Bridging the chasm between geophysics and reservoir engineering

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Taiwan

May 25, 2014

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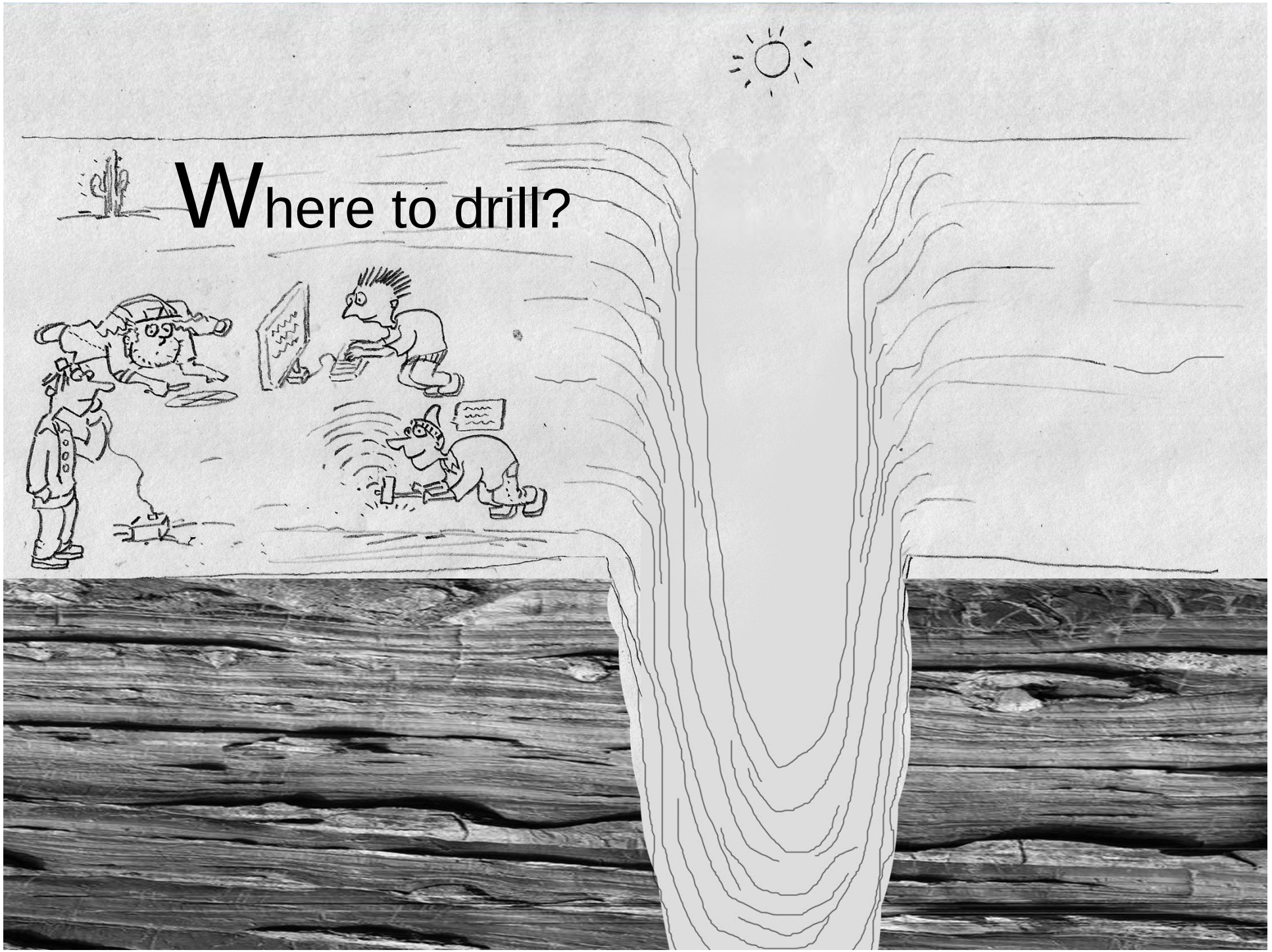
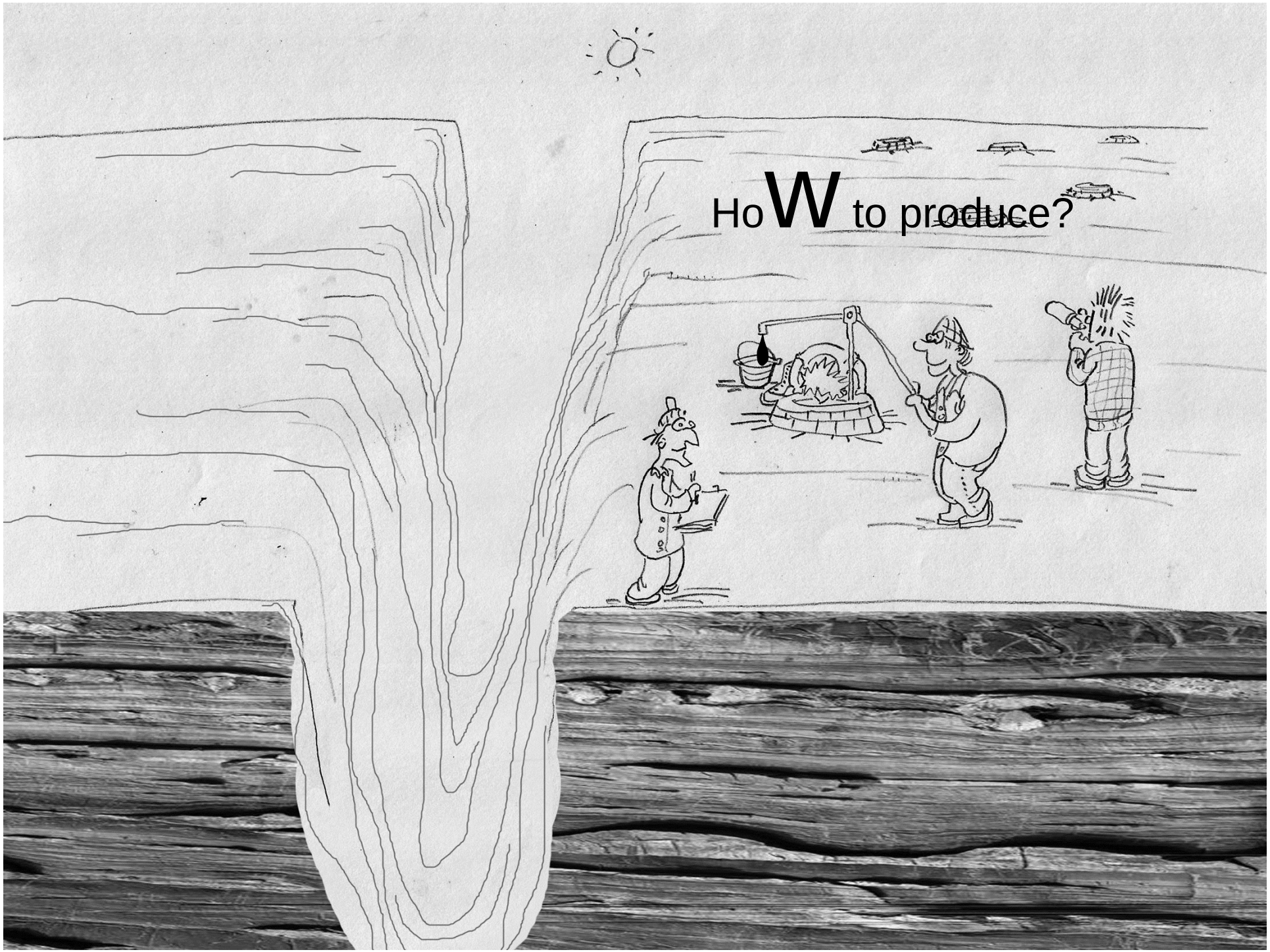
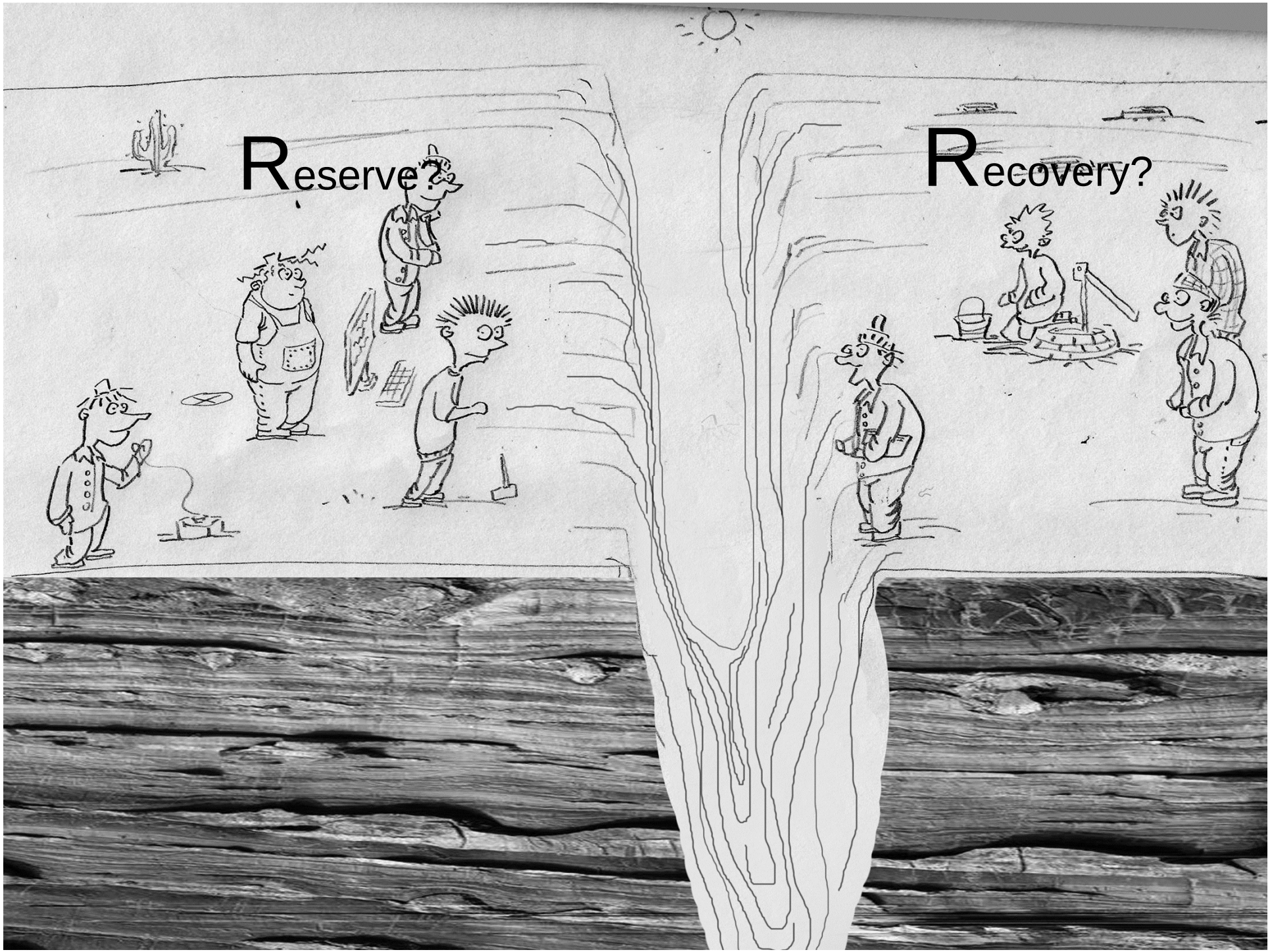
Outline

