RESERVOIR CHARACTERIZATION PROJECT

Formation Lithology Classification: Evaluation of Machine Learning Methods

Nadima Dwihusna, MS student

November 14th, 2019

COLORADOSCHOOLOFMINES

Outline

- Introduction
- Study Area and Geological Facies Description
- Machine Learning Application to Facies Classification
- Results

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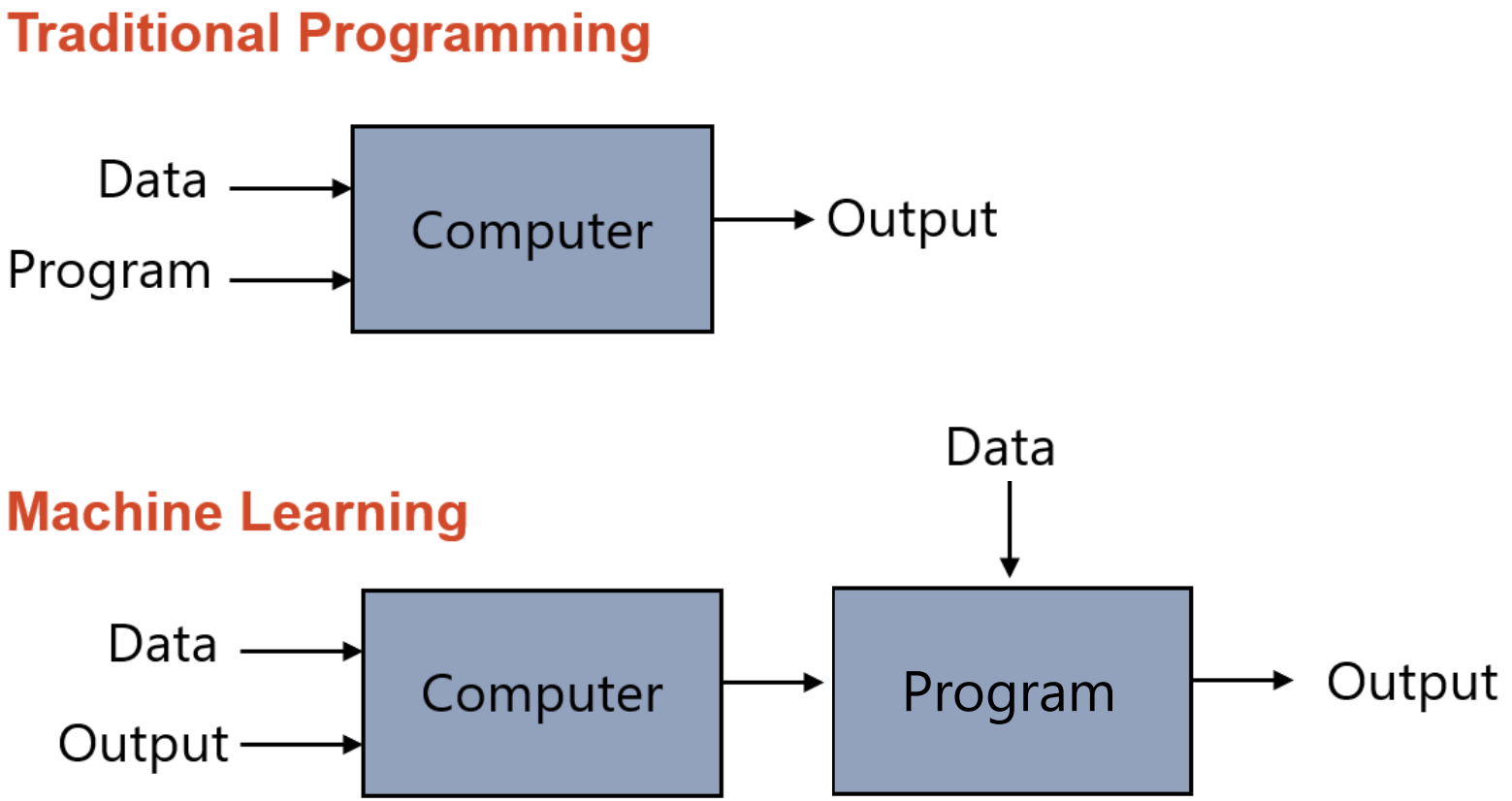
What is Machine Learning (ML)?

RCP
In pursuit of new ideas

Field of study that gives computers the ability to learn without being explicitly programmed (Arthur Samuel [1959])



Types of Machine Learning

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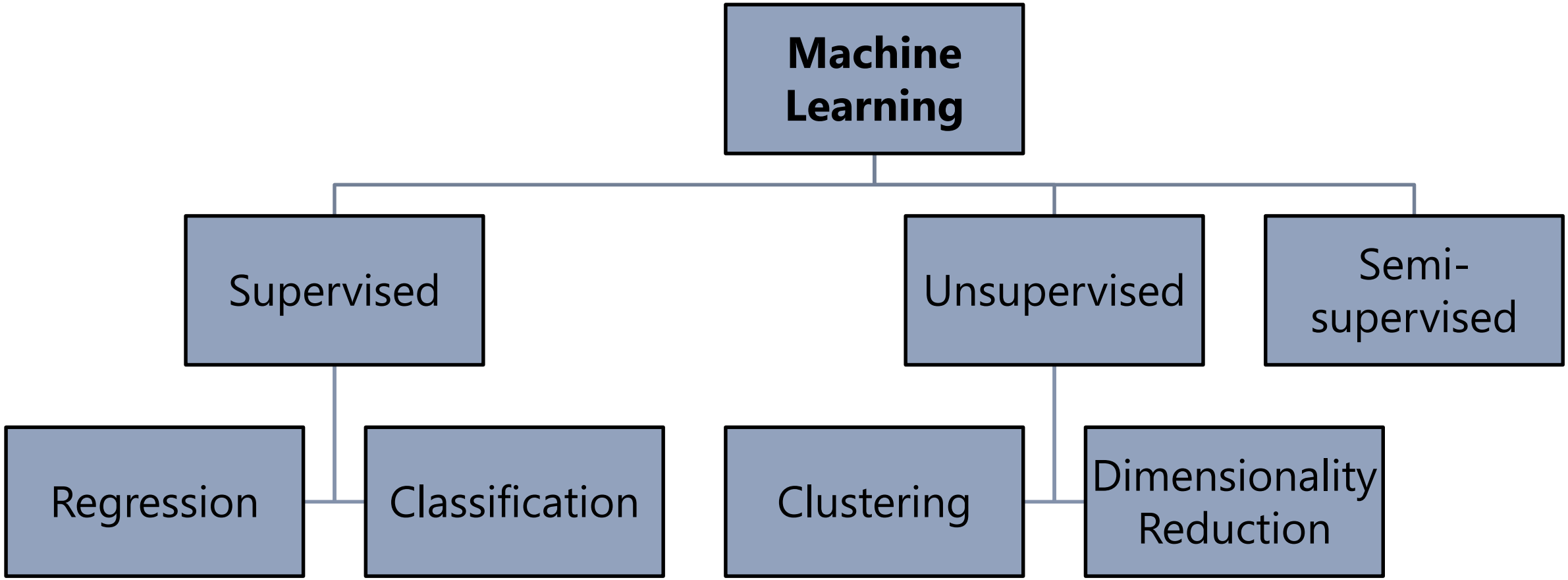

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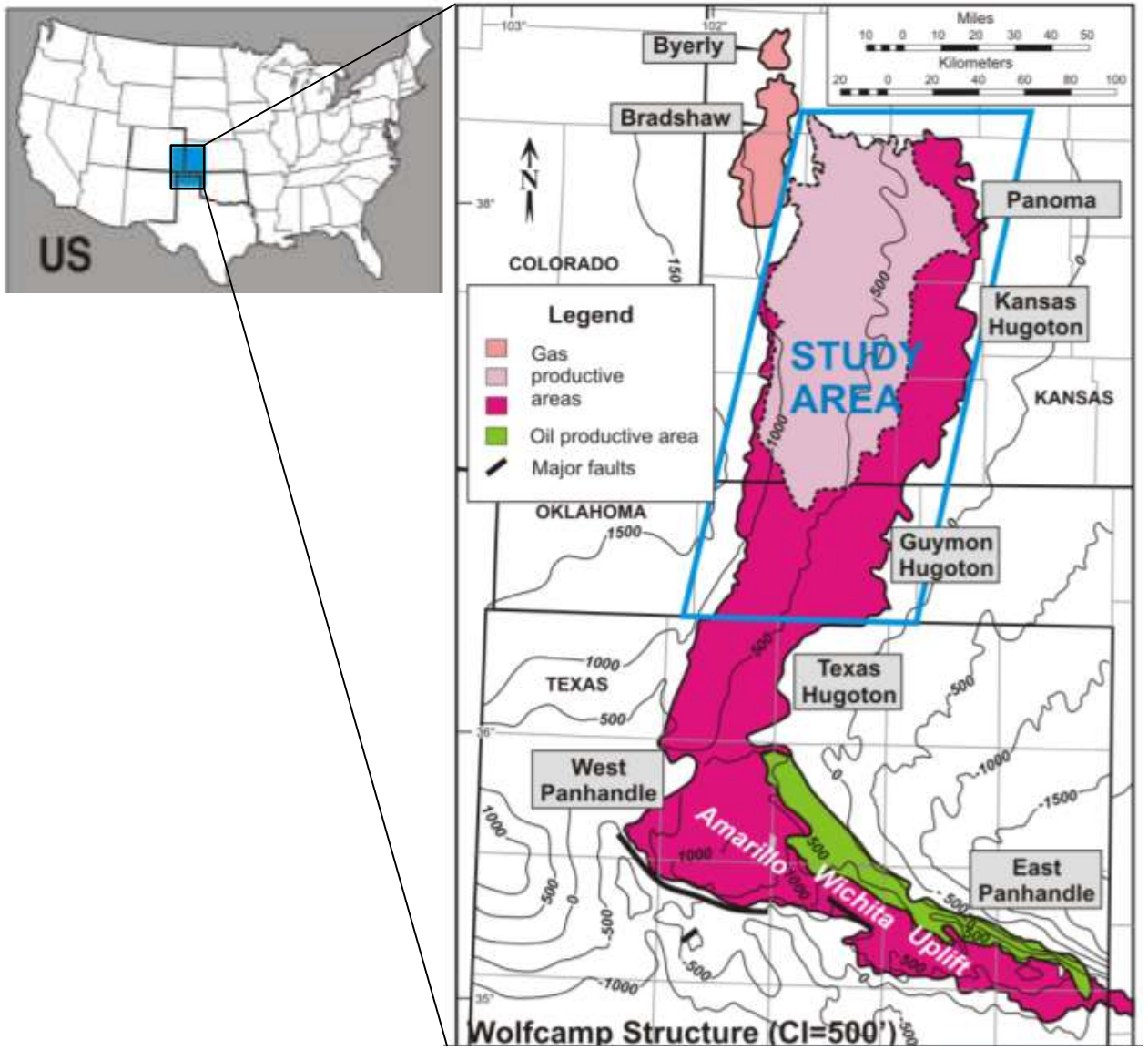
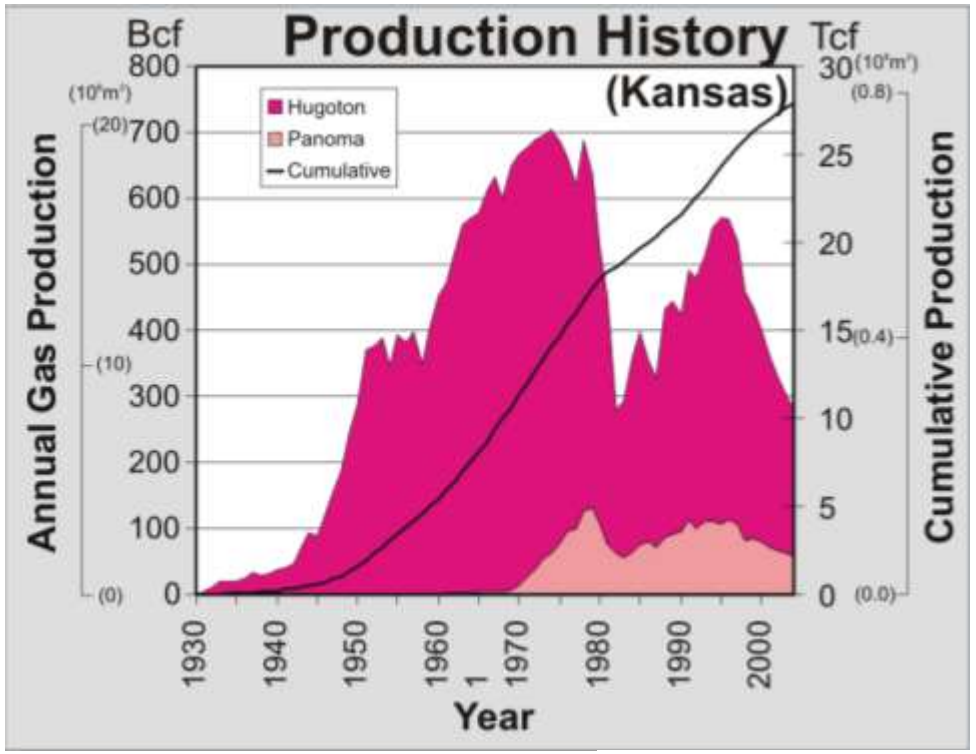
Hugoton and Panoma Study Area



(Kansas Geological Survey)

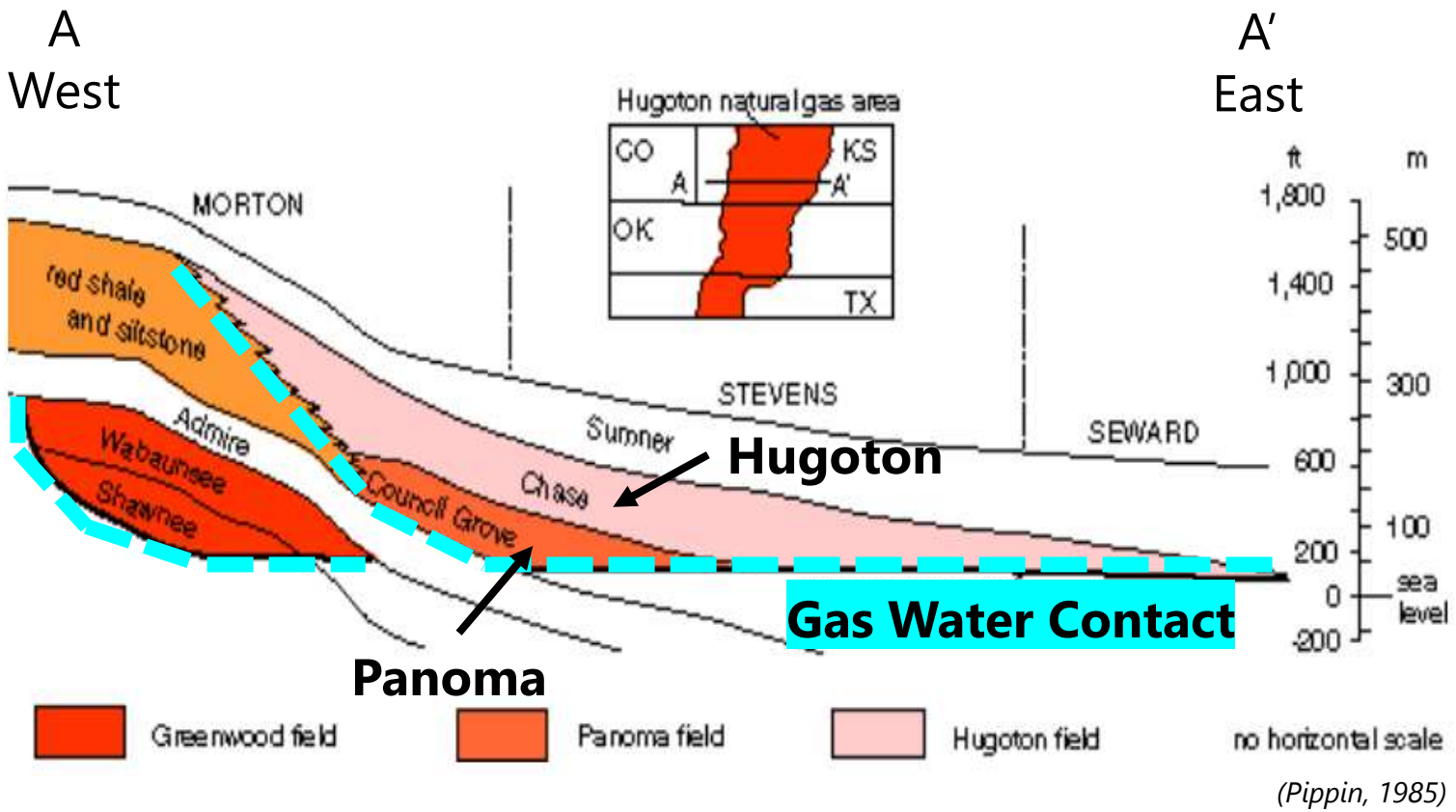


(Kansas Geological Survey)

Geological Facies Description

SYSTEM	SERIES	GROUP	Kansas fields
Permian	Leonardian	Sumner	
	Wolfcampian	Chase	Hugoton-Panoma Byerly Bradshaw
		Council Grove	
Pennsylvanian	Virgilian	Admire	Greenwood
		Wabaunsee	
		Shawnee	

(Zeller, 1968; Pippin, 1985)



(Pippin, 1985)

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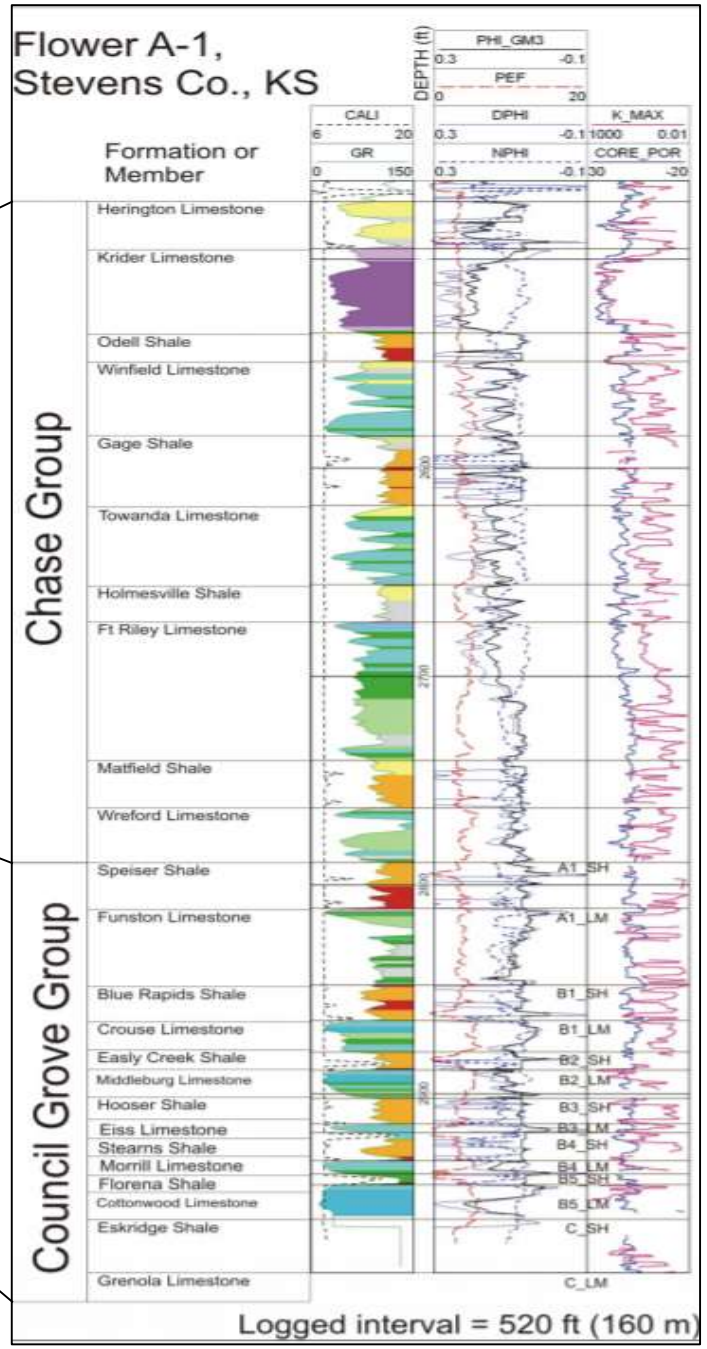

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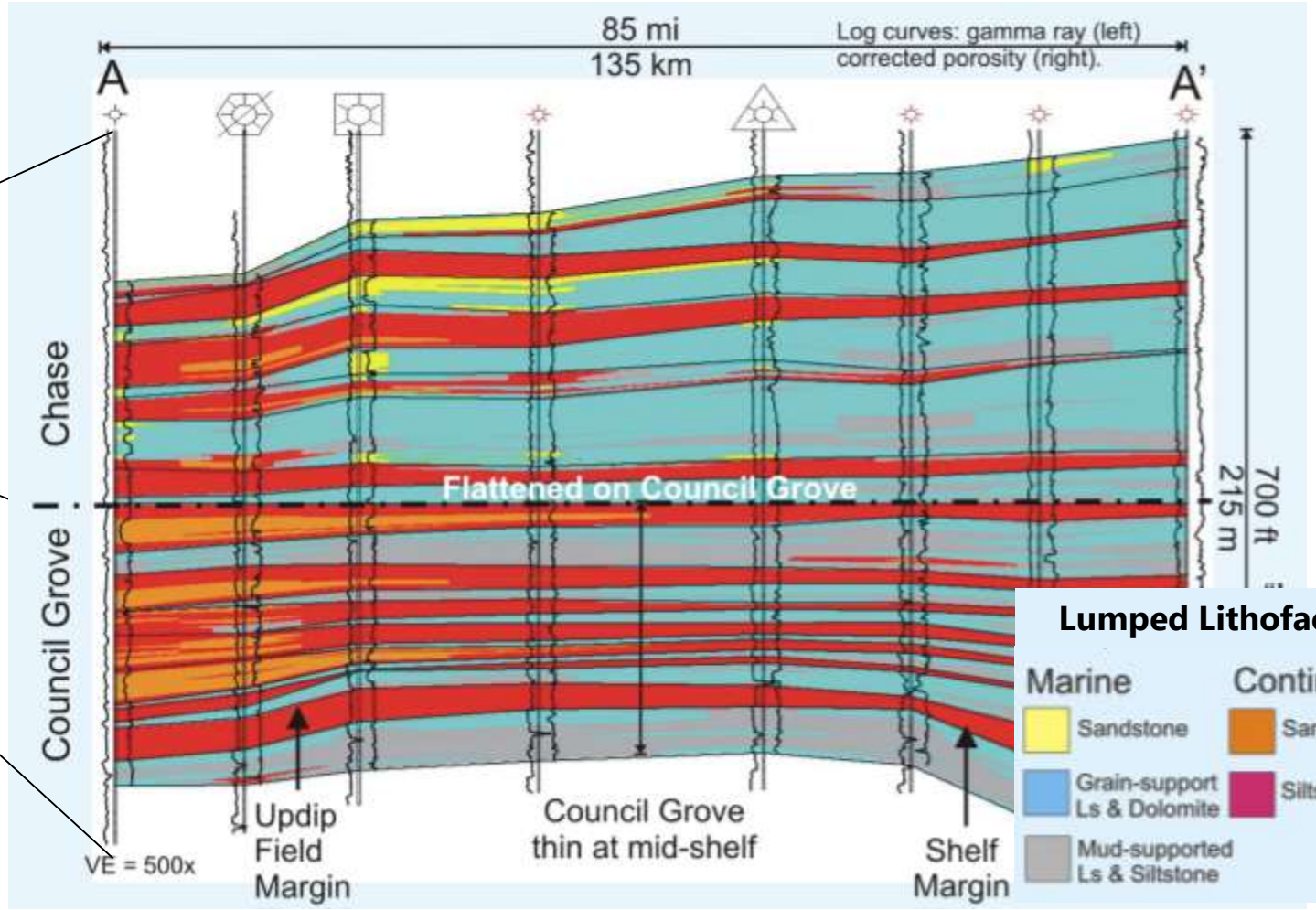
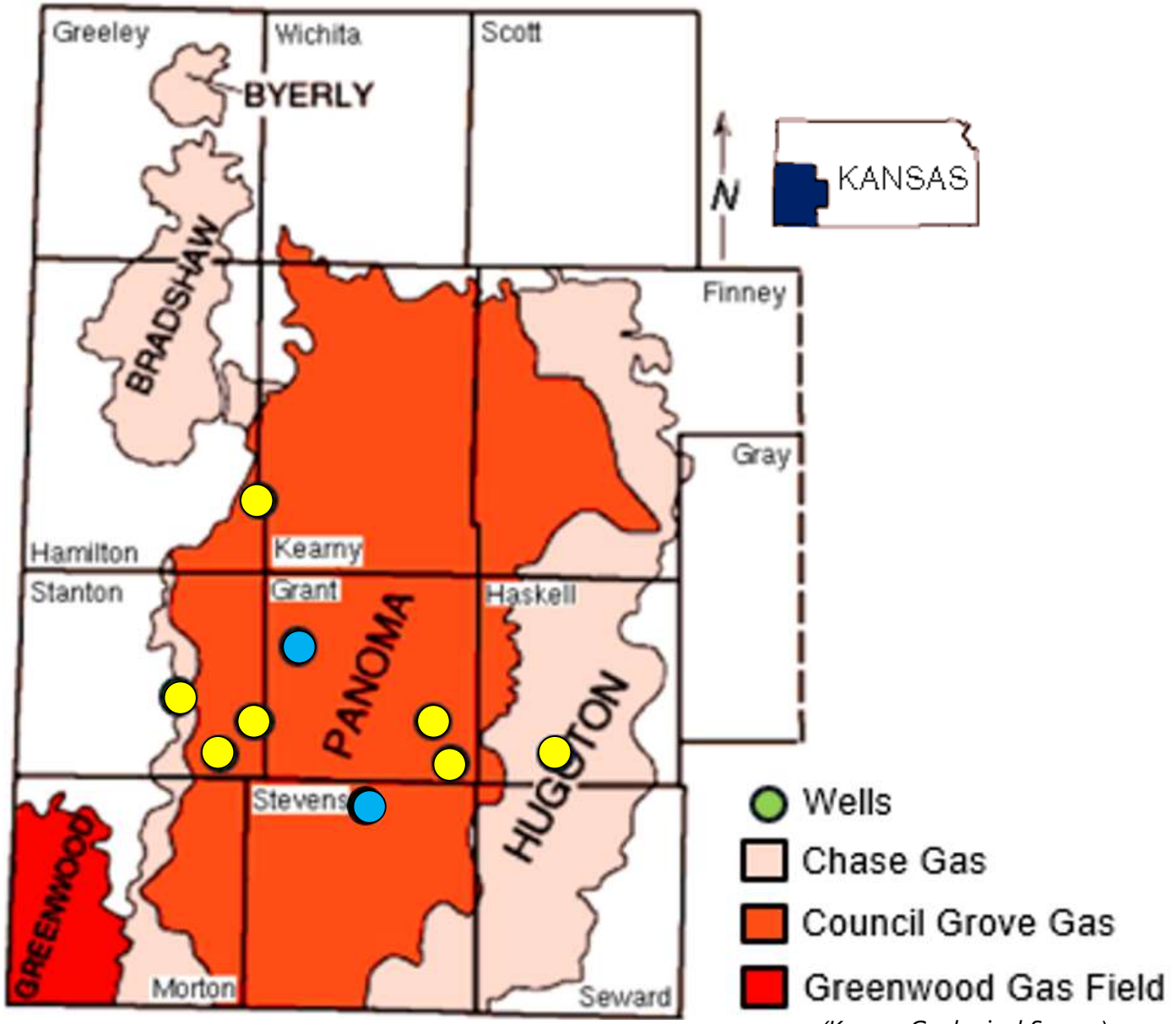


