IOR Centre workshop with Schlumberger

SLB research during the lifetime of the National IOR Centre of Norway – summary & way forward

Agenda

- Introduction
- Part I: Technology development – lessons learned
- Part II: Bringing data and research solutions together in the cloud*
- Part III: Summary and way forward

* hands-on sessions unfortunately cancelled due to covid restrictions

Team

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D&I - Modeling

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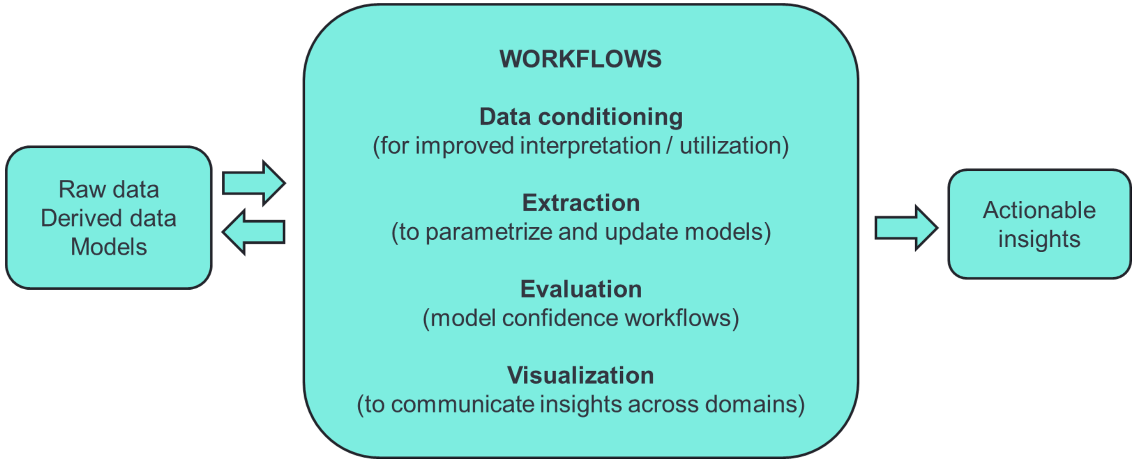
Senior Scientific Computing
Engineer, SNTC

What will we talk about?

Technology development – lessons learned

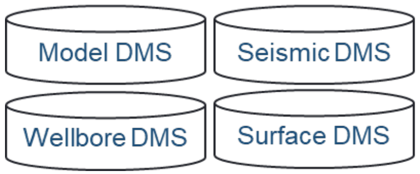


Integration, automation, auditability

Data and model confidence

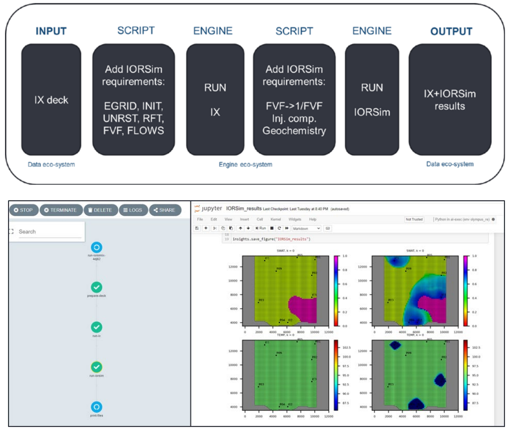
Actionable insights

Bringing data and research solutions together in the cloud

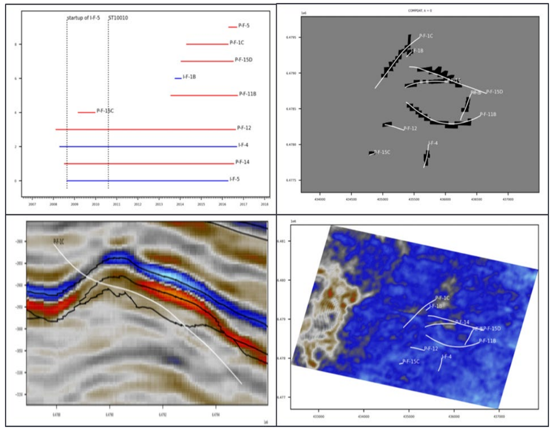


Engine eco-system

```
eclrun.exe
eclipse.exe
ix.exe
```



IX + IORSim in the cloud



Templated analysis*

*Data through courtesy of Equinor and former Volve license partners: https://www.equinor.com/content/dam/statoil/documents/what-we-do/Equinor-HRS-Terms-and-conditions-for-licence-to-data-Volve.pdf

Introduction

Schlumberger

What are **your** objectives?

«I want to make better decisions faster»

«I want to become more efficient»

«I want to share my knowledge with others»

«I want to take part in the energy transition»

«I want to make use of all available data in my analysis»

«I want to include all relevant processes in my modeling»

«I want to develop new digital skills»

«I want to have fun while making an impact»

«I want to find the right solution to the right problem»

SLB research focus in Norway during lifetime of the IOR Centre: Improving and automating subsurface characterization workflows

Raw data
Derived data
Models

⇄

WORKFLOWS

Data conditioning
(for improved interpretation / utilization)

Extraction
(to parametrize and update models)

Evaluation
(model confidence workflows)

Visualization
(to communicate insights across domains)

⇒

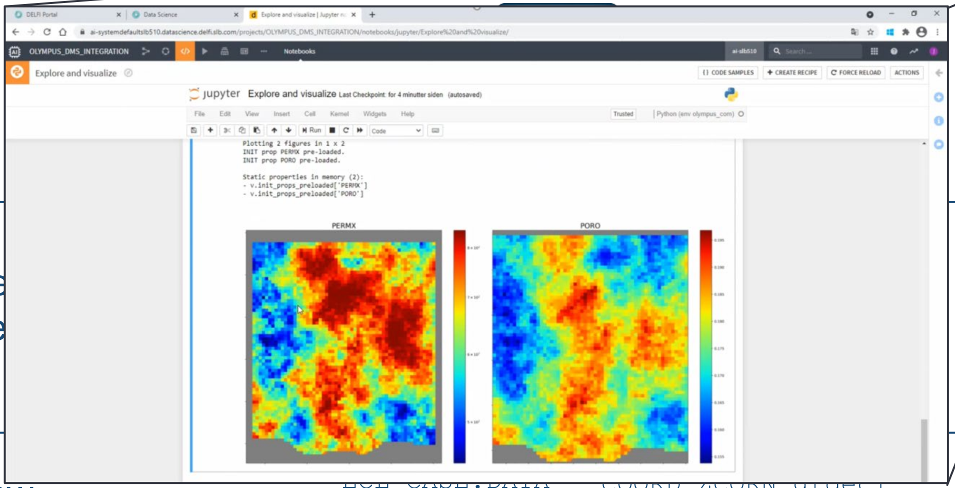
Actionable insights

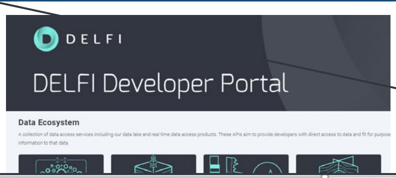
New access patterns enabled by liberated data and engines

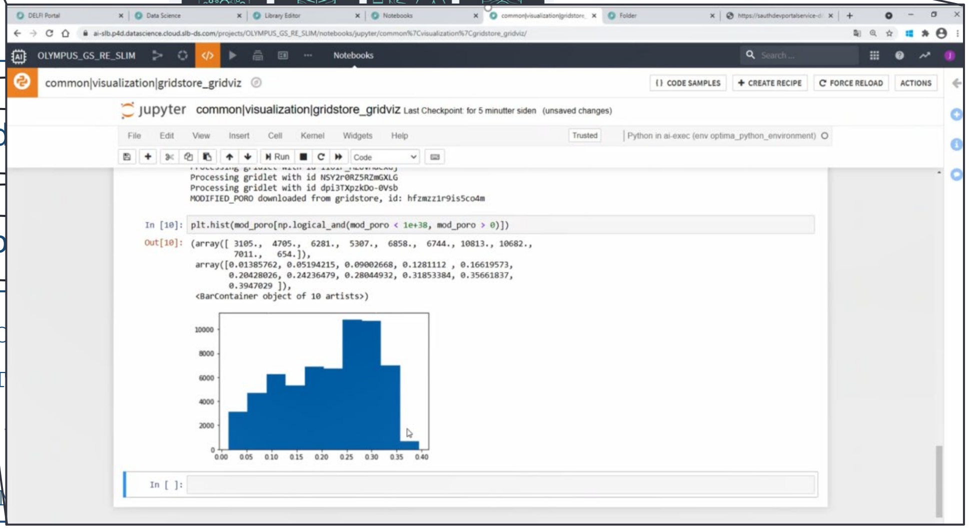
End users — Consume — Request features — Consume & innovate — Fast track Customize

Applications: ECL, IX, VIS, DELFI native apps — «NEW SWEET SPOT» — TIBCO Spotfire, data iku, jupyter, python Package Index

APIs







Data manage... system and e...

Mod...

Wellb...

DATA — Raw, Derived, Modeled

ECL_CASE.DATA COORD_ZCORN.grdecl IX_CASE.afi IX_C...
ECL_CASE.EGRID PORO.grdecl POROSITY.gsg POROSIT...
ECL_CASE.INIT ECL_CASE.UNRST IX_CASE.INIT IX_CASE...
ECL_CASE.h5 ECL_CASE.SMSPEC IX_CASE.h5 IX_CASE.SM...

Advantages of a cloud environment for research solutions

<u>Before</u>

Peer-to-peer setup and maintenance

Difficult to share and collaborate

<u>Now</u>

Setup and maintenance once and for all (software-as-a-service)

Open and extensible

Easier to share examples and collaborate

Shared environment for both petro-technical experts and data scientists

Workshop focus

- Part I: Technology development – lessons learned
  - Reservoir modeling and simulation / history matching
  - Analysis of seismic data
- Part II: Bringing data and research solutions together in the cloud
  - Liberated data and engines (IORSim as the most recent example)
  - Democratizing innovation through «innovation toolkit»
  - Examples and demos
- Part III: Way forward
  - The digital journey of geoscientists and reservoir engineers
  - Energy transition
  - Closing remarks
- Please ask questions, share experience and give advise!

Questions and comments?

Next: Technology development – lessons learned

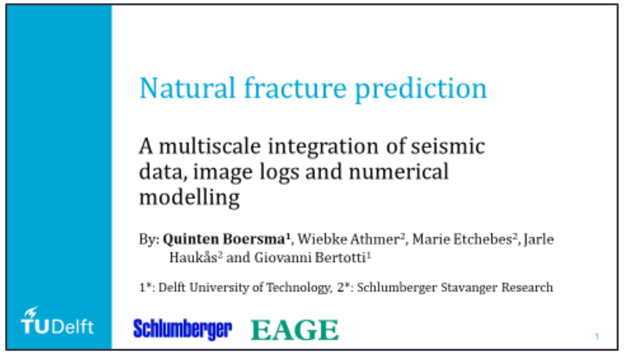
Part I: Technology development – lessons learned

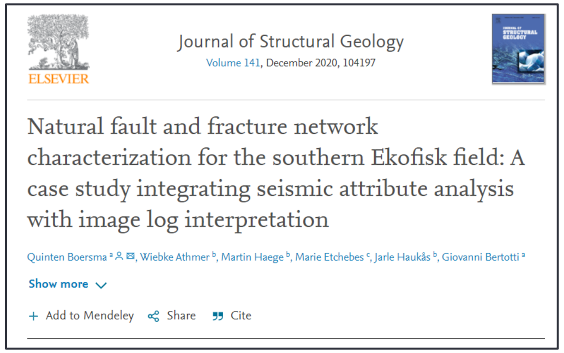
Schlumberger

Overview

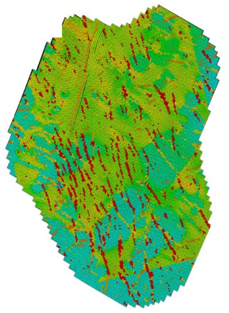
- Methodology and workflow development
- Tests on real data (e.g. Ekofisk)
- Cross-domain G&G and RE focus

- Reservoir modeling and simulation / history matching
- Analysis of seismic data

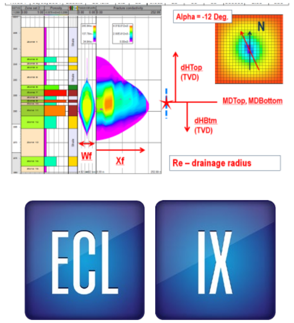




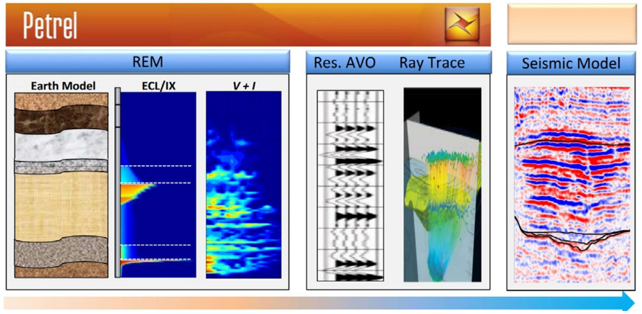
Reservoir modeling and simulation / history matching



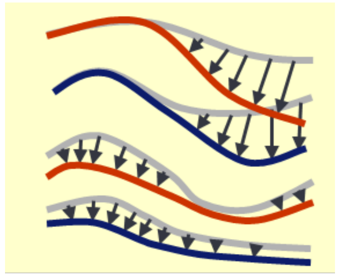
High resolution gridding (LGR)
Data-driven property modeling



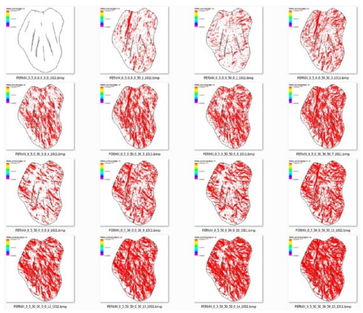
Simulation tools
Extensibility (e.g. IORSim)



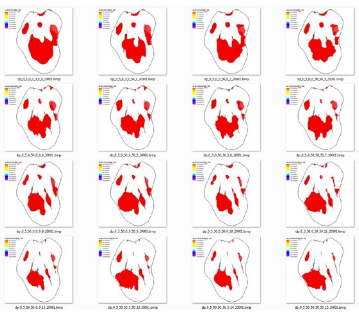
Simulation results to synthetic seismic



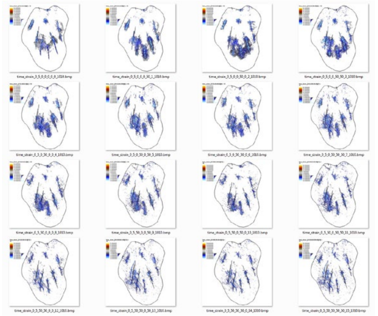
4D data extraction
(e.g. time shift & time-strain)



Multiple realizations (permeability)



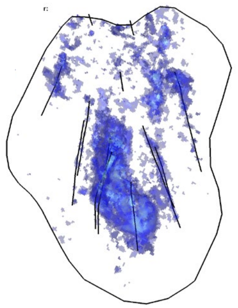
Simulated changes (pressure, saturation)



Predicted 4D (time-strain)

Model vs data
Rank / accept / reject

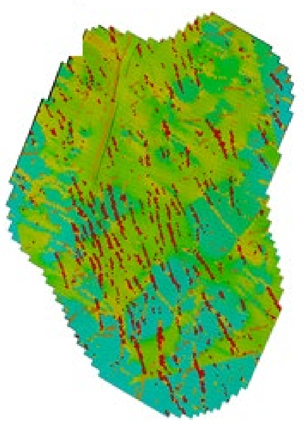
Orchestration



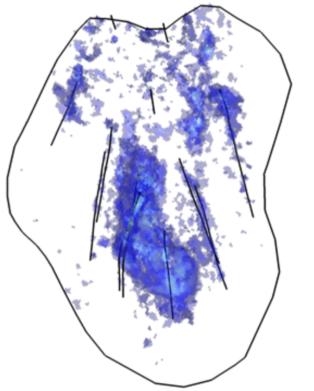
Observed 4D (time-strain) in grid

Ref: Analysis of enhanced permeability using 4D seismic data and locally refined simulation models, J. Haukås, W. Athmer, J.Ø.H. Bakke, Q.D. Boersma, A. Bounaim, M. Etchebes, P.G. Folstad, R.Moe, C. Pacheco and E. Tolstukhin. IOR Norway 2018.

Lessons learned



What are actionable insights?

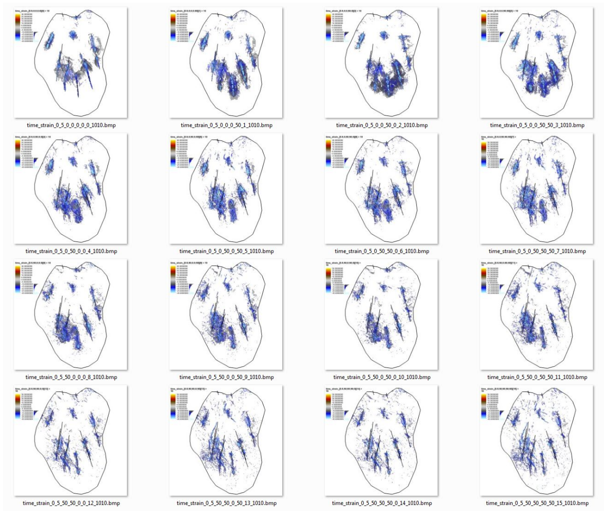


- Need better ways of capturing and sharing **insights**
- Focus on data and model **confidence** and **auditability**

- Need quicker turn-around: Gather data – interpret – extract – model – revisit

- Need to improve **automation** and **portability across projects**

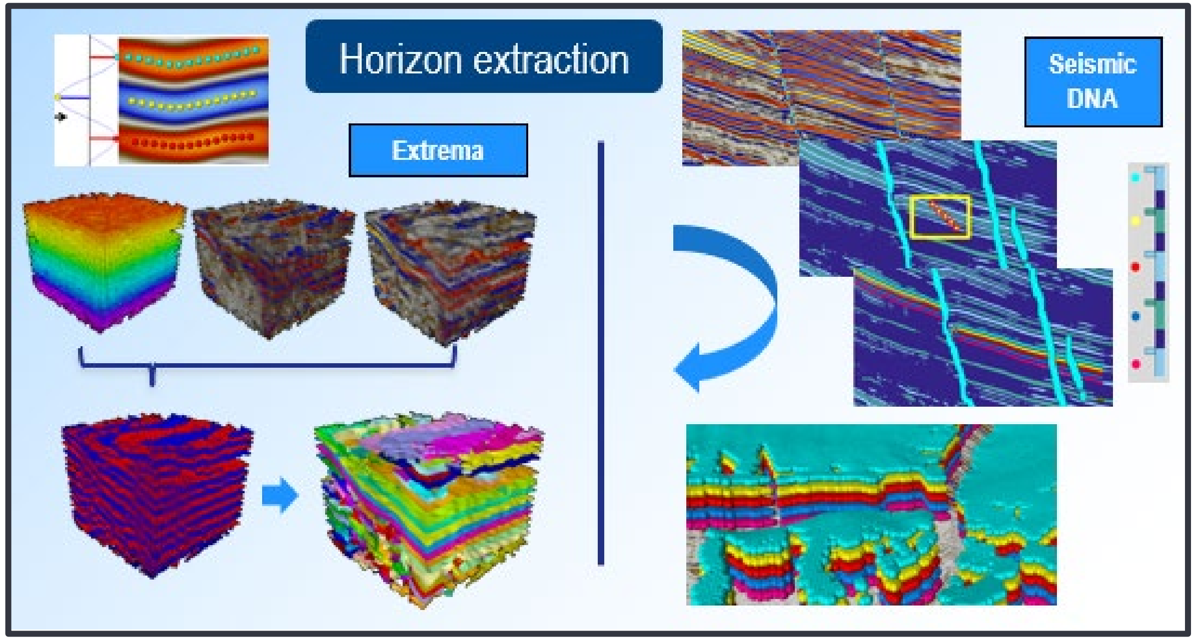
- Vision: *Automatically scan through all data, find interpretable features and relationships, update models and continuously discuss impact / gaps / possible improvements

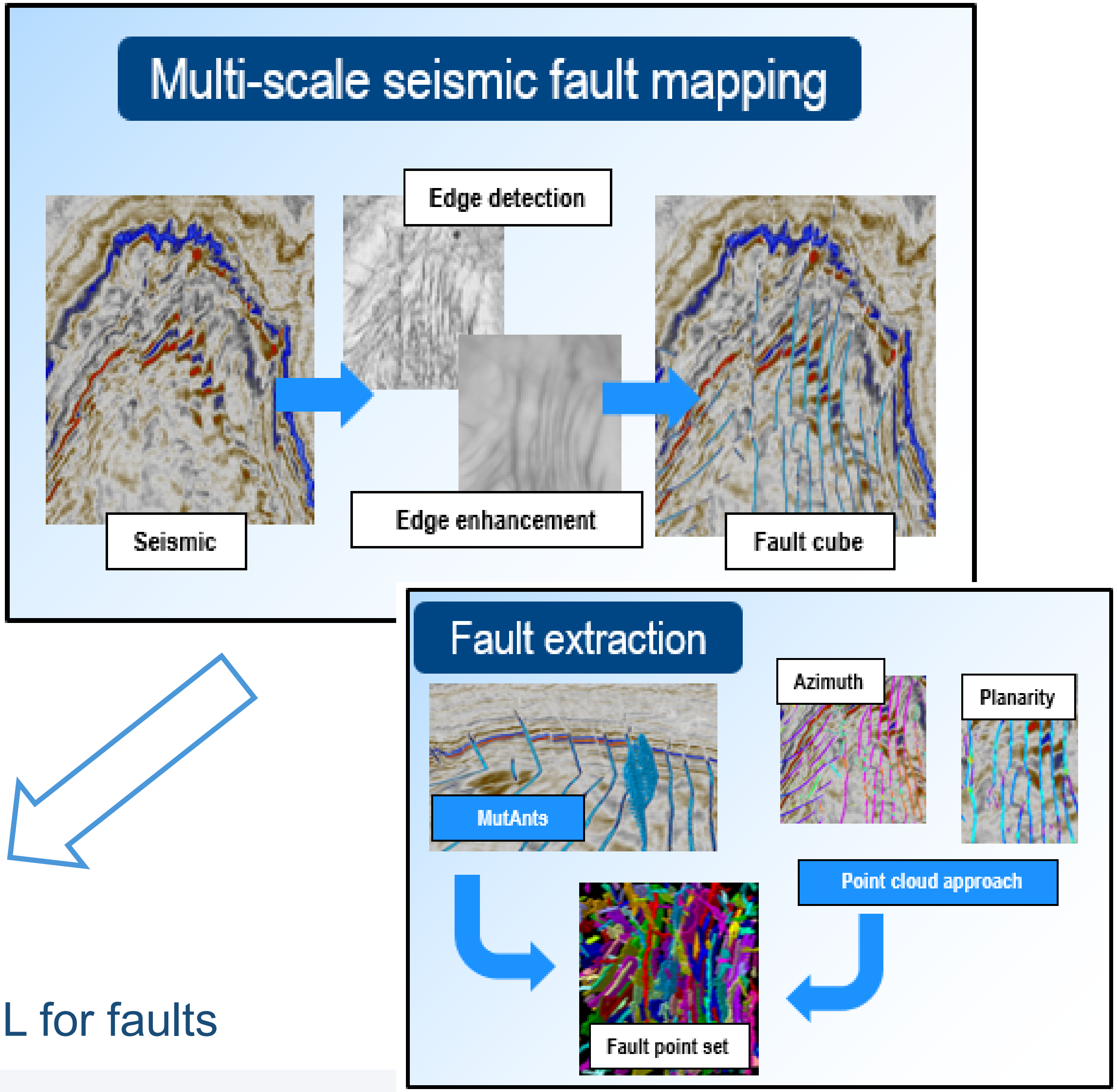


* addressed in Part II: Bringing data and research solutions together in the cloud

Ref: Analysis of enhanced permeability using 4D seismic data and locally refined simulation models, J. Haukås, W. Athmer, J.Ø.H. Bakke, Q.D. Boersma, A. Bounaim, M. Etchebes, P.G. Folstad, R.Moe, C. Pacheco and E. Tolstukhin. IOR Norway 2018.