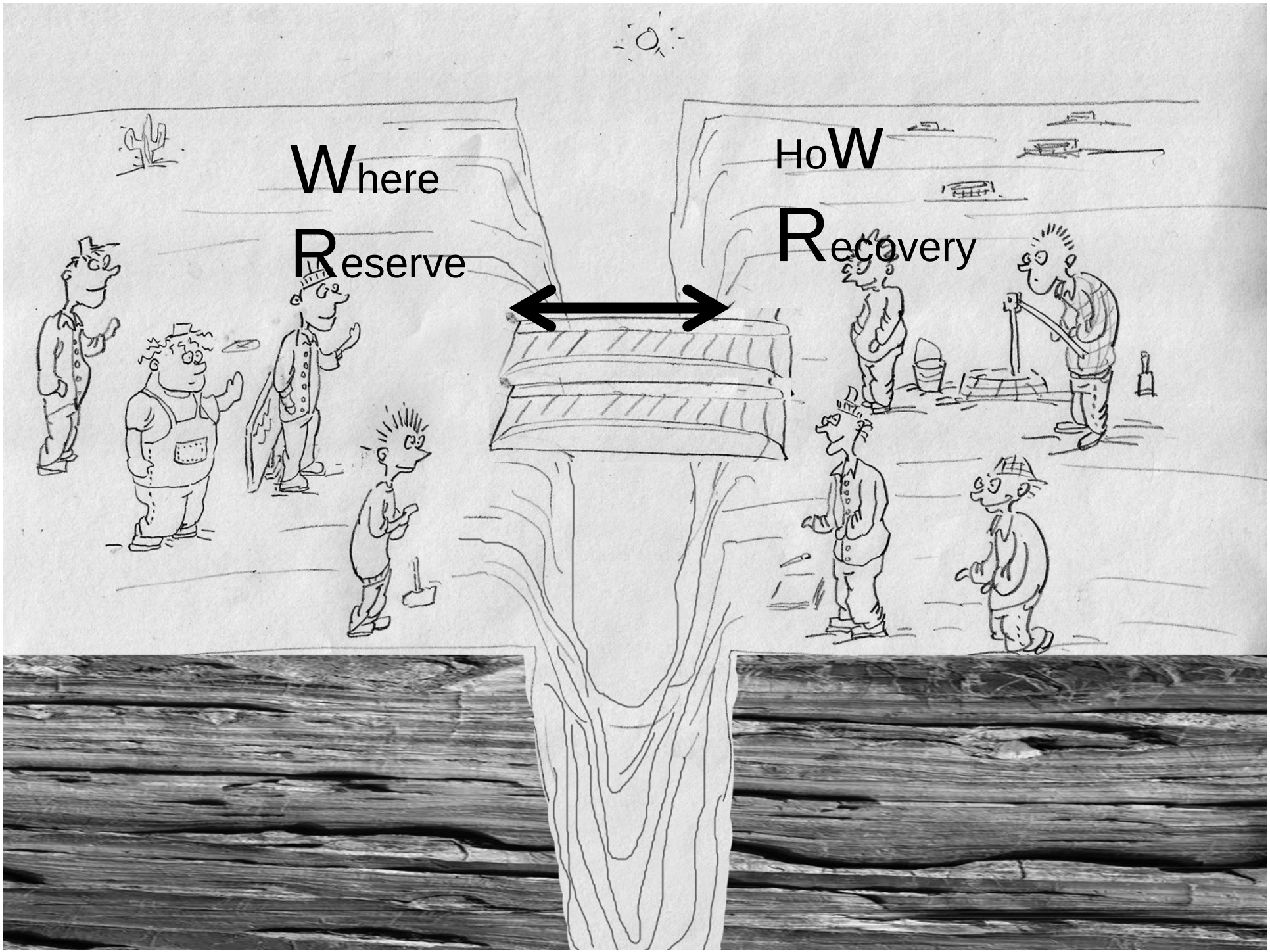
- Overview
- Bridging in Data Domain
- Bridging in Model Domain
- Optimization
- Summary

Where to drill?