(Zeller, 1968; Pippin, 1985)

Well Log Dataset

- Total of 9 Wells
  - 7 training wells
  - 2 blind test wells



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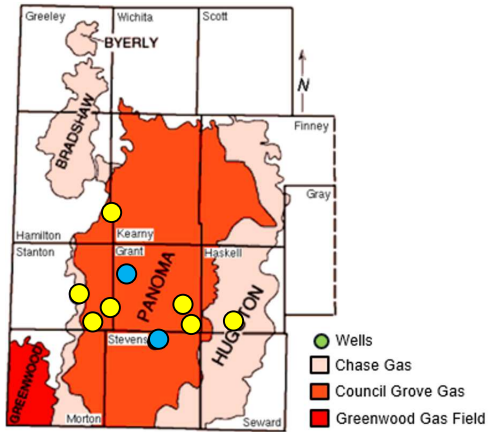
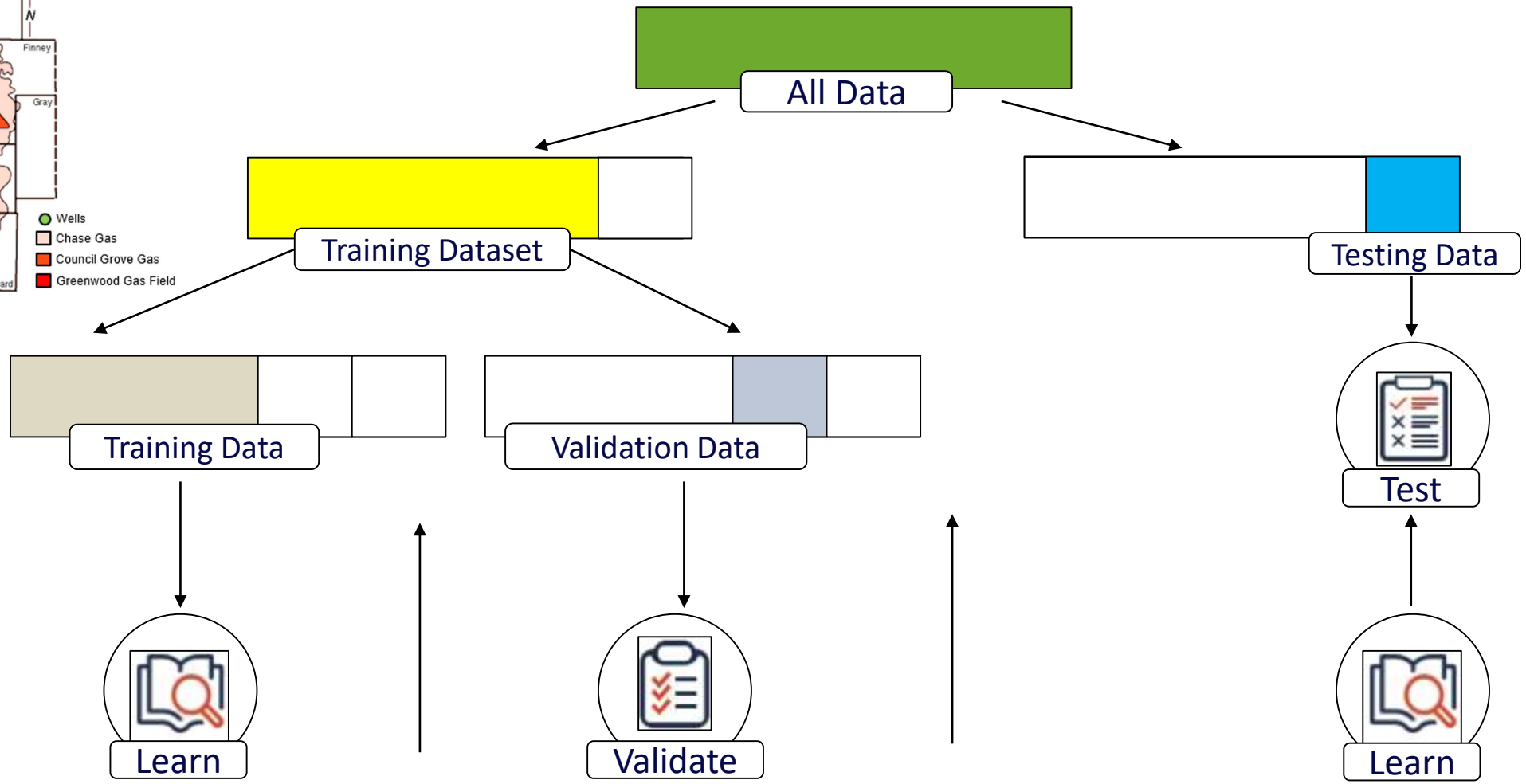
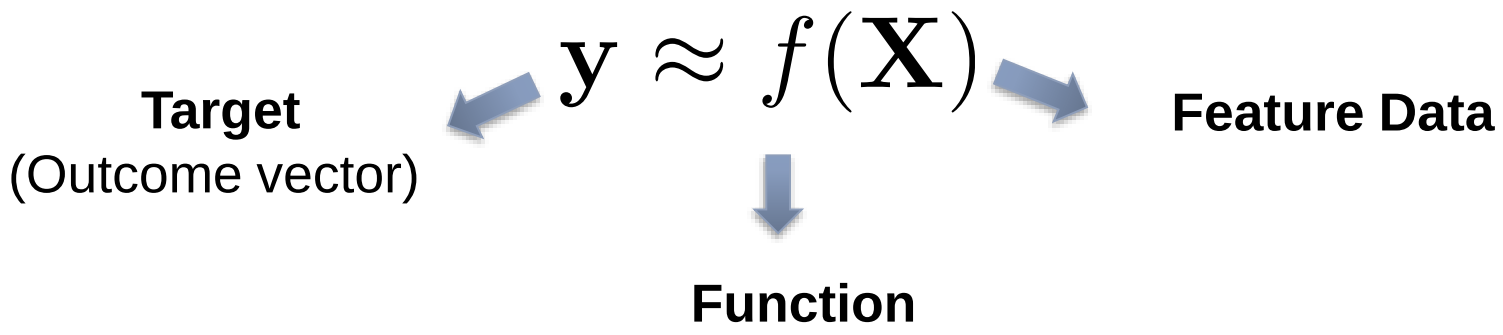




Training and Testing



- Training dataset

$$\mathbf{y} \approx f(\mathbf{X})$$

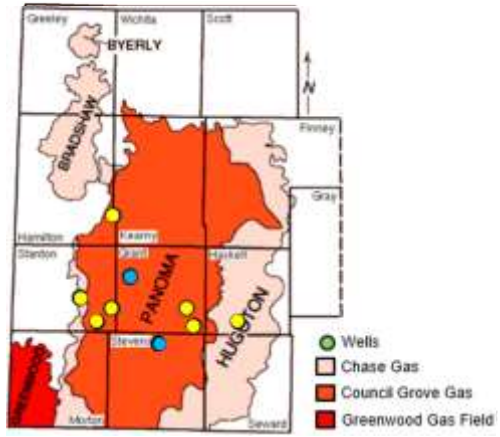
- Testing data

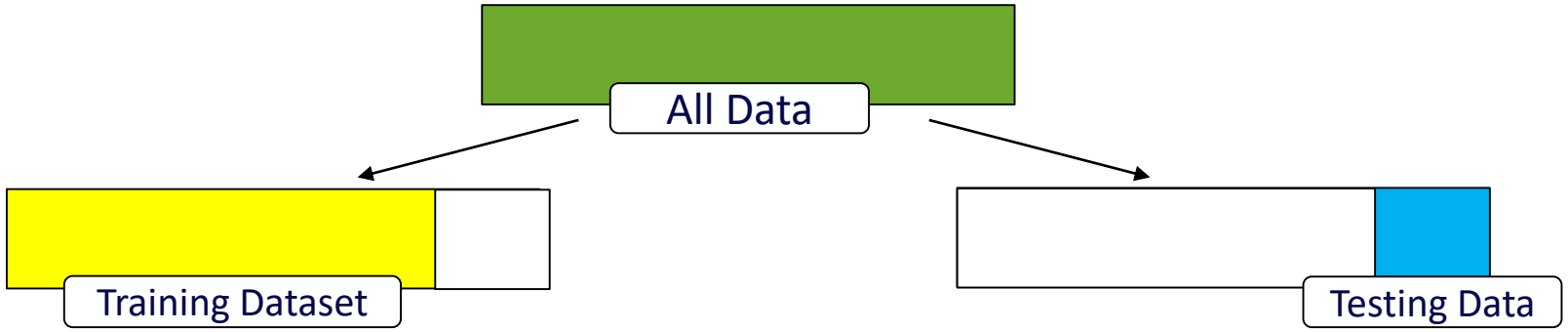
$$\mathbf{y} \approx f(\mathbf{X})$$

Known

Unknown

Training and Testing





- Training dataset

$$\mathbf{y} \approx f(\mathbf{X})$$

- Testing data

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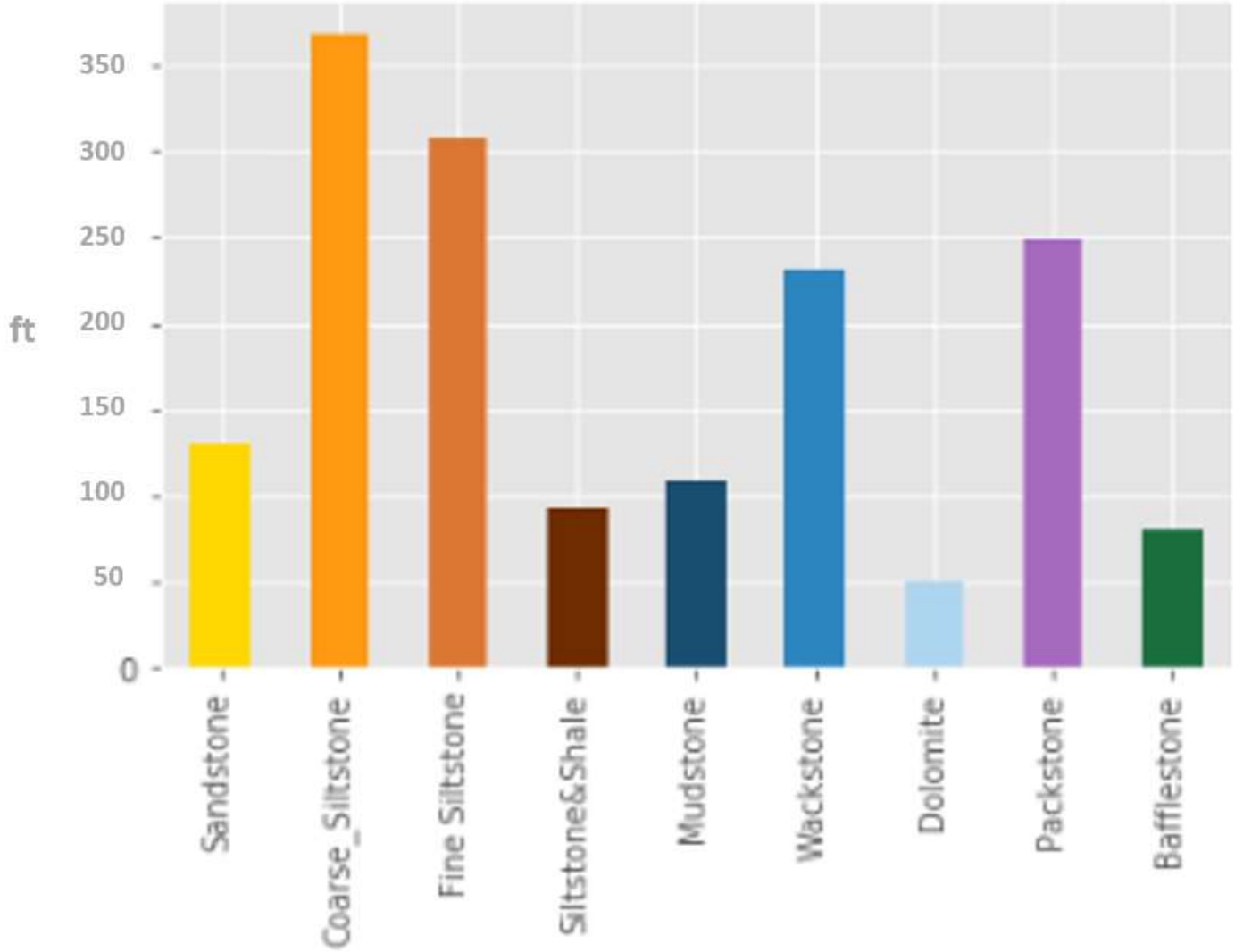
Unknown

Dataset Processing

- 9 discrete rock facies
  1. Sandstone
  2. Coarse siltstone
  3. Fine siltstone
  4. Siltstone and Shale
  5. Mudstone
  6. Wackestone
  7. Dolomite
  8. Packstone
  9. Bafflestone



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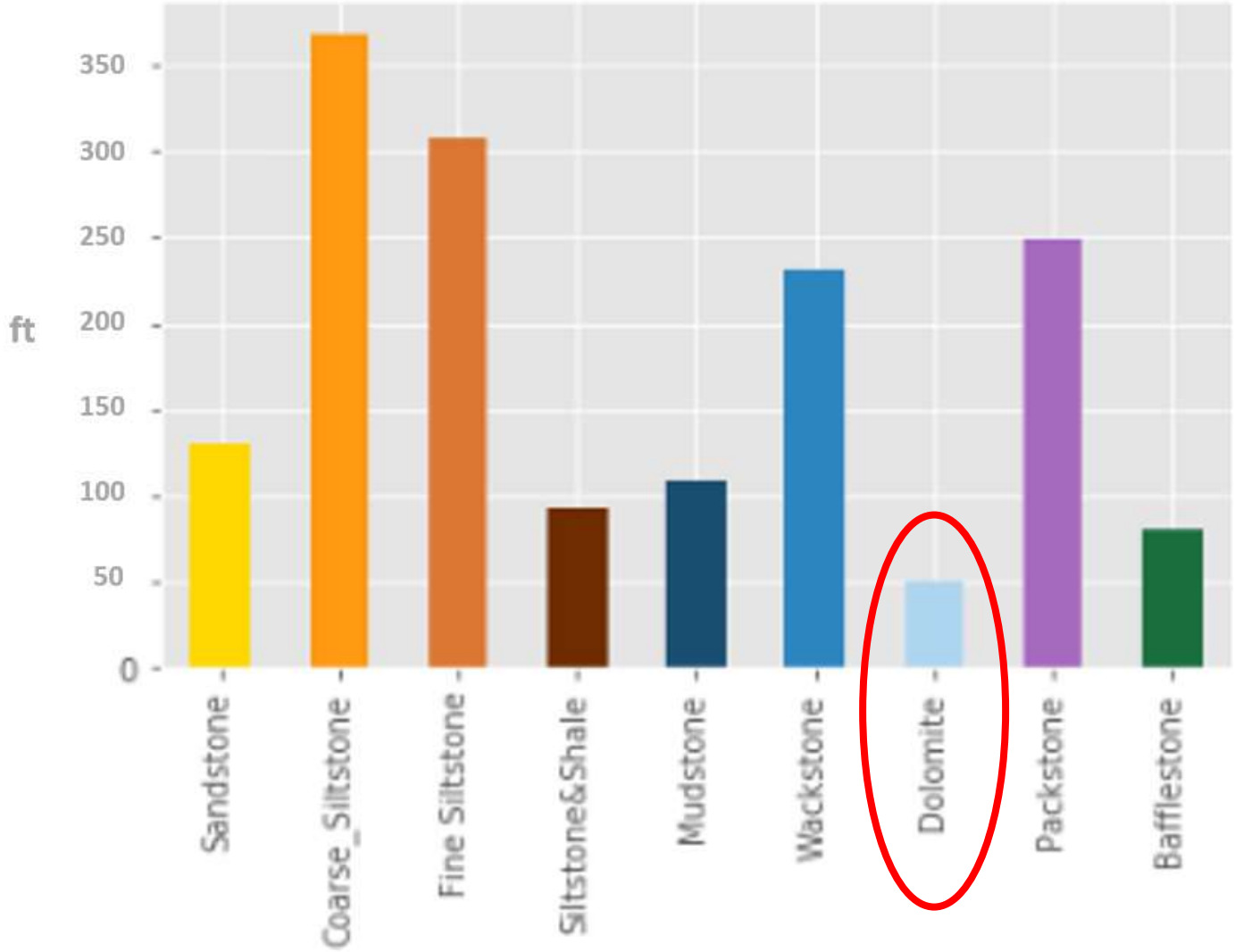

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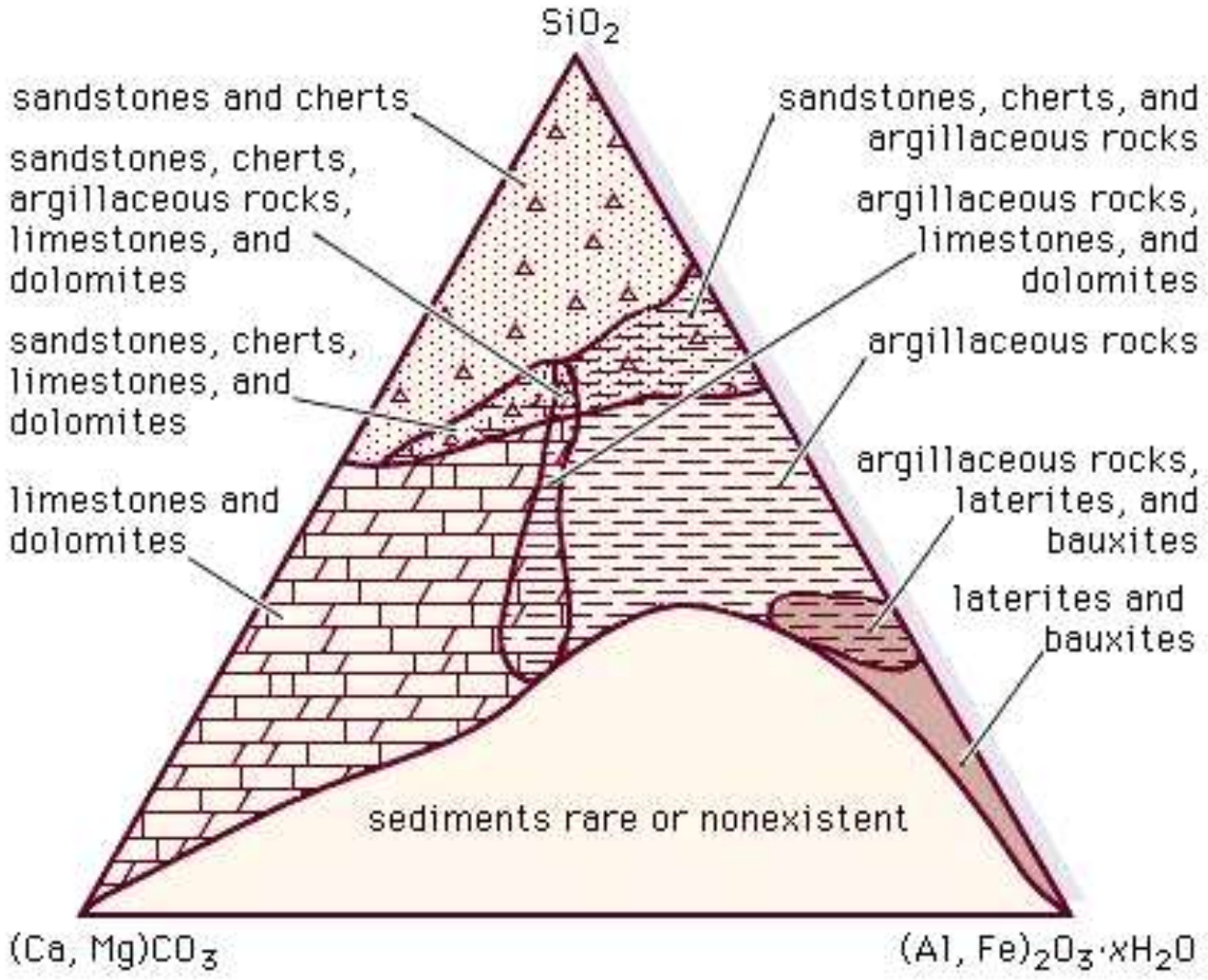

(Encyclopedia Britannica, 1985)

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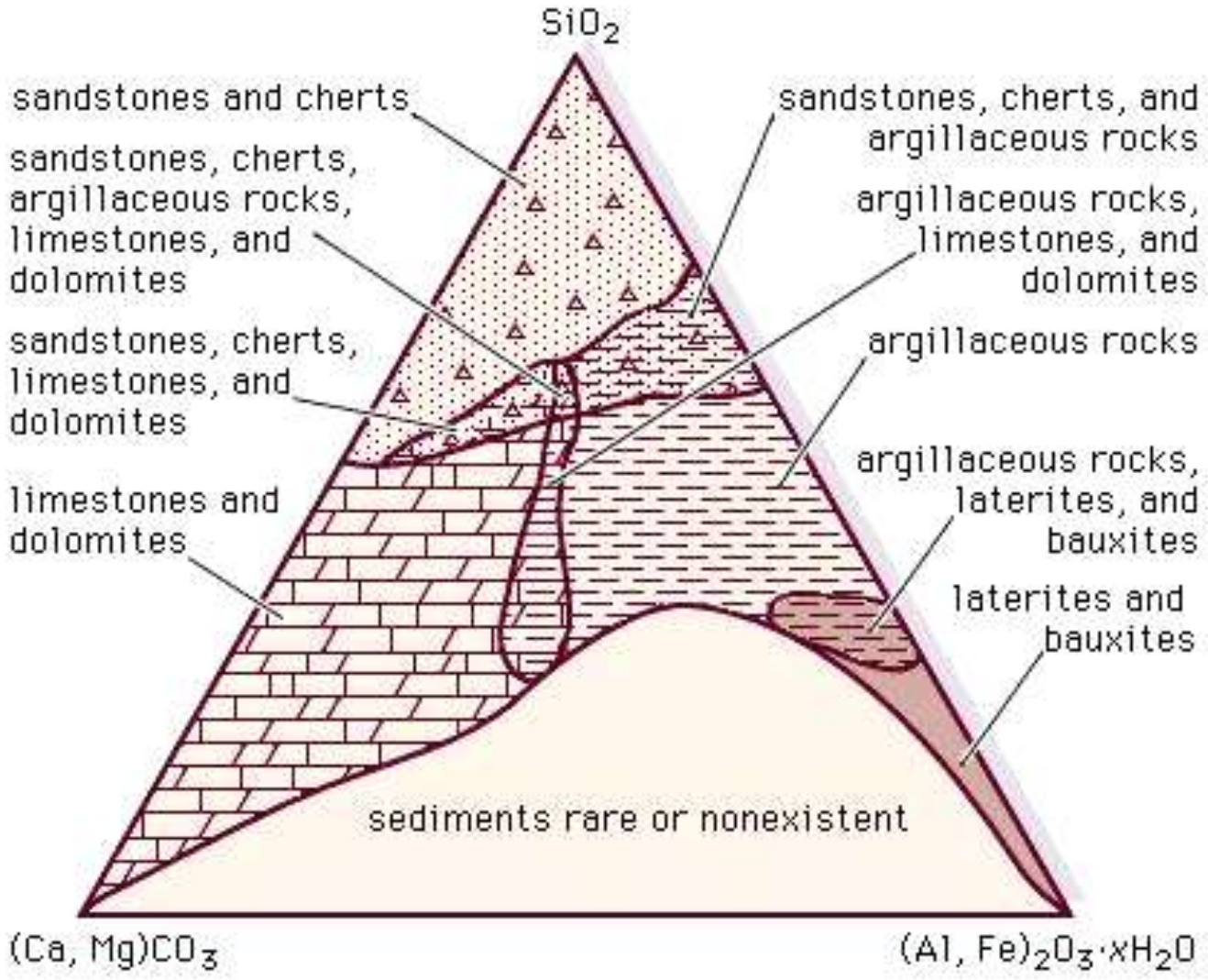

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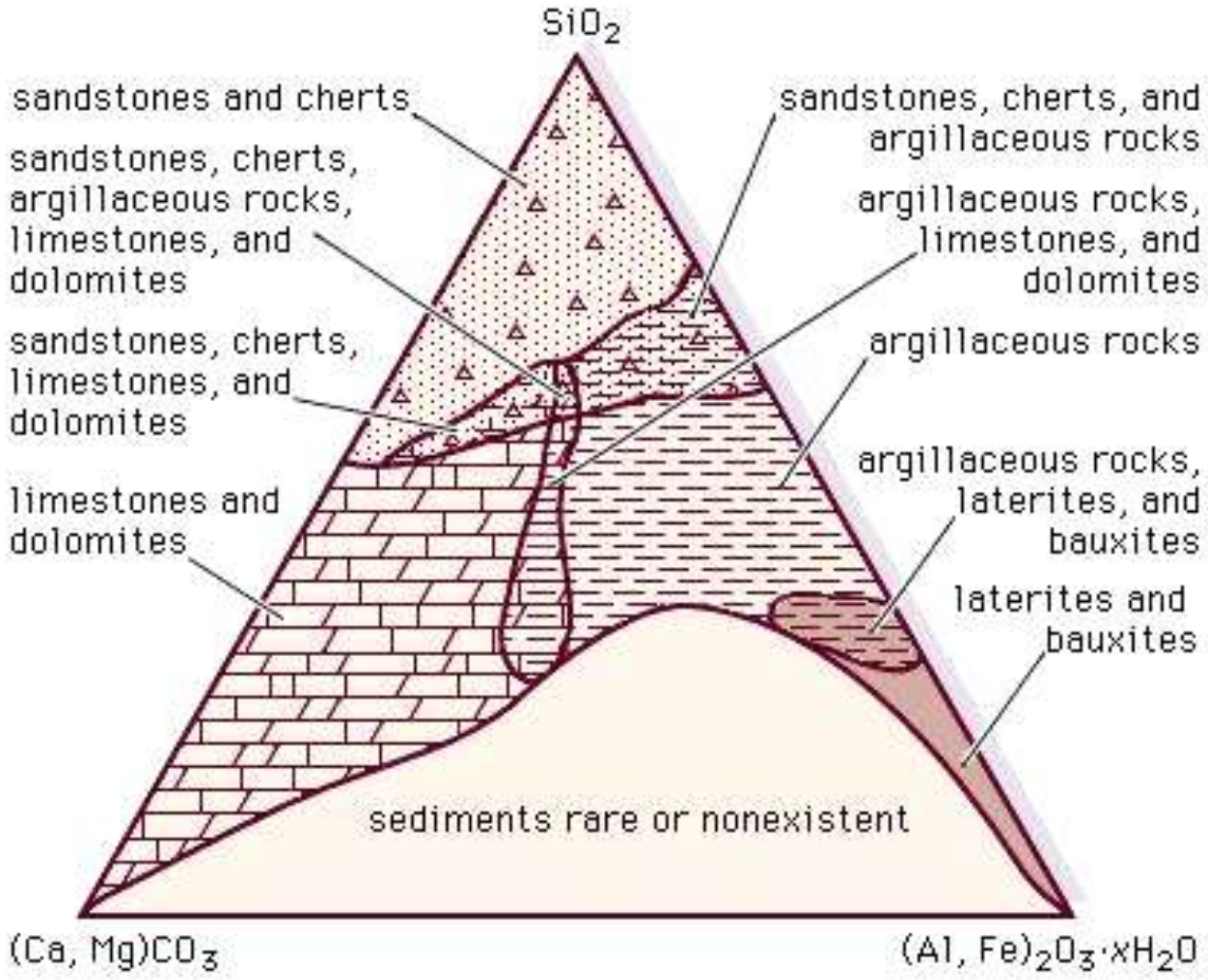

