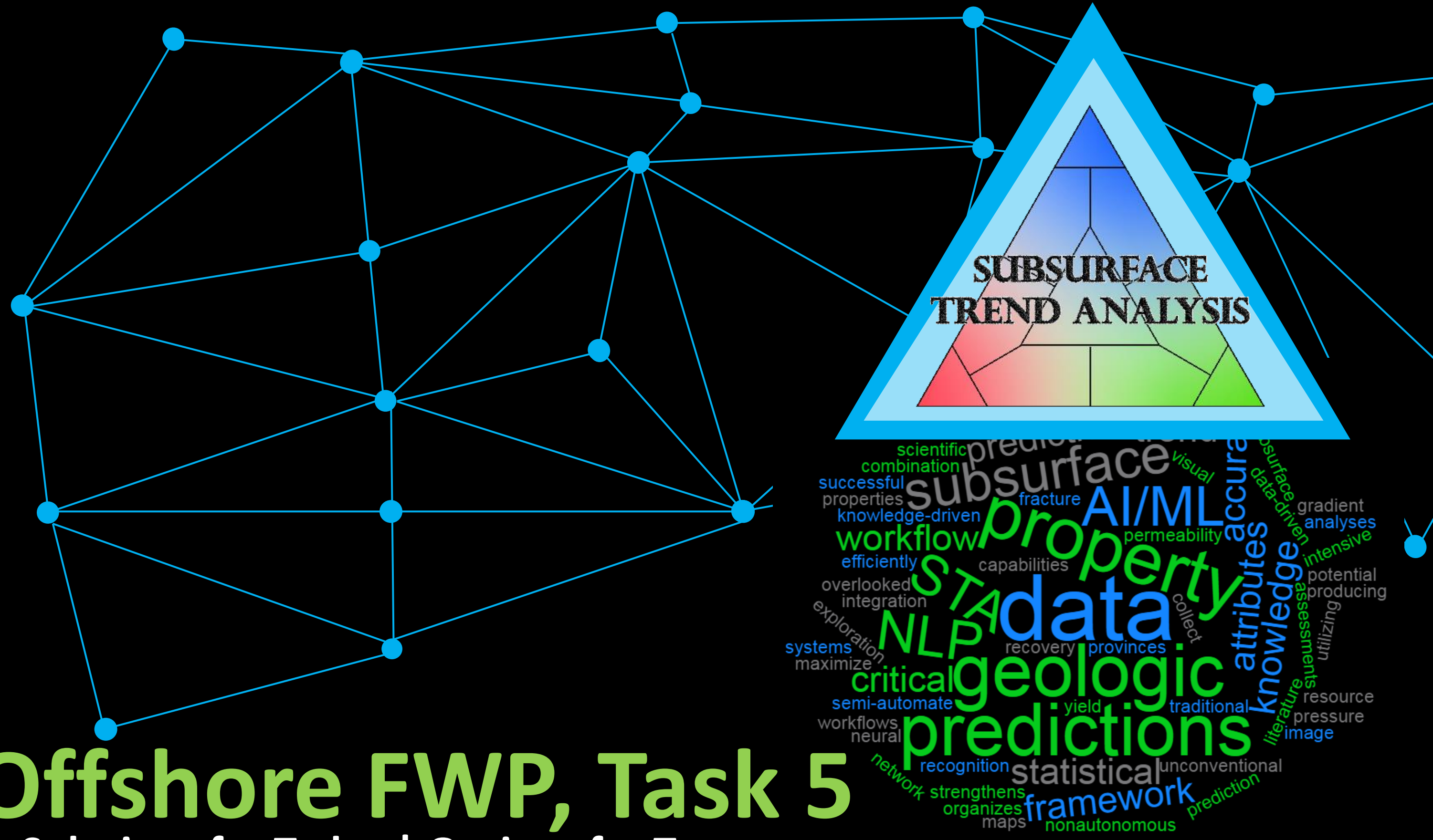
Geohazards & Subsurface Uncertainty Smart Modeling

Project team: MacKenzie Mark-Moser[1,2], Anuj Suhag[1,3], Kelly Rose[1], Patrick Wingo[1,2] Andrew Bean[1,2], Scott Pantaleone[1,3], Brendan Hoover[1,2], Jennifer Bauer[1]

[1]National Energy Technology Laboratory [2]Leidos Research Support Team, [3]Oak Ridge Institute for Science & Education

NATIONAL ENERGY TECHNOLOGY LABORATORY

Virtual Project Review Meeting
Oct. 26th 2020



Offshore FWP, Task 5

Solutions for Today | Options for Tomorrow

This Research was executed through the NETL Research and Innovation Center's Offshore Research field work proposal. Research performed by Leidos Research Support Team staff was conducted under the RSS contract 89243318CFE000003.

U.S. DEPARTMENT OF ENERGY

Geohazards and Subsurface Uncertainty Smart Modeling

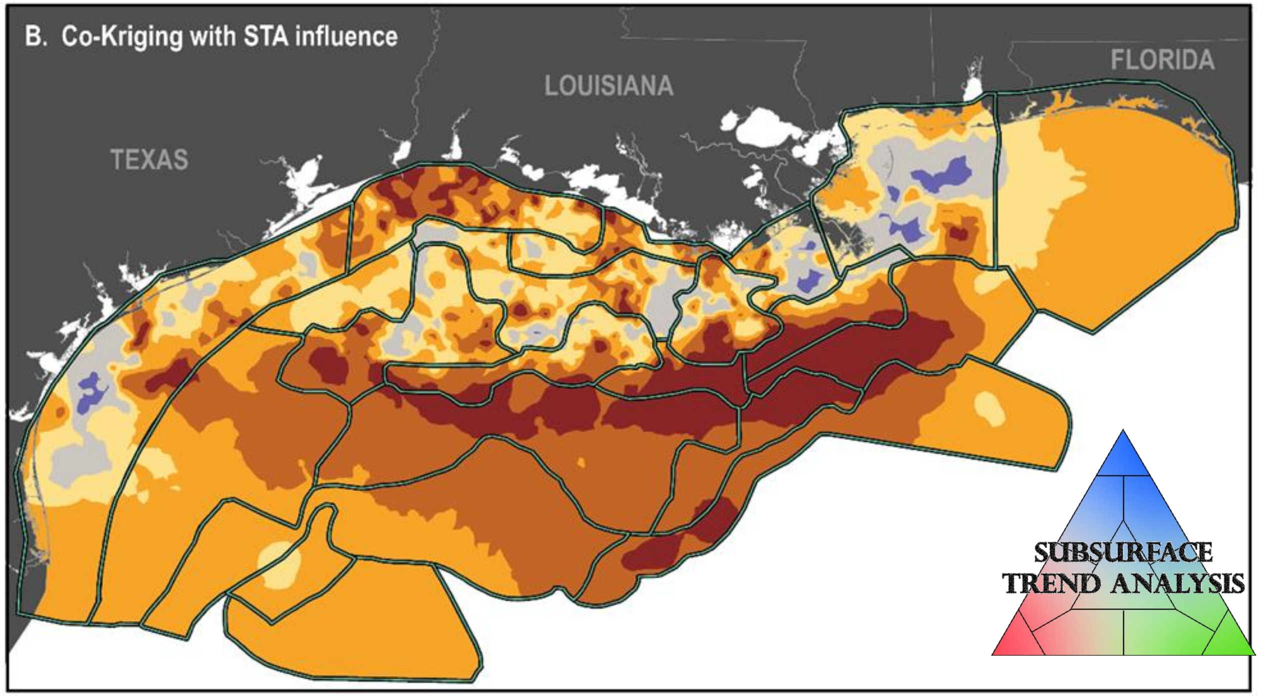
Integrating AI/ML to improve prediction of subsurface reservoir properties and geohazards

NATIONAL ENERGY TECHNOLOGY LABORATORY

https://edx.netl.doe.gov/offshore

Why is this work important?

