Geohazards and Subsurface Uncertainty Smart Modeling

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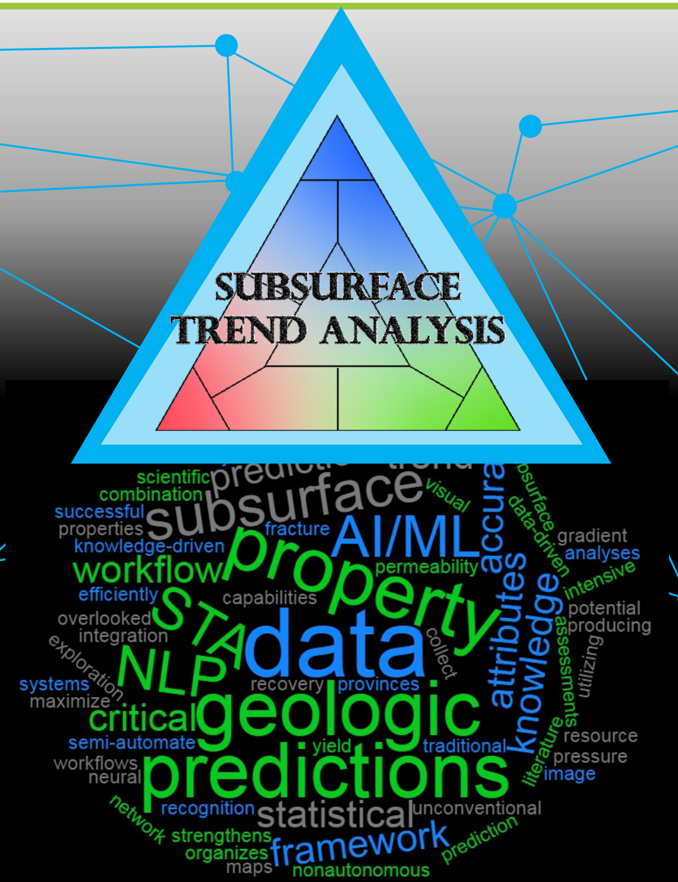
FWP Task 5



Carbon Management and Oil and Gas
Research Project Review Meeting
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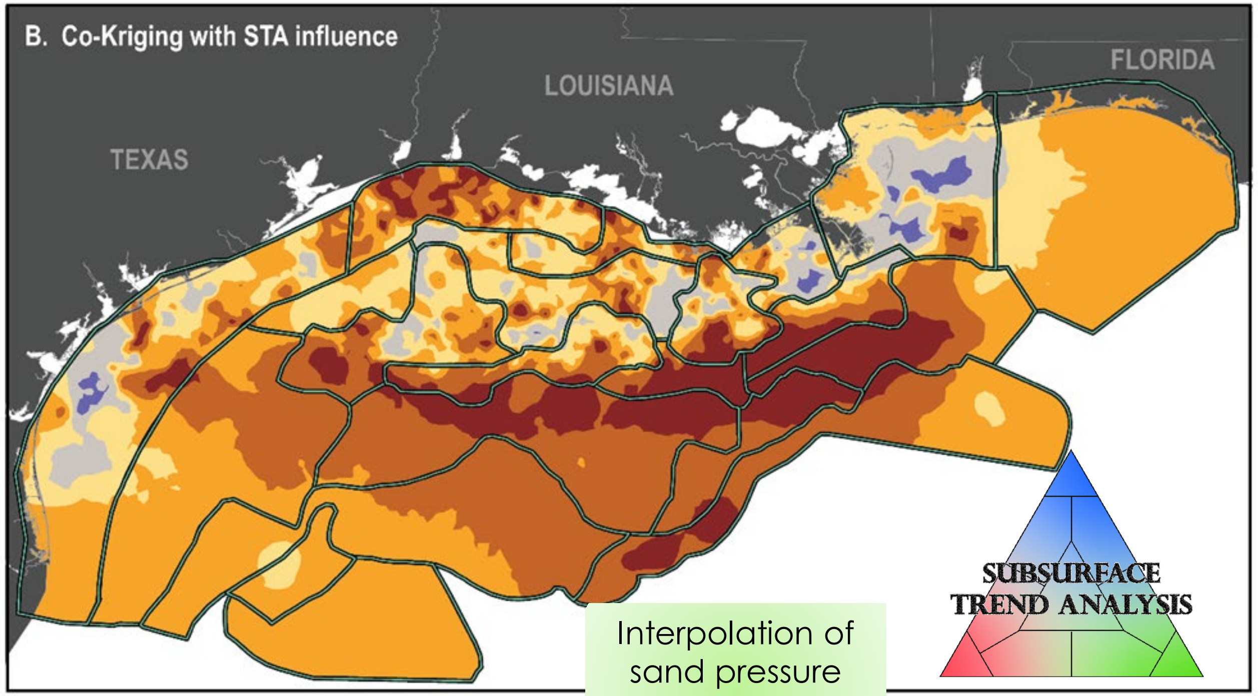
Geohazards and Subsurface Uncertainty Smart Modeling

Integrating AI/ML to improve prediction of subsurface conditions

Why is this work important?

- **Improved subsurface property analysis can increase safety and efficiency of offshore activities and reduce environmental and economic impacts to onshore communities, e.g. identifying geohazards, spill prevention, infrastructure risk**



Interpolation of sand pressure gradient in the Gulf of Mexico

Rose et al., 2020

Issue/R&D Need

- Complication of offshore sedimentary systems and the heterogeneous subsurface introduces hazards and risks that are difficult to constrain and predict
- Ongoing operations increase the risk of spills in offshore regions
- There is a need for rapid, accurate, and efficient tools that effectively predict subsurface conditions, even in areas with little to no data

Task objectives

- Develop a 3D, adaptive smart tool using the Subsurface Trend Analysis (STA) method framework
- Test and validate the STA smart tool in the GOM

Offshore Portfolio Task 5

Research Problem:

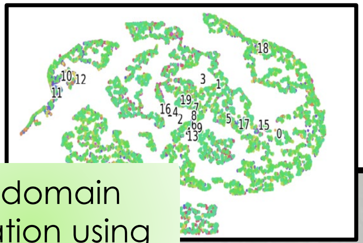
- Offshore sedimentary systems are complicated, and heterogeneous subsurface introduces hazards and risks that are hard to constrain and predict pre-drill leading to deleterious impacts, such as the Macondo blowout and Deepwater Horizon spill in 2010
- There is a need for rapid, accurate, and efficient tools that effectively predict pre-drill subsurface conditions, even in areas with little to no data

Proposed Research:

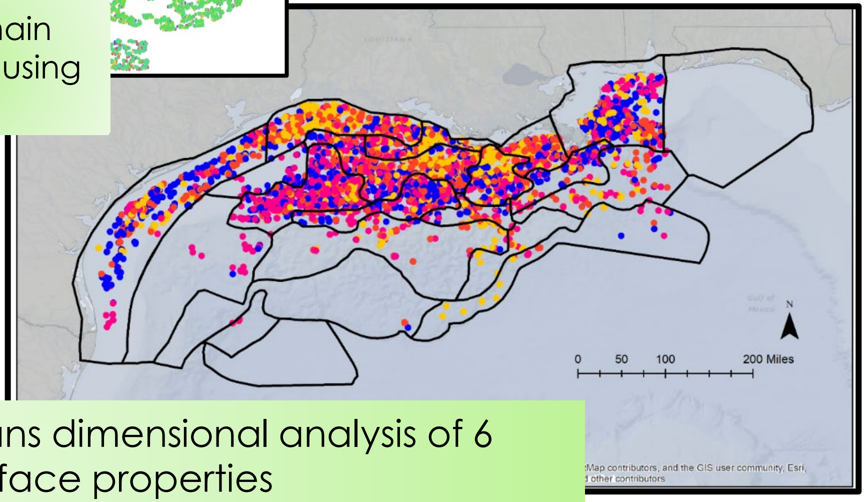
- Develop a 2-D, and eventually 3-D, real-time "smart" tool using the Subsurface Trend Analysis method framework
- Integrate machine learning and artificial intelligence (AI/ML) to improve efficacy and robustness of analyses
- Test and validate the AI/ML-enhanced STA Tool utilizing LWD/SWD datasets and analyses of structural complexity in the Gulf of Mexico (GOM)

Benefit:

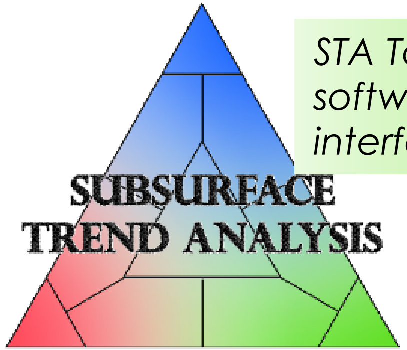
- Reduction of subsurface hazards and risks by utilizing these predictions to assist in efficient geohazard prevention and resource estimation, e.g., prevention of oil spills, CO_2 storage estimation, rare earth element enrichment, and geothermal prospects