Automated extraction of key surfaces and faults

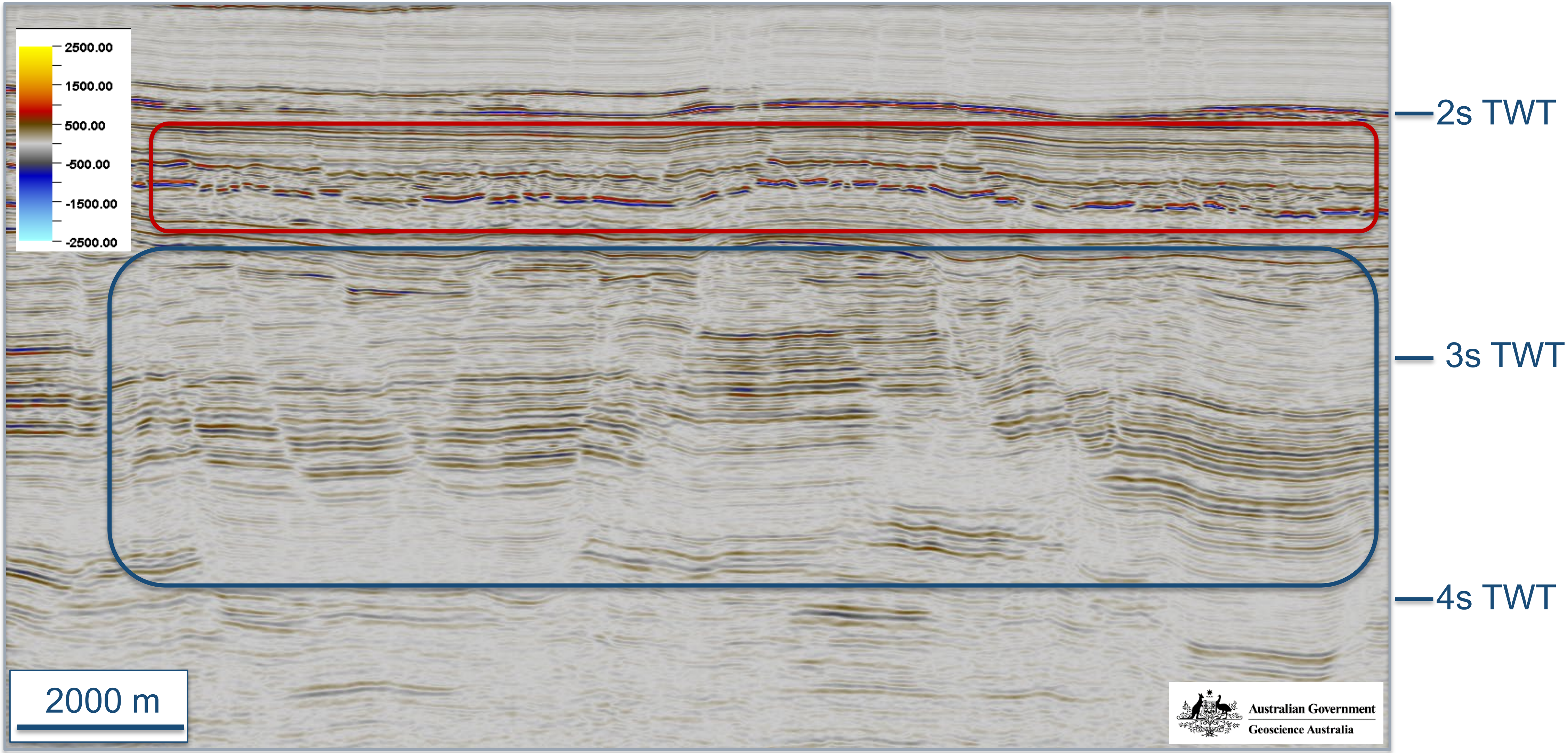




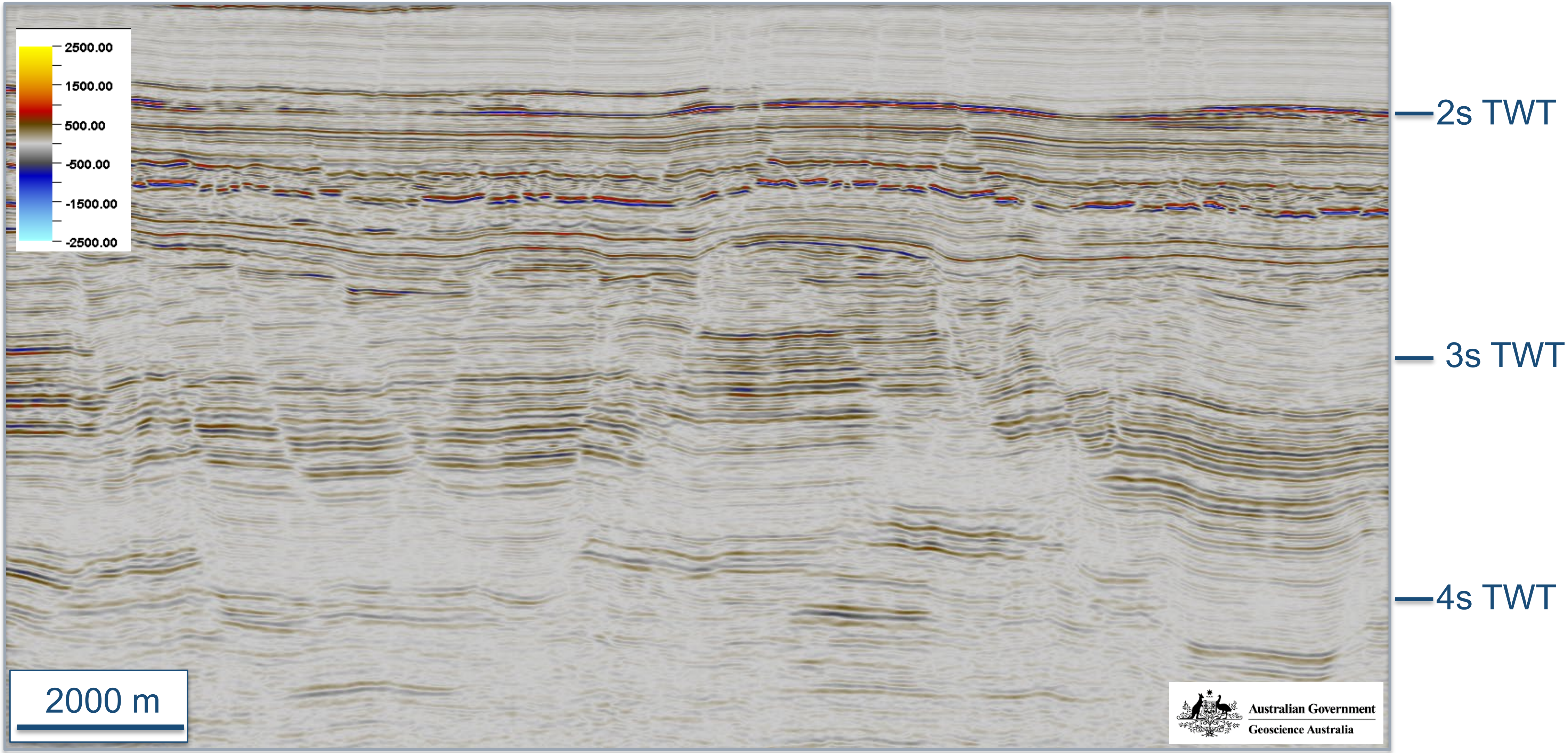
Machine Learning

Development from manual interpretation to ML for faults

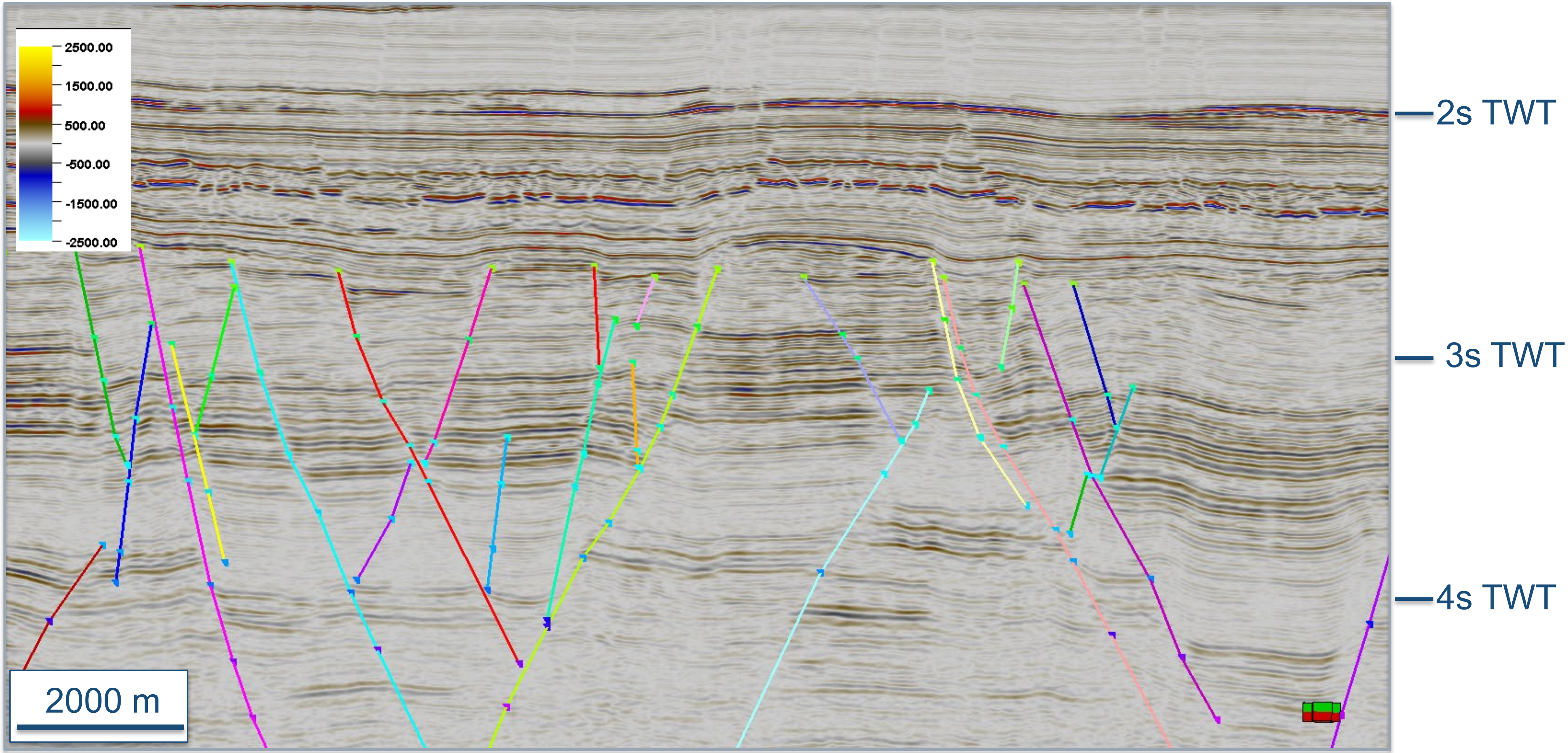
Seismic-scale faults



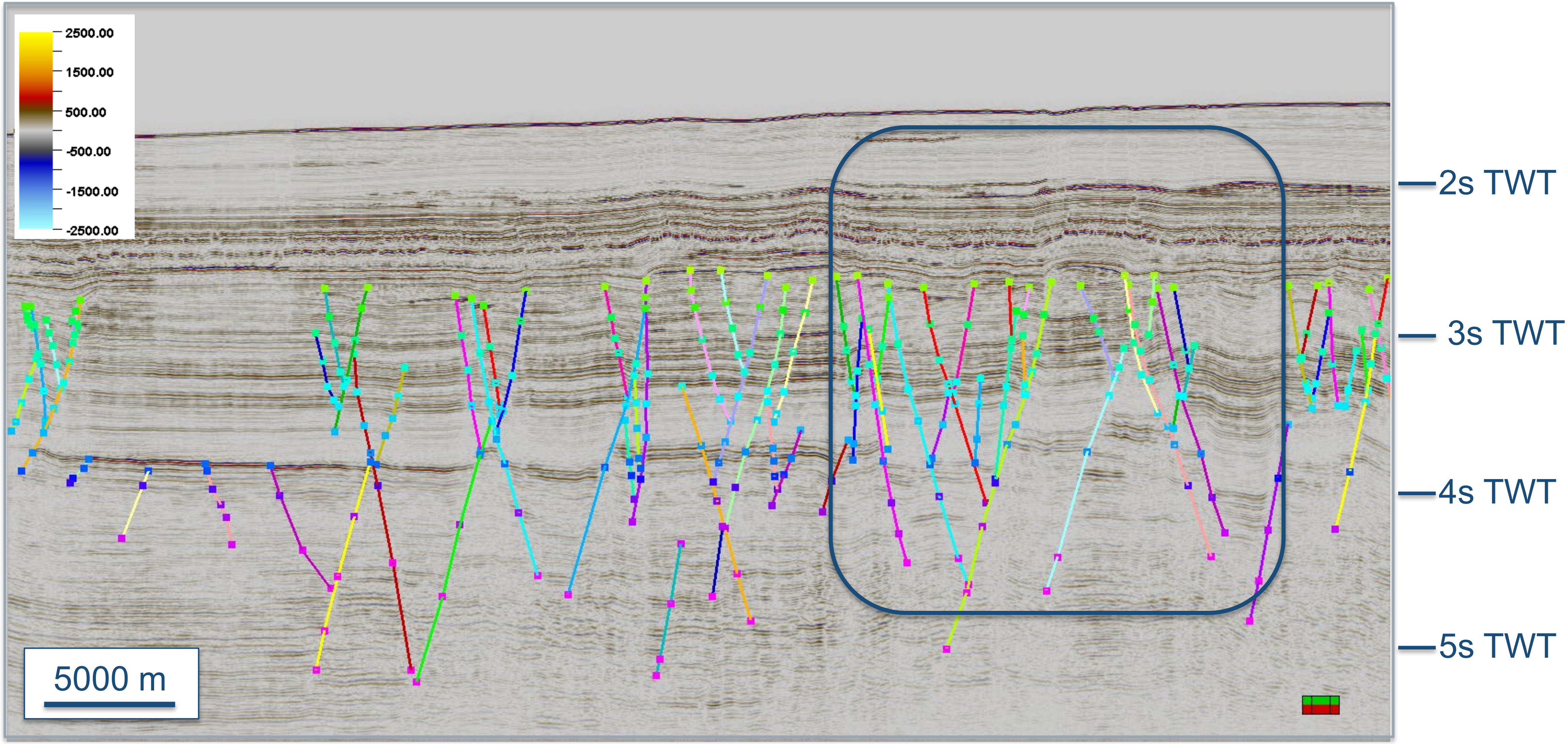
Large-scale faults



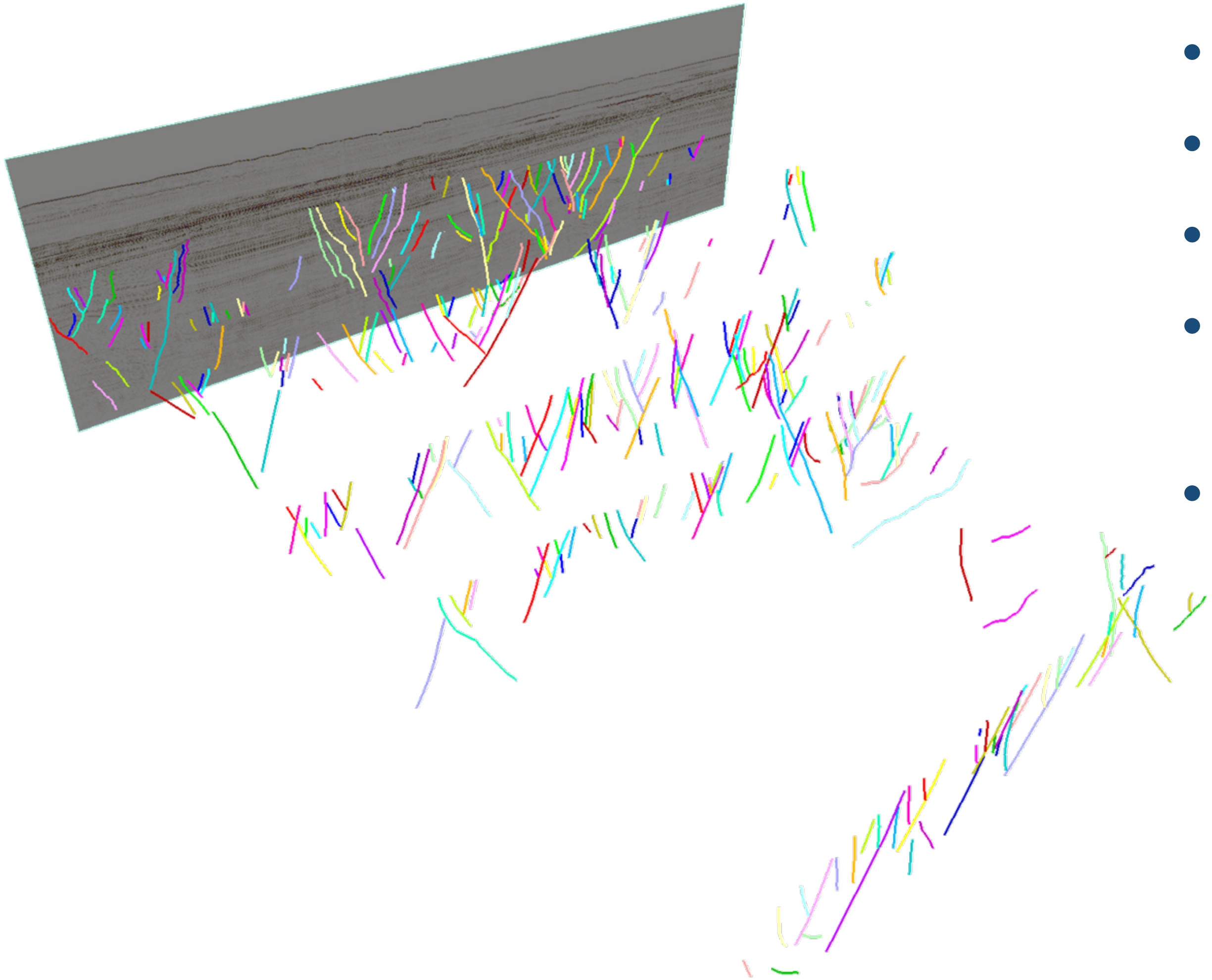
Large-scale faults – manual interpretation



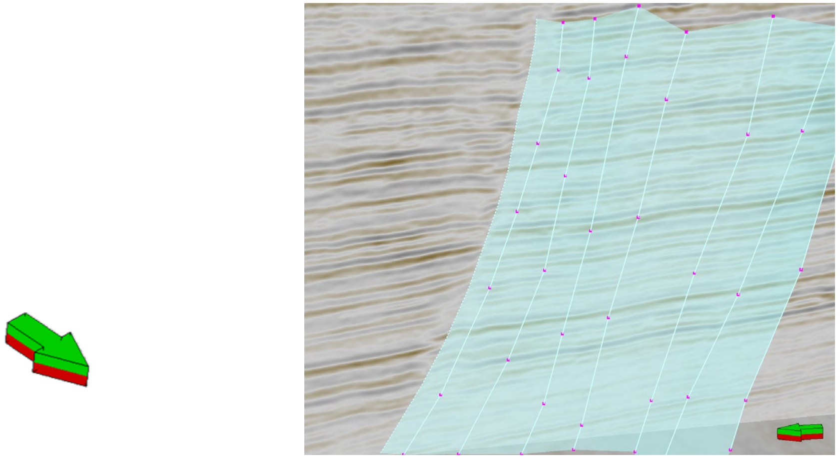
Large-scale faults – manual interpretation



Large-scale faults – manual interpretation

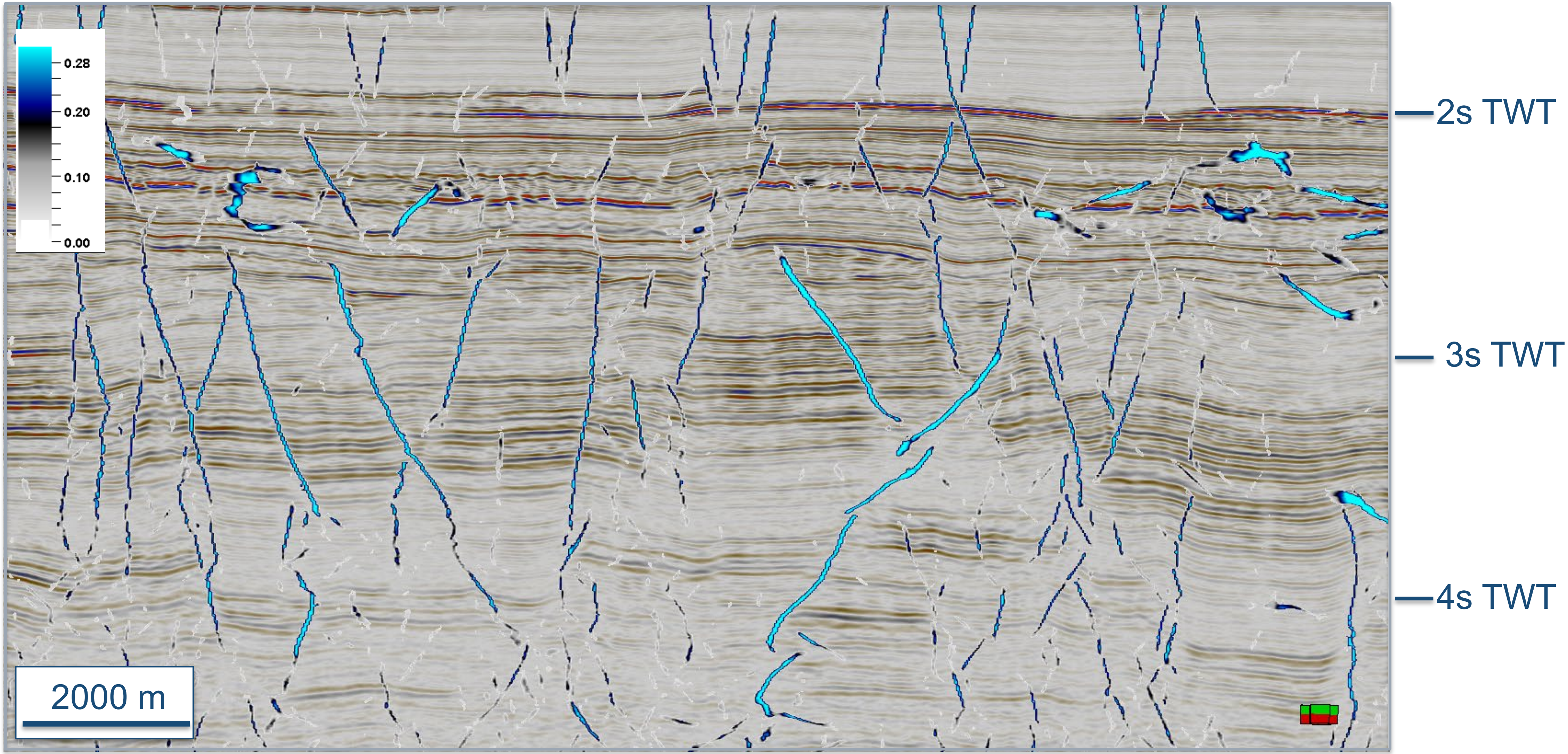


- Interpretation on every n-th section
- Focus on main faults
- Time-consuming
- Result dependent on interpretation grid and user epxerience
- Limited accuracy due to interpolation across unmapped areas