Improved subsurface property analysis for resource, geohazard predictions, and real-time drilling risk reduction can increase safety and efficiency of offshore operations and reduce hazards and cost, including for EOR



Issue/R&D Need

- Complication of offshore petroleum systems and the heterogeneous subsurface introduces hazards and risks that are difficult to constrain and predict
- 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

Project Objective

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

Offshore Unconventional FWP

Task 5 - Geohazards & Subsurface Uncertainty Smart Modeling

NATIONAL ENERGY TECHNOLOGY LABORATORY

Research Problem:

Offshore petroleum systems are complicated, heterogenous subsurface introduces hazards and risks that are hard to constrain, predict pre-drill leading to deleterious impacts, such as the Macondo blowout in 2010 or just the average “dry hole”.

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:

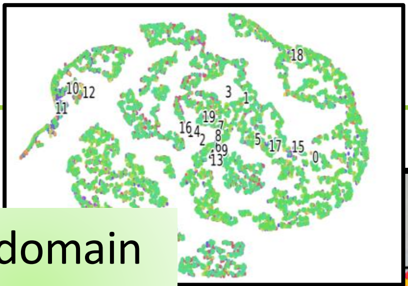
Develop a 2-D, and eventually 3-D, **real-time “smart” tool** using the Subsurface Trend Analysis method framework.

Integrate machine learning and artificial intelligence (ML/AI) to improve efficacy and robustness of analyses.

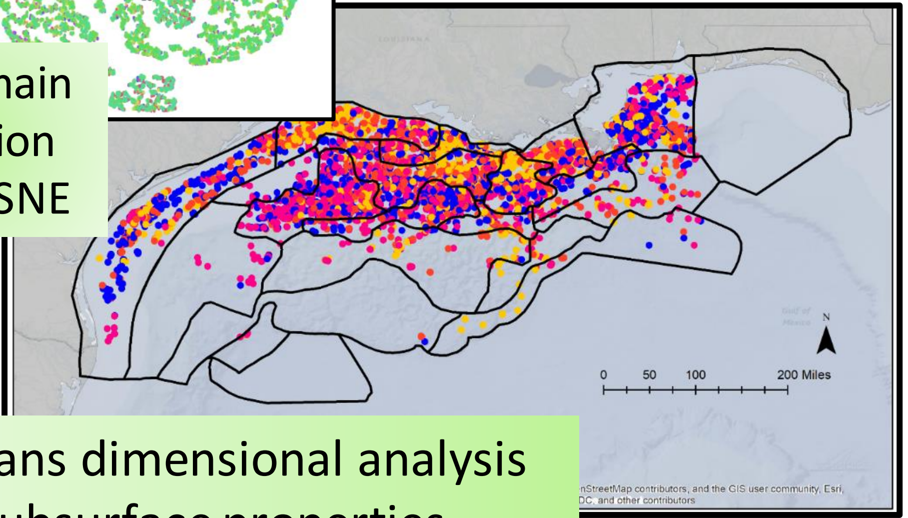
Test and validate the **ML/AI-enhanced STA Tool** utilizing LWD/SWD datasets and analyses of structural complexity in the Gulf of Mexico (GOM).

Benefit:

Reduction of pre-drill hazards and risks and utilizing these predictions to assist in efficient and successful resource management, e.g., geohazard risk mitigation, oil/gas extraction or CO2 storage.



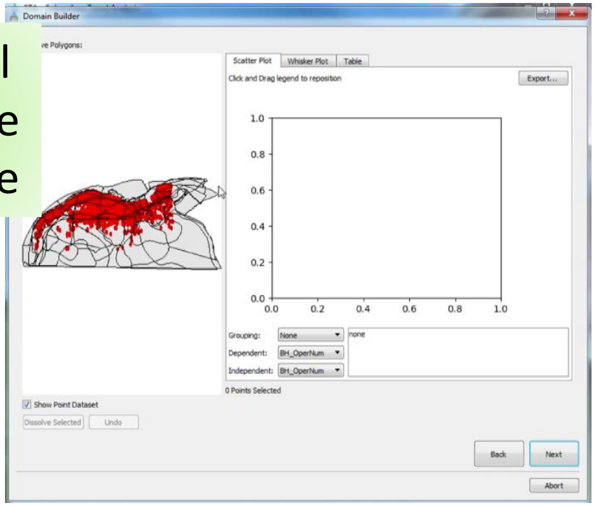
STA domain validation using t-SNE



K-means dimensional analysis of 6 subsurface properties

SUBSURFACE TREND ANALYSIS

STA Tool software interface



Subsurface Resource Assessment --- NETL's Geo-Data Science: Inventing Intelligent Solutions to DOE FE Data, R&D Needs

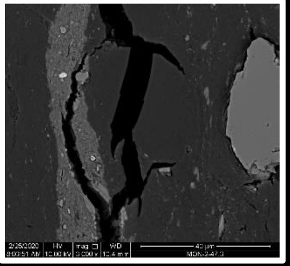
- Inform
- Analyze & Optimize
- Integrate & Label
- Explore & Transform
- Move & Store
- Discover & Collect

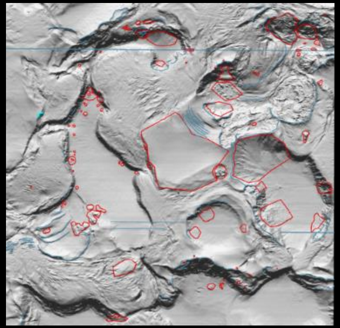
Developing & innovating ***data, metadata, & tools*** *for a range of needs*

Micro → Well → Field → Reservoir → Regional

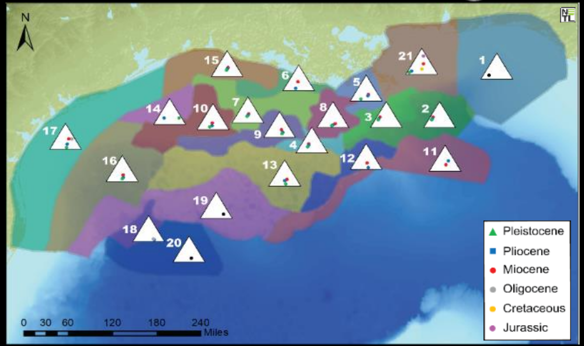
Data & geo-science methods to improve prediction and analyses ***across scales of investigation***