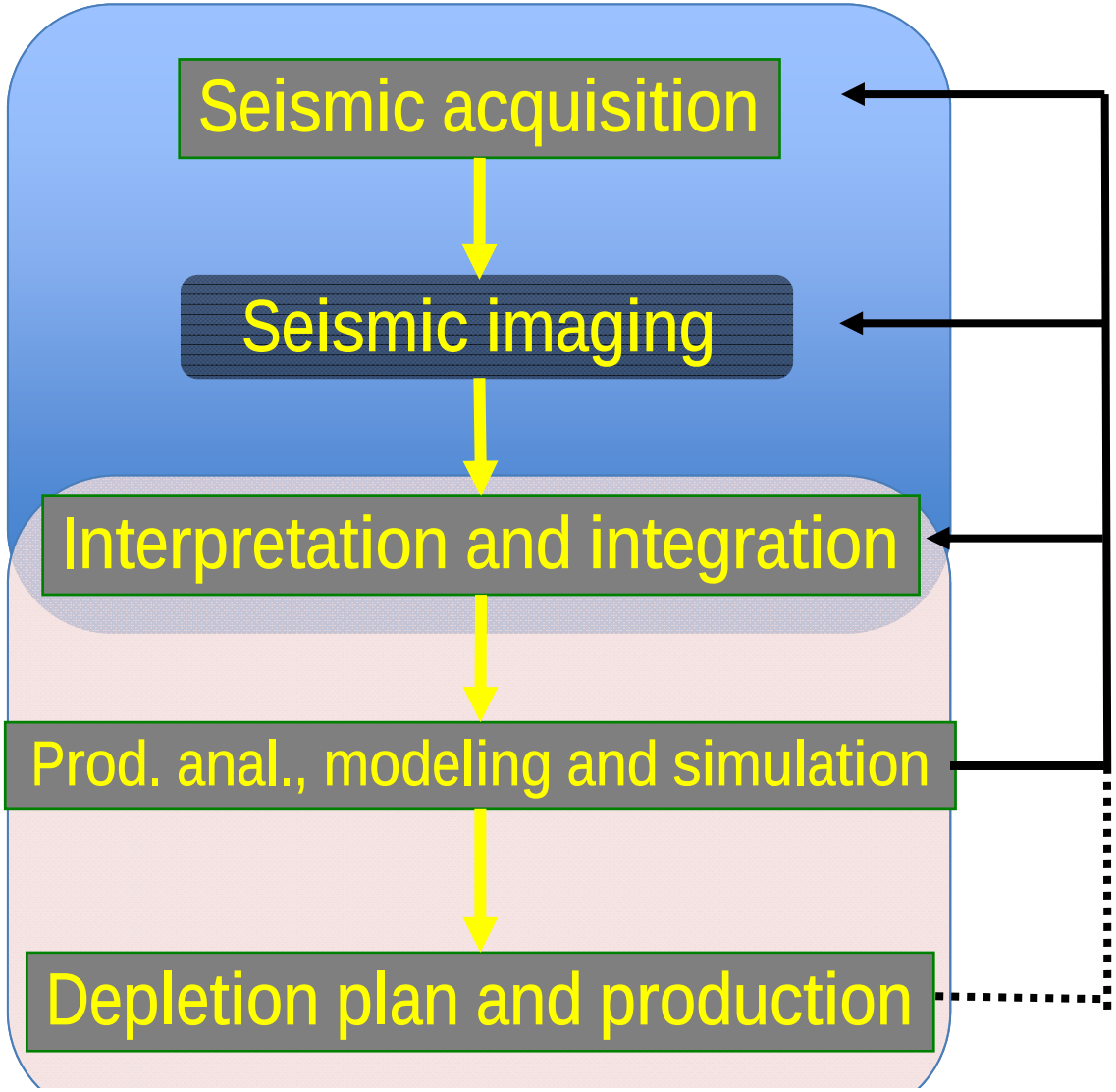



How to produce?


Reserve?
Recovery?


Where
Reserve
HoW
Recovery

Bridging: Close-the-Loop

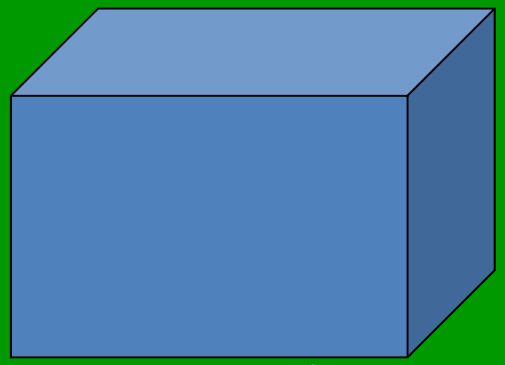


Use reservoir and production data to further update seismic interpretation and vice versa

“Bridging” Methodologies

Data-based

Material balance



Solve for

Hydrocarbon in Place

Drive Mechanism

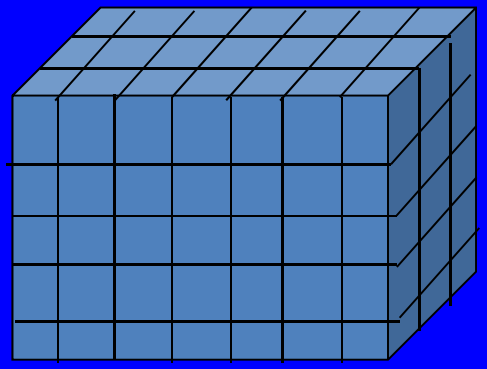
Connectivity

Reconcile seismic with spatial information

Data-Based Close-the-Loop

Model-based

Reservoir Simulation



Solve for

Pressure

Saturation

Constrain model to seismic and production history

Model-Based Close-the-Loop

Data-based “Close-the-Loop”

- Data consistency analysis
- Interpretation of spatial characteristics using the time-dependent production data

Model-based “Close-the-Loop”

- Common reservoir model
- Comparison of synthetic seismic (4D, prestack, 3D,…, etc.) with observed
- Update model according to seismic and production mismatches
- Reservoir property inversion