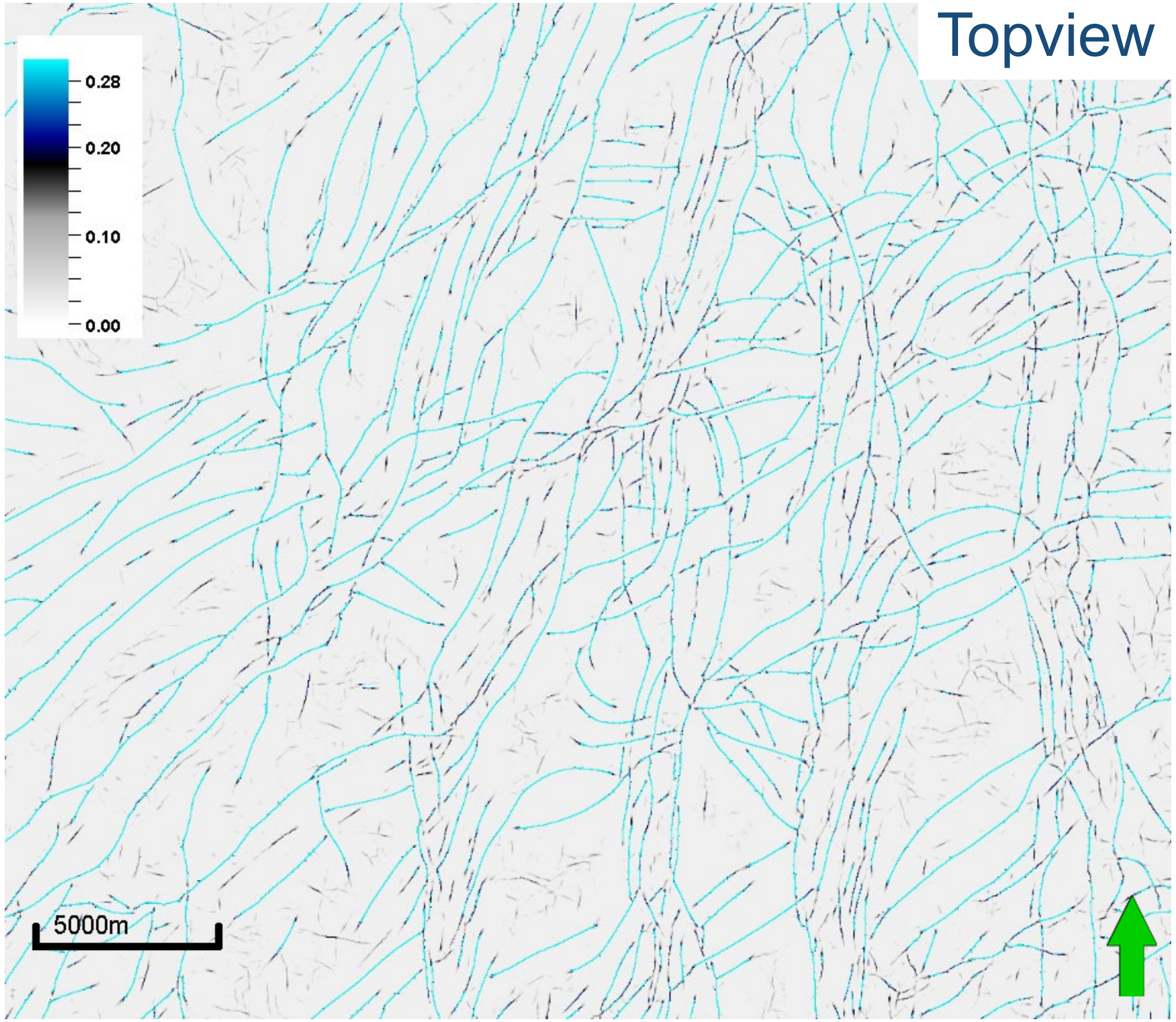


Multi-scale faults – attribute-based mapping

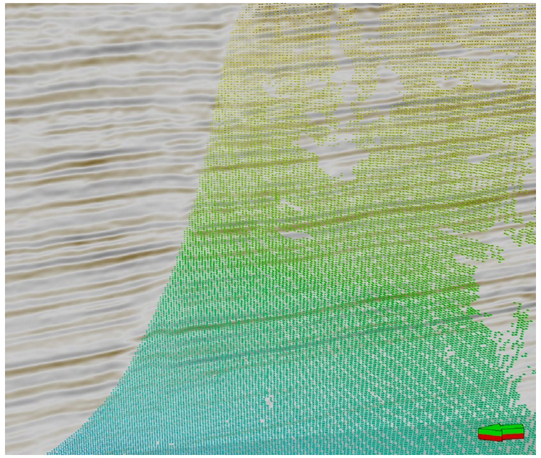
Edge detection
↓
Edge enhancement I
↓
Background adjustment
↓
Edge enhancement II
↓
Fault cube generation
↓
Ridge-optimized fault cube



Multi-scale faults – attribute-based mapping



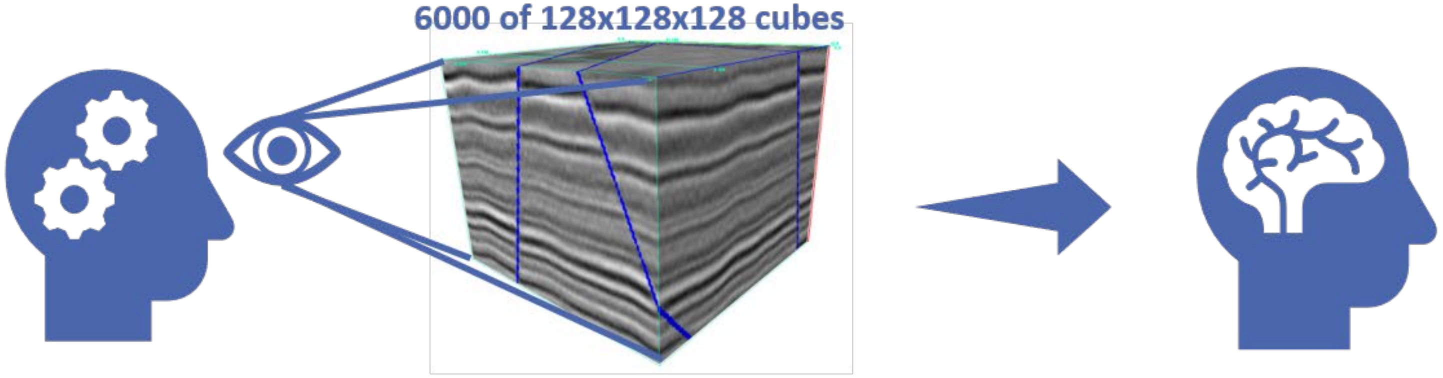
- Combination of seismic attributes
- Focus on multi-scale faults
- Accuracy at seismic sample resolution, determined by the seismic condition (e.g. signal-to-noise ratio)
- Faster than manual interpretation, but attribute computation takes time

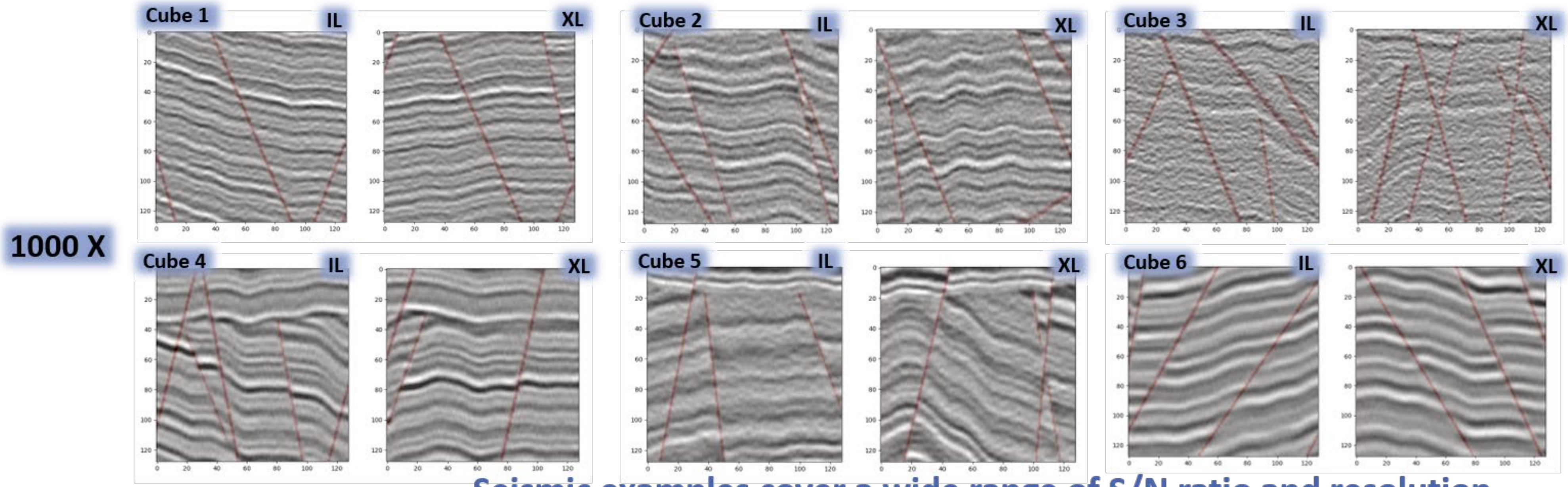


Seismic-scale faults – ML approach

- Machine learning (ML) is a subdivision of artificial intelligence (AI) in which algorithms such as neural networks (NN) are designed to learn from data
- ML training is typically performed on
  - labeled images derived from a subset of the same seismic data with corresponding fault interpretations
  - seismic and interpretation of other surveys
  - synthetic seismic and labels
- **Synthetic training** data has the advantages over interpretations on real data that no seismic data is needed, labelling is sample-accurate, no expert interpreter is needed, and the volume of training data is only hardware-limited

3D CNN trained by synthetic data

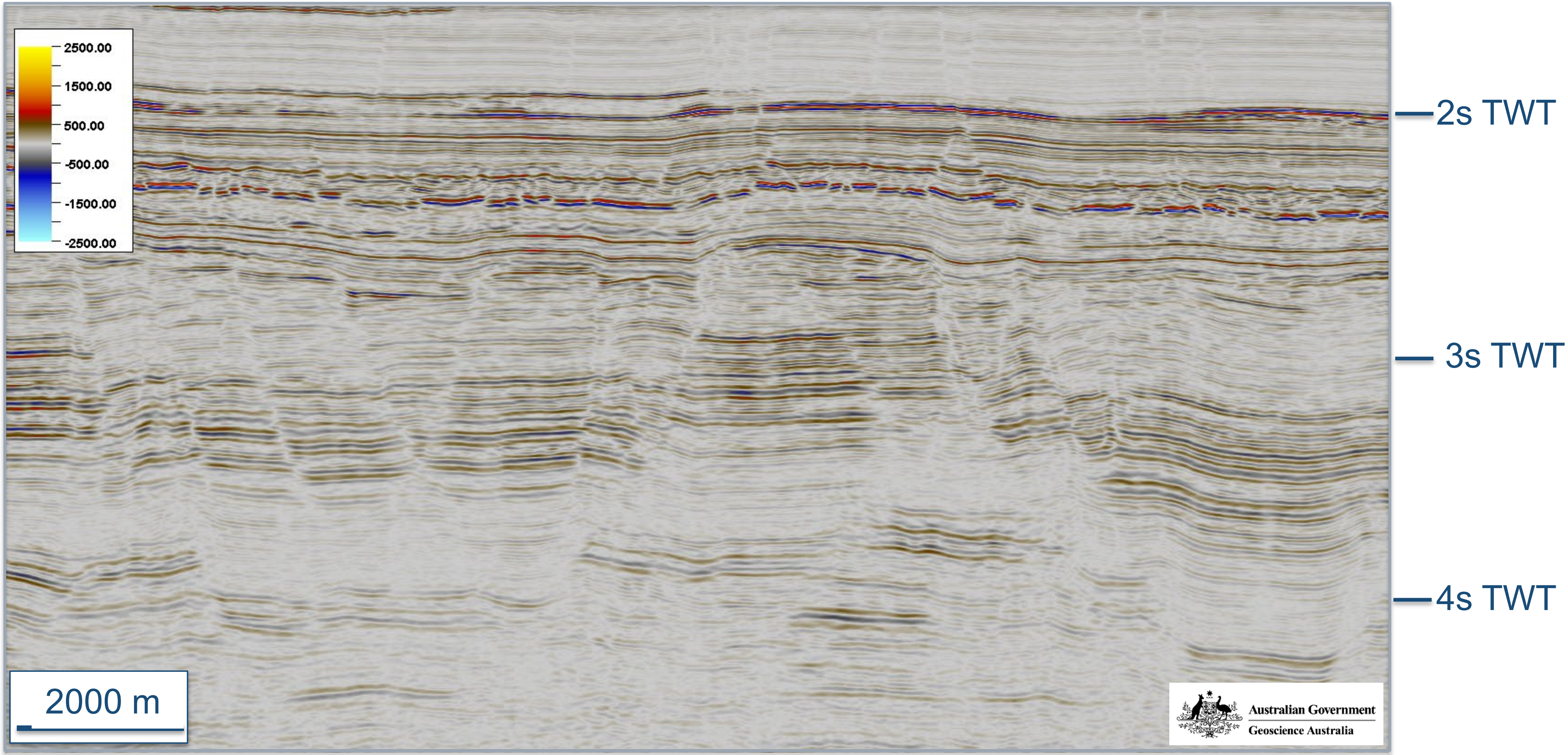




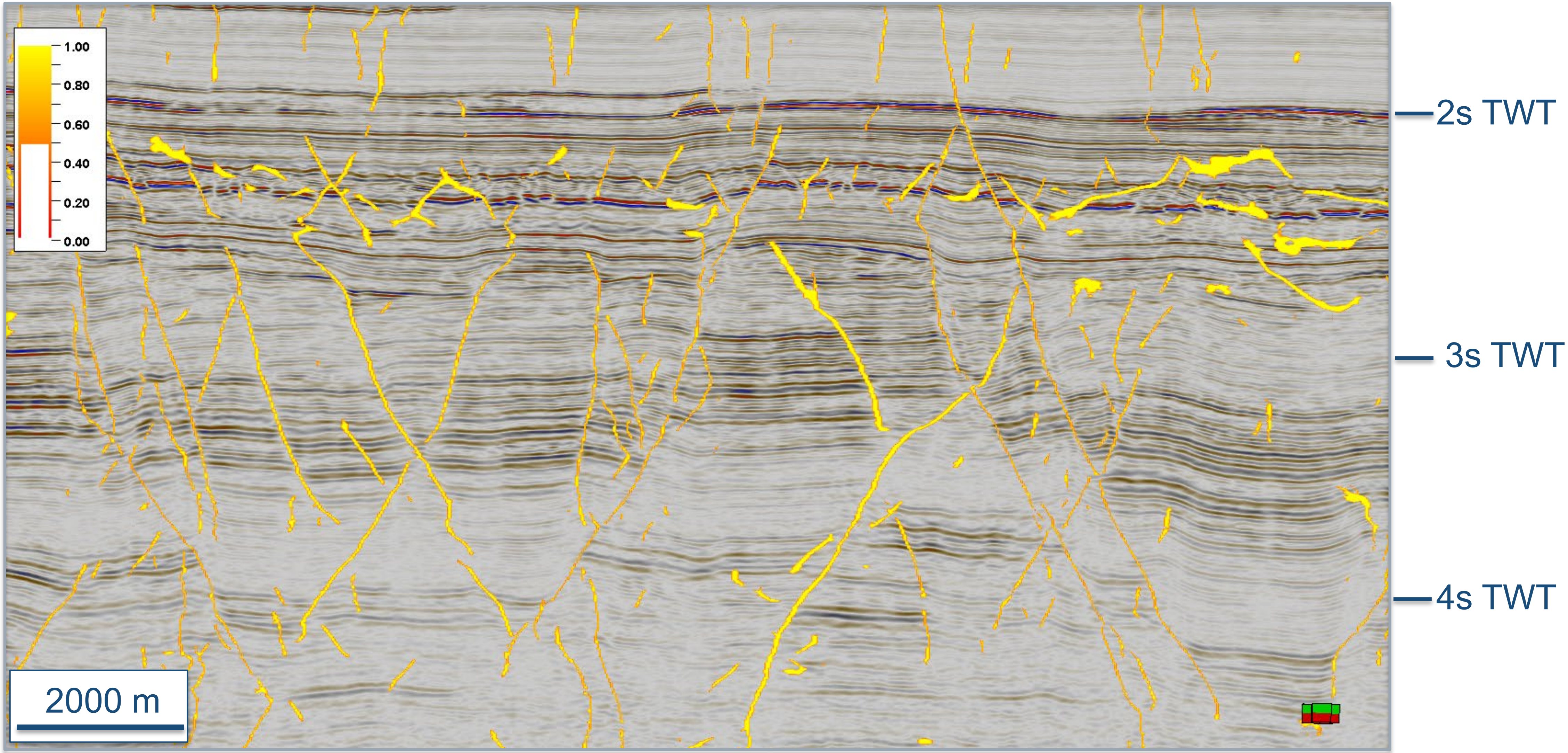
- Reflectivity
- Faulting
- Deformation/folding
- Erosion/unconformity
- Diapirs
- Regional amplitude variations
- Variation in bandwidth
- Coherent noise

