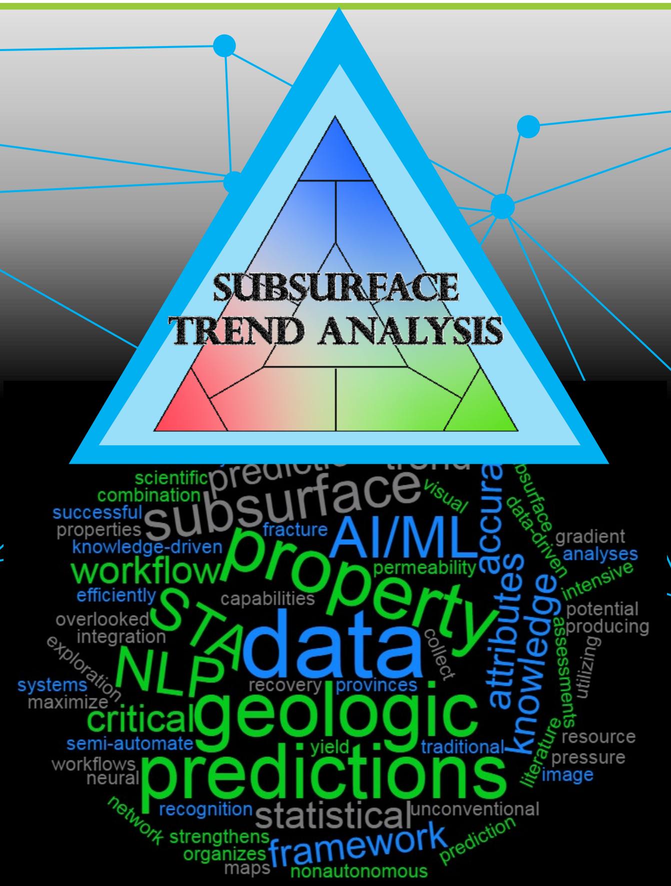
Geohazards and Subsurface Uncertainty Smart Modeling with the Subsurface Trend Analysis Tool

MacKenzie Mark-Moser, Co-PI
NETL Support Contractor



NETL Resource Sustainability Meeting
Oct. 27, 2022

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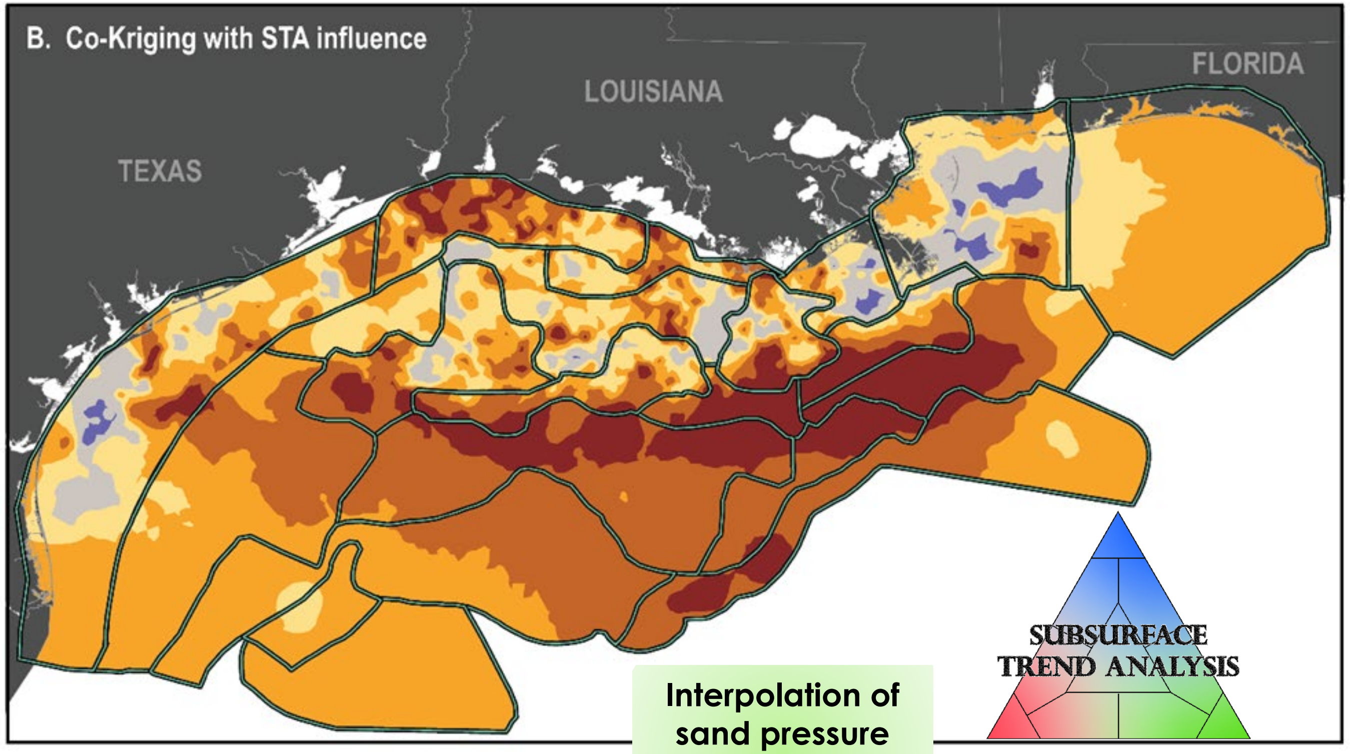
Geohazards and Subsurface Uncertainty Smart Modeling

Integrating Artificial Intelligence/Machine Learning (AI/ML) to Improve Prediction of Subsurface Conditions



Interpolation of sand pressure gradient in the Gulf of Mexico

Rose et al., 2020

Issue/R&D Need

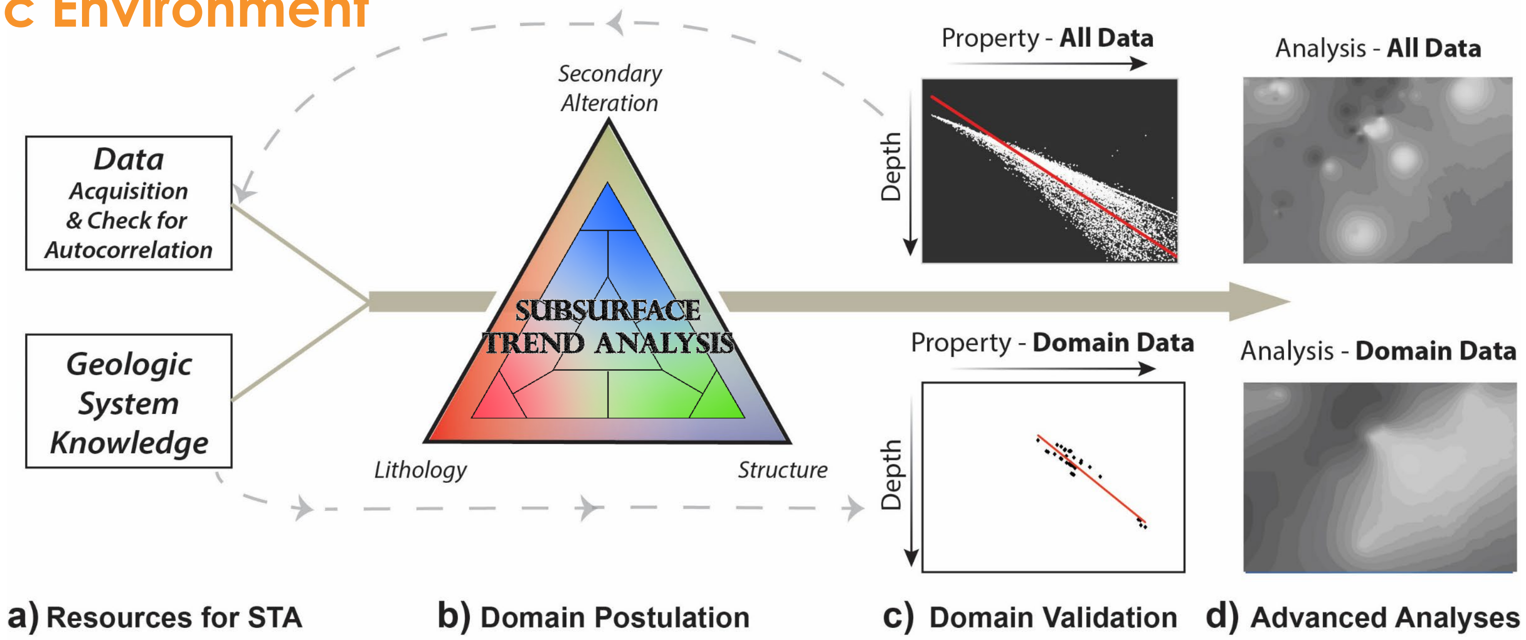
- Subsurface introduces hazards that are difficult to constrain and predict
- **Ongoing operations increase risk** in offshore regions
- There is **a need for rapid, accurate, and efficient tools that predict subsurface conditions**, even in areas with little to no data

Task Objectives

- Develop a 2D/3D, adaptive smart tool using the Subsurface Trend Analysis (STA) method framework
- Test and validate the STA smart tool in the offshore Gulf of Mexico (GOM)
- Release the tool for public use

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 to an AI/ML, 2D/3D adaptive Smart Tool: the STA Tool