Micro





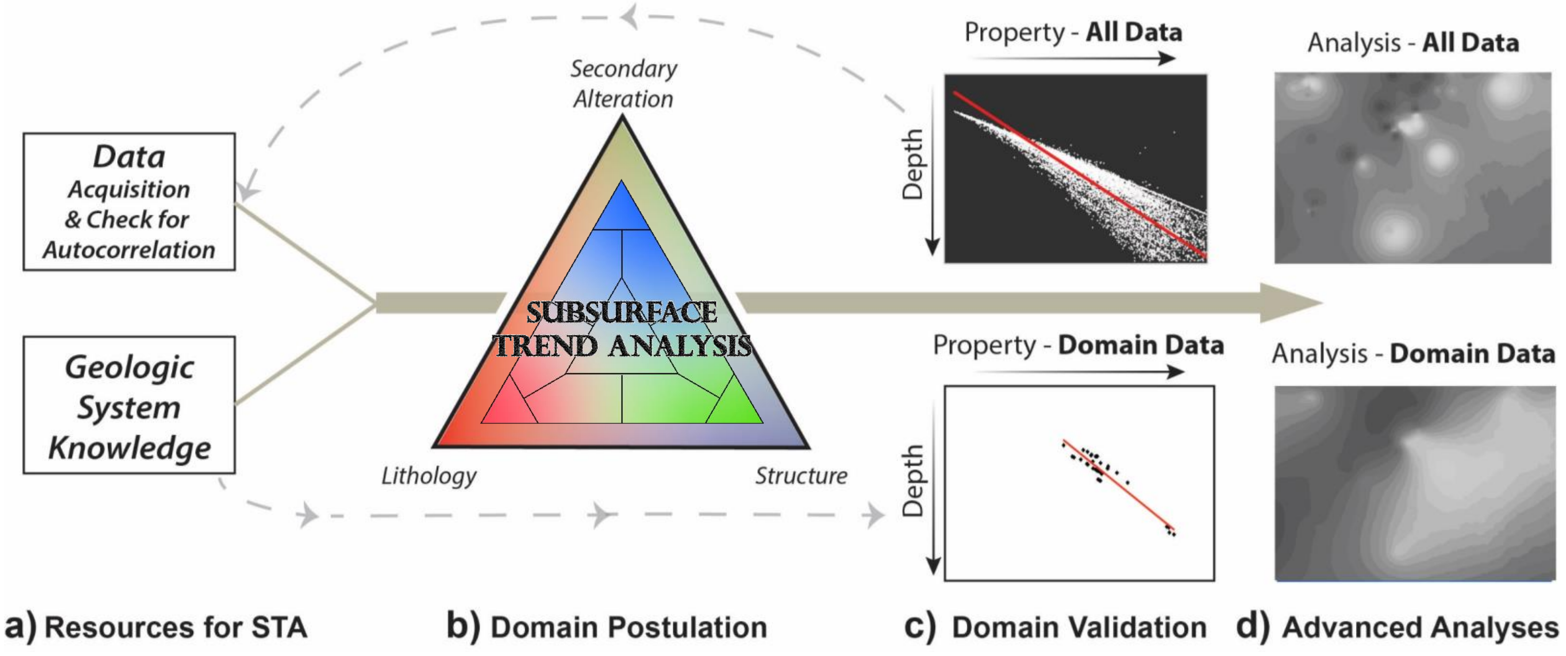
Regional



Subsurface Trend Analysis

An AI/ML-informed methodical framework to predict subsurface properties and the geologic environment

Subsurface property	Scale (finer→ coarser)
Reservoir thickness	Reservoir, field, region, basin
Lithologic composition	Reservoir, field, region, basin
Porosity	Well, reservoir, field, region, basin
Reservoir pressure	Reservoir, field
In situ pressure	Well, reservoir, field, region, basin
Reservoir temperature	Reservoir, field
In situ temperature	Well, reservoir, field, region, basin
Permeability	Reservoir, field, region, basin
Natural fractures	Reservoir, field
Secondary alteration (e.g., diagenesis, mineralization)	Reservoir, field, region, basin
Structural complexity	Reservoir, field, region, basin



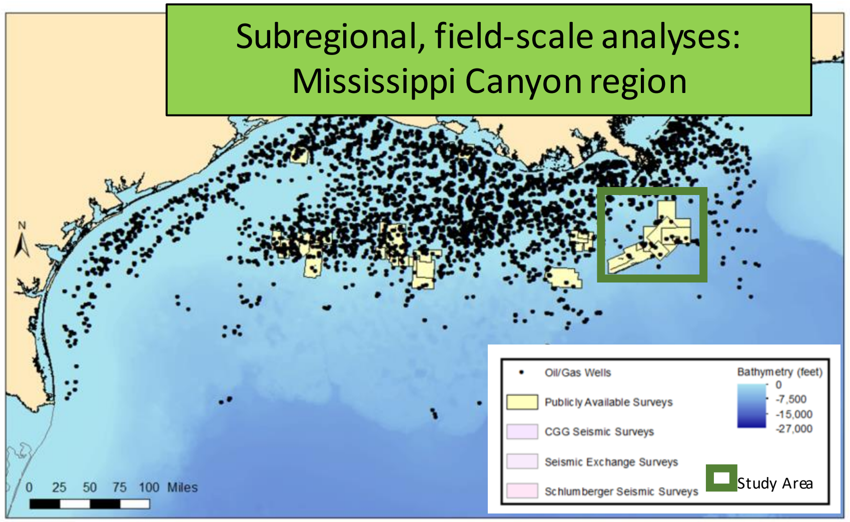
Initial method published: Rose, K., Bauer, J.R., and Mark-Moser, M. **(2020)** Subsurface trend analysis, a multi-variate geospatial approach for subsurface evaluation and uncertainty reduction, Interpretation

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

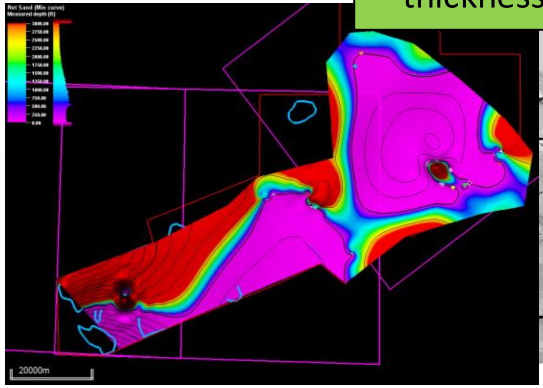
Seafloor & subsurface characterization for STA geohazard analysis and reservoir property prediction

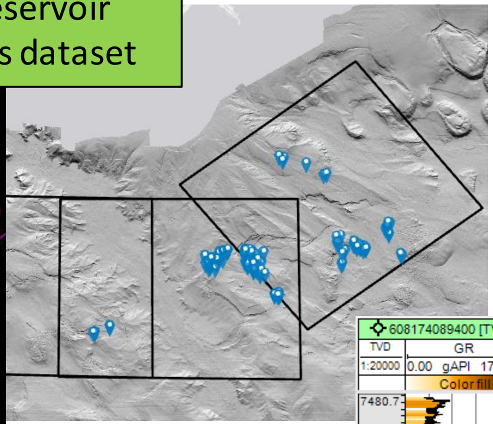
- **Identifying subsurface characteristics through seafloor feature mapping coupled with seismic interpretation**
- **Generating new subsurface property data for offshore petroleum systems**

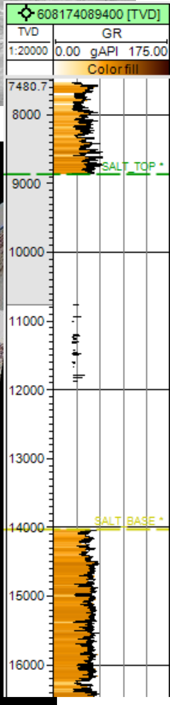
Subregional, field-scale analyses: Mississippi Canyon region