Seismic examples cover a wide range of S/N ratio and resolution

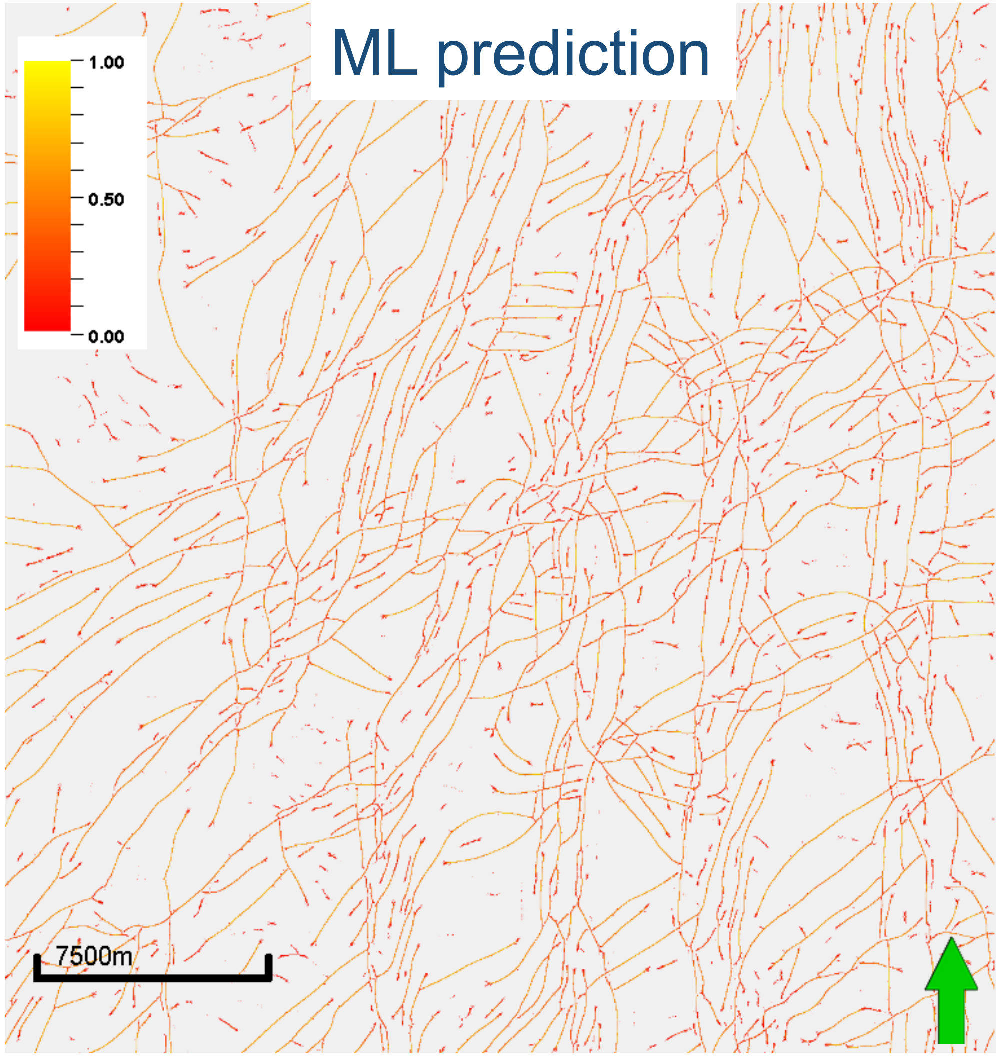
Seismic-scale faults

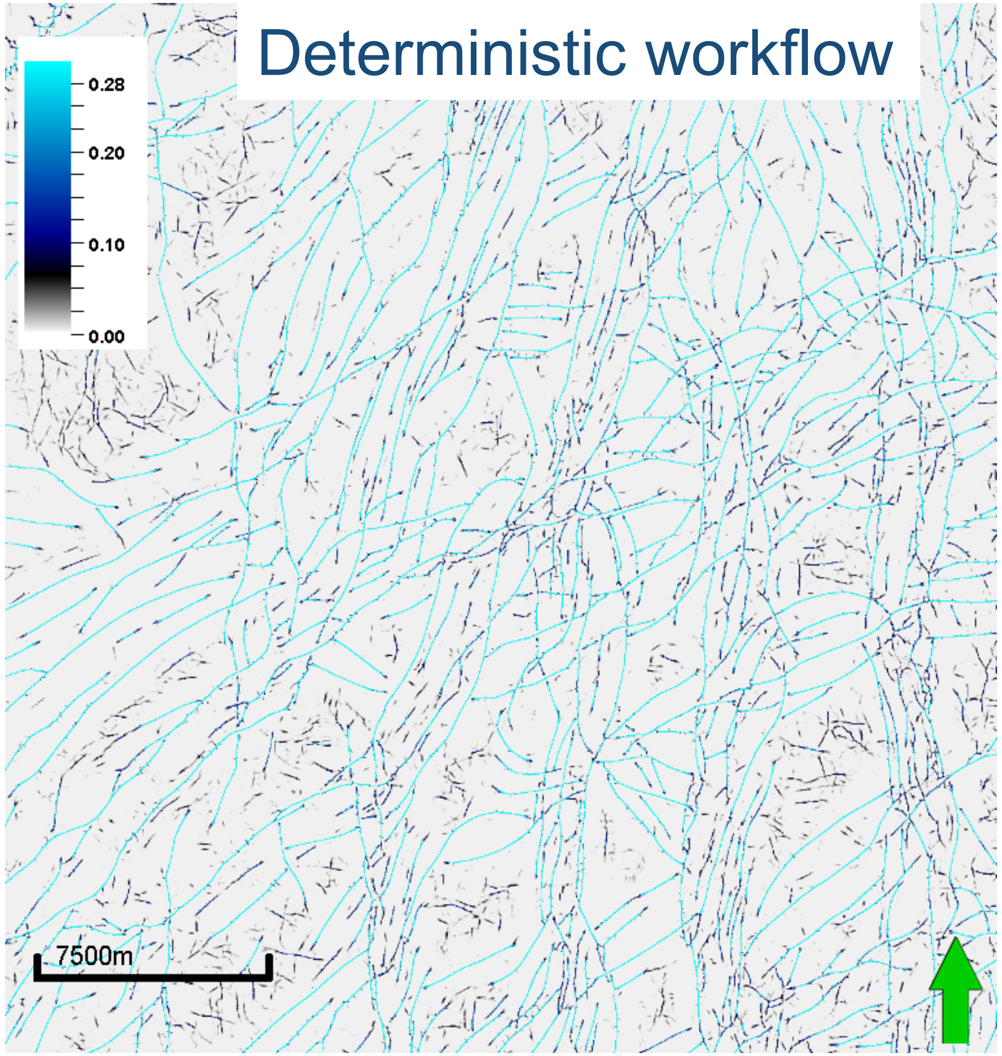


ML fault prediction



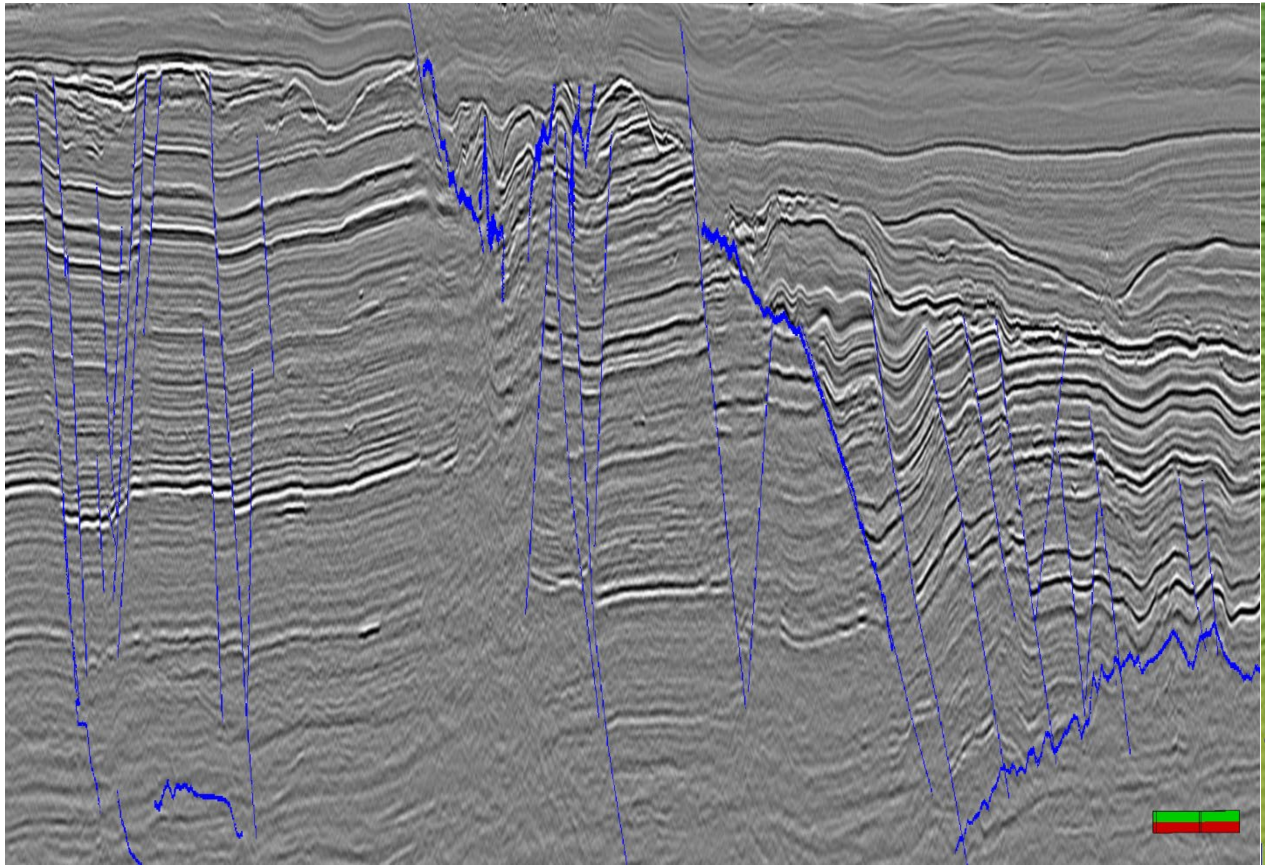
Comparison of ML faults with deterministic result



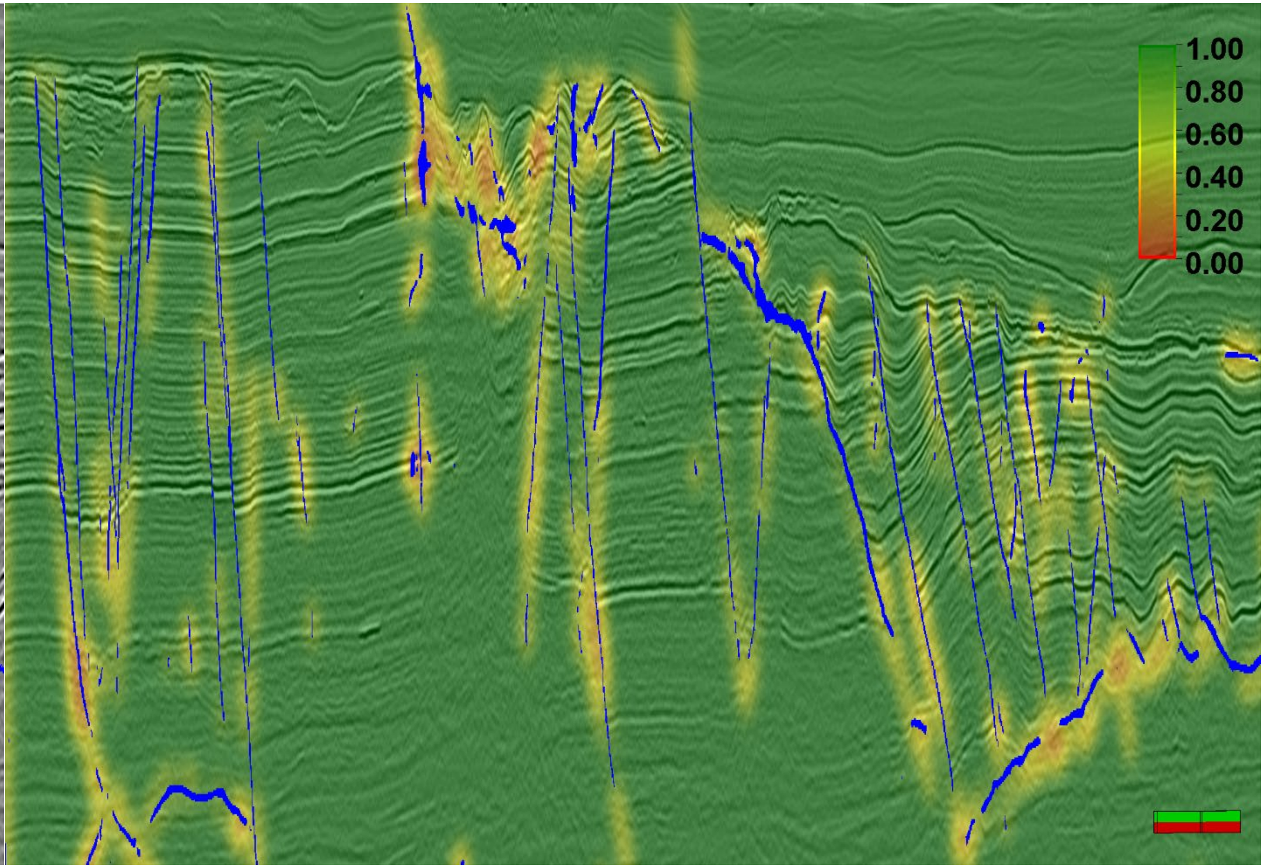


Metric

3D manual interpretation



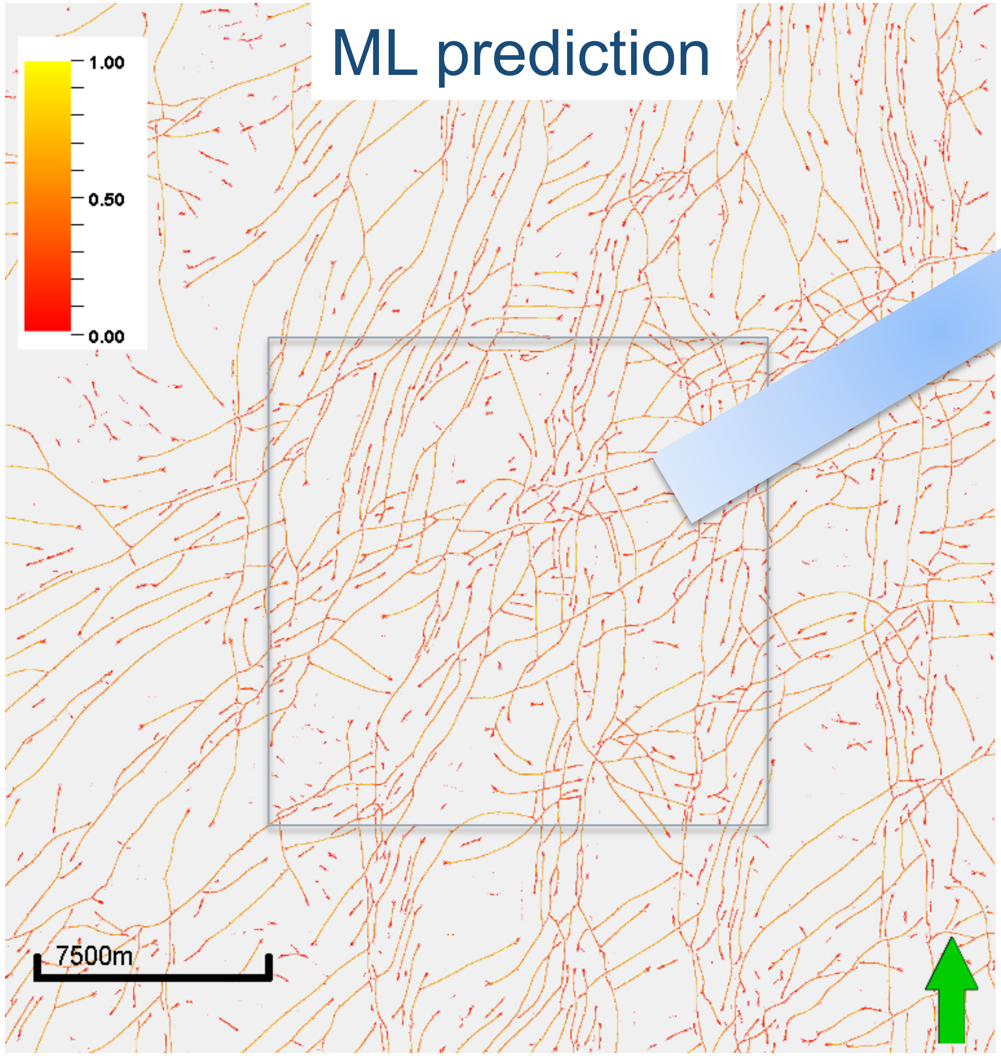
3D synthetic ML prediction

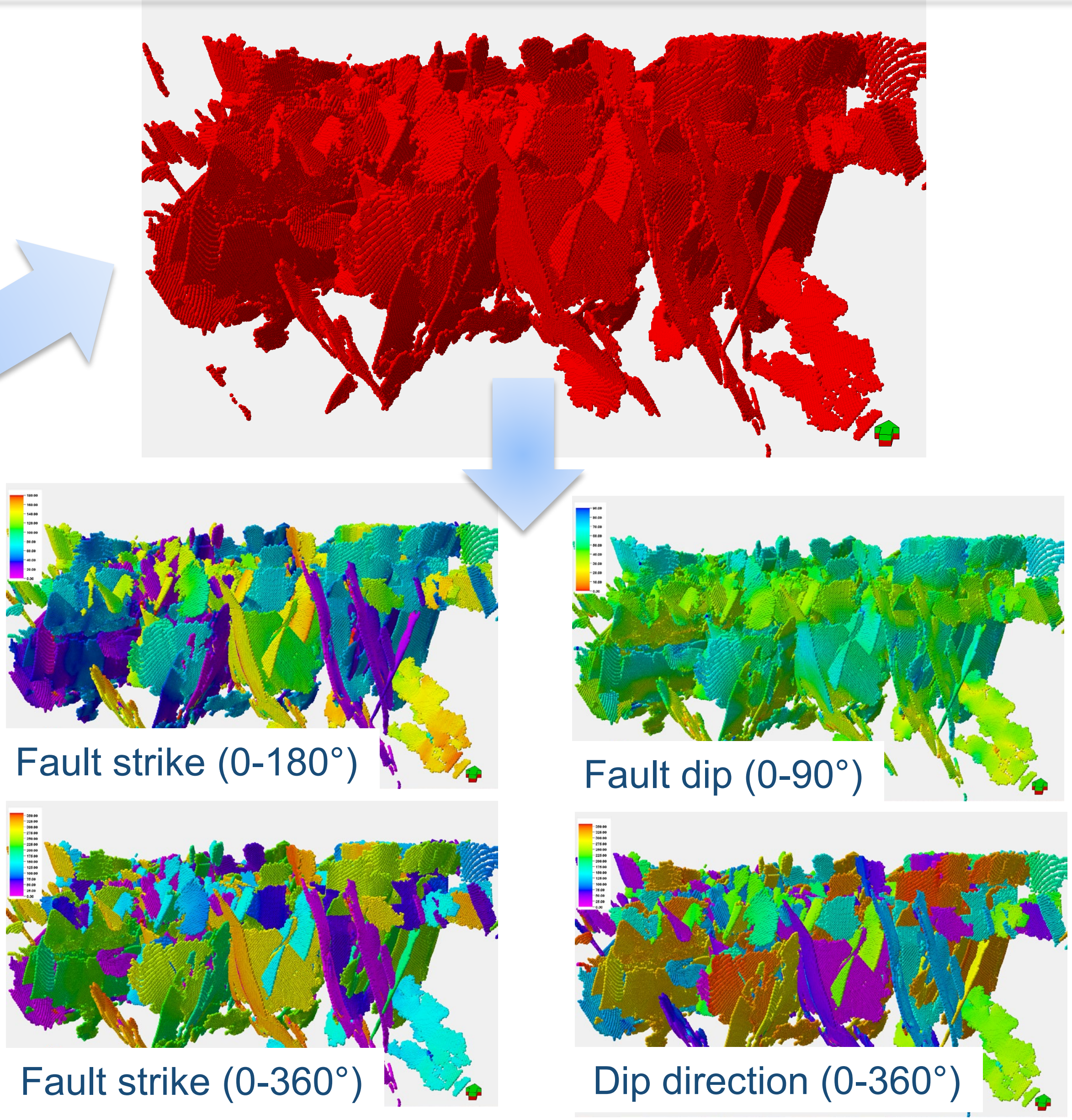


SARAJAERVI et al. (2020): Robust Evaluation of Fault Prediction Results: Machine Learning Using Synthetic Seismic. *First EAGE Digitalization Conference & Exhibition*, Online.

BOUNAIM et al. (2013): Large Fault Extraction Using Point Cloud Approach to a Seismic Enhanced Discontinuity Cube. *75th EAGE Conference & Exhibition incorporating SPE EUROPEC 2013*, London.

Fault extraction





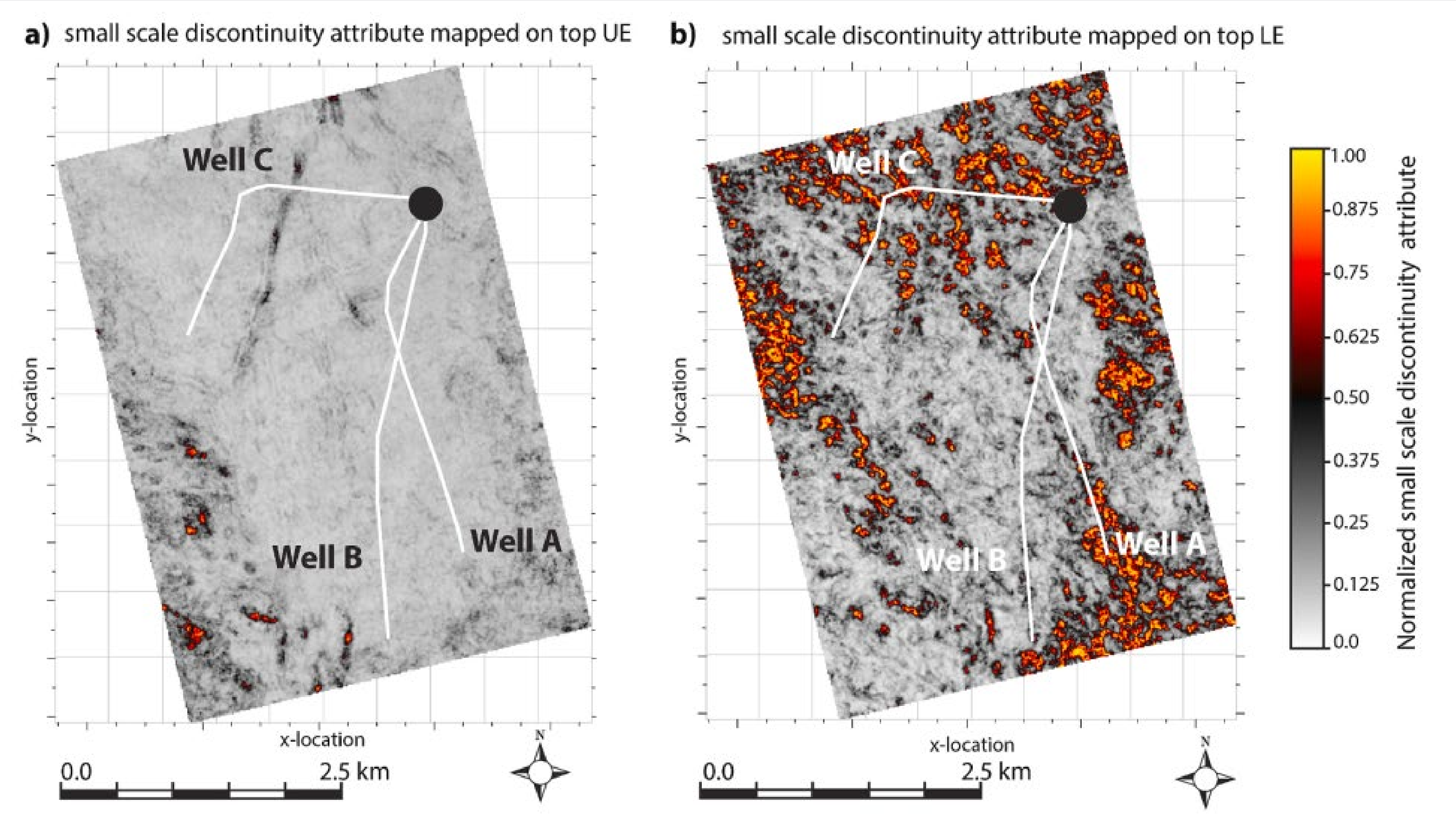
Fracture characterization: new seismic attribute

References:

Haege, M., Maxwell, S., Sonneland, L. & M. Norton (2014), New 3-D seismic vector attribute explains hydraulic fracture behavior, *The American Oil & Gas Reporter*, 86-91, March.

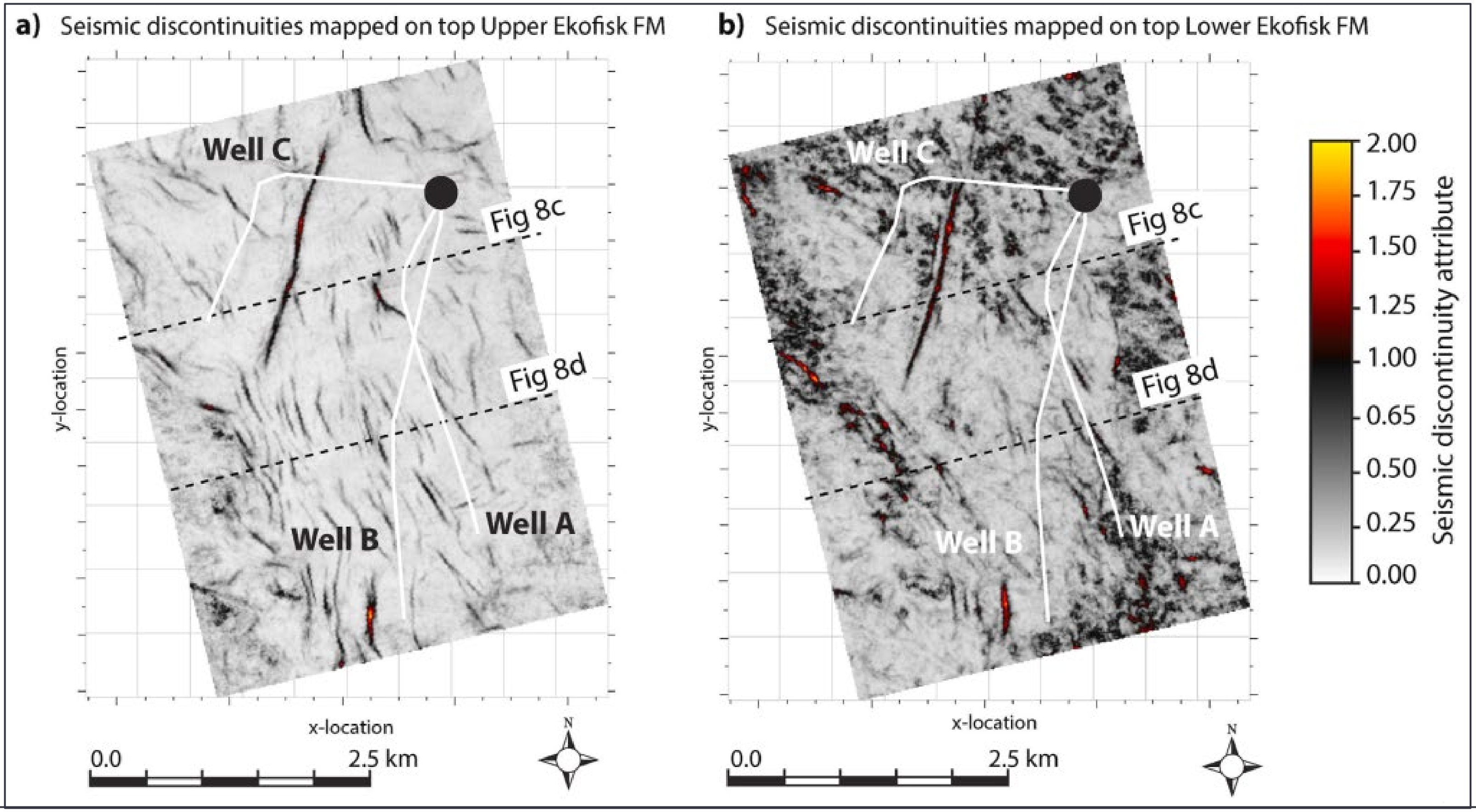
Bounaim, A., Etchebes, M., Jarle, H., Borgos, H., Fotland, B. H. & L. Sonneland (2019), Vector attributes: A family of advanced seismic attributes to assist in geological interpretation, *SEG International Exposition and Annual Meeting*, SEG-2019-3214107 .

Fracture characterization: rock fabric



Boersma, Q., Athmer, W., Haege, M., Etchebes, M., Haukas, J. & G. Bertotti (2020), Natural fault and fracture network characterization for the southern Ekofisk field: A case study integrating seismic attribute analysis with image log interpretation, *Journal of Structural Geology*, 141 (104197).

