Interpretation of Downhole Physical Property Logs

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Workshop 8: "Improving Exploration with Petrophysics: The Application of Magnetic Remanence and Other Rock Physical Properties to Geophysical Targeting"

KORE GEOSYSTEMS

Denison Mines

Density Prediction from Multi-element Geochemistry data

Case Study

Denison Mines Wheeler River

Leading mining into the future.

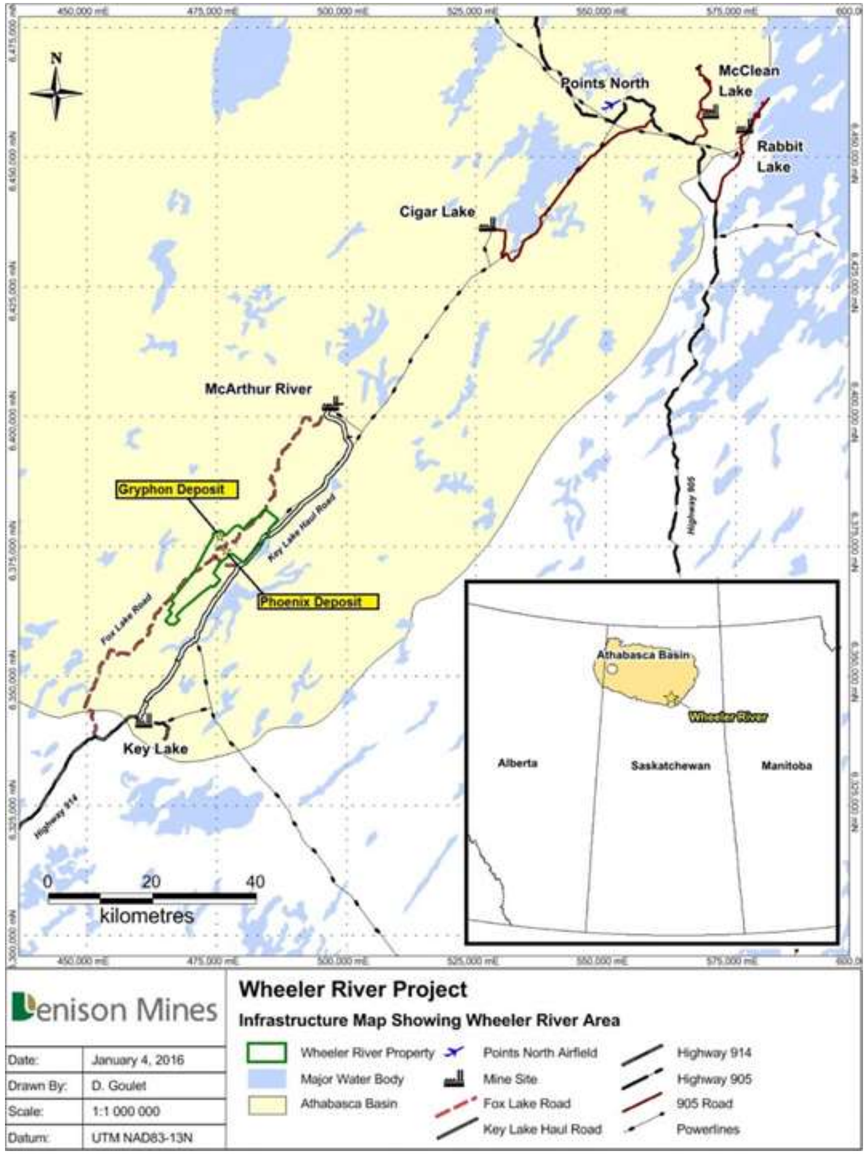
Project Objective

- **Build a density model for input to a constrained gravity inversion.**

- 35 boreholes with downhole density measurements
- 716 boreholes with multielement geochemistry data
- Can we successfully apply a predictive analytics (ML) to leverage / extract value from existing data?
- Accurate predictive models would significantly improve the understanding of density distribution across the deposit, without the requirement or cost of acquiring additional density data.

Project Location

- Wheeler River property is located along the eastern edge of the Athabasca Basin in northern Saskatchewan
- 35 km north-northeast of the Key Lake mill
- 35 km southwest of the McArthur River uranium mine
- The Wheeler River property is host to the Phoenix uranium deposit and the Gryphon uranium deposit, discovered in 2008 and 2014, respectively.

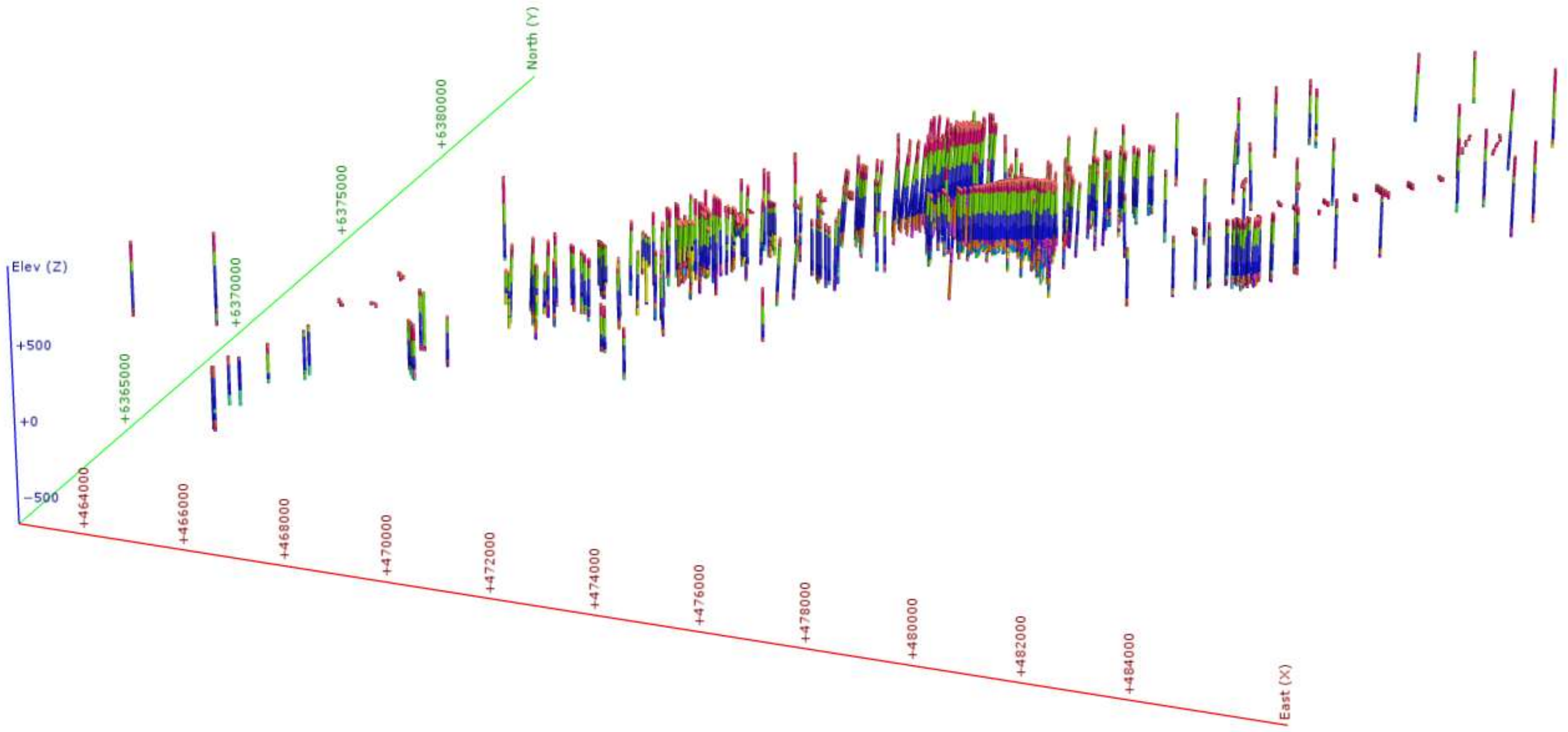


Dataset Overview

- **Boreholes**
  - **716**
- Datasets
  - Multielement Geochemistry
    - 251 Boreholes | Old Lab Method (3A_ICP)
    - 465 Boreholes | New Lab Method (3A_ICP,3AMS)
  - Downhole Density (DGI Geoscience)
    - 35 Boreholes

Dataset Overview

- **716 Boreholes**



Dataset Overview

- Boreholes
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- **Datasets**
  - **Multielement Geochemistry**
    - **251 Boreholes | Old Lab Method (3A_ICP) (64 element)**
    - **465 Boreholes | New Lab Method (3A_ICP,3AMS) (64 element)**
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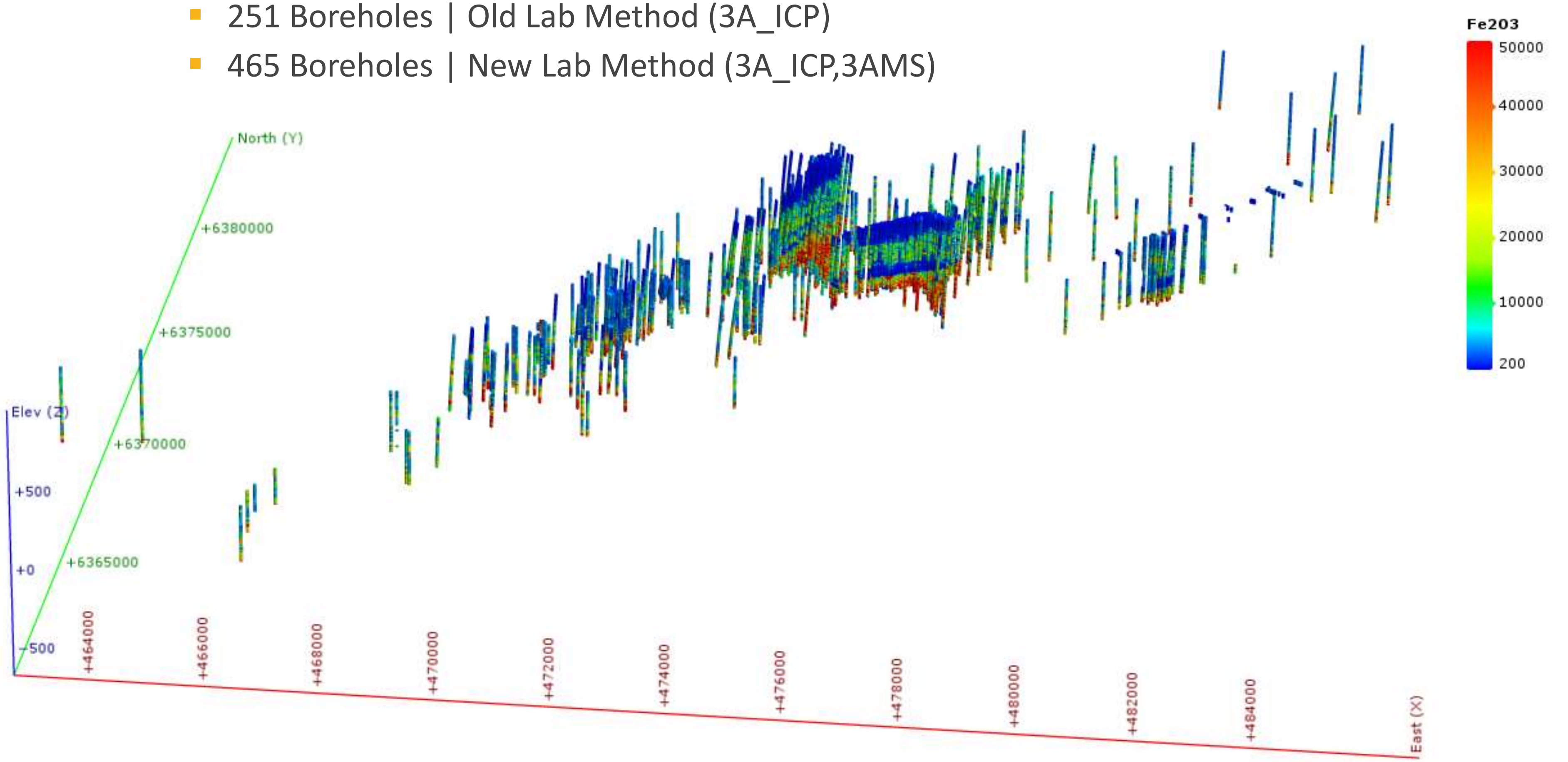

