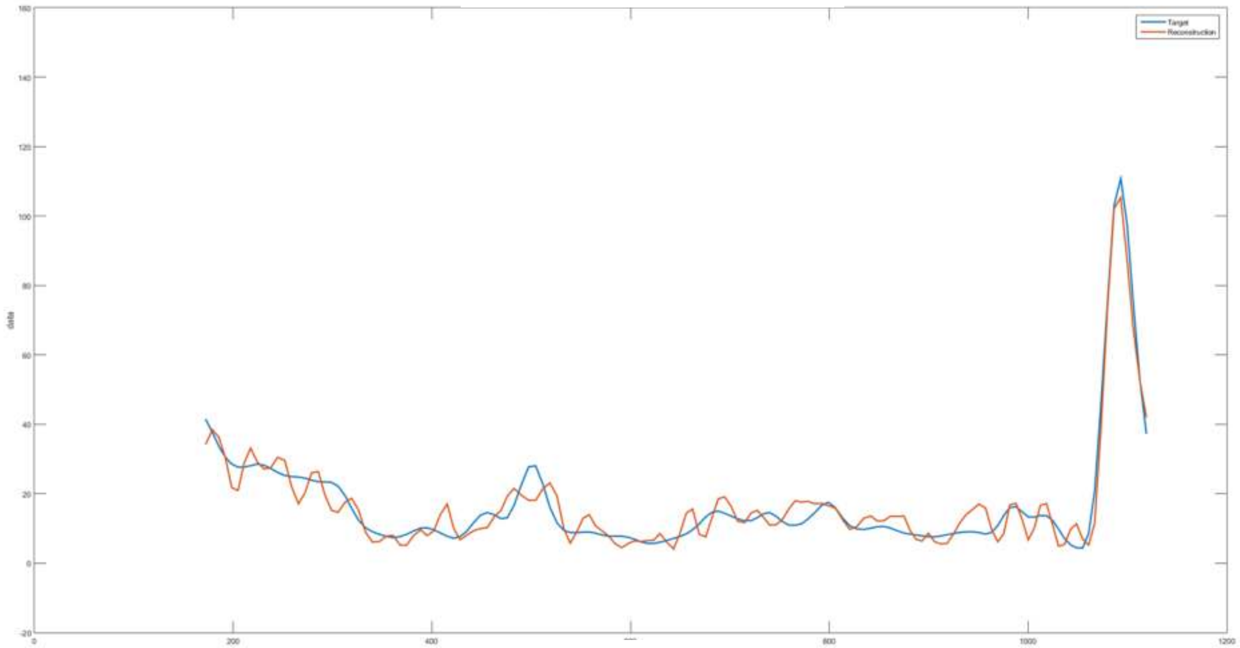
Weald - Bletchingley 2 Resistivity short

4 Smooth Correlation 80%



Depth (m)

8 Smooth Correlation 97%



Depth (m)