Fracture characterization: rock fabric



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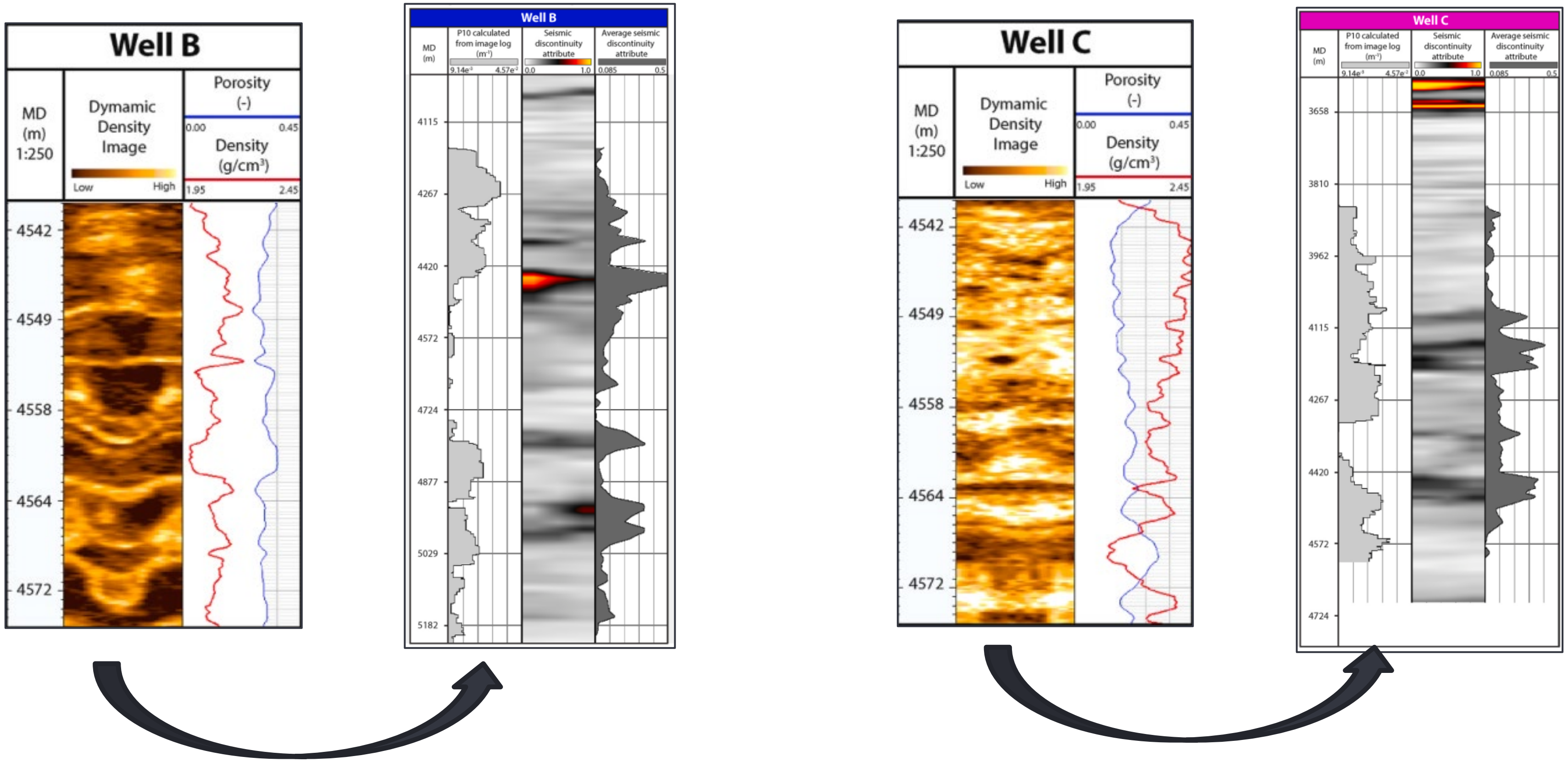
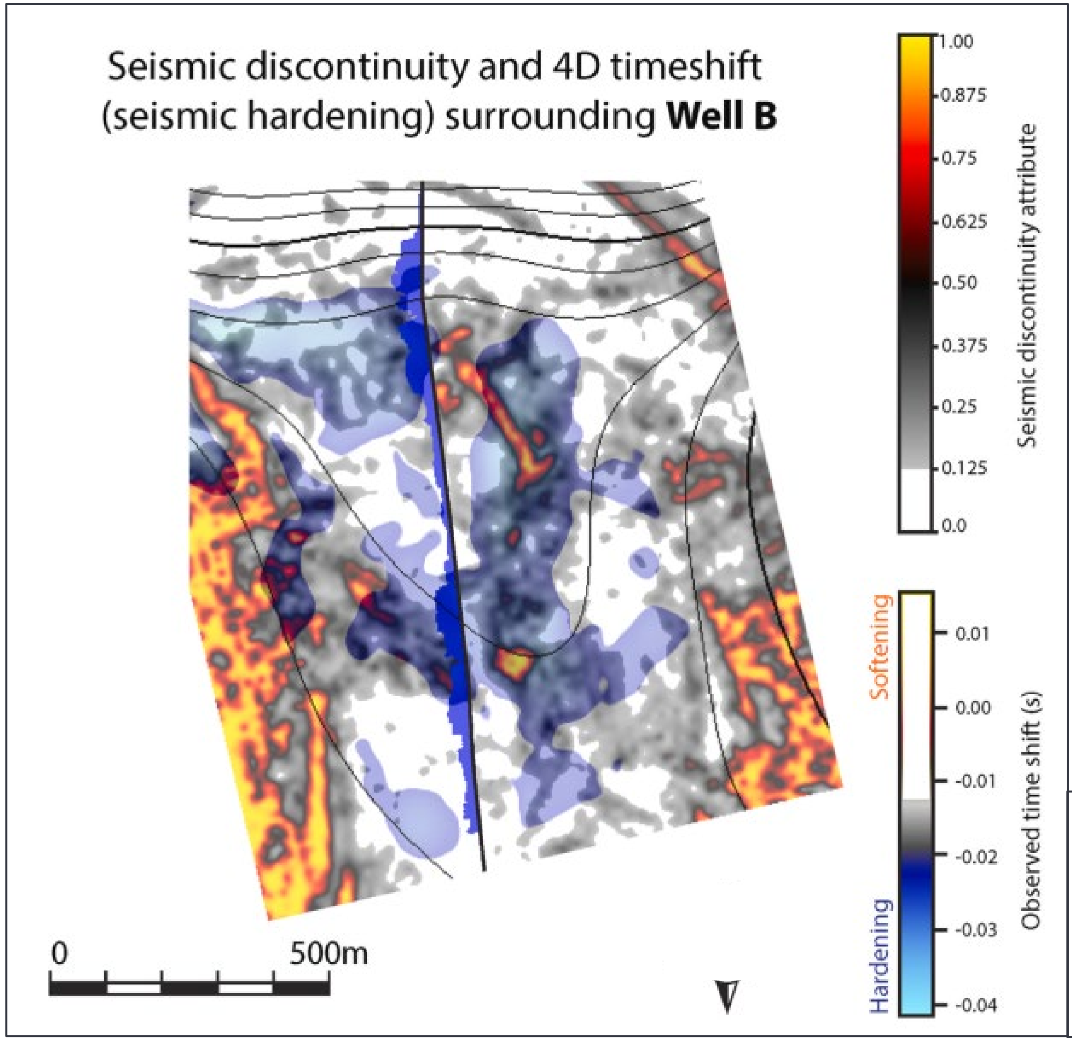
Fracture characterization: validation of rock fabric attribute



Boersma, Q., Athmer, W., Haege, M., Etchebes, M., Haukas, J. & G. Bertotti (2020), Natural fault and fracture network characterization for the southern Ekofisk field: A case study integrating seismic attribute analysis with image log interpretation, *Journal of Structural Geology*, 141 (104197).

How to generate insights?



-> integrate with other observations

Rock fabric and seismic 4D time shift:

- negative time shift (seismic hardening)

- increase of water saturation, rock compaction, pressure depletion, channelized fluid flow

Boersma, Q., Athmer, W., Haege, M., Etchebes, M., Haukas, J. & G. Bertotti (2020), Natural fault and fracture network characterization for the southern Ekofisk field: A case study integrating seismic attribute analysis with image log interpretation, *Journal of Structural Geology*, 141 (104197).

4D seismic analysis

4D seismic analysis means we **analyze two or more repeated 3D seismic** surveys to extract useful **insights and changes** that have occured during the time lapse **for better decision making**:

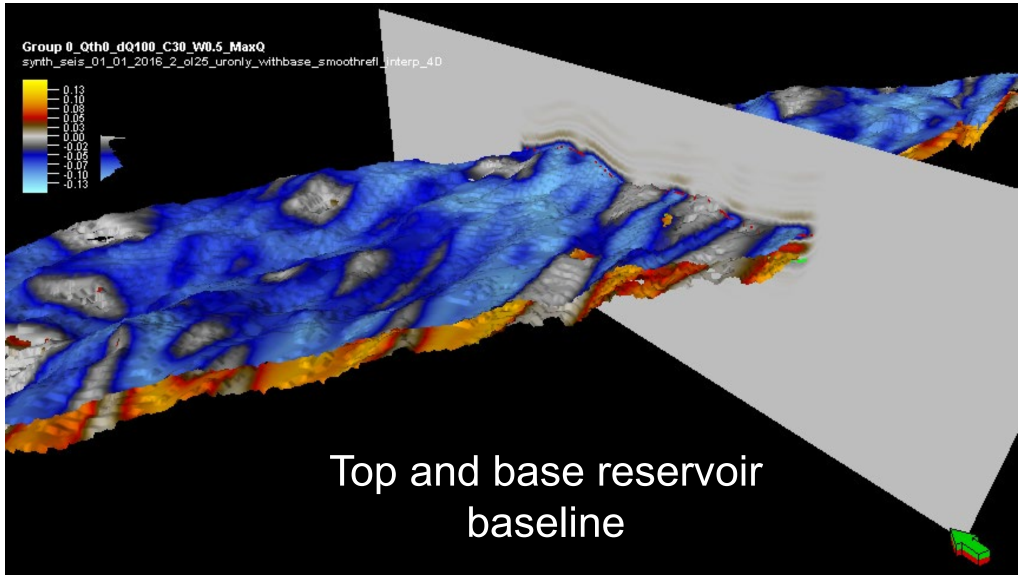
Two approaches have been developed:

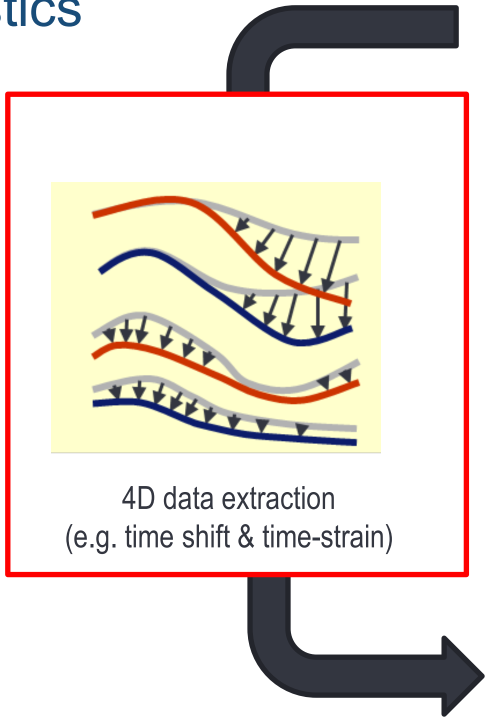
1. Directly use the results from 3D seismic interpretation: Faults, Horizons…etc
   - Signal consistent and seismic resolution preserved
   - Multi-scale geological structures
   - Interval-based 4D attributes
2. Non-rigid matching: well established 4D algorithm, Python version
   - Flexibility and less parametrization required
   - Constrained and validated by signal consistent time lapse extracted horizons

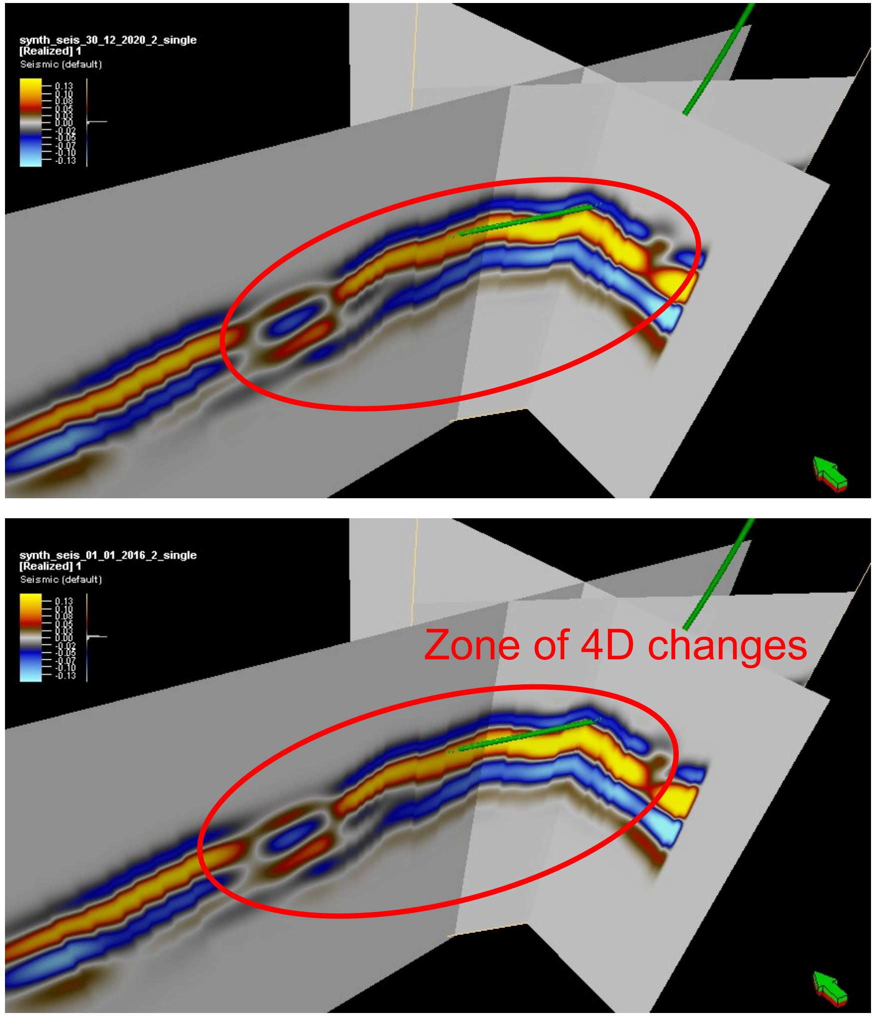
3. Illustration through Olympus benchmark case study

4D seismic analysis – Olympus case study

The Olympus field is a synthetic reservoir model prepared as an optimization exercise for field development optimization, with complex geological reservoir characteristics







4D seismic analysis – Technical aspects

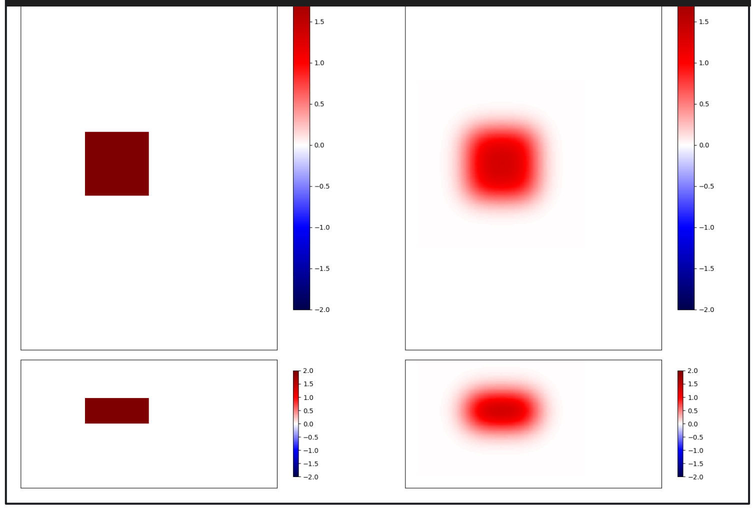
- The reservoir engineer can **adopt a dynamic approach to evaluate/calculate the 4D attributes** for the area of interest
- 4D time shift / time strain can be estimated using horizon-based approach: using directly the **extracted and quality-checked horizons** from baseline and monitor
- The elevation difference is calculated to quantify the vertical-shift and how much two similar horizons have shifted their position (elevation) from one time-lapse to another
- It is possible then to use horizon-based time-shift range to constrain the parametrization of non-rigid matching algorithm and convergence
- **Interval-based 4D attributes** for detailed analysis of thin / multiple reservoirs

NRM3D python version – Validation and interaction

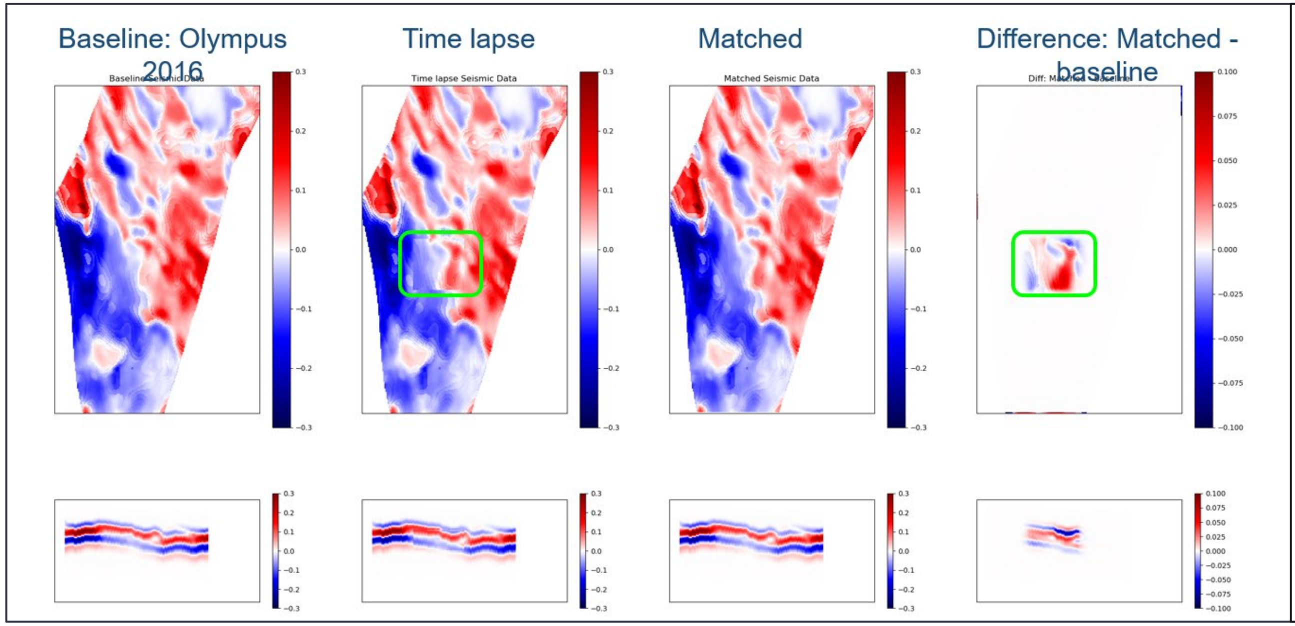
- Generate 4D synthetic seismic and recover time-shift, 4D amplitude
- Lessons learned: convergence rate, optimal parametrization, 4D change expected?

Constant/smoothed vertical shift

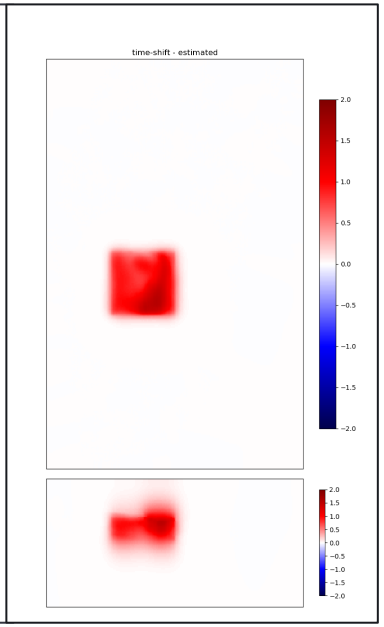
```
# Test NRM3D Analytically:
disp3d_test = np.zeros_like(disp_tl)
disp3d_test[2,50:100,150:200,30:50] = 2
```



NRM matched seismic and 4D amplitude difference



Retrieved time shift



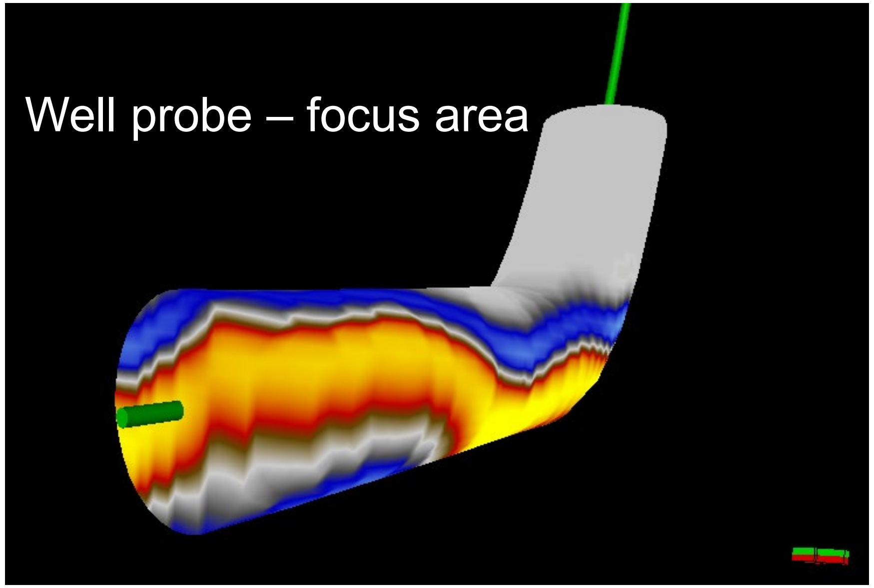
NRM3D python version – Benefits and insights

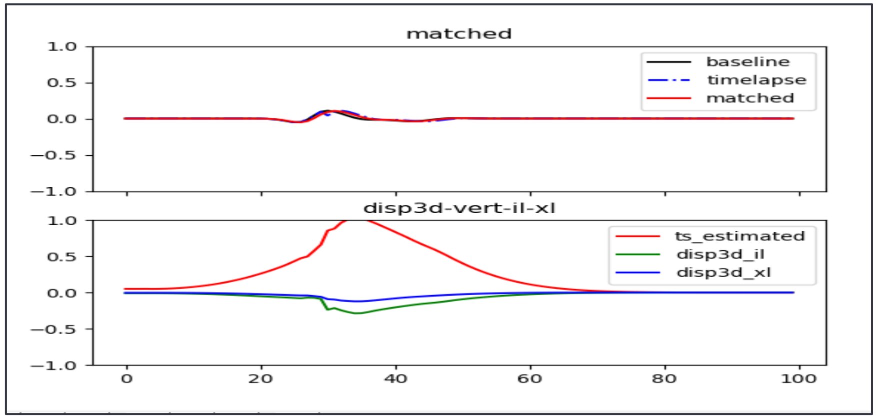
- NRM3D is well-established algorithm
- Python version allows more flexibility, interaction, iterative process when needed
- Before: Generate 4D attributes/cubes and map on surfaces – **limited interactive changes allowed** – have to manipulate different windows
- Now: Generate 4D attributes with optimized parametrization, constrained with ‘explicit time shift from horizon-based approach’, and extend to **‘run on the fly’** within focus area, e.g., along wells
- **Integration** of different data **to filter zones with combined strong 4D changes and well activity**, structures…which previously required different workflows

How to build an automatic workflow for 4D uncertainty evaluation?

