SeReM: MATLAB® Seismic Reservoir Modeling

An integrated, adaptive solution for 3D modeling and inversion of petrophysical facies properties

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MathWorks
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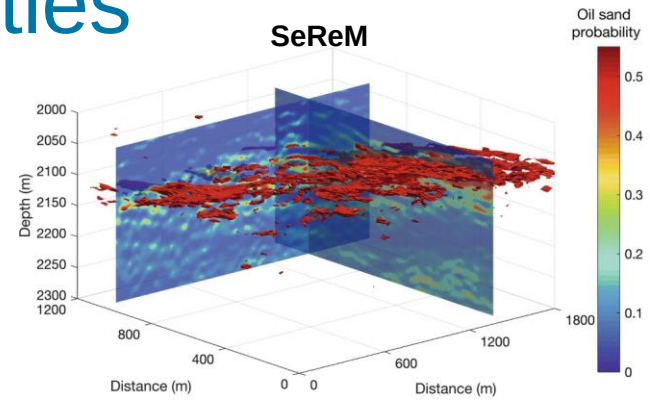


Artificial Intelligence | Big Data Analysis | Deep Learning | Machine Learning | Reinforced Learning | Predictive Analytics | Internet of Things | Process Optimization | Process Digitization | Process Automation | Value Chain Integration

MathWorks®
Accelerating the pace of engineering and science

Outline

- MathWorks® digital solutions
- SeReM: MATLAB® Seismic Reservoir Modeling
  - SeReM in a nutshell
  - SeReM highlights
  - SeReM examples
  - SeReM resources

MathWorks Digital Solutions
Fact Sheet Highlights

- MathWorks® is a private company founded in Massachusetts, USA in 1984 to:
  - Provide the ultimate computing environment for technical computation, visualization, design, simulation, and implementation
  - Accelerate the pace of discovery, innovation, development, and learning in engineering and science
- MathWorks® has developed major digital solutions for industry and academia:
  - MATLAB®, the language of engineers and scientists, for algorithm development, data analysis, visualization, and numerical computation.
  - Simulink®, a block diagram environment for model-based design and simulation of multidomain and embedded engineering systems; plus…
  - …over 120 digital products for data analytics, image/signal processing, control systems, robotics, deep learning, digital twins, and many, many more.

MathWorks® Digital Transformation Solutions

Digital Transformation Solutions Ecosystem

Digital Transformation Process

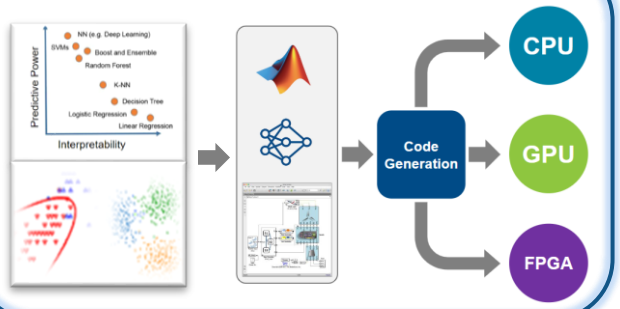
Energy sector demands
- Process optimization
- Sustainability compliance
- Circular economy innovation
- Energy transformation

Digital technology enablers
- AI/ML & HPC computing
- IoT, digital twins & robotics
- Process digitization (modeling, simulation, predictive analysis)

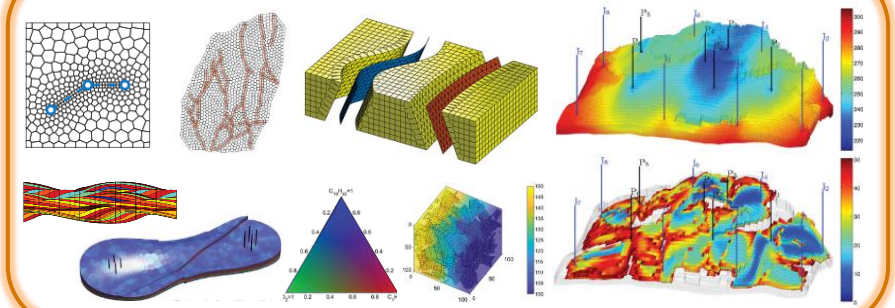
Digital business outcomes
- Prompt big data-driven analysis
- Asset performance optimization
- Value chain automation
- Process optimization & integration

MathWorks® Digital Transformation Solutions

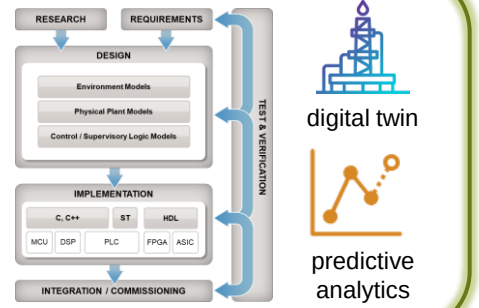
AI/ML & HPC Integration



Computational Modeling & Simulation*



Process Automation



Challenges & Outcomes

Key transformational challenges
- Organizational barriers
- Unclear ROI from digital
- New digital skills and expertise
- Siloed vs integrated digitization

Value of digital technology
- Accelerated decision making
- Preventive decision making
- Agile production optimization
- Adaptive integrated platforms

ROI as a digital business*
- Upstream: $5/boe incr. ROI
- Downstream: $1/boe incr. ROI
- Up to 20% in extra reduction of carbon emissions (scope 1 & 2)

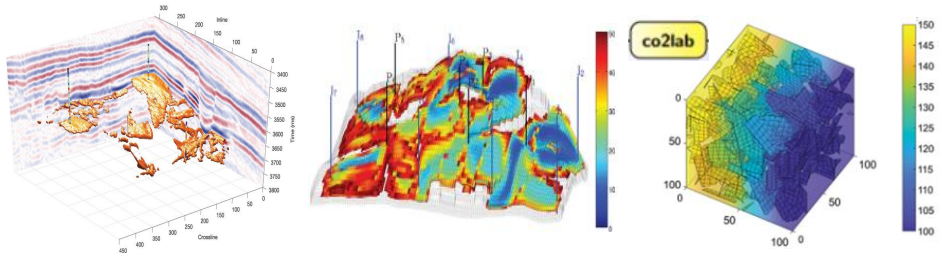
* Sources: Hassmann *et al* (2022) – Technology transformation in oil and gas. McKinsey& Co.
Lie *et al* (2021) – Advanced modeling with MATLAB Reservoir Simulation Toolbox. Cambridge University Press

MathWorks® in Energy Resources
Customizable Digital Solutions for Upstream & Downstream

MathWorks® Solutions | **Process Modeling & Simulation** | **Process Optimization & Automation**

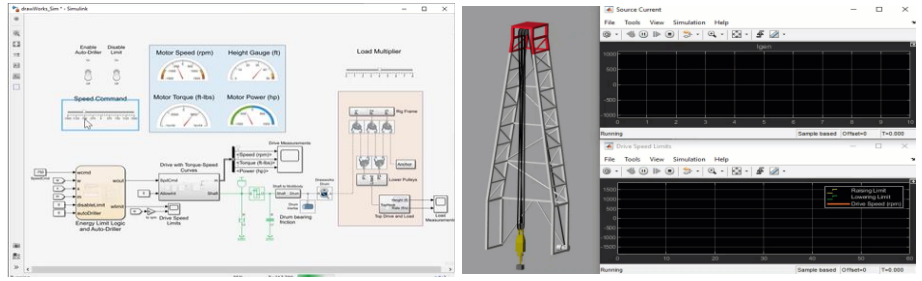
Subsurface

SeReM + MRST
MATLAB® Reservoir Modeling & Simulation



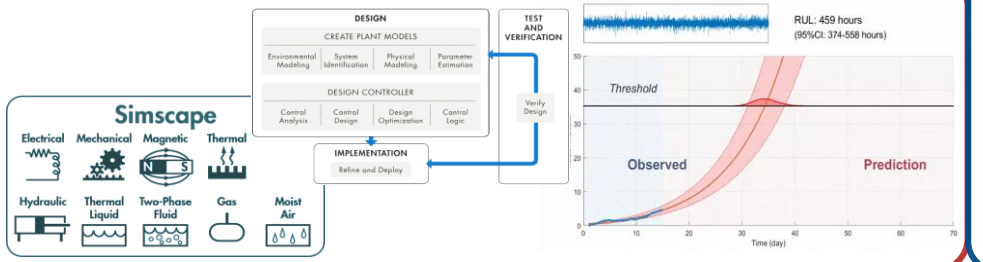
Oilfield

Drilling Digital Twin
Simulink® Surface Drilling Automation



Plant

Plant Digital Twin
MATLAB® & Simulink® Predictive Maintenance



- MATLAB® Production Server
- MATLAB® Cloud Service
- MATLAB® Quantum Computing
- Parallel Computing Toolbox
- GPU Computing Toolbox
- Simulink® Simscape
- Image/Signal Processing Toolboxes
- Computer Vision Toolbox
- Machine Learning Toolbox
- Deep Learning Toolbox

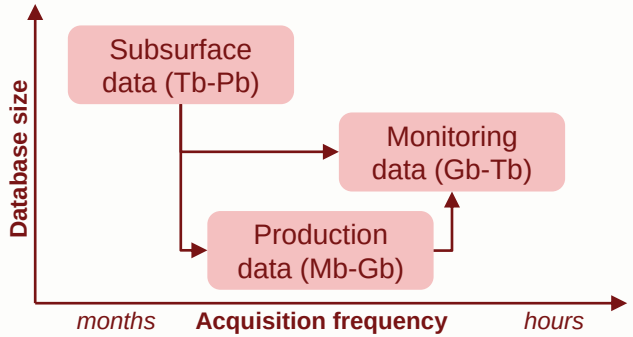
MathWorks® in Energy Resources

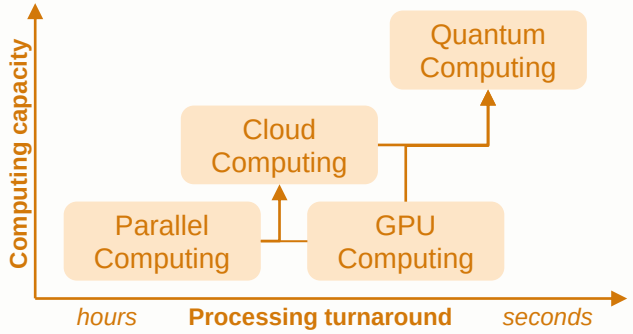
Data Science Workflow for Big Data Analysis