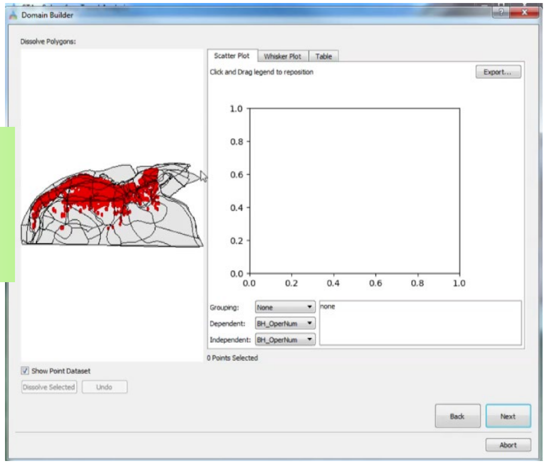
STA domain validation using t-SNE



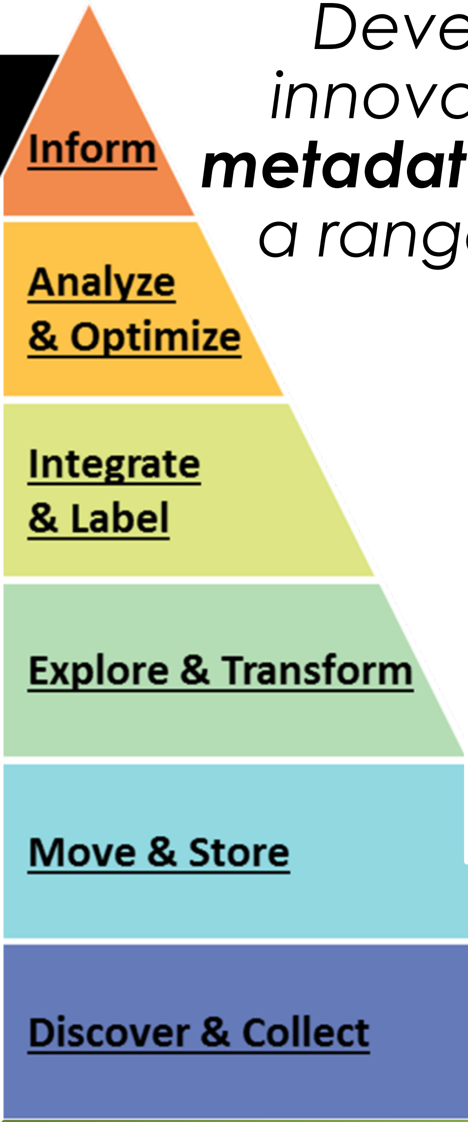
K-means dimensional analysis of 6 subsurface properties



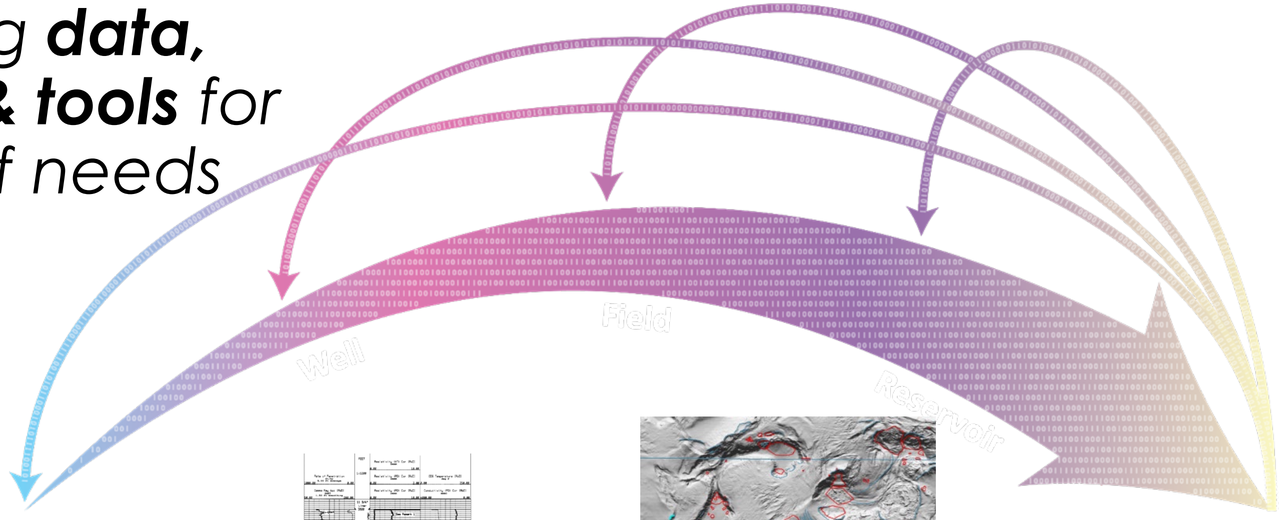
STA Tool software interface

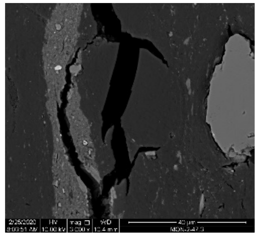


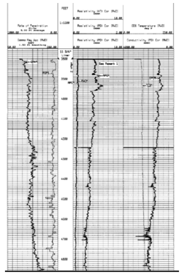
NETL's Geo-Data Science

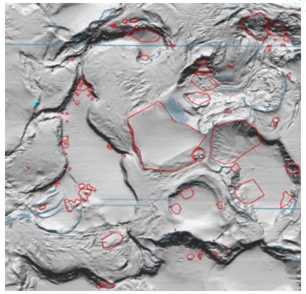


Developing & innovating ***data, metadata, & tools*** *for a range of needs*

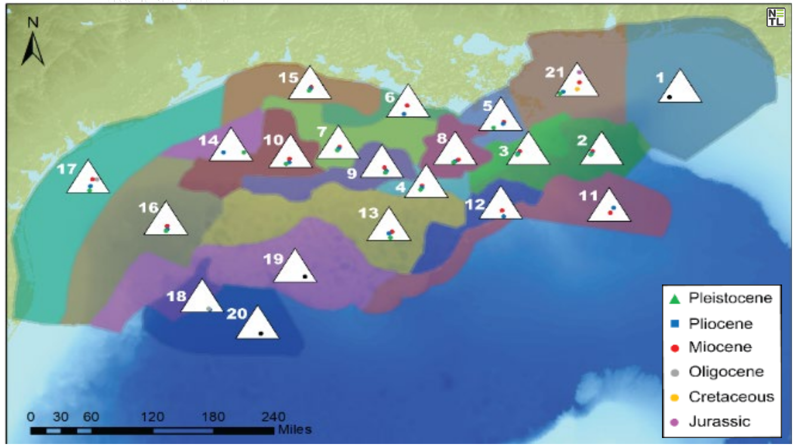






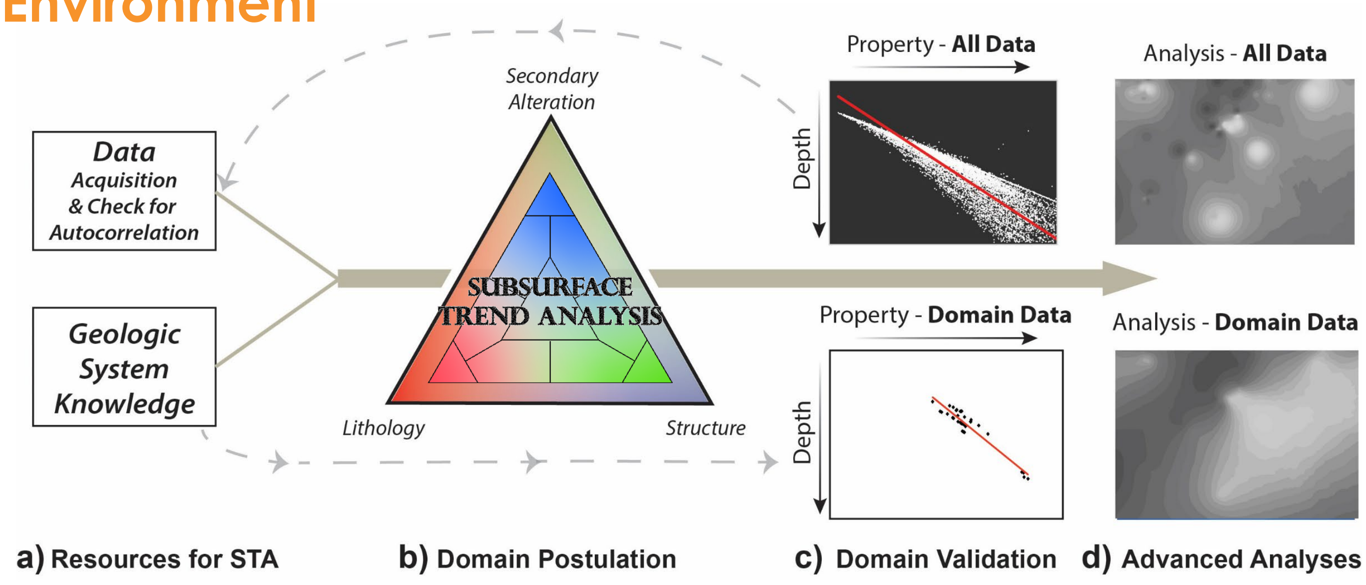


Data & geo-science methods to improve prediction and analyses ***across scales of investigation***



Subsurface Trend Analysis

An AI/ML-Informed Methodical Framework to Predict Subsurface Properties and the Geologic Environment



Initial method published: Rose, K., Bauer, J.R., and Mark-Moser, M. **(2020)** Subsurface Trend Analysis, a multi-variate geospatial approach for subsurface evaluation and uncertainty reduction, Interpretation

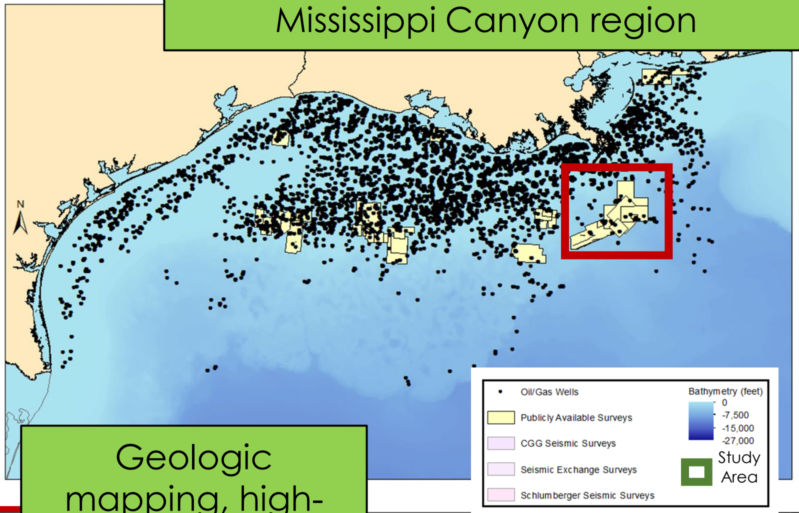
Initially developed to address spill risks following Deepwater Horizon