Flexible parametrization in NRM3D Python version allows for:

- Detection of **small and local 4D changes** – suitable for analysis around a well or wells, and for focus area with a given scenario to be verified
- Identification of localized zones with strong 4D changes – also **trace-based analysis**
- **Integration** of multiple 2D, 3D and 4D data for more **reservoir analytics**
- Automatic iterative process to **evaluate 4D uncertainty** within a zone – which 4D effect is real? Input to reservoir simulation



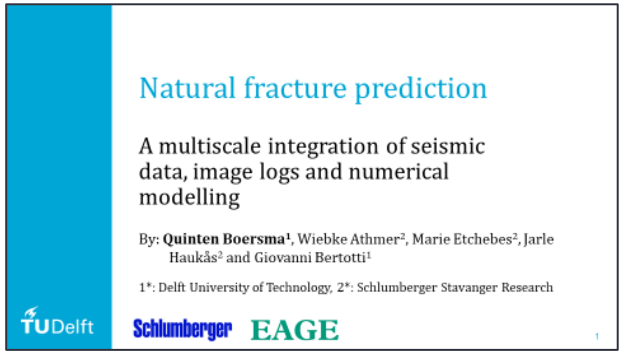


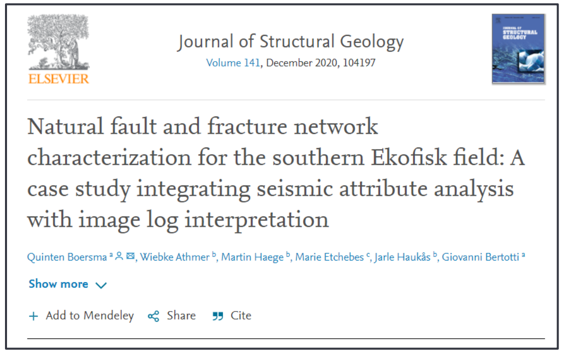
Automatic extraction of trace with strongest time shift and eventually lateral shift

Summary

- Cross-domain G&G and RE focus
- Insights – confidence / uncertainty
- Sensitivity studies – turnaround time
- Integration – automation – auditability

- Published papers
- Material in IOR Centre archive





- Focus gradually shifted towards the digital journey of geoscientists and reservoir engineers

Questions and comments?

Next: Bringing data and solutions together in the cloud
10 min break?

Part II: Bringing data and solutions together in the cloud

Schlumberger

Cool... But how can I access these research solutions?

BEFORE AND NOW

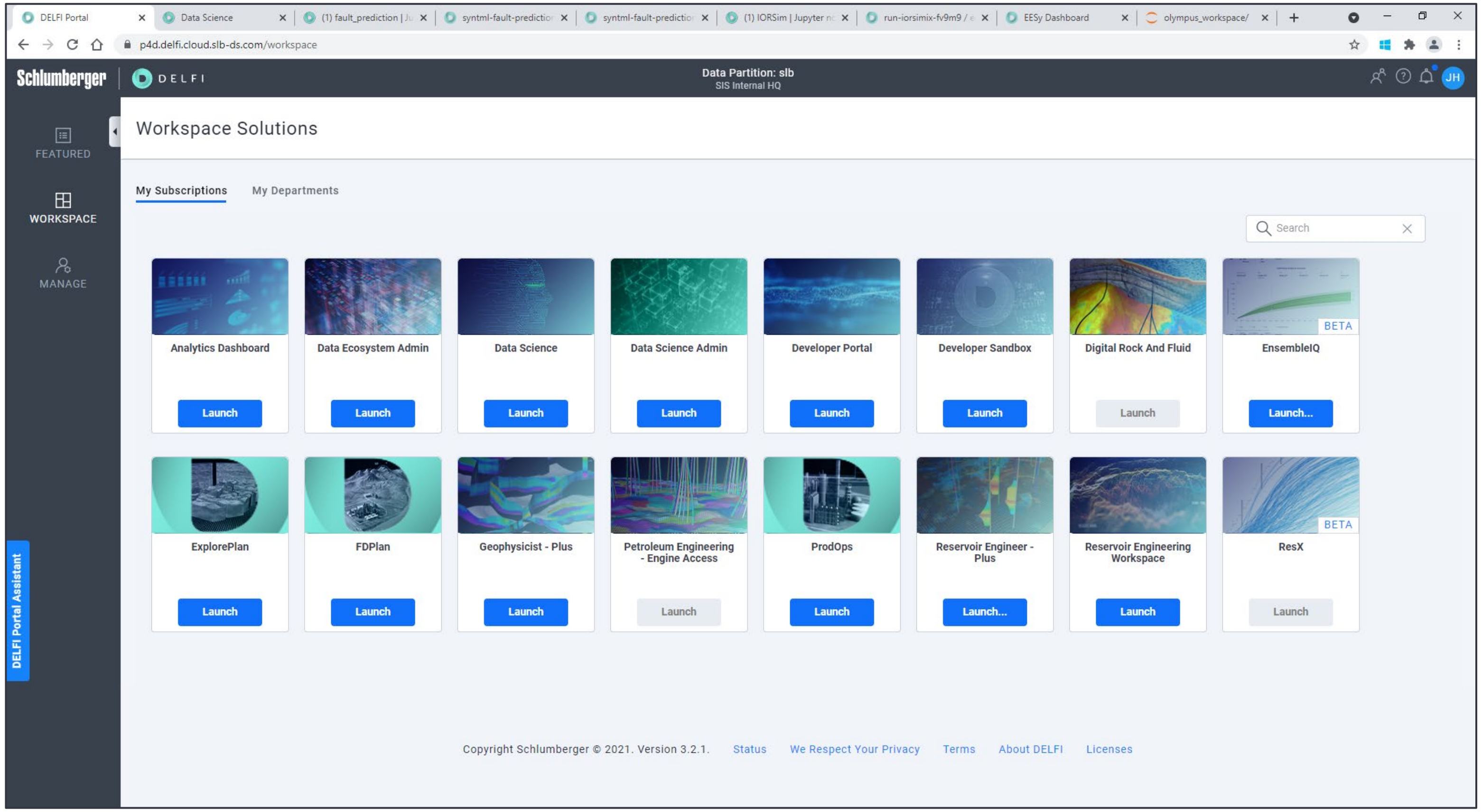
Ocean for Petrel
Prototype plug-ins

Executable code (e.g. IORSim)

Install on your computer
Dongle license or similar

Keep track of data yourself
(import files, edit decks)

NOW AND IN THE FUTURE



Software-as-a-service (subscription) – engines and data eco-system

Important concepts

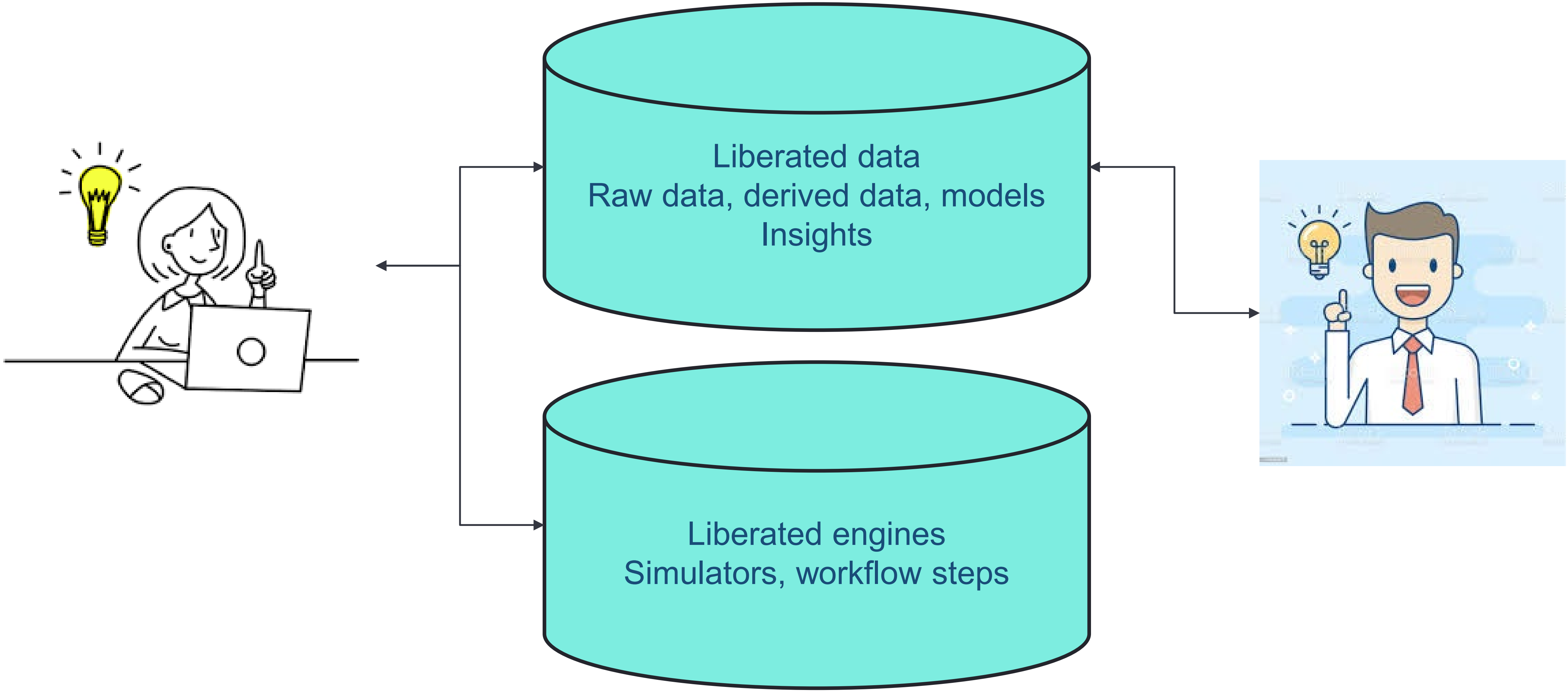
- Liberated data
- Data eco-system
- OSDU = Open Subsurface Data Universe

Data and models are accessible in the cloud through APIs (security: user access token)

- Liberated engines
- Engine eco-system

All engines (simulators, ML algorithms, etc.) are accessible in the cloud through APIs (security: user access token)

Collaborative multi-user environment



Innovation toolkit helps democratize innovation

- Application which offers both no code (buttons and drag-drop) and low code (scripts)
- Out-of-the-box machine learning
- Customizable python environment allowing developers to bring python modules and non-developer to put together workflows
  - Gather and load data
  - Run engines (e.g. simulators)
  - Analyse data and results
  - Visualize
- Composable workflows
- Templates / examples / low code / no code

jupyter

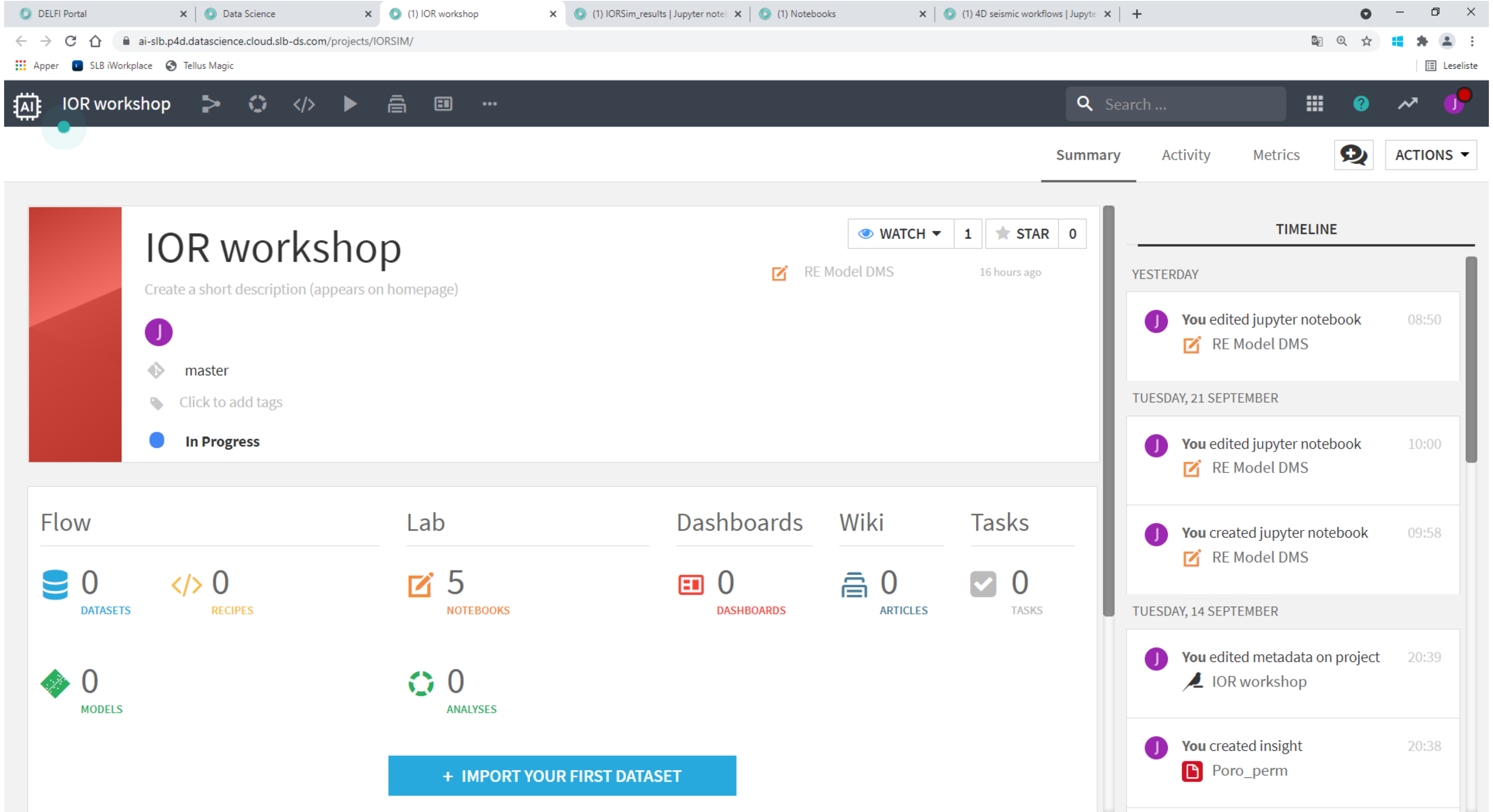
python Package Index

data iku

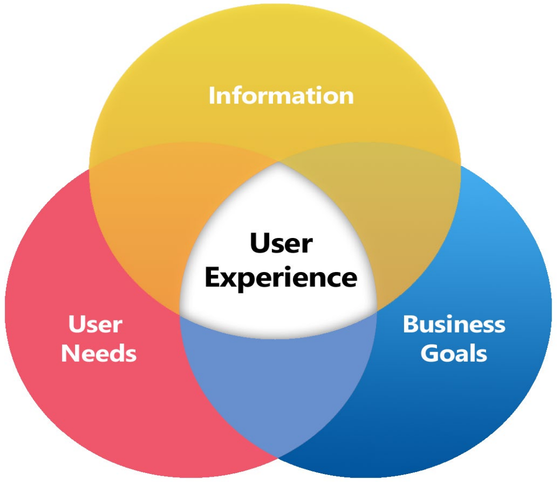
Python libraries (customized virtual environment)

```
import numpy as np
import matplotlib.pyplot as plt

from dataiku import insights

from olympus_com.delfi import data_management as dm
from olympus_com.delfi import data_structures as ds
from olympus_com.delfi import ecl_utils as eu
from olympus_com.visualize import matplotlib_utils as mu
```

Dataiku – 3rd party data science app hosted in DELFI



Flexibility versus user experience



- Python skills – full flexibility, but user threshold
- Traditional consumer – apps, knowledge boards
- Middle ground? Simple scripts, templates, customization

- Aim: democratize innovation, improve efficiency and cross-domain collaboration
- Find the right balance between **manual** work / analysis (user driven) and **automatic** workflows / QC (developer or system driven)

Work patterns

Model + Simulator = Results

Data + Workflow = Derived data / model

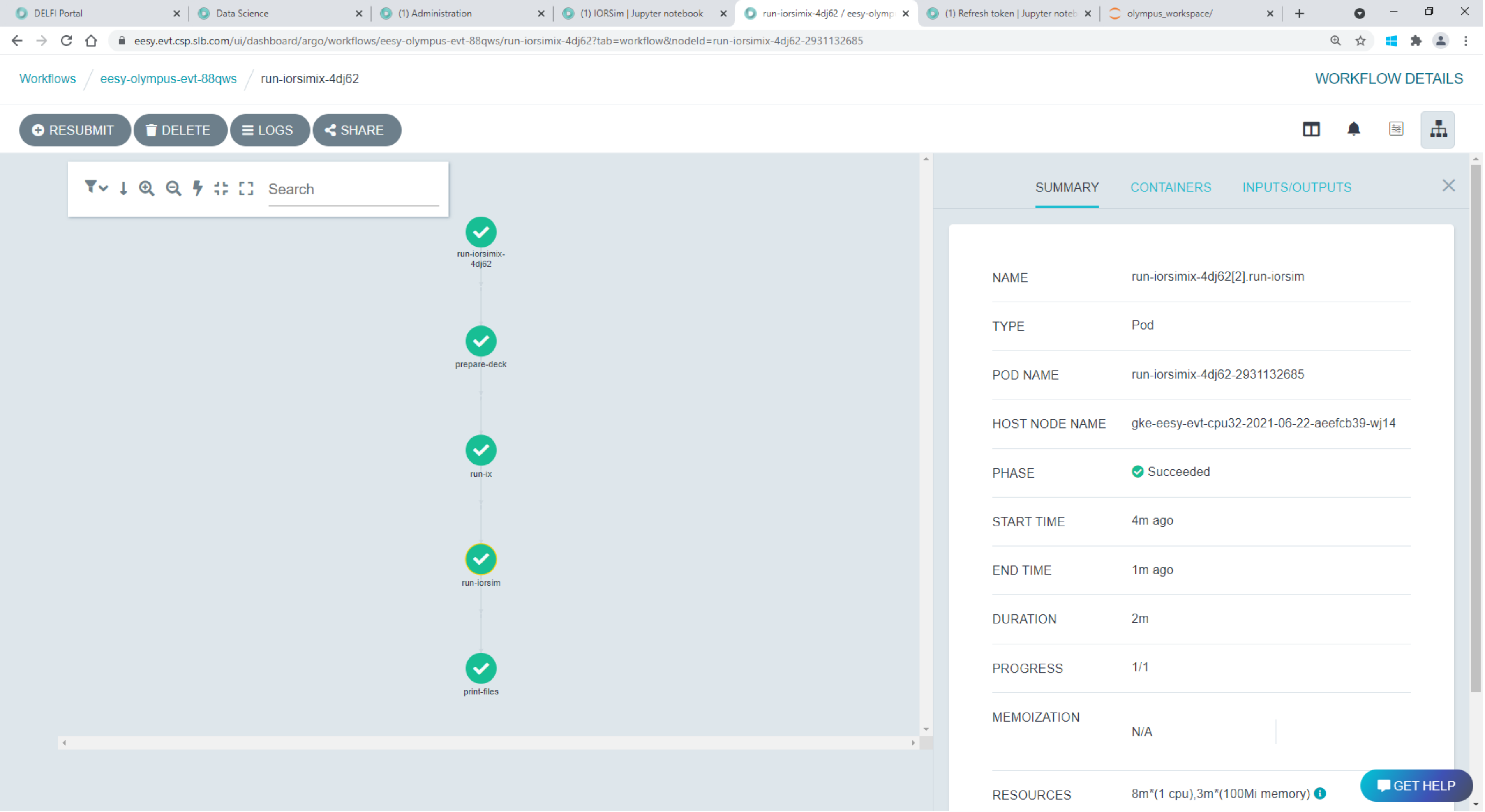
Data / model + Workflow = Insights

Models, data, results and insights accessible to all (data eco-system) – enabler for collaboration and automation

Cloud flexibility I: Liberated engines, e.g. IX+IORSim

INPUT	SCRIPT	ENGINE	SCRIPT	ENGINE	**OUTPUT**
IX deck	Add IORSim requirements: EGRID, INIT, UNRST, RFT, FVF, FLOWS	RUN IX	Add IORSim requirements: FVF->1/FVF Inj. comp. Geochemistry	RUN IORSim	IX+IORSim results
Cloud data	Cloud engine				Cloud data

Orchestration: Dataiku + Jupyter notebook + Python library

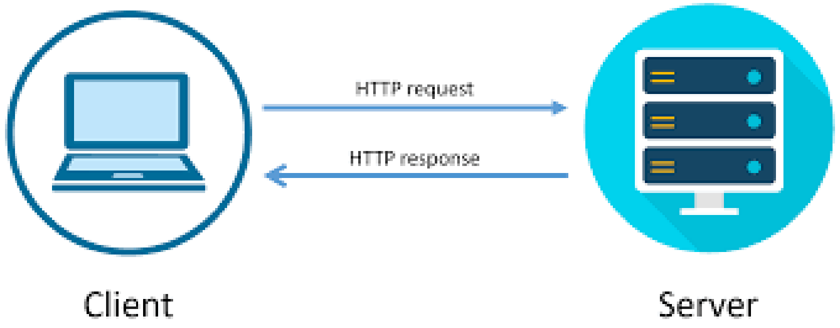


Cloud flexibility II: Data management system (DMS)

- Domain data and models stored in the cloud

- Data ingestion = upload bulk and metadata
- Metadata searchable via http request (API call)
- Bulk data retrieved through http request (API call)

- OSDU = Open Subsurface Data Universe
- DMS standardization

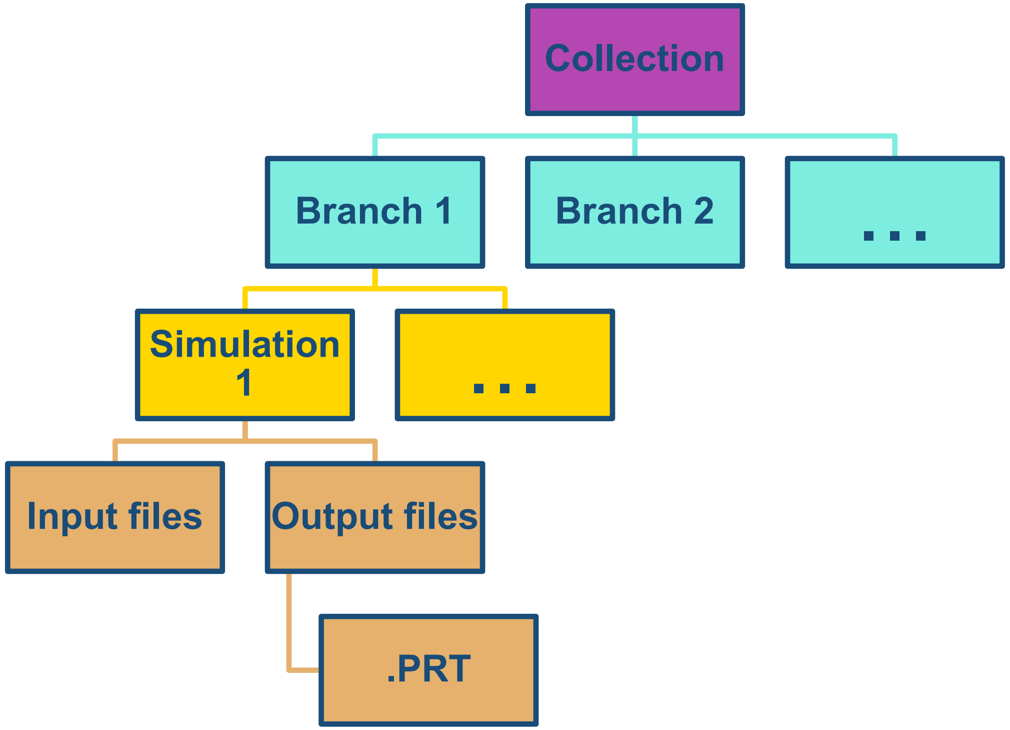


Sounds more complex than it really is...

RE Model DMS

Reservoir Engineering - Simulations V1 Alpha (Internal)

The Reservoir Engineering APIs provide a consistent set HTTP en
as the Simulations API, or use POST request for complex queries
envelopes for the data and links.