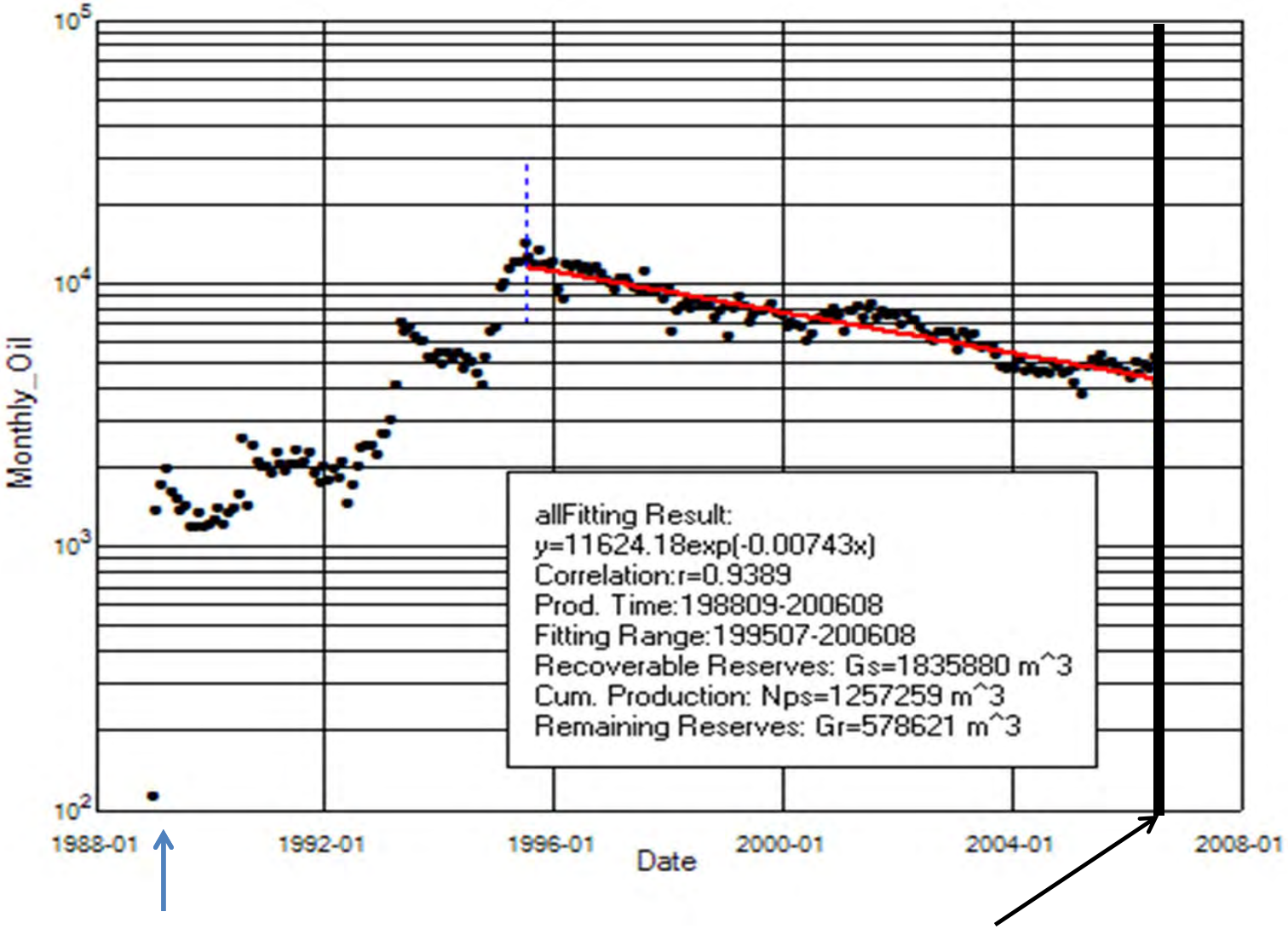
Optimization

- Use of historical production data
- Use of seismic data
- Use simplified model constrained by seismic for history matching
- Optimize production system to arrest decline

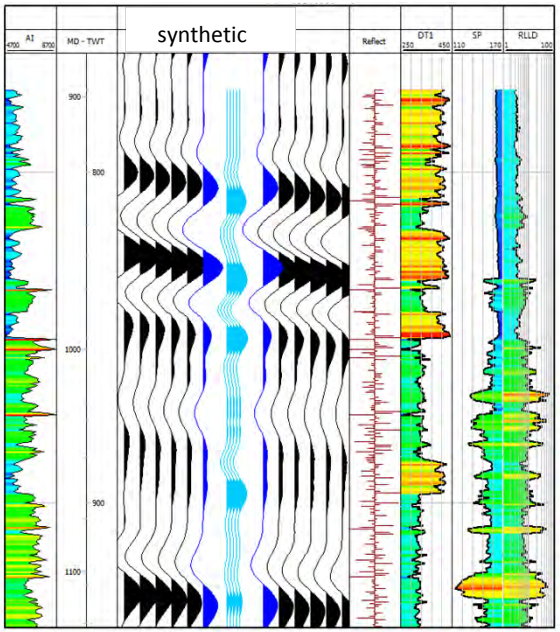
Data-based “Close-the-Loop” example: A field study

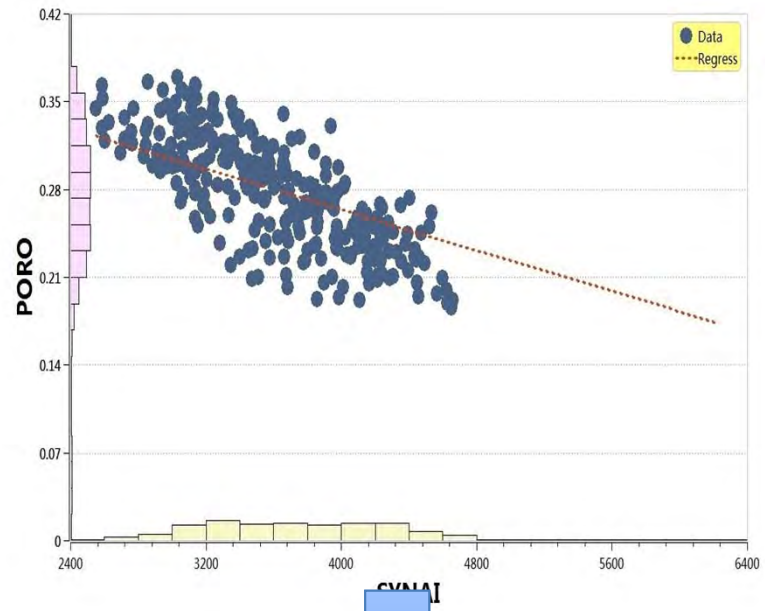
- Field starts to produce in 1989
- A new 3D seismic acquired in 2006, and reprocessed
- Goal: to explore the potential in the field using the new seismic survey