(Encyclopedia Britannica, 1985)

Log Measurements

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well_name	depth	facies	gr	ild_log10	deltaphi	phind	pe
Blackfoot1A	2793.0	3	77.45	0.664	9.9	11.915	4.6
Blackfoot1A	2793.5	3	78.26	0.661	14.2	12.565	4.1
Blackfoot1A	2794.0	3	79.05	0.658	14.8	13.050	3.6
Blackfoot1A	2794.5	3	86.10	0.655	13.9	13.115	3.5
Blackfoot1A	2795.0	3	74.58	0.647	13.5	13.300	3.4

Facies Labels **Feature Variables**

Log Measurements

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In pursuit of new ideas

Wireline Log Abbreviations

gr	Gamma Ray
ild_log10	Deep Induction Log
phind	Neutron-Density Porosity
deltaphi	Neutron-Density Porosity Difference
pe	Photoelectric Log

well_name	depth	facies	gr	ild_log10	deltaphi	phind	pe
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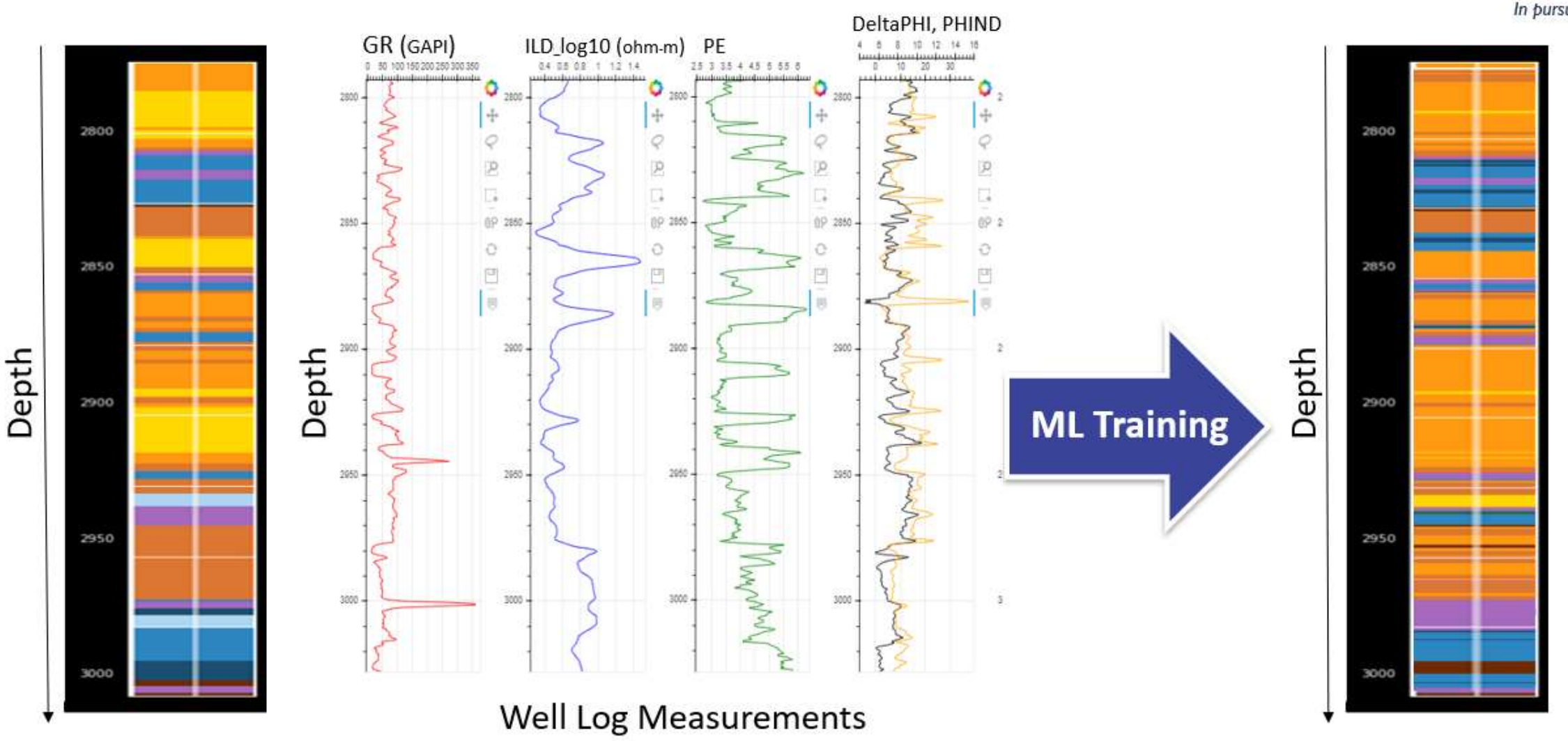
Depth
2800
2850
2900
2950
3000
GR (GAPI)
ILD_log10 (ohm-m)
PE
DeltaPHI, PHIND
Depth
Well Log Measurements
ML Training
Depth
2800
2850
2900
2950
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Facies Labels
Feature Variables
Facies Predictions

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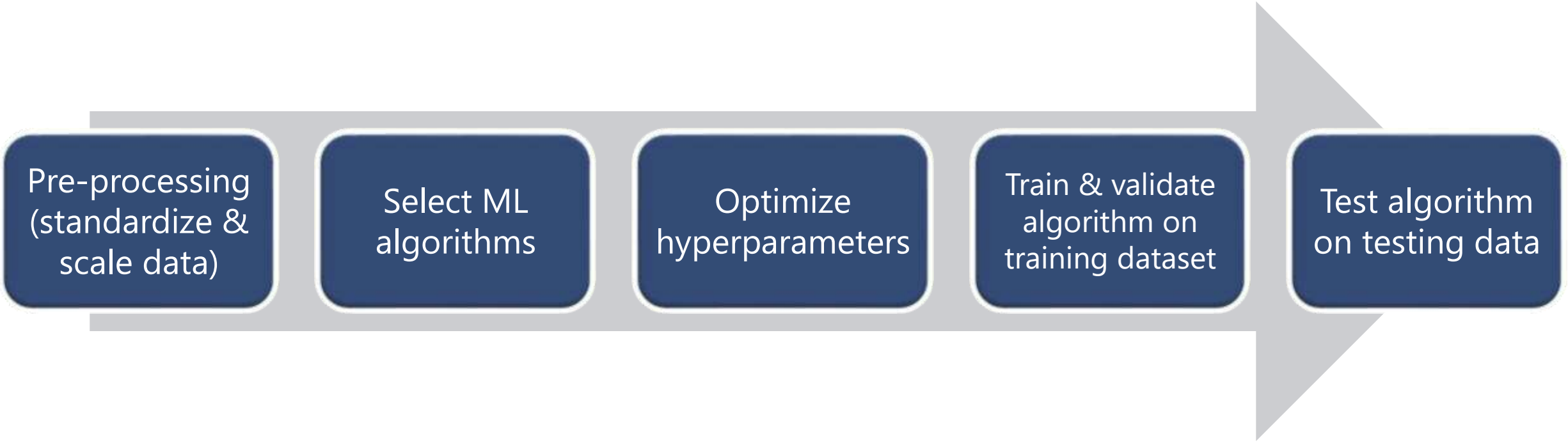
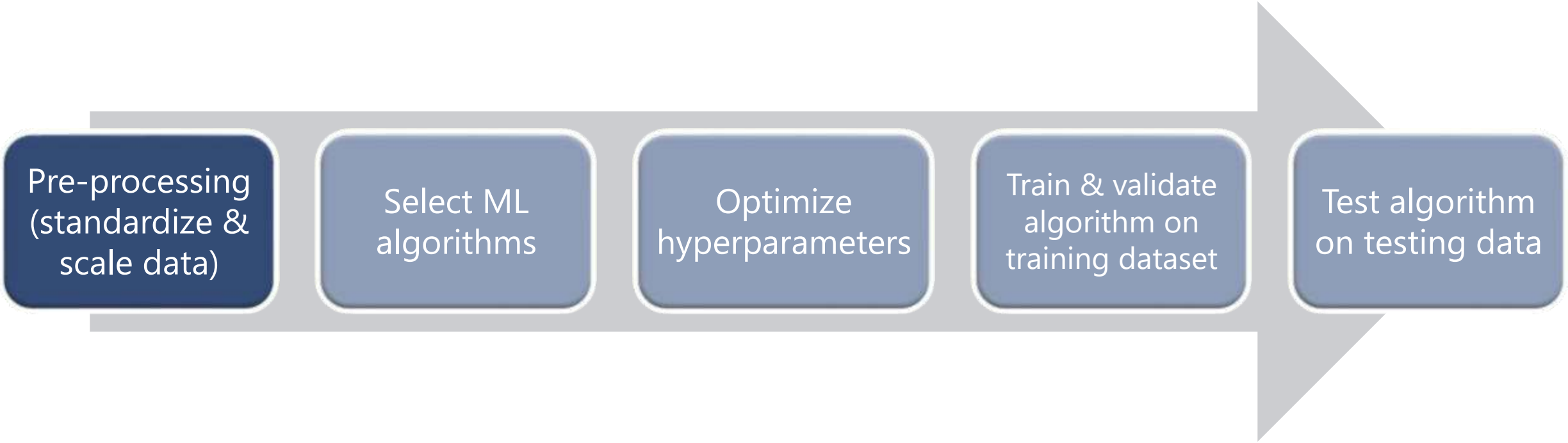
Machine Learning Workflow



Machine Learning Workflow



Processed Training Wells

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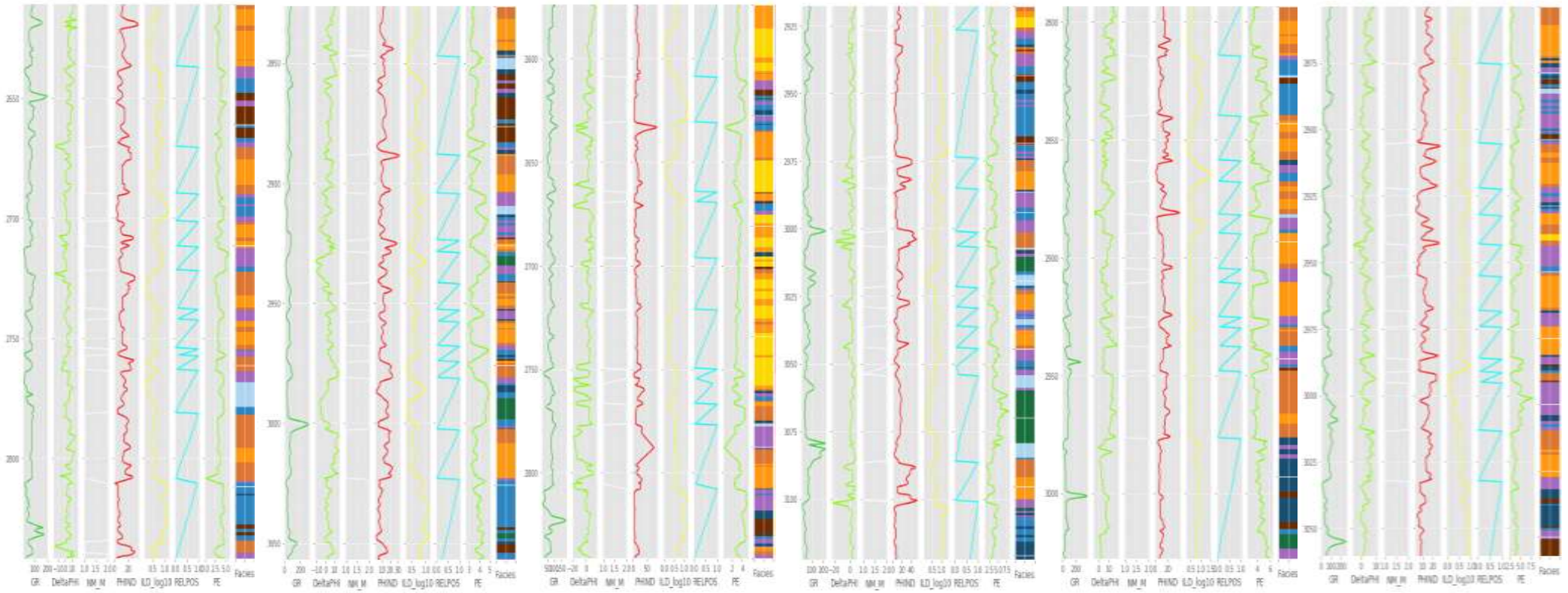
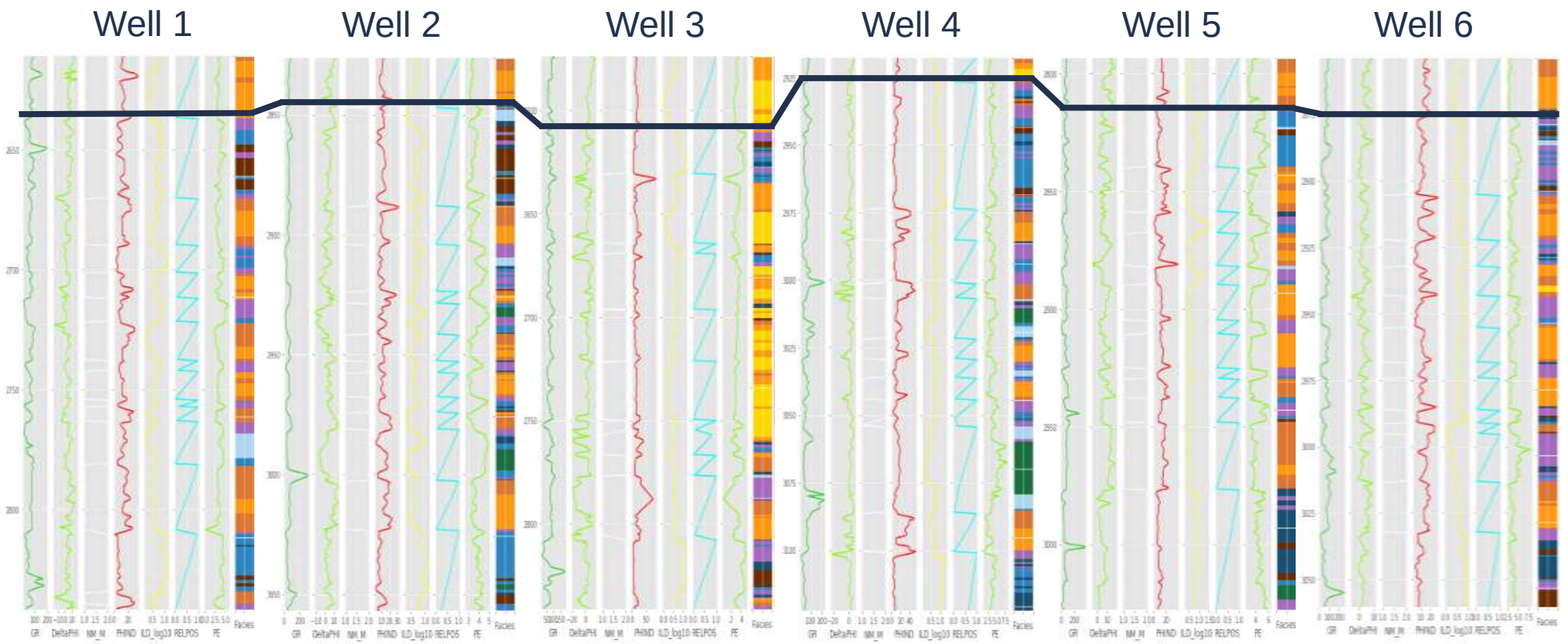
Well 1 | Well 2 | Well 3 | Well 4 | Well 5 | Well 6

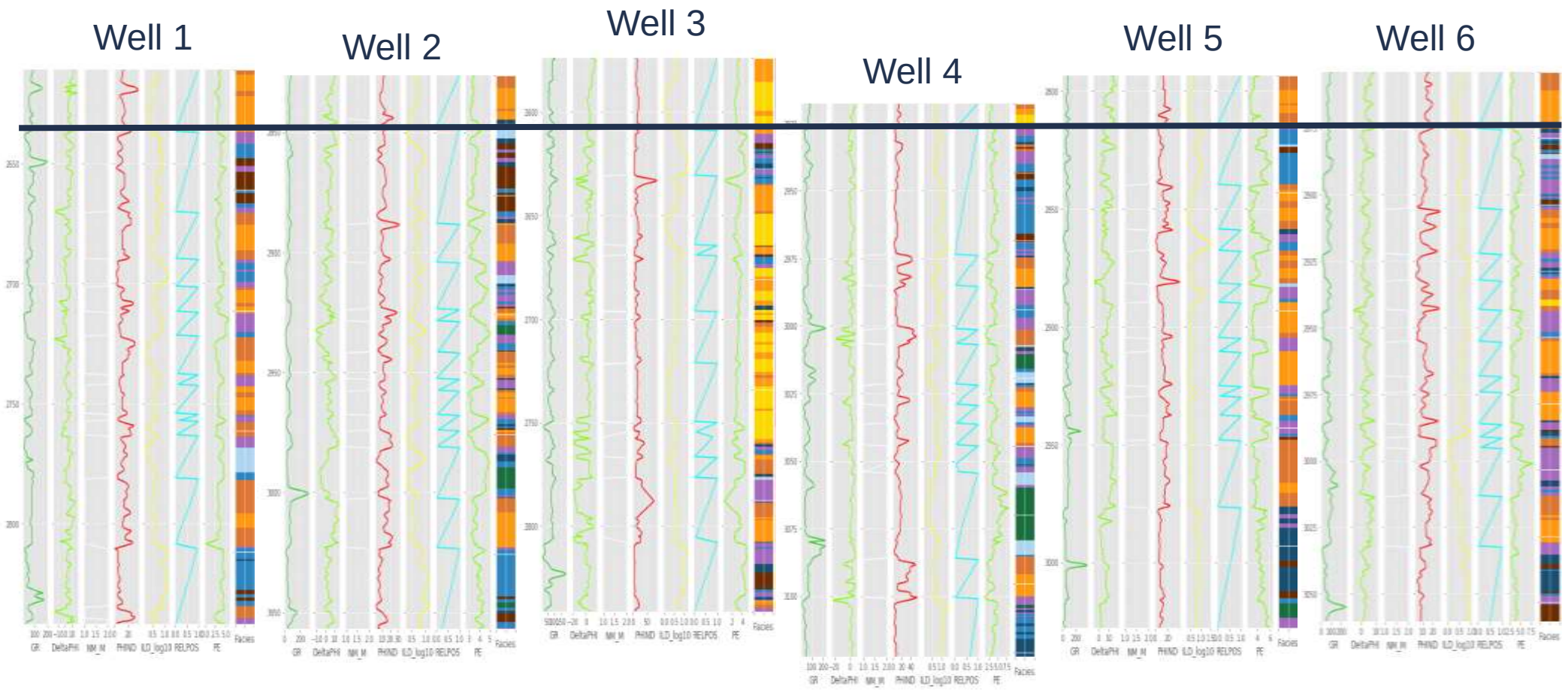


- Bafflestone
- Packstone
- Dolomite
- Wackestone
- Mudstone
- Siltstone & Shale
- Fine Siltstone
- Coarse Siltstone
- Sandstone

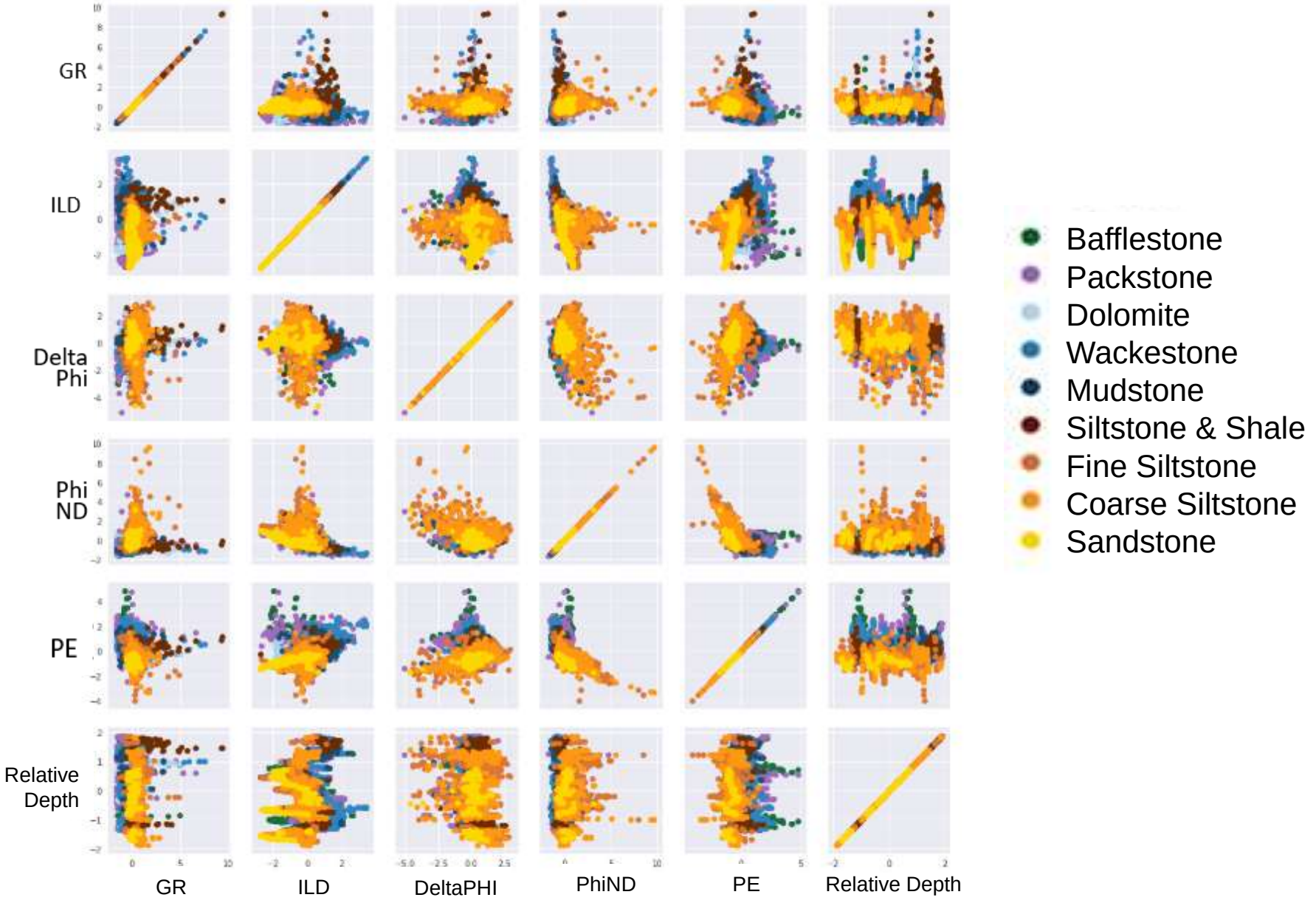
Processed Training Wells



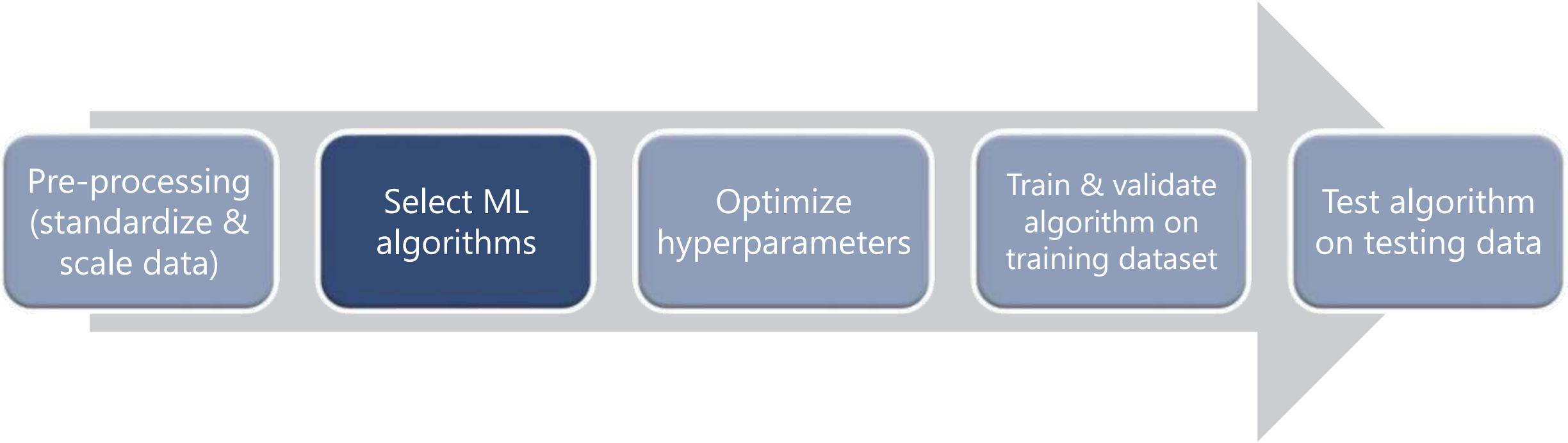
Processed Training Wells



Labeled Feature Clusters



Machine Learning Workflow



Types of Machine Learning

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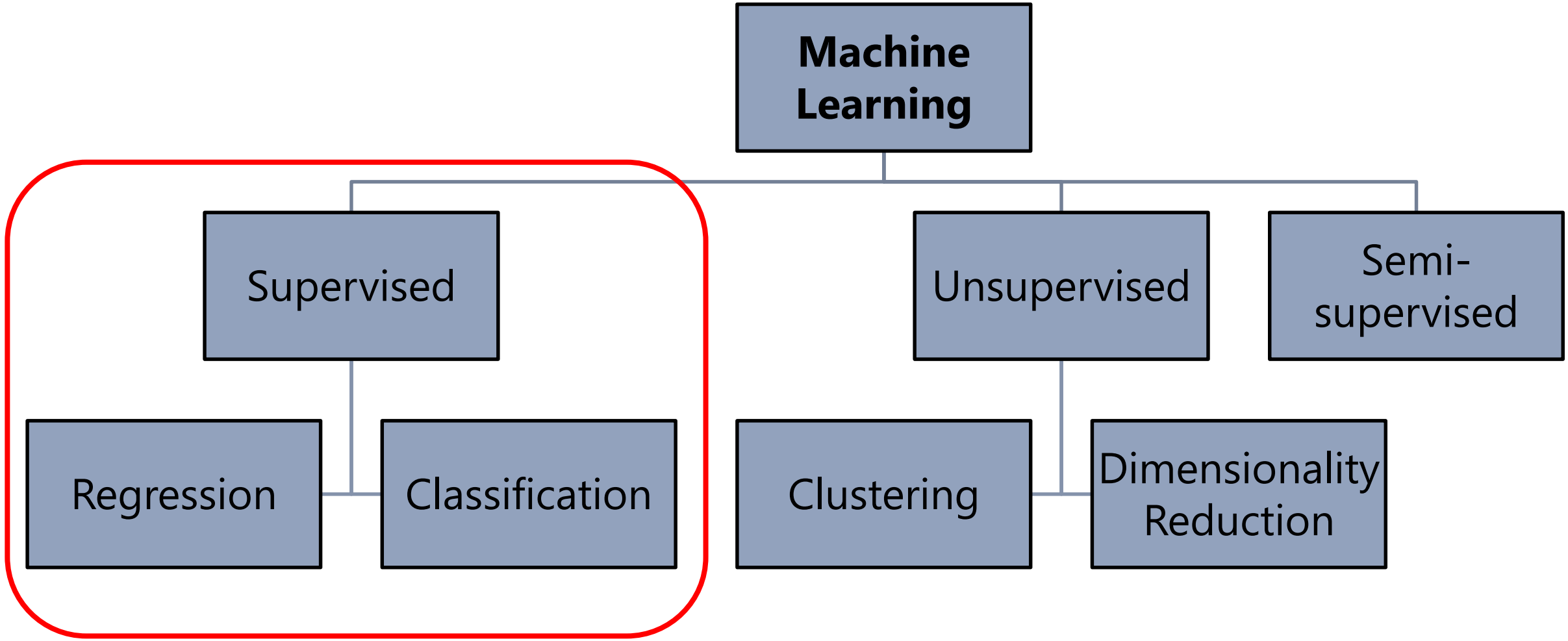
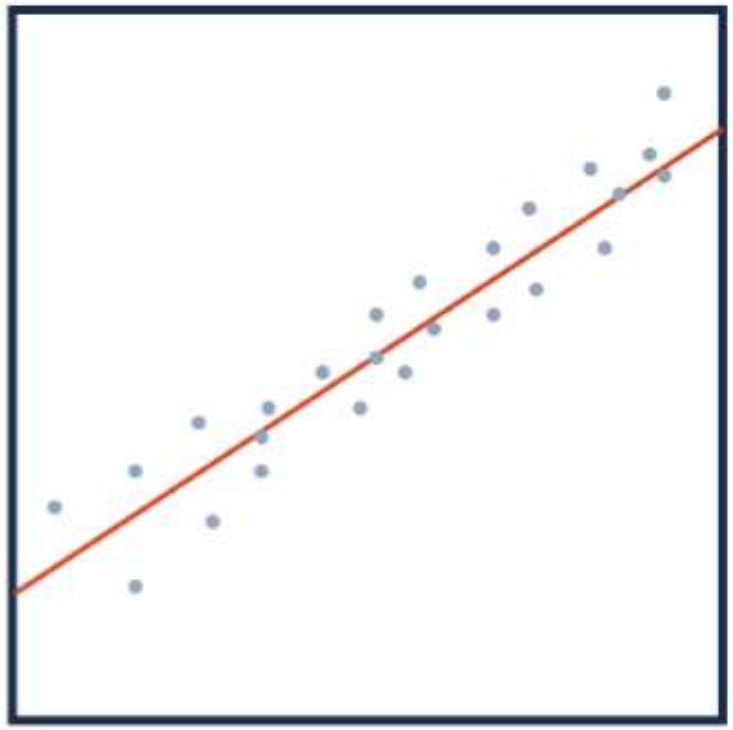
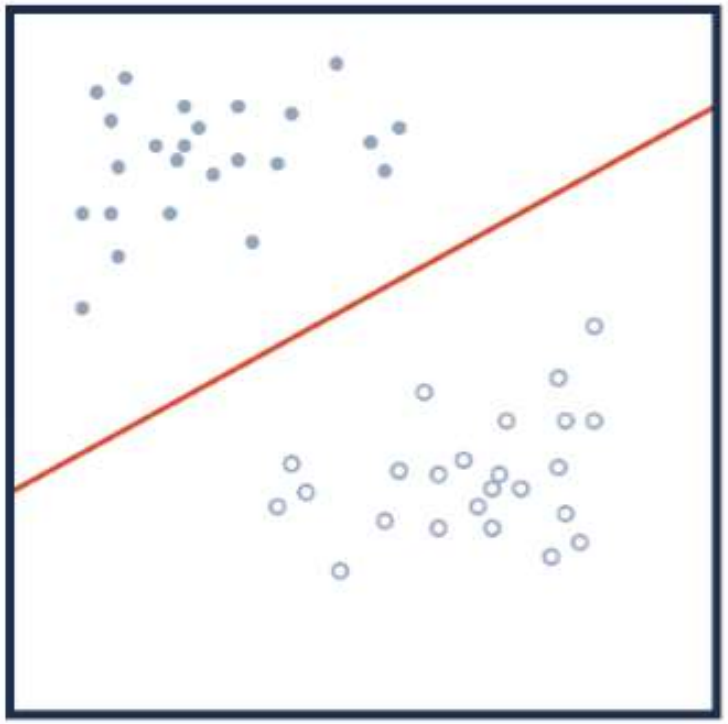


What is Supervised Machine Learning?