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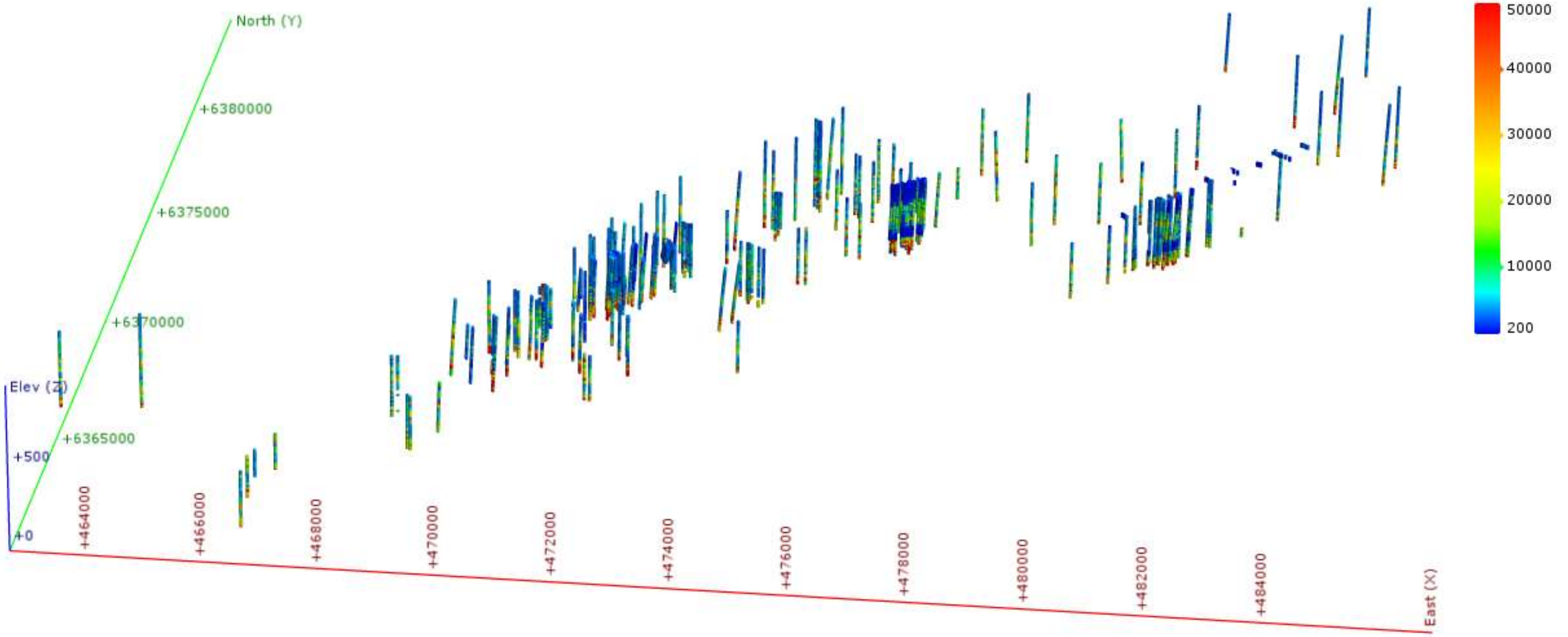

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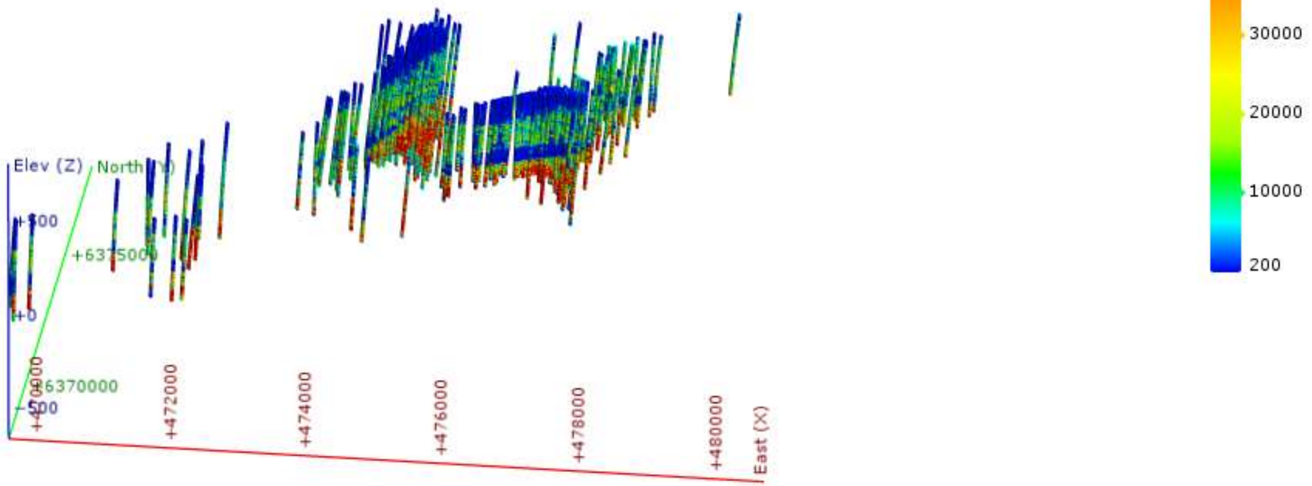

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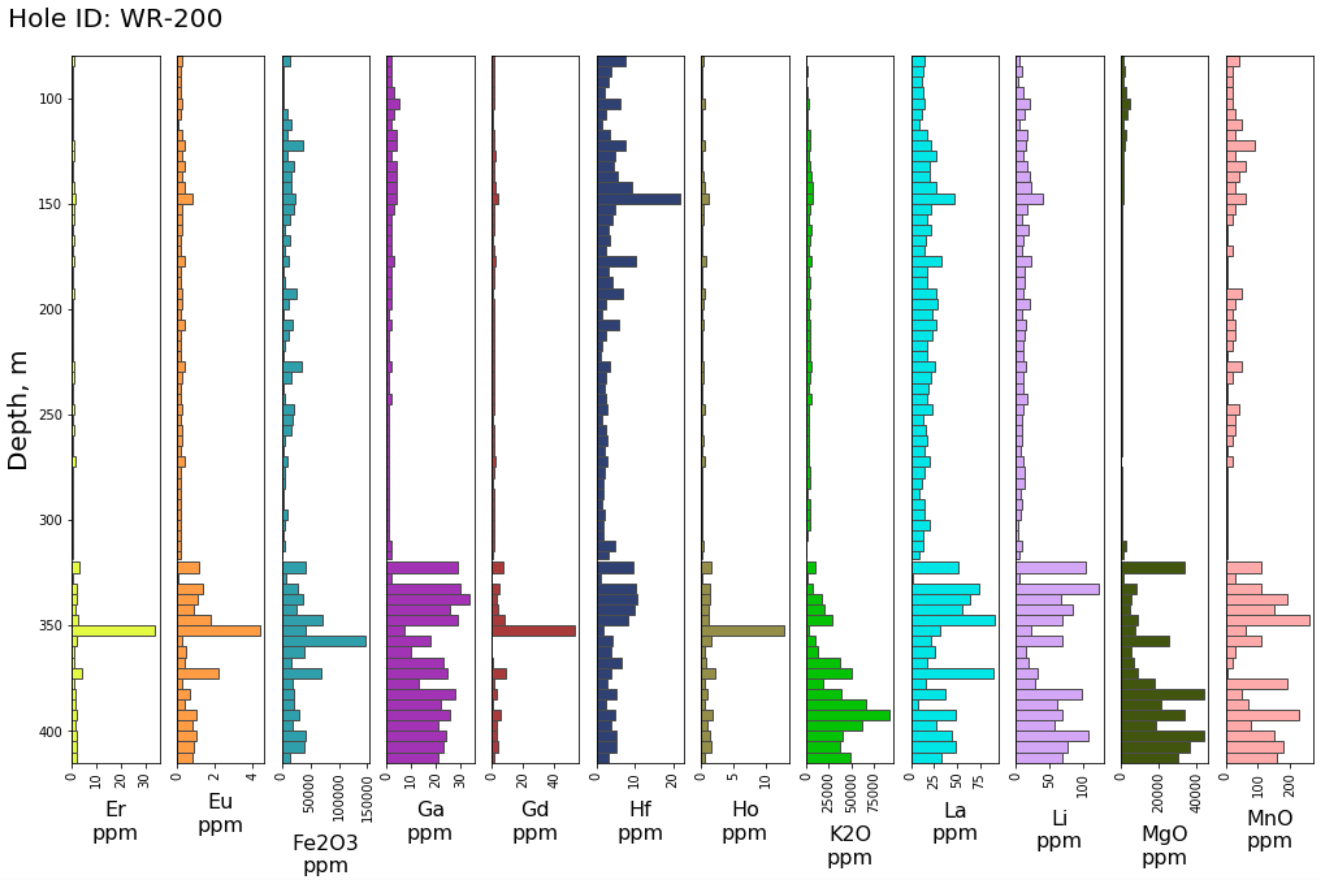

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  - Multielement Geochemistry
    - 251 Boreholes | Old Lab Method (3A_ICP)
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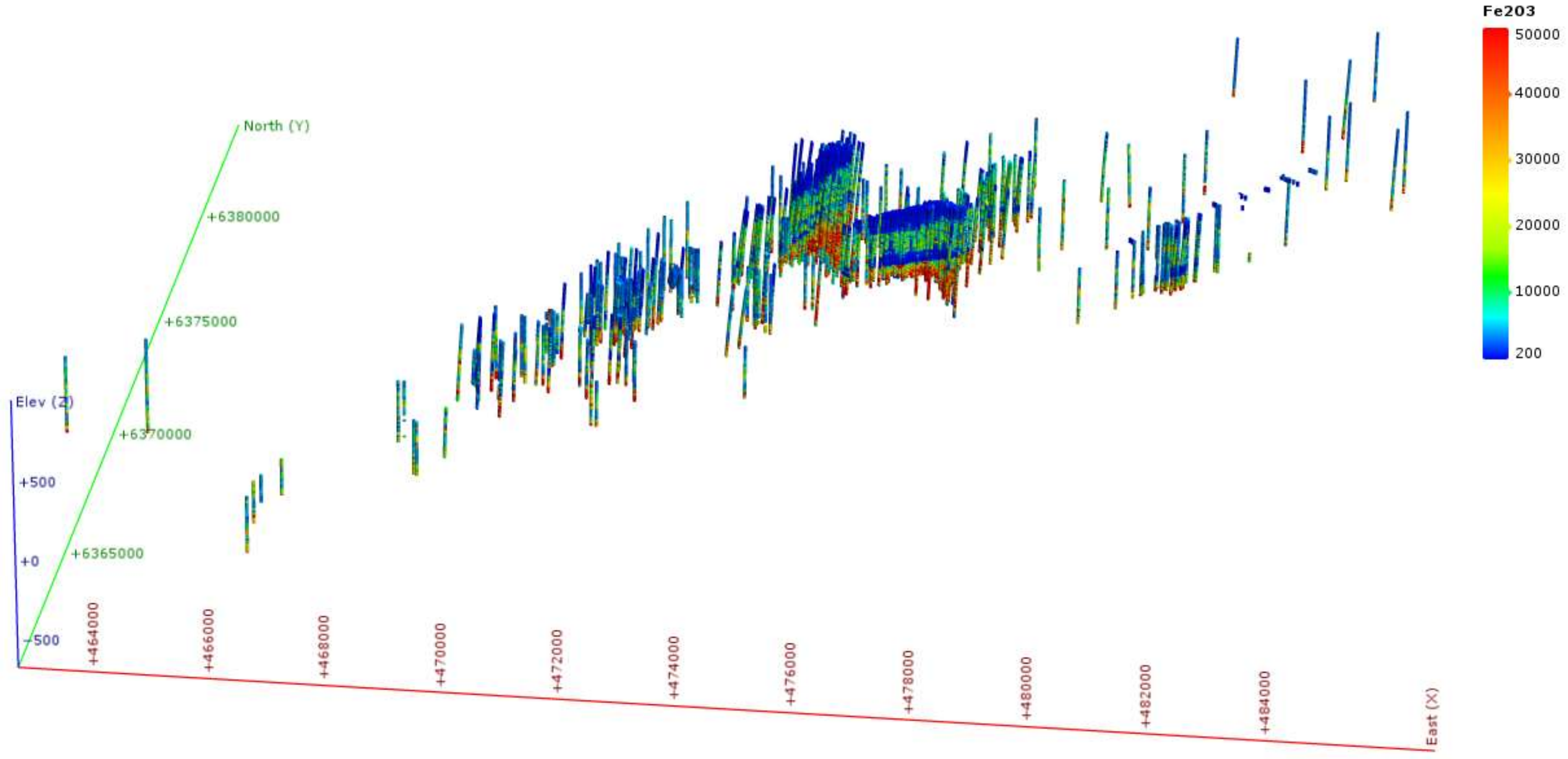
  - **Downhole Density (DGI Geoscience)**
    - **35 Boreholes (15 – Old Geochem, 18 New Geochem, 2 – No Geochem)**