Validated method is expanding under this task to an AI/ML, 3D/4D Smart Tool: the STA Tool

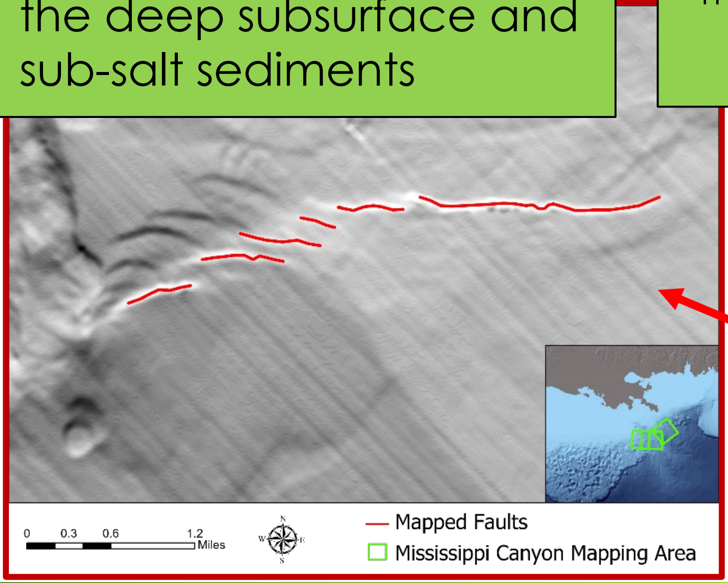
Seafloor & Subsurface Characterization for STA Geohazard Analysis

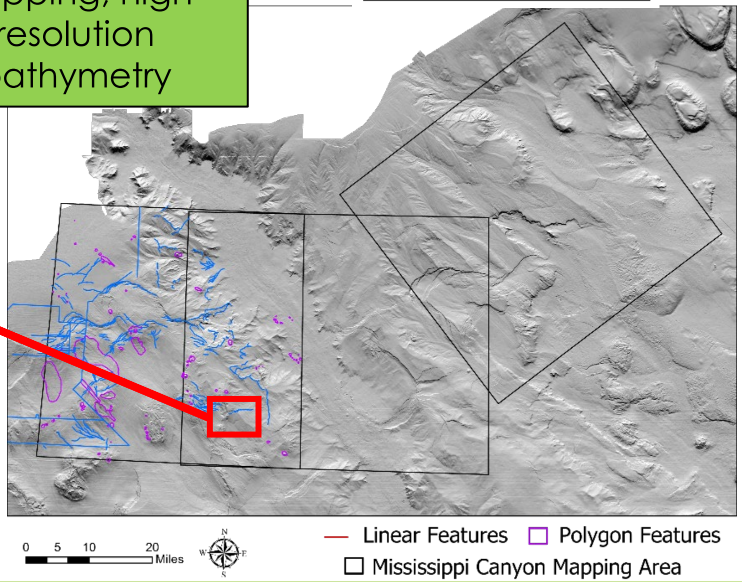
- Identifying subsurface characteristics through seafloor feature mapping coupled with seismic interpretation
- Generating new subsurface property data for offshore sedimentary systems to inform geohazard prediction in the deep subsurface and sub-salt sediments

Subregional, field-scale analyses: Mississippi Canyon region

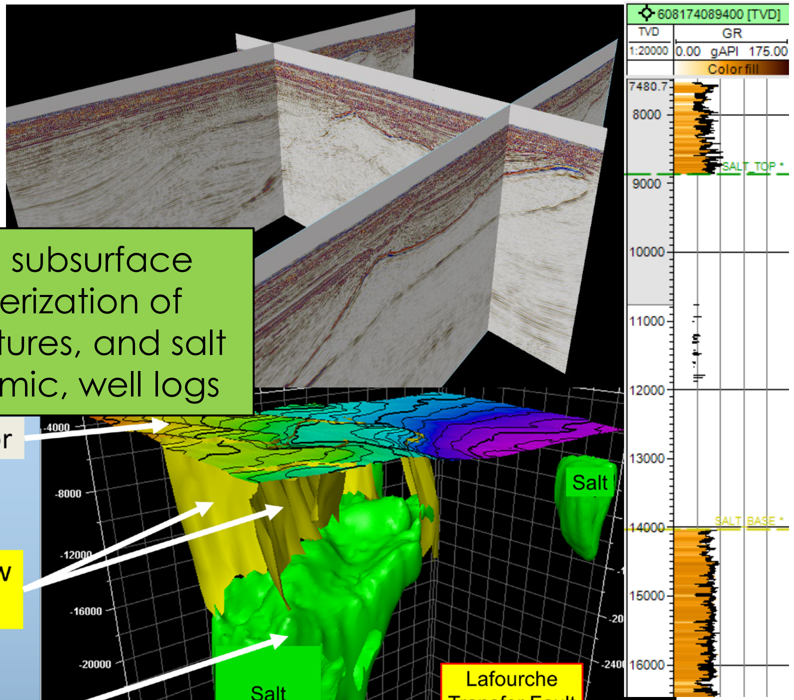


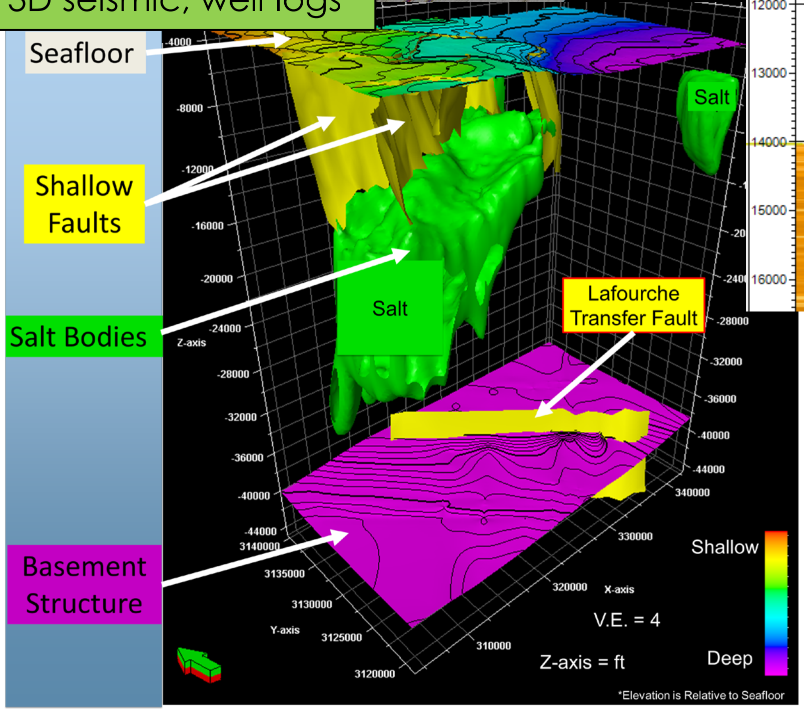
Geologic mapping, high-resolution bathymetry





Ongoing subsurface characterization of faults, fractures, and salt via 3D seismic, well logs





STA Tool: Present & Future 2D Work

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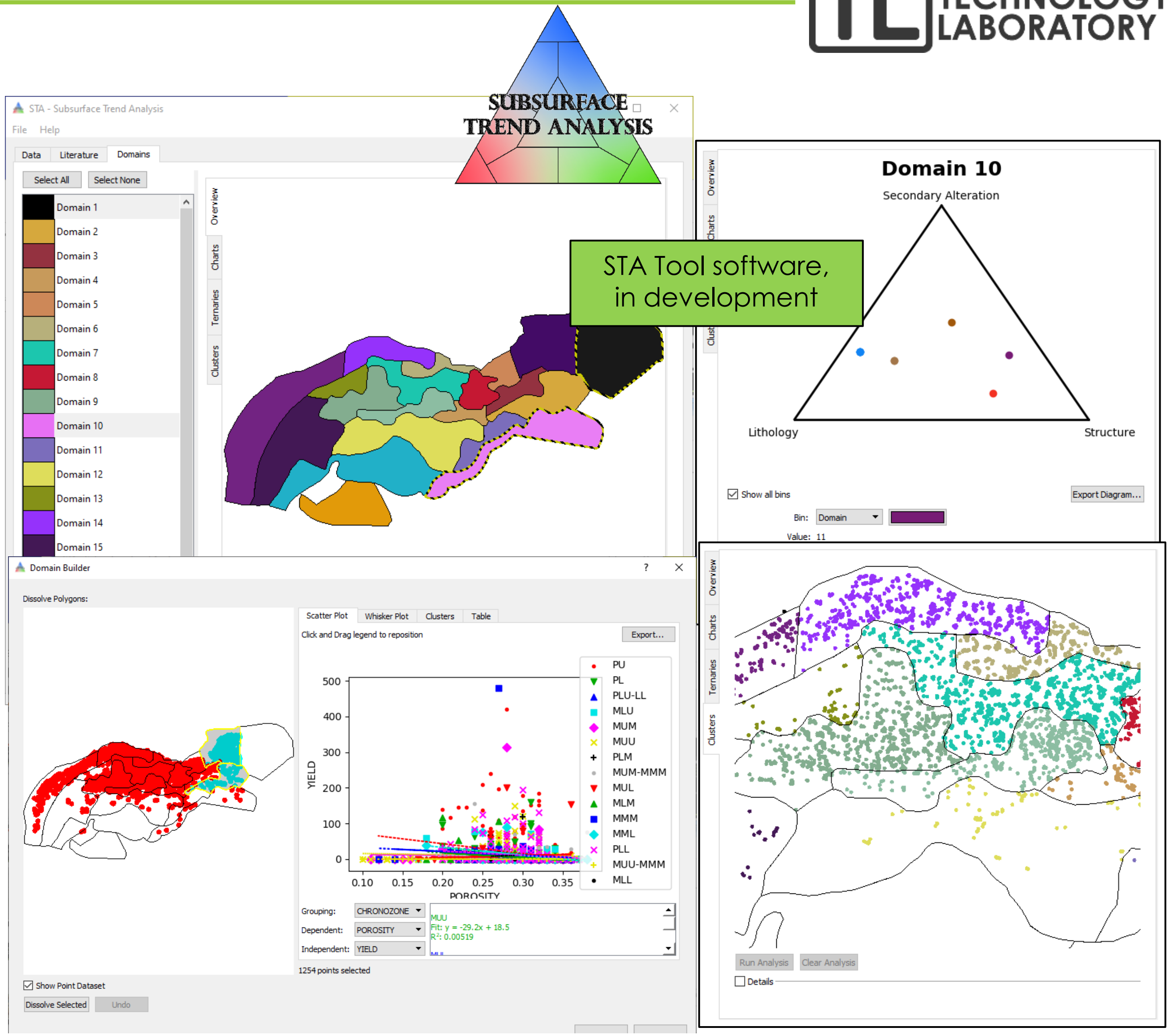
STA Tool – a *virtual research assistant* designed to:

- Organize and visualize disparate big data and knowledge resources
- Simplify and automate geologic domain formation
- Provide and execute multi-dimensional statistical analyses and validation
- Utilize ML to characterize property trends and predictions

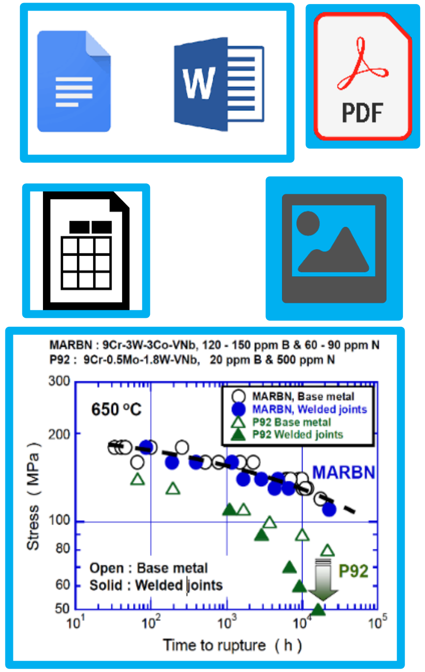


Current Development Efforts

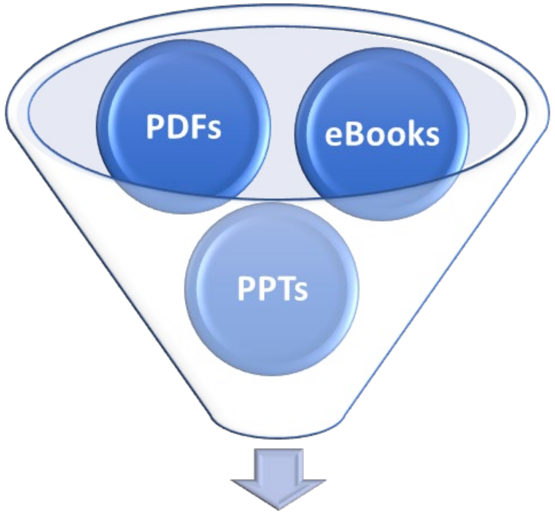
- Advanced property dataset analysis for structural complexity
- Additional Integration of ML/NLP
  - Suggestions of relevant literature (NLP)
  - Identifying and suggesting domains to researcher (supervised ML)
- Adaptive integration of field data
  - Integrate and update subsurface property predictions with new data

Natural Language Processing for Unstructured Data

Extracting Knowledge

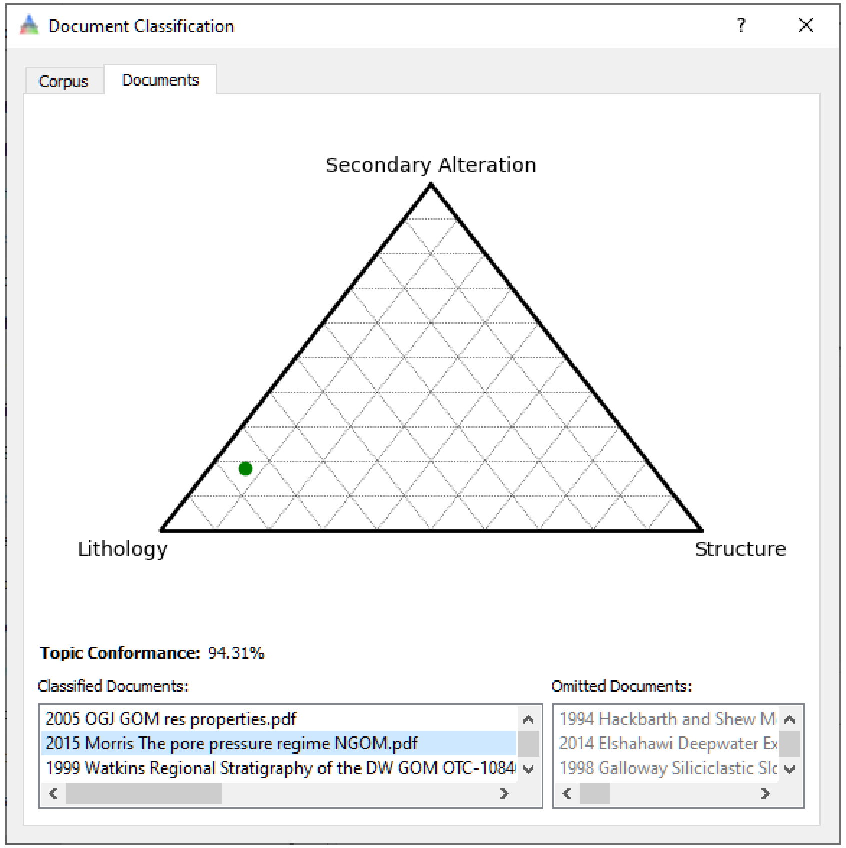


Energy Data eXchange



Structured digital data

Latent Dirichlet Allocation
topic model
Jaccard similarity-based
categorization
GeoVec



Mining data from documents, R&D products, presentations, etc., using NLP

Document topic classified in three desired categories

CNN Image Embedding

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AI Identification of Geologic Knowledge for Enhanced and Comprehensive Analysis

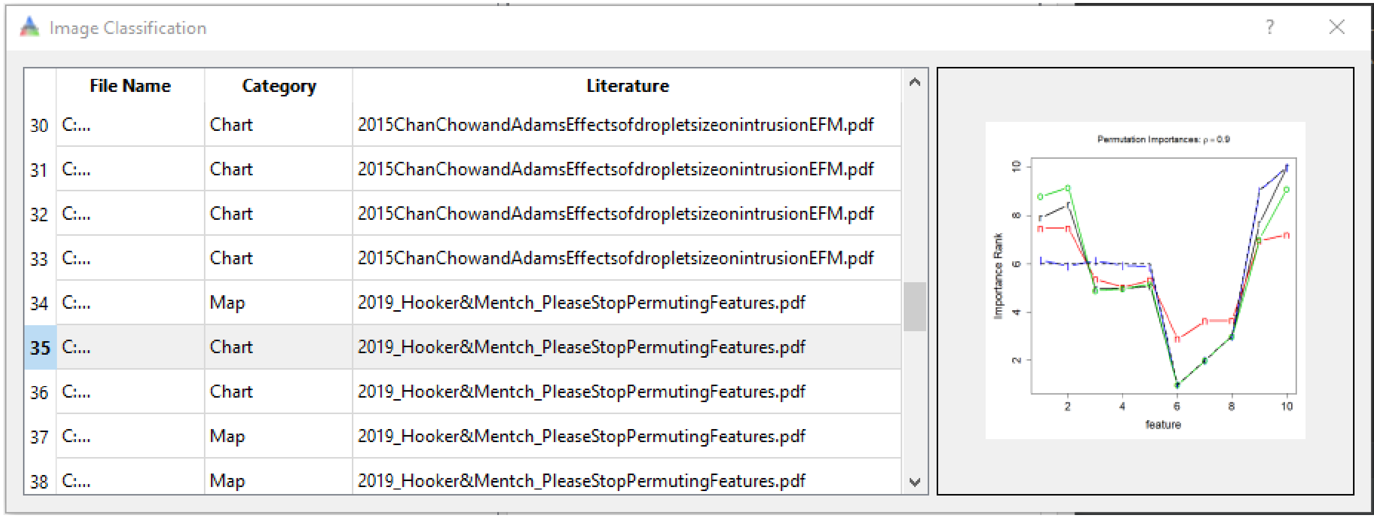
Feature objective: Develop a model that allows user to feed unstructured data and search for an item of interest, e.g., geologic map, and returns all relevant images back to the user–saving hours of work and reducing error.

Transfer learning using VGGNet, trained on thousands of images.

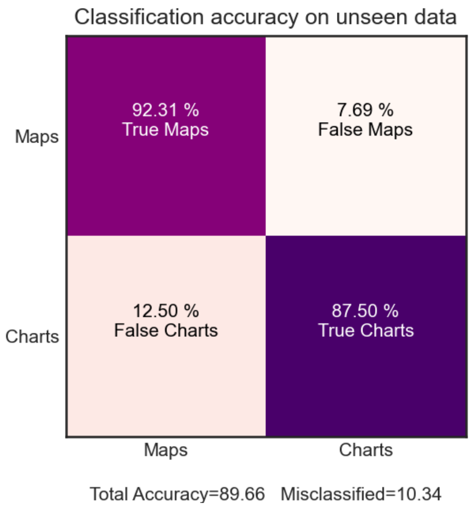
User interface built and integrated into STA Tool.