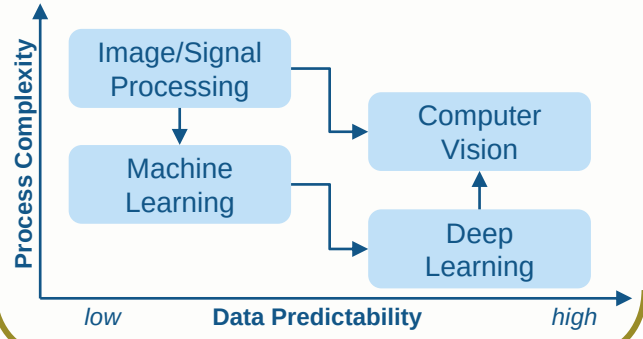
Data Processes

- **Big-Data Gathering**
- **High-Power Computing**
- **Predictive Analytics**

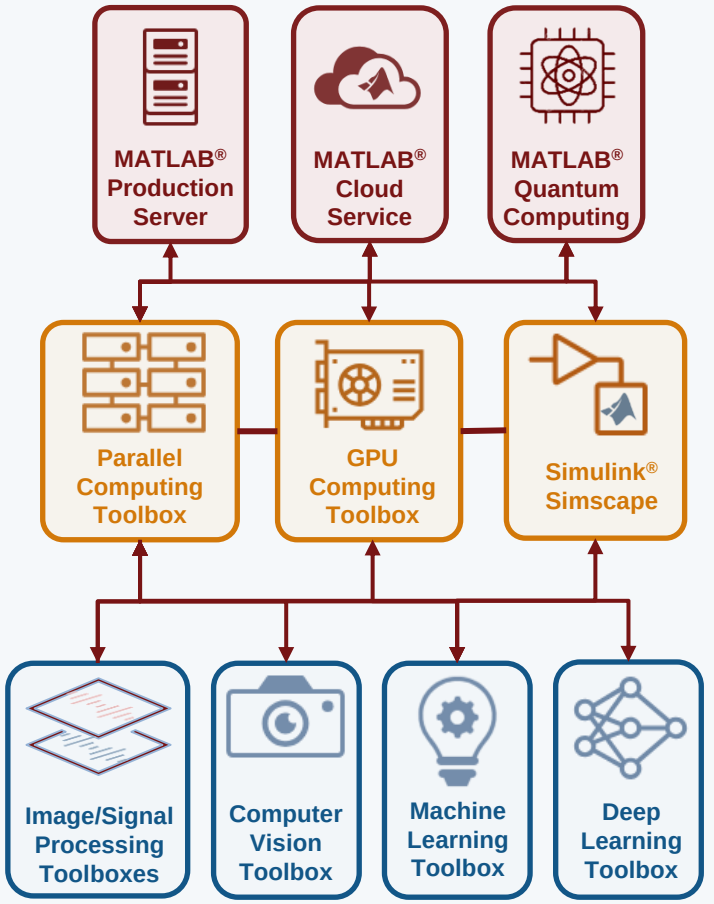
Technical Requirements







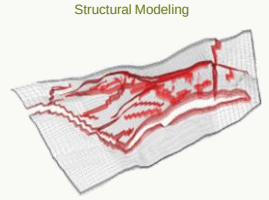
MATLAB® & SIMULINK®

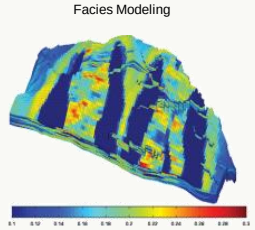


Business Applications

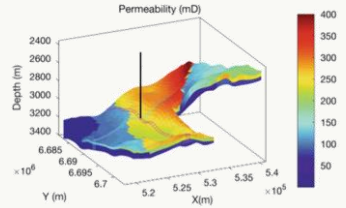
UPSTREAM

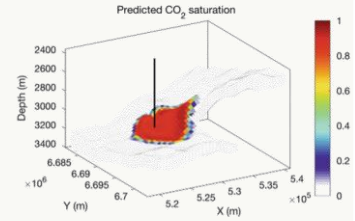
Subsurface Process Modeling





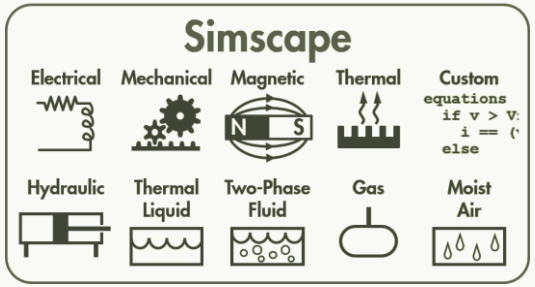
Subsurface Process Simulation



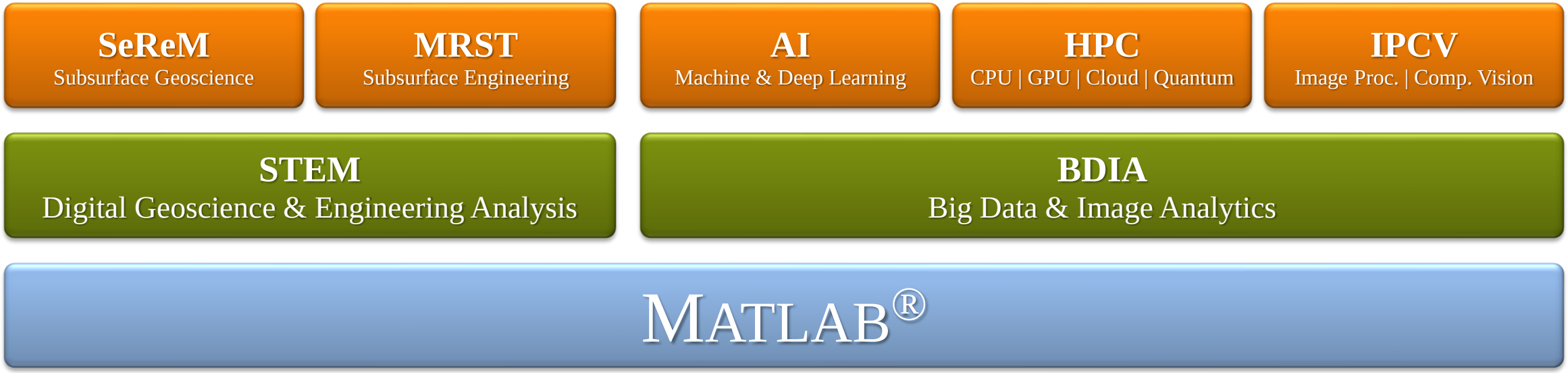


DOWNSTREAM

Dynamic Process Modeling & Simulation



MathWorks® – Digital Subsurface Toolset (v2023)



Key technology differentiators

- Customizable STEM and BDIA toolboxes developed and fully interconnected on MATLAB® platform
- Model-based and data-driven geoscience & engineering workflows to maximize data & image usage
- MathWorks® support, training, and development of data science, engineering, and analytics solutions
- Adaptive digital solutions to assess and integrate new energy processes using high-end technologies
- Low-cost, high-quality software solution to maximize technical expertise, IT infrastructure, and budget
- 200+ energy companies globally currently use MATLAB® solutions across upstream and downstream

SeReM: MATLAB® Seismic Reservoir Modeling Toolkit

- SeReM is a MATLAB®-based toolbox developed to model and invert for reservoir facies properties from seismic data away from well control
- SeReM was developed by Research Geoscientists from University of Wyoming to offer geophysical modeling methods for facies property characterization using seismic, rock-physics, and Bayesian inverse theory
- SeReM contains Bayesian inversion methods to predict the spatial distribution of petrophysical and elastic properties from seismic using analytical solutions for both linear and non-linear geostatistical simulations
- SeReM is a MATLAB® open-source toolkit available at GitHub

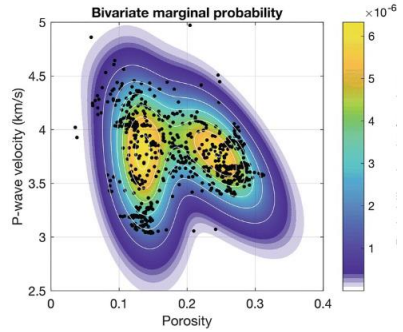
Key Advantages of SeReM

- MATLAB®-based environment to customize and adapt seismic modeling and inversion workflows to support subsurface characterization
- Wide range of 3D data-driven solutions to describe reservoir properties in complex lithological environments with multi-fluid saturation conditions
- Proven successful to predict geological facies distribution at multiple scales
- Robust stochastic inversion methods for data-driven facies characterization
- Optimized linear and nonlinear methods to integrate well & seismic data

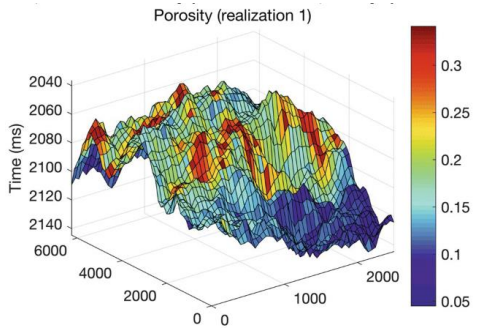
SeReM in a nutshell
Reservoir properties from seismic inversion and facies classification

SeReM
MATLAB Seismic Reservoir Modeling

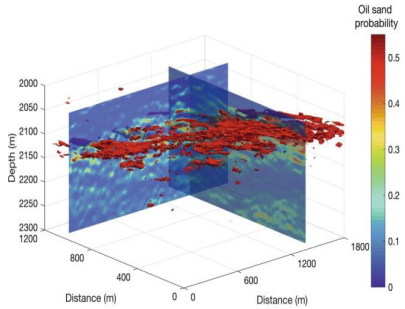
Rock physics modeling



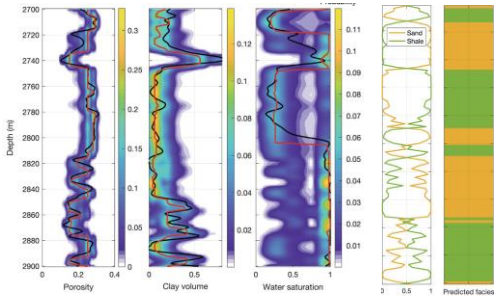
3D seismic inversion



3D facies classification



Seismic Petrophysical facies

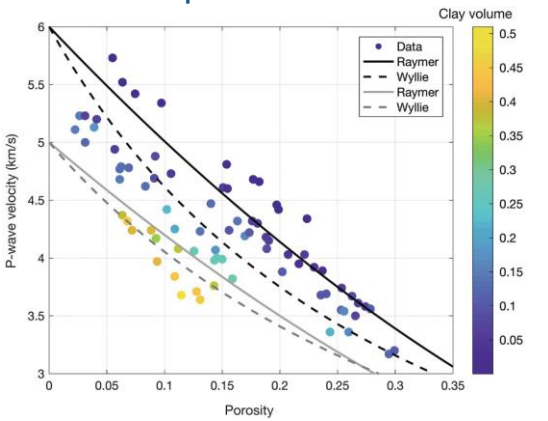


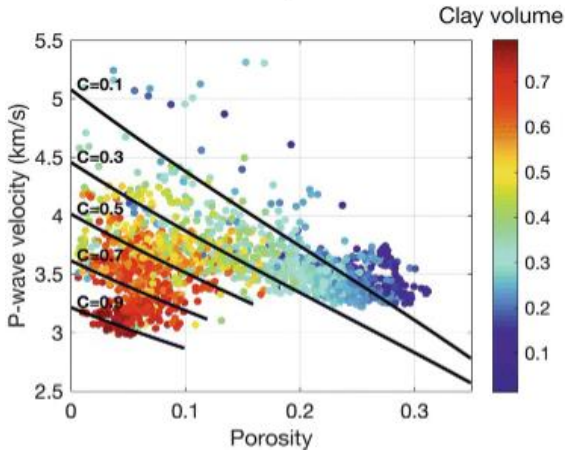
- Rock physics models based on theoretical, empirical, and data-driven (deterministic/probabilistics) templates
- Property upscaling honoring geostatistical distributions of large (seismic) and small (well log) data sampling
- Geostatistical model propagation methods including co/kriging, sequential indicator & truncated Gaussian simulations, Markov Chains, and multi-point statistics
- Seismic Bayesian inversion for petrophysical properties and facies classification bound by rock physics models
- Integrated applications for uncertainty analysis, time-lapse seismic inversion, electromagnetic inversion, production history matching, carbon storage, and more

SeReM highlights

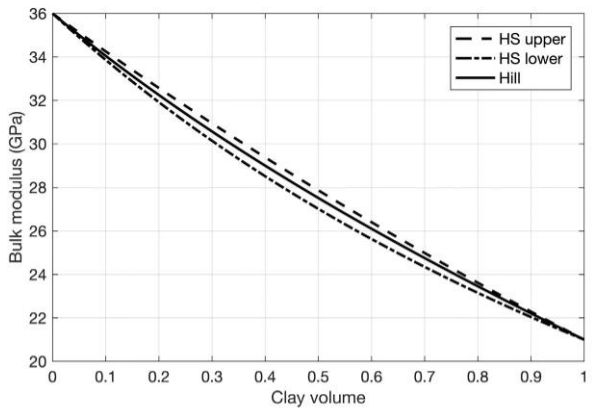
Rock physics models based on poroelastic effective media relations for solid and fluid phases and inclusion models to support mixed lithologies and fractured facies