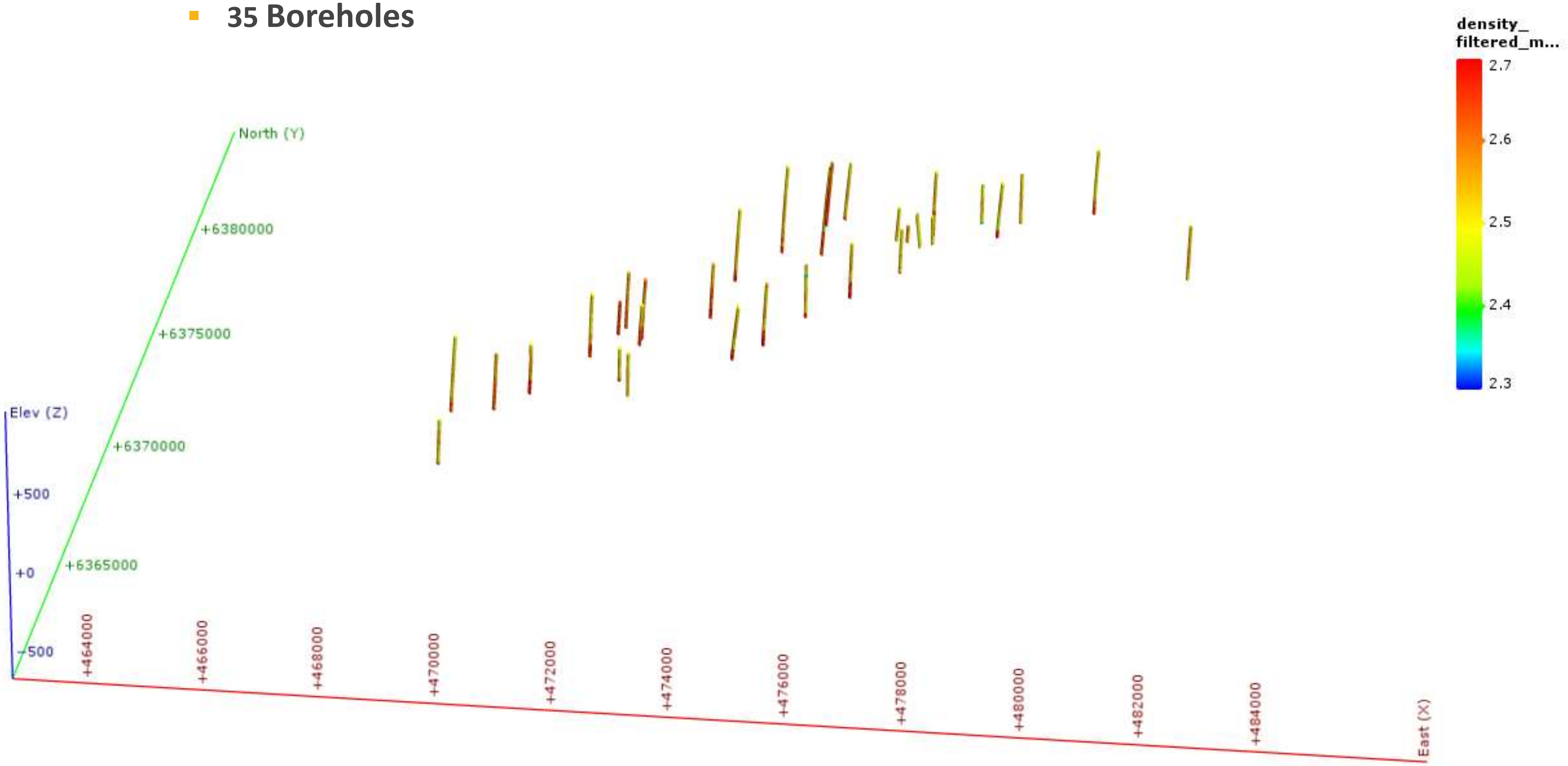
Dataset Overview

- **716 Boreholes**



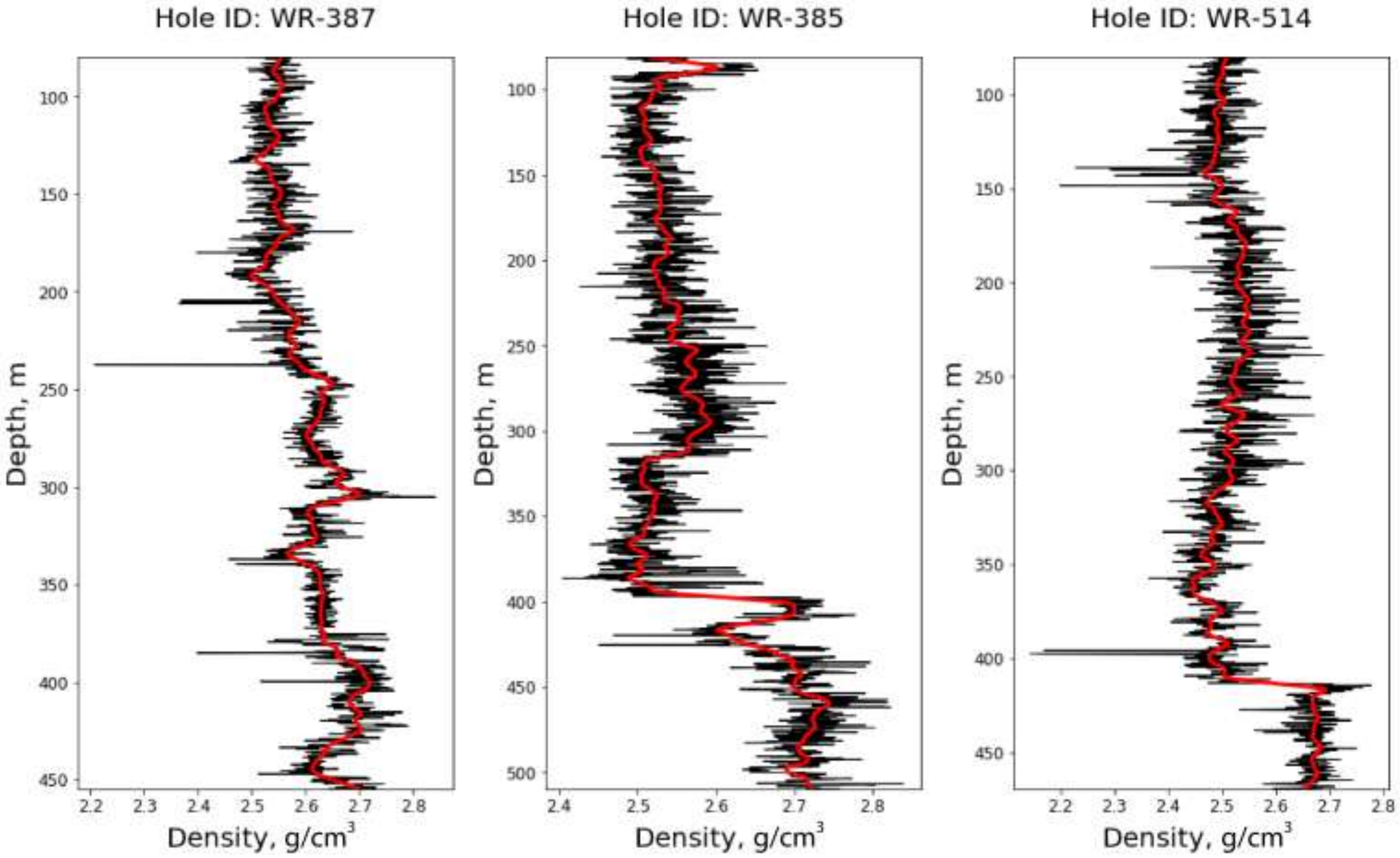
Dataset Overview

- Downhole Density (DGI Geoscience)
  - **35 Boreholes**



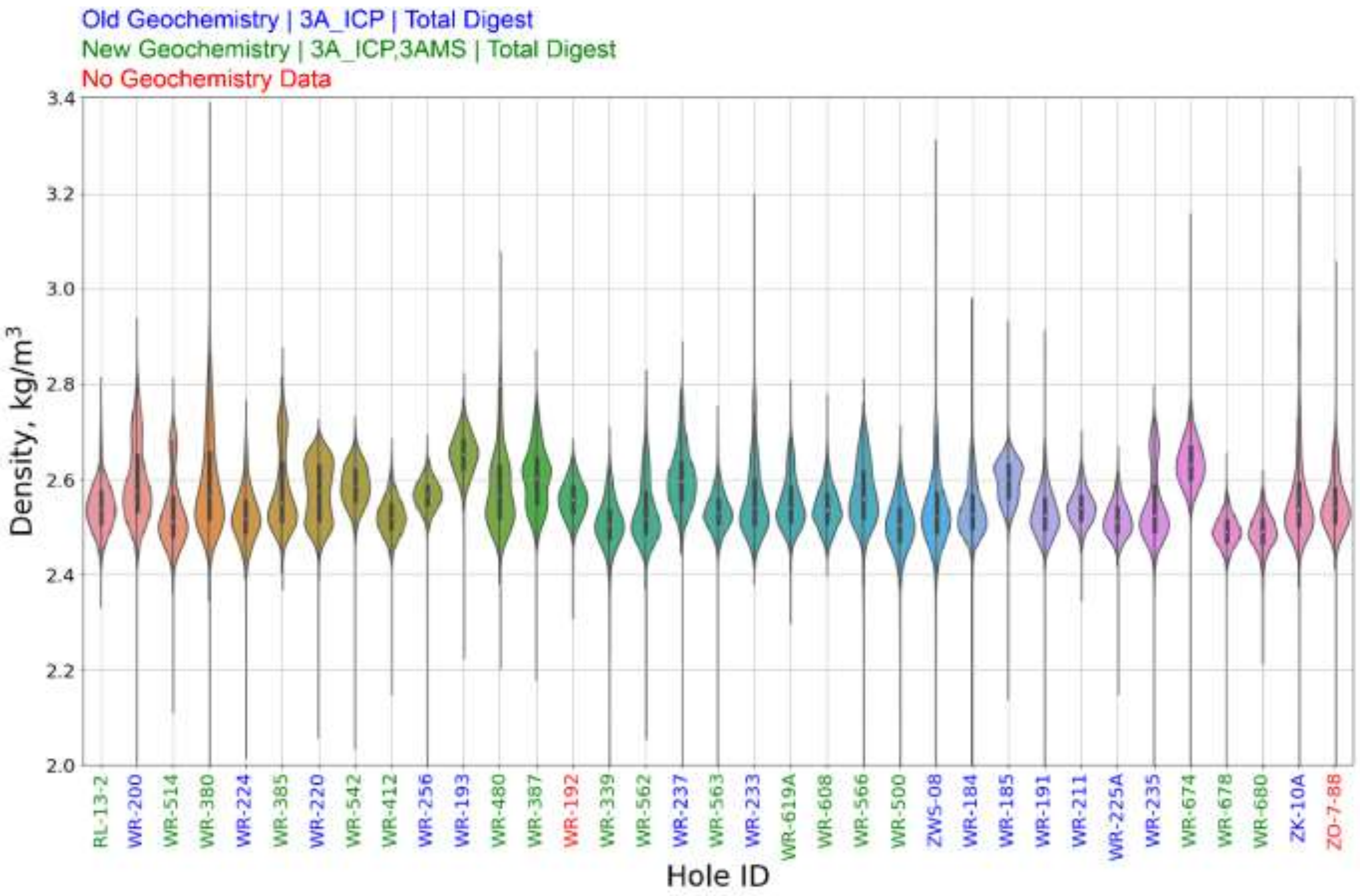
Dataset Overview

- Downhole Density (DGI Geoscience)
  - 35 Boreholes (smoothed using a robust locally weighted regression method)