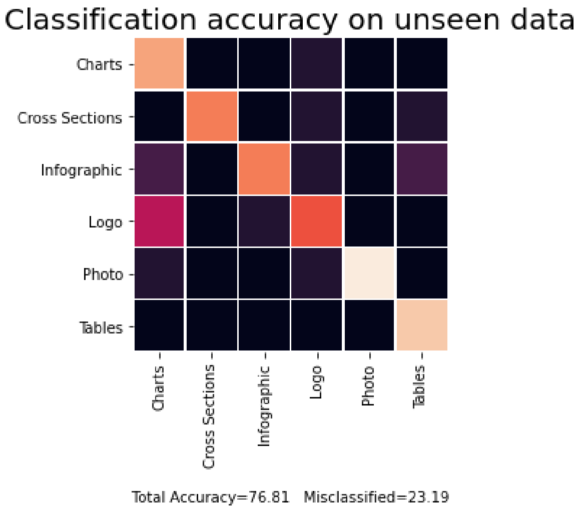
Total accuracy, single class: 89.6%
Total accuracy, multi-class: 76.8%

To be further validated and tested with geologic image repositories from NETL, USGS, NASA.



	File Name	Category	Literature
30	C:...	Chart	2015ChanChowandAdamsEffectsofdropletsizeonintrusionEFM.pdf
31	C:...	Chart	2015ChanChowandAdamsEffectsofdropletsizeonintrusionEFM.pdf
32	C:...	Chart	2015ChanChowandAdamsEffectsofdropletsizeonintrusionEFM.pdf
33	C:...	Chart	2015ChanChowandAdamsEffectsofdropletsizeonintrusionEFM.pdf
34	C:...	Map	2019_Hooker&Mentch_PleaseStopPermutingFeatures.pdf
35	C:...	Chart	2019_Hooker&Mentch_PleaseStopPermutingFeatures.pdf
36	C:...	Chart	2019_Hooker&Mentch_PleaseStopPermutingFeatures.pdf
37	C:...	Map	2019_Hooker&Mentch_PleaseStopPermutingFeatures.pdf
38	C:...	Map	2019_Hooker&Mentch_PleaseStopPermutingFeatures.pdf





High Dimensional Analyses of Subsurface Properties

Gulf of Mexico Application

Gulf of Mexico dimensional analysis use-case utilizes reservoir properties:

- Initial pressure
- Initial temperature
- Porosity
- Permeability (log)
- Water saturation
- Chronozone

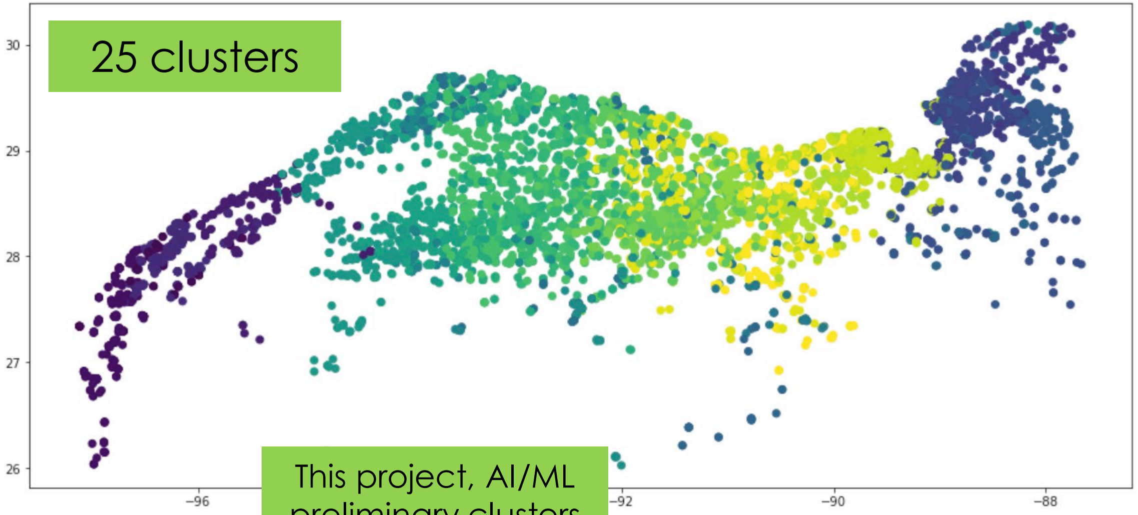
Standard analysis generated 21 geologic domains.

High dimensional analysis reveals 25 clusters.

Further analysis in progress to tune the model and understand relationship to geologic domains.

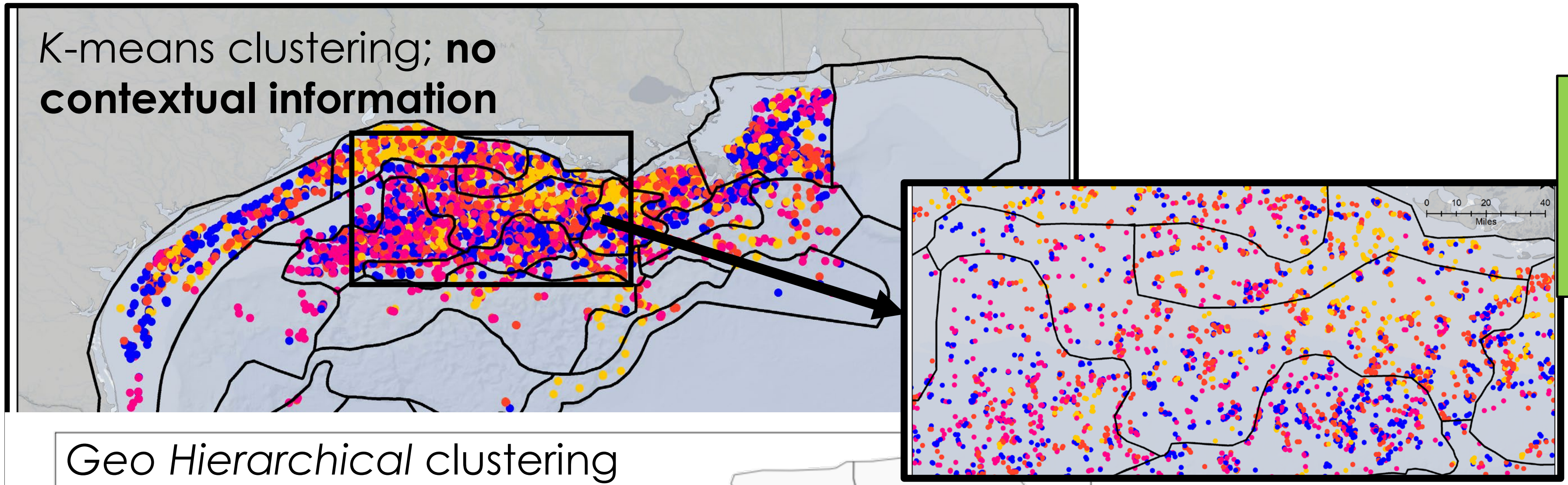
Hyperparameter tuning improves cohesion score and ultimately predictions.