Concept: All types of simulation models carefully organized in a hierarchy:

Collection – unique ID

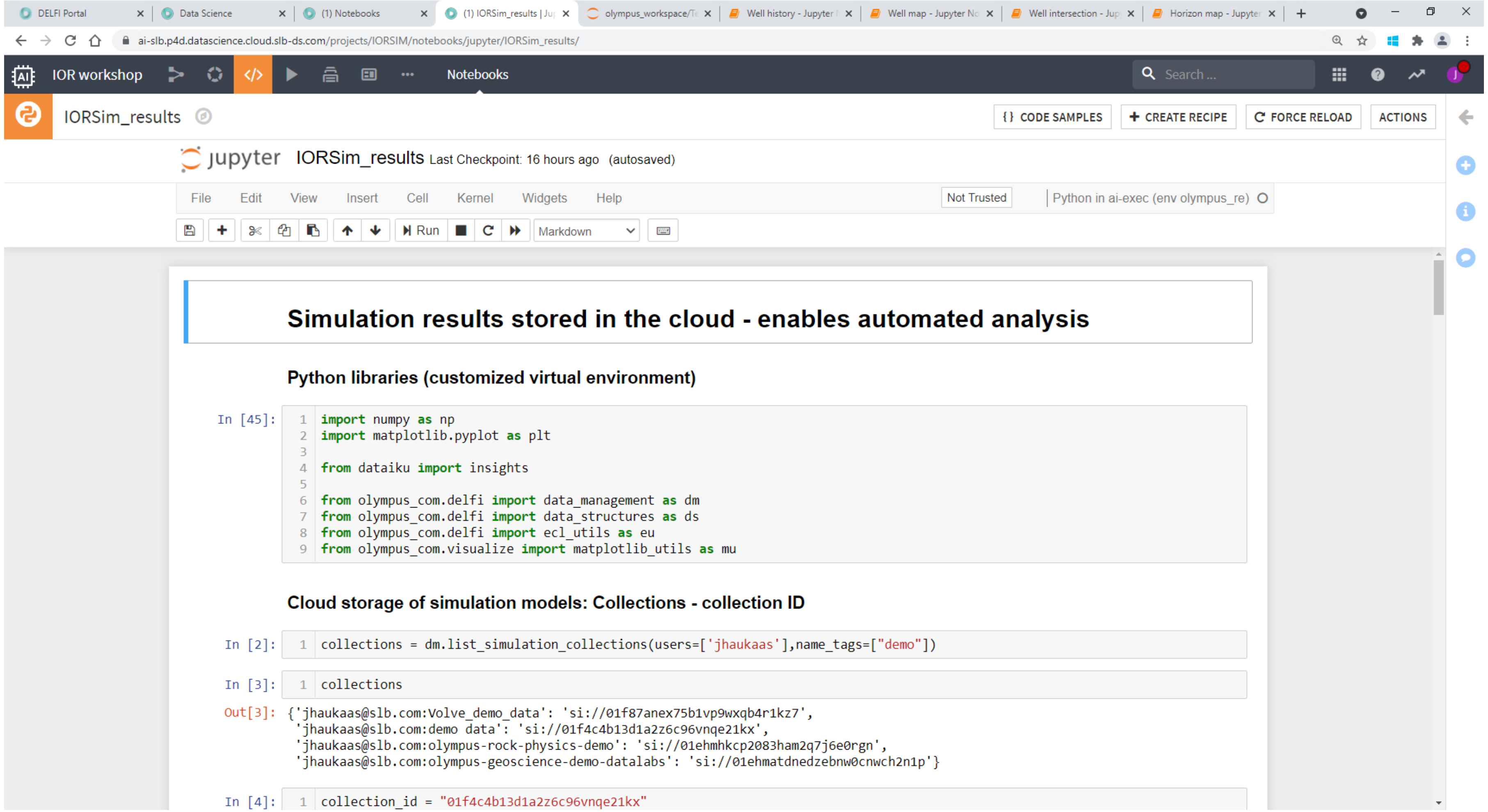
Simulation – unique ID

File (input and output) – unique ID

Benefit: Repeat same workflow on multiple simulation cases (e.g. run IORSim on all available IX models)

Accessible through APIs
Same APIs used by commercial ensemble workflow and prototype workflows shown here

Example: RE Model DMS – simulation models and results



DELFI

Schlumberger

Other DMS data

- Seismic
- Surfaces / horizons
- Wellbore

(covered in demo later)

Questions so far?

<u>Claim:</u> liberation of data and engines is a key enabler for integration, automation, new solutions (e.g. AI / ML) and improved efficiency

Data eco-system???

Engine eco-system?

IX-IORSim automated???

Next: Analyse data and simulation results

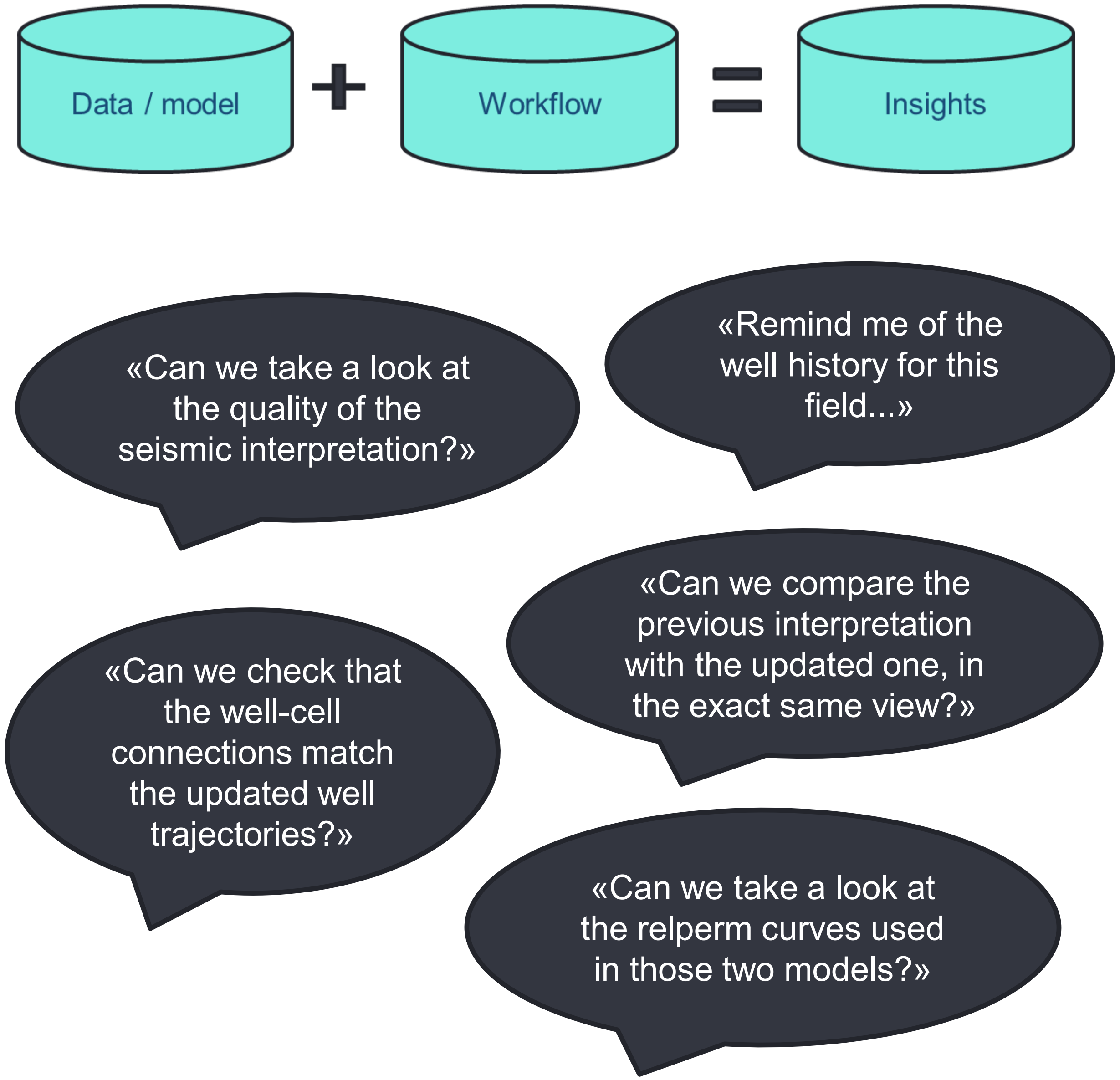
Templated analysis

- Enabler: Raw data, derived data and models available in data eco-system

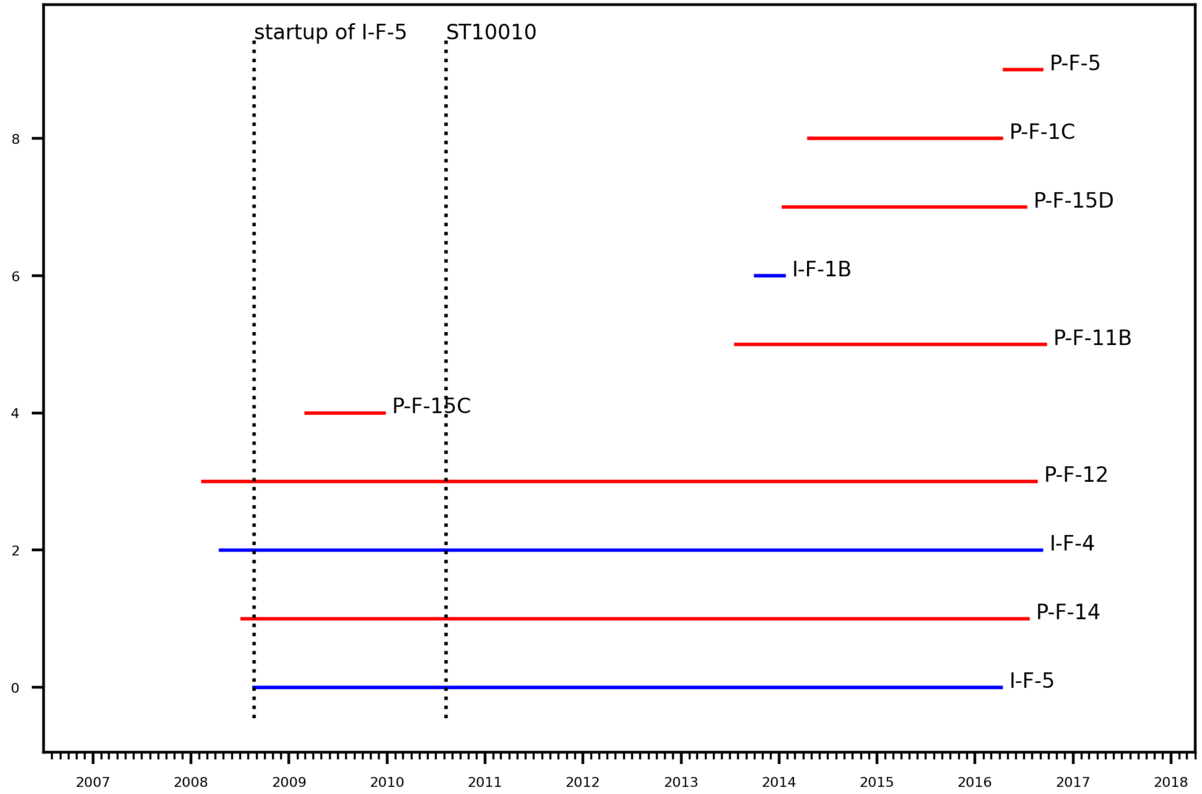
- Opportunities:
  - Check / QC simulation model
  - Check / QC seismic and well data
  - Extract and map features into simulation grid
  - Run updates / uncertainty analysis
  - **Automate**, e.g. across multiple realizations and across different fields

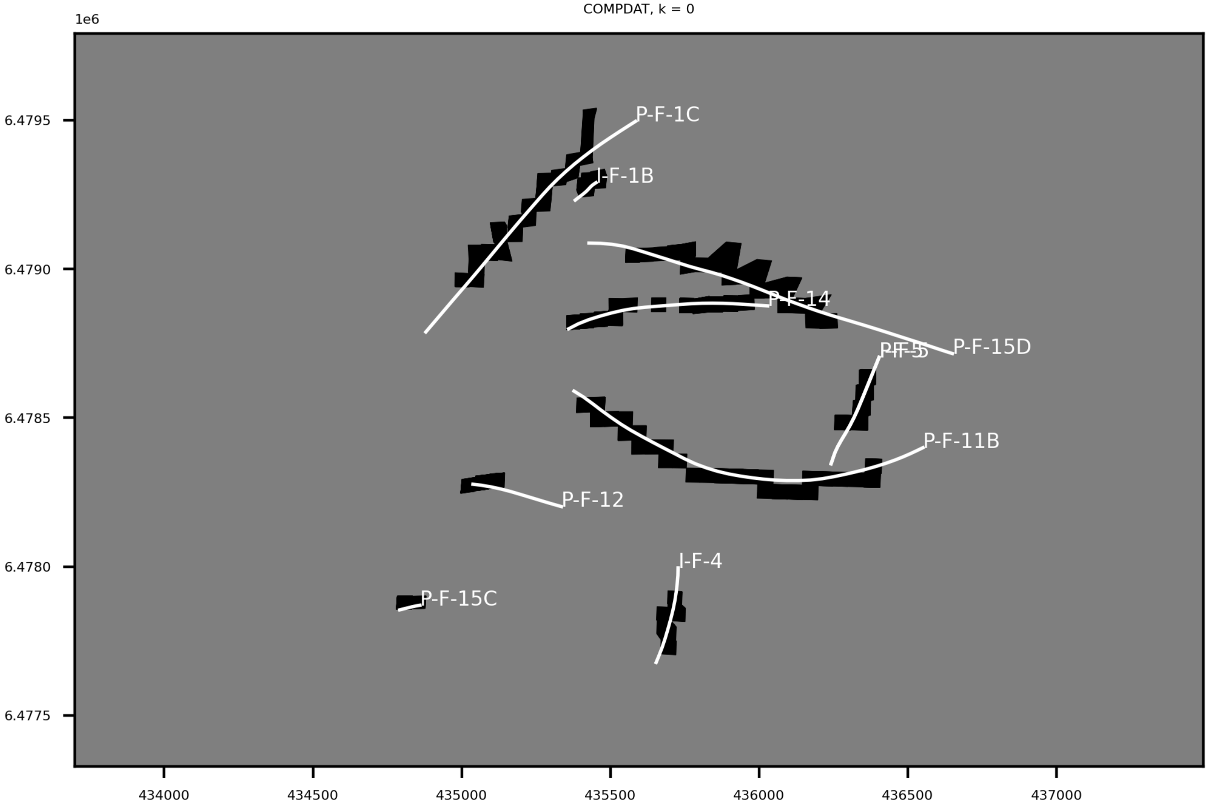
- Objective: produce **actionable insights**

- **Pictures** that everybody can relate to!



Example 1: Well history, well locations





Data through courtesy of Equinor and former Volve license partners: https://www.equinor.com/content/dam/statoil/documents/what-we-do/Equinor-HRS-Terms-and-conditions-for-licence-to-data-Volve.pdf

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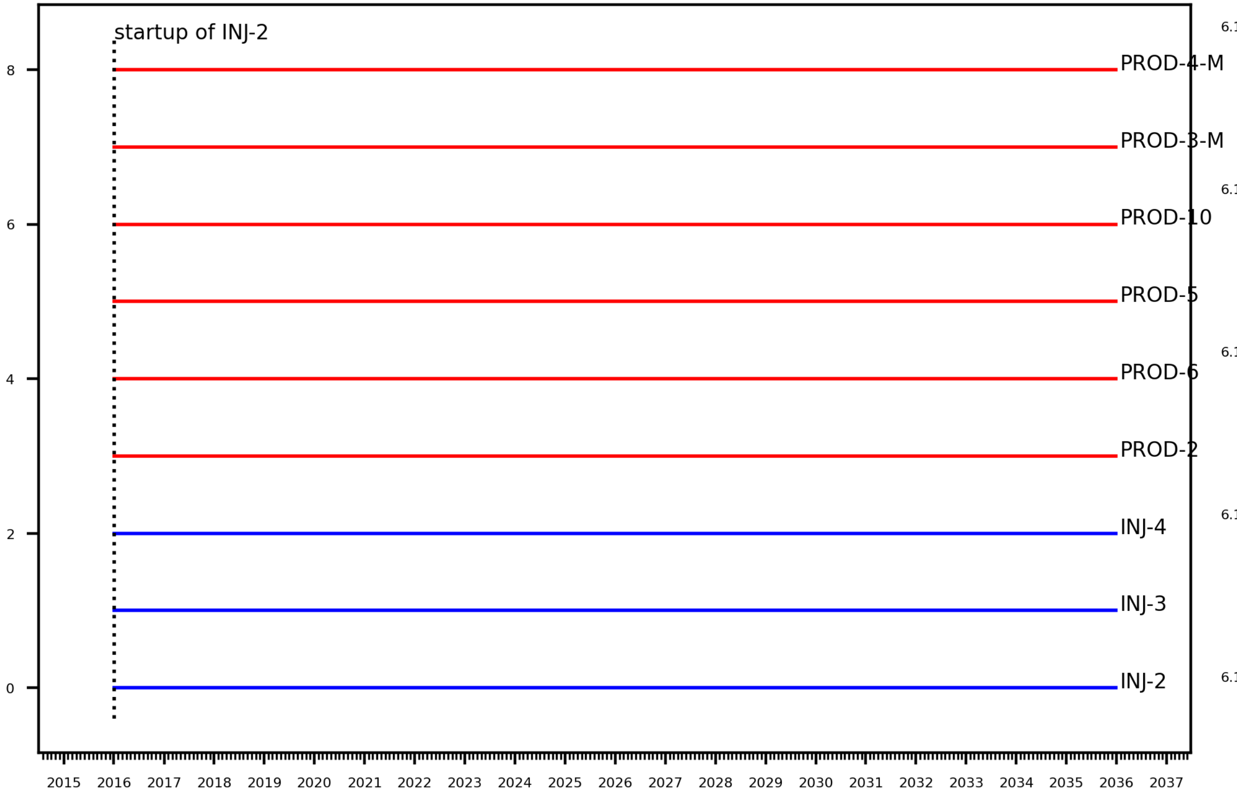
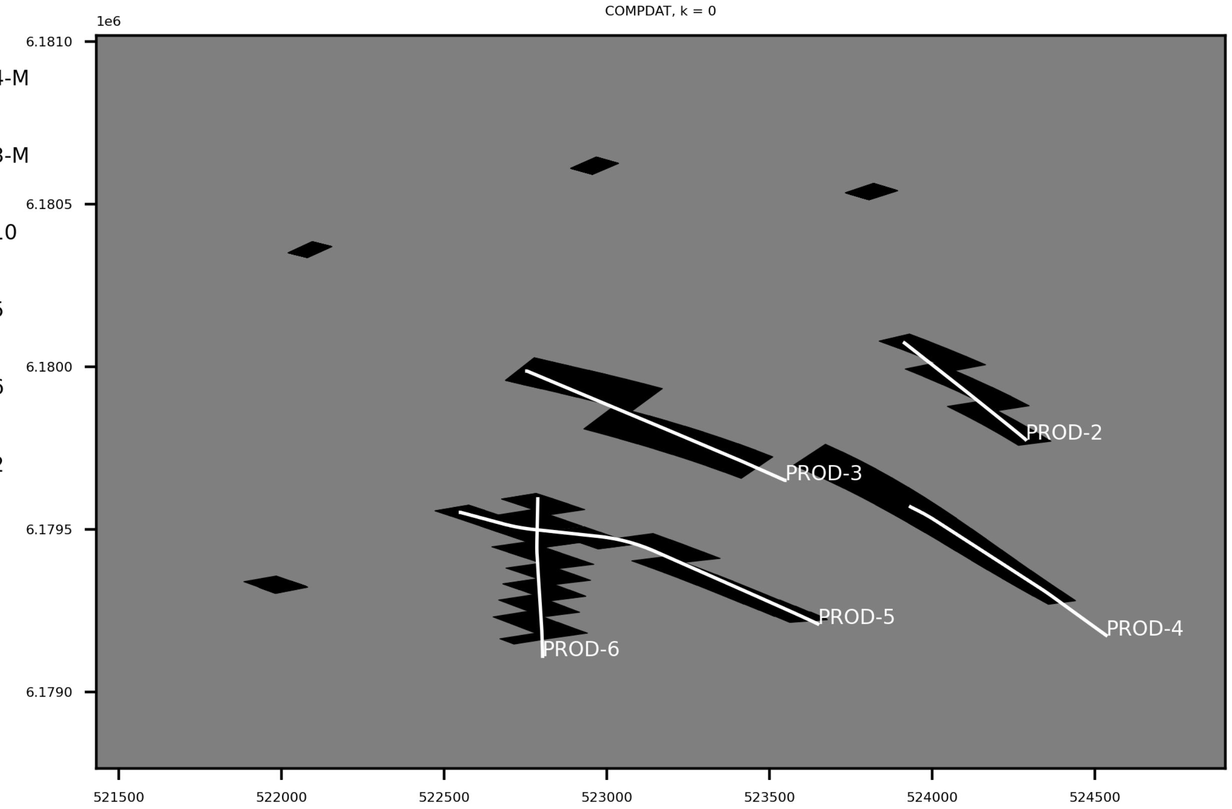
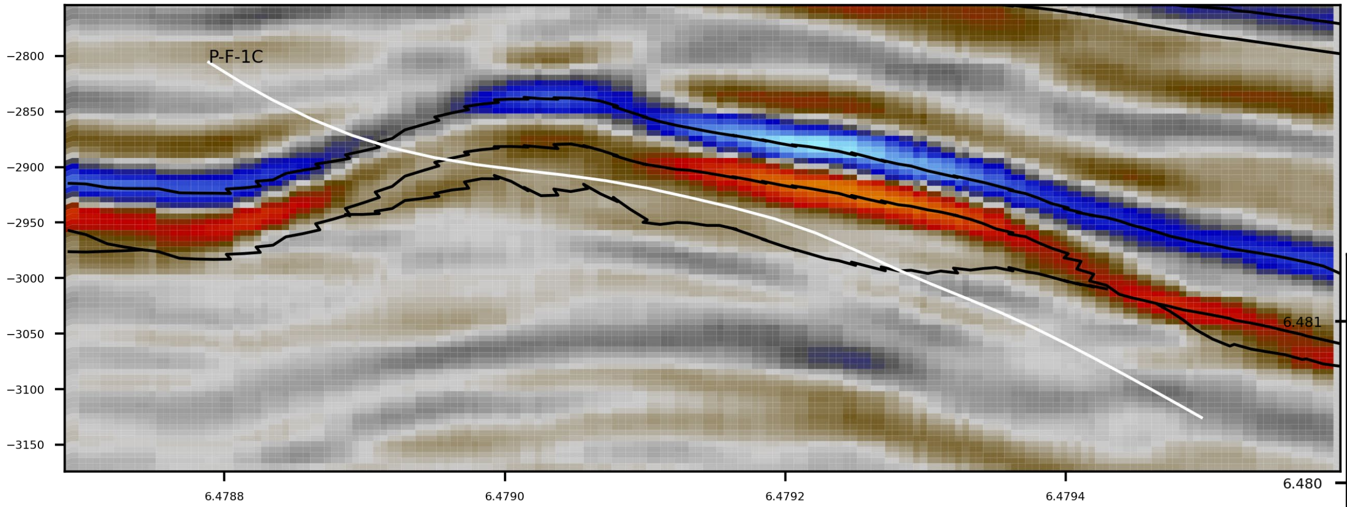
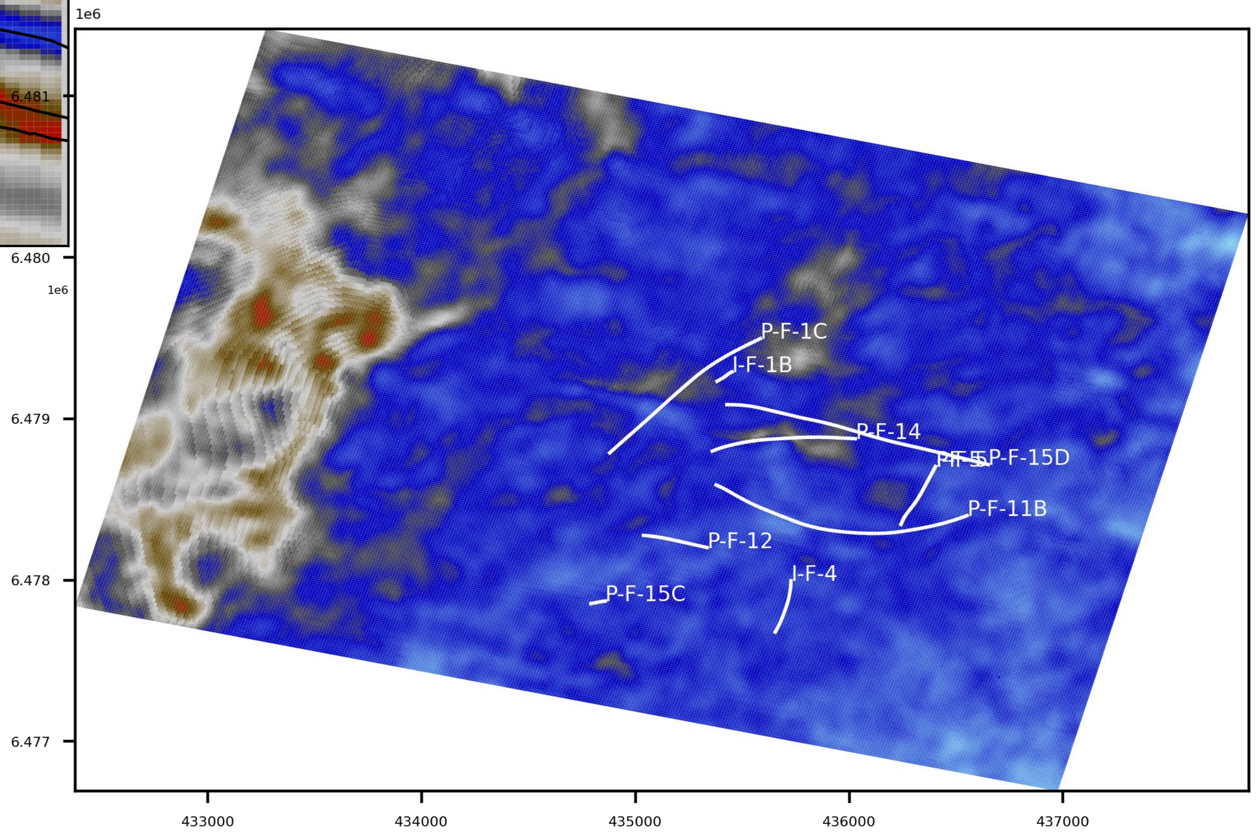