History and Field Decline

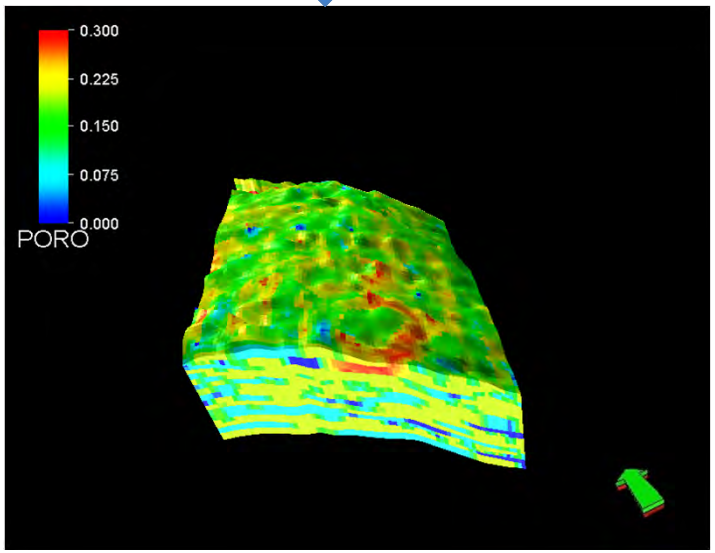


Typical seismic to reservoir

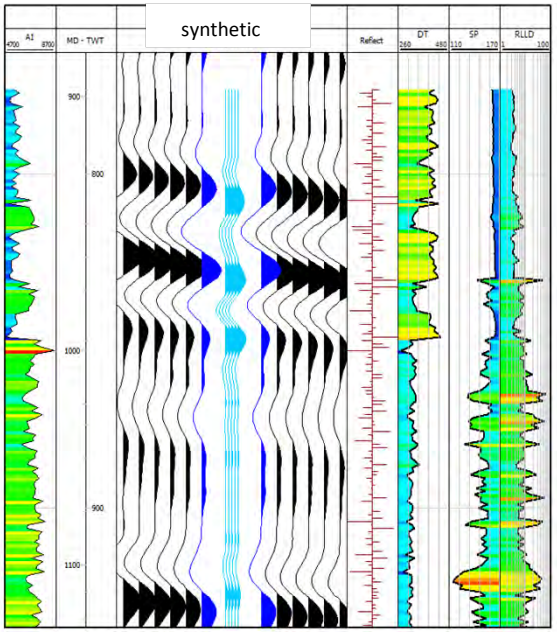


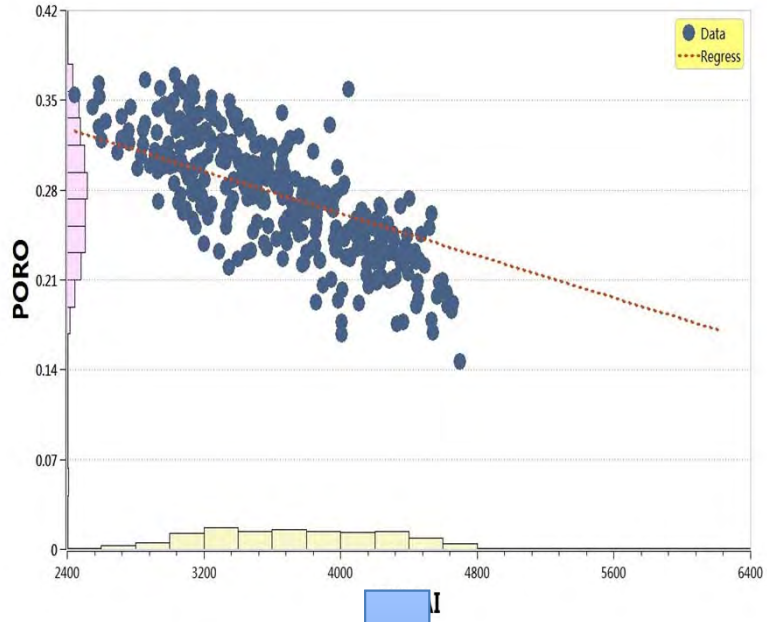


- Treat seismic as static
- Correlation with wells
- Co-modeling

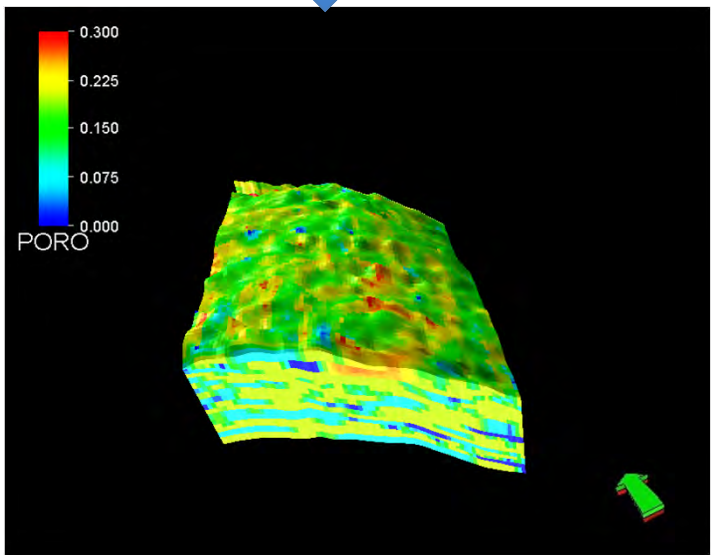


Typical seismic to reservoir

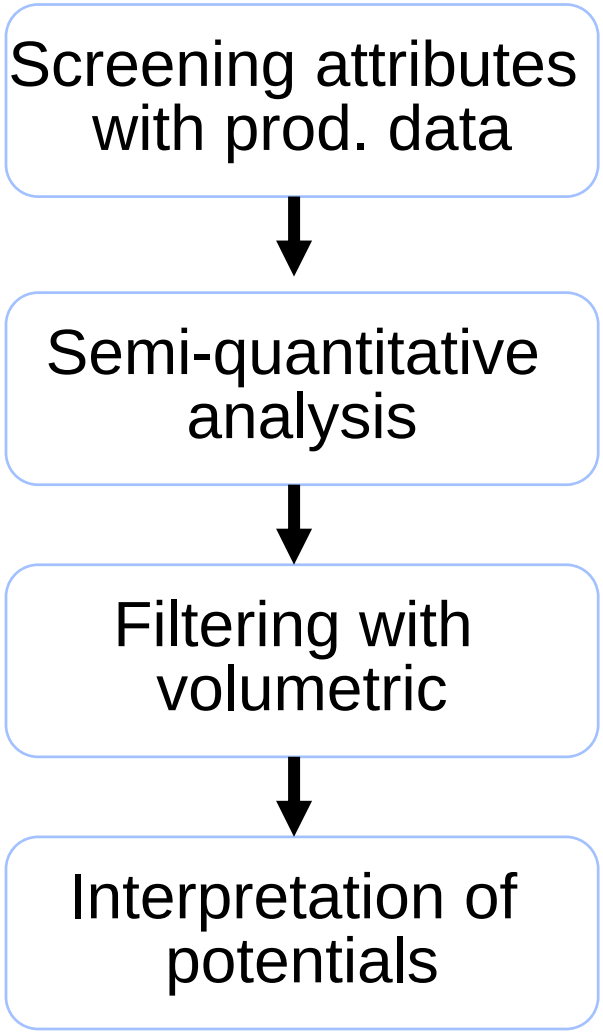




- Time-depend.?
- Use of seismic for dynamic behavior?
- Co-engineering?