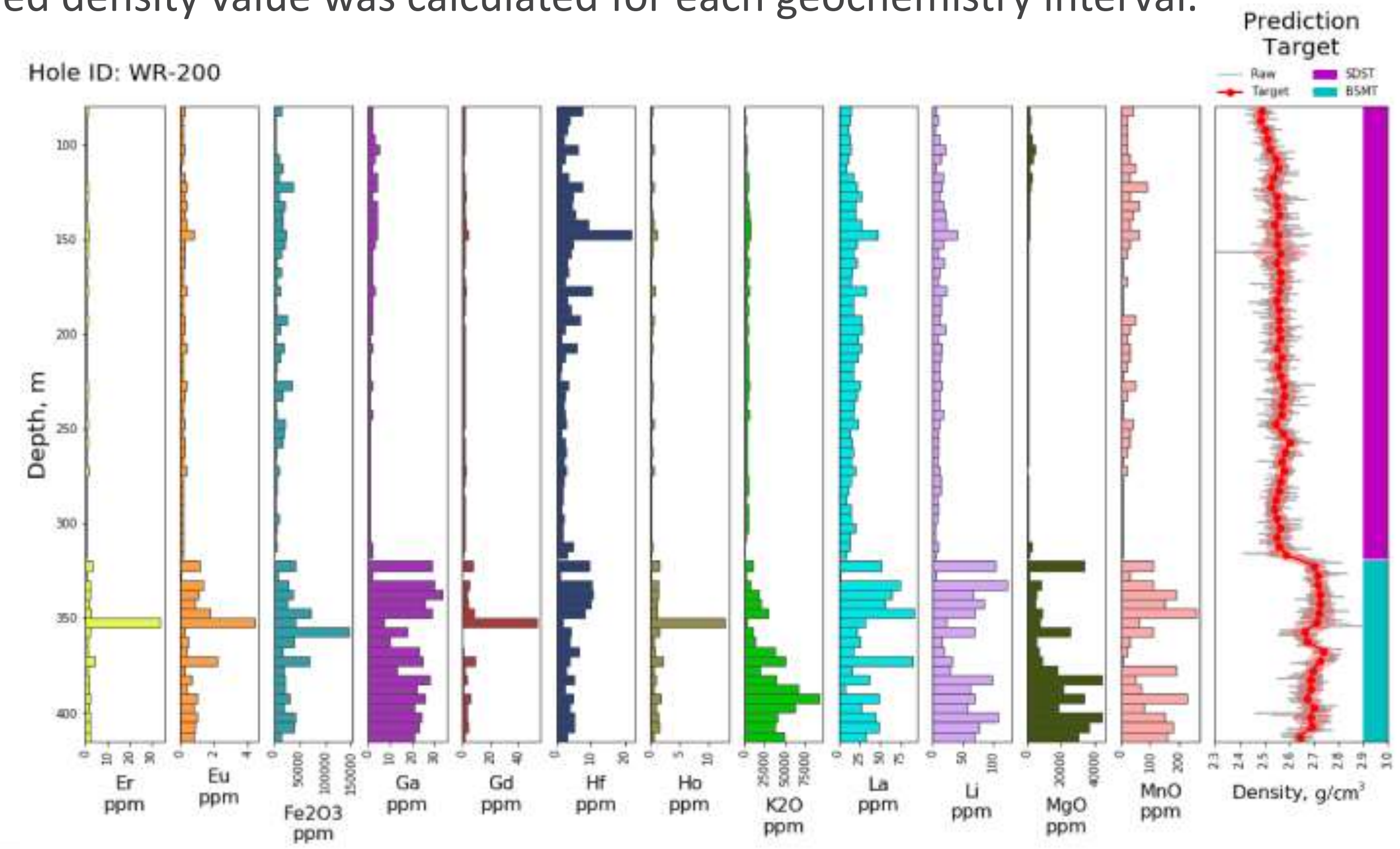
Dataset Overview

- Downhole Density (DGI Geoscience)
  - 35 Boreholes (15 – Old Geochem, 18 New Geochem, 2 – No Geochem)



Merge Datasets

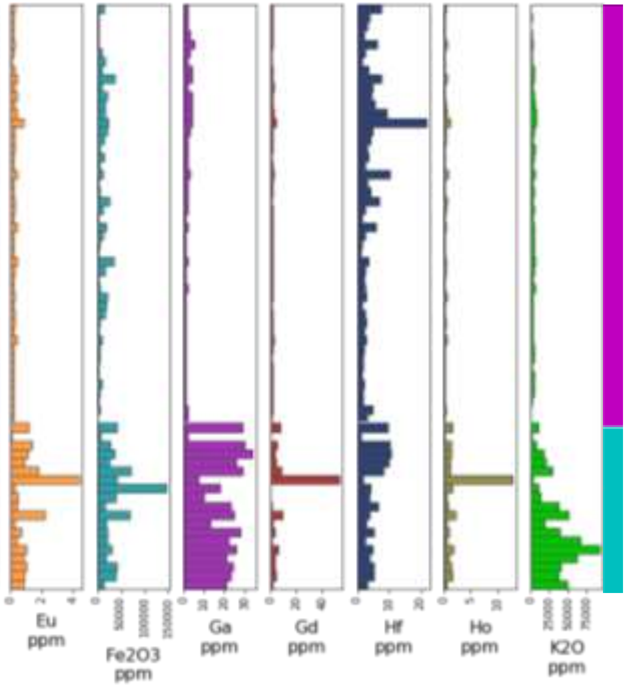
- All data sets QA/QC'd, with problem data omitted or corrected
- Collocated density and geochemistry data was merged together for use with machine learning.
- Median smoothed density value was calculated for each geochemistry interval.



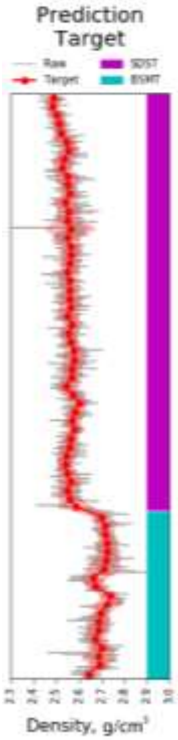
Machine Learning Strategy

- Train two sets of machine learning models:
  - 251 Boreholes | Old Lab Method (3A_ICP)
  - 465 Boreholes | New Lab Method (3A_ICP,3AMS)

Geochemistry + Lithology Domain



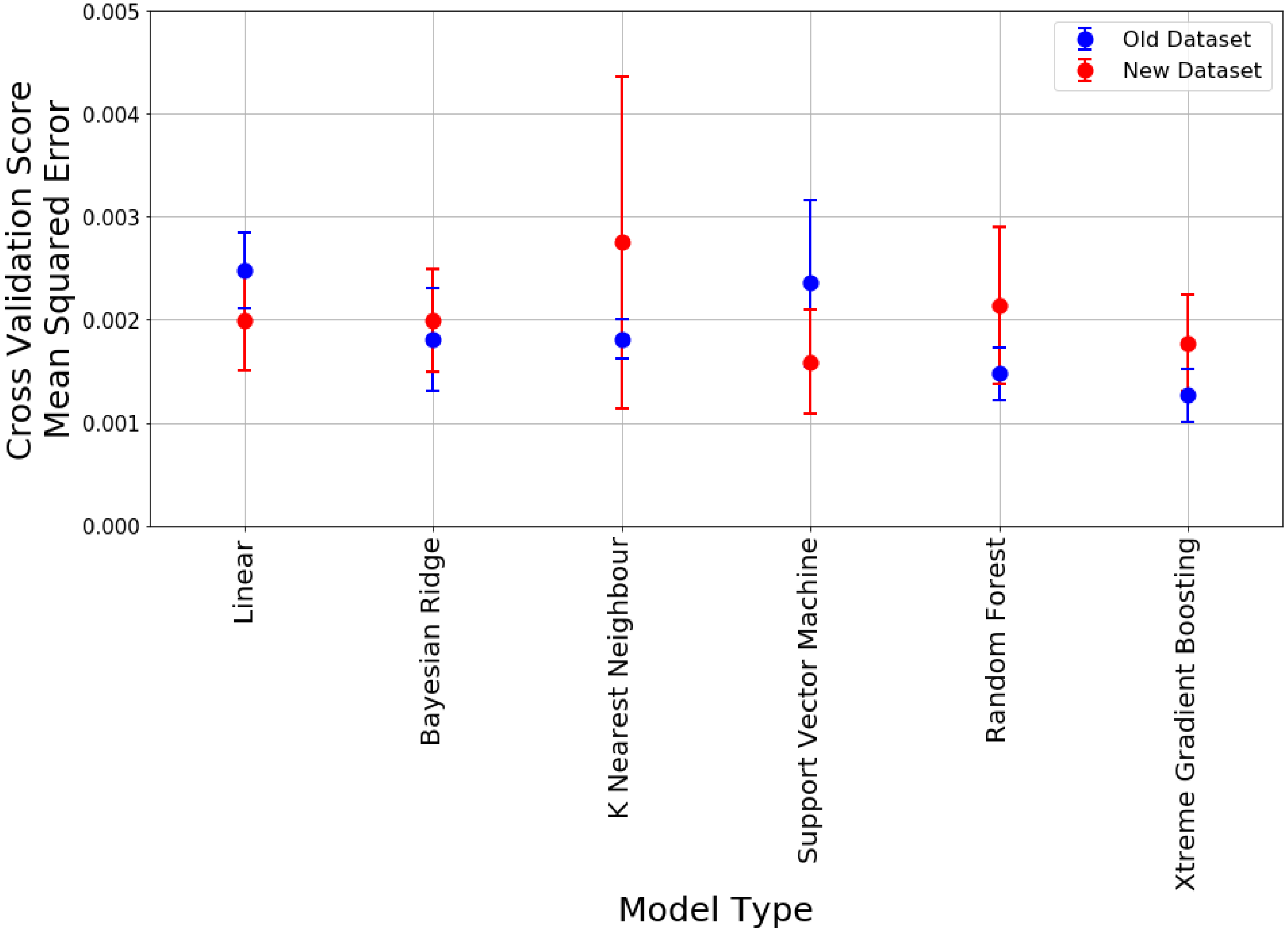
ML Model Training



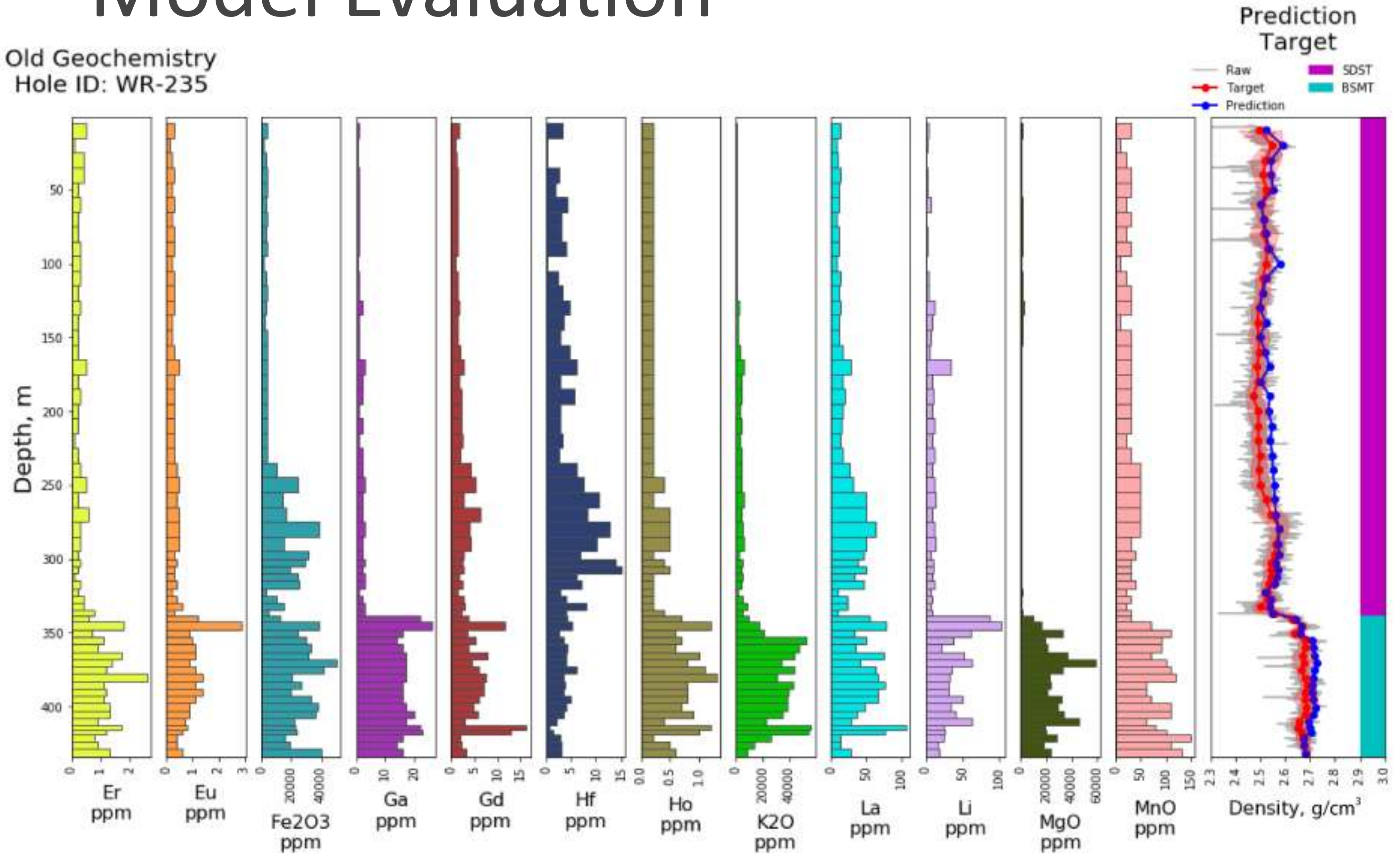
Machine Learning Strategy

- Machine Learning Algorithms
  - Linear
  - Bayesian Ridge
  - K Nearest Neighbors
  - Support Vector Machine
  - Random Forest
  - Xtreme Gradient Boosting