Subsurface Trend Analysis Tool

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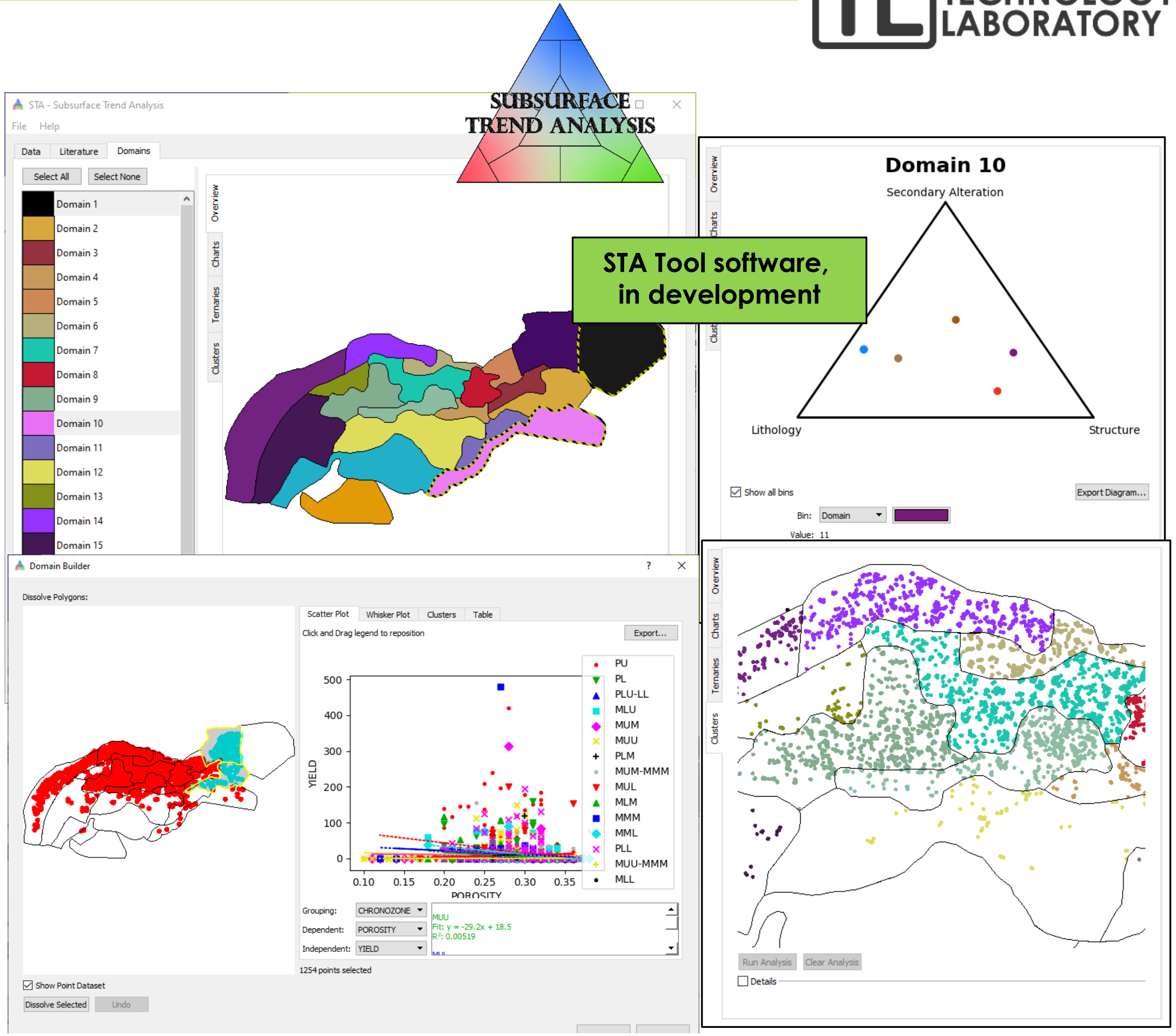
<u>STA Tool – a *virtual research assistant* designed to:</u>

- Organize and visualize disparate big data and knowledge resources
- Simplify and automate geologic domain formation
- Provide and execute statistical analyses and validation
- Utilize AI/ML to accelerate knowledge gathering and subsurface property analysis

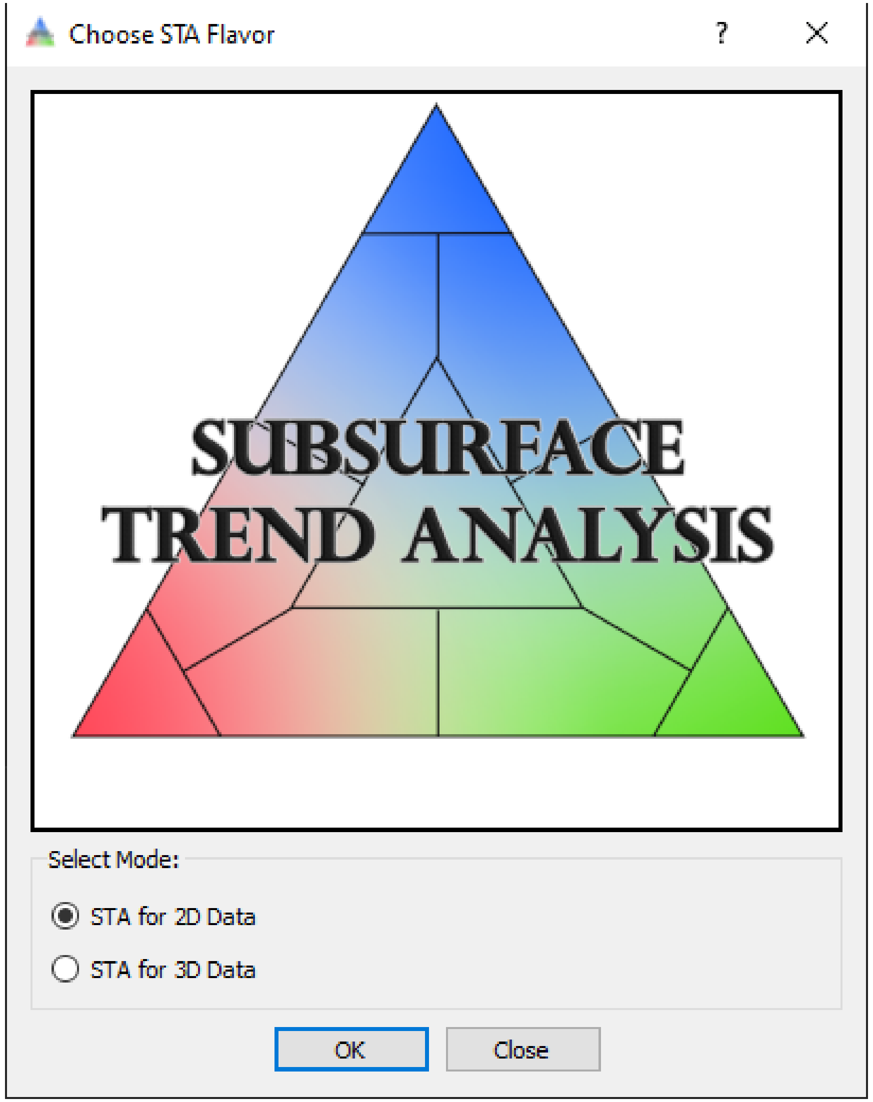


STA Tool Analytical Components

NATIONAL ENERGY TECHNOLOGY LABORATORY

2D STA Components

- Autocorrelation
- Literature management
  - Natural Language Processing (NLP)
  - CNN embedded image analysis
- Domain Builder – GIS file import, data and polygon viewer, analytical charts
  - Statistical charts
  - AI/ML statistical analyses
- Wireline analysis – ingests .las files to update data



3D STA Components (in dev)

- 3D Domain Builder
- 3D Interpolation
- Wireline analysis conversion to 3D in progress