Example 2: Seismic data, horizons, wells





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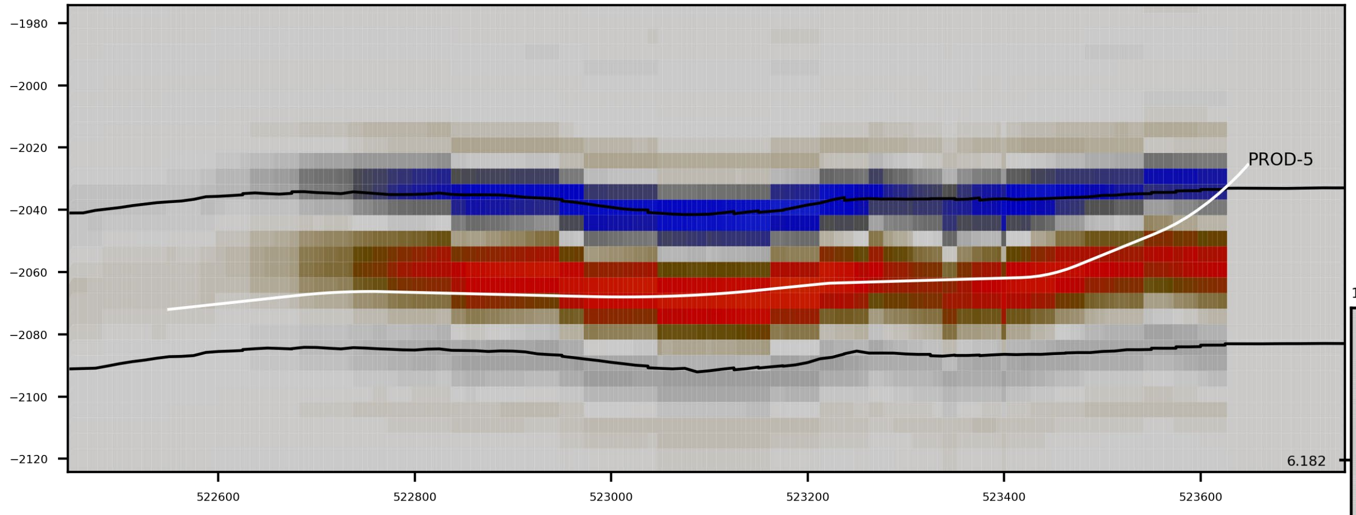
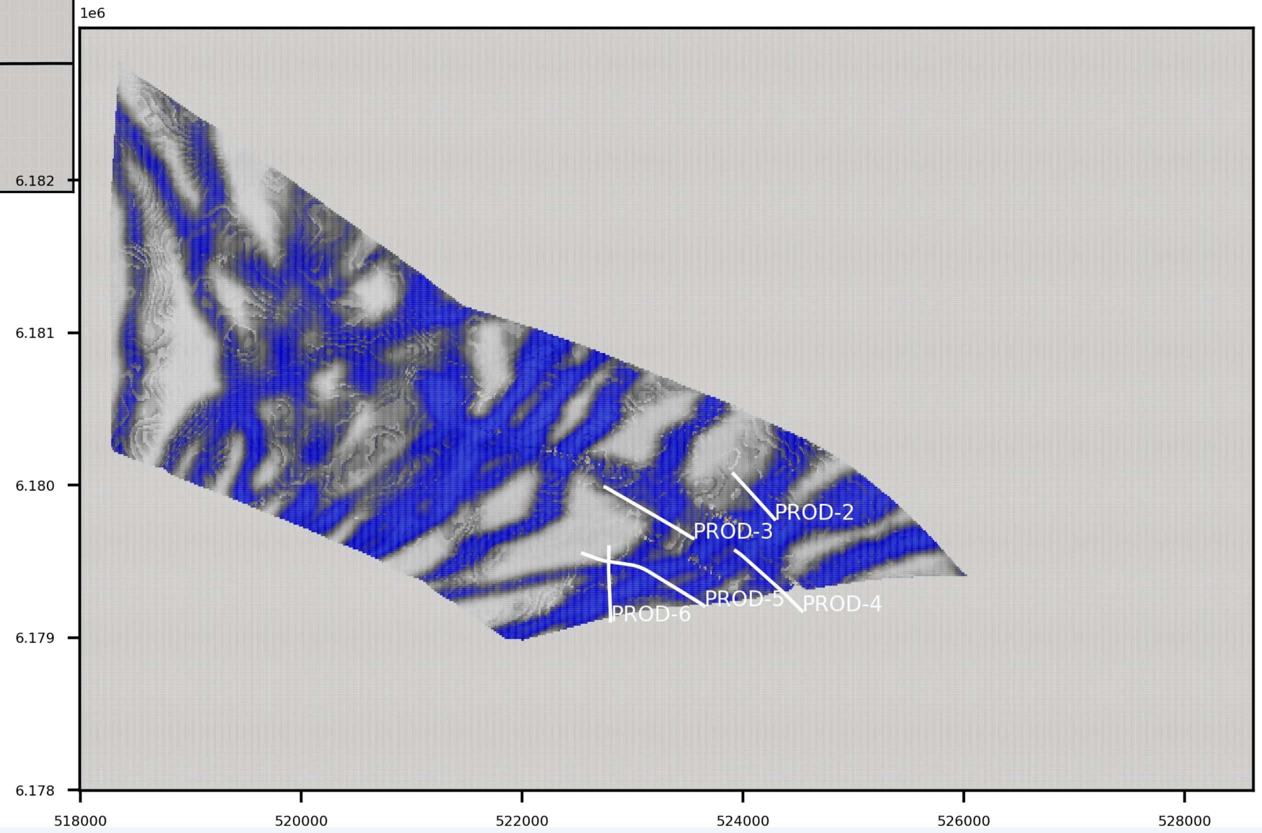
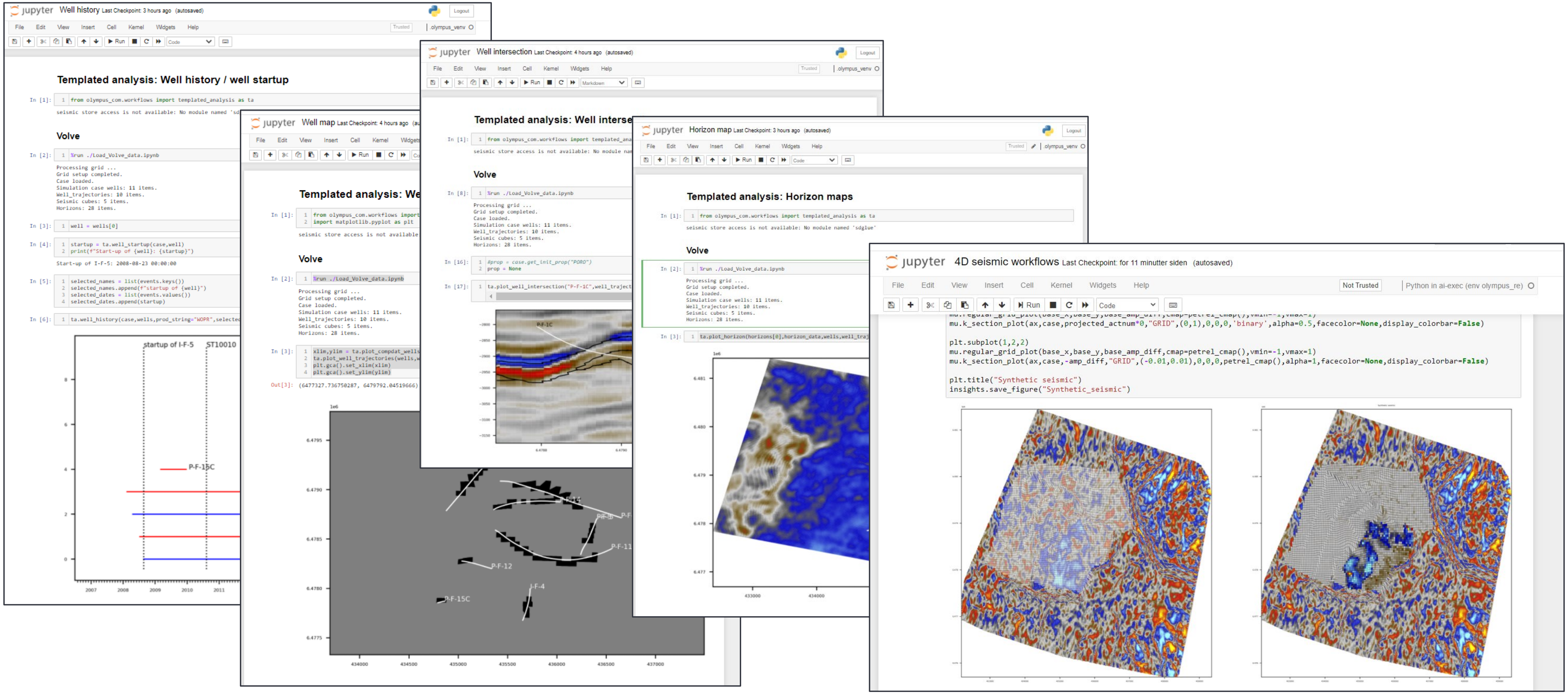




Demo / Jupyter notebooks



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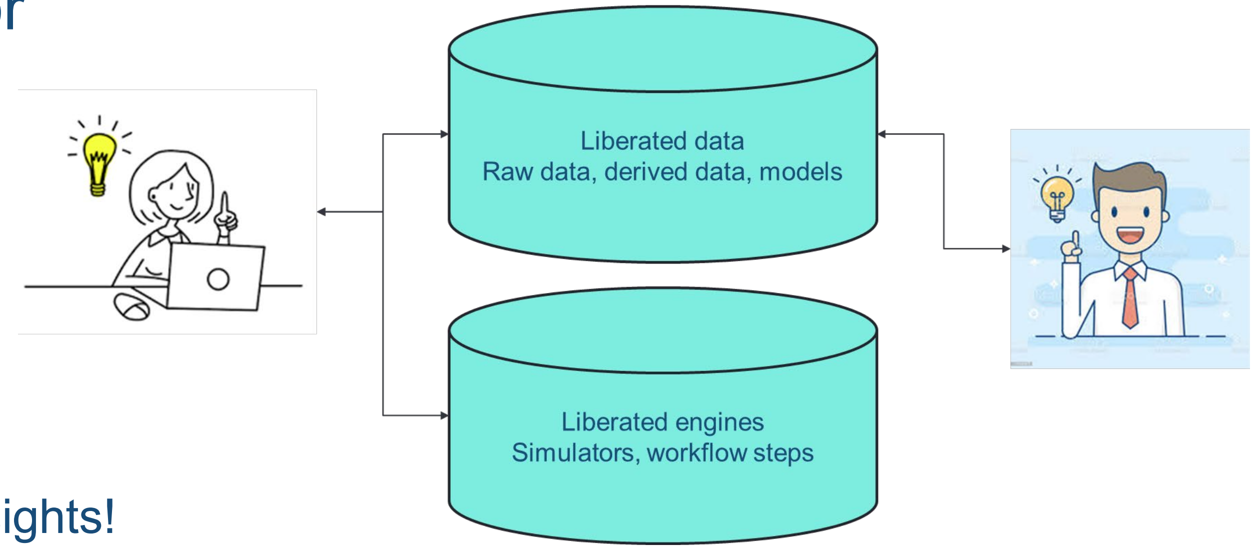
Collaboration

- Visualization templates easy to make, similar ideas developed by e.g. Equinor (webviz)
- Liberated data and engines are key, otherwise finding data and setting up the system will be inefficient
- Key issues
  - «Cool pictures – so what?» - need actionable insights!
  - Find the right solution to the right problem
  - Contributions from non-developers – democratizing innovation
  - User experience – new ways of working?



Questions and comments?

Next: Summary and way forward

Part III: Summary and way forward

Schlumberger

What are **your** objectives?

«I want to make better decisions faster»

«I want to become more efficient»

«I want to share my knowledge with others»

«I want to take part in the energy transition»

«I want to make use of all available data in my analysis»

«I want to include all relevant processes in my modeling»

«I want to develop new digital skills»

«I want to have fun while making an impact»

«I want to find the right solution to the right problem»

Way forward: digital journey of geoscientists and reservoir engineers

- A lot of new concepts that may seem overwhelming
  - Liberated data, data management system, OSDU
  - Liberated engines, cloud compute
  - APIs
- A lot of new opportunities for a broad range of users
  - Traditional applications enriched
  - New apps (no-code solutions) – consumer's view
  - Innovation democratized through low-code options
  - Maximum flexibility and automation through full-code experience
- What makes **you** more efficient / happy?

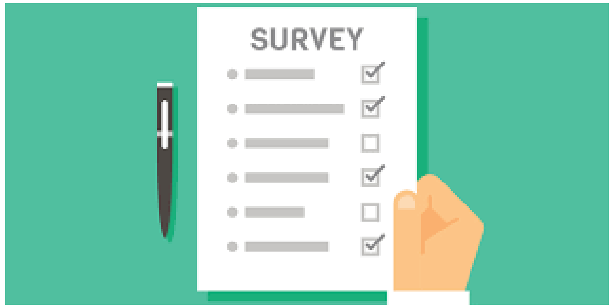
Will new digital tools and systems change the way we work?

- Bring research solutions faster to market?
- Find the right solution to the right problem?

- Less frustration?
- More frustration?

- Integration, Automation, Auditability

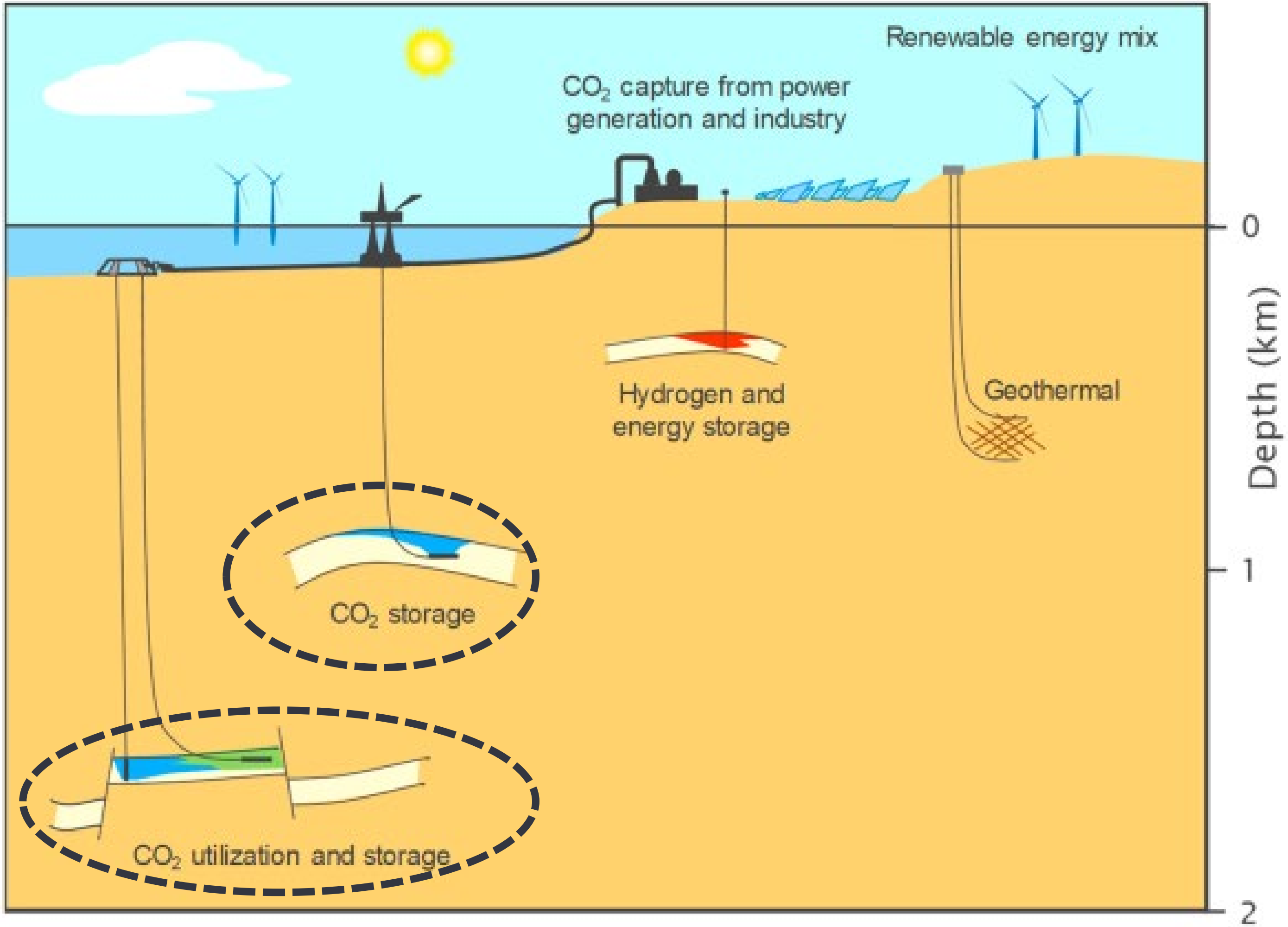
- Combine domain knowledge and data science
- Education / upskilling



«Focus on what you want, not what you don't want!»

Future applications: Energy transition

Deployment of integrated and complementary low-carbon energy solutions



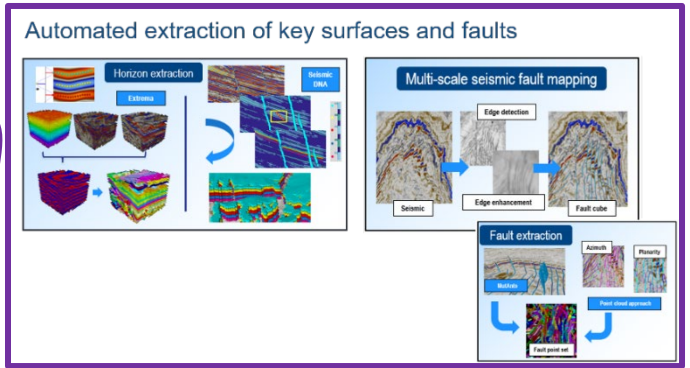
Source: P. S. Ringrose, 2018

Future applications: Energy transition – Knowledge transfer

The outcome from the IOR Centre collaboration has direct **impact** on the **Energy Transition** processes

CO2 monitoring is just one example in the development and demonstration of many potential technologies involved in CCS as a part of **the emerging low-carbon energy mix**

- Technology-wise:
  - Quantitative and qualitative geological interpretation for potential CO2 storage site appraisal and characterization
  - The role of time lapse technology as reservoir monitoring and surveillance tool
  - Quantitative integration of 4D seismic with reservoir simulation



Future applications: Energy transition – Learning by Doing

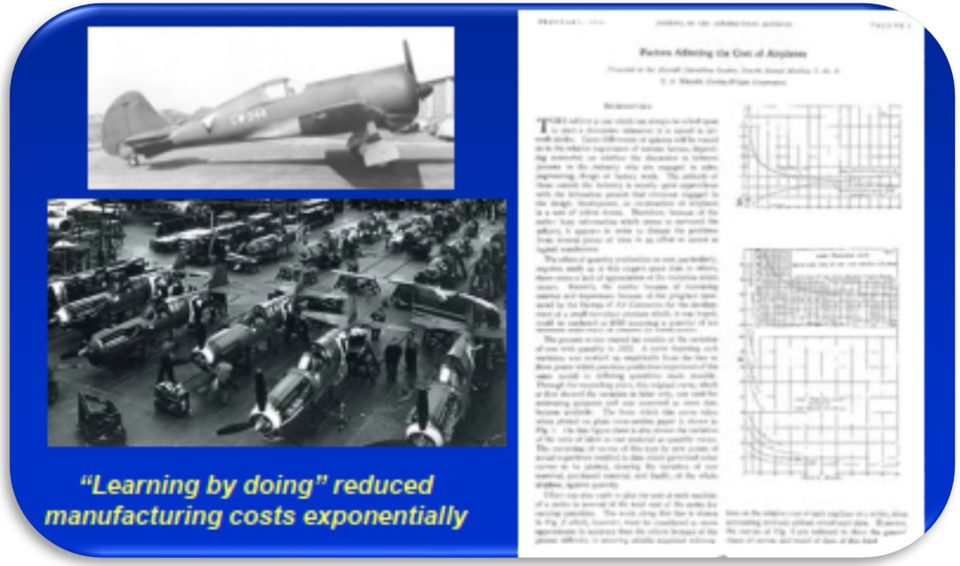
- CCUS is expected to be a large component of the future that can make hydrocarbons clean energy

- Subsurface engineering and geoscience understanding of CO_2 EOR and sequestration are key areas of research

- It is expected that technological developments will play a large role in determining both the energy mix of the future and optimal CCUS implementation programs

- New cost-efficient monitoring technologies are necessary

- “Learning by doing and using” / "learning rate" can contribute to reducing the costs towards energy transition and meeting net zero targets



T.P. Wright (1936) found that the cost of making airplanes declined with increasing experience

Closing remarks

- Quite a journey – and the journey continues
- New petrosenter call 2021
- Cloud platform for research solutions?
- Openness and collaboration; Innovation Factori
- Make sure to serve both petro-technical experts and data scientists!