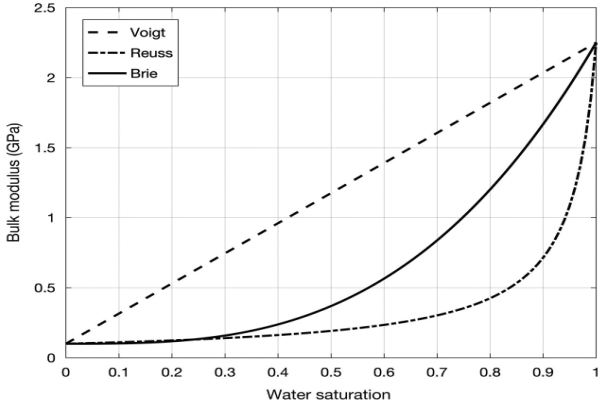
Empirical models



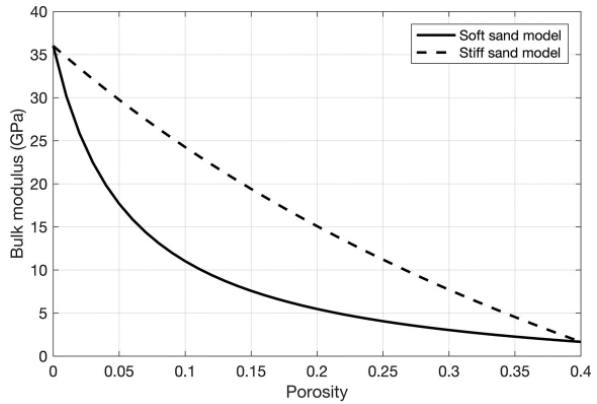


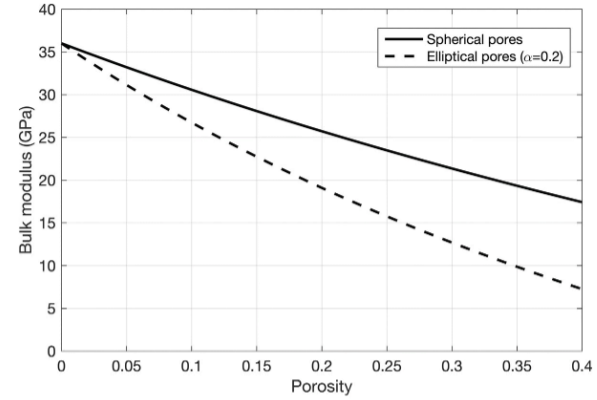
Elastic rock & fluid models



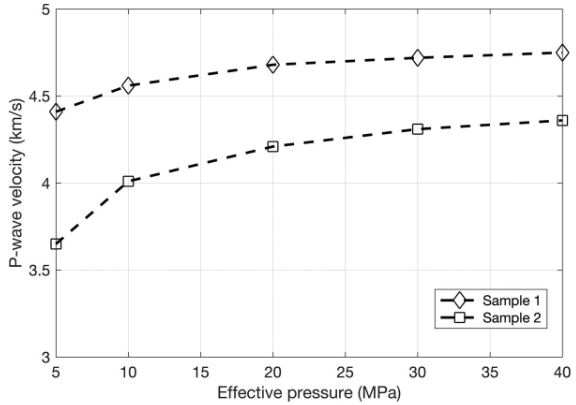


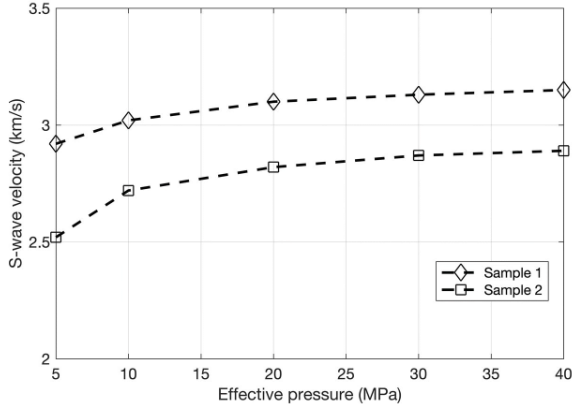
Granular & fracture inclusion models





Effective pressure models

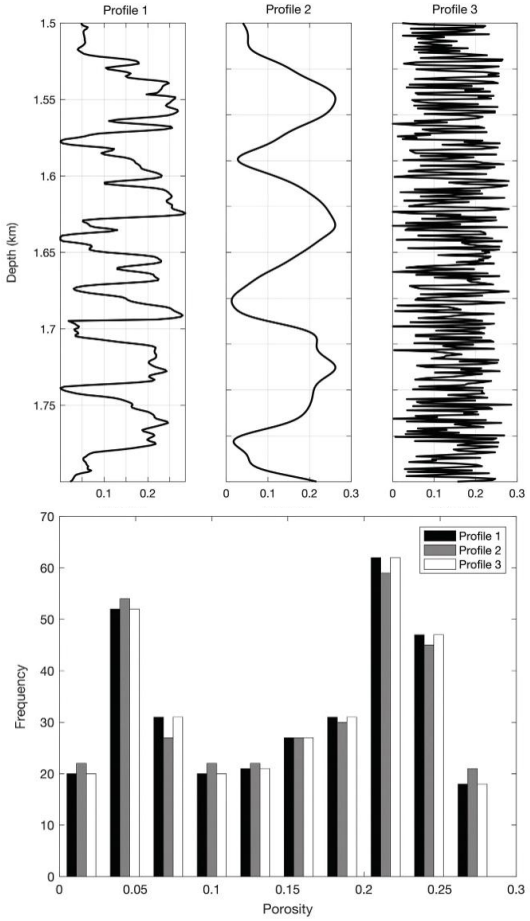




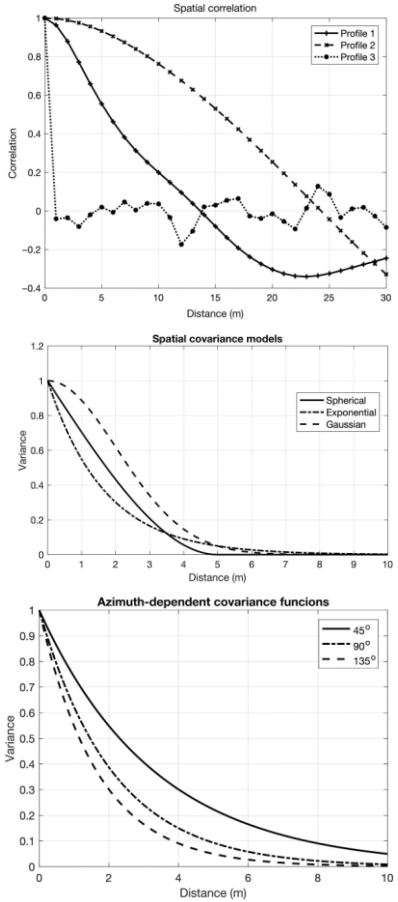
SeReM highlights

Continuous geostatistical models supported by multi-scale, spatial correlations, azimuth-dependent covariograms, and sequential simulations to distribute data honoring distance, anisotropy, and redundancy