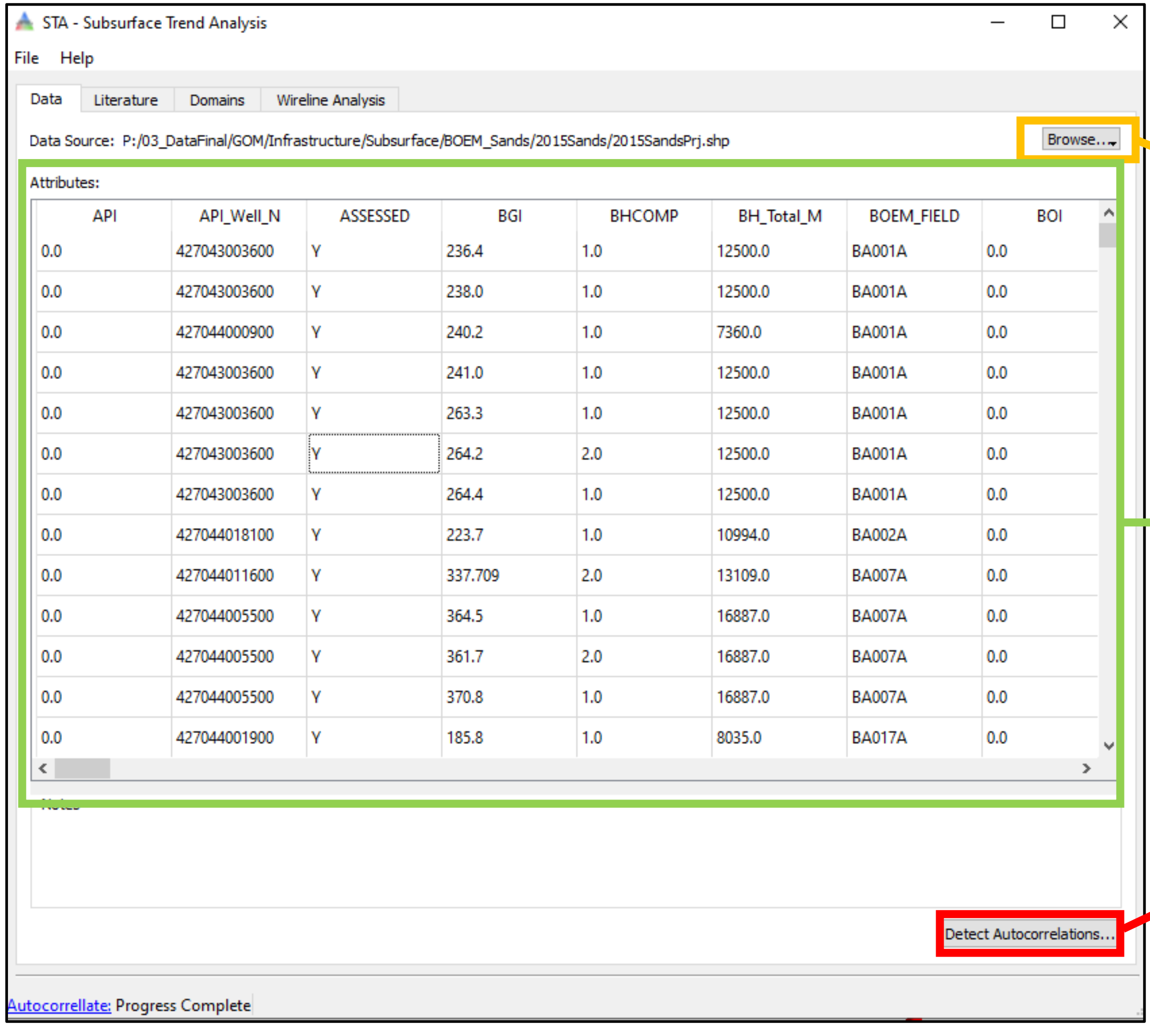
Download the 2D STA Tool

https://edx.netl.doe.gov/dataset/subsurface-trend-analysis-2d-tool

3D Tool to be released Dec. '22

Knowledge and Data Management in the STA Tool

Spatial Data upload and autocorrelation check

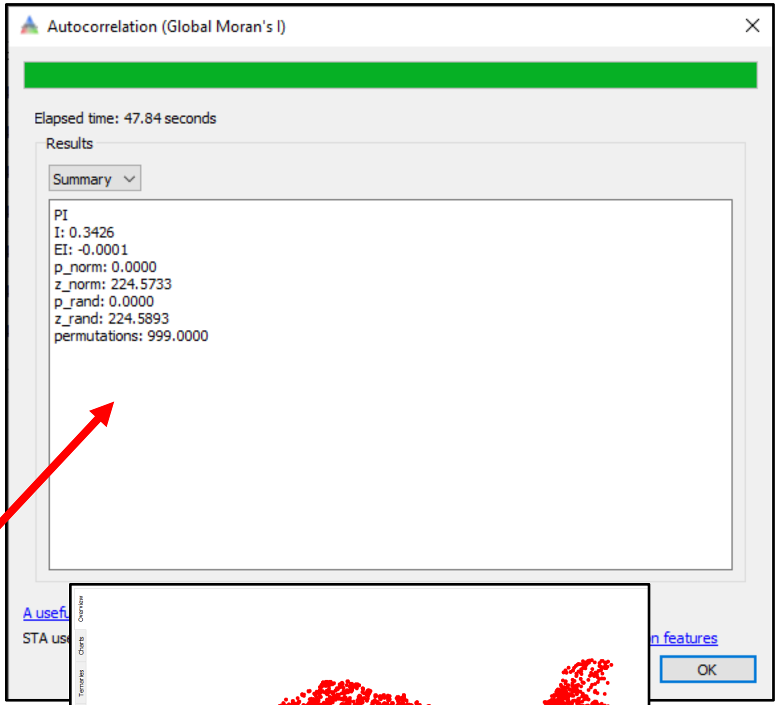


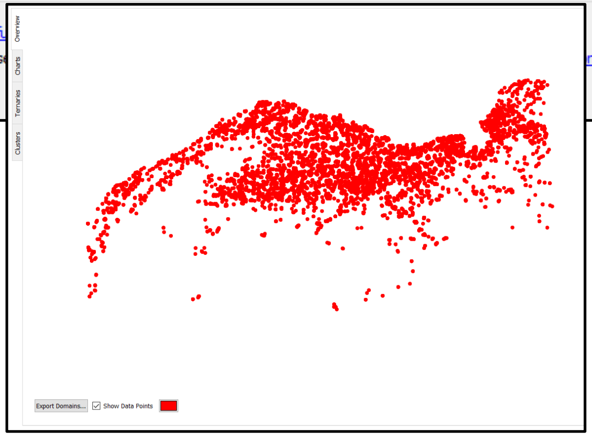
API	API_Well_N	ASSESSED	BGI	BHCOMP	BH_Total_M	BOEM_FIELD	BOI
0.0	427043003600	Y	236.4	1.0	12500.0	BA001A	0.0
0.0	427043003600	Y	238.0	1.0	12500.0	BA001A	0.0
0.0	427044000900	Y	240.2	1.0	7360.0	BA001A	0.0
0.0	427043003600	Y	241.0	1.0	12500.0	BA001A	0.0
0.0	427043003600	Y	263.3	1.0	12500.0	BA001A	0.0
0.0	427043003600	Y	264.2	2.0	12500.0	BA001A	0.0
0.0	427043003600	Y	264.4	1.0	12500.0	BA001A	0.0
0.0	427044018100	Y	223.7	1.0	10994.0	BA002A	0.0
0.0	427044011600	Y	337.709	2.0	13109.0	BA007A	0.0
0.0	427044005500	Y	364.5	1.0	16887.0	BA007A	0.0
0.0	427044005500	Y	361.7	2.0	16887.0	BA007A	0.0
0.0	427044005500	Y	370.8	1.0	16887.0	BA007A	0.0
0.0	427044001900	Y	185.8	1.0	8035.0	BA017A	0.0

User upload of point dataset

Data attribute viewer

Autocorrelation detection





Natural Language Processing for Unstructured Data

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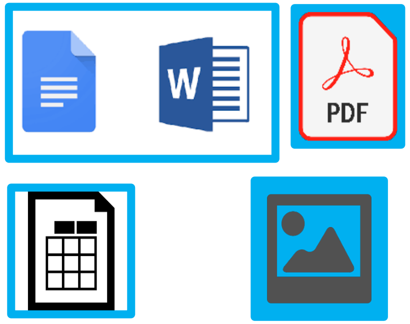
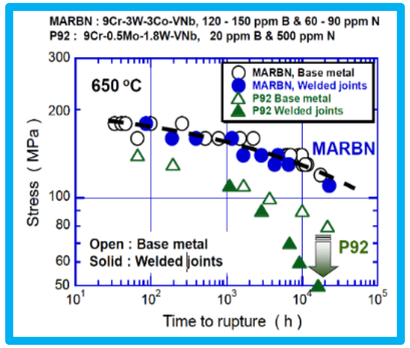
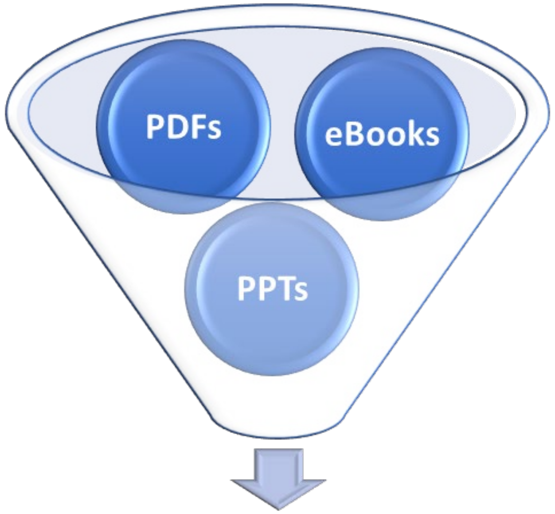
Extracting Knowledge