Model Evaluation



Model Evaluation



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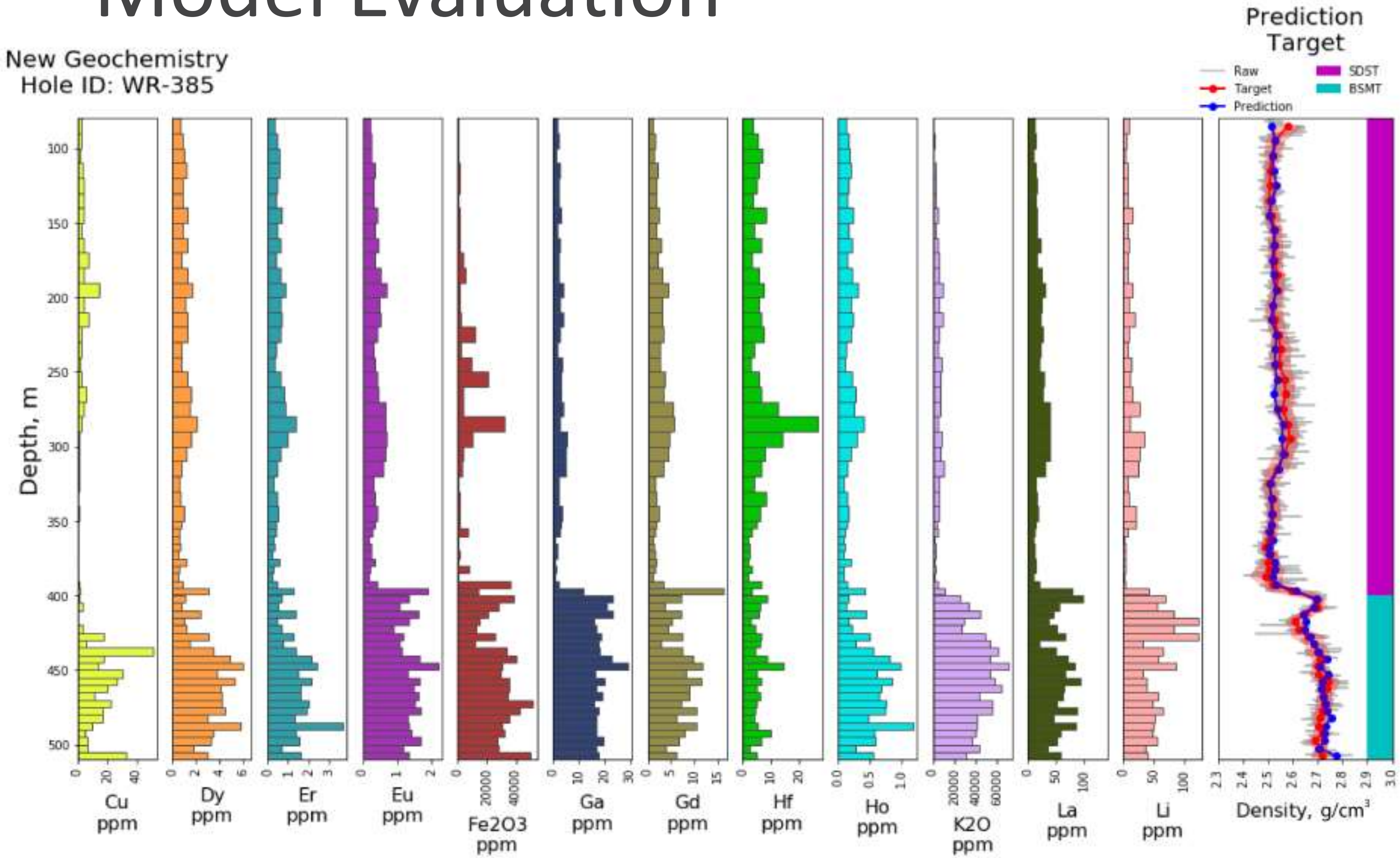

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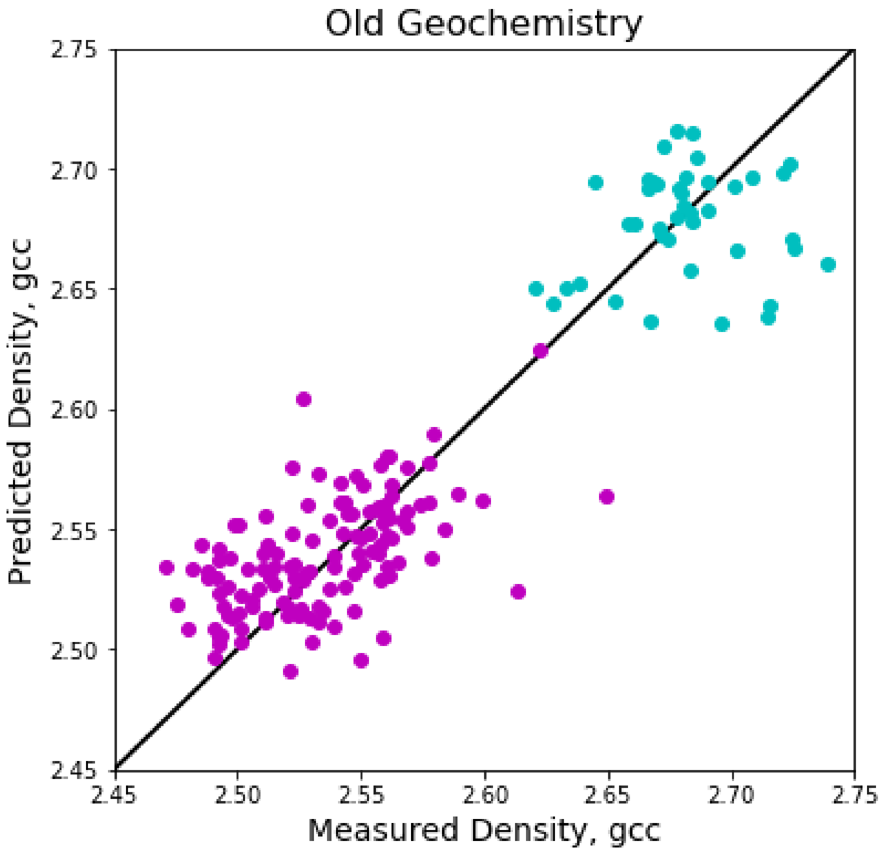
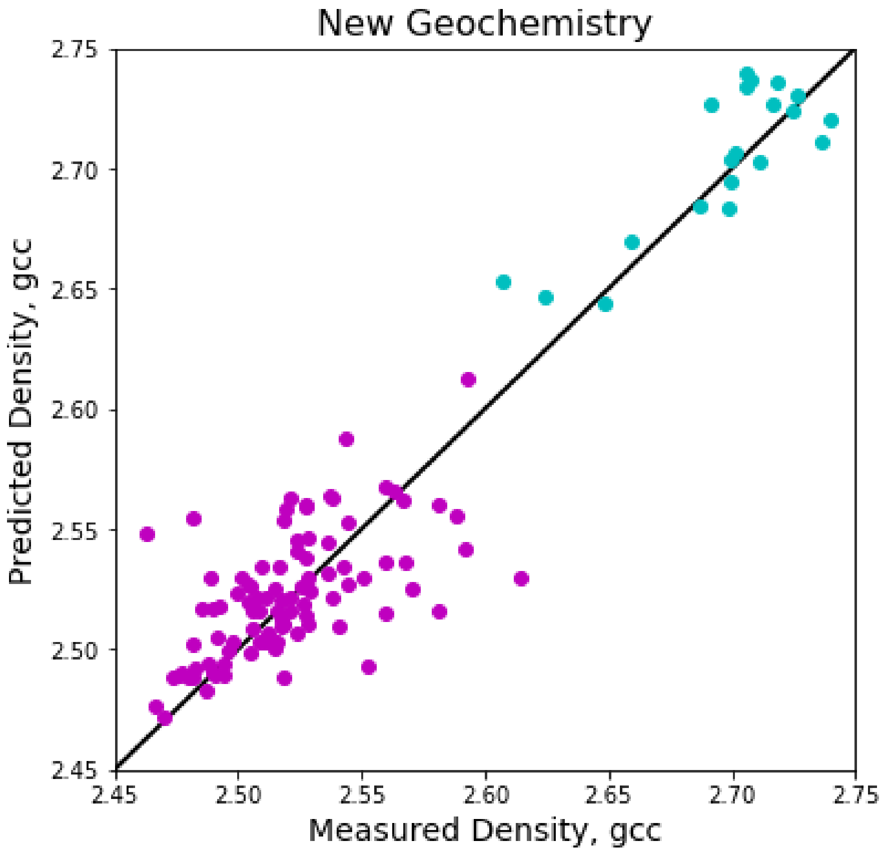
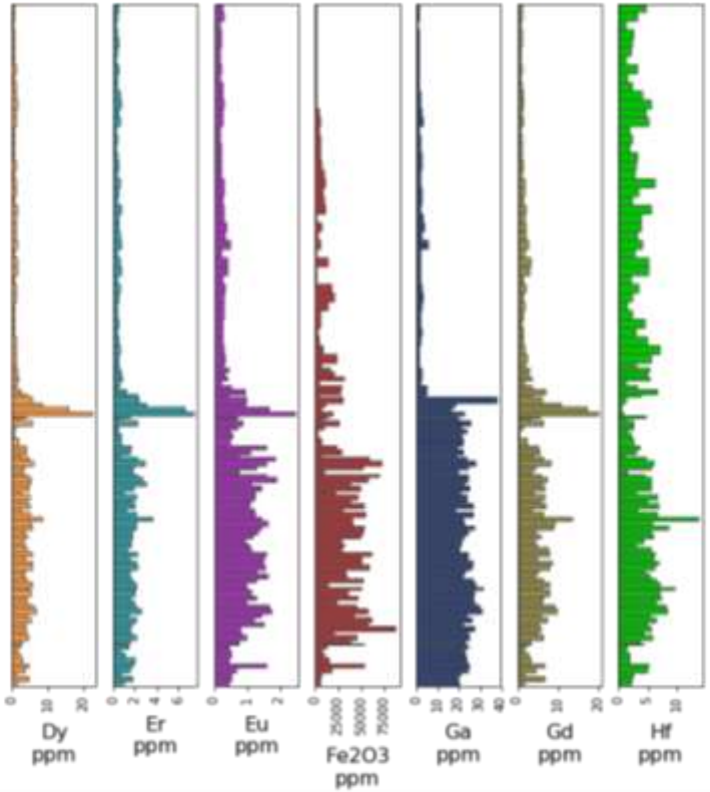




Density Prediction

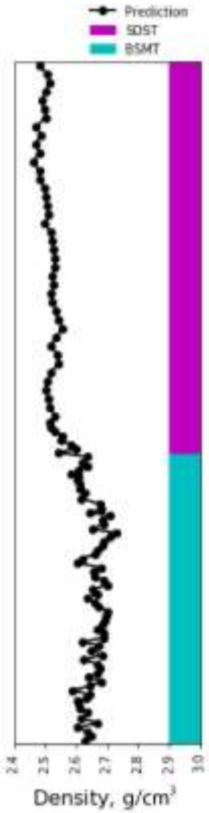
- Predict density on all boreholes where only geochemistry data exists