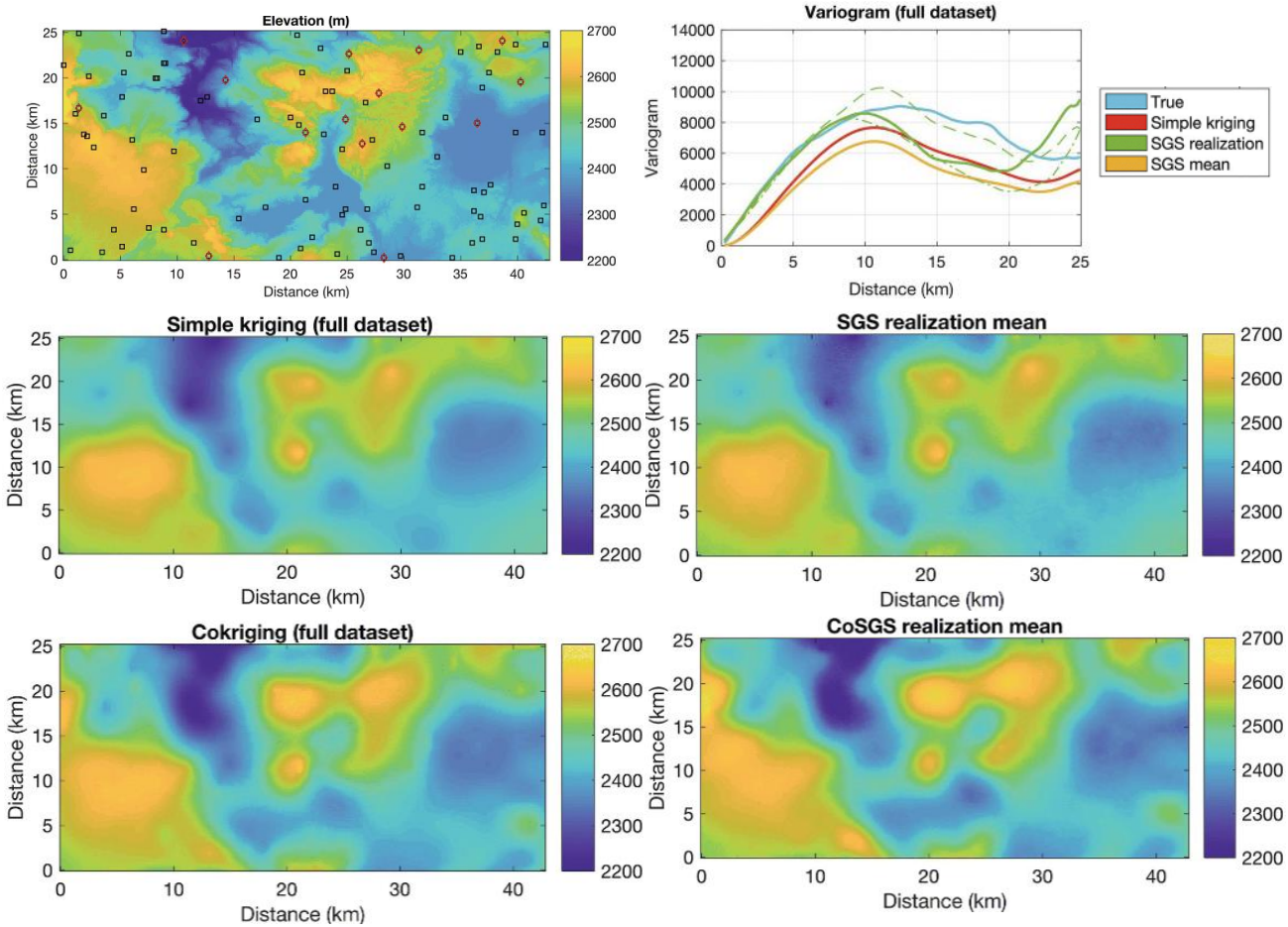
Multi-scale correlations



Spatial covariograms



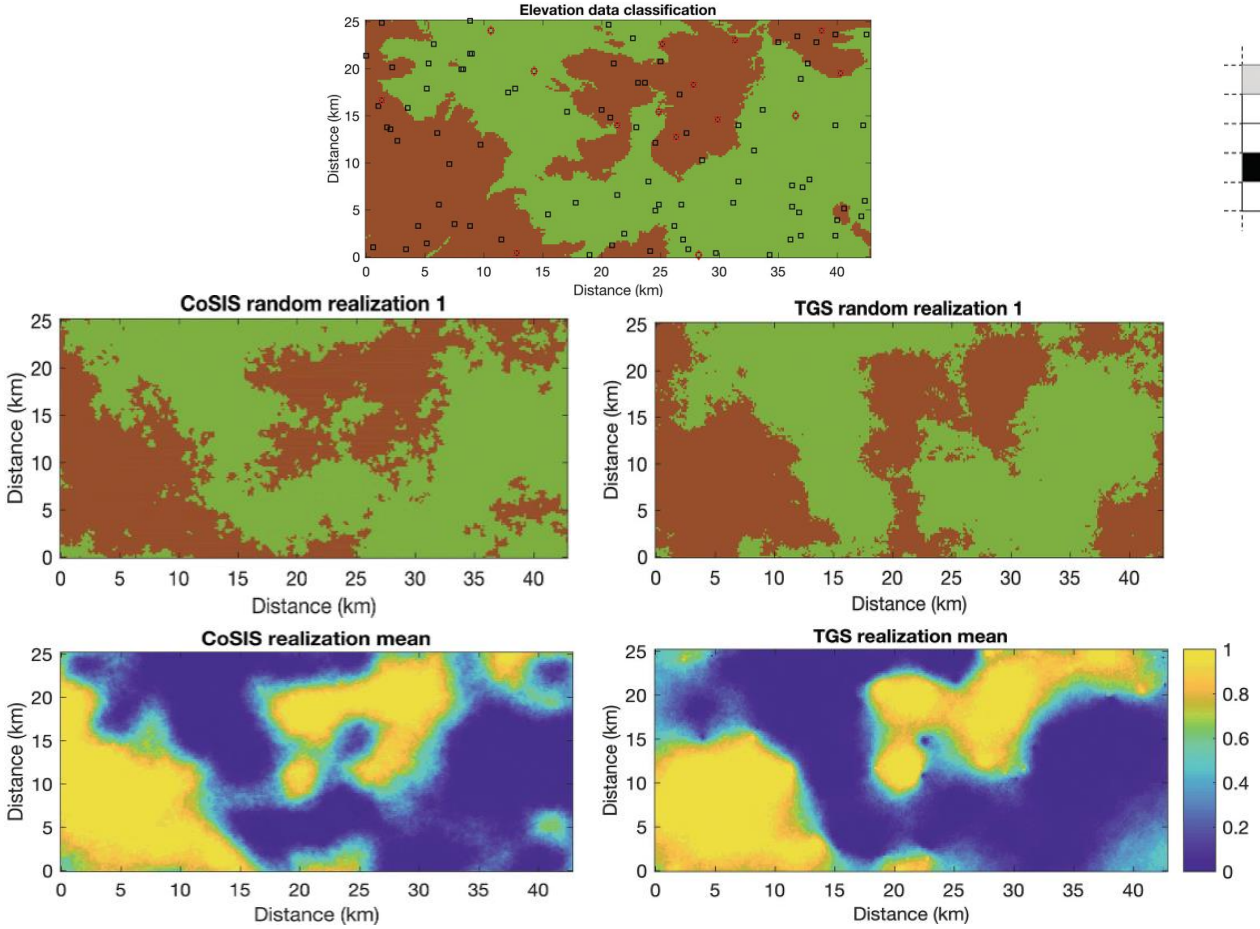
Spatial Kriging and Sequential Simulations (Example: Elevation)



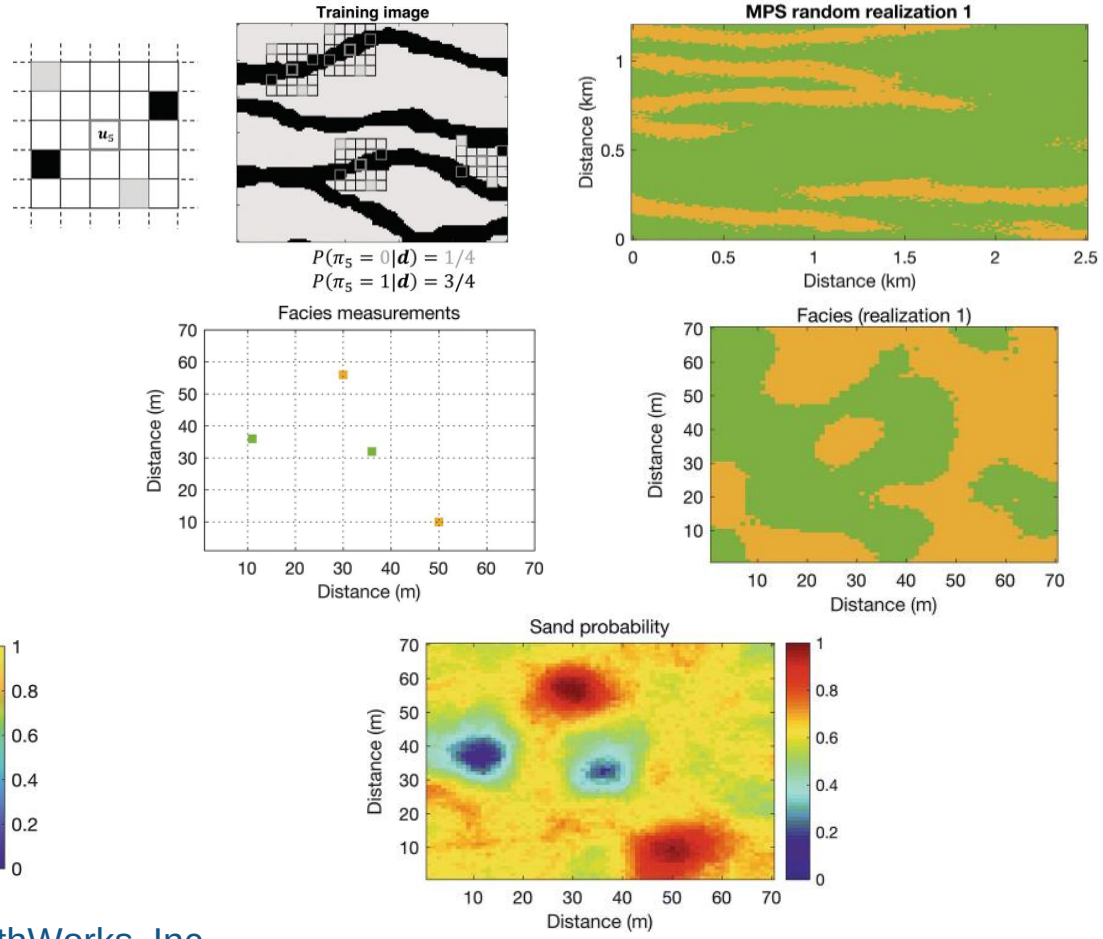
SeReM highlights

Discrete geostatistical models to distribute sedimentary facies and geobodies and their properties using indicator kriging, sequential, and truncated simulations, multi-point statistics, and machine learning images

Indicator co-simulation & truncated Gaussian simulation



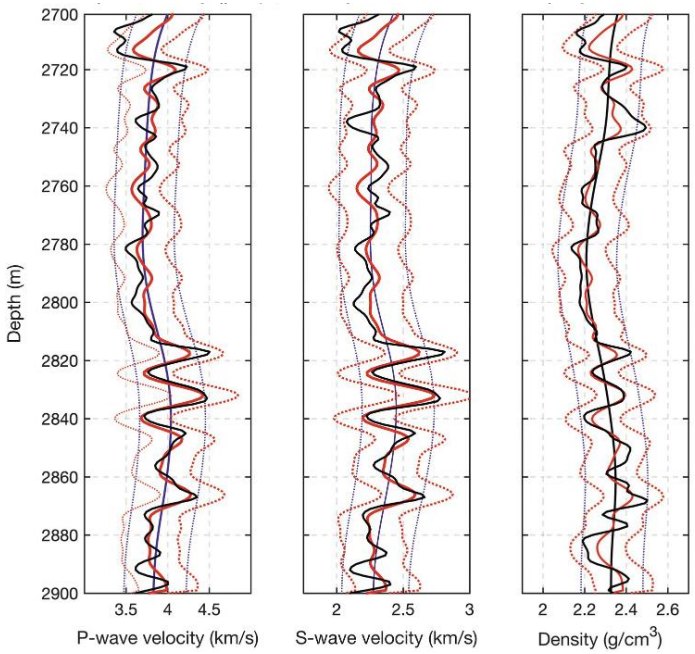
Training images & discrete facies property classification



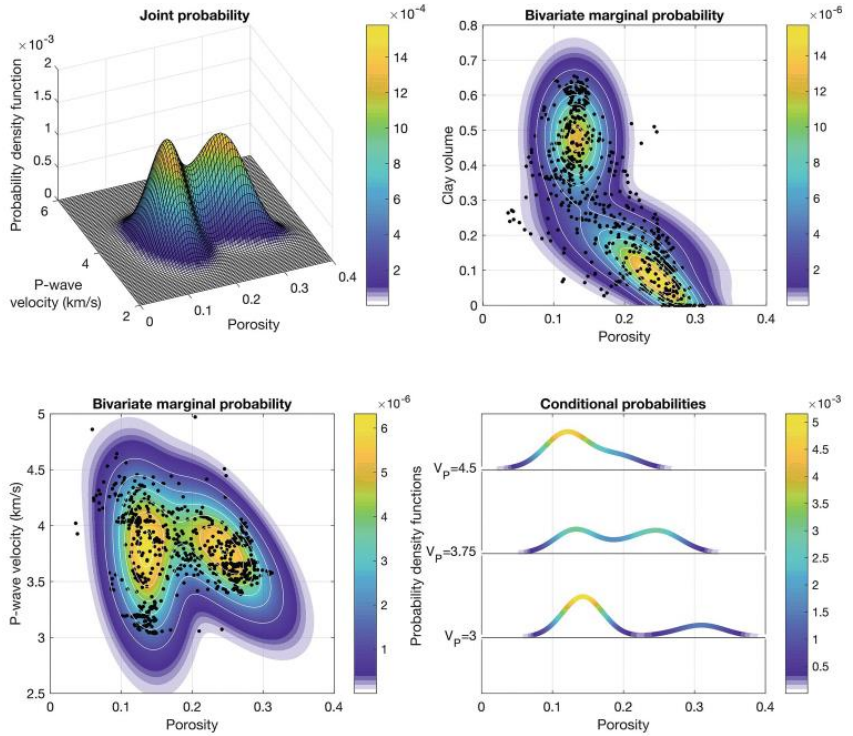
SeReM highlights

Seismic modeling & inversions to extract rock and fluid properties from elastic and petrophysical data using multi-variate Gaussian mixture models and Bayesian linearized AVO & rock physics inversion algorithms

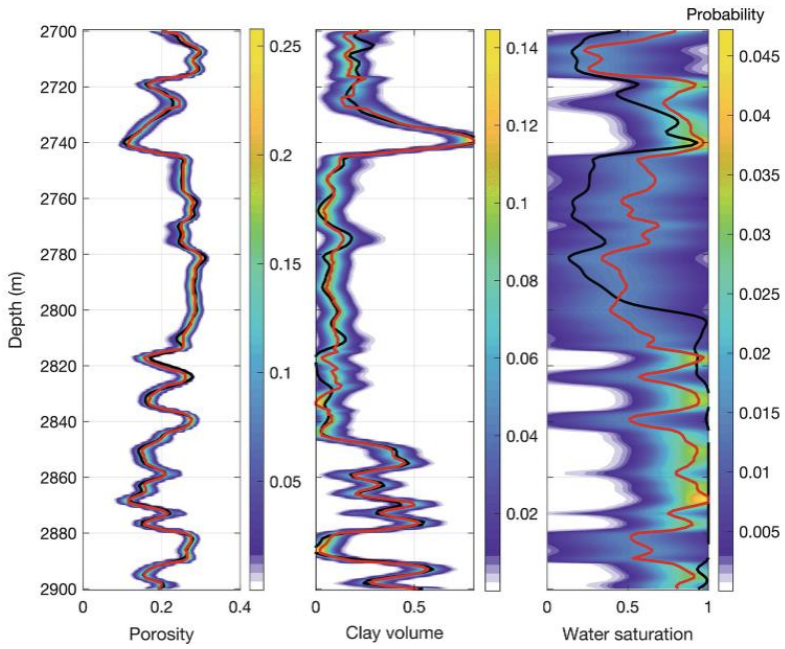
Bayesian linearized AVO inversion for seismic elastic properties