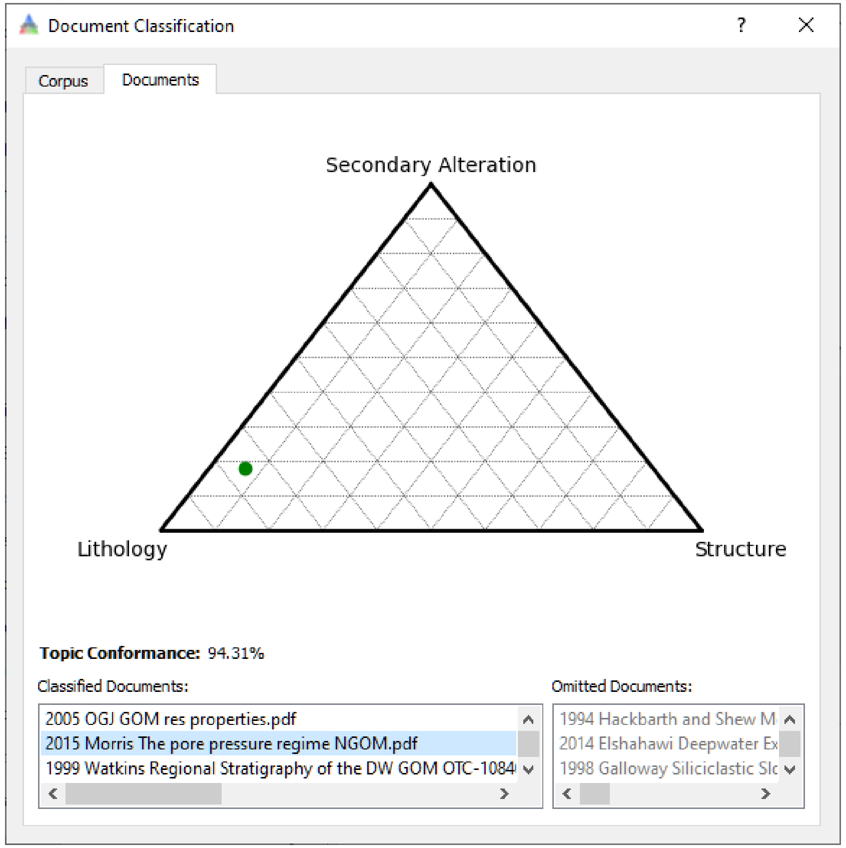




EDX™ Energy Data eXchange



Structured digital data

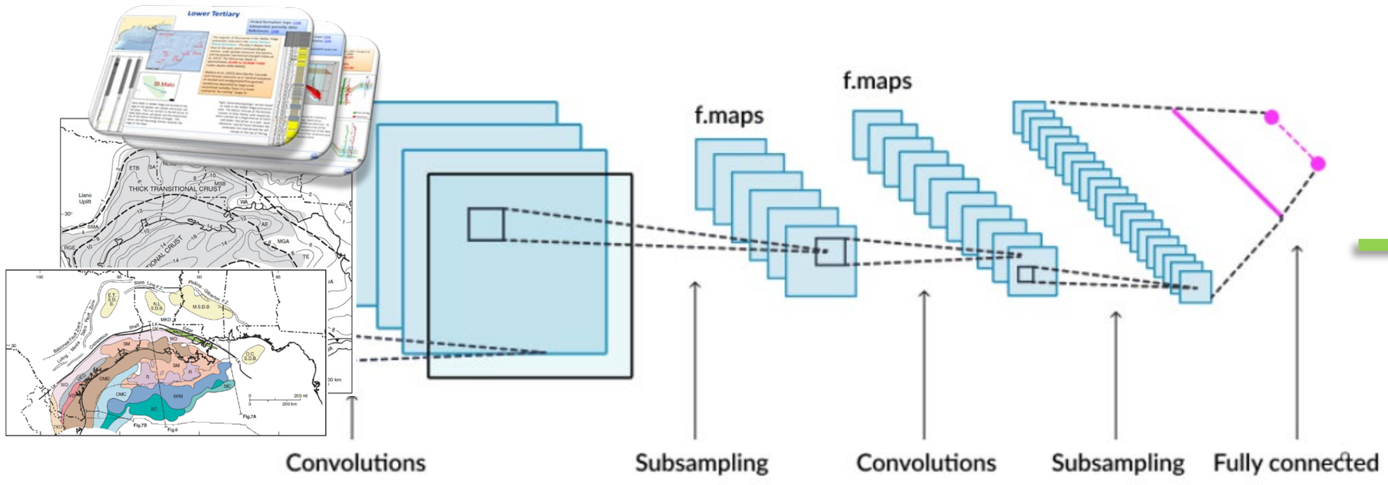


Mining data from documents, R&D products, presentations, etc., using NLP

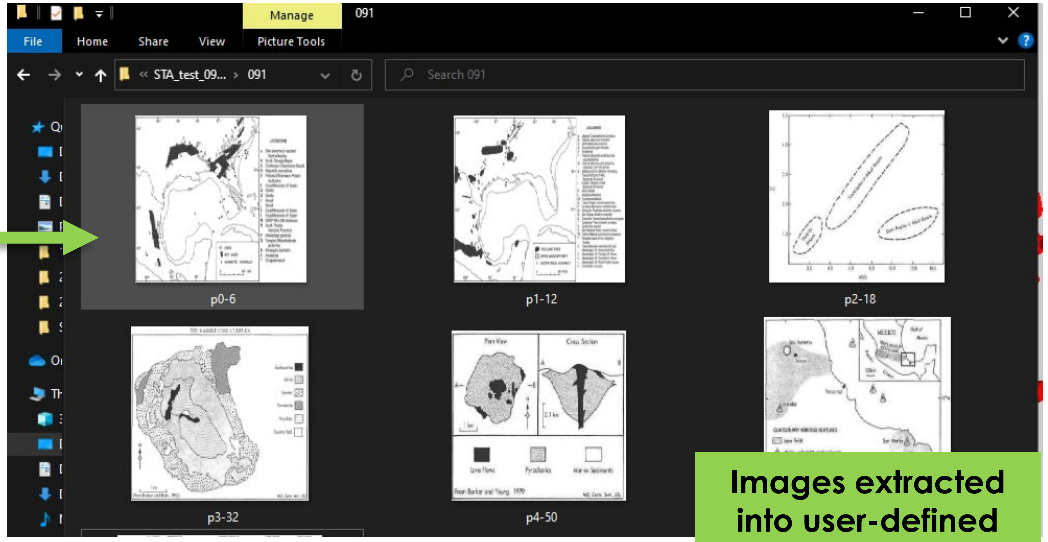
Latent Dirichlet Allocation topic model
Jaccard similarity-based categorization

Computer Vision for Image Extraction

Extracting Knowledge



Source: MissingLink.ai



Images extracted into user-defined folder

- User feeds unstructured data to Convolutional Neural Network model that returns all relevant images, **saving hours of work and reducing error**
- Transfer learning via VGGNet, tested on >1300+ images
- Multiclass image identification accuracy ~77%