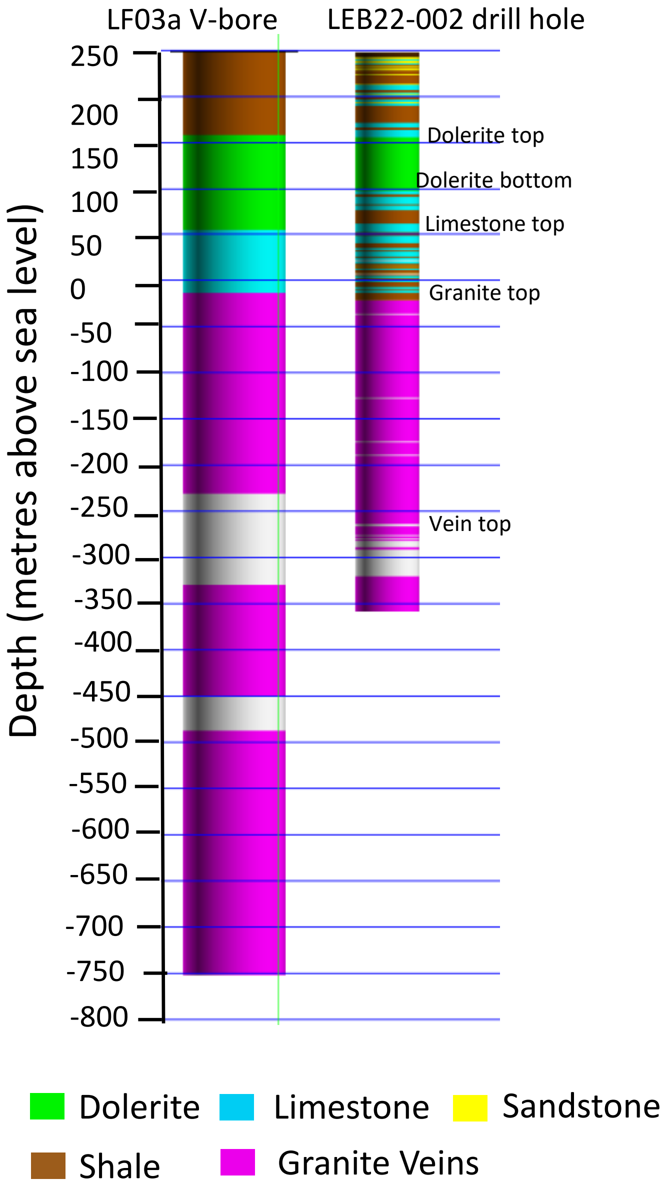
Target

Reconstruction

- The CalcData Mix for Resistivity Short at Bletchingley 2 shows a correlation of 80% using a 4 Smooth & correlation of 97% for an 8 Smooth.
- This is a good result.