Geochemistry + Lithology Domain



ML Model Trained

Density Prediction



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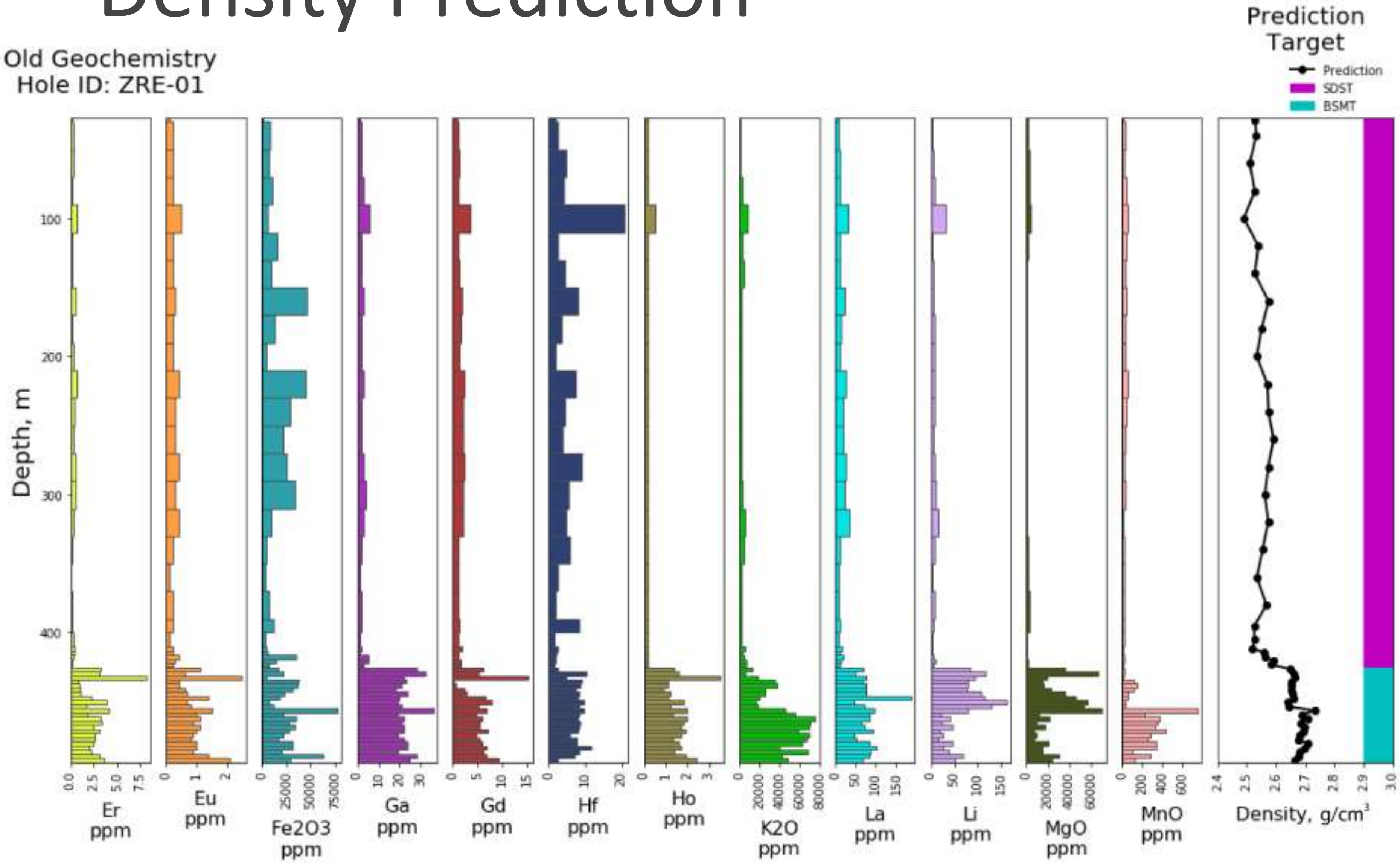

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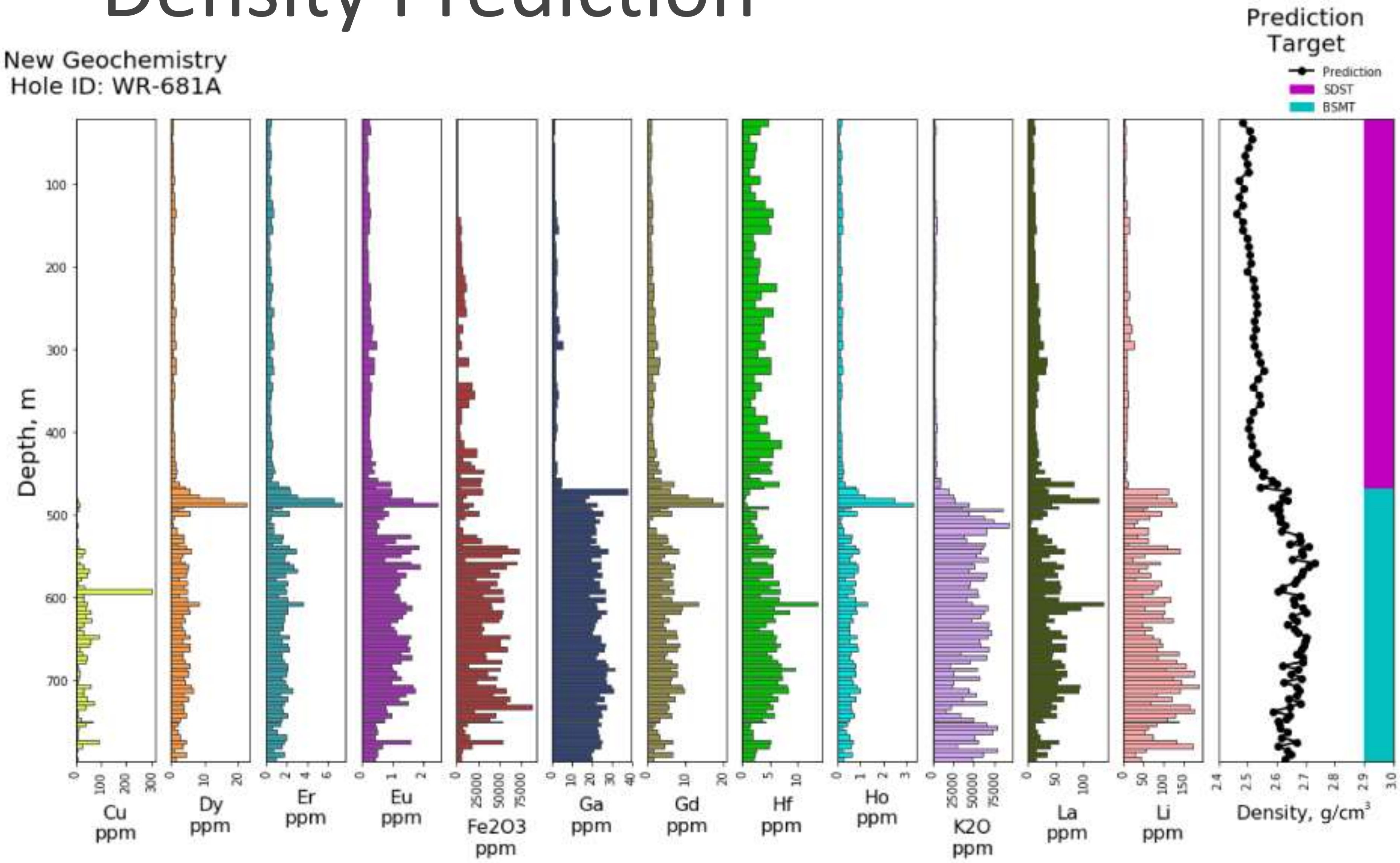
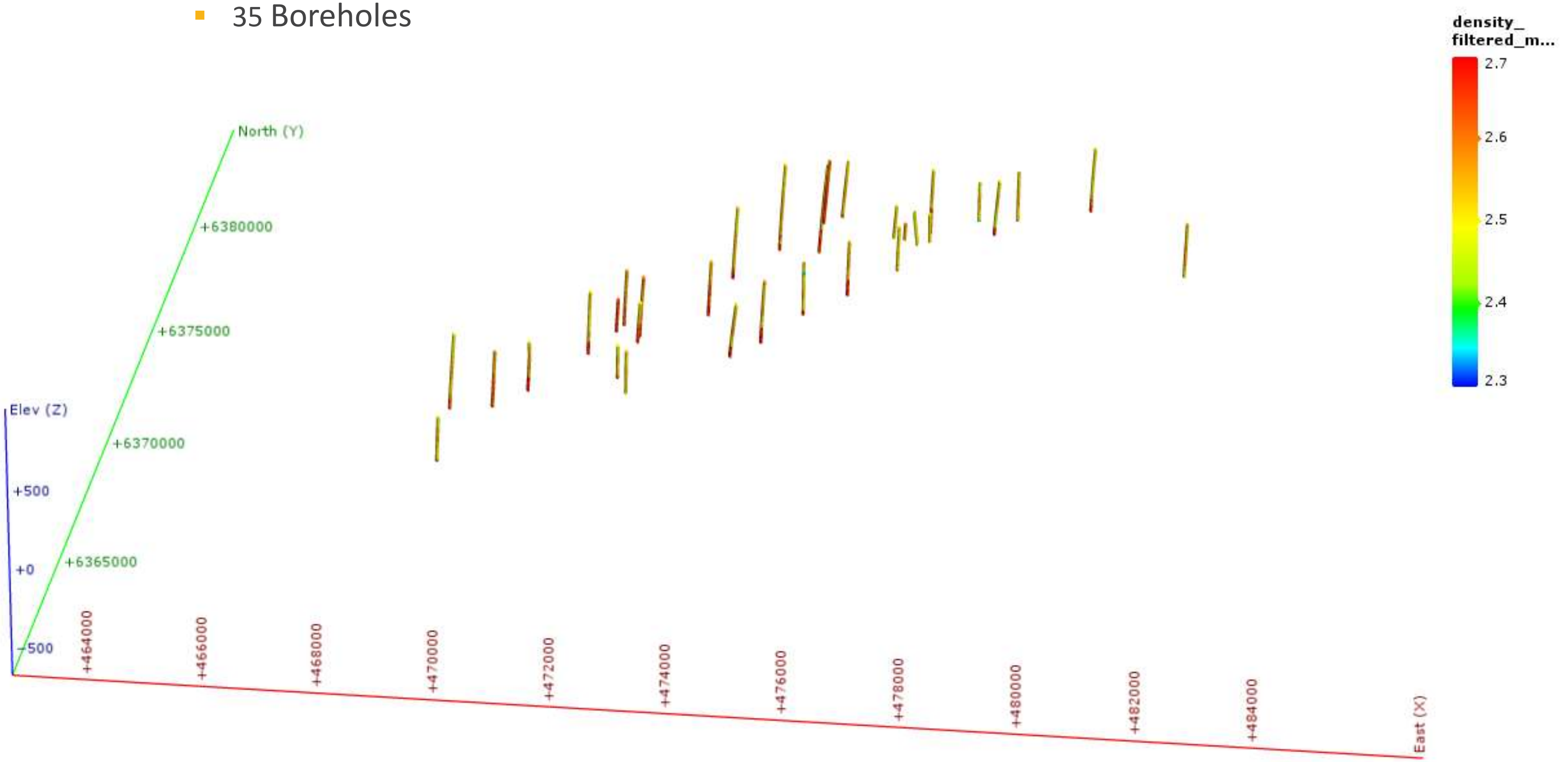