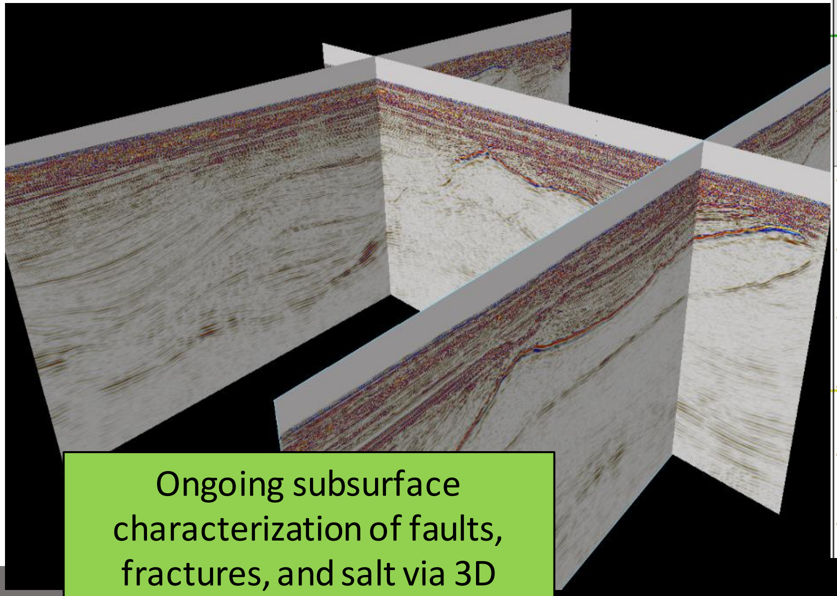


New reservoir thickness dataset

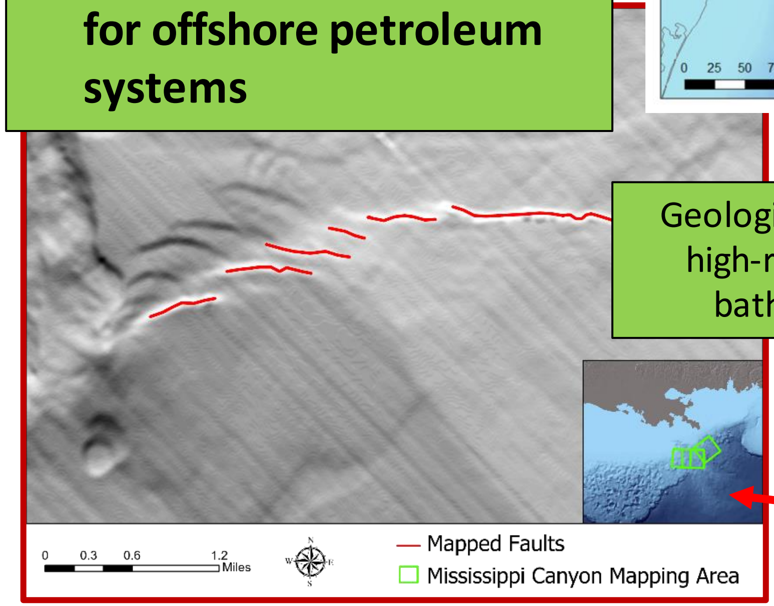


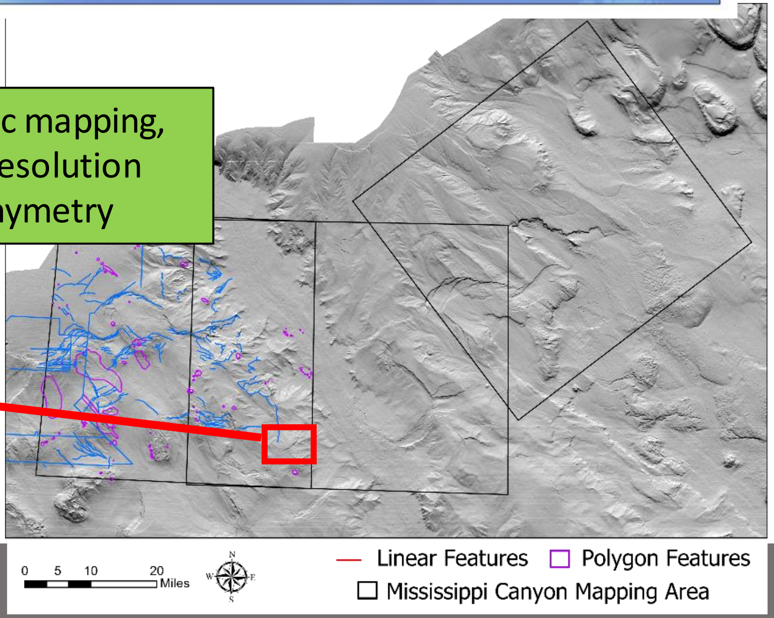






Geologic mapping, high-resolution bathymetry





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

STA Tool: Present & Future 2D Work

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

Organize and visualize disparate big data and knowledge resources

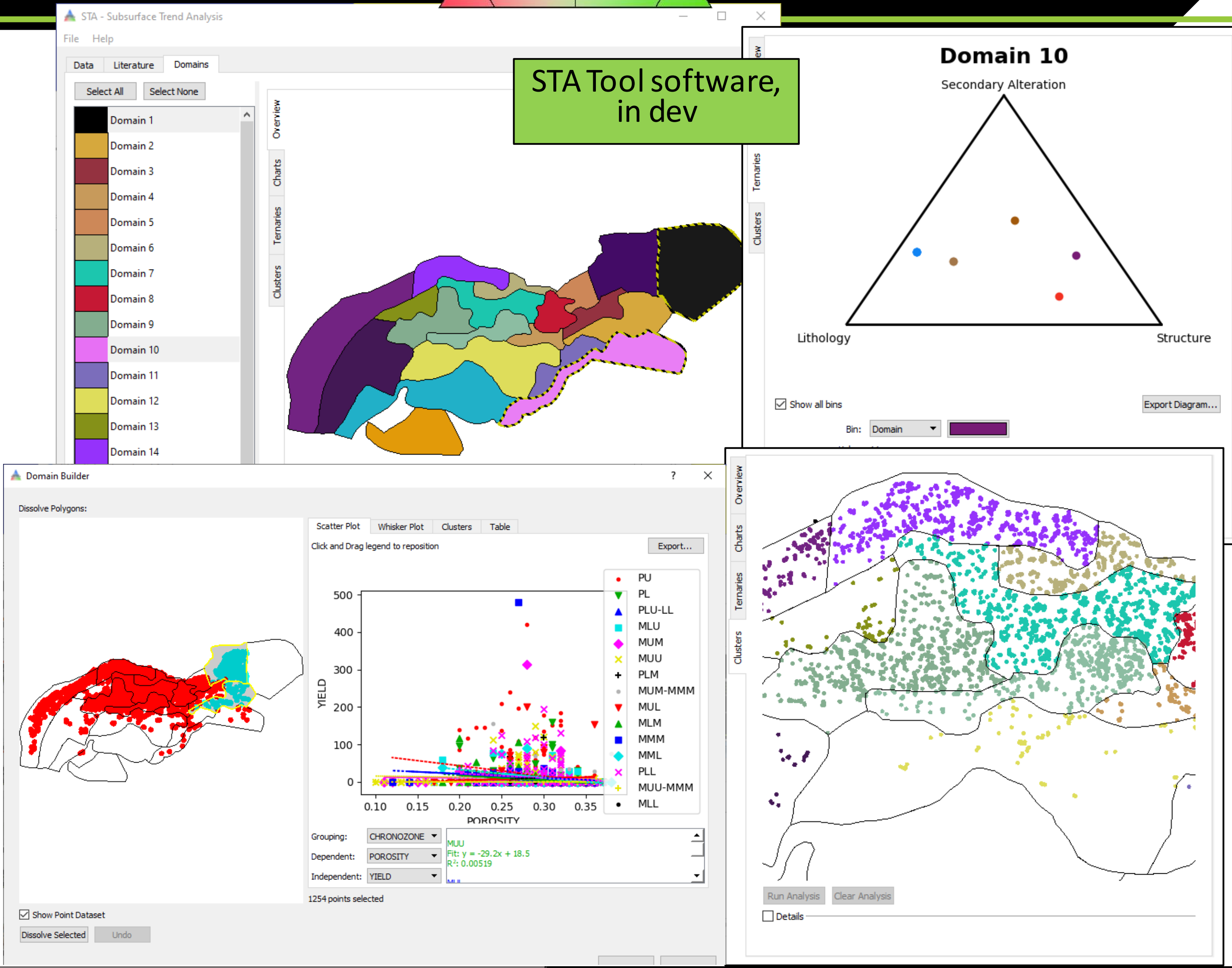
Simplify and automate geologic domain formation

Provide and execute multi-dimensional statistical analyses and validation

Utilize ML to characterize property trends and predictions

Current Development Efforts

- Advanced property dataset analysis including reservoir thickness and fractures
- Additional Integration of ML/NLP
  - Suggestions of relevant literature (NLP)
  - Identifying and suggesting domains to researcher (supervised ML)
- Ability to ingest real-time data
  - Predict reservoir properties during in-field operations