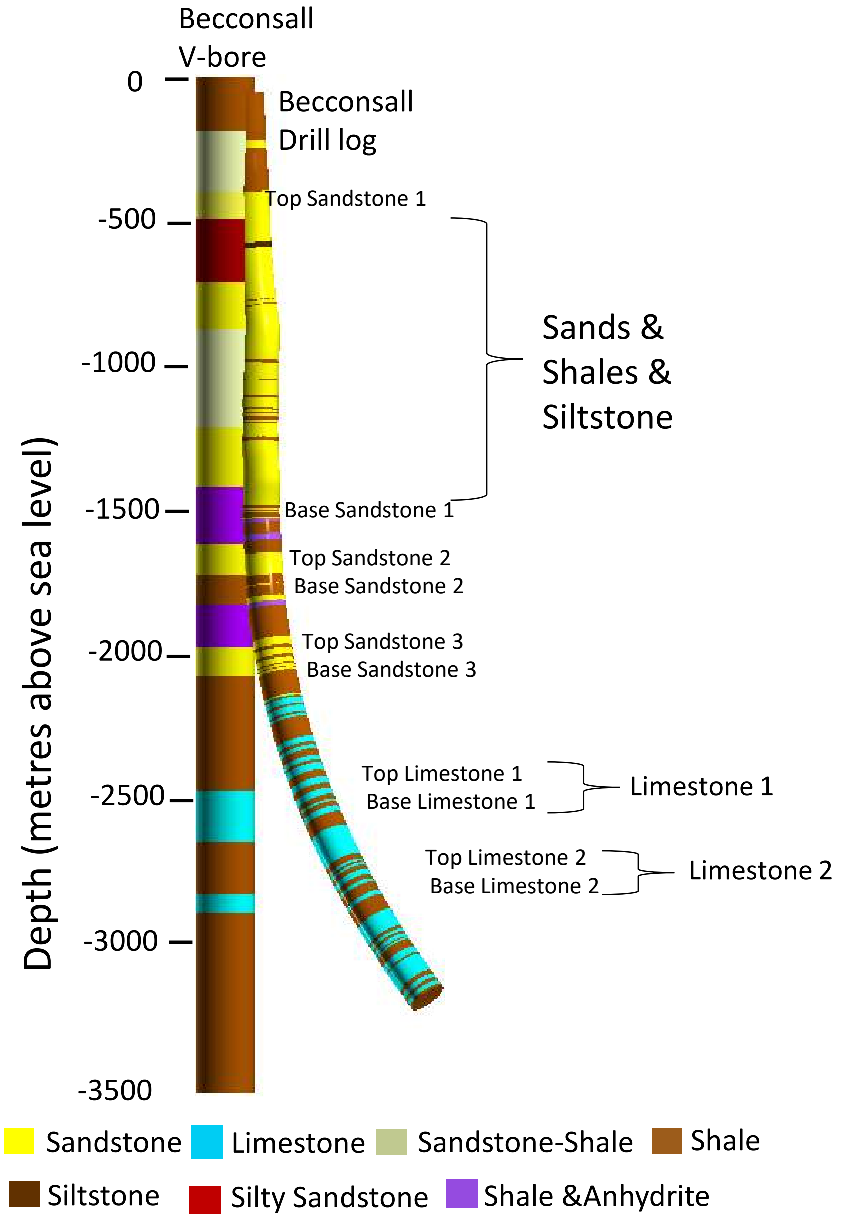
Zonation

Durham Lithology



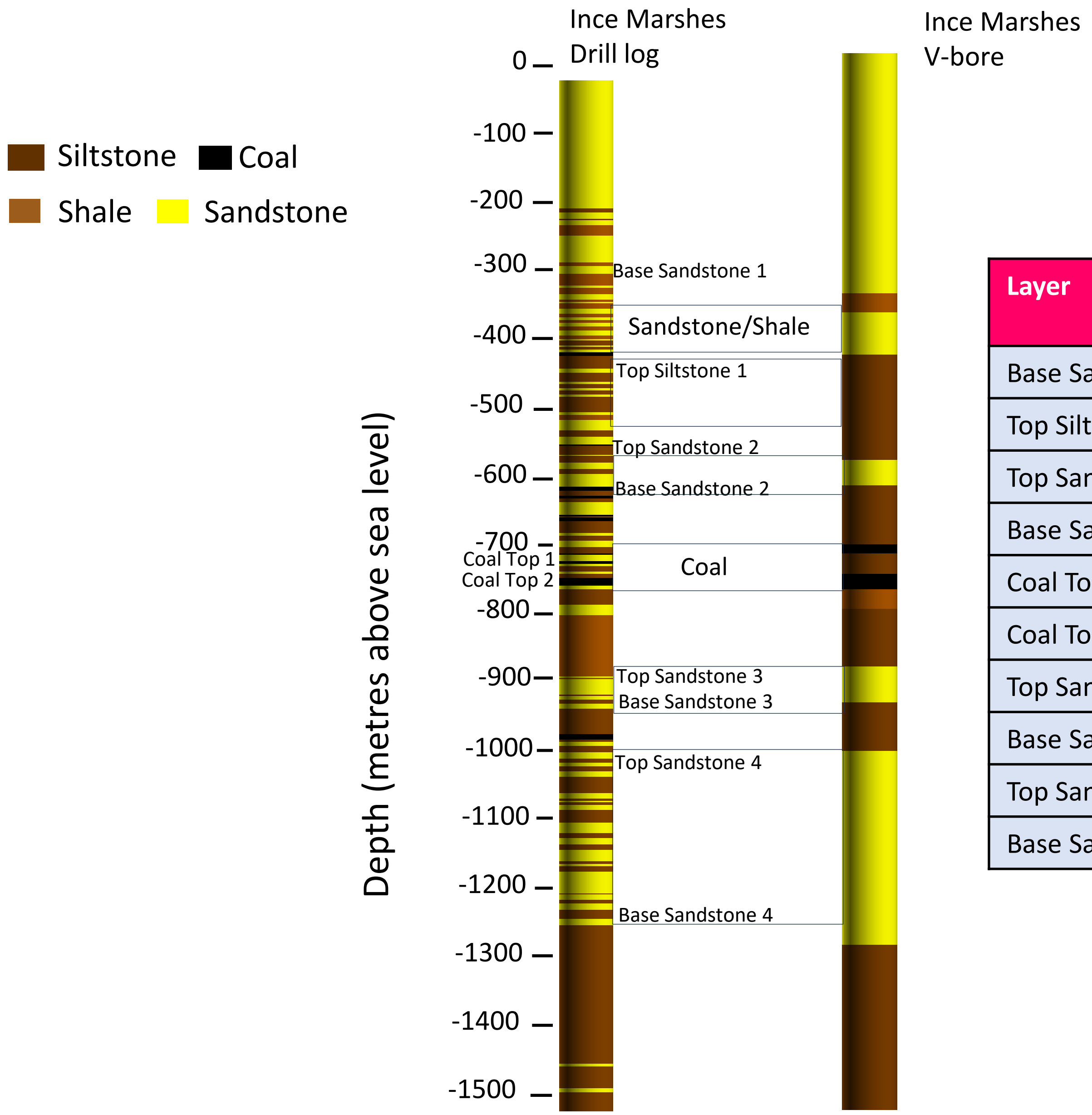
Layer	Drill log Depth (m)	V-bore Depth (m)	Difference (m)	Difference (%)
Dolerite Top	156.6	160	3.4	2.125
Dolerite Bottom	94.2	56.6	37.6	39.9
Limestone Top	59.2	52.6	6.6	11.1
Granite Top	-22.4	-14.5	7.9	35.3
Vein Top	-266	-231.8	34.2	12.857