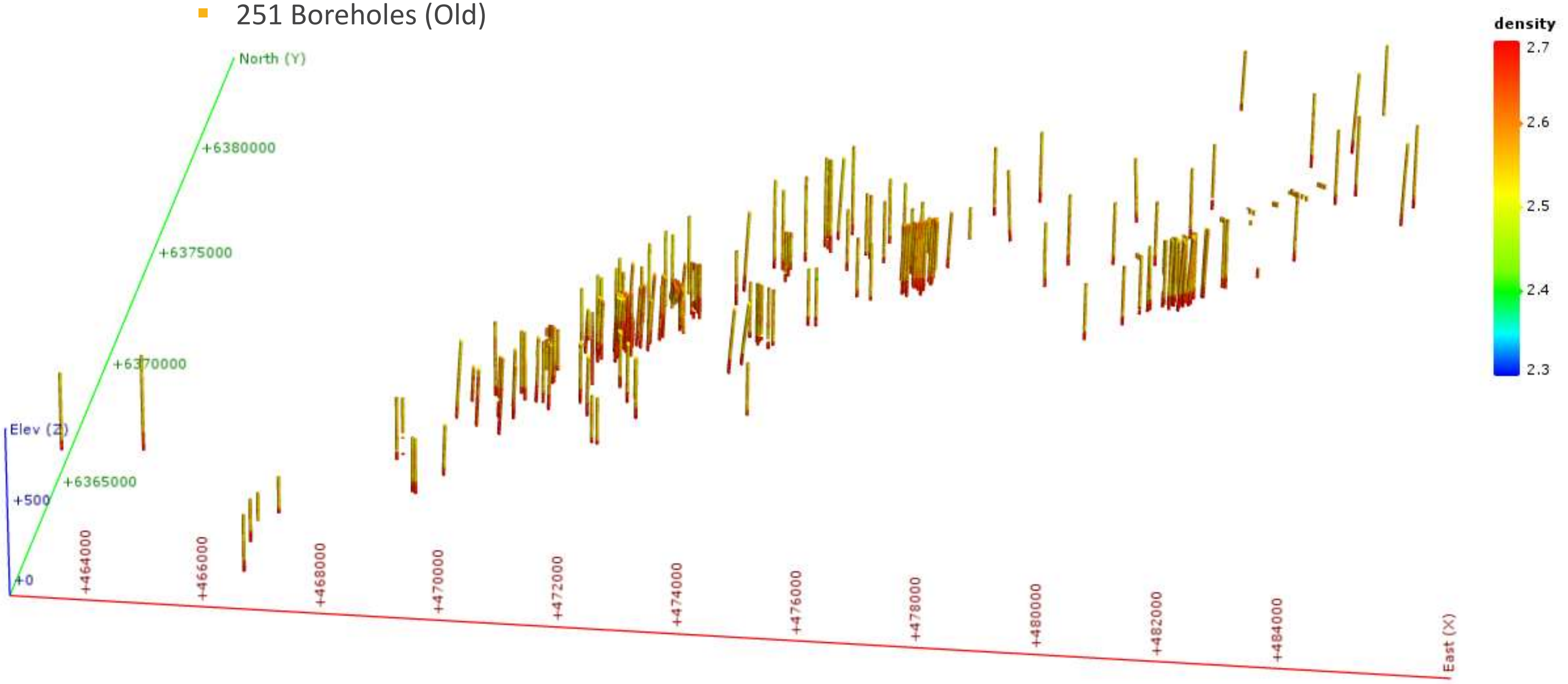
Density Prediction

- Downhole Density (DGI Geoscience)
  - 35 Boreholes



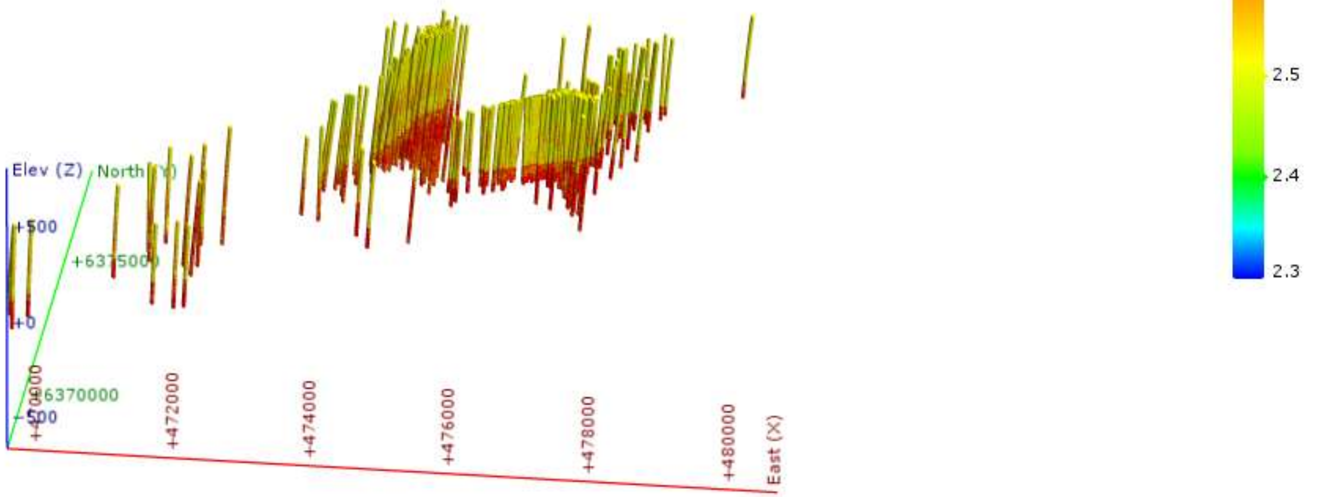
Density Prediction

- Density Prediction
  - 251 Boreholes (Old)



Density Prediction

- Density Prediction
  - 465 Boreholes (New)



Density Prediction

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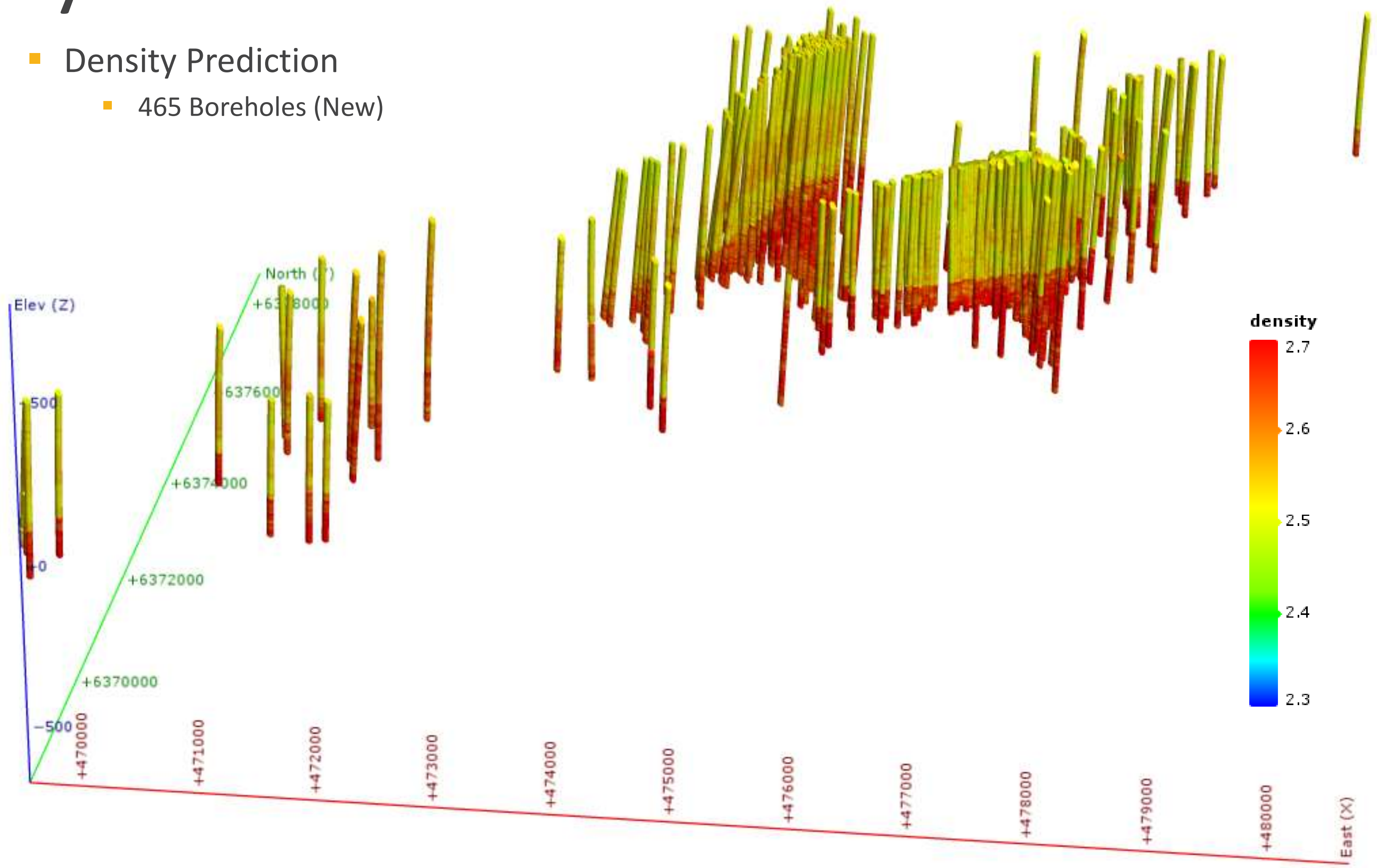
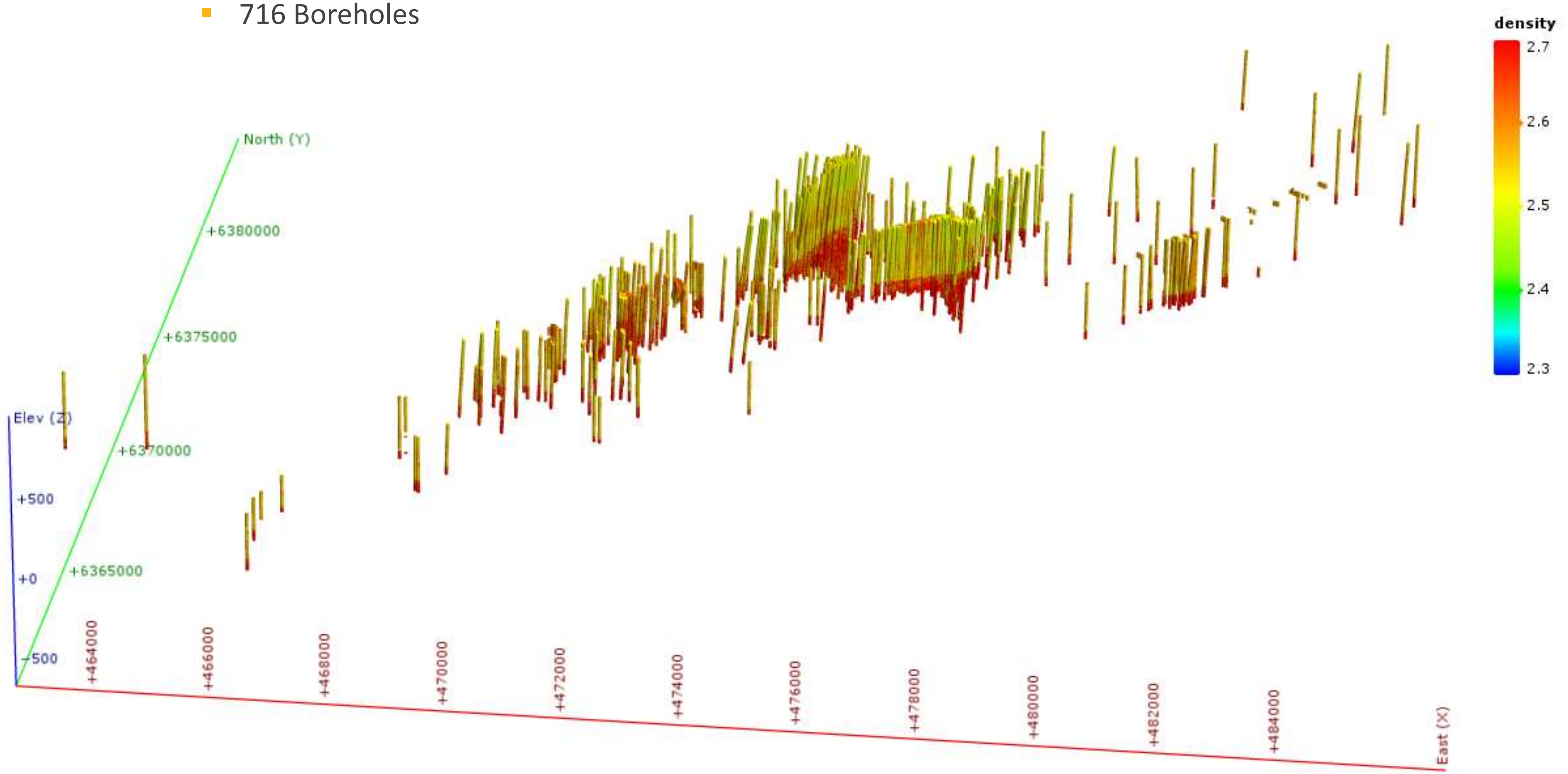
  - 465 Boreholes (New)