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

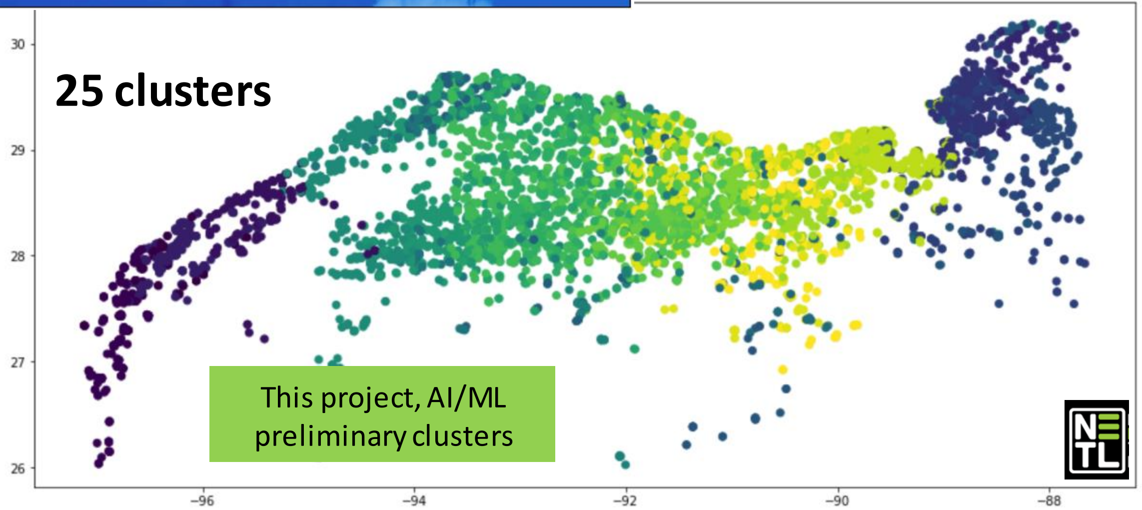
Standard analysis generated 21 geologic domains

High dimensional analysis reveals 25 clusters

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

Previously published STA domains

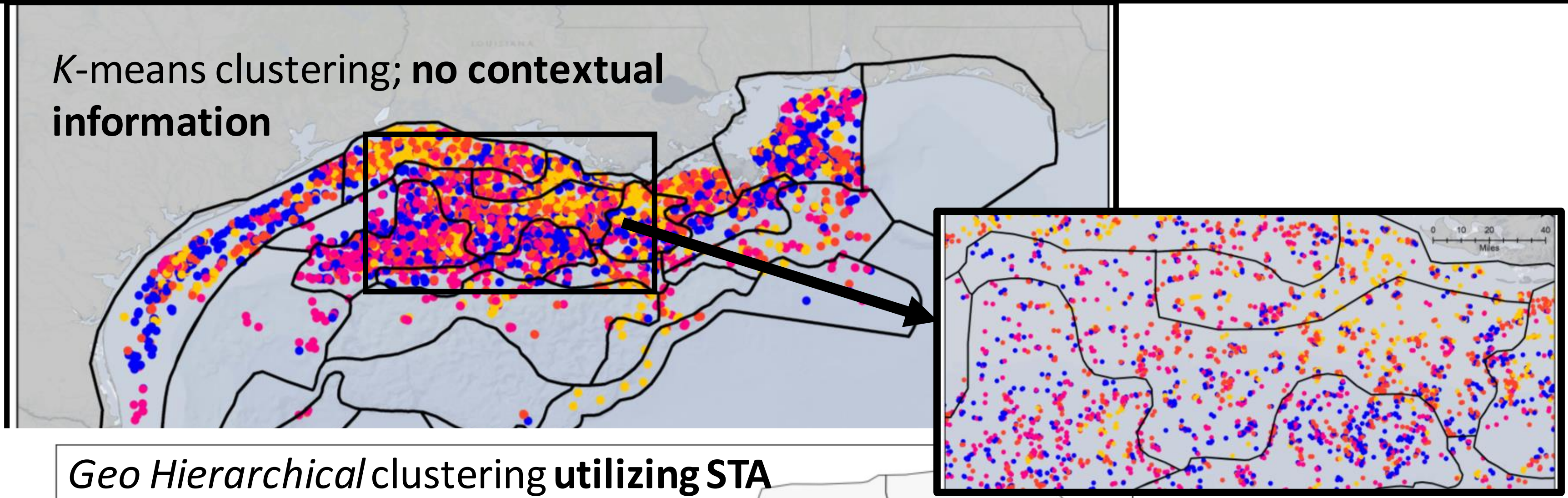
Rose et al., 2020, Mark-Moser et al., 2018



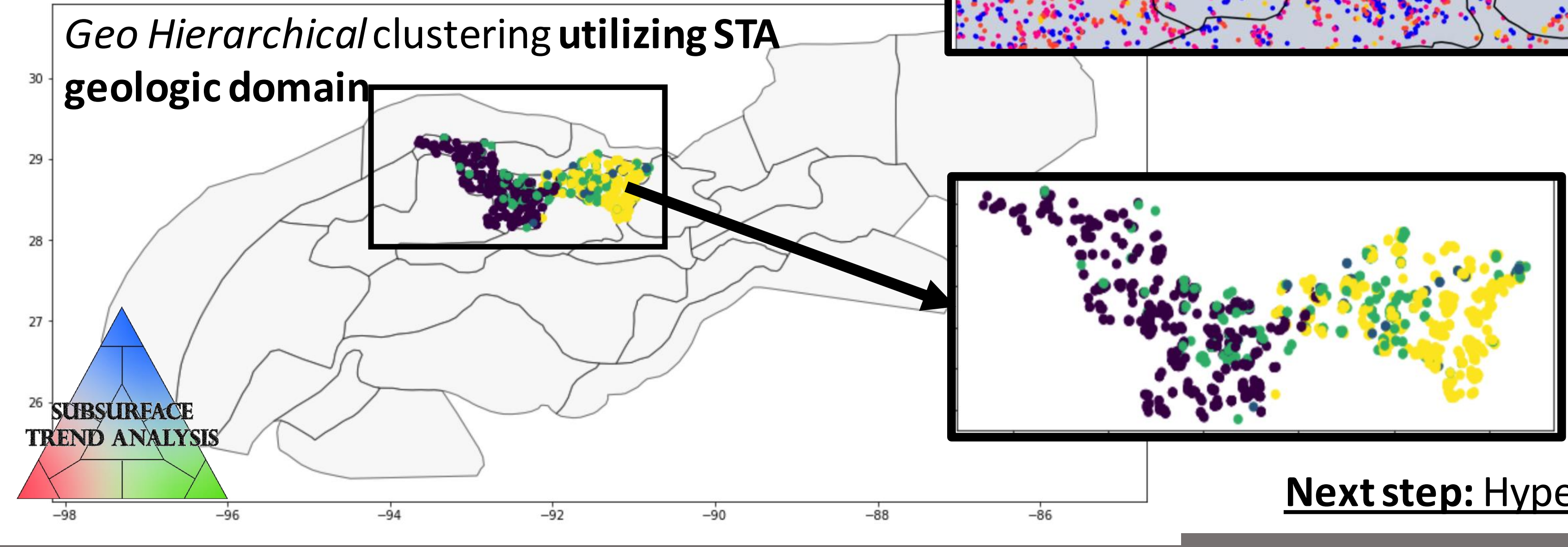
References: Hartigan & Wong, 1979; Hotelling et al., 1933; van der Maarten & Hinton, 2008; Ester et al., 1996; McInnes et al., 2018, Edelsbrunner et al., 2002