Rose et al., 2020, Mark-Moser et al., 2018

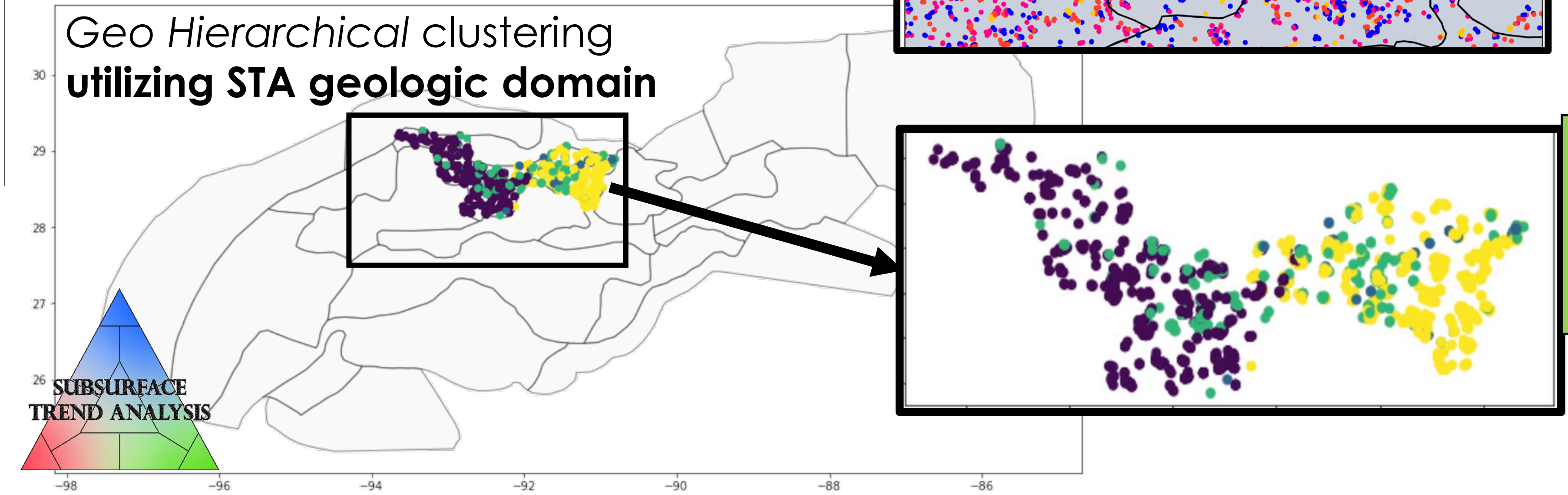


Domain Validation & Universal Clustering Analysis

Gulf of Mexico Application



- **Four** clusters
- Poor continuity among clusters
- Cohesion score = ~10



- **Three** clusters
- Improved continuity among clusters
- Cohesion score: ~3

3D Enhancements & Adaptive Prediction

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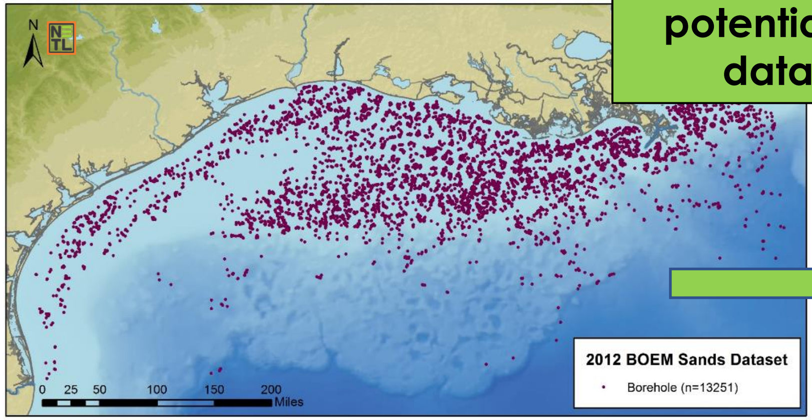
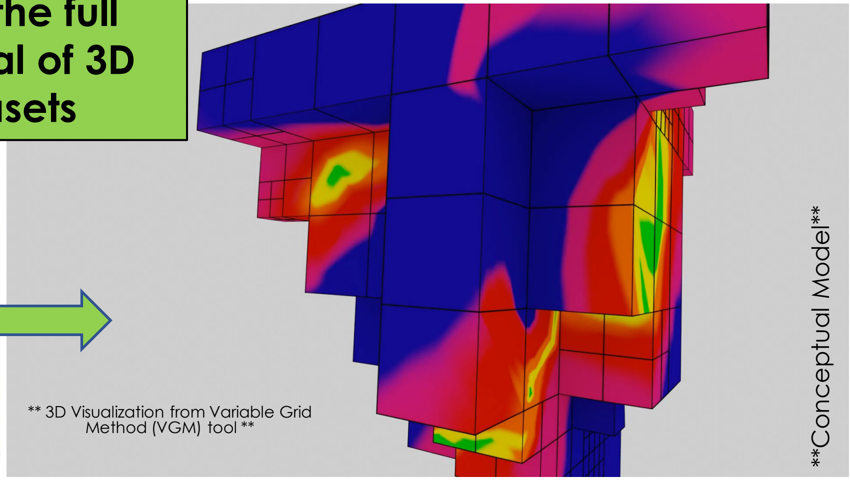
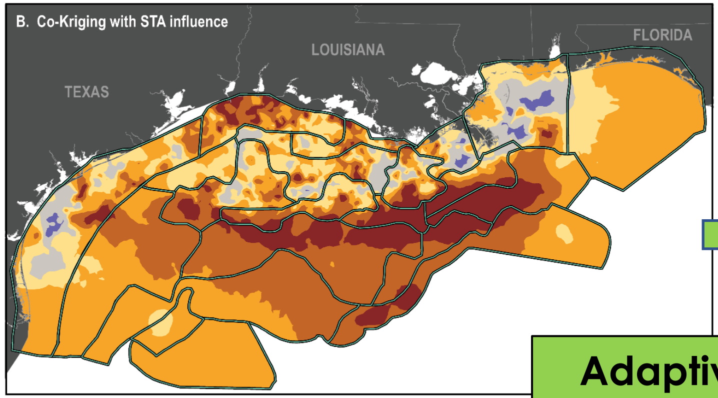
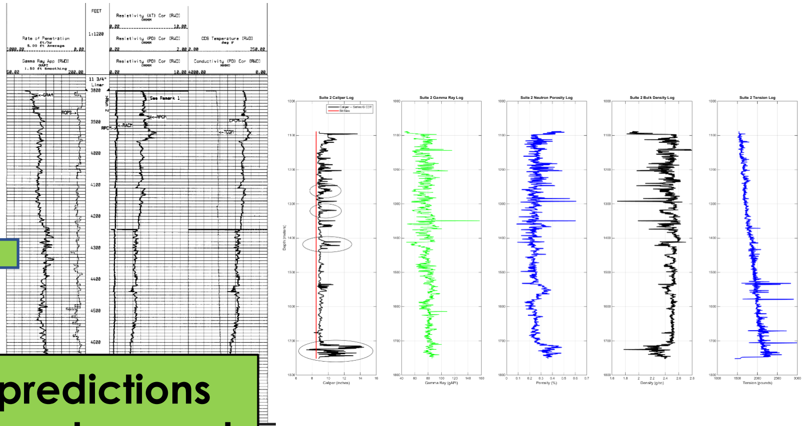
- The STA methodology is being extended into 3D data analysis
  - The structures being analyzed are 3D in nature
  - More detailed data → better predictions
- STA Tool will provide utilities to better understand data
  - 3D visualizations to gain perspective on data & subsurface predictions
  - Integrating geologic systems knowledge and field data to update prediction of subsurface conditions

STA tool seeks to utilize the full potential of 3D datasets





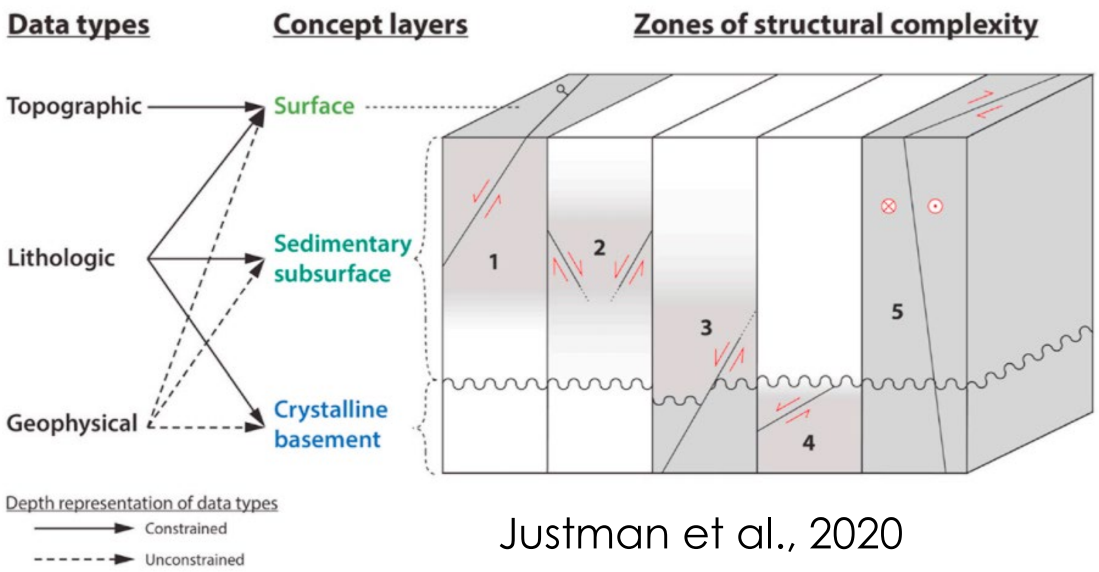




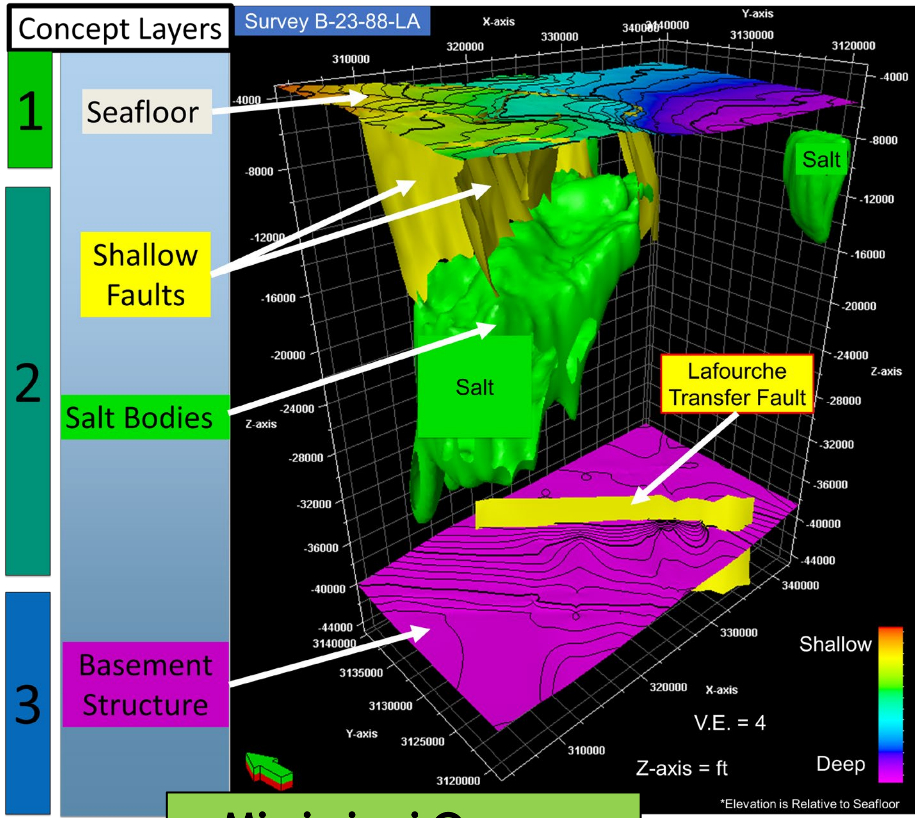
Adaptive predictions informed by advanced knowledge and statistics

Integrating NETL AI/ML Geodata Science Methods to Improve Subsurface Predictions: STA + SIMPA