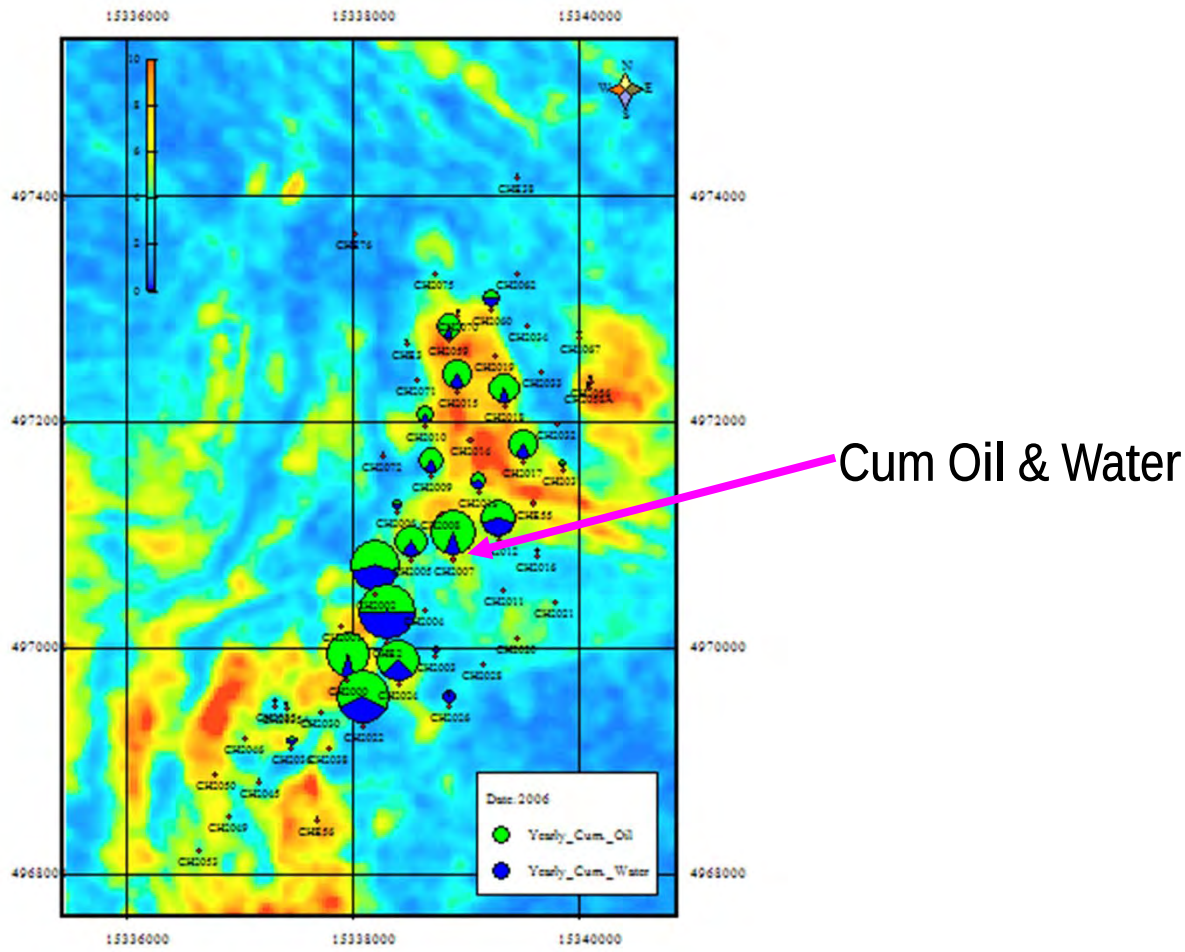


A procedure for data-based “Close-the-Loop”



Production data + Seismic ➔ Interpretation

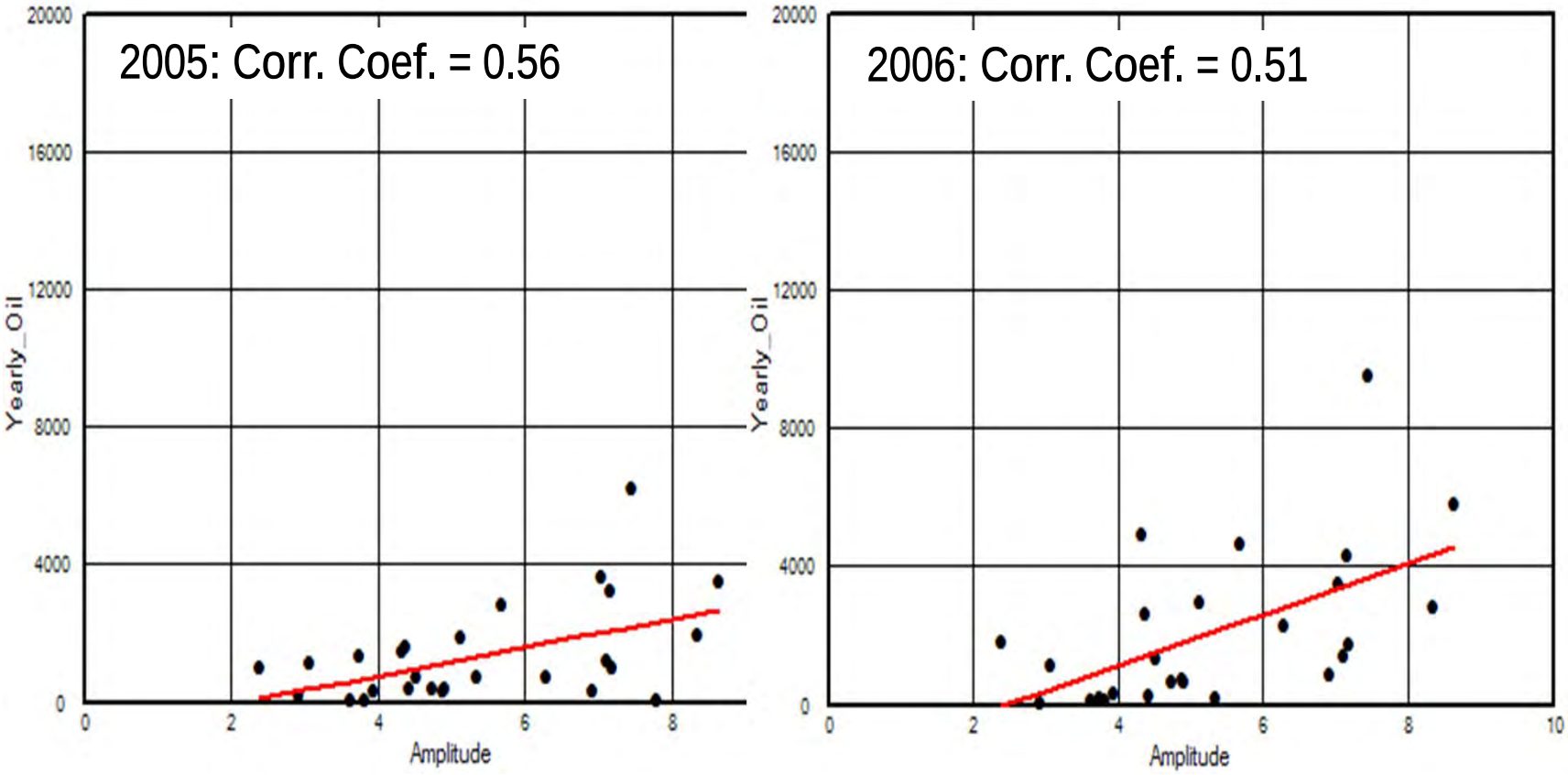
Step 1: Screening - Amplitude and Cum. Oil & Cum. Water