Domain Validation & Universal Clustering Analysis

Gulf of Mexico application



- 4 clusters
- Poor continuity among clusters
- Cohesion score = ~10

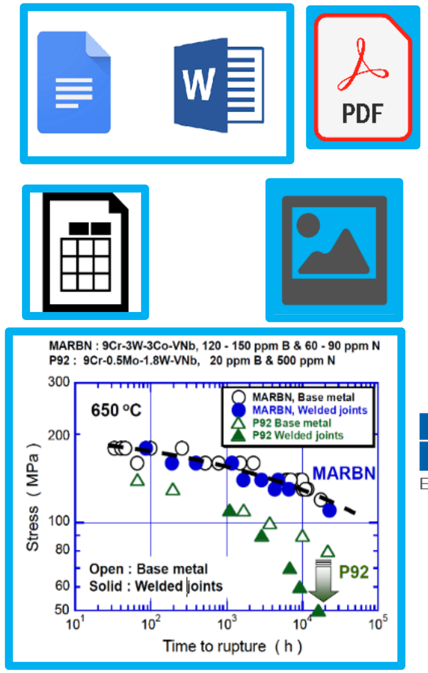


- 3 clusters
- Improved continuity among clusters
- Cohesion score: ~3

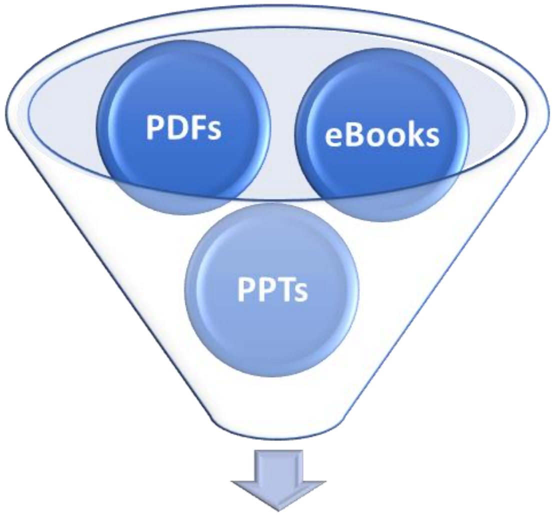
<u>**Next step:** Hyper-parameter tuning with variogram</u>

Natural Language Processing for unstructured data

Extracting knowledge



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



Structured digital data

Latent Dirichlet Allocation topic model

Jaccard similarity-based categorization

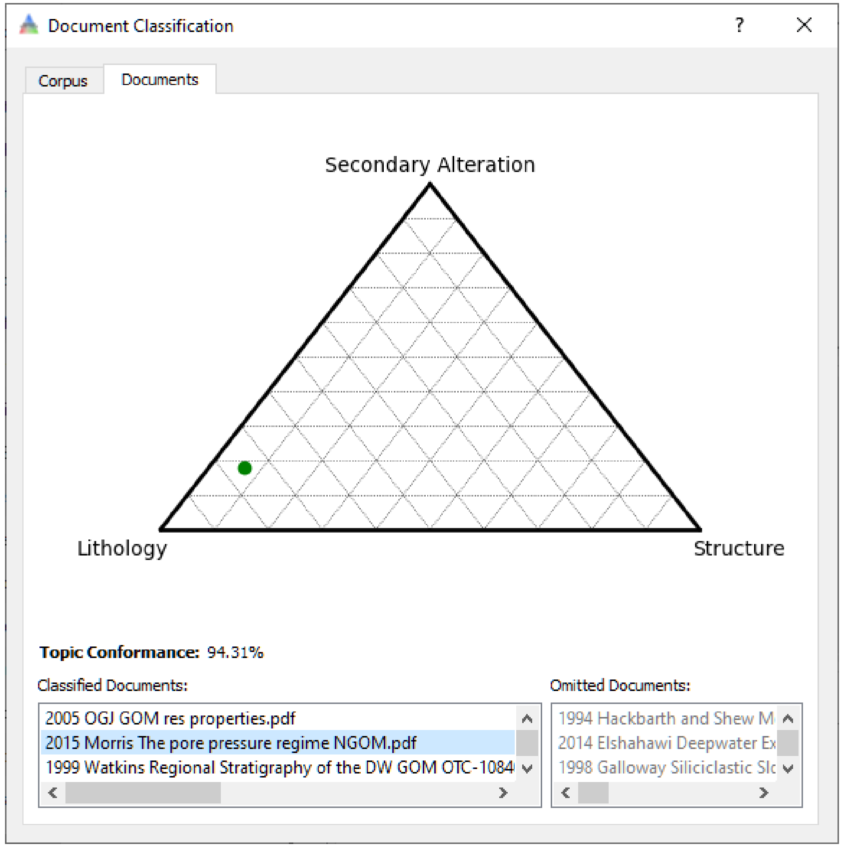
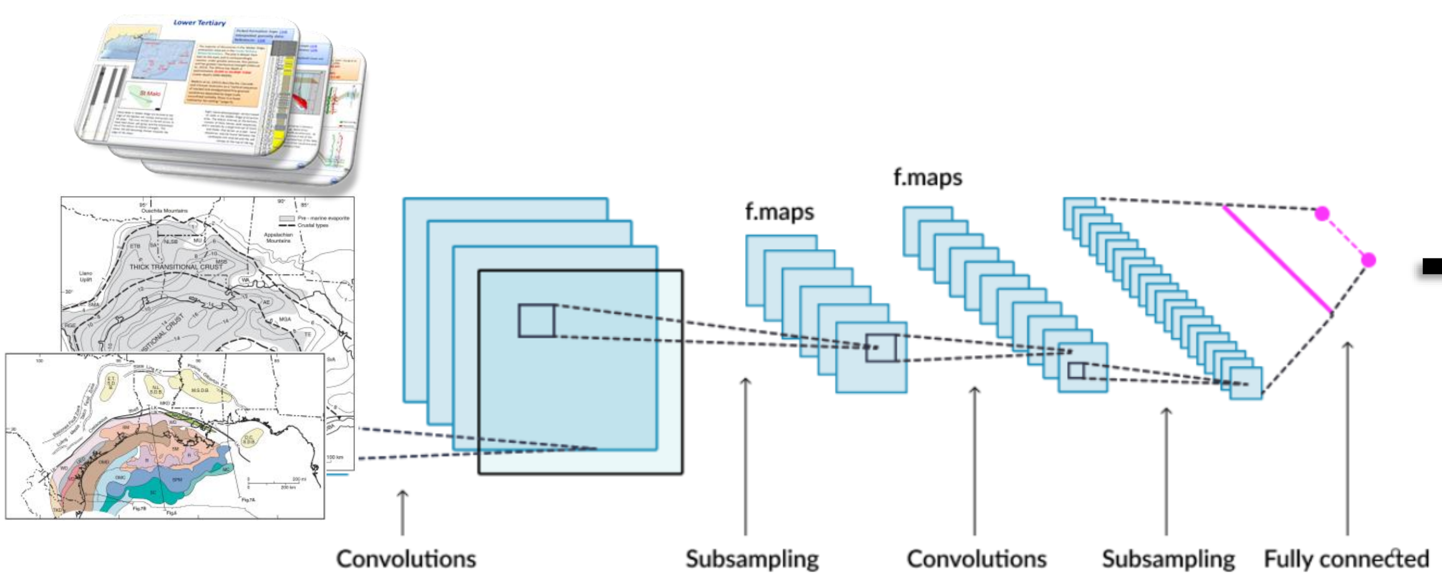
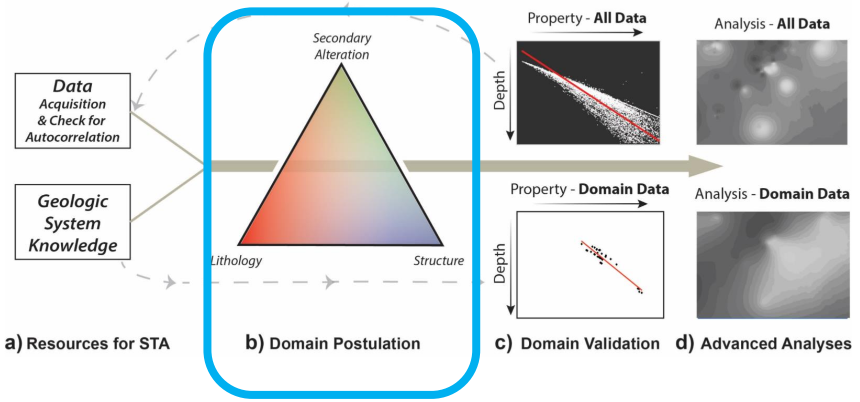