- **Spatially Integrated Multi-variate Probabilistic Assessment (SIMPA) utilizes fuzzy logic to predict structural complexity**
- **When combined with STA, provides improved geologic constraint through structure-informed domains**



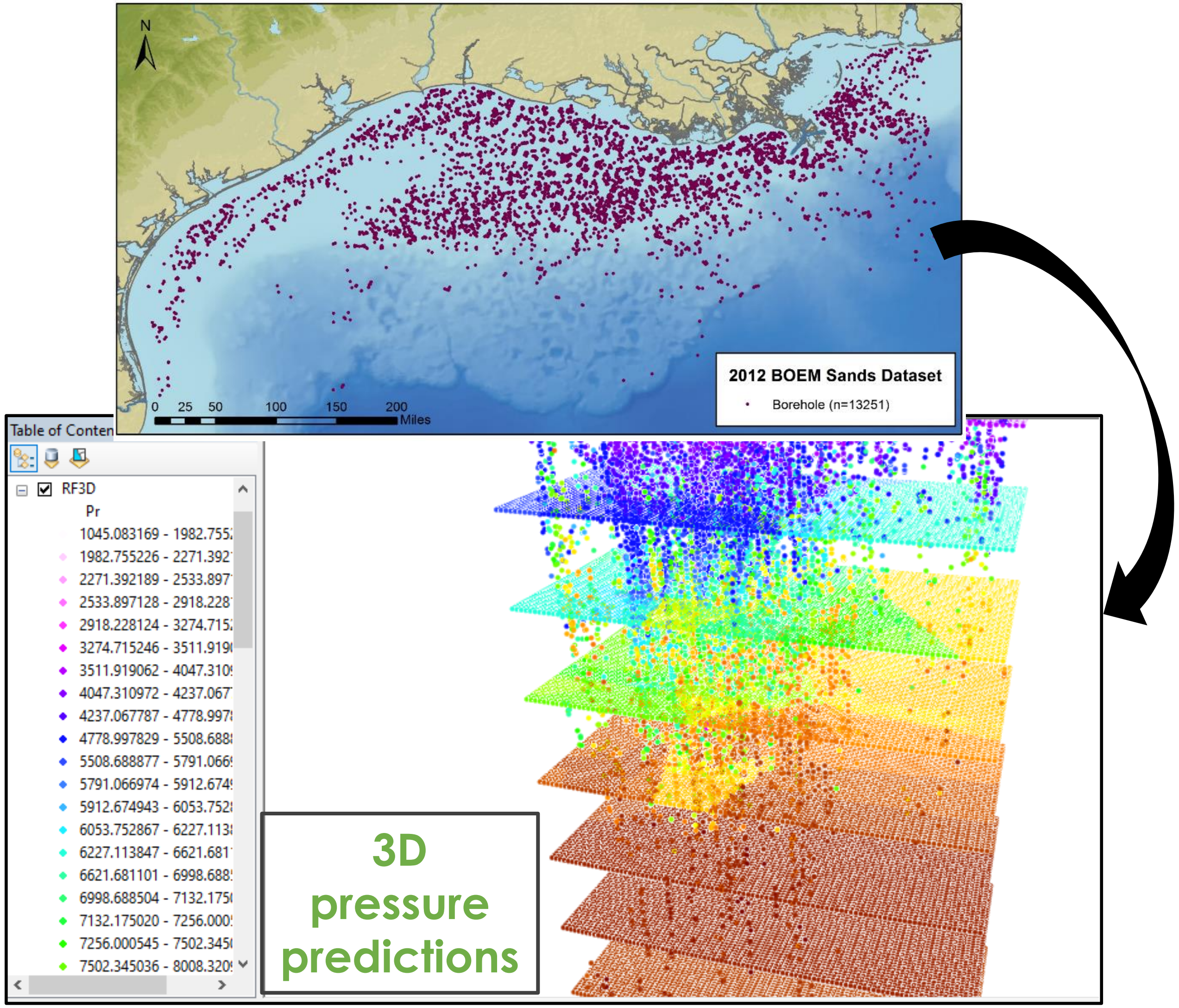
Justman et al., 2020



Mississippi Canyon subsurface model

Expanding Property Prediction to 3D

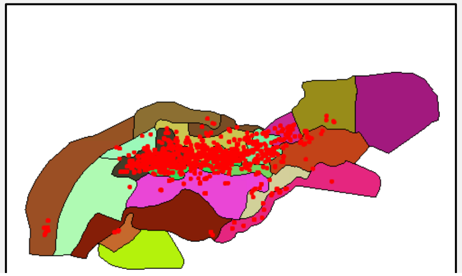
- 3D interpolations of property predictions can be explored to better constrain the subsurface and forecast risks
- The current method in development is a variation on Multivariate Adaptive Regression Splines (MARS)
- Assumes training data are sparse in relation to geological features, lithology and structural features have impact on predictor variables, therefore Model knots are related to physical features
- Adaptation utilizes intentional overfitting of MARS by segmentation at model knots and refits MARS to each segment
- Ultimately, model produces 3D property predictions

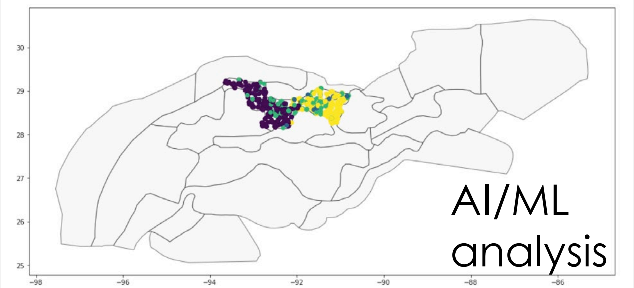


Adaptive Module to Incorporate Field Data

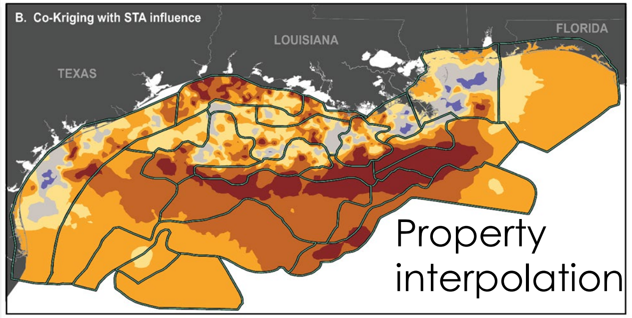
- **Additional tool module in development to incorporate field data (e.g., wireline, fiber optic, geophysical data)**
- **STA adjusts initial analysis with new data**
- **Module utilizes AI/ML to find perturbations that indicate geohazards, e.g., kicks, loss of geothermal circulation events**
- **Produces maps and depth intervals of caution**

A. Statistical analysis: [project name, input properties]



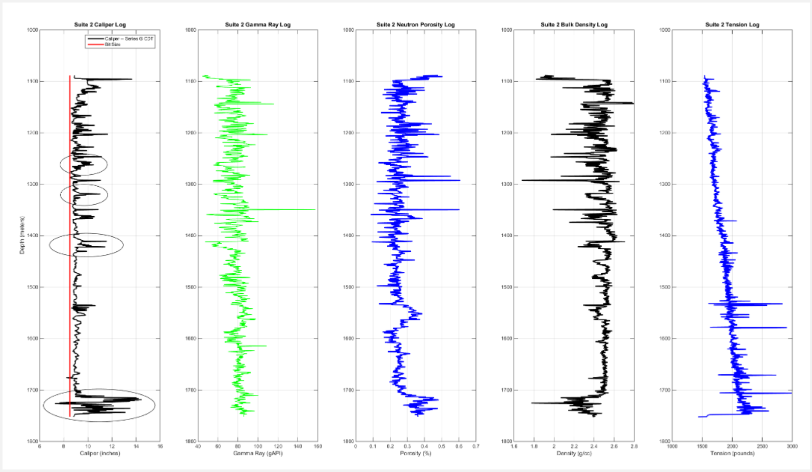


AI/ML analysis

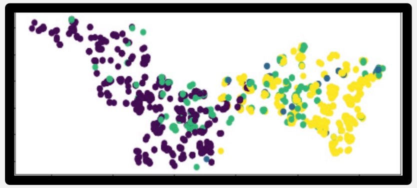


Property interpolation

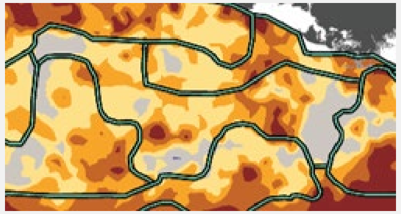
B. Enter field data: [file type]



C. Domain scale analysis, responds to field data



D. Adjusts domains



E. Flags hazardous conditions

Offshore Unconventional FWP

Key Team Members: PI – Kelly Rose - CO-PI – Mackenzie Mark-Moser

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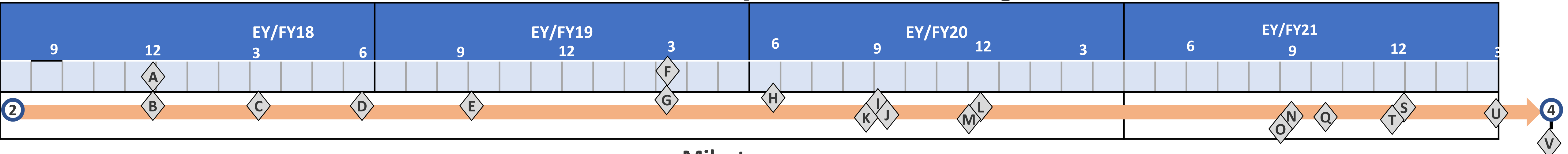