Lancashire - Zonation



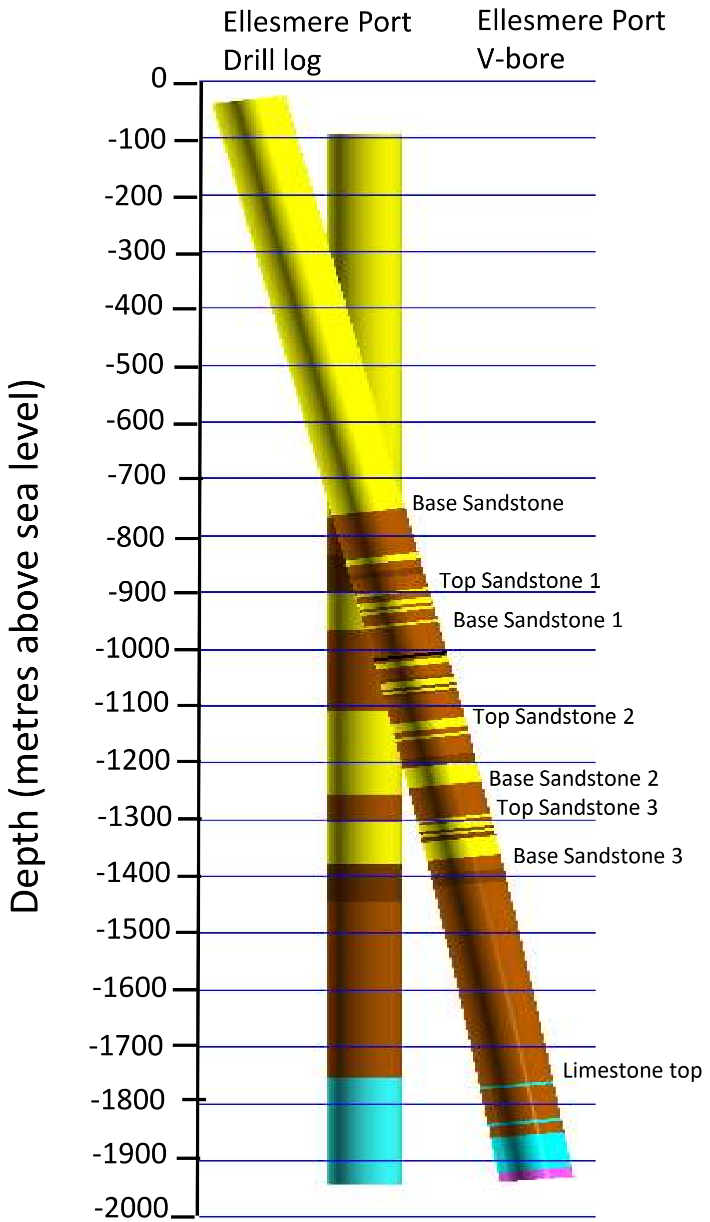
Layer	Drill log Depth (m)	V-bore Depth (m)	Difference (m)	Difference (%)
Top Sandstone 1	-381	-395.6	14.6	3.69
Base Sandstone 1	-1468.3	-1415.4	52.9	3.60
Top Sandstone 2	-1627.1	-1603	24.1	1.48
Base Sandstone 2	-1713.7	-1708.9	4.8	0.28
Top Sandstone 3	-1901.3	-1954.2	52.9	2.71
Base Sandstone 3	-2016.7	-2055.2	38.5	1.87
Top Limestone 1	-2363.1	-2459.3	96.2	3.91
Base Limestone 1	-2507.4	-2613.2	105.8	4.05
Top Limestone 2	-2690.2	-2791.2	101	3.61
Base Limestone 2	-2757.5	-2882.6	125.1	4.34

Cheshire - Zonation



Layer	Drill log Depth (m)	V-bore Depth (m)	Difference (m)	Difference (%)
Base Sandstone 1	-313.2	-339.8	26.6	7.8
Top Siltstone 1	-430	-435.1	5.1	1.17
Top Sandstone 1	-594.3	-588.6	5.7	0.95
Base Sandstone 2	-628.1	-628.1	0	0
Coal Top 1	-733	-718.5	14.5	1.97
Coal Top 2	-765.8	-761.3	4.5	0.58
Top Sandstone 3	-911.4	-897.8	13.6	1.5
Base Sandstone 3	-957.6	-948.6	9	0.93
Top Sandstone 4	-1009.5	-1022	12.5	1.22
Base Sandstone 4	-1279.2	-1306.3	27.1	2.07