Gaussian mixture models for multi-variate distribution of elastic & petrophysical properties



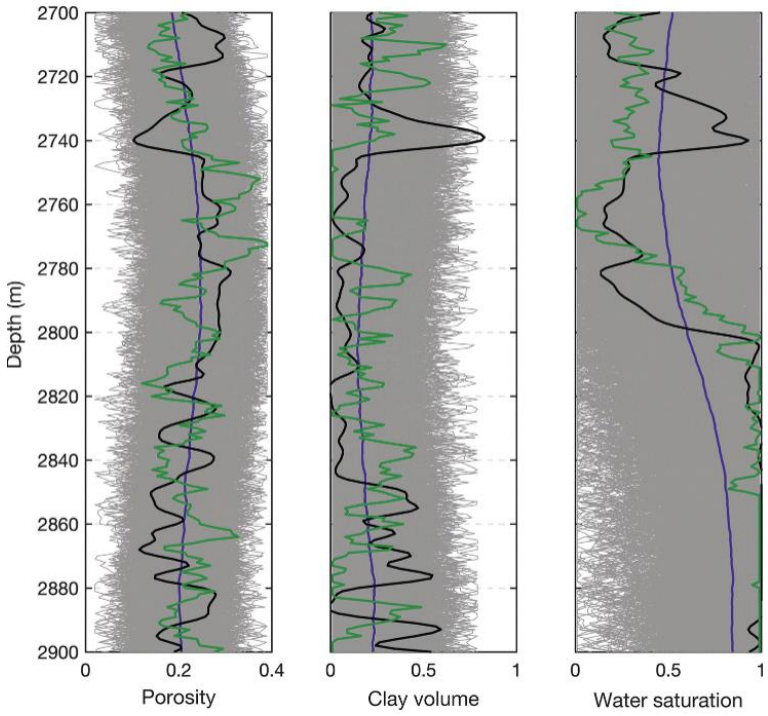
Bayesian linearized rock physics inversion for seismic petrophysical properties



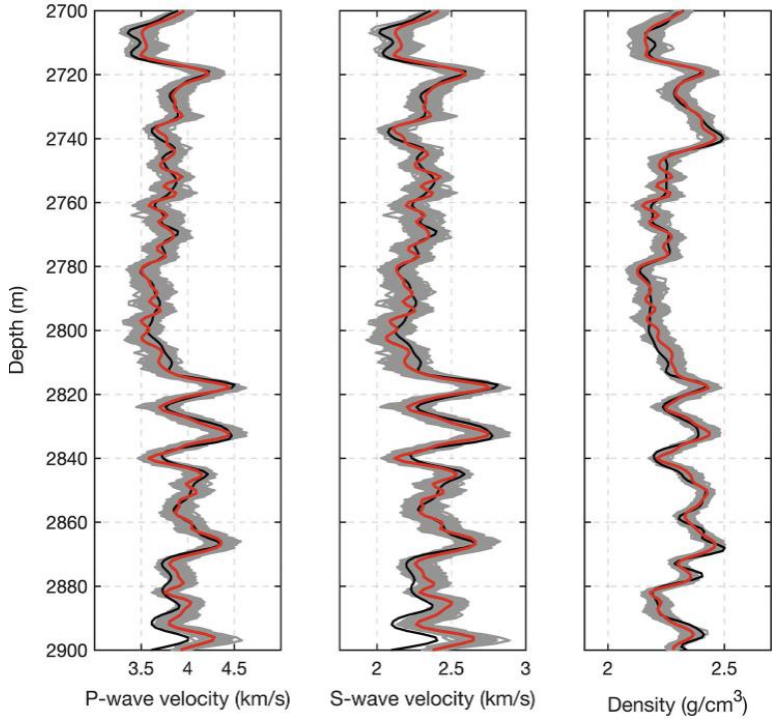
SeReM highlights

Seismic geostatistical inversions based on Markov Chain Monte Carlo & Gradual Deformation stochastic optimization methods and harmonic functions to generate consistent elastic and petrophysical properties

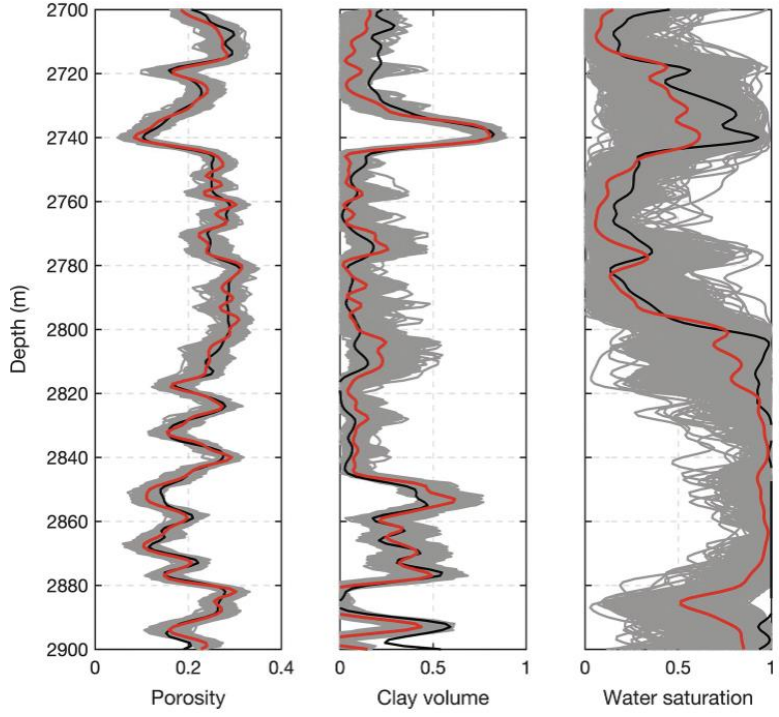
Prior petrophysical properties perturbed using gradual deformation



Posterior elastic properties
Posterior Mean | Actual Well Logs



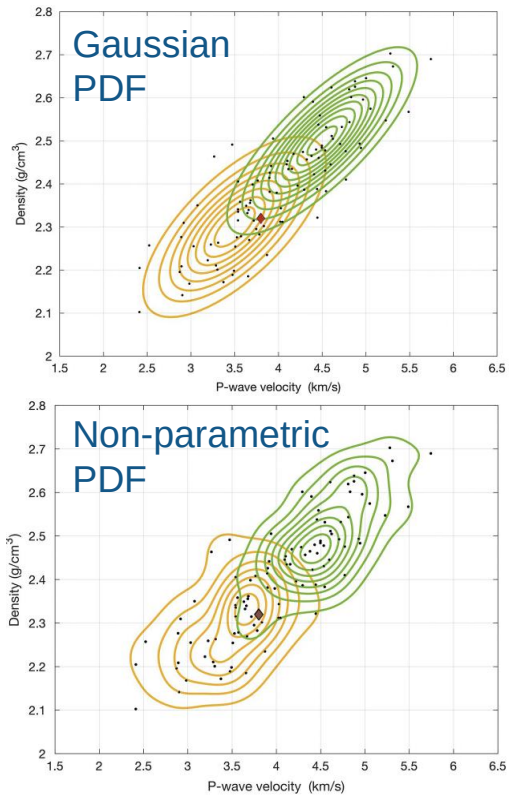
Posterior petrophysical properties
Posterior Mean | Actual Well Logs

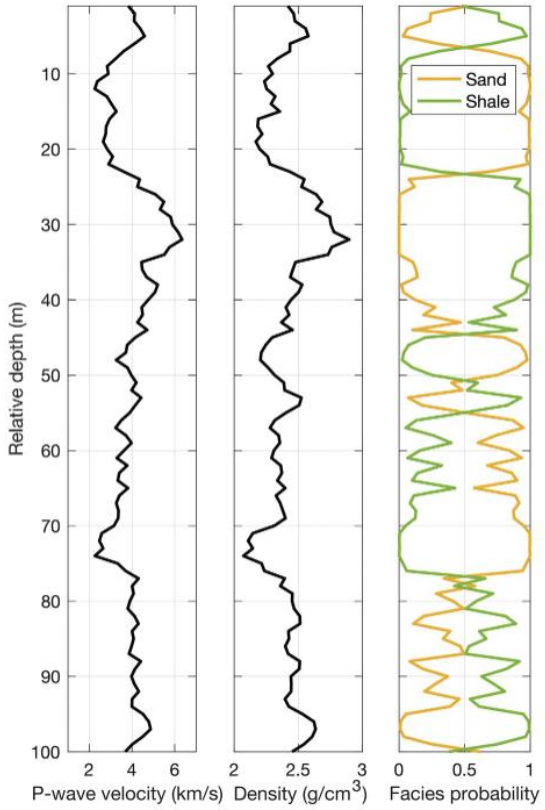


SeReM highlights

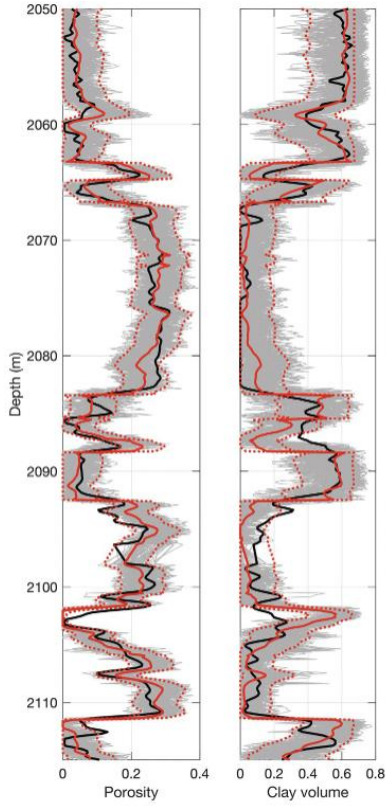
Seismic facies inversion based on discrete, multi-variate Bayesian classification using Ensemble Smoother (ES) and Multimodal Markov Chain Monte Carlo (MMCMC) inversion methods