Reproc. Amplitude

Seismic attribute and production data patterns consistent

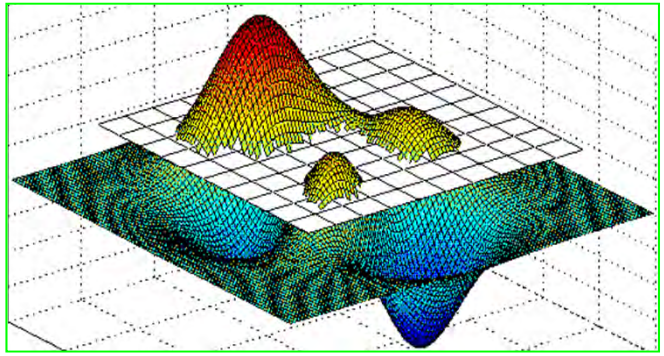
Step 2: Quantified relationship



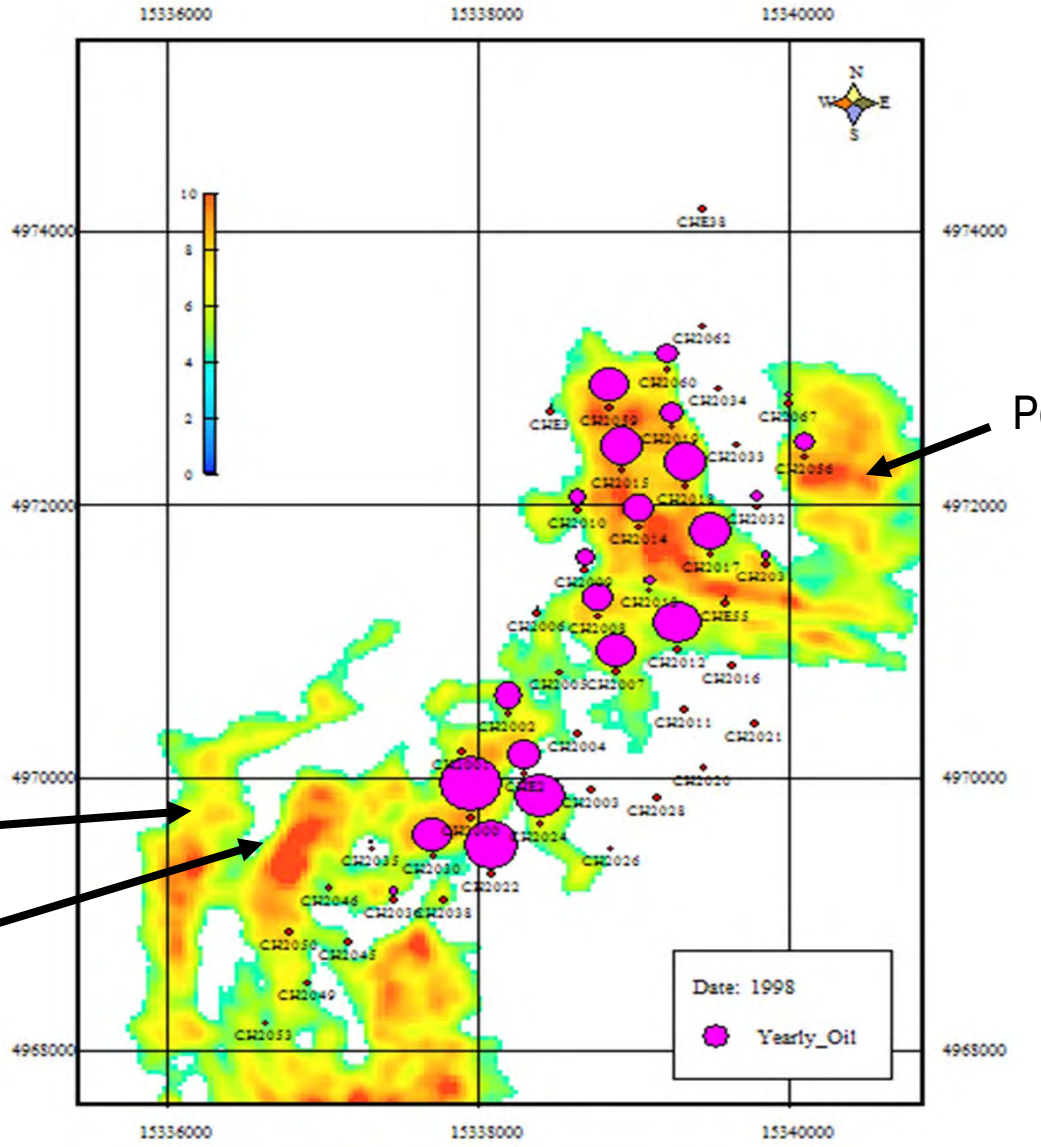
Favorable correlation indicates consistency of seismic attribute and production data

Step 3: Filtering of amplitude
Region growing with wells, matching reserves

Volumetric matching
of seismic, region filtering
and total support volume
(reserves) from production
data for potential screening