Regression

- Predict continuous quantity output
  - Eg. Predicting the value of porosity given P-wave velocity and density



Classification

- Predict discrete class label output
  - Eg. Given GR and Porosity log, predicting lithology as sand/shale

Supervised Machine Learning Methods

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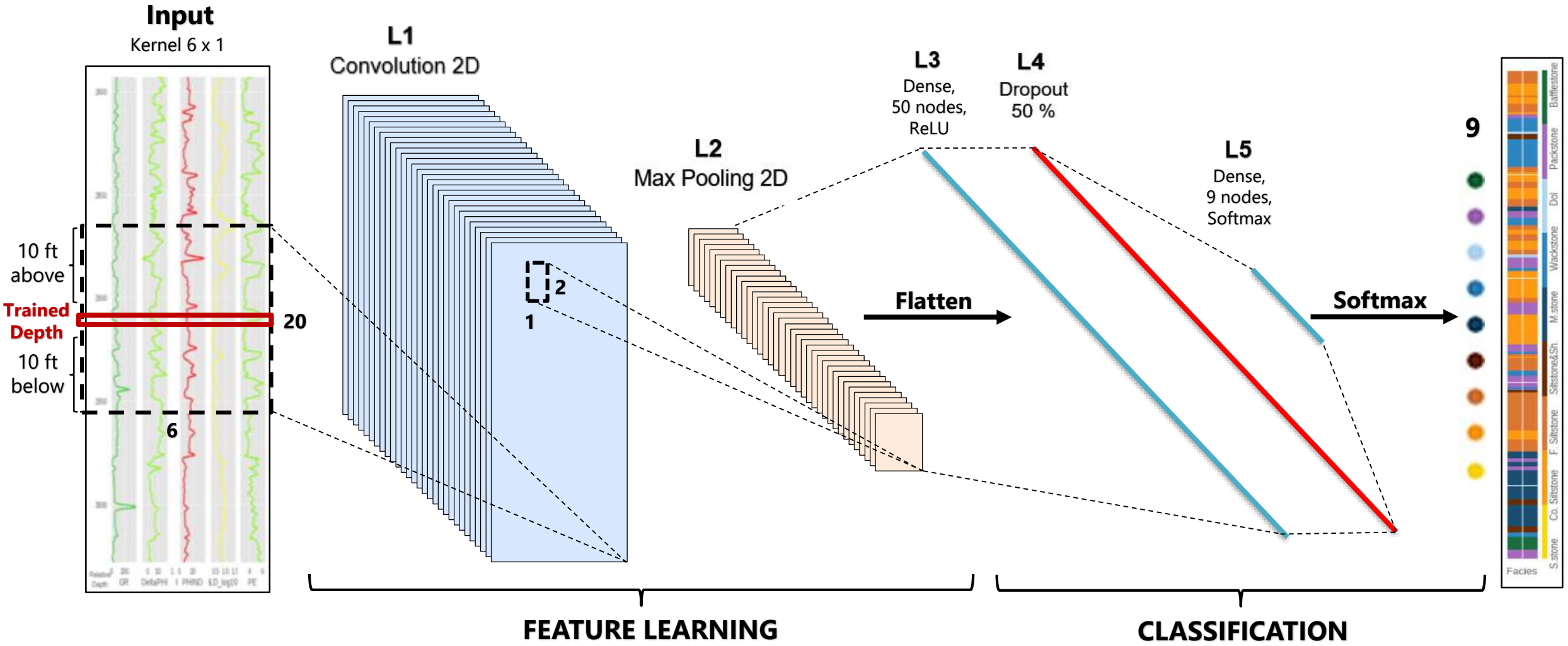
In pursuit of new ideas

1. K–Nearest Neighbors (KNN)
2. Support Vector Machine (SVM)
3. Random Forest
4. Multilayer Perceptron (MLP) Neural Network
5. 2D Convolutional Neural Network (CNN)

2D Convolutional Neural Network



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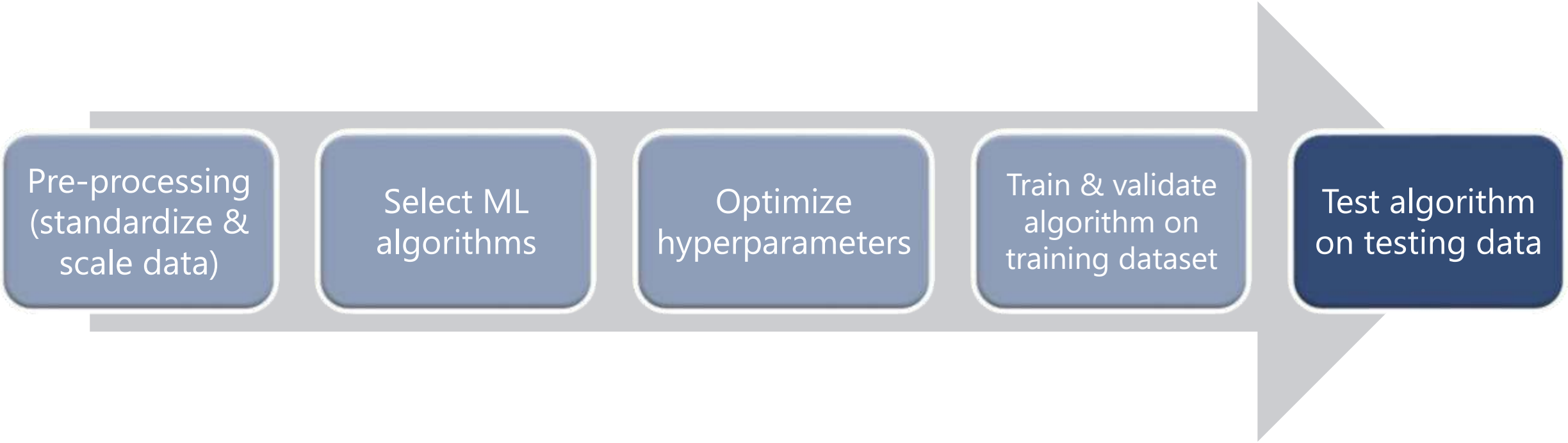

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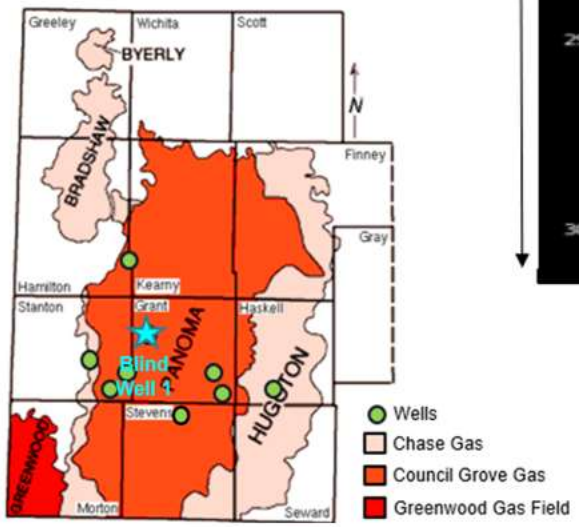
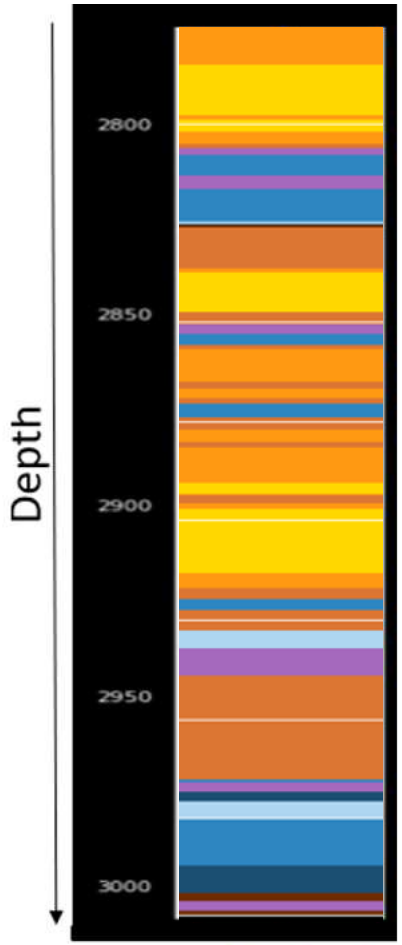
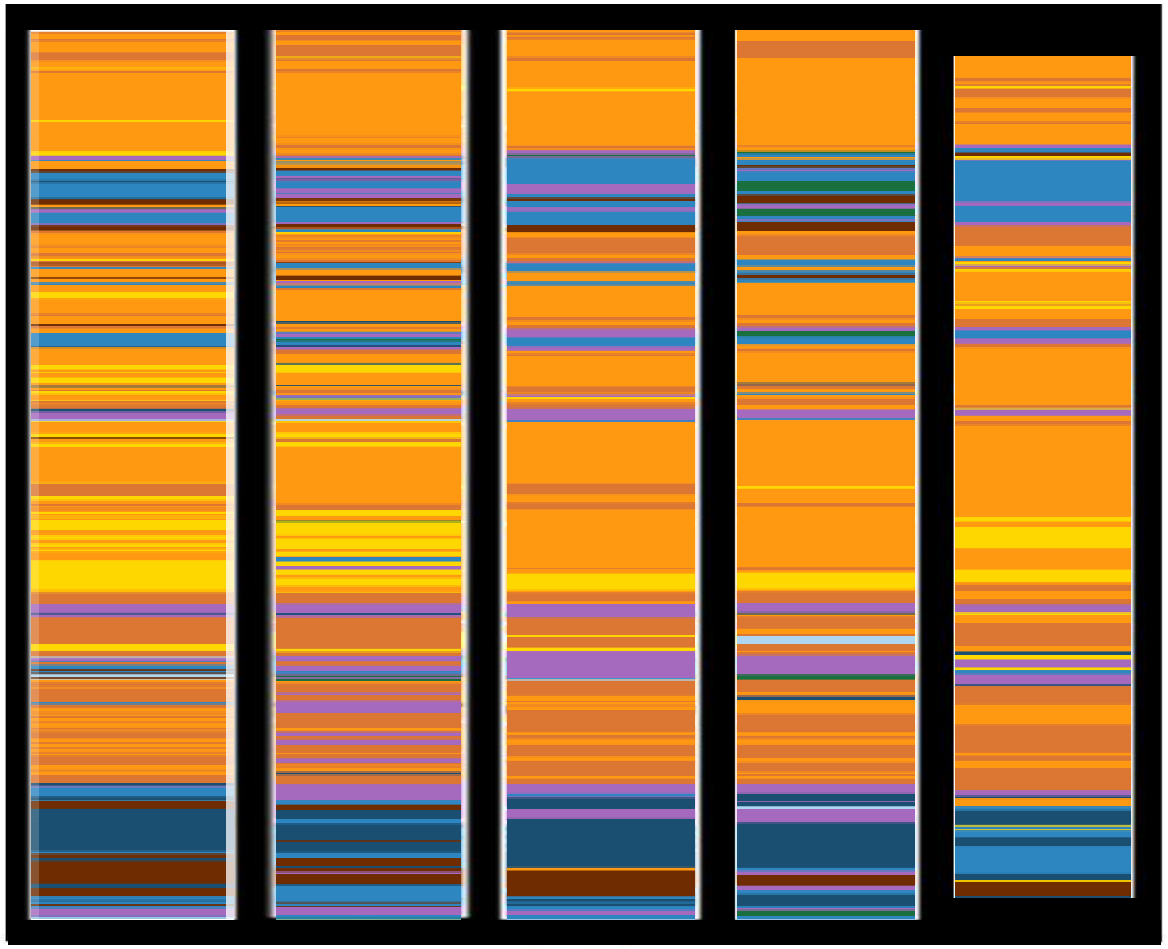
Blind Well 1 – Testing Results

RCP
In pursuit of new ideas







Labeled Facies	KNN	SVM	Random Forest	MLP	CNN
	35 %	38 %	46 %	41 %	50 %

Blind Well 1 – Testing Results

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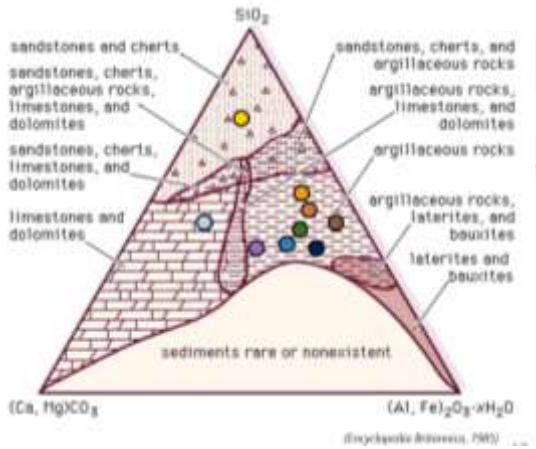
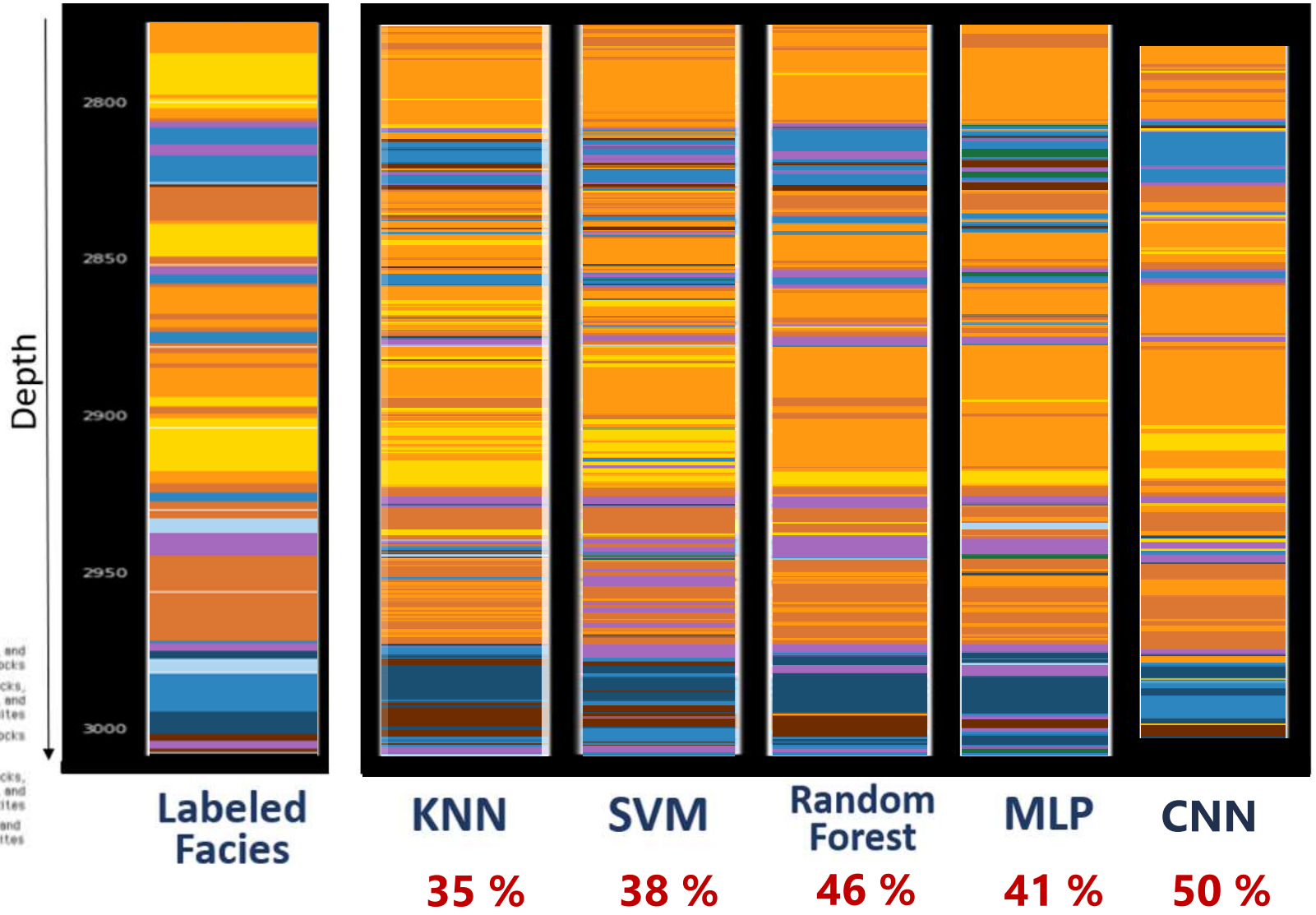
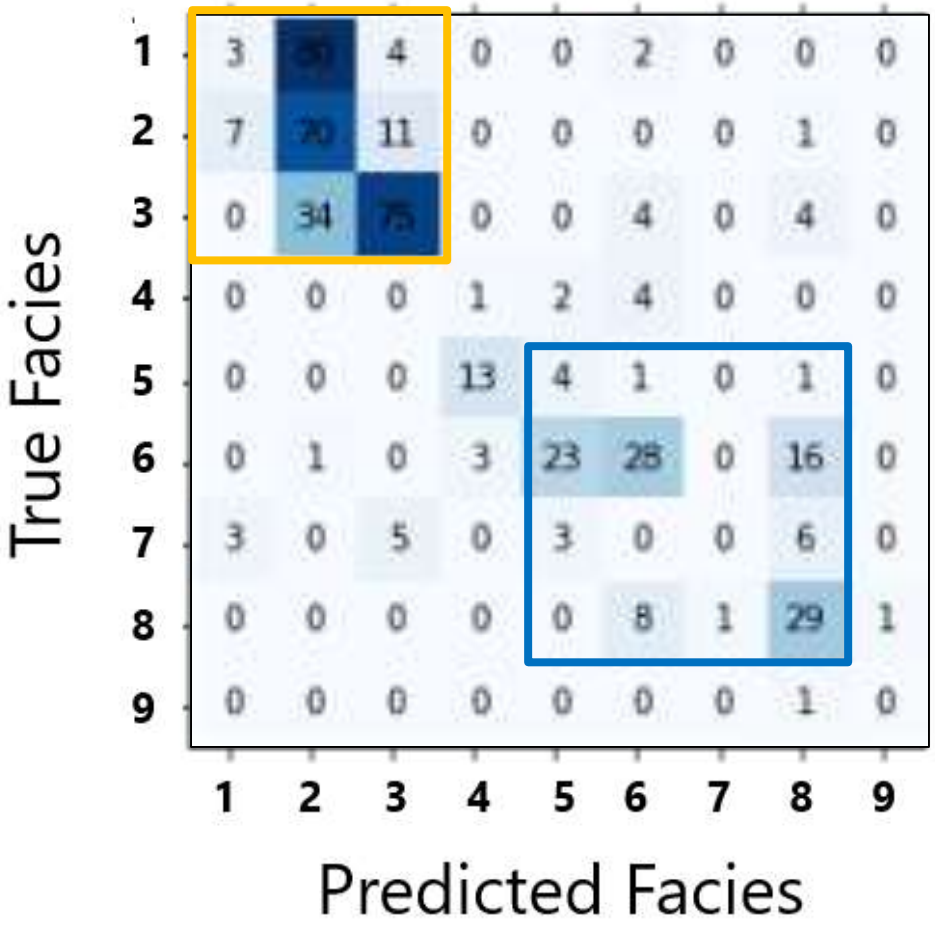




Confusion Matrix

- Allows visualization of an algorithm's performance



Rock Facies

1. Sandstone
2. Coarse siltstone
3. Fine siltstone
4. Siltstone and Shale
5. Mudstone
6. Wackestone
7. Dolomite
8. Packstone
9. Bafflestone

Blind Well 1 – Testing Results

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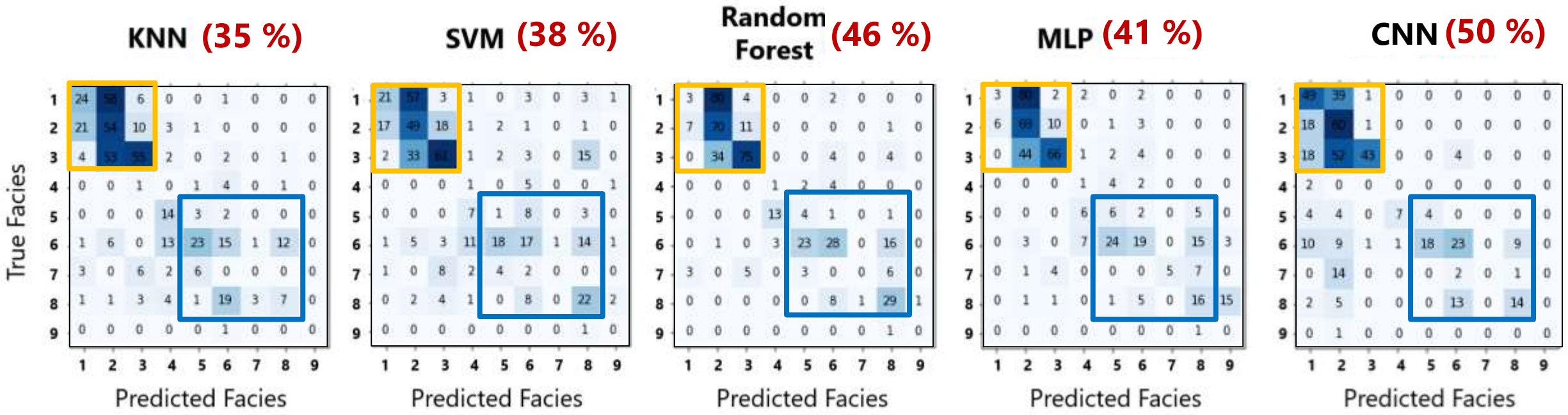