Prior multi-variate Bayesian facies classification

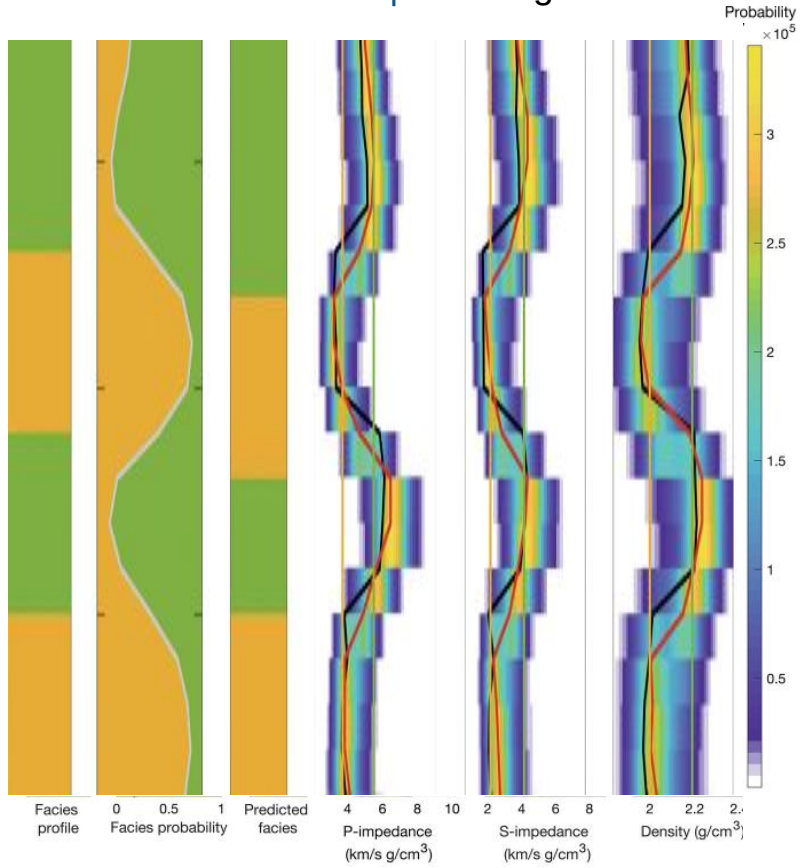




ES inversion
for petrophysics
Posterior | Well Logs



MMCMC inversion
for seismic facies and elastic probabilities
Posterior | Well Logs

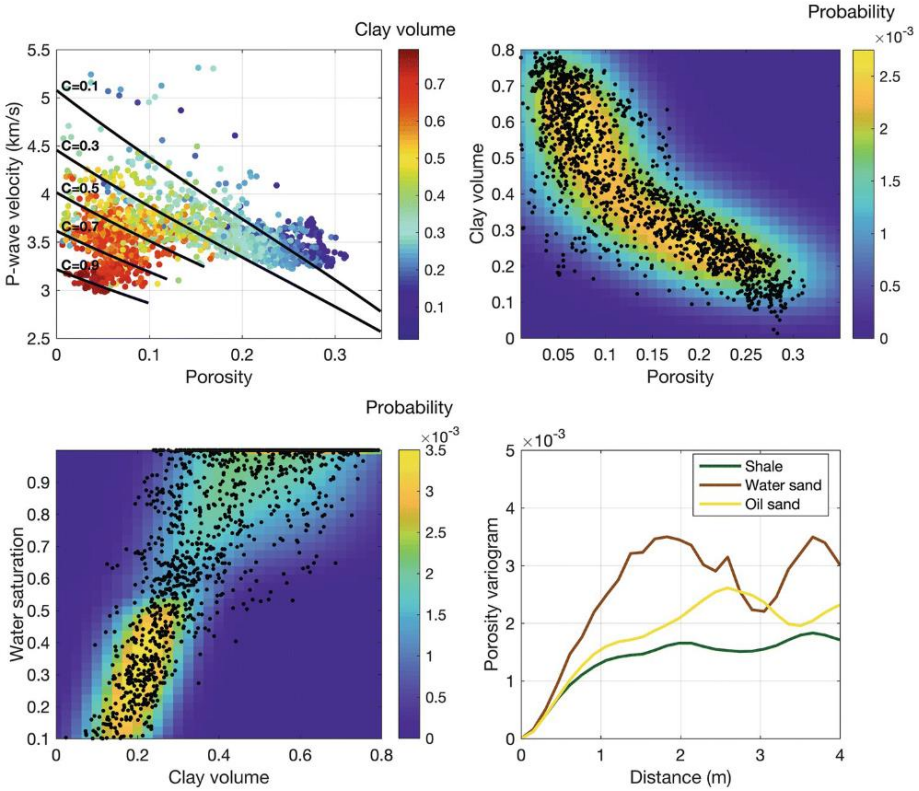


SeReM examples

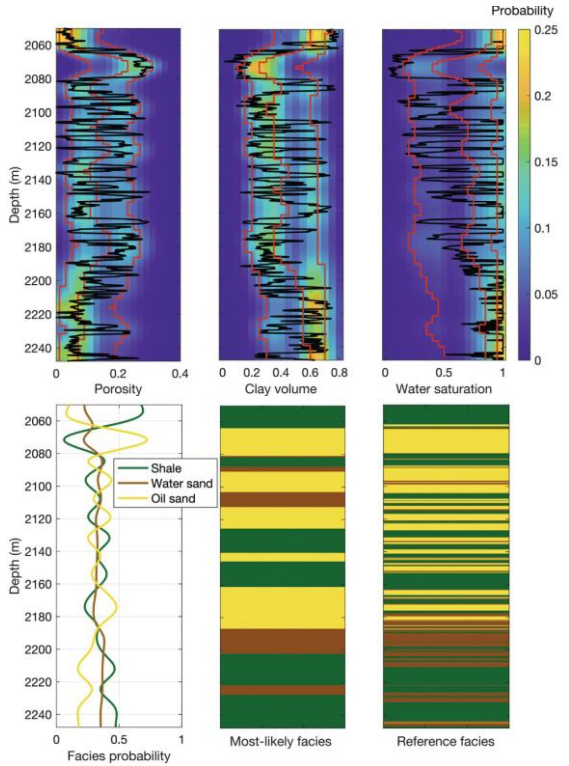
Bayesian linearized inversion for petrophysical properties (Norwegian Sea | Clastics)

Source: [Grana and Della Rossa (2010)]

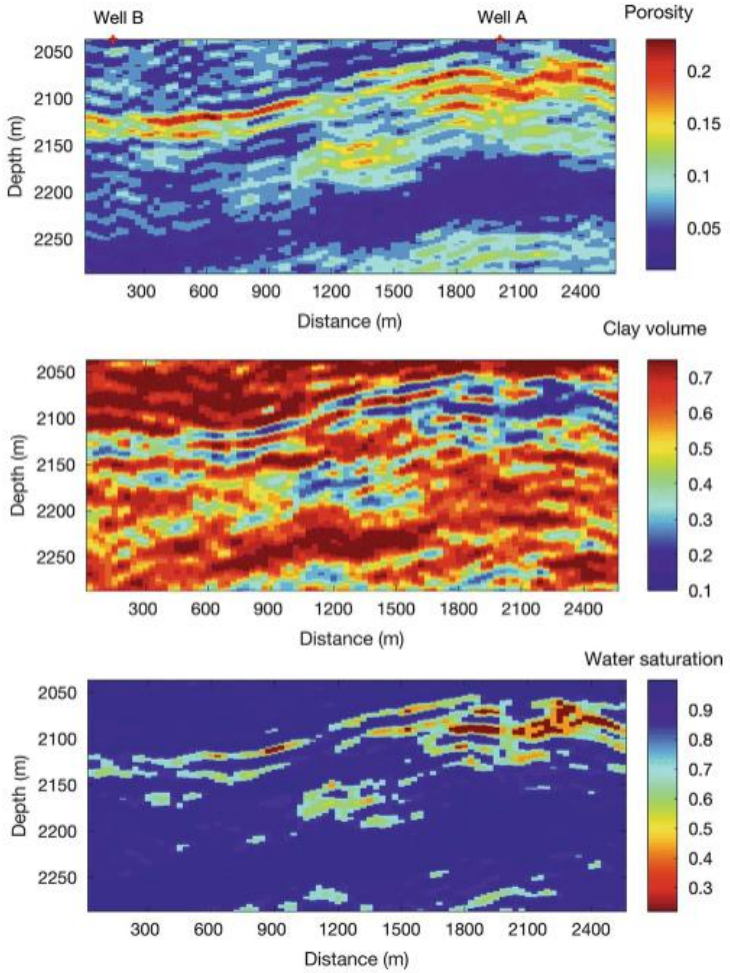
Non-parametric rock physics modeling
& spatial facies distribution