Fig. Document topic classified in three desired categories

NLP & computer vision for image extraction

Extracting knowledge





Training convolutional neural network for image identification of spatial geologic information: geologic maps, provinces

Natural language processing to identify content from figure captions

CNN image embedding

AI identification of geologic knowledge for enhanced and comprehensive analysis

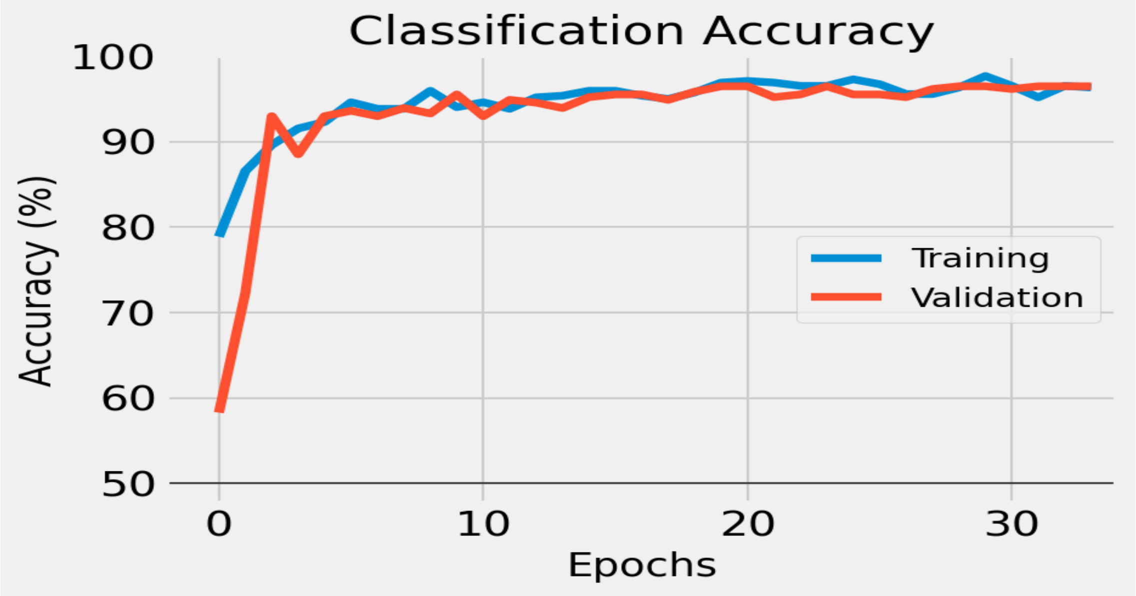
Feature objective: Develop a model that allows user to feed unstructured data and search for an item of interest, e.g. geologic map, and returns all relevant images back to the user– saving hours of work and reducing error.

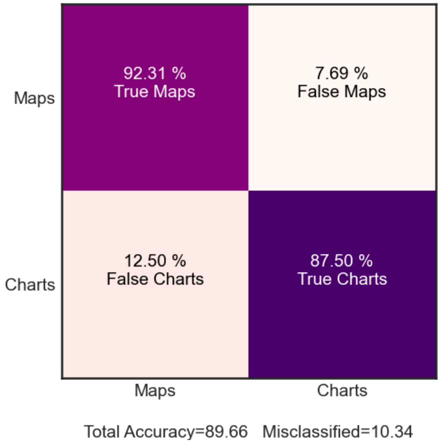
Transfer learning using VGGNet, trained on thousands of images

500 testing images and 200 validation images

Total accuracy: 89.6%

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

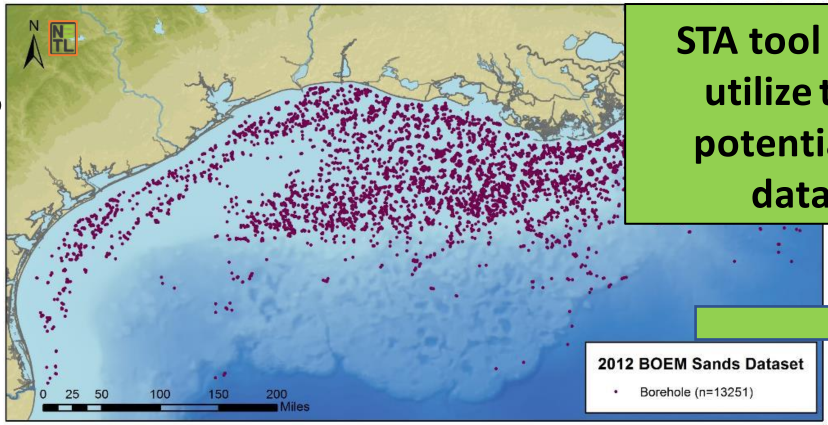




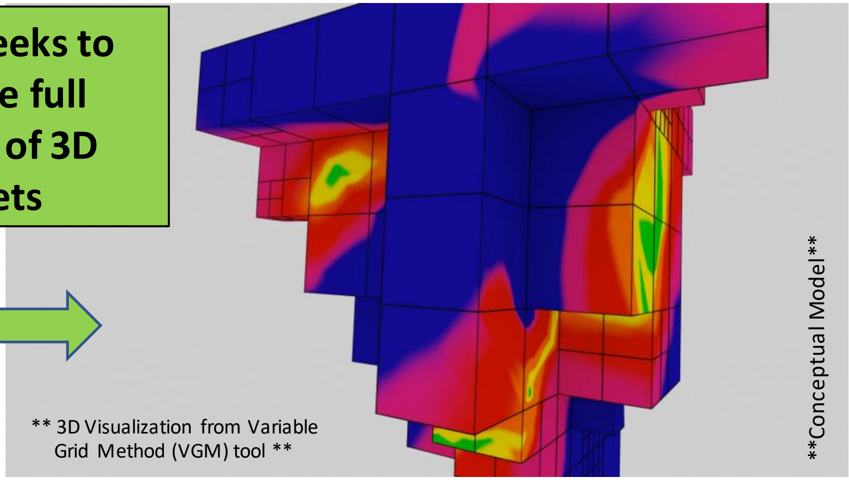
Next steps:
3D, 4D enhancements for real-time prediction

The STA methodology is being extended into 3D data analysis

- The structures being analyzed are 3D in nature, which has influence on characteristics critical to resource operations
- More detailed data → better predictions
- Use of fuzzy logic tool in combination