Breadth of Statistical Analytics in STA Tool

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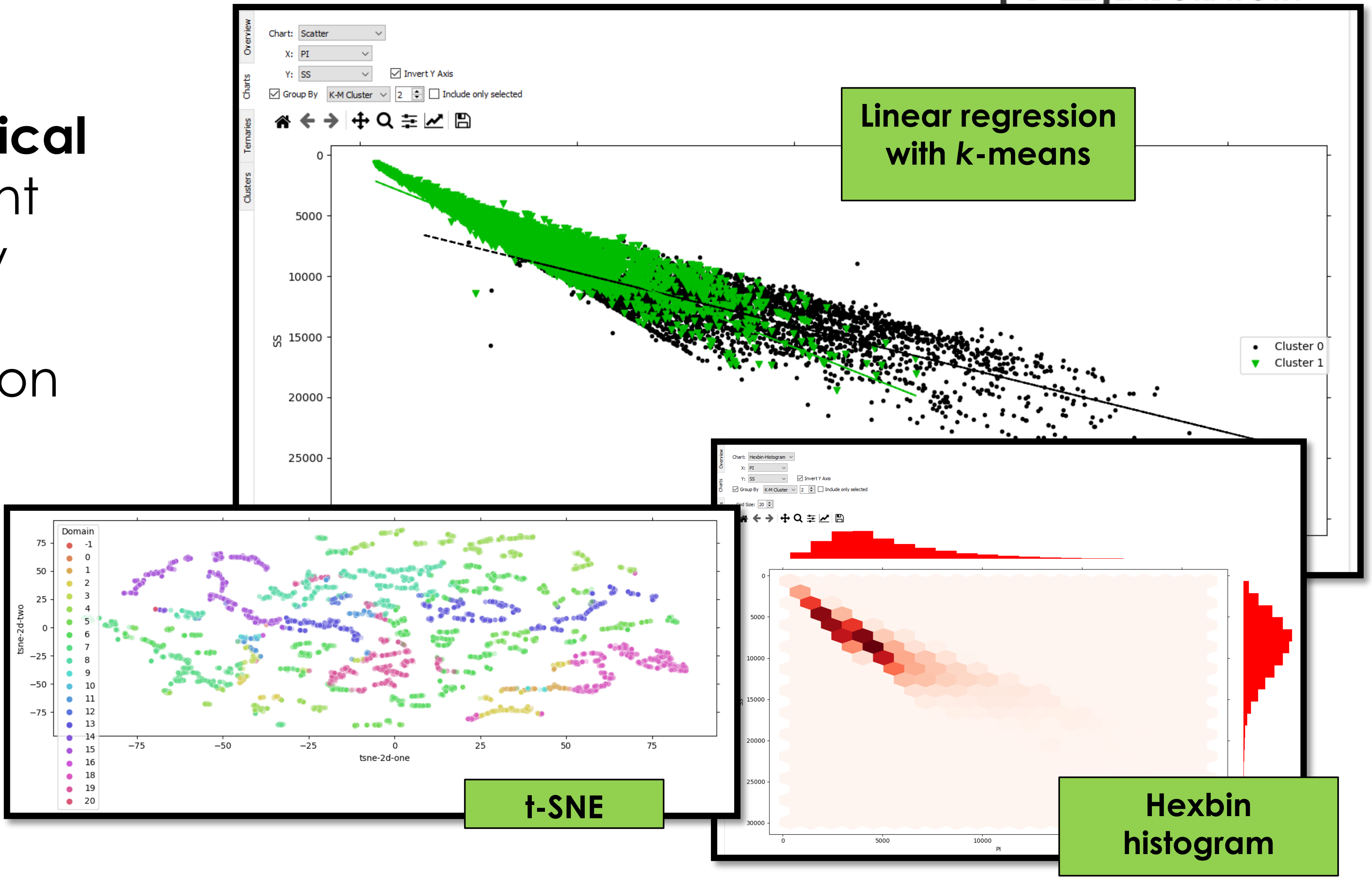
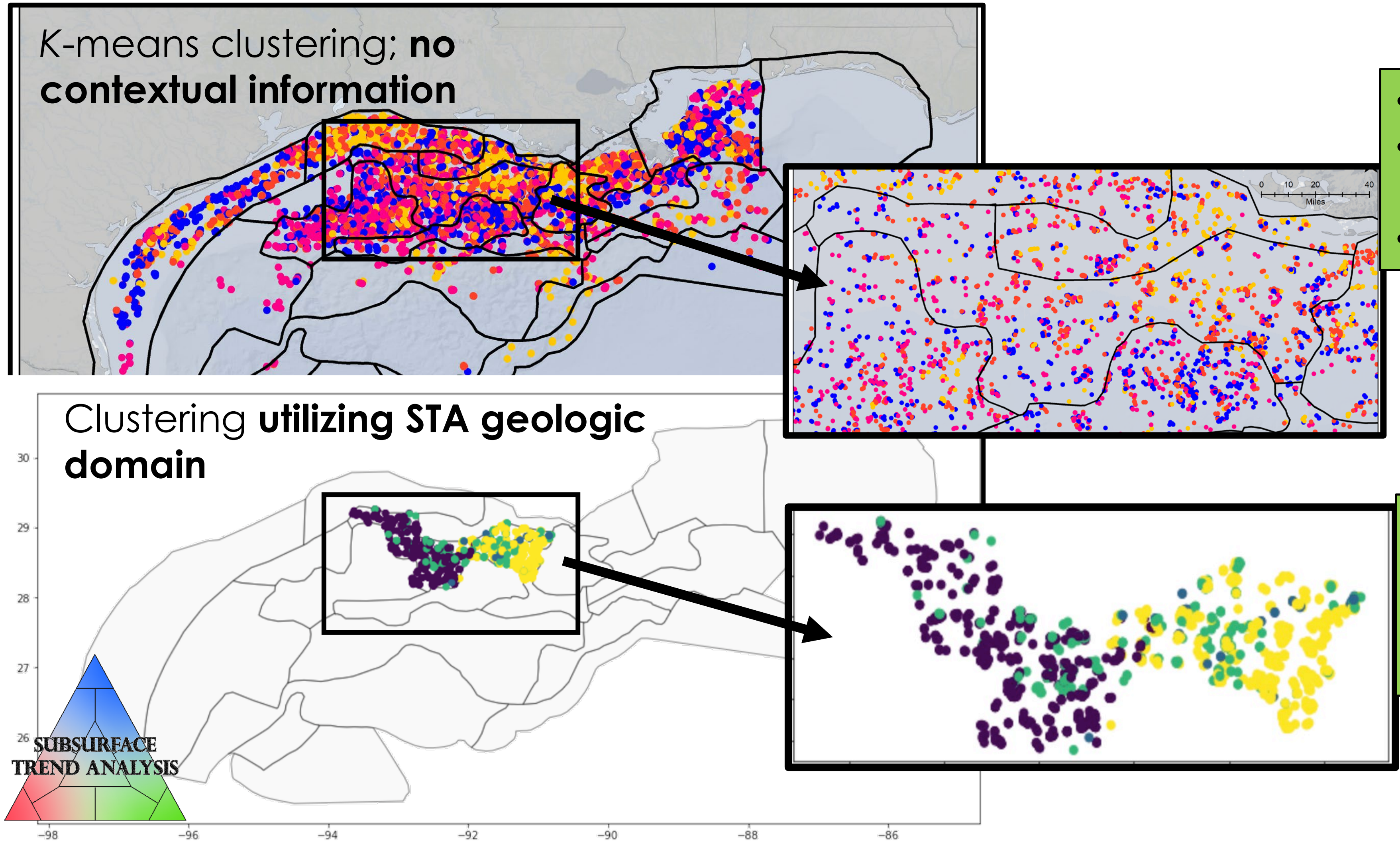
STA Tool provides both classic and AI/ML statistical analyses for broad insight into subsurface property data:

- Scatter (linear regression included)
- Box-and-whisker
- Hexbin-histogram
- DBSCAN
- t-SNE
- *k*-means



Domain Validation and Clustering Analysis

Gulf of Mexico application using reservoir properties



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

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

3D Enhancements and Adaptive Prediction

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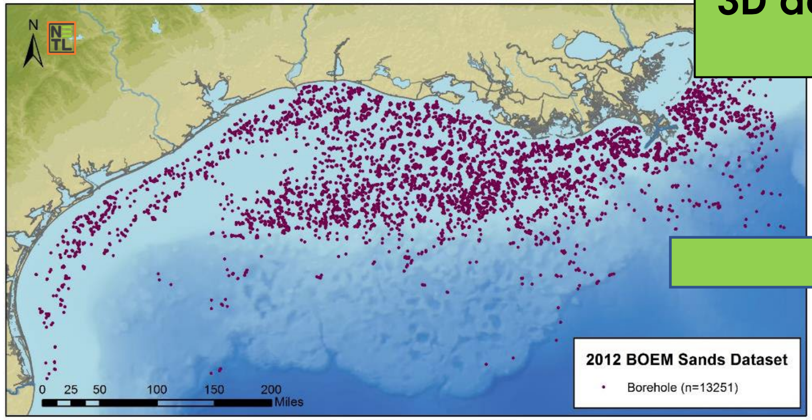
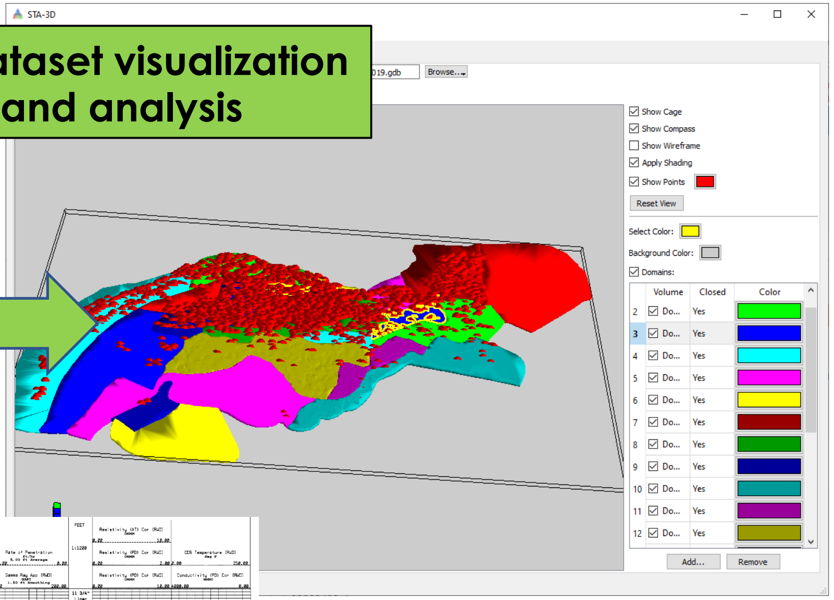
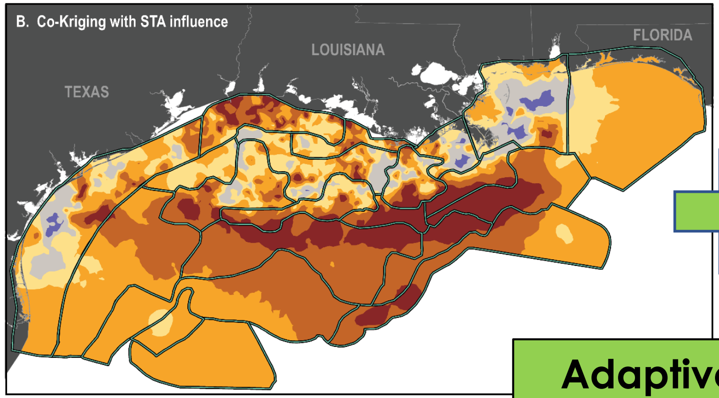
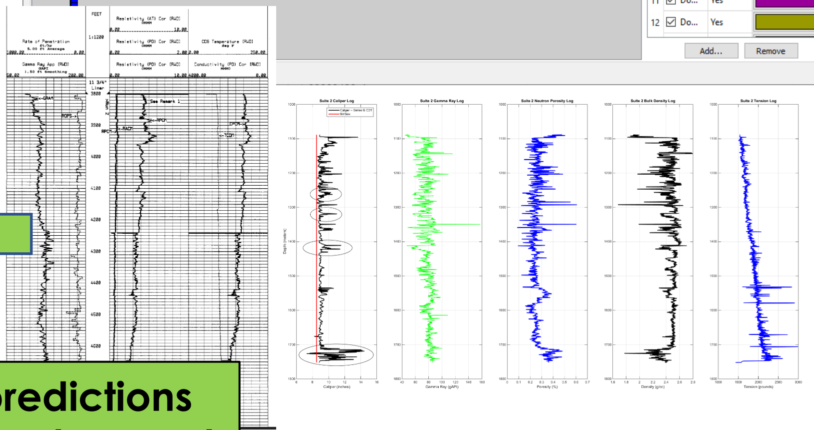
- 3D visualizations to gain perspective on data and subsurface predictions
- Integrating geologic knowledge and new field data to update prediction of subsurface conditions