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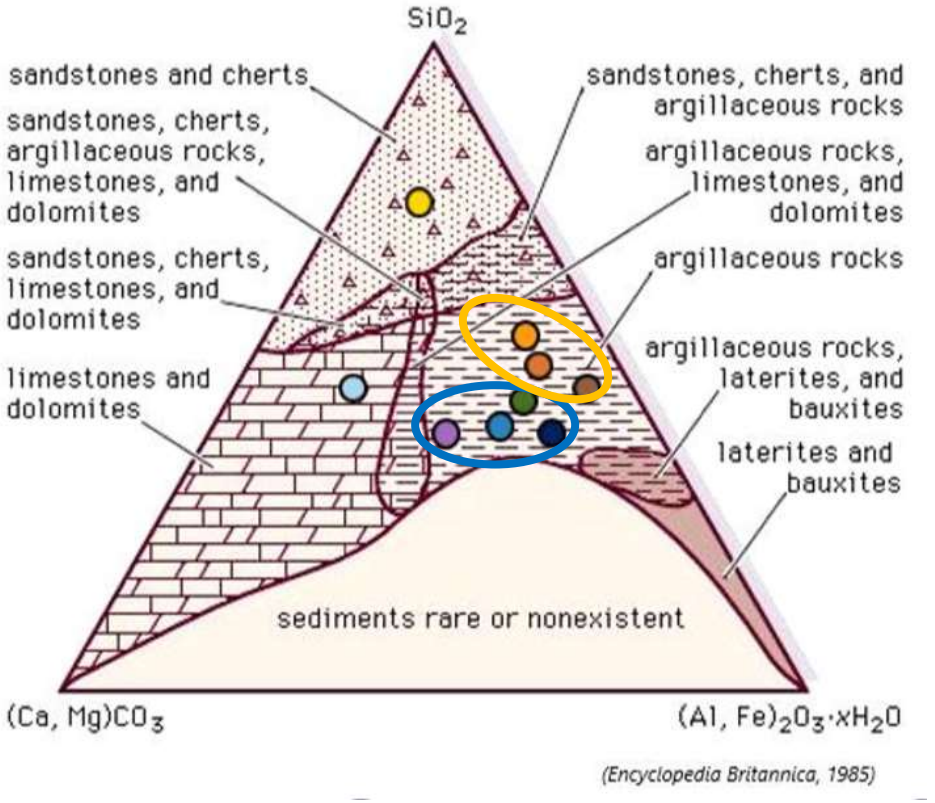
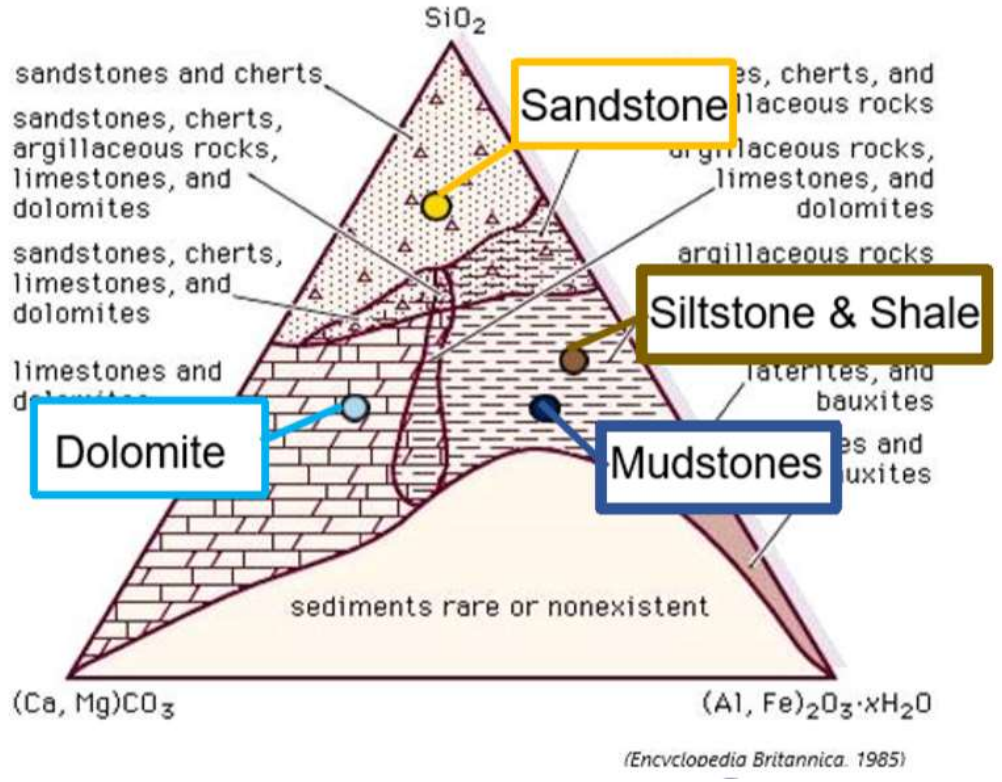
Dataset Processing





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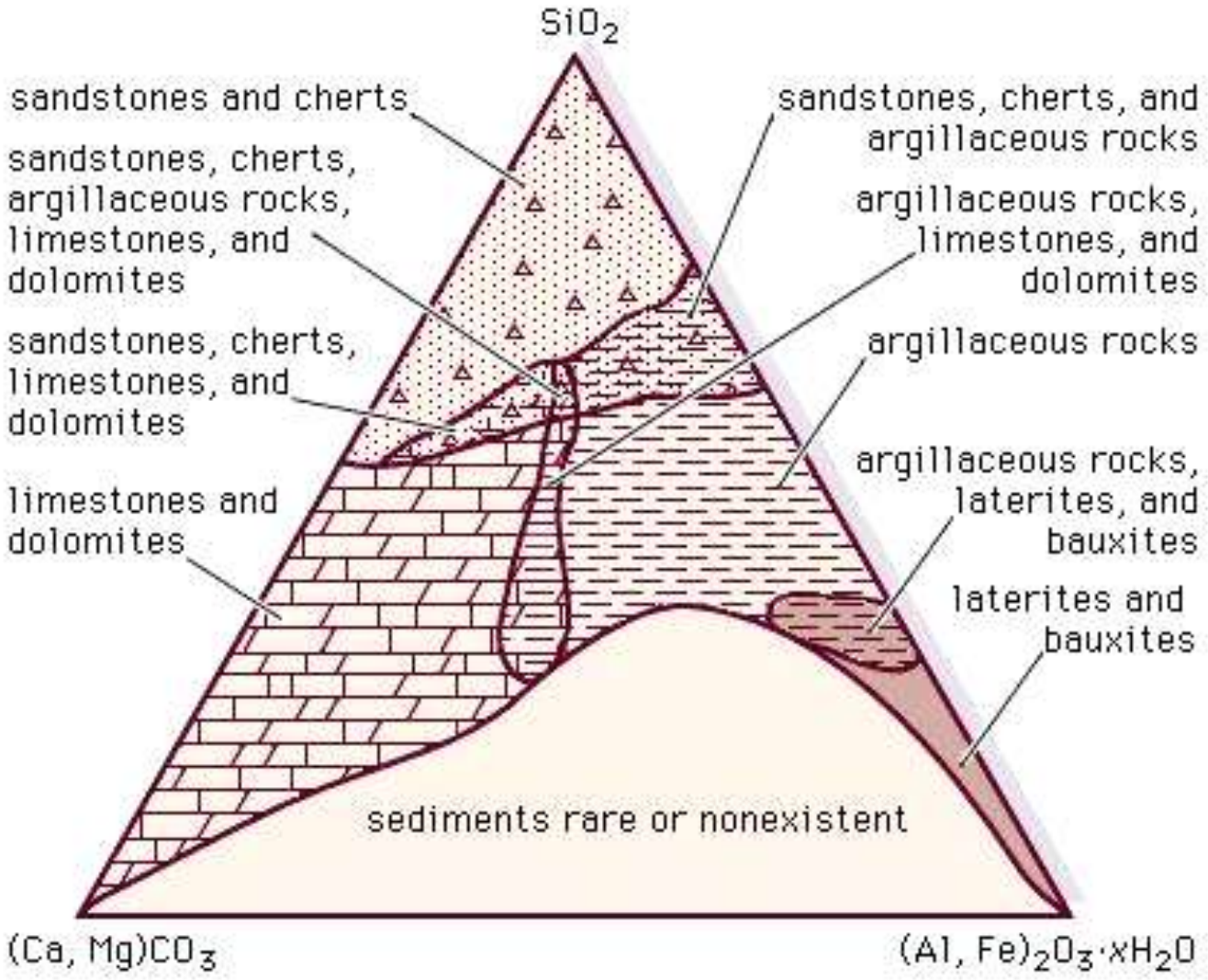

(Encyclopedia Britannica, 1985)

Dataset Processing (4 lumped lithofacies)

- 9 discrete rock facies

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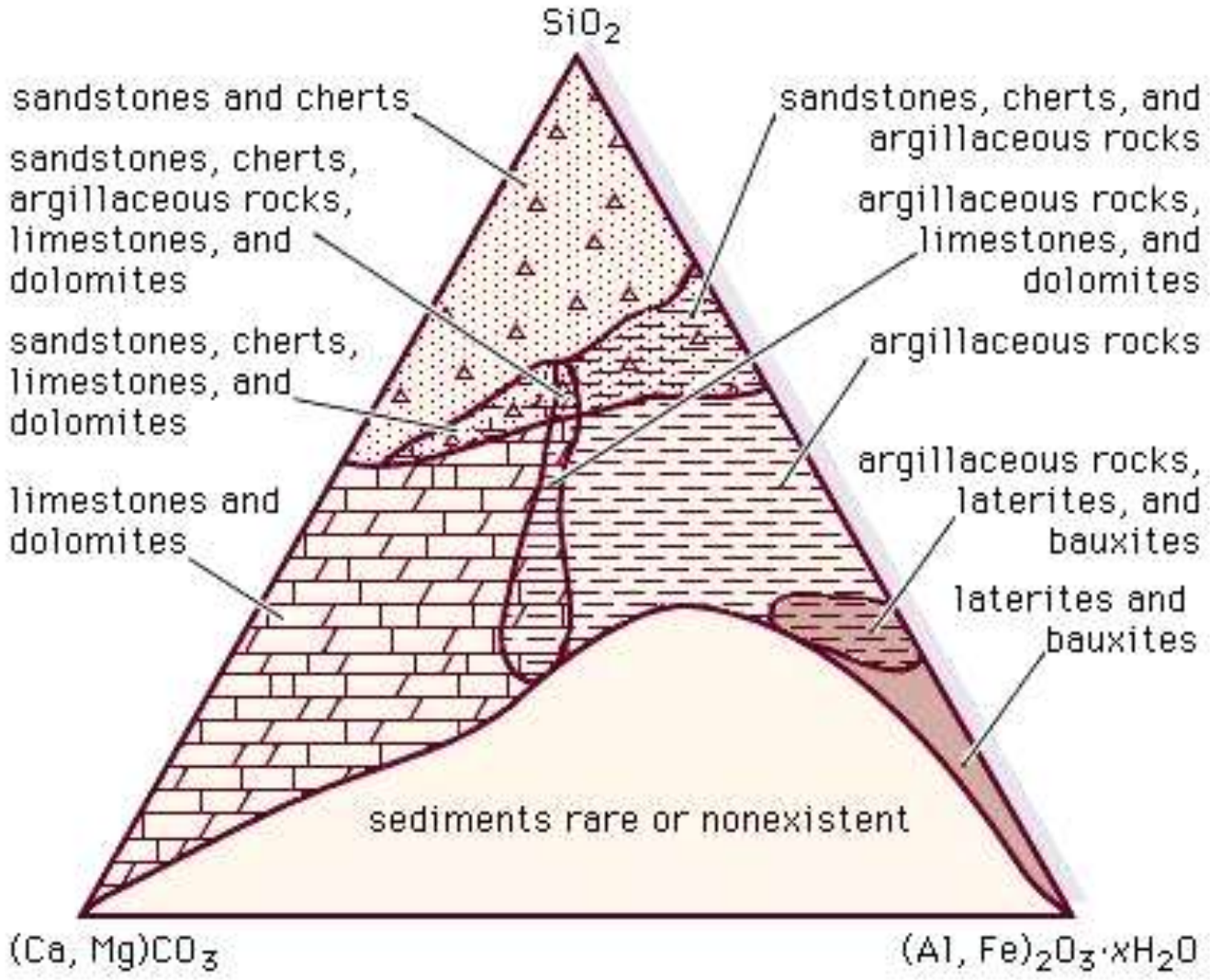

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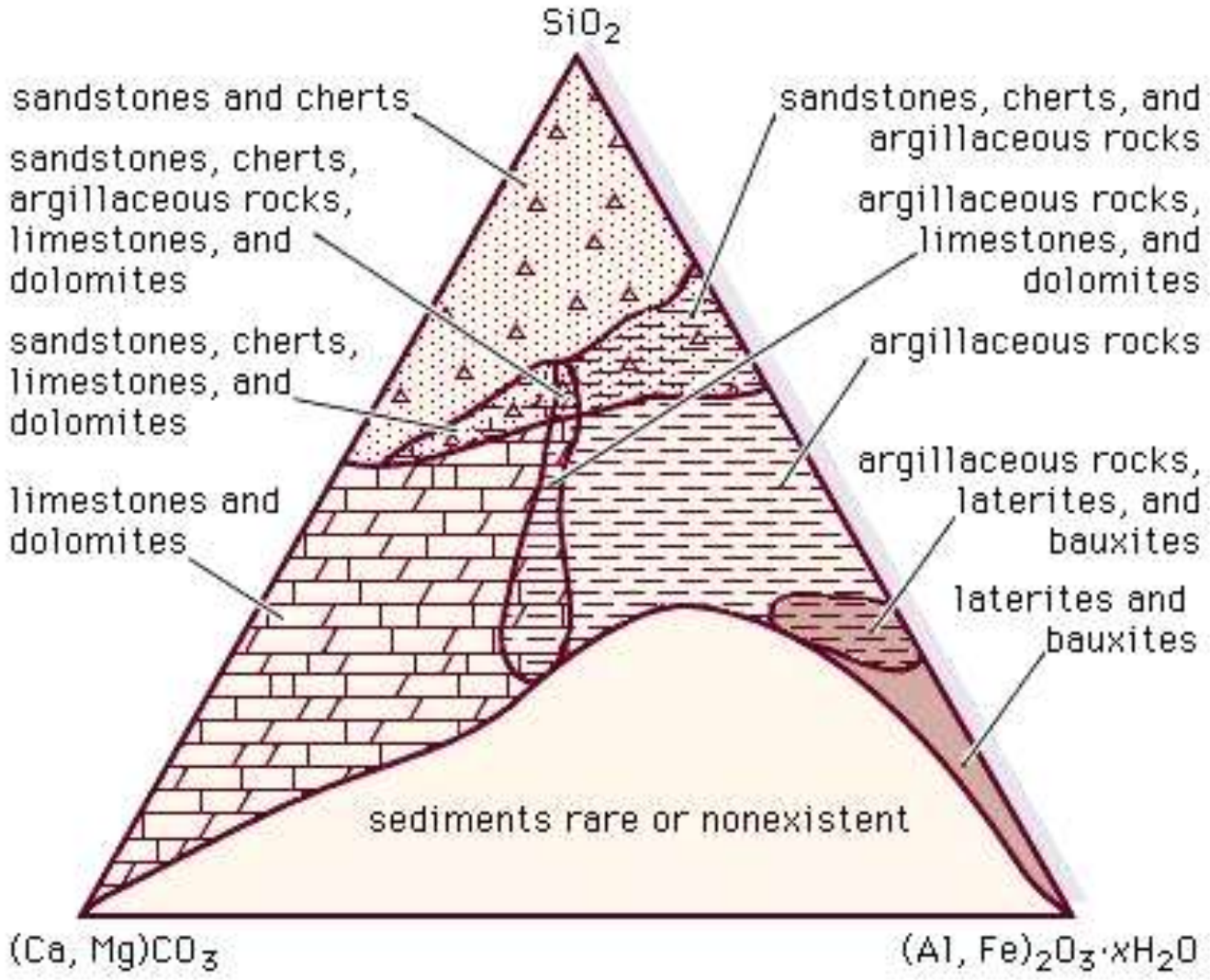
4. Siltstone and Shale
5. Mudstone
6. Wackestone
7. Dolomite
8. Packstone
9. Bafflestone



(Encyclopedia Britannica, 1985)

Pre-processed Training Wells

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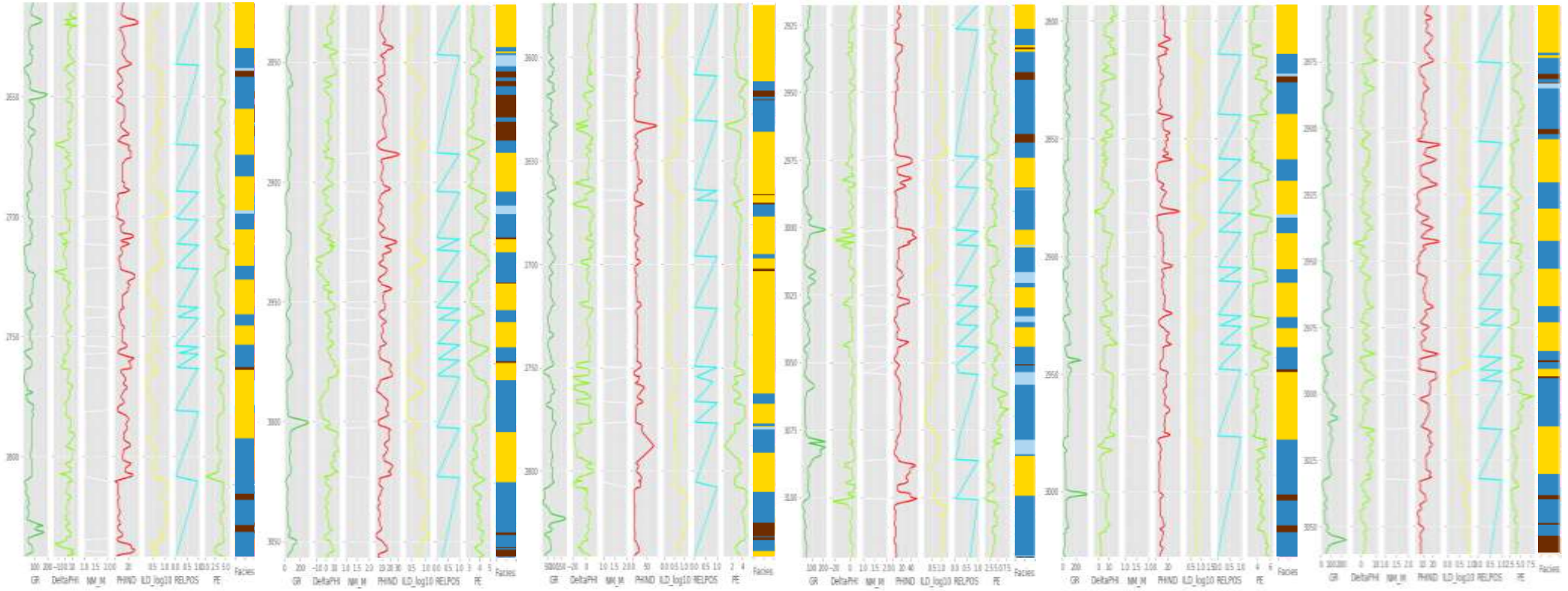
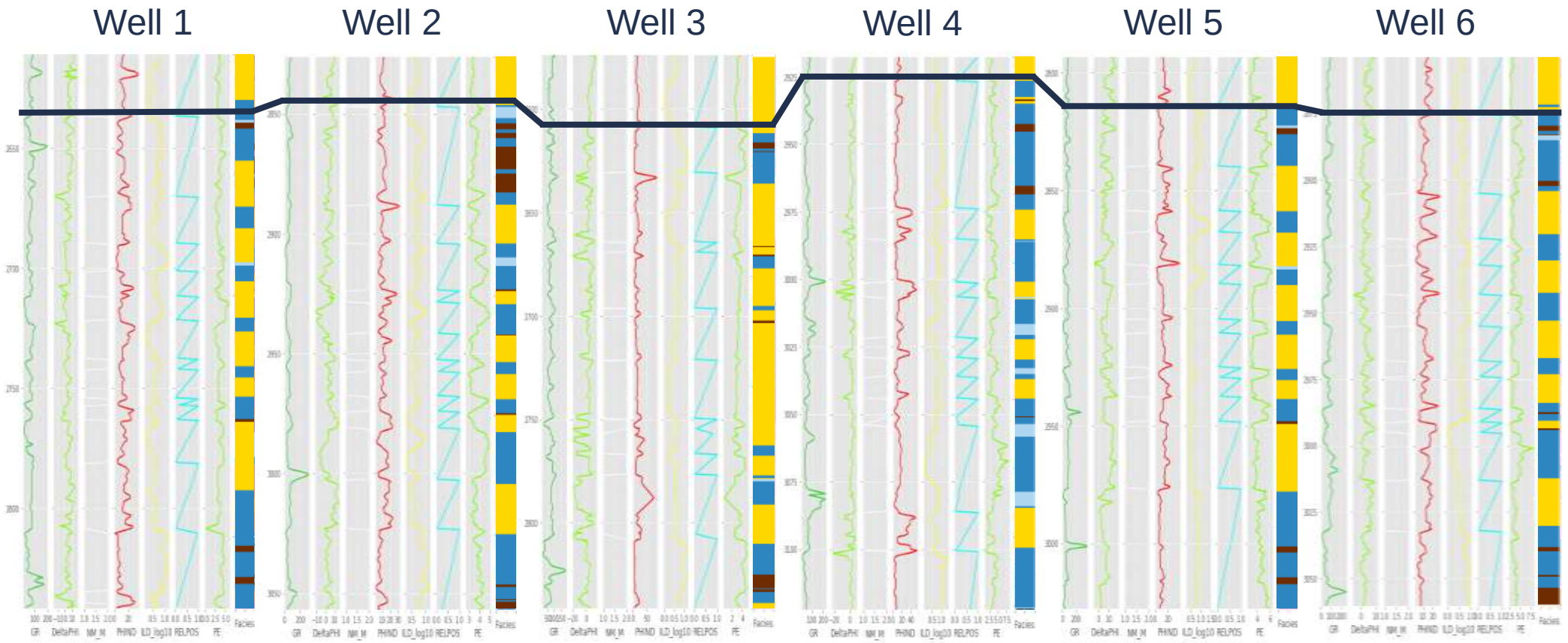
Well 1 | Well 2 | Well 3 | Well 4 | Well 5 | Well 6



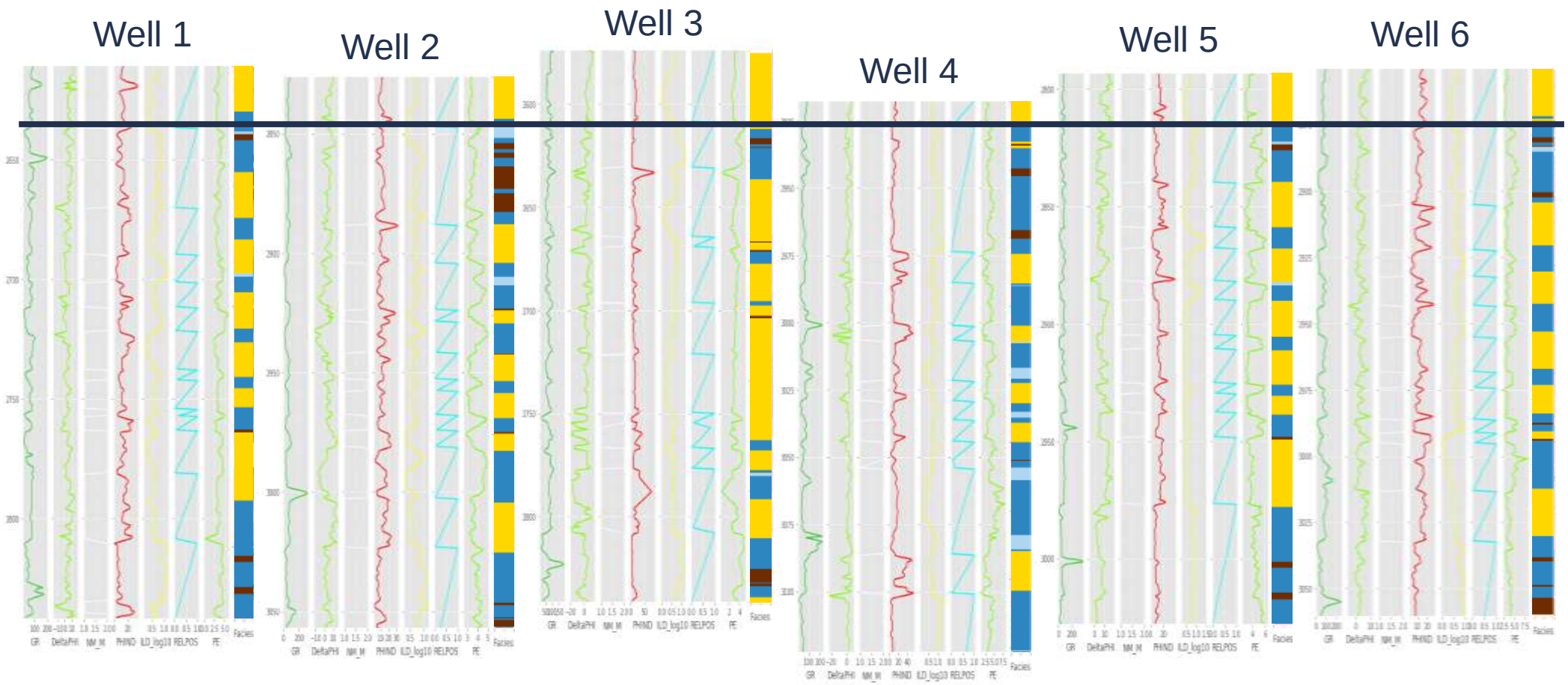
- Mudstones
- Dolomite
- Siltstone & Shale
- Sandstone, Fine & Coarse Siltstone