Petrophysical facies probabilities
From seismic Bayesian inversion



Petrophysical property inversion

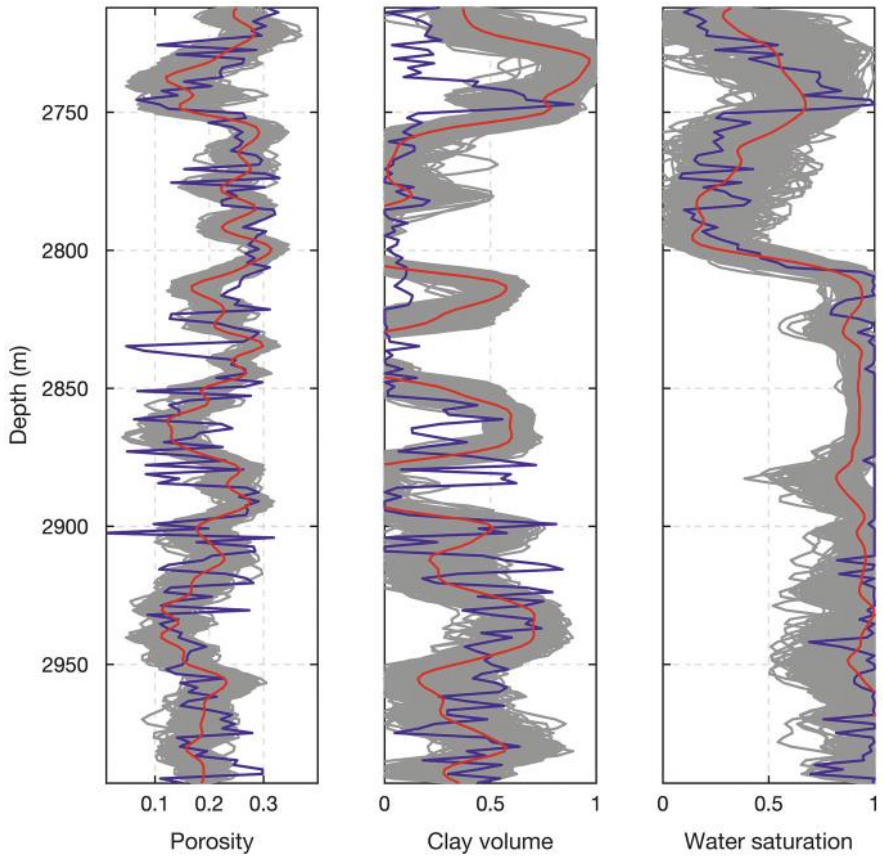


SeReM examples

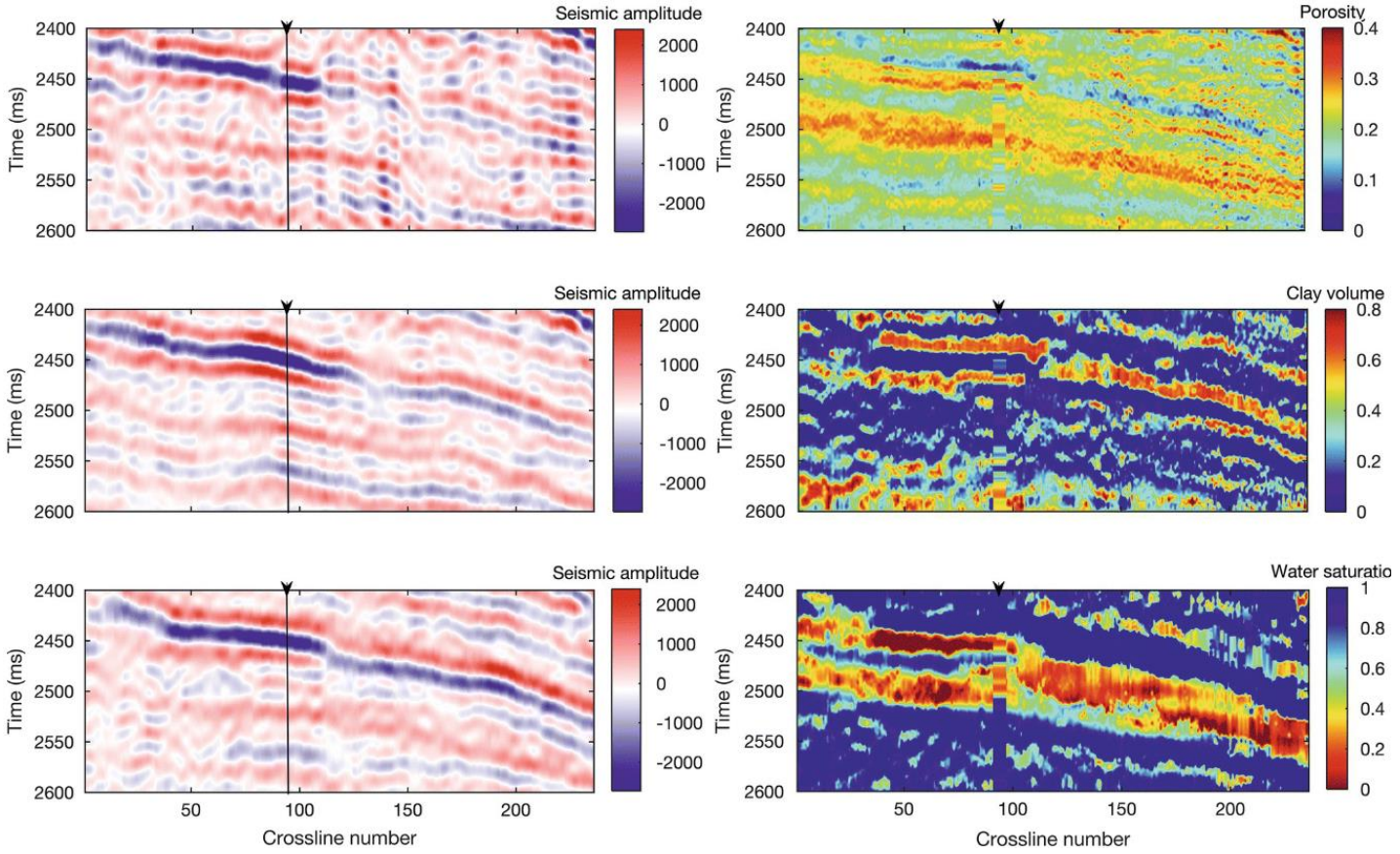
Ensemble Smoother (ES) inversion for elastic & petrophysical properties (Norne field, Norway| Clastics)

Source: [Liu and Grana (2018)]

Stochastic modeling of petrophysical logs
(posterior mean | well logs)



Partial seismic stacks (*left*) and seismic petrophysical inversion results (*right*)

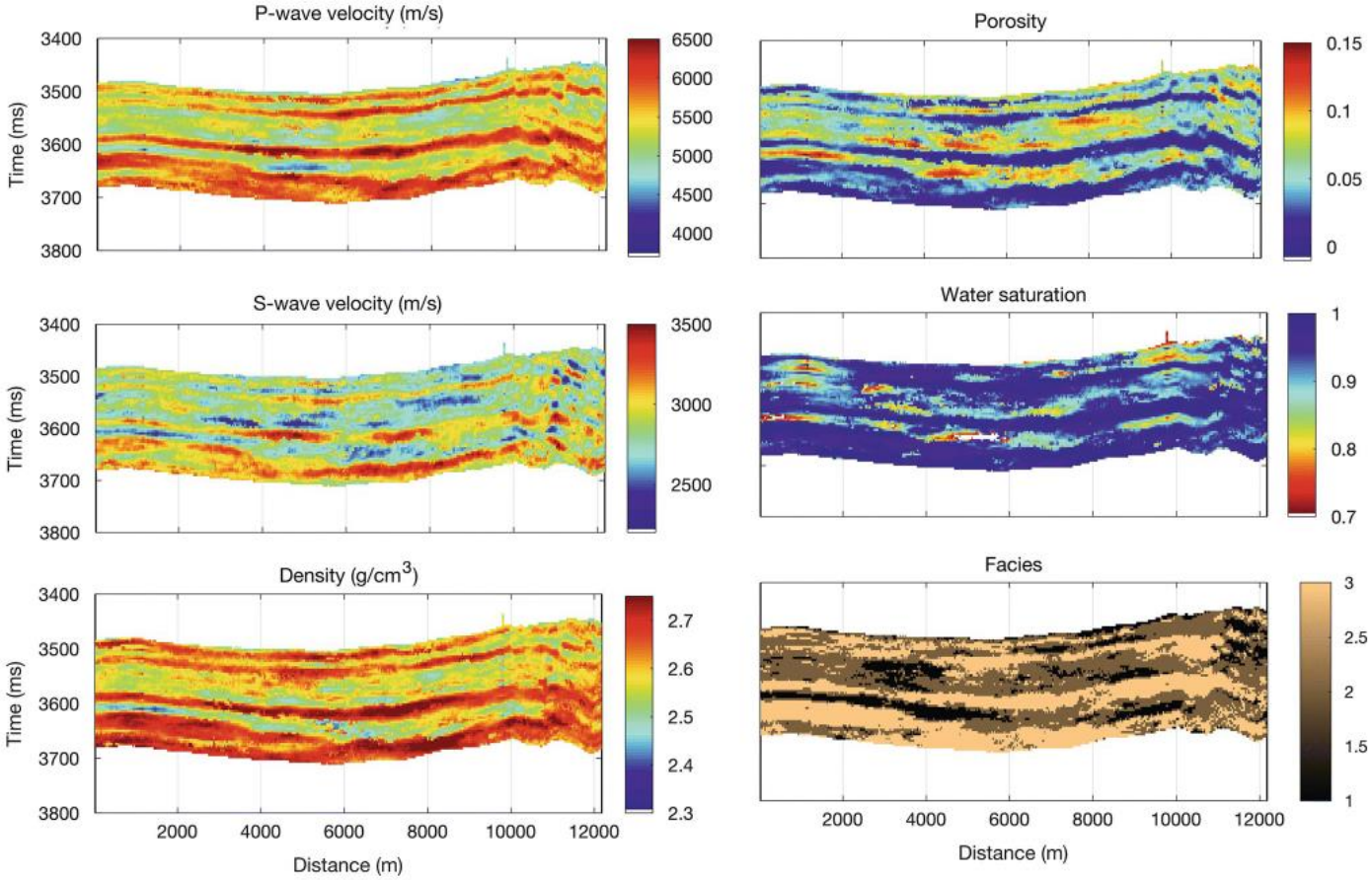


SeReM examples

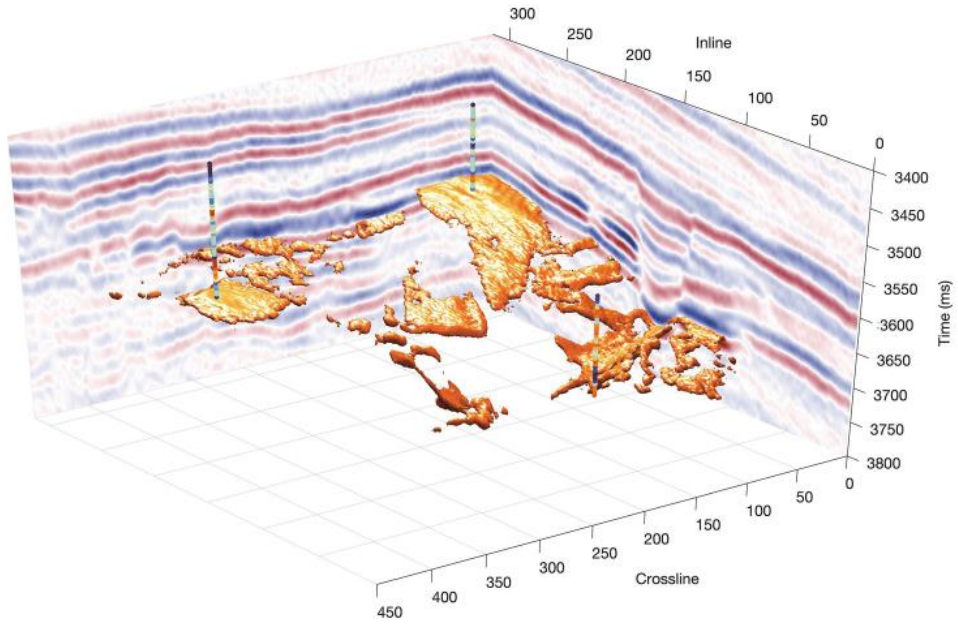
Multimodal Markov Chain Monte Carlo (MMCMC) petro-elastic inversion (Offshore Brazil| Carbonates)

Source: De Figuereido *et al* (2018)

Elastic (*left*) and Petrophysical (*right*) MMCMC seismic facies inversion
(carbonate facies: 1 – high-porosity; 2 – mid porosity; 3 – low porosity)



3D facies geobody
(probability of high-porosity carbonate > 65%)

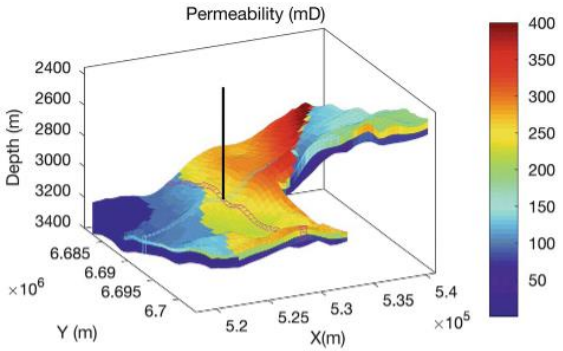


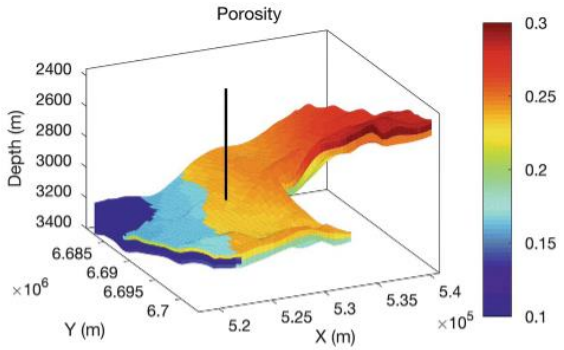
SeReM examples

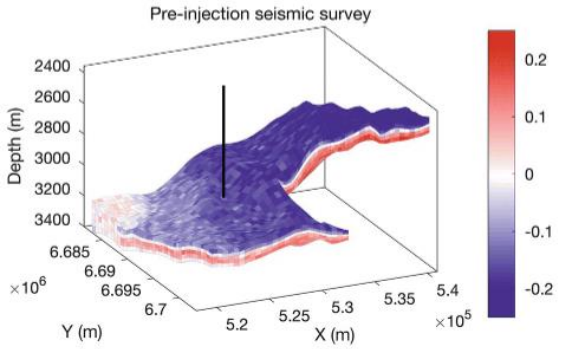
Time-lapse (4D) CO2 modeling, inversion, and uncertainty analysis (Troll field, Norway| Saline Aquifer)

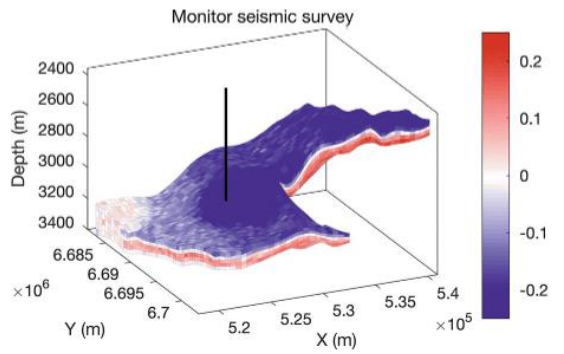
Sources: Liu and Grana (2020); Ayani *et al* (2020)