3D dataset visualization and analysis







Adaptive predictions informed by advanced knowledge and statistics

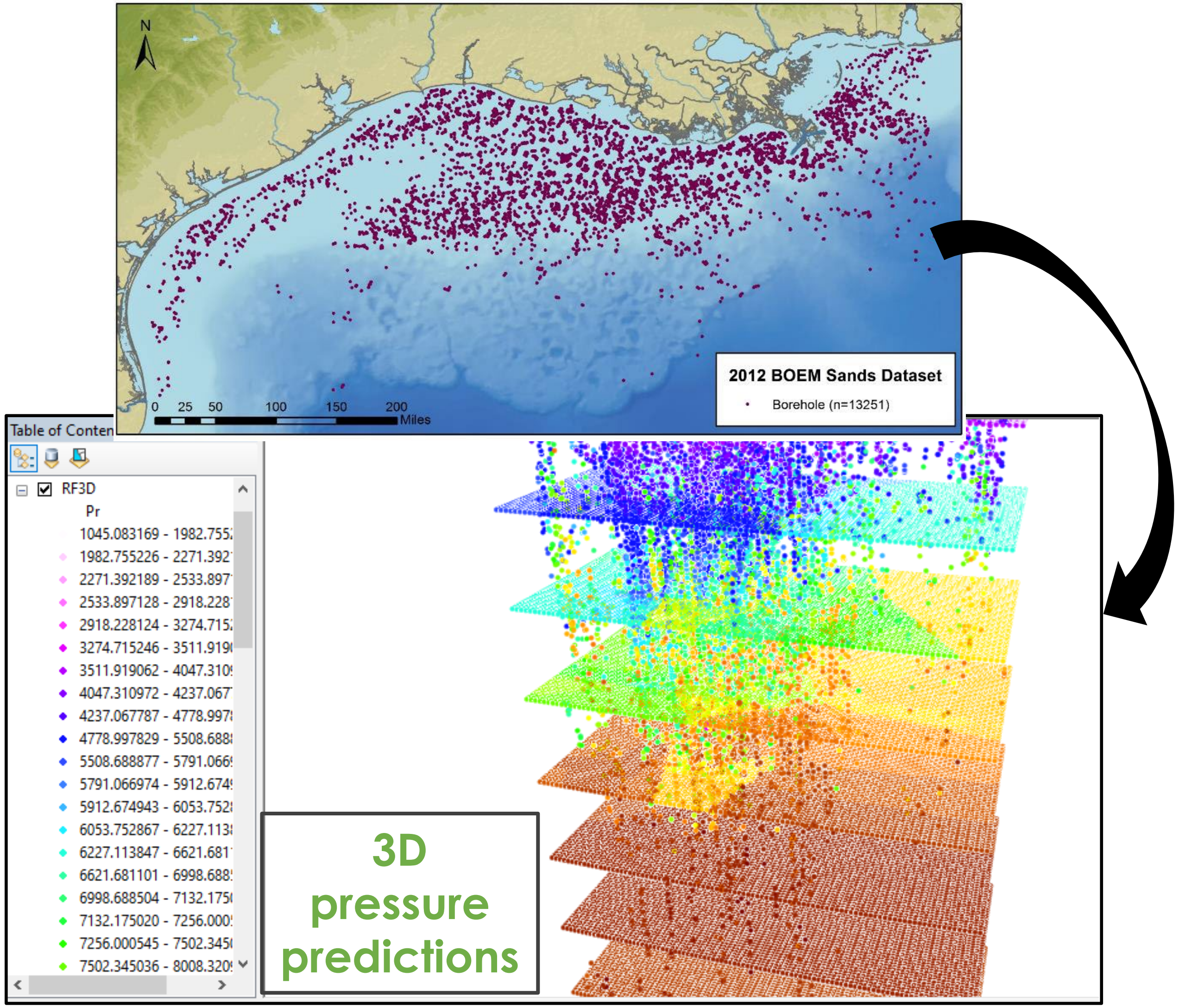
Expanding Property Prediction to 3D

- 3D interpolations of property predictions can constrain subsurface conditions and forecast hazards

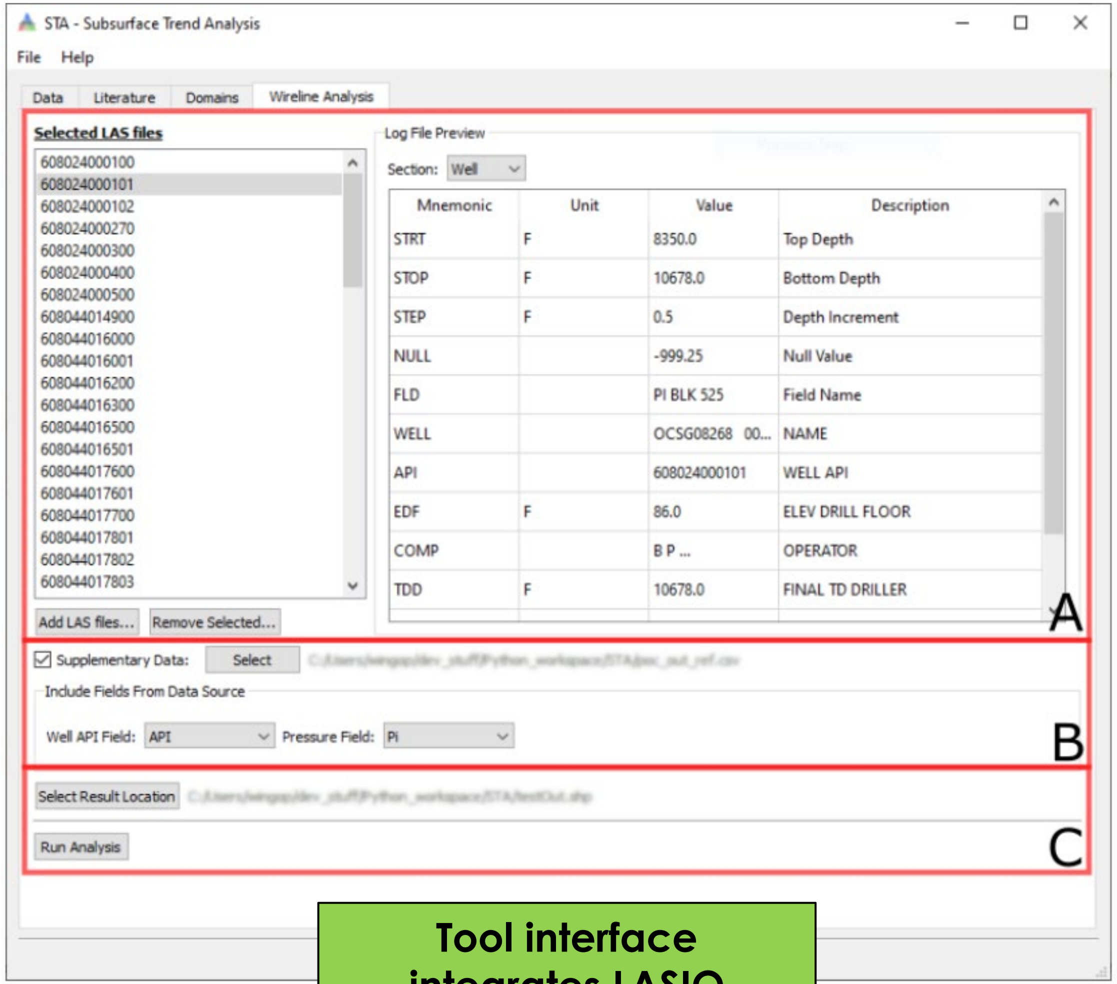
- **This method expands variography from 2D to 3D**

- **Integrates multiple variables,** including quantitative and qualitative information, for 3D co-kriging

- Ultimately, model produces 3D subsurface property predictions



2D/3D Wireline Analysis



Tool interface integrates LASIO Python package

Automated Wireline Analysis performs the following:

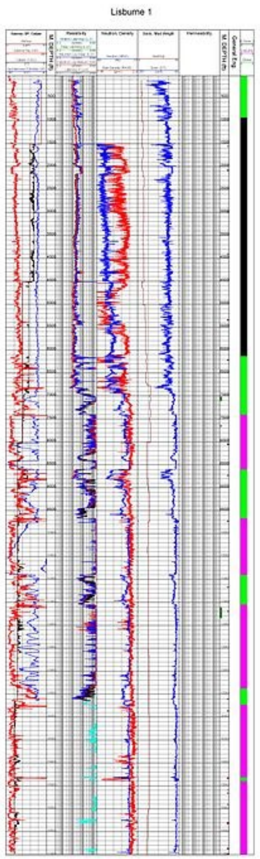
A -- LAS File management

B -- Additional data inputs

C -- Analysis run and output

Updates previously existing point data with newly extracted properties from well logs

3D version in dev calculates overburden stress to indicate pressure along the wellbore