Pre-processed Training Wells

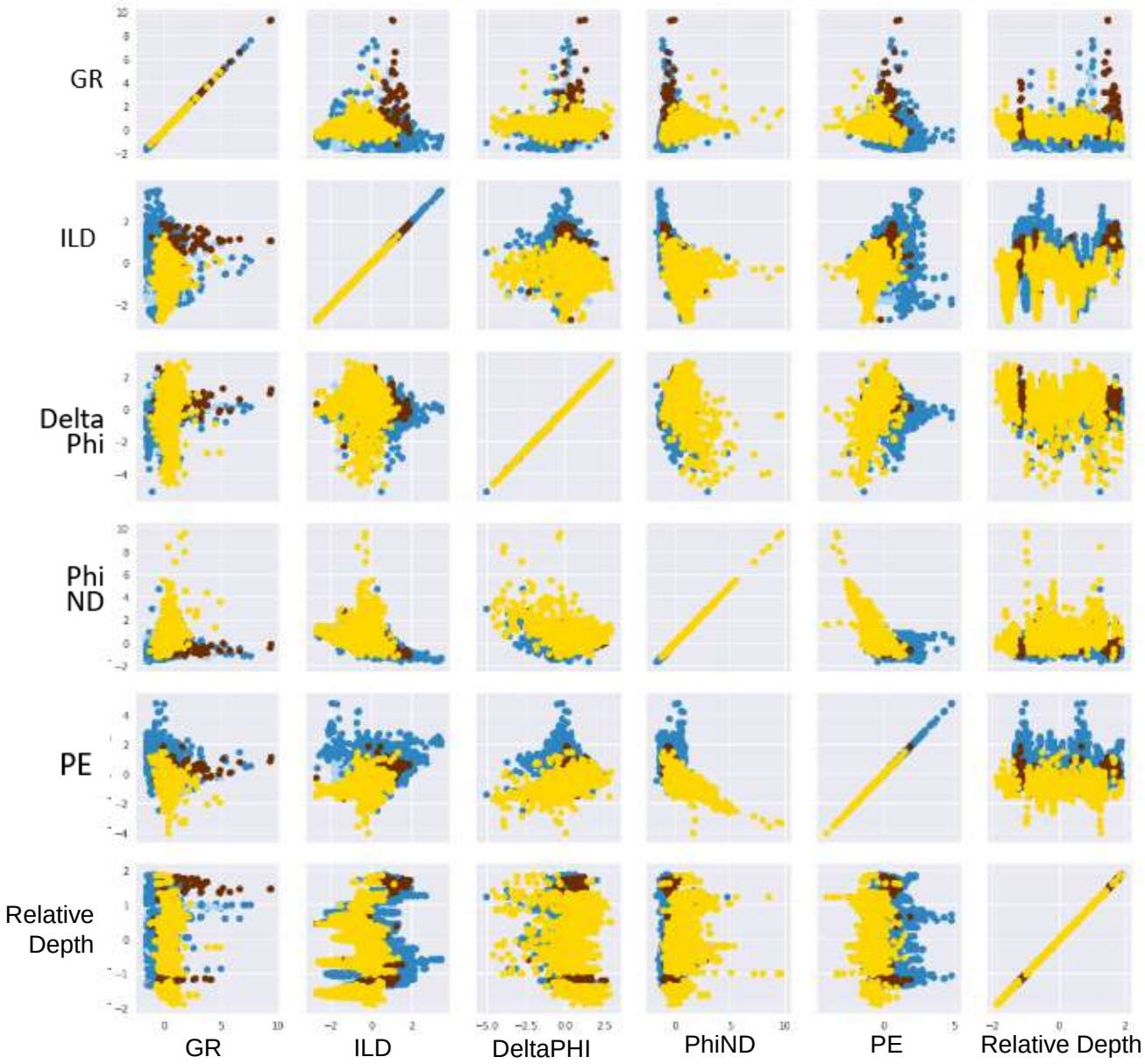
RCP
In pursuit of new ideas



Pre-processed Training Wells

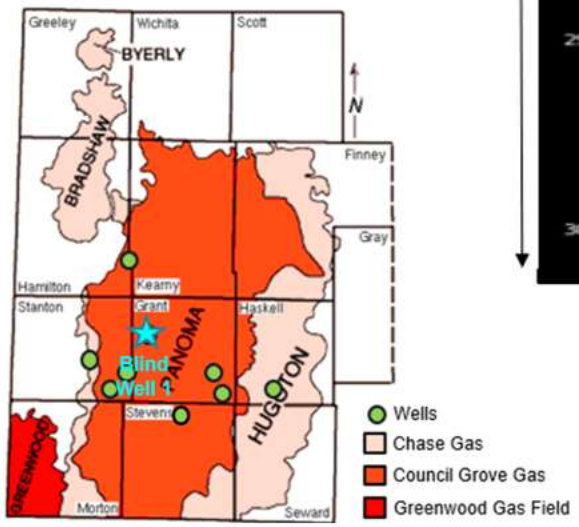


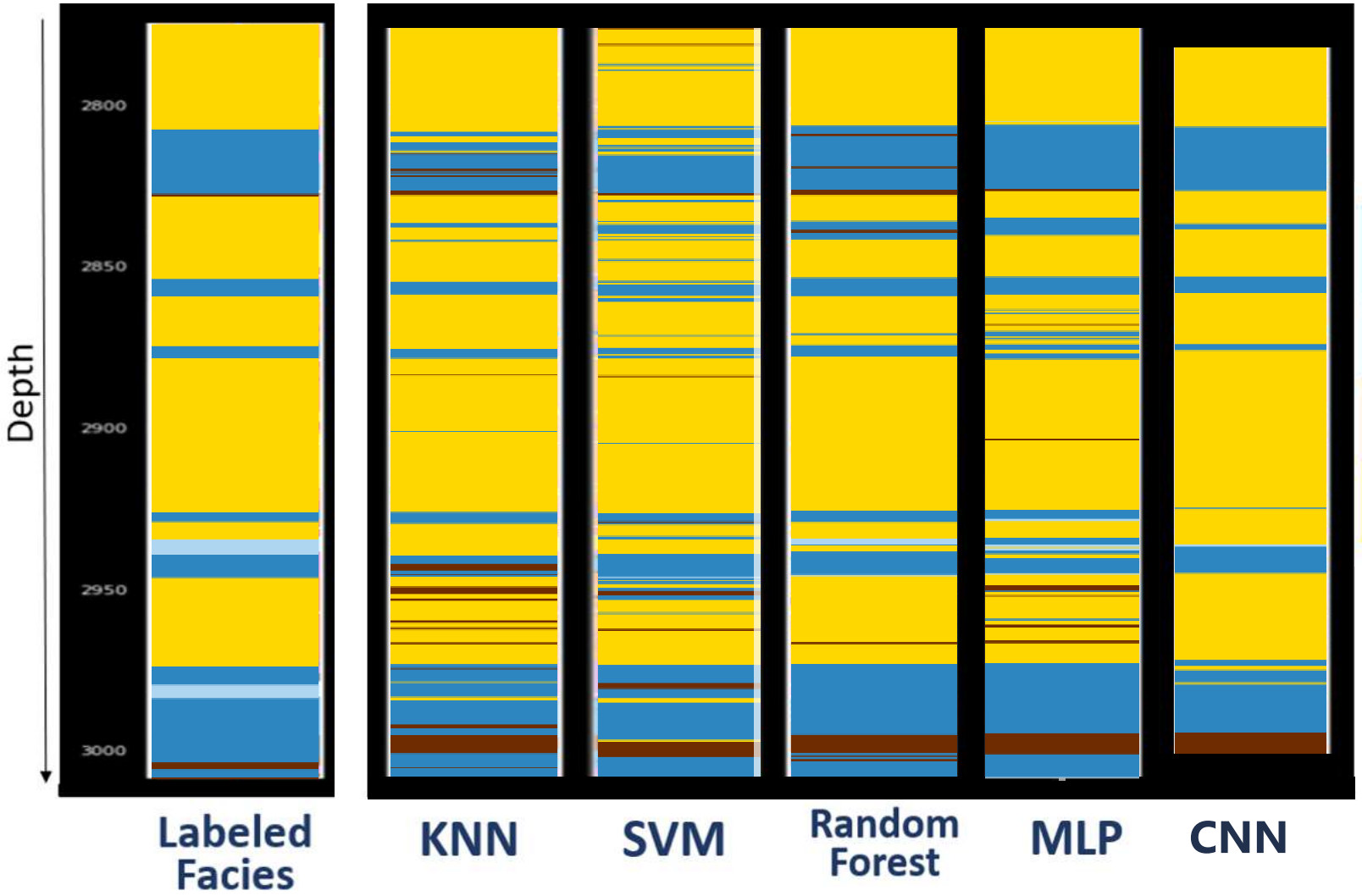
Labeled Clusters



- Mudstones
- Dolomite
- Siltstone & Shale
- Sandstone, Fine & Coarse Siltstone

Blind Well 1 – Testing Results





Labeled Facies	KNN	SVM	Random Forest	MLP	CNN
	82 %	79 %	88 %	83 %	89 %

Blind Well 1 – Testing Results

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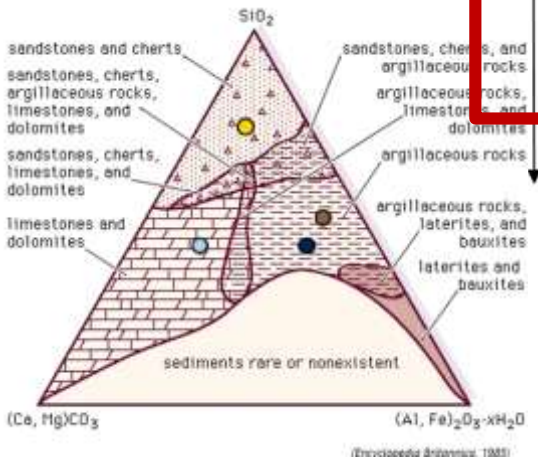
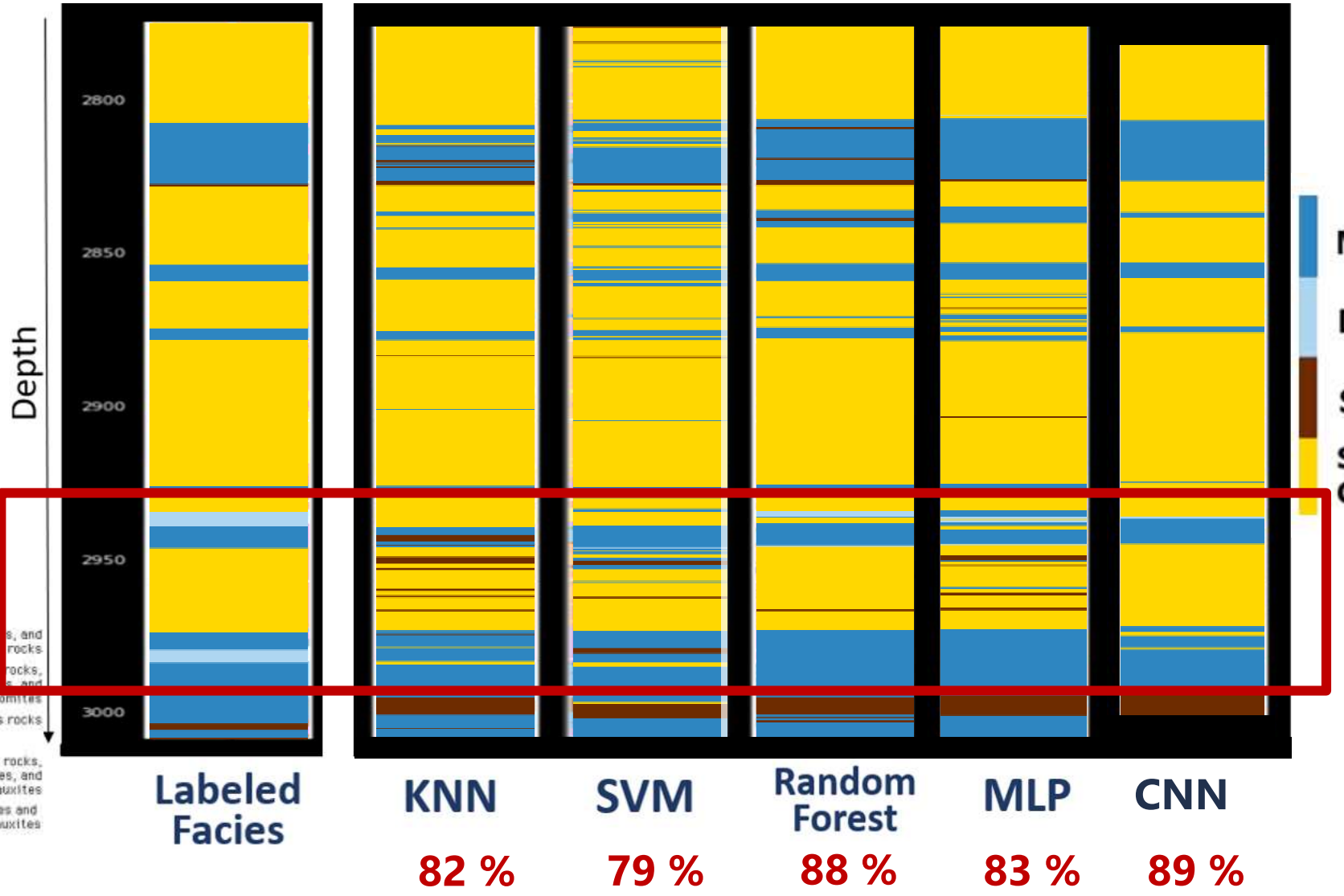
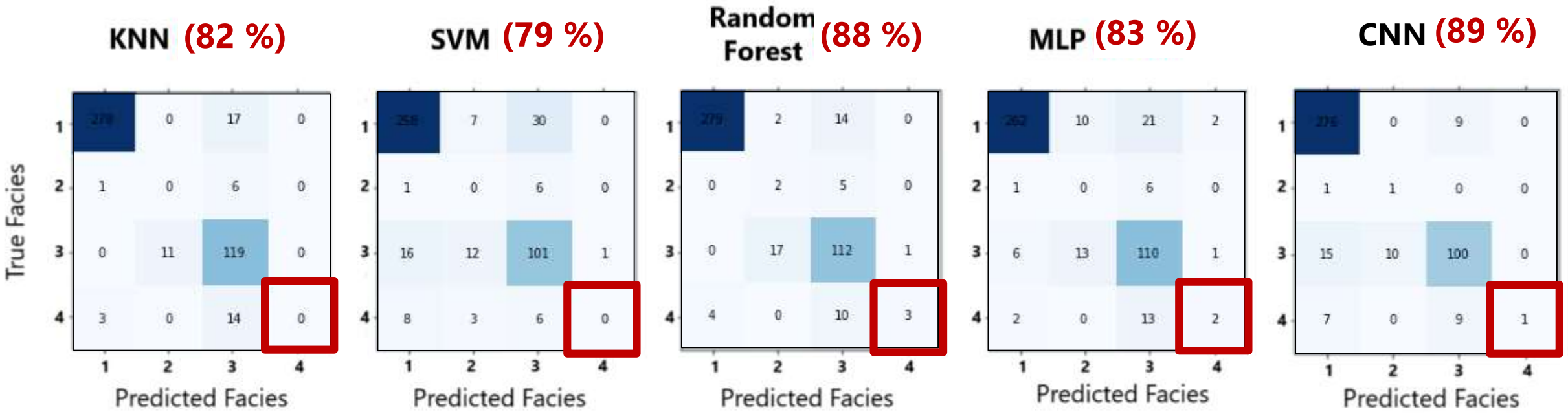




Blind Well 1 – Testing Results



Rock Facies

1. Sandstone, Fine and Coarse Siltstone
2. Siltstone and Shale
3. Mudstones
4. Dolomite

Adding Dolomite in Training Dataset

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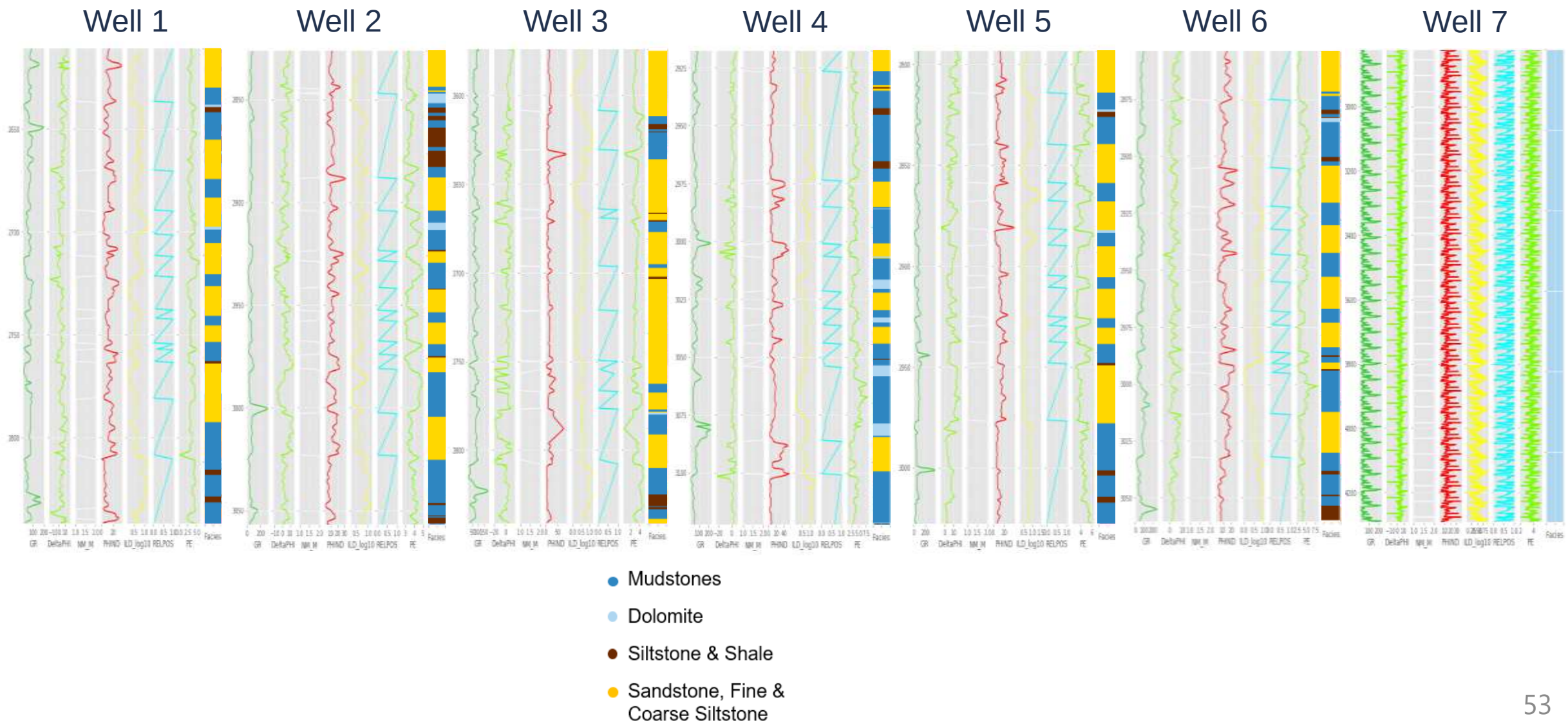
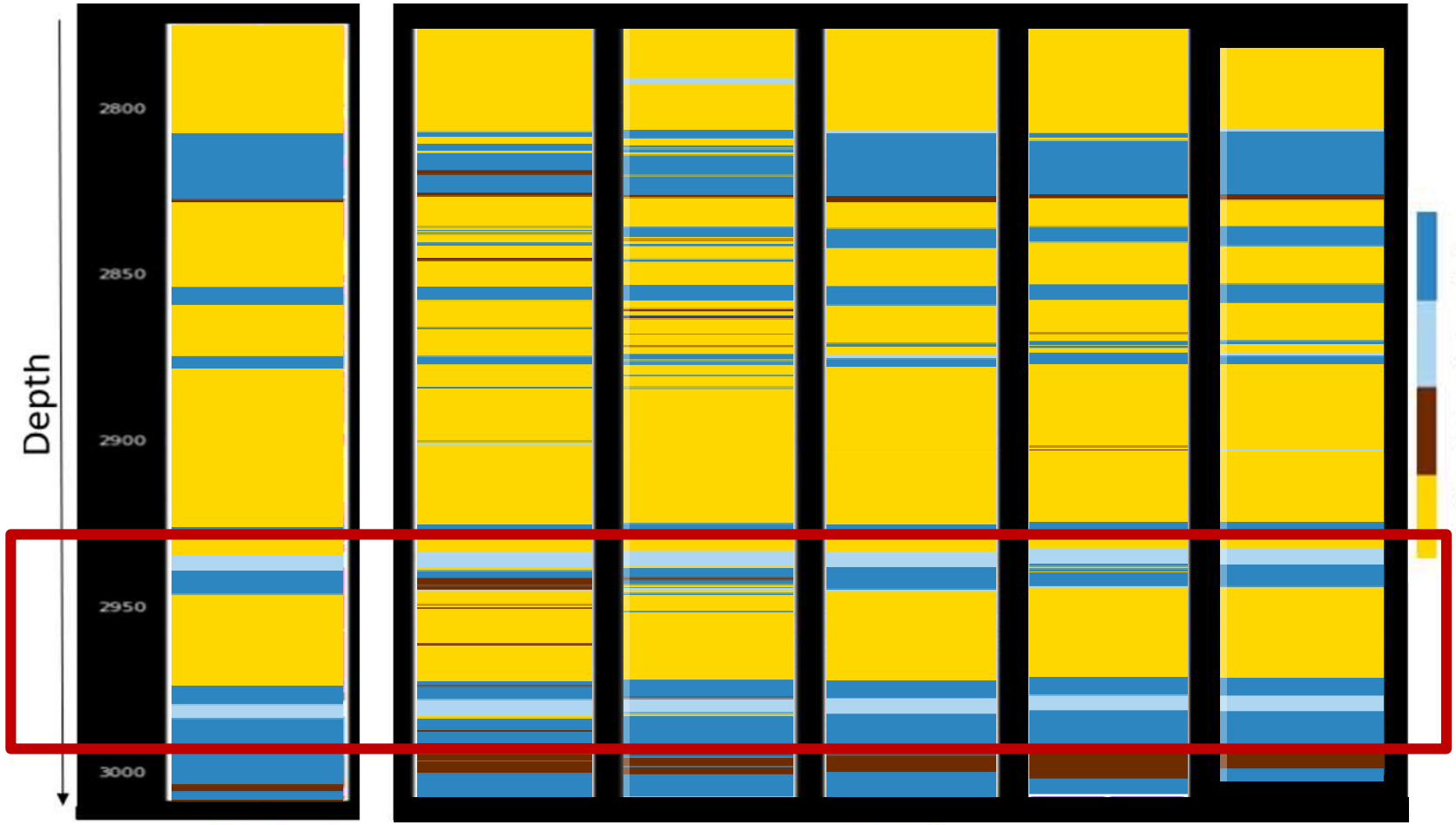
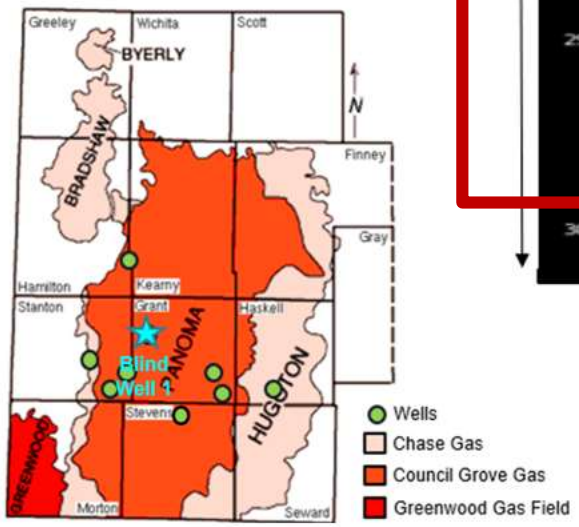


Blind Well 1 – Testing Results

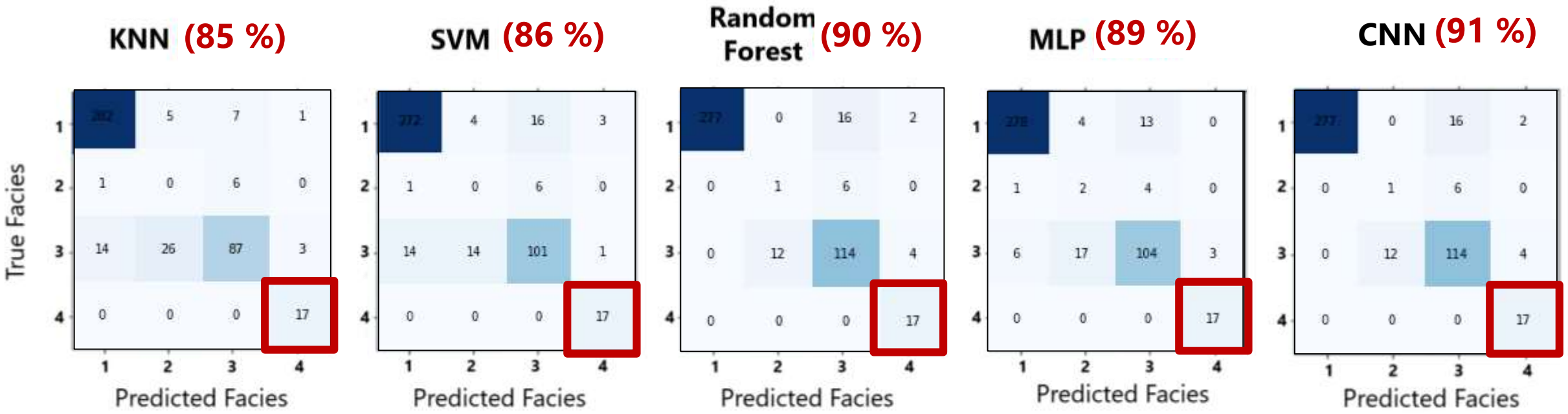
RCP
In pursuit of new ideas



Labeled Facies	KNN	SVM	Random Forest	MLP	CNN
	85 %	86 %	90 %	89 %	91 %



Blind Well 1 – Testing Results



Rock Facies

1. Sandstone, Fine and Coarse Siltstone
2. Siltstone and Shale
3. Mudstones
4. Dolomite

Conclusion

- Lithofacies classification using ML
  - Strong match in overall lithofacies sequence and boundaries
  - Perform best with optimized hyperparameters and more training data

Conclusion

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  - Strong match in overall lithofacies sequence and boundaries
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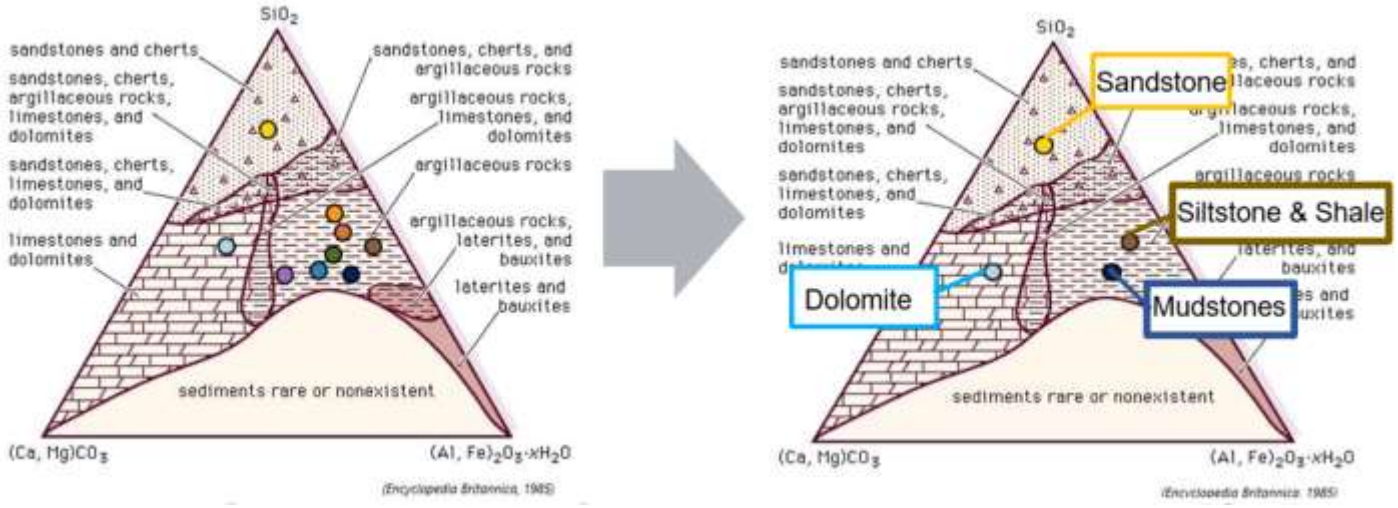
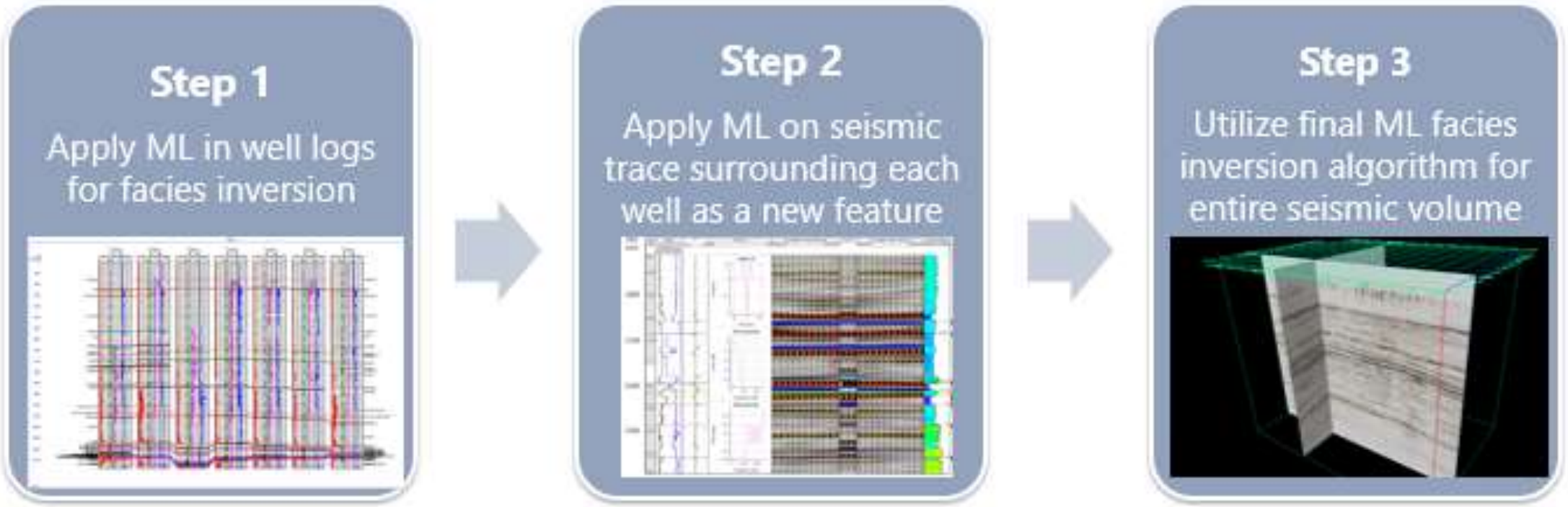


Conclusion

- Lithofacies classification using ML
  - Strong match in overall lithofacies sequence and boundaries
  - Perform best with optimized hyperparameters and more training data
- Supervised ML methods tend to perform more accurately with more differential facies to classify
- Strong match in lithofacies classification especially from Random Forest **(90%)** and 2D CNN **(91%)**