Milestones

Number	Date	Description
EY20.5.H	06/2020	Initiate STA analysis of GOM subregion to refine use of the STA at multiple scales (wellbore-to-field scale) and provide a validation/test of the enhanced STA tool.
EY20.5.I	09/2020	Continue analysis of advanced subsurface properties in the central GOM and use new 3-D approach and visualization techniques as available. These may include CO_2 and/or H_2S occurrence, fracture and fault distributions, and reservoir thickness. The team will pick one of these variables, based on data availability, and initiate an STA analysis for this parameter.
EY20.5.J	09/2020	Release of the ML-NLP enhanced STA beta tool for 2-D analytics.
EY20.5.K	09/2020	Initiate development of 3-D analytical and visualization logic into the ML-NLP-STA tool.
EY20.5.L	12/2020	Finalize development of ML driven neural network analysis of statistical dimensions and image embedding.
EY20.5.M	12/2020	Initiate 3-D analysis use-case using STA analysis with a separate fuzzy logic-driven NETL tool of a GOM subregion for subsurface structural complexity or other advanced subsurface property. This effort will use high-resolution bathymetry to map seafloor features (this has ties to Offshore Task 6.0 goals) in combination with geophysical datasets to constrain the GOM subsurface and basement boundary to understand and forecast subsurface structural complexity (areas of more likely faults and fractures) and uncertainty.
EY20.5.N	09/2021	Continue and finalize development on the component to handle real-time ingestion of subsurface geologic property data from LWD/SWD and wireline data streams. Real-time subsurface prediction and uncertainty reduction by combining STA with LWD/SWD data streams in the 2-D ML/AI STA tool.
EY21.5.O	09/2021	Evaluate and implement beta augmented reality/virtual reality (AR/VR) capabilities that may be paired with outputs from the tool for 3-D visualization of STA properties, end-user benefit.
EY21.5.P	–	If appropriate, seek and engage a partner for a DOE TCF proposal to commercialize ML-NLP enhanced STA tool during summer of 2021.
EY21.5.Q	09/2021	Complete journal manuscript describing and documenting the 2-D ML/AI enhanced STA model and validation use-case from EY/FY20.
EY21.5.R	10/2021	Complete application of the 3-D ML/AI enhanced STA model, test case, initiated in EY/FY20 for structural complexity and bathymetric analytics. Evaluate for any changes or enhancements required to finalize and validate the tool.
EY21.5.S	12/2021	Complete a 2-D validation test case for 2-D ML NLP enhanced STA tool. The STA hybrid GOM analysis (see previous bullet) and/or the LWD/SWD real-time property capability can be used for this validation.
EY21.5.T	12/2021	Improve and finalize development of 3-D analytical and visualization logic into the ML-NLP enhanced STA tool.
EY21.5.U	03/2022	Enhance handling of real-time ingestion of subsurface geologic property data from LWD/SWD and wireline data streams. Real-time subsurface prediction and uncertainty reduction by combining STA with LWD/SWD data streams in the 3-D ML/AI STA tool.
EY22.5.V	06/2022	Complete development, testing, and validation of the 3-D ML NLP enhanced STA tool.

Chart Key

TRL Score | Go / No-Go Timeframe | Project Completion | Milestone

Publications, Presentations, External Interest

Upcoming & Past

Upcoming Publications

- Mark-Moser, M., Rose, K., Suhag, A., Wingo, P., Hoover, B., Bean, A., Pantaleone, S., and Bauer, J., Analysis of Spatial Patterns and Trends of Subsurface Properties in the Gulf of Mexico with an Artificial Intelligence Framework. In preparation.

Upcoming Presentations

- Pantaleone, S., Mark-Moser, M., Bean, A., Walker, S., Rose, K. Accepted. Forecasting 3D Structural Complexity with AI/ML Methods: Mississippi Canyon, Gulf of Mexico. **AAPG/SEG IMAGE conference 2021**, Sept. 26th-Oct. 1, Denver, CO/Virtual.
- Rose, K., Mark-Moser, M., Suhag, S., Bauer, J. Submitted, invited talk. Improving prediction of subsurface properties using a geoscience informed, multi-technique, artificial intelligence approach. **AGU Fall Meeting 2021**, Dec. 13-17, New Orleans, LA/Virtual. Session: H071 – Machine Learning Applications in Geosciences Modeling and Measurement.
- Mark-Moser, M., Wingo, P., Duran, R., Dyer, A., Zaengle, D., Suhag, A., Hoover, B., Pantaleone, S., Shay, J., Bauer, J., Rose, K. Submitted. AI/ML integration for accelerated analysis and forecast of offshore hazards. **AGU Fall Meeting 2021**, Dec. 13-17, New Orleans, LA/Virtual. Session: EP027 - Proven AI/ML applications in the Earth Sciences.

Past publications*

- Rose, K., Bauer, J.R., and Mark-Moser, M., 2020, A systematic, science-driven approach for predicting subsurface properties, *Interpretation, 8:1, 167-181* https://doi.org/10.1190/INT-2019-0019.1
- Mark-Moser, M.; Miller, R.; Rose, K.; Bauer, J.; Disenhof, C. Detailed Analysis of Geospatial Trends of Hydrocarbon Accumulations, Offshore Gulf of Mexico; NETL-TRS-13-2018; NETL Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Albany, OR, 2018; p 108. DOI: 10.18141/1461471.

Past Presentations*

- Machine Learning for Oil and Gas, November 2020
- SMART Webinar December 2019
- AGU Fall Meeting 2019
- Machine Learning for Unconventional Resources 2019
- AAPG Special Topic Forum Invited Talk 2018
- Geological Society of America 2017

External Interest

Datasets

- Mark-Moser, M. Subsurface Trend Analysis domains for the northern Gulf of Mexico, 3/25/2020, https://edx.netl.doe.gov/dataset/subsurface-trend-analysis-domains-for-the-northern-gulf-of-mexico, DOI: 10.18141/1606228

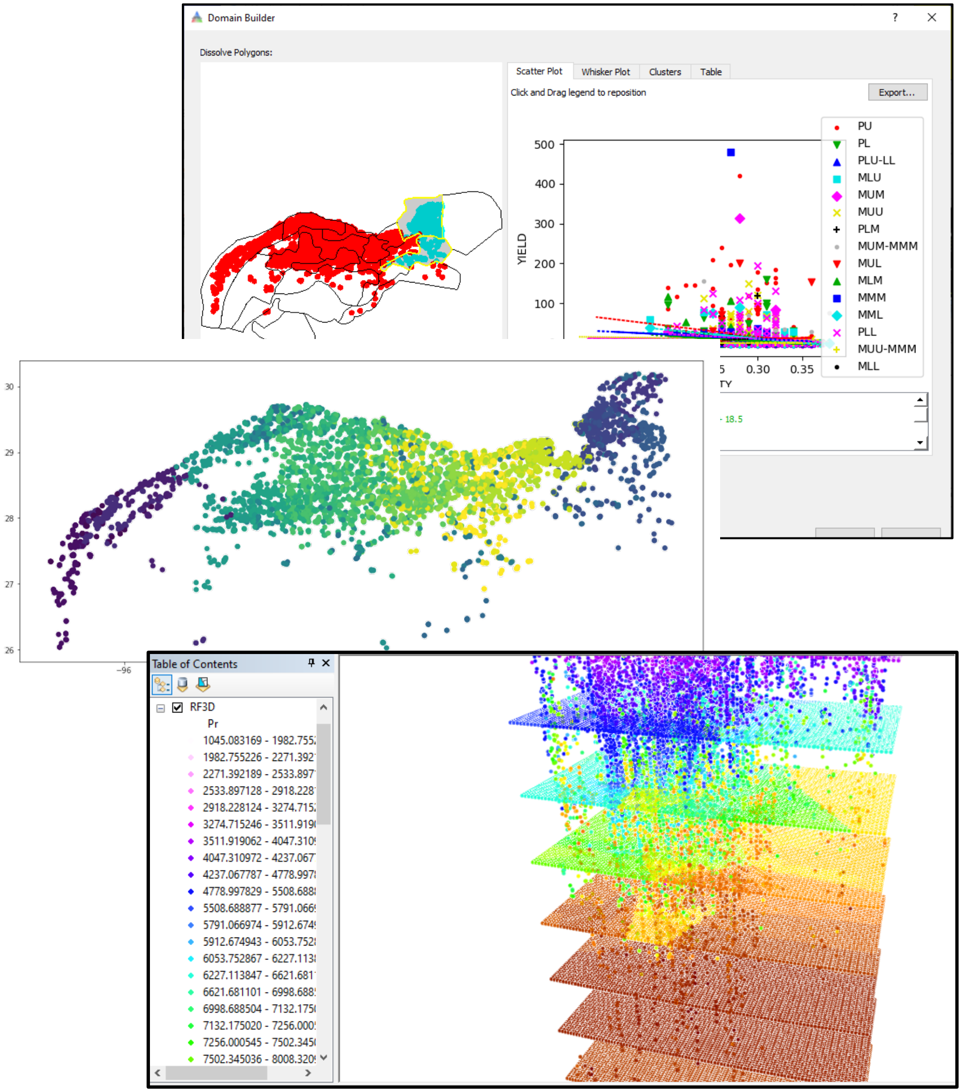
*Previous project ended in 2016. Some of these are subsequent products from that relate to this ongoing AI/ML offshore geohazard research effort

Key Takeaways

- The STA method was born from environmental goals of DOE's offshore oil spill prevention program requiring an understanding of subsurface conditions

- We are continuing to explore AI/ML solutions to accelerating and improving the steps of the STA method for better subsurface predictions

- Project will produce a **science-based, ML-NLP, 3D/4D tool for prediction** of **subsurface conditions** that is validated and tested in the offshore Gulf of Mexico and adapts to new data inputs



Products available at https://edx.netl.doe.gov/offshore/

Values Delivered

- An STA tool that can be used at various scales, from the basin to wellbore, for subsurface geohazard prediction and monitoring

- More accurate predictions of subsurface conditions that may be used to understand engineered-natural systems and prevent major environmental impacts that may result from offshore and other subsurface activities

SUBSURFACE TREND ANALYSIS

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Offshore R&D

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