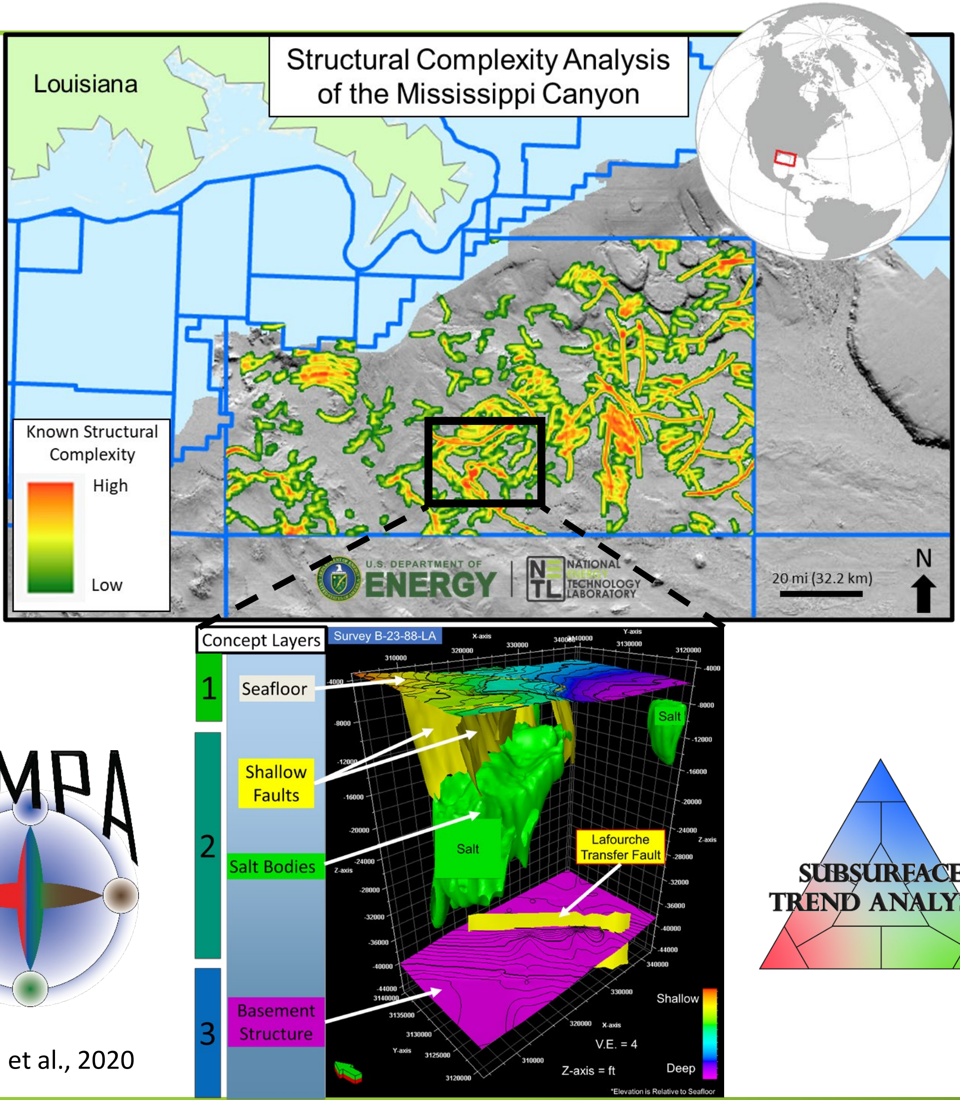


Source: USGS

Generating Datasets to Validate Geohazard Analysis in the STA Tool

- Use case: Mississippi Canyon in the Gulf of Mexico

- Multiple datasets analyzed
  - Seafloor fault mapping, seismic, basement structure
  - Subsurface data analyzed using **SIMPA** to produce STA geologic domains
  - Combined with spatial wellbore data to test tool capabilities



SIMPA

Justman et al., 2020

SUBSURFACE TREND ANALYSIS

3D STA Domains for 3D Tool visualization and testing

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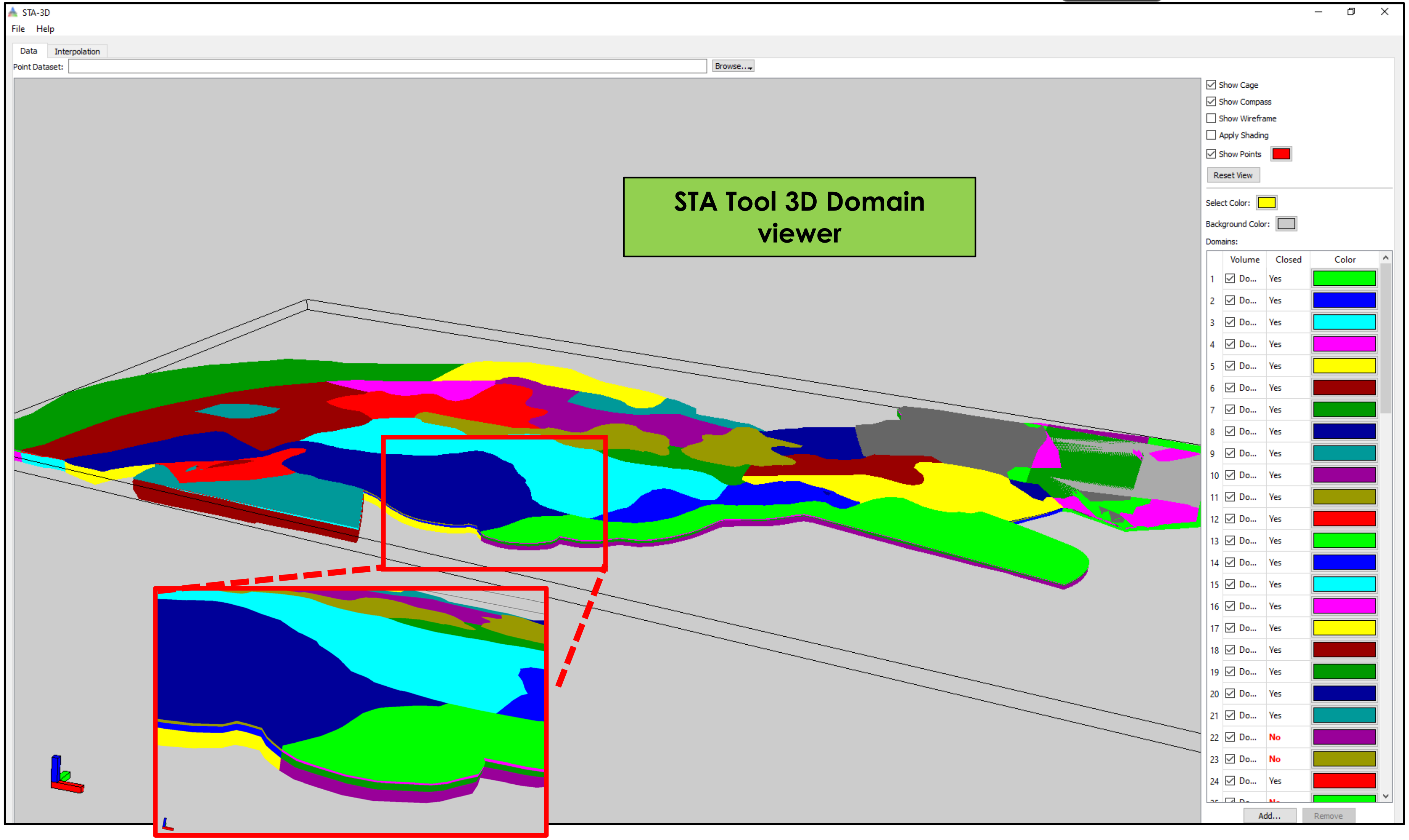
- Basin-scale 3D STA Domains based on chronozone analysis from original STA Gulf of Mexico use case
- To be utilized with 3D co-kriging interpolation

EON	ERA	PERIOD		EPOCH		Ma
Phanerozoic	Cenozoic	Quaternary		Holocene		0.011
				Pleistocene	Late	0.8
					Early	2.4
		Tertiary	Neogene	Pliocene	Late	3.6
					Early	5.3
				Miocene	Late	11.2
					Middle	16.4
					Early	23.0
			Paleogene	Oligocene	Late	28.5
					Early	34.0
				Eocene	Late	41.3
					Middle	49.0
					Early	55.8
				Paleocene	Late	61.0
					Early	65.5
	Mesozoic	Cretaceous		Late		99.6
				Early		145
		Jurassic		Late		161
				Middle		176
				Early		200
		Triassic		Late		228
				Middle		245
				Early		251
	Paleozoic	Permian		Late		260
				Middle		271
				Early		299
		Pennsylvanian		Late		306
				Middle		311
				Early		318
		Mississippian		Late		326
				Middle		345
				Early		359
		Devonian		Late		385
				Middle		397
				Early		416
		Silurian		Late		419
				Early		423
		Ordovician		Late		428
				Middle		444
				Early		488
		Cambrian		Late		501
				Middle		513
				Early		542