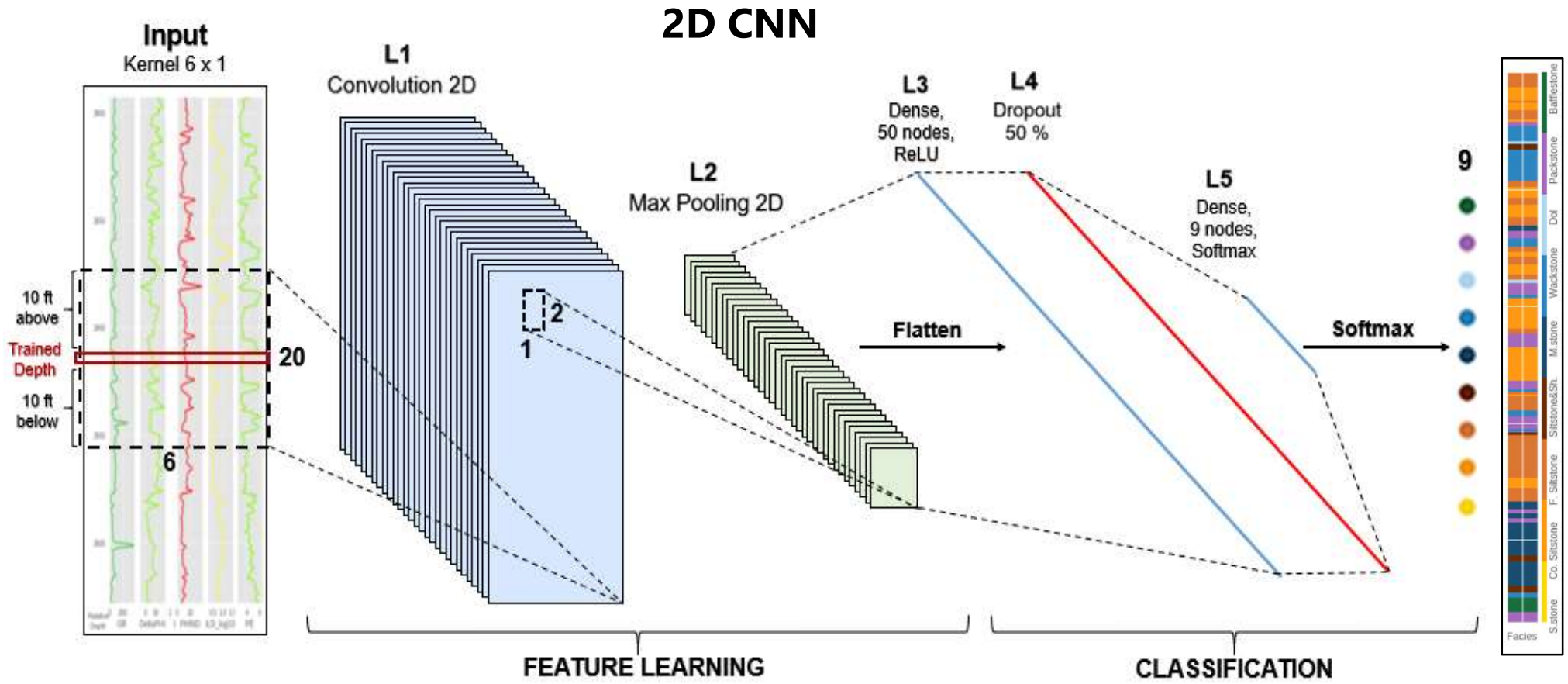
Future Work

- Develop Machine Learning facies inversion workflow for mapping of reservoirs in Raudhatain Field, Kuwait



Future Work

- Develop Machine Learning facies inversion workflow for mapping of reservoirs in Raudhatain Field, Kuwait



Acknowledgement

Thank you RCP industry sponsors

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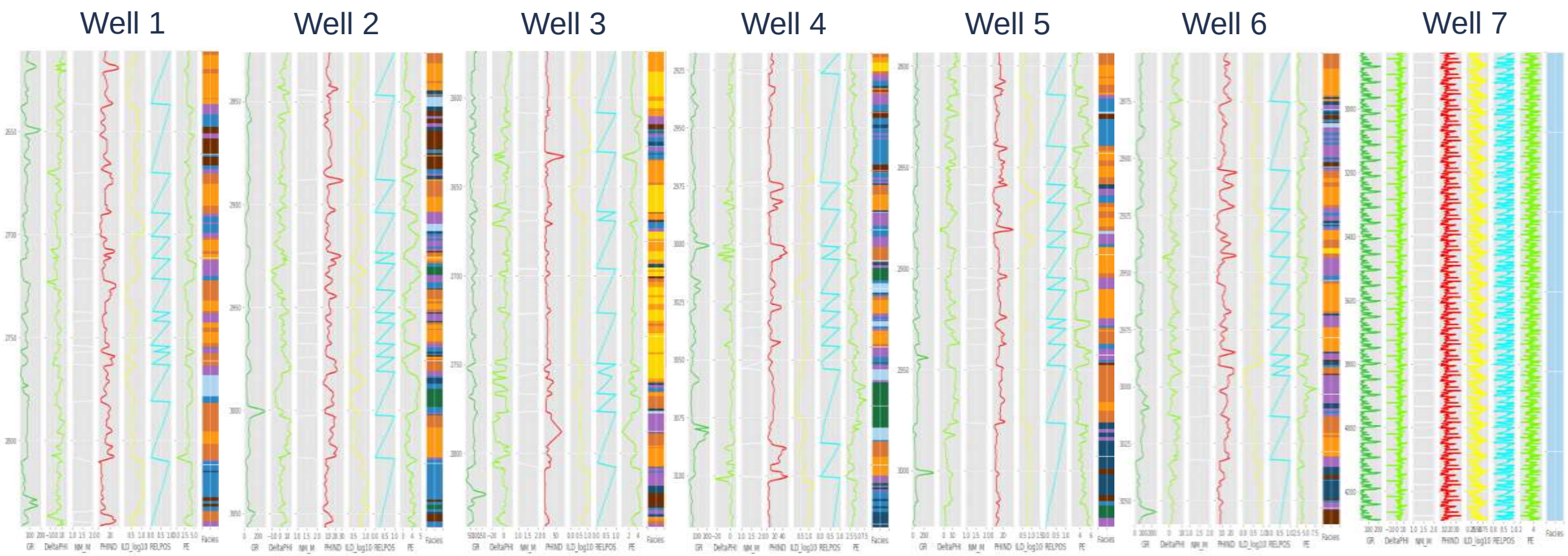
Processed Training Wells



Blind Well 1 – Adding Dolomite in Training Set

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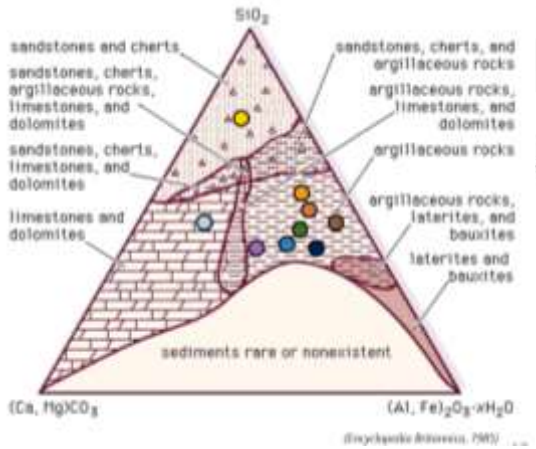

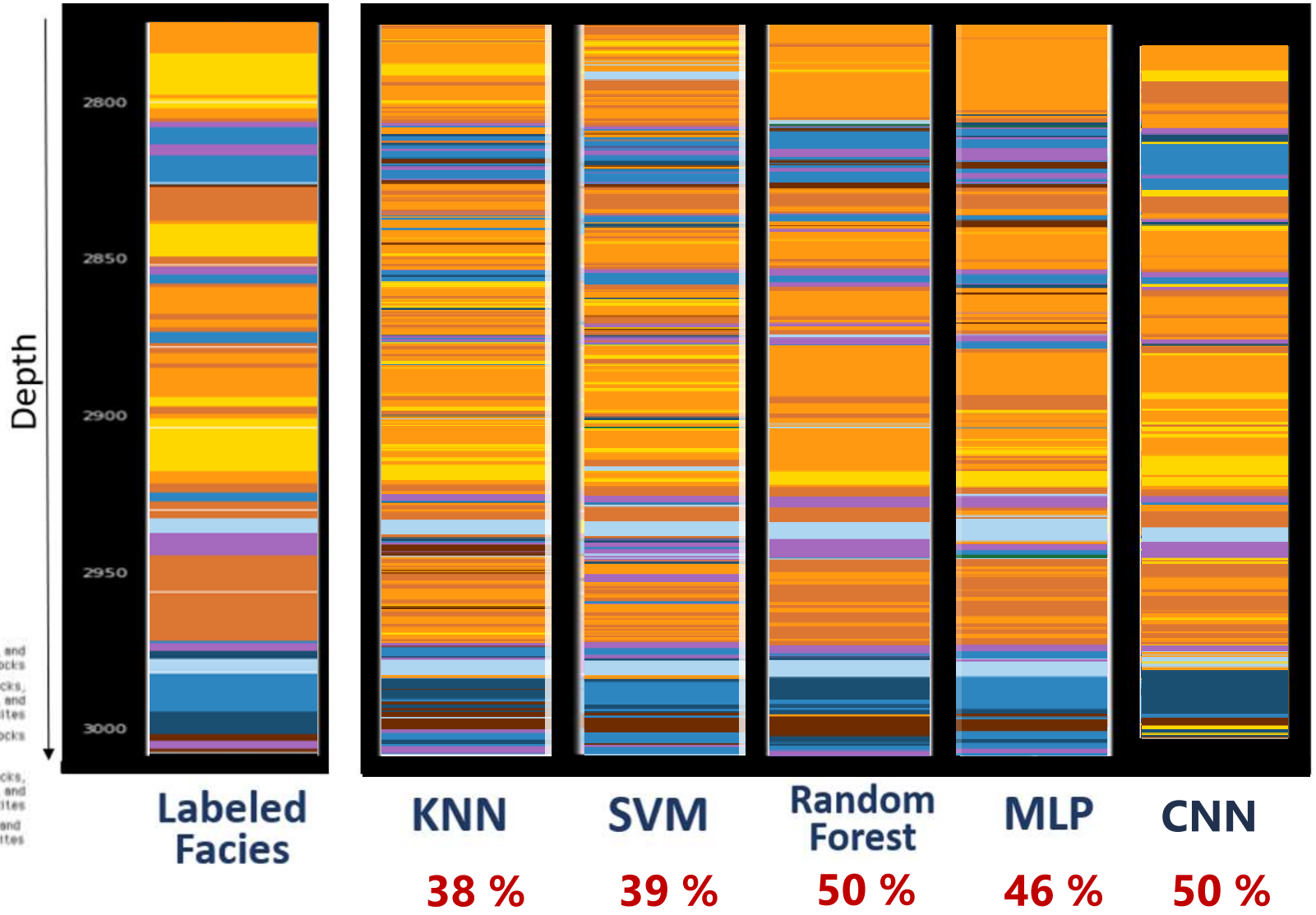

Blind Well 1 – Adding Dolomite in Training Set

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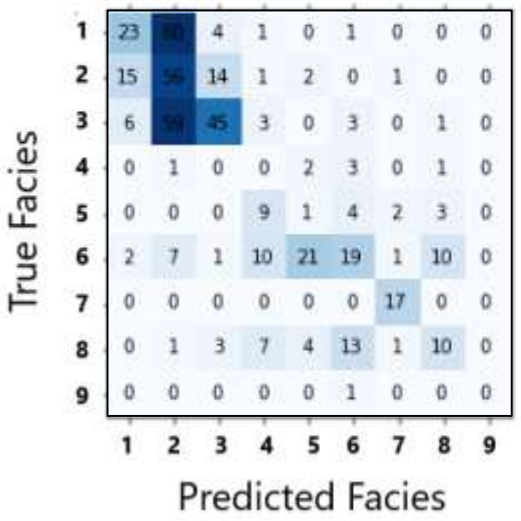
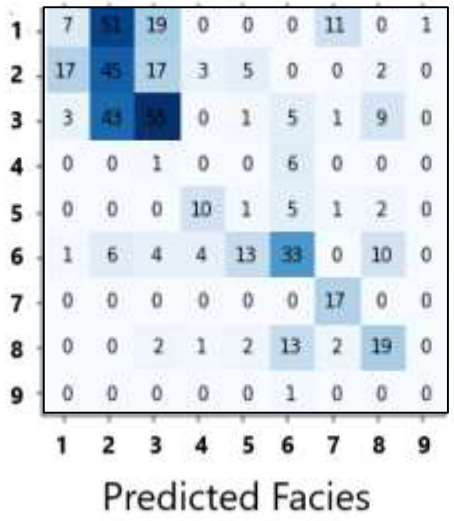
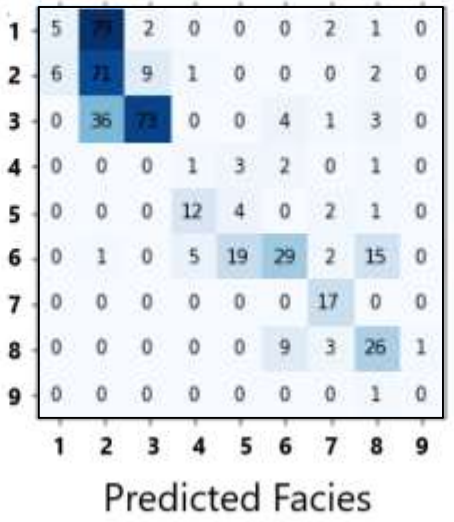
KNN (38 %)



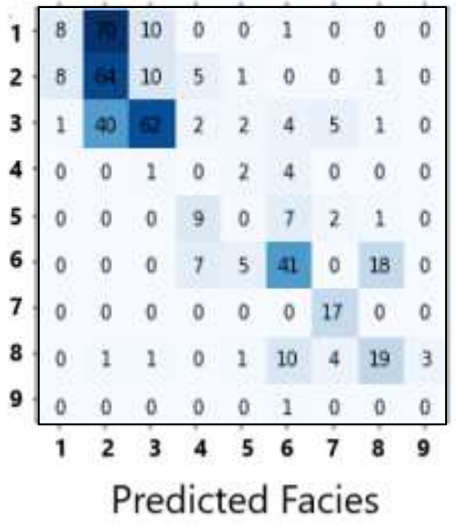
SVM (39 %)



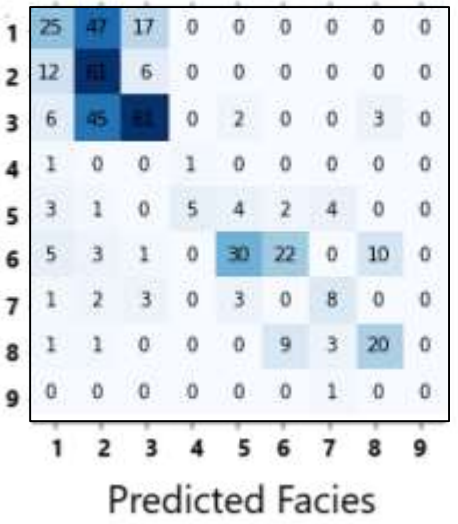
Random Forest (50 %)



MLP (46 %)



CNN (50 %)



Rock Facies

1. Sandstone
2. Coarse siltstone
3. Fine siltstone
4. Siltstone, Shale
5. Mudstone
6. Wackestone
7. Dolomite
8. Packstone
9. Bafflestone

INDEX – TRAINING AND TESTING RESULTS

Testing and Training Results (9 Lithofacies)

RCP
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Training Data Accuracy

	After Standard Scaling Train and Test	Drop Gamma Ray (GR)	Drop Resistivity (ILD_log 10)	Drop Neutron Density Porosity Difference (Delta_PHI)	Drop Nuetron Density Porosity (NDPHI)	Drop Photoelectric (PE)	Drop (Delta_PHI) and (NDPHI)	Use Relative Depths as 6th feature	Use Relative Depths as the only feature	Only use four features from PCA
SVM	**97.32%**	87.86%	87.34%	87.94%	89.38%	46.77%	70.37%	**99.60%**	35.14%	**89.66%**
RF	64.34%	83.31%	82.99%	83.55%	84.90%	84.35%	78.75%	**89.54%**	45.13%	84.38%
KNN	41.43%	78.19%	78.08%	79.39%	78.99%	78.63%	75.80%	85.06%	32.74%	79.79%
MLP	65.14%	58.47%	58.31%	61.38%	59.42%	79.39%	55.11%	68.53%	38.08%	58.63%
CNN 100 epochs	50.85%	78.02%	81.38%	78.66%	79.11%	80.14%	70.53%	77.83%	8.32%	
CNN 5 epochs	59.70%	79.11%	**82.78%**	79.53%	80.59%	80.51%	71.66%	78.58%	8.66%	
Average	63.81%	77.17%	77.62%	78.18%	78.36%	73.86%	70.11%	**84.11%**	31.88%	78.12%

Testing Data Accuracy

	After Standard Scaling Train and Test	Drop Gamma Ray (GR)	Drop Resistivity (ILD_log 10)	Drop Neutron Density Porosity Difference (Delta_PHI)	Drop Nuetron Density Porosity (NDPHI)	Drop Photoelectric (PE)	Drop (Delta_PHI) and (NDPHI)	Use Relative Depths as 6th feature	Use Relative Depths as the only feature	Only use four features from PCA
SVM	38.08%	31.63%	39.87%	40.09%	36.08%	37.19%	34.74%	38.31%	41.20%	31.63%
RF	**50.33%**	41.87%	**52.12%**	46.55%	49.00%	46.77%	43.43%	46.77%	35.14%	42.98%
KNN	38.53%	35.19%	39.20%	38.08%	34.30%	38.08%	33.41%	35.19%	30.73%	32.96%
MLP	41.43%	44.77%	46.33%	45.66%	44.54%	42.76%	47.88%	41.20%	32.74%	47.22%
CNN 100 epochs	**50.35%**	44.52%	**51.75%**	44.76%	47.32%	43.82%	34.73%	48.95%	16.78%	
CNN 5 epochs	**51.05%**	44.52%	49.88%	**52.91%**	44.06%	42.89%	36.13%	**50.58%**	8.89%	
Average	43.74%	39.59%	45.85%	43.03%	42.25%	41.73%	38.84%	42.08%	31.32%	38.70%

Testing and Training Results (4 Lithofacies)

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Training Data Accuracy

	After Standard Scaling Train and Test	Drop Gamma Ray (GR)	Drop Resistivity (ILD_log 10)	Drop Neutron Density Porosity Difference (Delta_PHI)	Drop Nuetron Density Porosity (NDPHI)	Drop Photoelectric (PE)	Drop (Delta_PHI) and (NDPHI)	Use Relative Depths as 6th feature	Use Relative Depths as the only feature	Only use four features from PCA
SVM	**99.20%**	93.89%	95.41%	96.41%	96.57%	96.09%	90.42%	**99.72%**	64.46%	96.29%
RF	86.62%	90.22%	91.13%	91.85%	91.73%	92.01%	90.42%	94.21%	68.77%	91.61%
KNN	92.41%	89.94%	90.58%	92.13%	91.41%	90.73%	89.58%	94.29%	61.46%	91.09%
MLP	91.33%	86.34%	87.22%	90.34%	88.98%	91.85%	90.54%	93.85%	65.69%	88.58%
CNN 100 epochs	**97.58%**	96.48%	97.43%	96.82%	96.90%	96.56%	96.10%	97.16%	57.06%	
CNN 5 epochs	**97.99%**	96.67%	**97.58%**	96.90%	97.54%	97.12%	90.44%	97.31%	57.02%	
Average	93.43%	91.37%	92.35%	93.51%	93.12%	93.45%	91.41%	**95.85%**	63.49%	91.89%

Testing Data Accuracy

	After Standard Scaling Train and Test	Drop Gamma Ray (GR)	Drop Resistivity (ILD_log 10)	Drop Neutron Density Porosity Difference (Delta_PHI)	Drop Nuetron Density Porosity (NDPHI)	Drop Photoelectric (PE)	Drop (Delta_PHI) and (NDPHI)	Use Relative Depths as 6th feature	Use Relative Depths as the only feature	Only use four features from PCA
SVM	79.96%	74.61%	75.95%	80.40%	81.74%	80.18%	87.08%	78.17%	78.40%	73.27%
RF	88.42%	86.19%	87.97%	89.09%	**89.98%**	86.64%	**89.53%**	88.64%	68.82%	88.64%
KNN	82.41%	77.28%	82.41%	82.41%	82.41%	84.19%	**89.53%**	82.63%	67.93%	84.41%
MLP	83.30%	79.96%	87.53%	85.52%	87.75%	84.19%	83.52%	79.73%	76.61%	87.75%
CNN 100 epochs	88.58%	84.15%	89.04%	**91.14%**	88.34%	86.95%	**90.44%**	88.34%	77.16%	
CNN 5 epochs	89.04%	84.62%	89.04%	**90.21%**	89.28%	87.65%	**90.44%**	88.58%	77.62%	
Average	83.52%	80.44%	84.58%	85.71%	86.04%	84.43%	**88.02%**	83.50%	73.78%	83.52%

Random Forest Feature Importance

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	Feature	Feature Importance
0	Gamma Ray (GR)	0.24394525
1	Resistivity (ILD)	0.21422884
4	Photoelectric Density (PE)	0.21242498
3	Neutron Density Porosity (PHIND)	0.19133538
2	Neutron Density Porosity Difference (DeltaPHI)	0.13806556

INDEX – PCA AND RELATIVE DEPTH

Blind Well 1 – Only Use PCA Features

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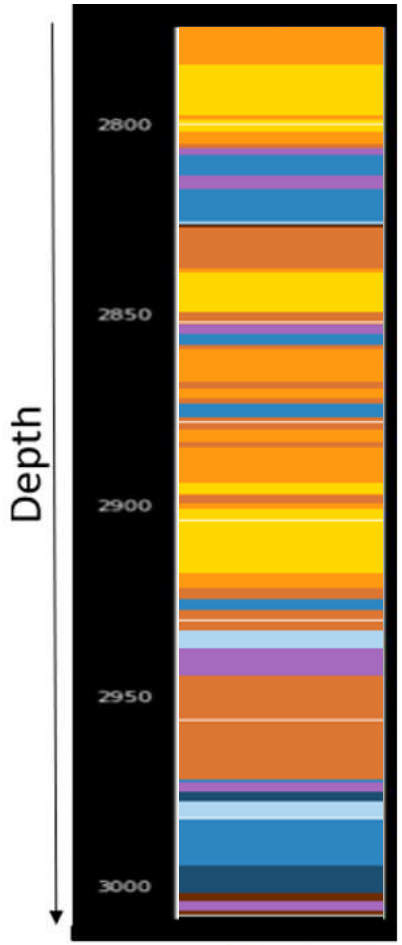
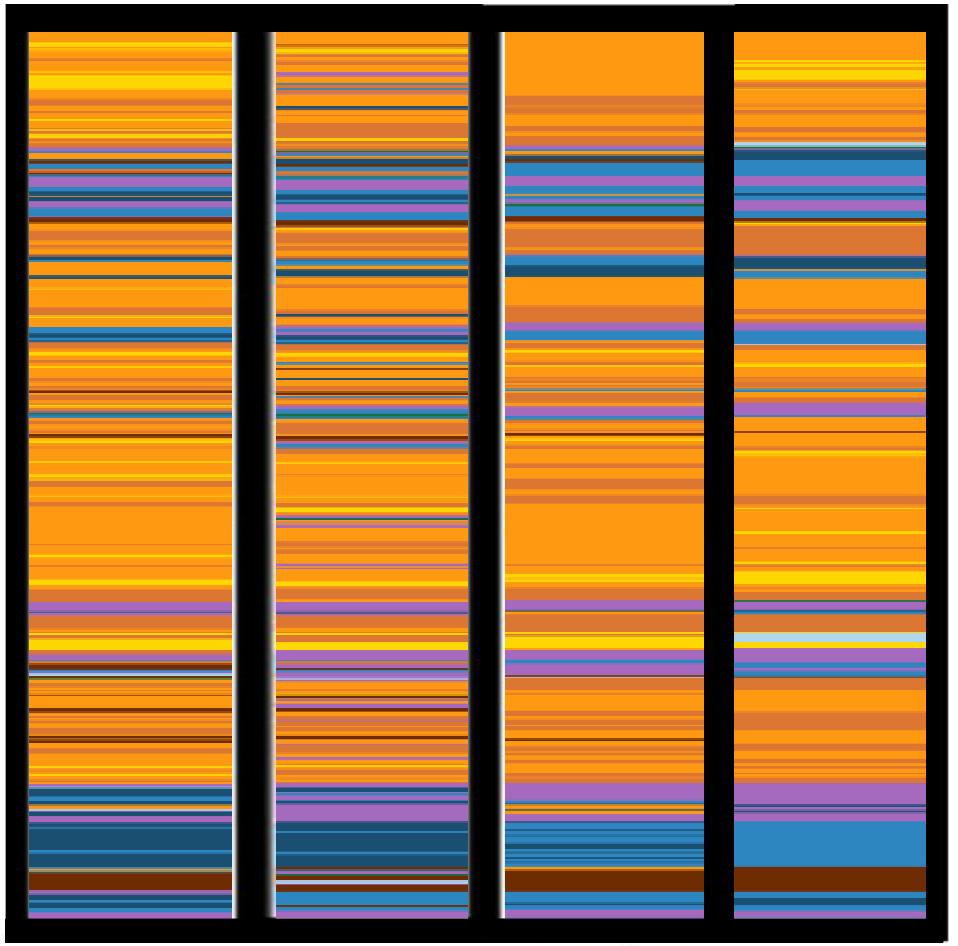




Bafflestone
Packstone
Dolomite
Wackestone
Mudstone
Siltstone & shale
Fine Siltstone
Coarse Siltstone
Sandstone