Reservoir property models (*above*)
and time-lapse (4D) seismic surveys (*below*)

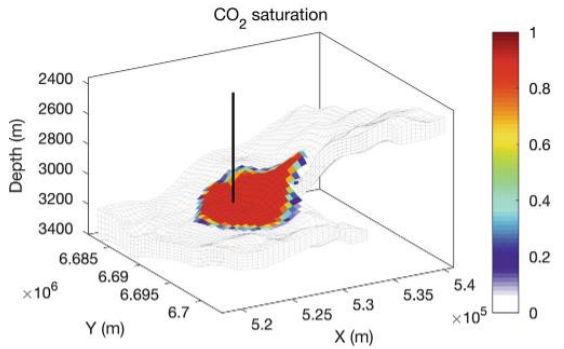


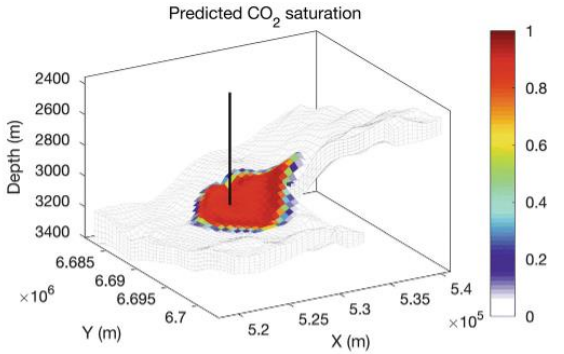


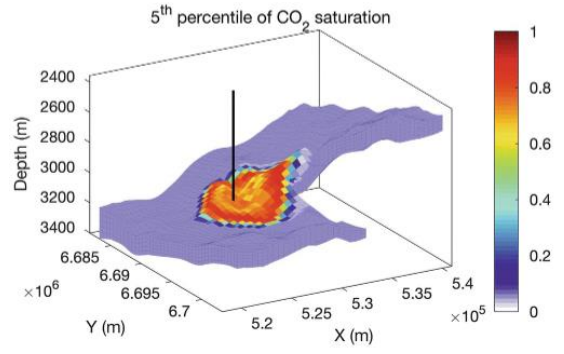


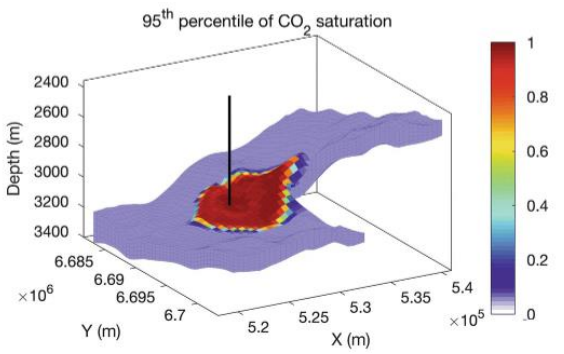


CO2 saturation model (*upper-left*) vs. predicted CO2 saturations
(*upper-right*) and 5%/95% percentiles (*lower*)

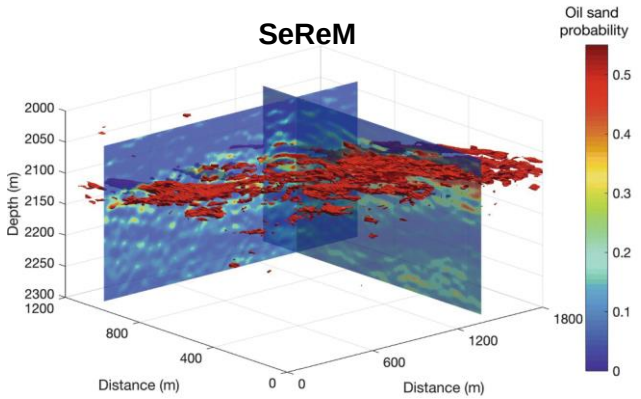








SeReM – MATLAB® code reference



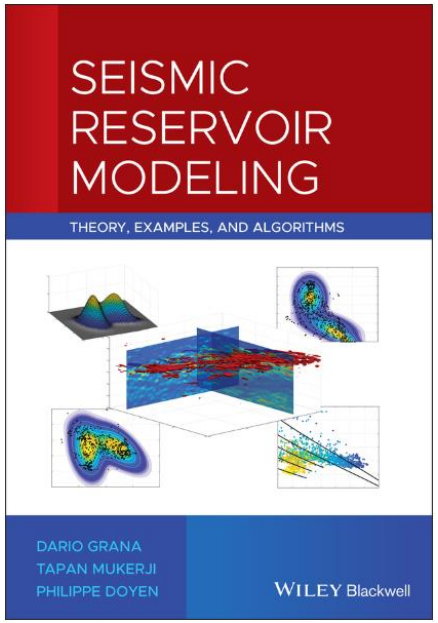
Link: https://seismicreservoirmodeling.github.io/SeReM/

The MATLAB® SeReM package includes five folders:

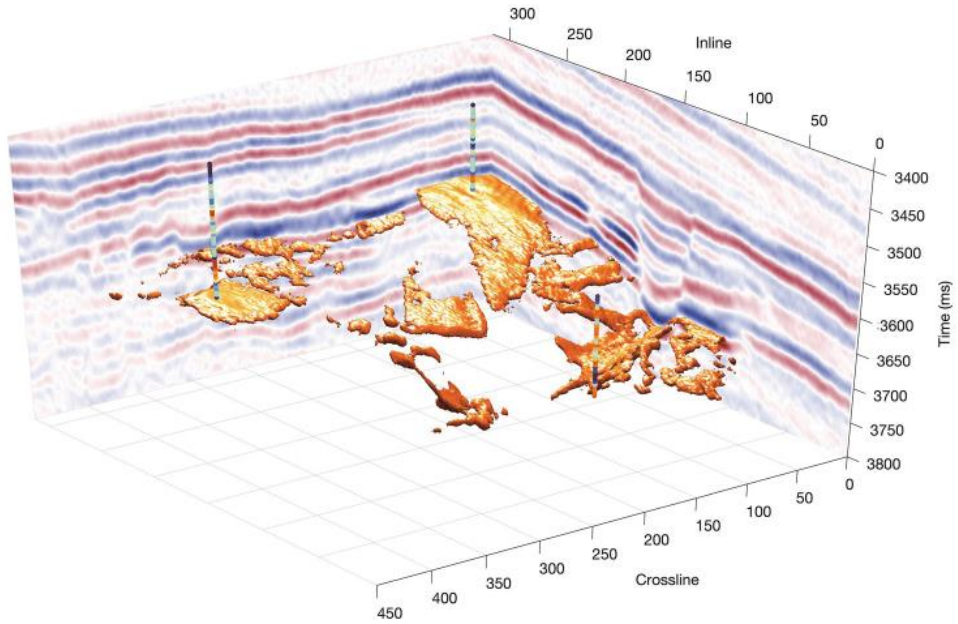
- **Data**: contains six datasets used for the examples and the elevation dataset from Yellowstone National Park.
- **RockPhysics**: contains functions for several rock physics models.
- **Geostats**: contains functions for kriging and geostatistical simulations of random variables.
- **Inversion**: contains functions for seismic and rock physics inversion using analytical and numerical solutions subdivided into : Seismic, Petrophysical, and Ensemble Smoother.
- **Facies**: contains functions for facies classification and simulation.

Reference book: Grana, D., Mukerji, T., and Doyen, P., 2021, Seismic reservoir modeling: Wiley.

MathWorks® SeReM Resources



MATLAB® Seismic Reservoir Modeling (SeReM)



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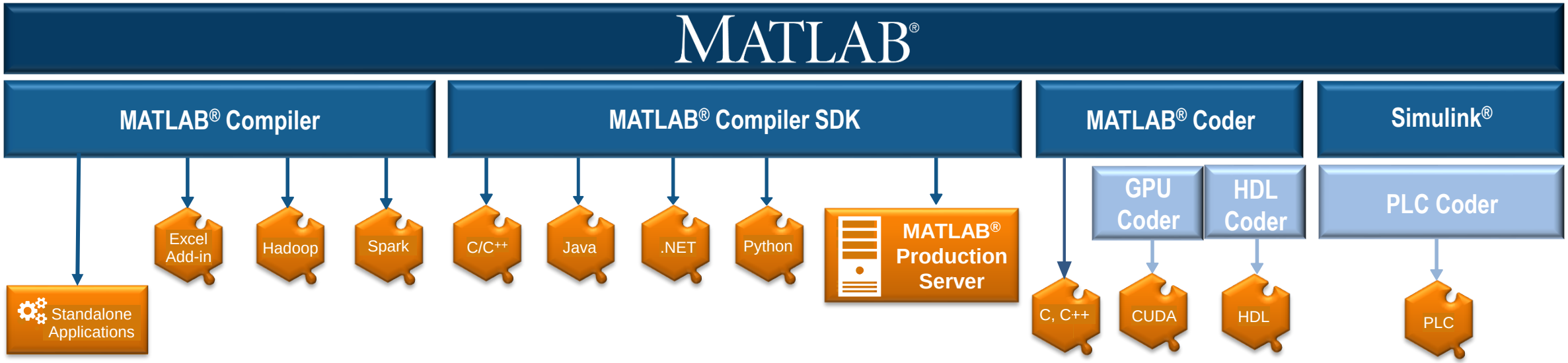

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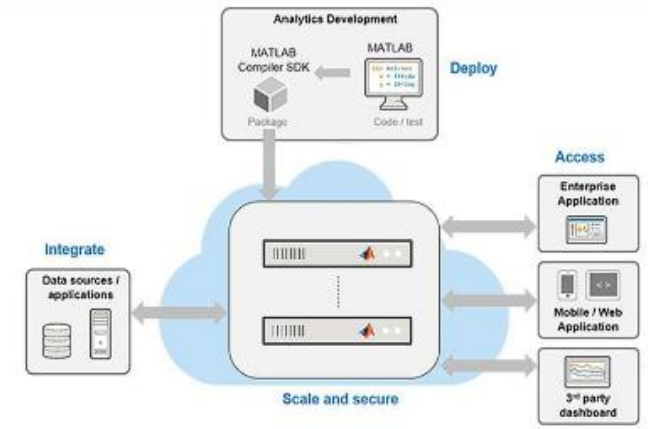

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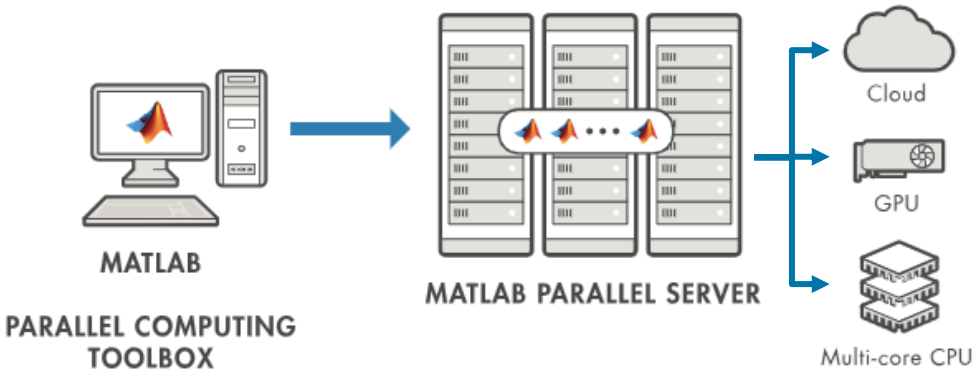

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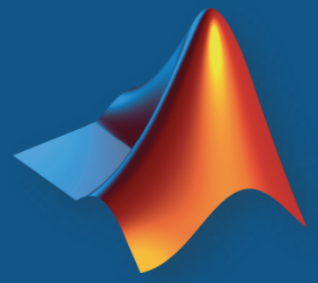

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