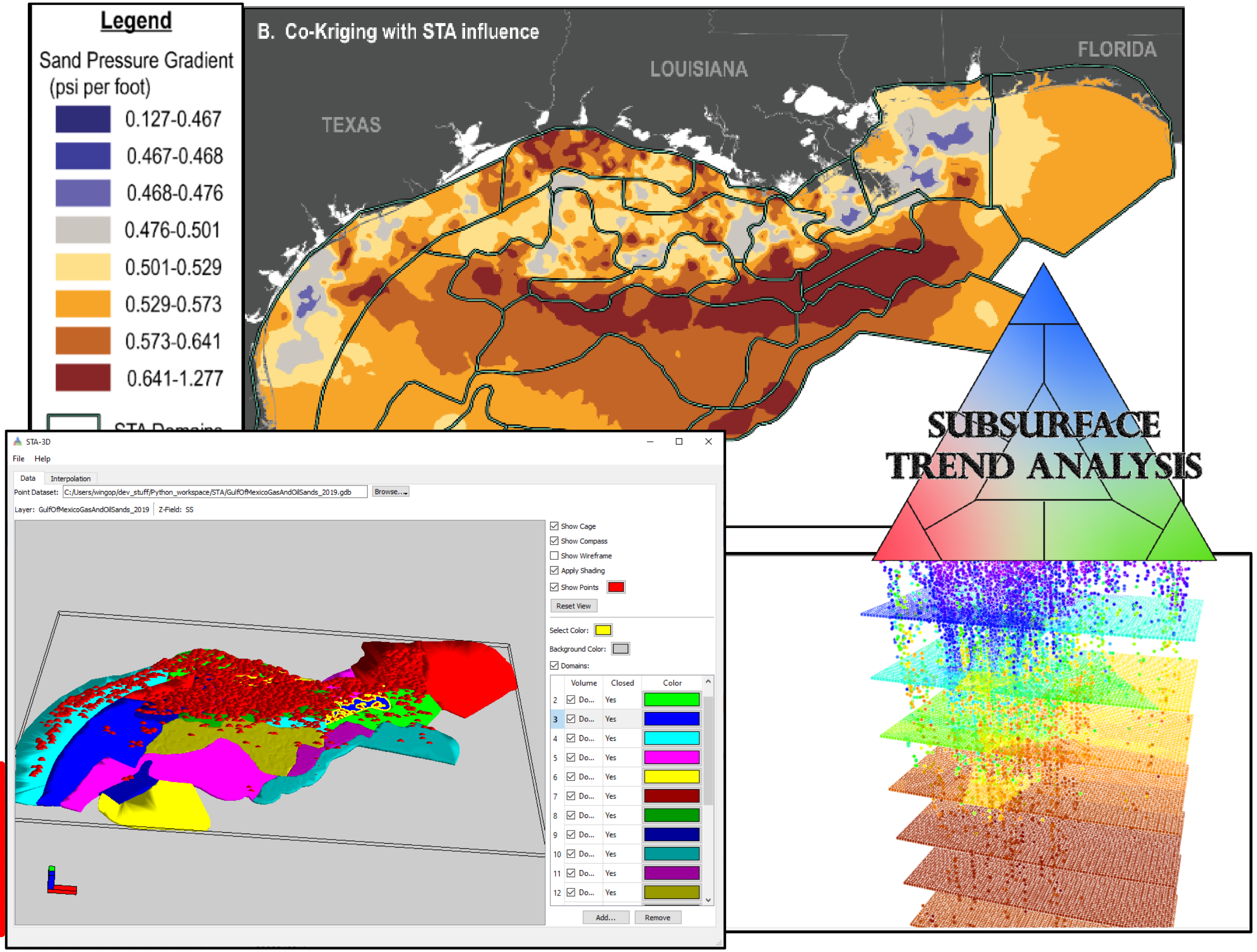


Summary

- **The STA Method and Tool integrate data, knowledge and science-based analytics** to accelerate data collection and knowledge integration, and improve predictions of subsurface properties

- **STA Method and Tool:**
  - Adapt to different regions and scales of analysis
  - Integrate newly acquired data and update predictions of subsurface properties
  - Seeks to provides insights where gaps in data and analytical tools exist

Download the 2D STA Tool!
https://edx.netl.doe.gov/dataset/subsurface-trend-analysis-2d-tool



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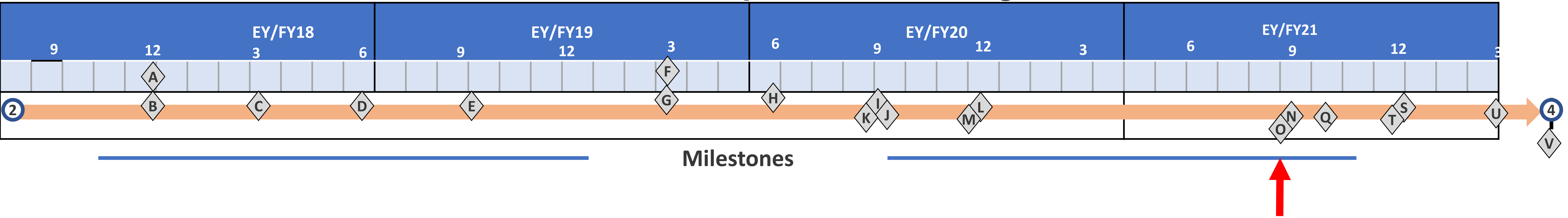
Offshore R&D

Offshore information available at https://edx.netl.doe.gov/offshore/

Offshore Unconventional FWP

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

Task 5: Geohazards & Subsurface Uncertainty Smart Modeling



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

NATIONAL ENERGY TECHNOLOGY LABORATORY

Upcoming Publications

- Mark-Moser, M., Rose, K., Suhag, A., Wingo, P., Hoover, B., Bean, A., Pantaleone, S., and Bauer, J., Exploring integrated data science techniques for subsurface property trend analysis and prediction. In prep, Computers & Geosciences
- Hoover, B., Zaengle, D., Mark-Moser, M. Enhancing knowledge discovery of unstructured data to support context in subsurface-modeling predictions. In prep, Environmental Modeling and Software

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

BERKELEY LAB Lawrence Berkeley National Laboratory · The University of Texas at Austin · Los Alamos National Laboratory EST. 1943 · Chevron · Lloyd's Register · 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 geohazard research effort

Advanced Offshore Research Task 5

Research Problem:

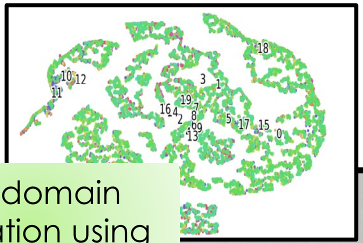
- Offshore sedimentary systems are complicated, and heterogeneous subsurface introduces hazards and risks that are hard to constrain and predict pre-drill leading to deleterious impacts, such as the Macondo blowout and Deepwater Horizon spill in 2010
- There is a need for rapid, accurate, and efficient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

Proposed Research:

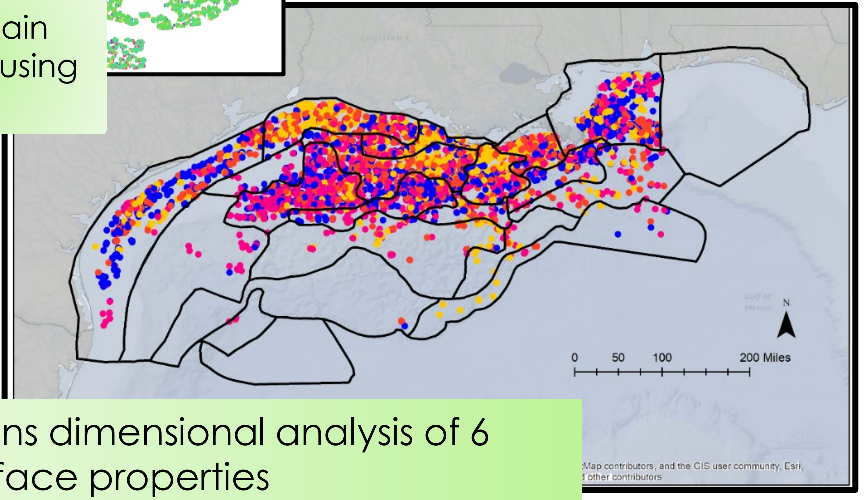
- Develop a 2D, and eventually 3D, real-time “smart” tool using the Subsurface Trend Analysis method framework
- Integrate machine learning and artificial intelligence (AI/ML) to improve efficacy and robustness of analyses
- Test and validate the AI/ML-enhanced STA Tool utilizing LWD/SWD datasets and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

Benefit:

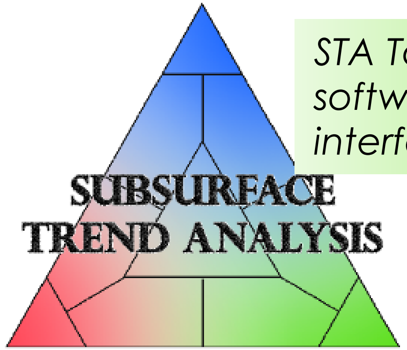
- Reduction of subsurface hazards and risks by utilizing these predictions to assist in efficient geohazard prevention and resource estimation, e.g., prevention of oil spills, CO_2 storage estimation, rare earth element enrichment, and geothermal prospects

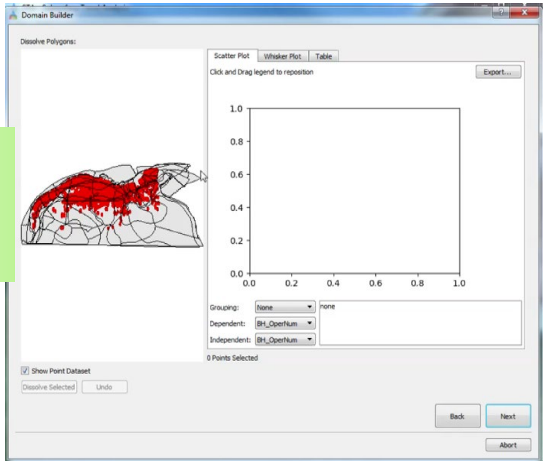


STA domain validation using t-SNE



K-means dimensional analysis of 6 subsurface properties





STA Tool software interface