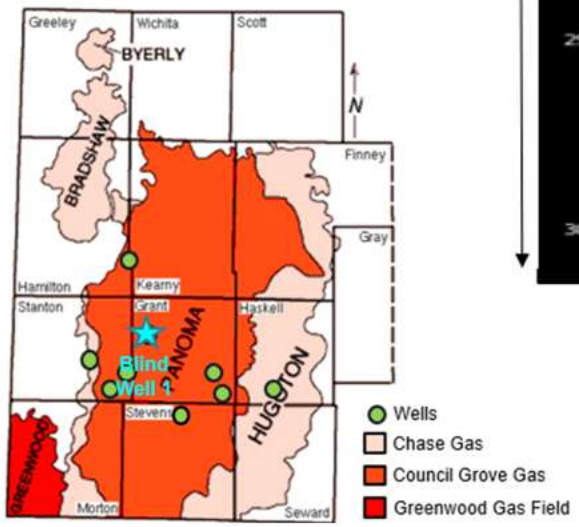
Labeled Facies

KNN 83 %

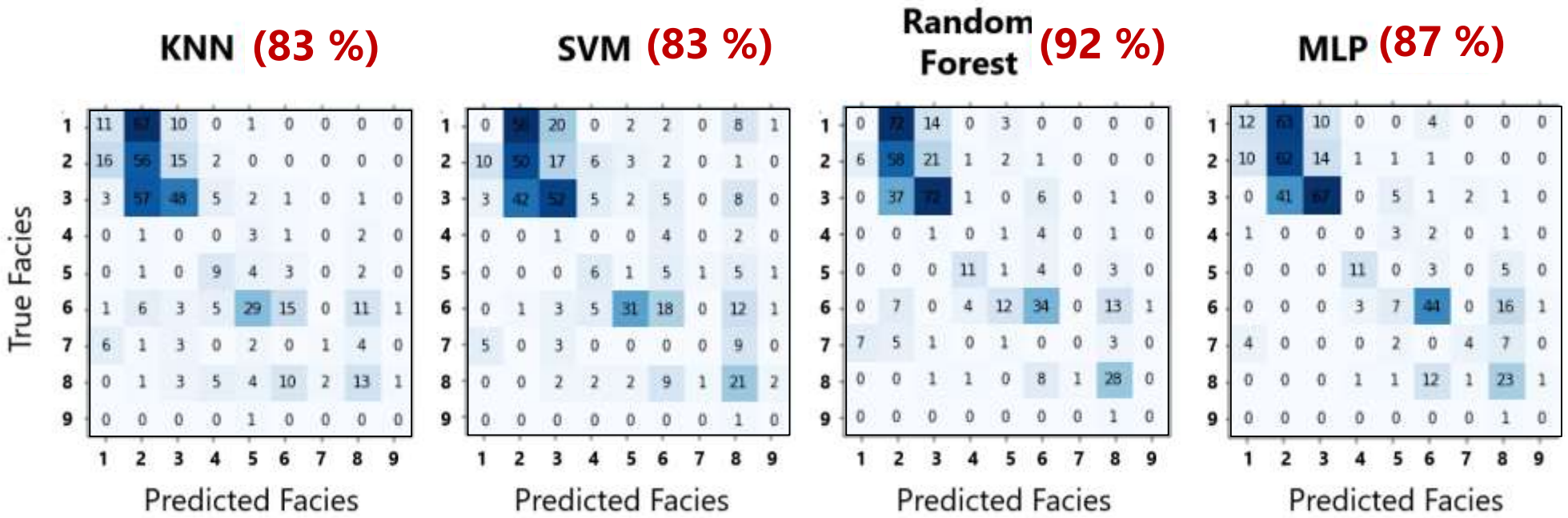
SVM 83 %

Random Forest 92 %

MLP 87 %



Blind Well 1 – Only Use PCA Features



Rock Facies

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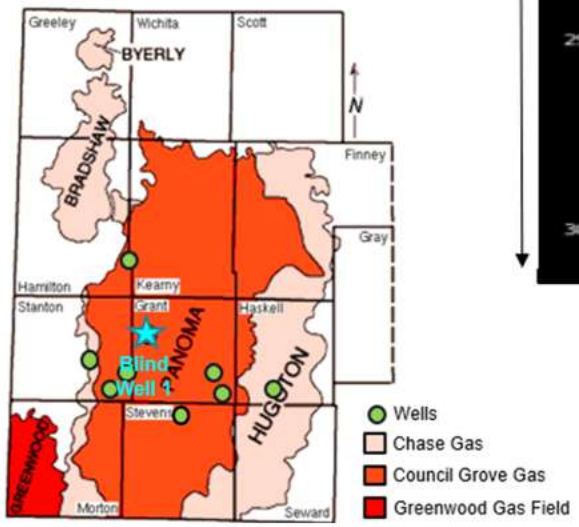
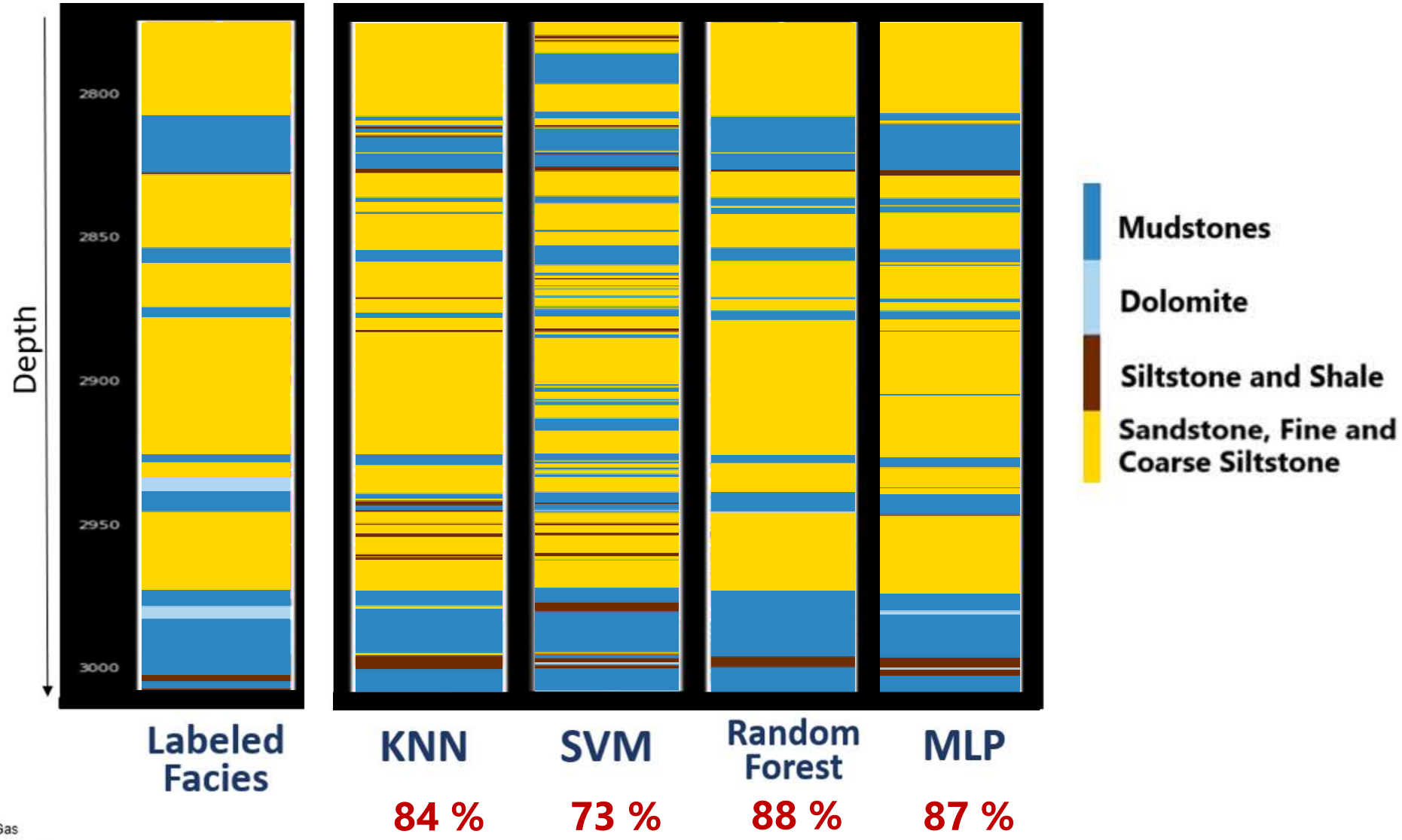
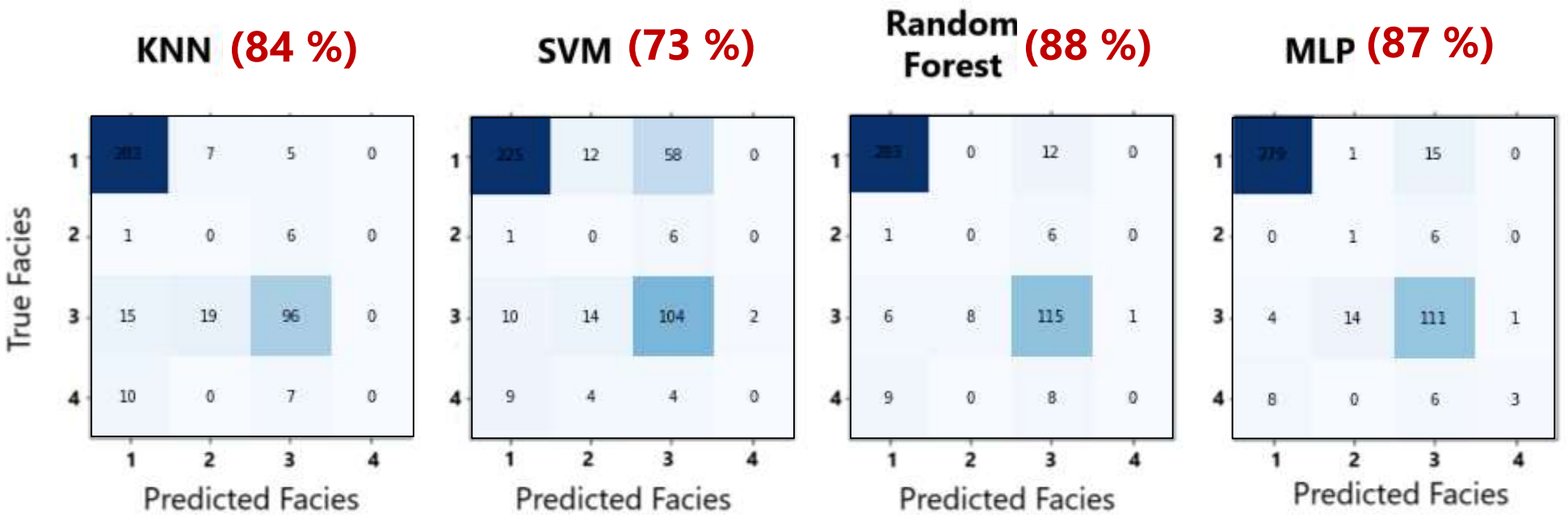




Blind Well 1 – Only Use PCA Features



Rock Facies

1. Sandstone, Fine and Coarse Siltstone
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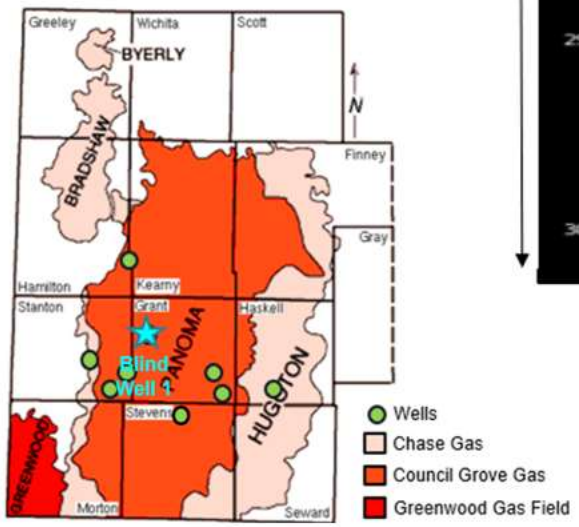
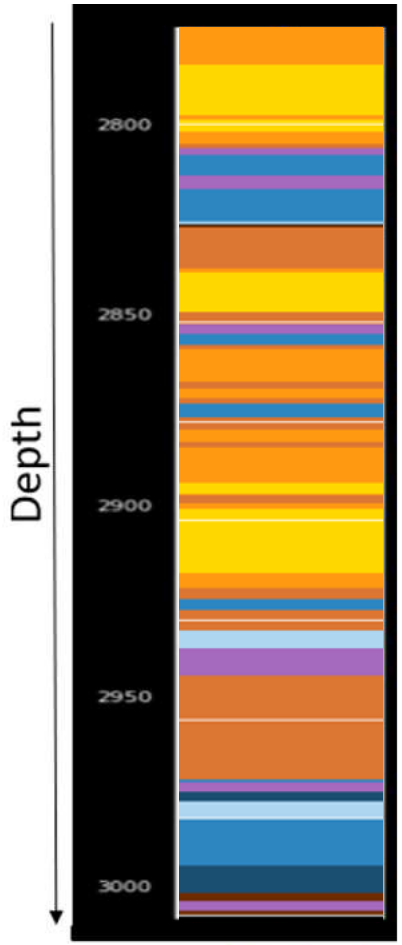
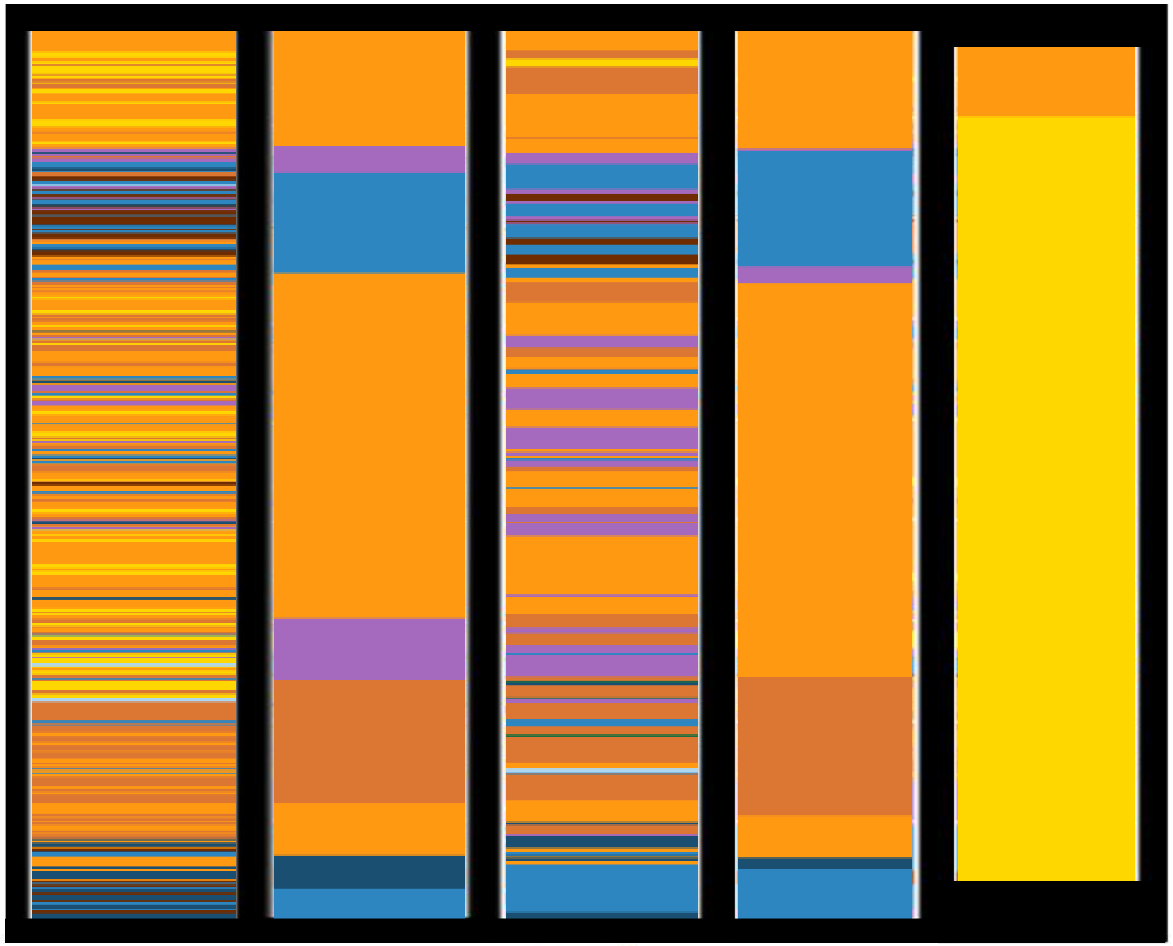
4. Dolomite

Blind Well 1 – Only Use Relative Depth







Labeled Facies	KNN	SVM	Random Forest	MLP	CNN
	30 %	41 %	35 %	32 %	16 %

Blind Well 1 – Only Use Relative Depth

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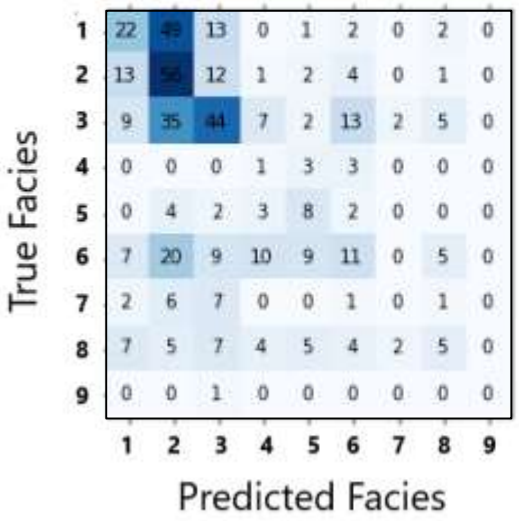
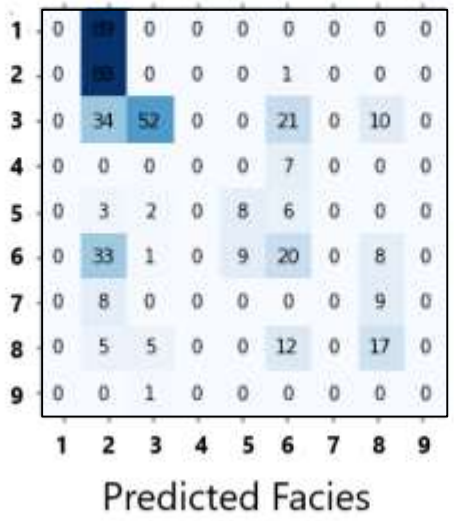
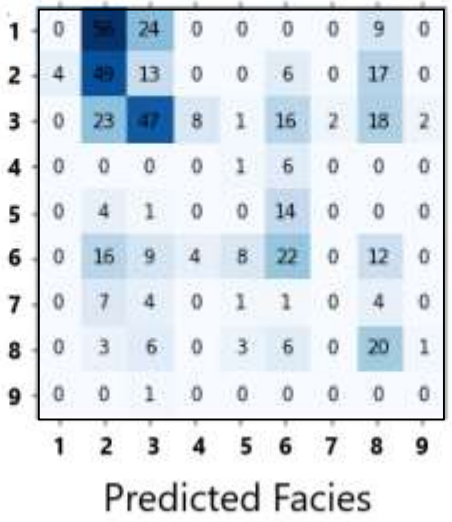
KNN (30 %)



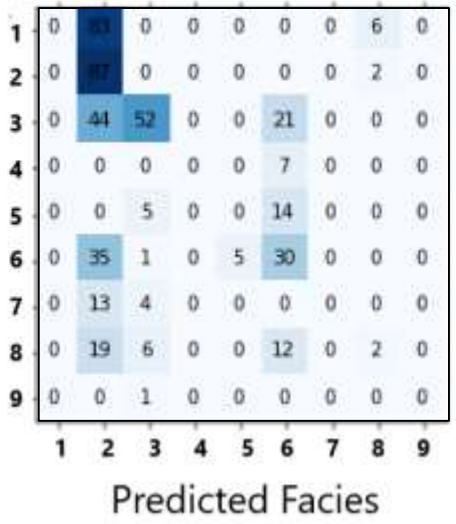
SVM (41 %)



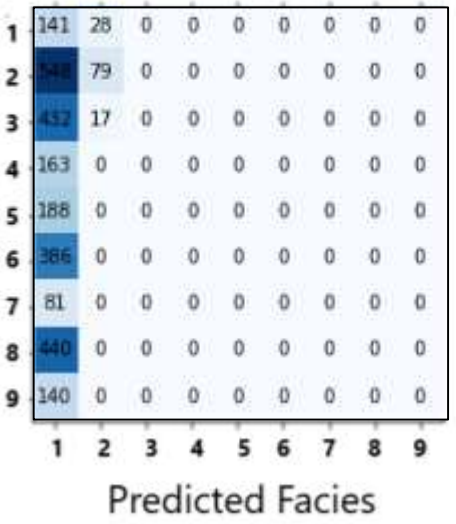
Random Forest (35 %)



MLP (32 %)



CNN (16 %)

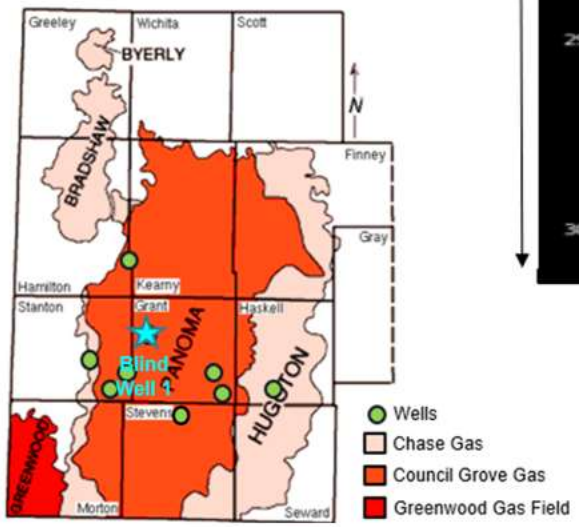


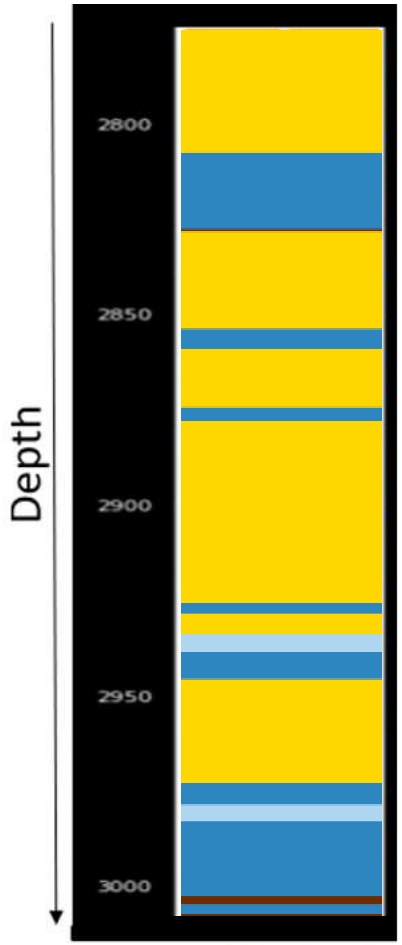
Rock Facies

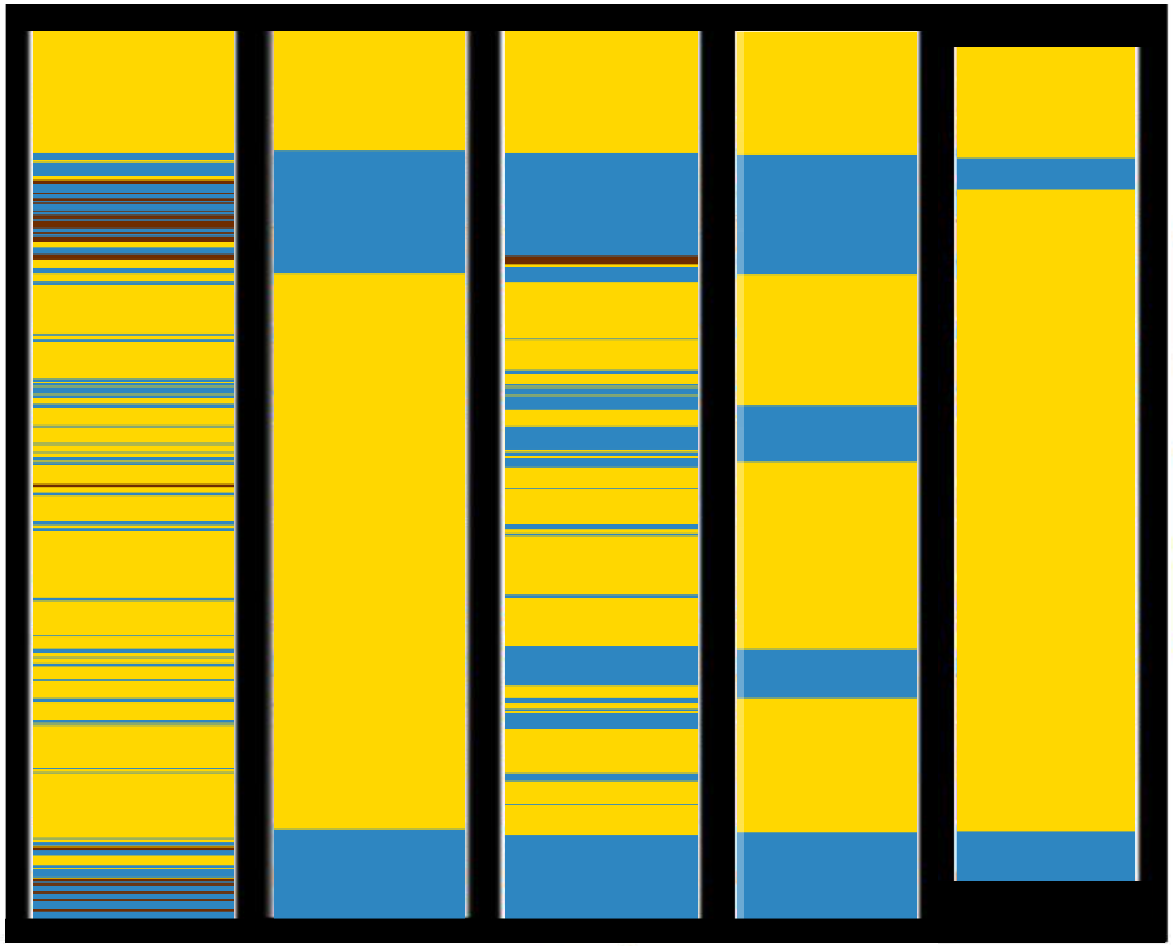
1. Sandstone
2. Coarse siltstone
3. Fine siltstone
4. Siltstone, Shale
5. Mudstone
6. Wackestone
7. Dolomite
8. Packstone
9. Bafflestone

Blind Well 1 – Only Use Relative Depth

RCP
In pursuit of new ideas







Mudstones

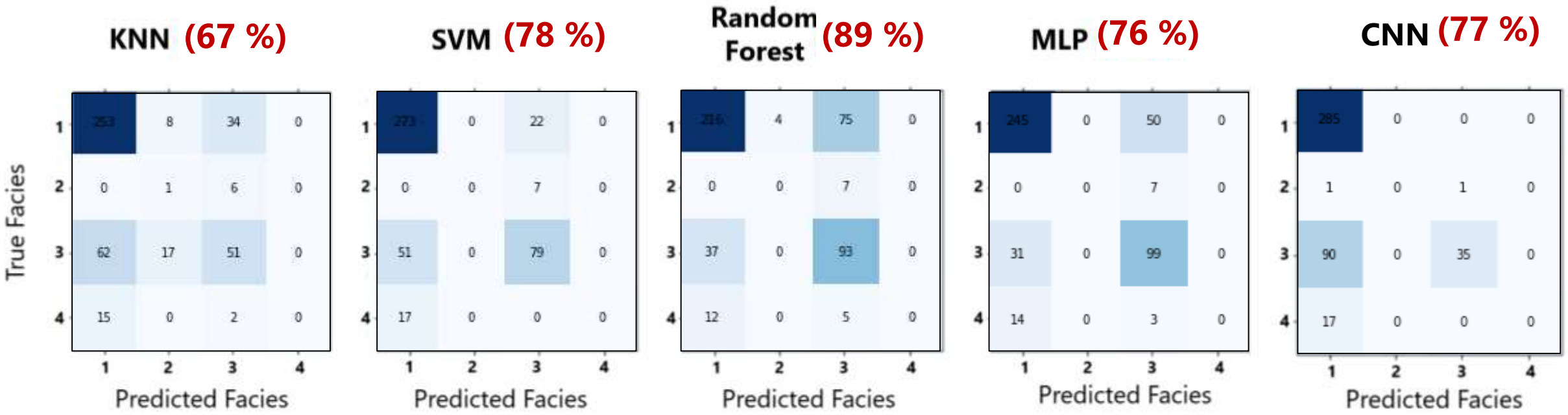
Dolomite

Siltstone and Shale

Sandstone, Fine and Coarse Siltstone

Labeled Facies	KNN	SVM	Random Forest	MLP	CNN
	67 %	78 %	89 %	76 %	77 %

Blind Well 1 – Only Use Relative Depth



Rock Facies

1. Sandstone, Fine and Coarse Siltstone
2. Siltstone and Shale
3. Mudstones
4. Dolomite