Density Prediction

- Density Prediction
  - 716 Boreholes



Density Prediction

- Downhole Density (DGI Geoscience)
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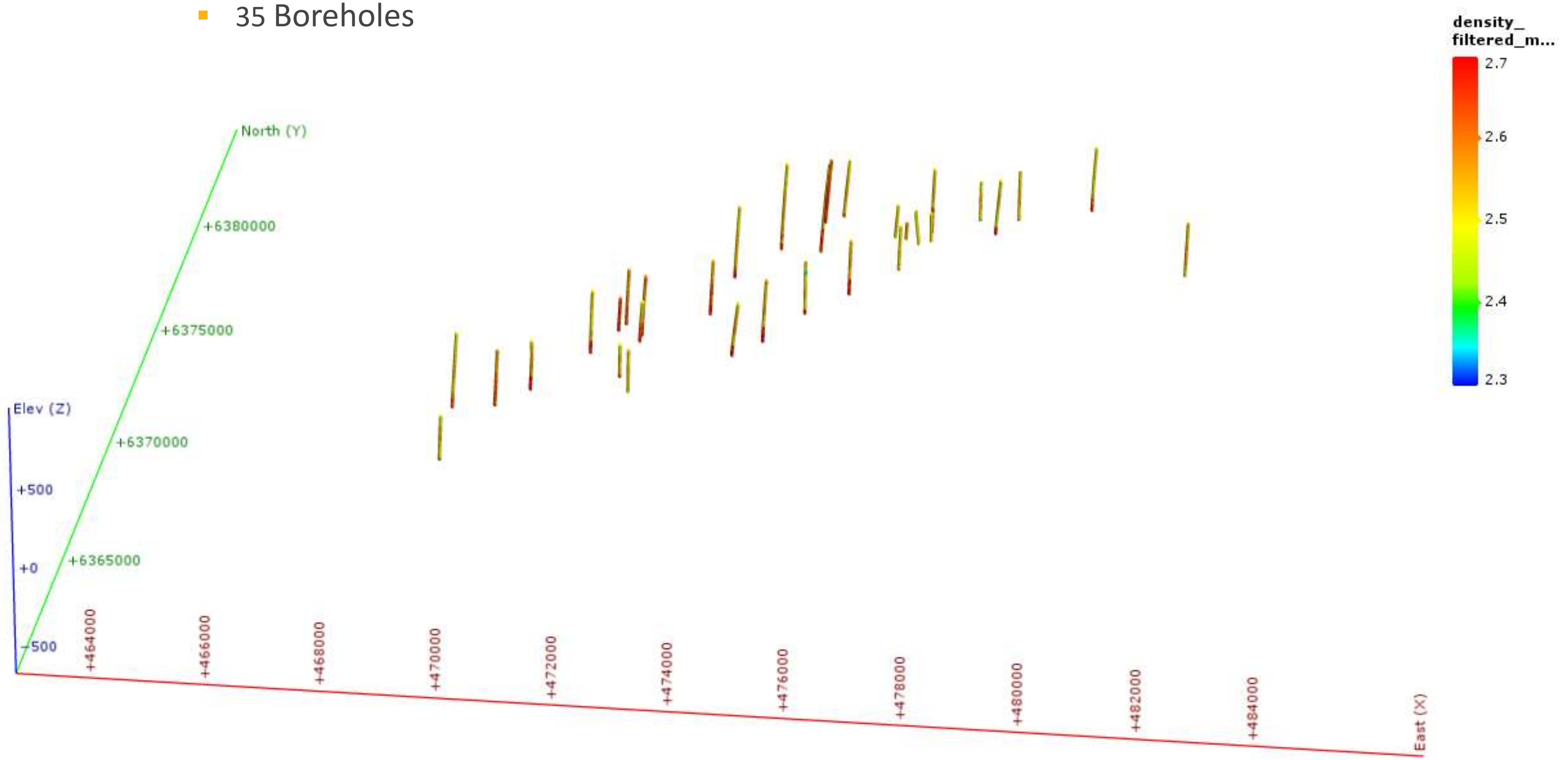
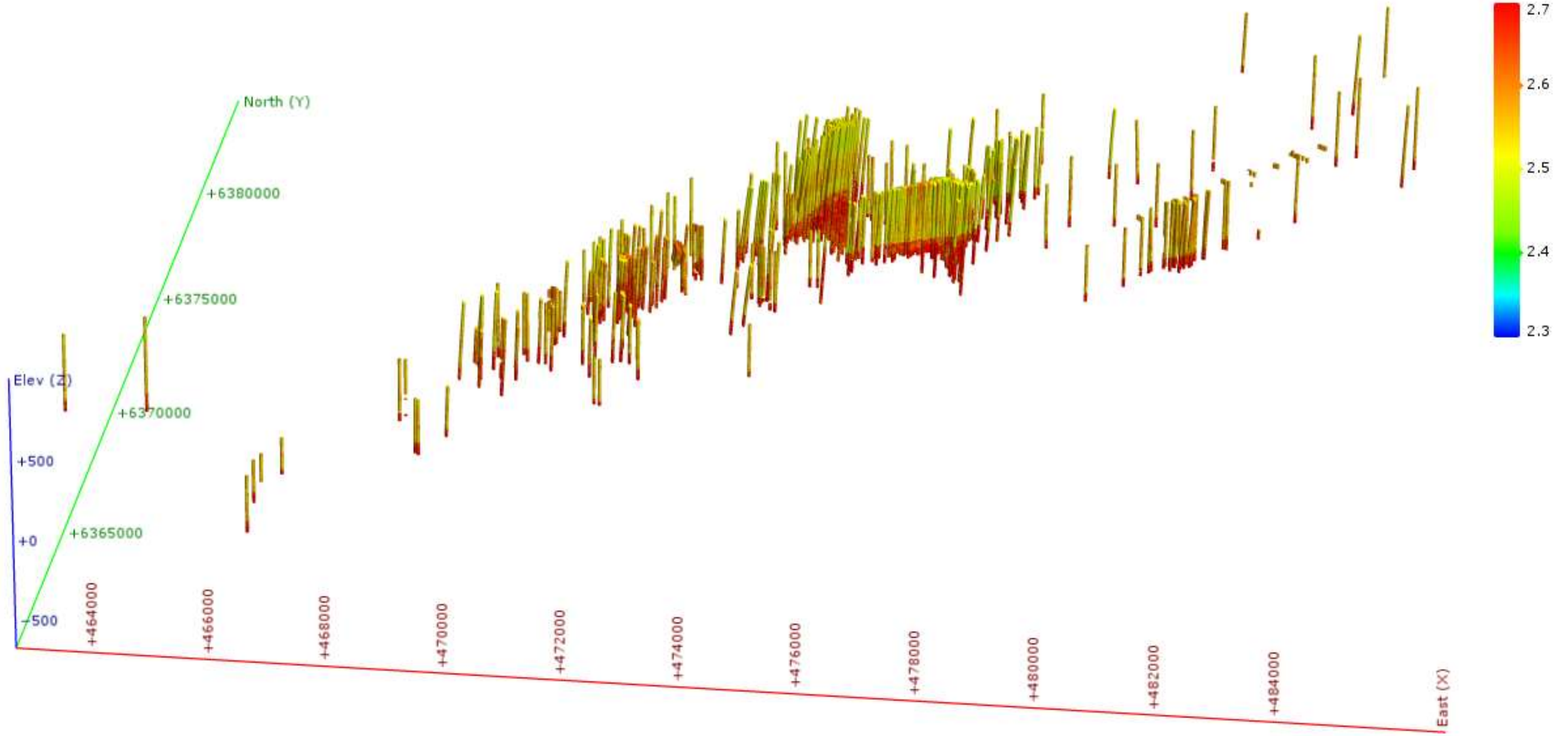


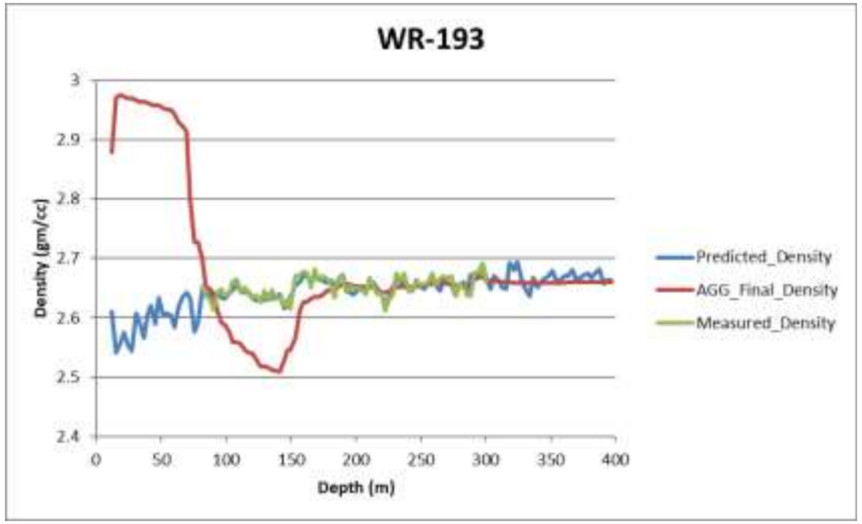
Density Prediction

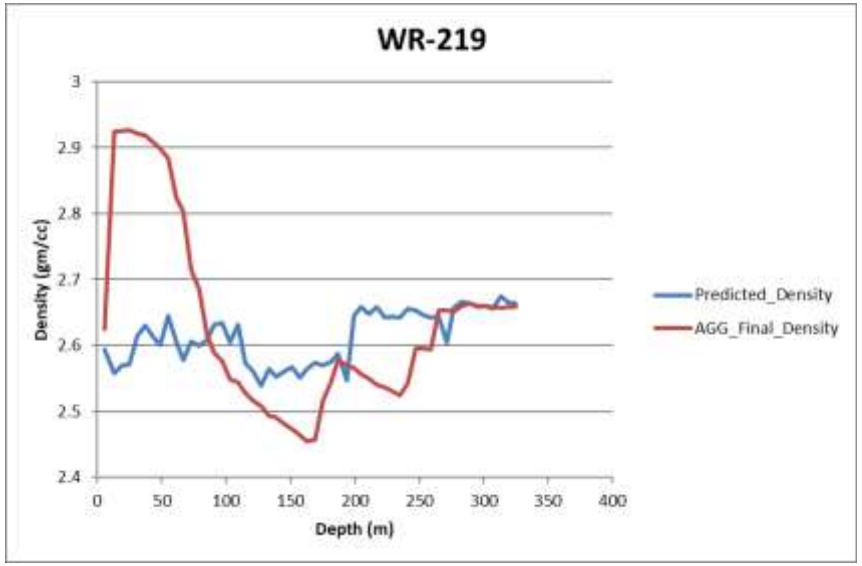
- Density Prediction
  - 716 Boreholes



Comparison with Inversion Results

- WR-193 inversion attempts to place a large density layer near surface
- Compensated for by a lower density unit immediately beneath (possible gibb's effect)
- High density unit placed at or near surface can be attributed to an artifact in the gravity data.
- WR-219, (same area) similar near surface artifact, but no predicted response.
- Provides a means of QA/QC processing to identify what holes may need to be logged for density.





Conclusions

- The density predictions from both new and old geochemistry data correlated well with measured density (hold out data)
- Test results indicate that the predictive models were effective in predicting density from multielement geochemistry
- The predictive models cost effectively improve our understanding of the density distribution across the deposit by leveraging the existing and abundant geochemistry data
- Augmented 35 boreholes of measured downhole density with 681 boreholes of predicted density totaling 716 boreholes of measured + predicted (20x increase) without the requirement or cost to acquire any new data.
- QA/QC work completed by Denison on the geochemistry data has had a very noticeable impact and lead to improved results.

Recommendations

- Conduct a comparative study of gravity inversion results - unconstrained vs constrained with 35 boreholes (measured) vs 716 (measured + predicted).
- Consider evaluating a similar approach with different prediction targets such as resistivity.
- Use prediction results to QA/QC measured density – potentially identify instrument calibration issues.

Acknowledgements

- Larry Petrie
- Denison Mines and its JV Partners
- DGI Geoscience Inc. (Chris Drielsma, Roxanne LeBlanc)
- Sebastian Goodfellow
- Peter Fullagar