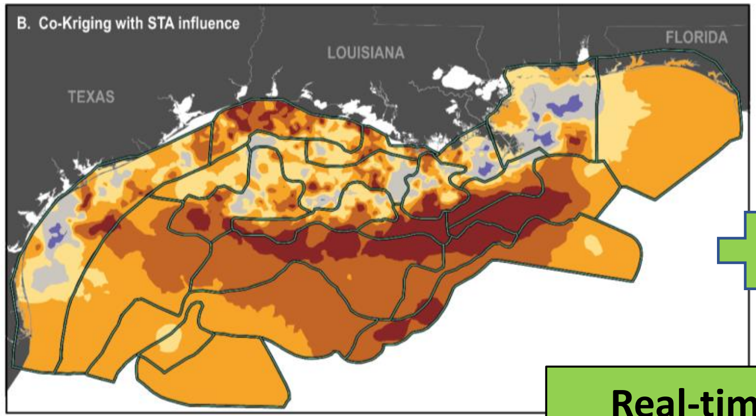


STA tool seeks to utilize the full potential of 3D datasets

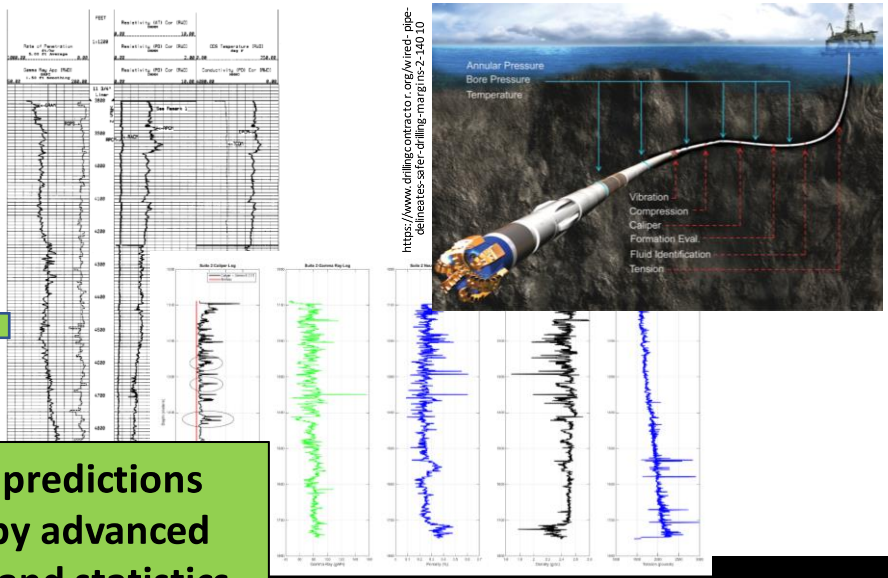


STA Tool will provide utilities to better understand data

- Custom 3D visualizations to gain perspective on data & subsurface predictions
- Integrating geologic systems knowledge and real-time data (e.g. LWD) to improve instantaneous predictions



+



https://www.drillingcontractor.org/wired-pipe-delineates-safer-drilling-margins-2-14010

Real-time predictions informed by advanced knowledge and statistics

SUBSURFACE TREND ANALYSIS

Publications & Presentations
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 - Improving Offshore Hydrocarbon Exploration with an Artificial Intelligence Framework. **In preparation**.

Upcoming Presentations

Mark-Moser, M., Suhag, A., Rose, K., Wingo, P. Invited talk, **accepted**. Optimizing prediction of reservoir properties with artificial intelligence, big data, and the Subsurface Trend Analysis method. Machine Learning for Oil and Gas 2020, Nov. 9-11, Virtual.

Mark-Moser, M., Romeo, L., Rose, K., Wingo, P., Duran, R. **submitted**. Assessment of natural and engineered systems data using machine learning to reduce offshore operational risks. Offshore Technology Conference, 2021. Houston, TX.

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*

- 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

2019 R&D 100 WINNER

Datasets

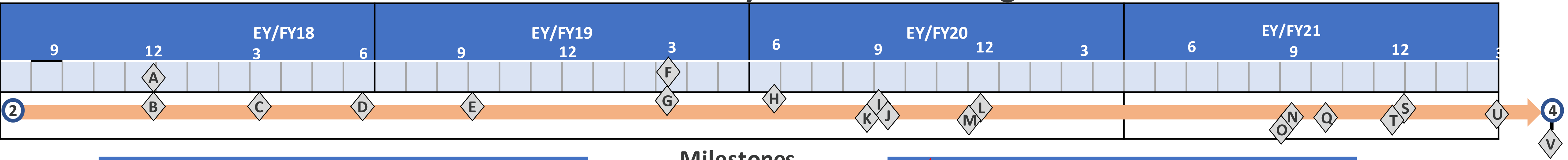
- Mark-Moser, M. Subsurface Trend Analysis domains for the northern Gulf of Mexico, 3/25/2020, https://edx.netl.doe.gov/dataset/subsurface-trend-analysis-domains-for-the-northern-gulf-of-mexico, DOI: 10.18141/1606228

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

Offshore Unconventional FWP

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

Task 5: Geohazards & Subsurface Uncertainty Smart Modeling



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. Realtime 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

Key Takeaways

SUBSURFACE TREND ANALYSIS

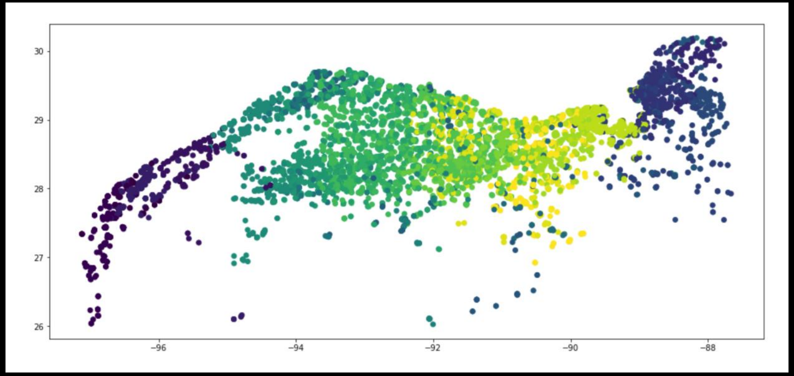
MacKenzie.Mark-Moser@netl.doe.gov
Anuj.Suhag@netl.doe.gov
Kelly.Rose@netl.doe.gov

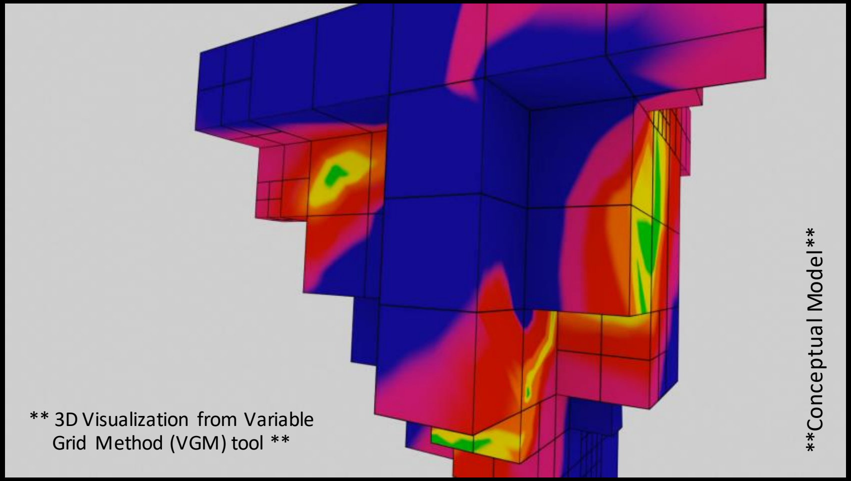
NATIONAL ENERGY TECHNOLOGY LABORATORY

•Assessment and prediction of offshore GOM subsurface properties key to assessing resource and geohazards

•Project will produce a **science-based, ML-NLP, 3D/4D tool for improved prediction** of **subsurface properties**

•Utilizing these predictions to assist in **efficient and successful reduction of pre-drill hazards and risks** associated with resource management, e.g., oil/gas extraction, EOR, or CO2 storage.





Values Delivered

- Development of a ML-NLP-STA tool that can be used at various scales, from the basin to wellbore, for subsurface exploration and real-time geohazard monitoring of sedimentary systems.

- Enhancement of the STA model into an ML-enhanced tool will improve efficiency, safety, optimize drilling operations to save costs, and improve resource predictions to improve access to domestic oil and gas resources.

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

U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY

Disclaimer & Acknowledgement

Acknowledgement: Parts of this technical effort were performed in support of the National Energy Technology Laboratory's ongoing research under the Offshore Unconventional Resources – DE FE-1022409 by NETL's Research and Innovation Center, including work performed by Leidos Research Support Team staff under the RSS contract 89243318CFE000003.