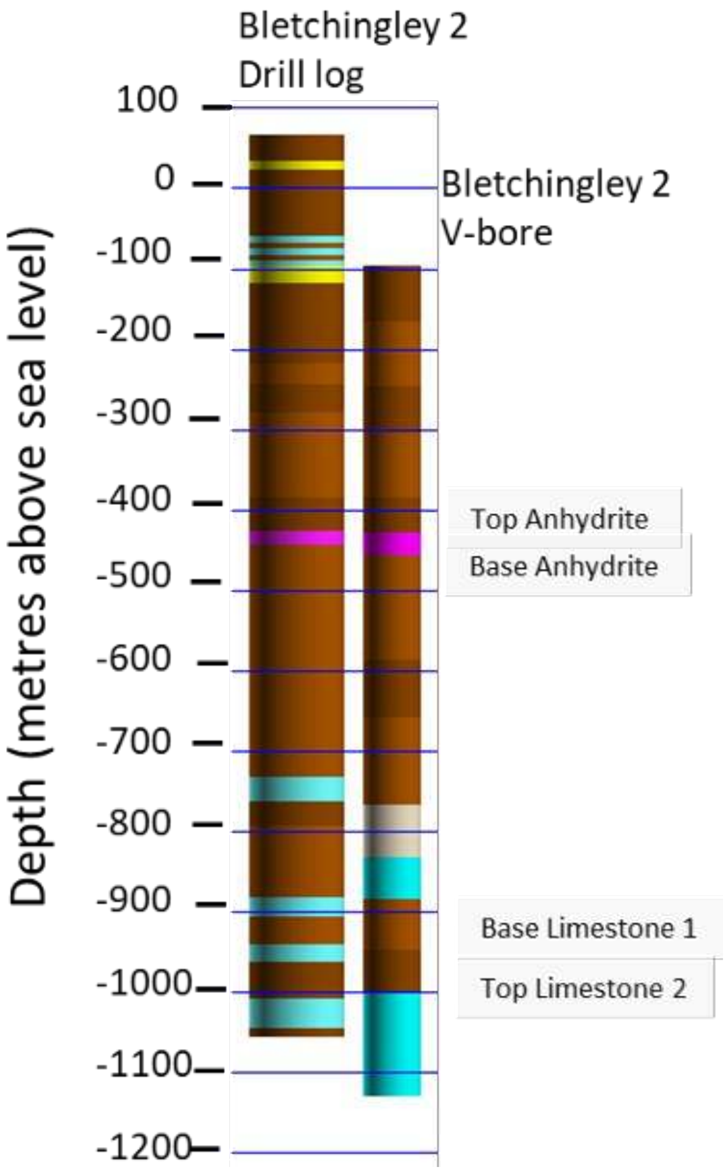
Cheshire - Zonation



Layer	Drill log Depth (m)	V-bore Depth (m)	Difference (m)	Difference (%)
Base Sandstone	-754.7	-766.3	11.6	1.51
Top Sandstone 1	-884.9	-898.2	13.3	1.48
Base Sandstone 1	-946.6	-948.7	2.1	0.22
Top Sandstone 2	-1138.5	-1115.4	23.1	2.02
Base Sandstone 2	-1225.2	-1239.6	14.4	1.16
Top Sandstone 3	-1301.1	-1283.1	18	1.38
Base Sandstone 3	-1379.4	-1359.1	18	1.30
Top Limestone	-1770.2	-1735.5	34.7	1.96

Siltstone
Sandstone
Shale
Limestone
Granite
Coal

Weald - Zonation



Layer	Drill log Depth (m)	V-bore Depth (m)	Difference (m)	Difference (%)
Top Anhydrite	-426.5	-430.2	3.7	0.86
Base Anhydrite	-443.3	-461	17.7	3.84
Base Limestone 1	-908.6	-886.2	22.4	2.46
Top Limestone 2	-1008.5	-1005.7	2.8	2.77

Limestone
Shale
Sand & Shale
Siltstone
Sandstone
Anhydrite

- Conclusions & Discussion

Conclusions & Discussion

- Results are encouraging
  - CalcData Mix showing high % matches
  - Zonation showing good depth matches
  - Zonation differentiating lithologies especially, sandstones, shales & limestones.

- How can we improve accuracy/reliability?
  - Further improvements by further training surface EM measurements on downhole tool measurements
  - Train on sites outside UK

- Why does it work?
  - EM waves penetrate sufficiently deep
  - Measurements and processing based on good science

Our Value Proposition becomes part of the solution

ECONOMICAL

We will be reducing exploration costs by up to 90%

CONVENIENT

Faster solution lessening the need for exploratory drilling

ENVIRONMENTALLY FRIENDLY

Harms the environment in no way

Gordon Stove
CEO & Co-founder

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