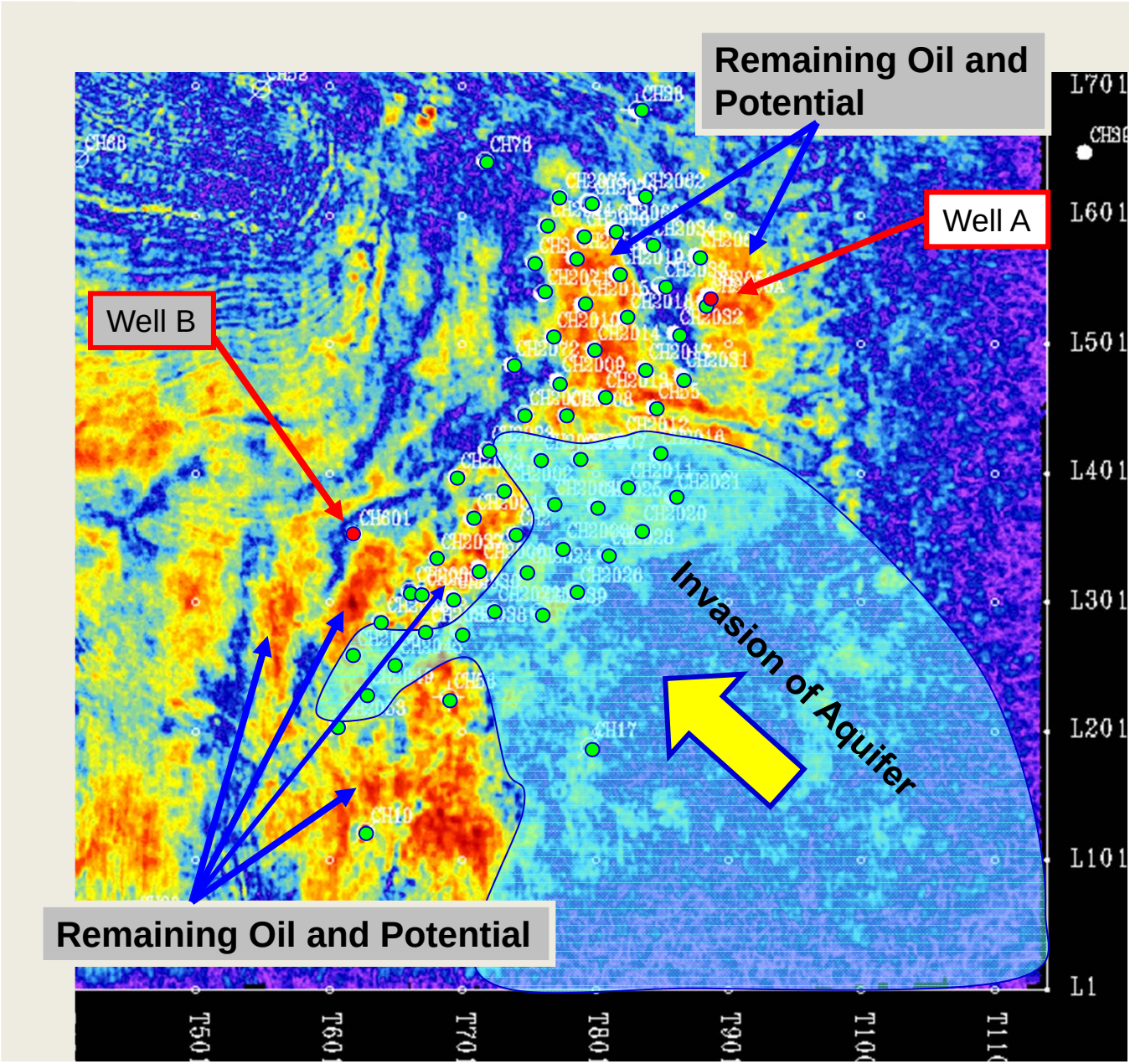
Potentials



Potentials

Step 4: Remaining potential and aquifer movement

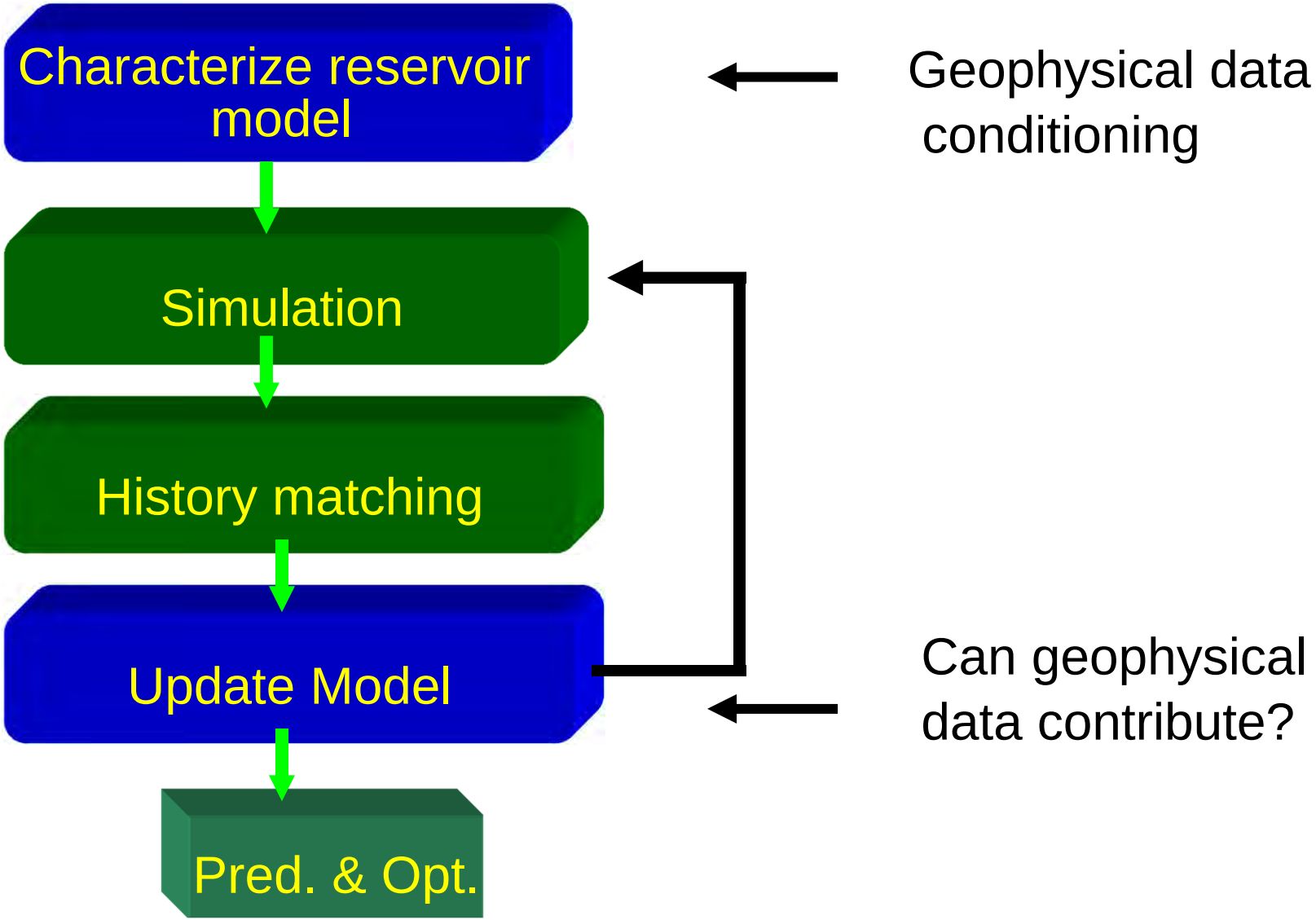
Where to adjust?



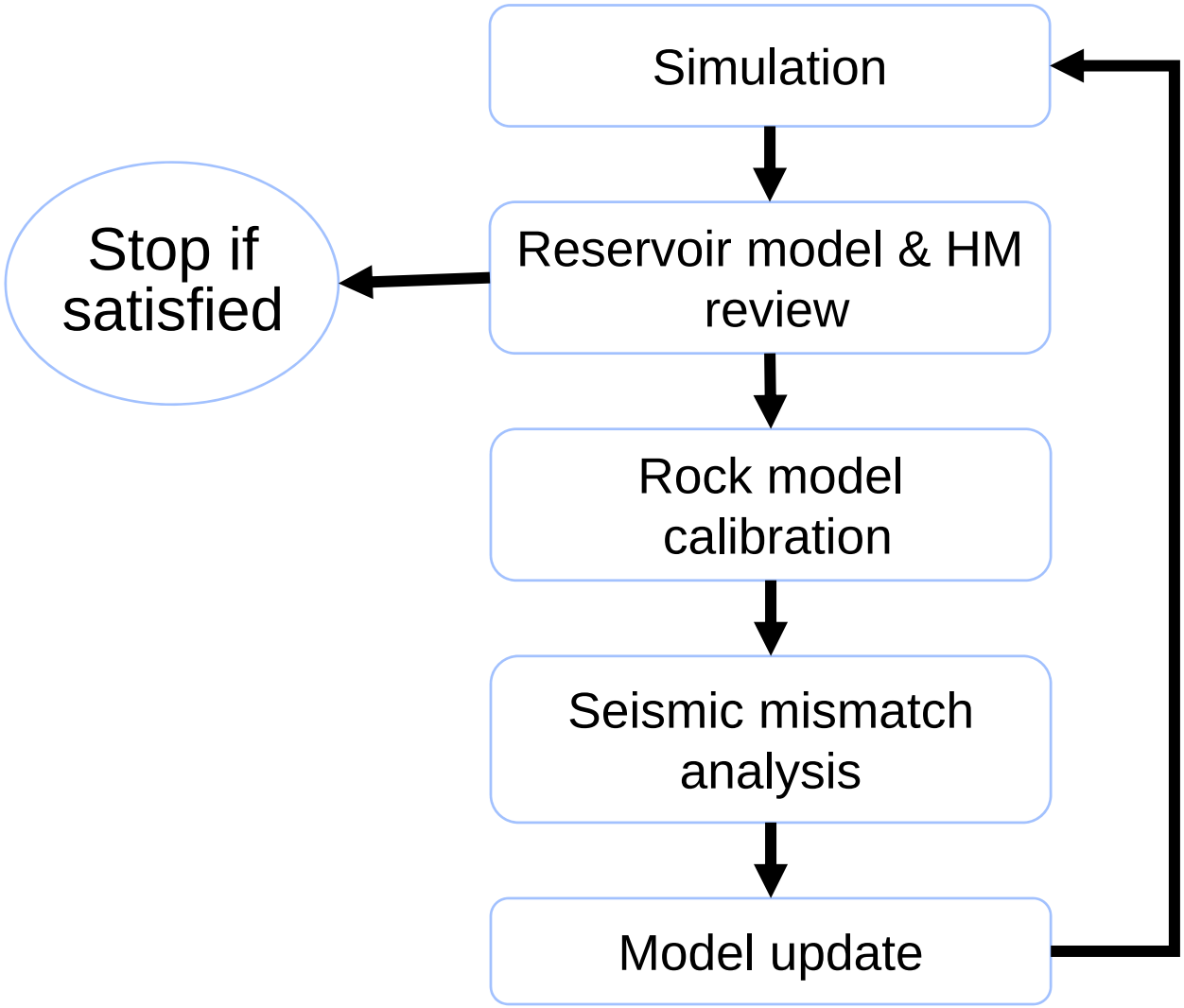
Model-based “Close-the-Loop” example 1: Field background

- **15 months production history**
  - **Original reservoir model available**
  - **Water-cut matched in general**
  - **High mismatch observed for individual wells**
- **Reasonable seismic data**
- **Goal: improving the *original reservoir model***

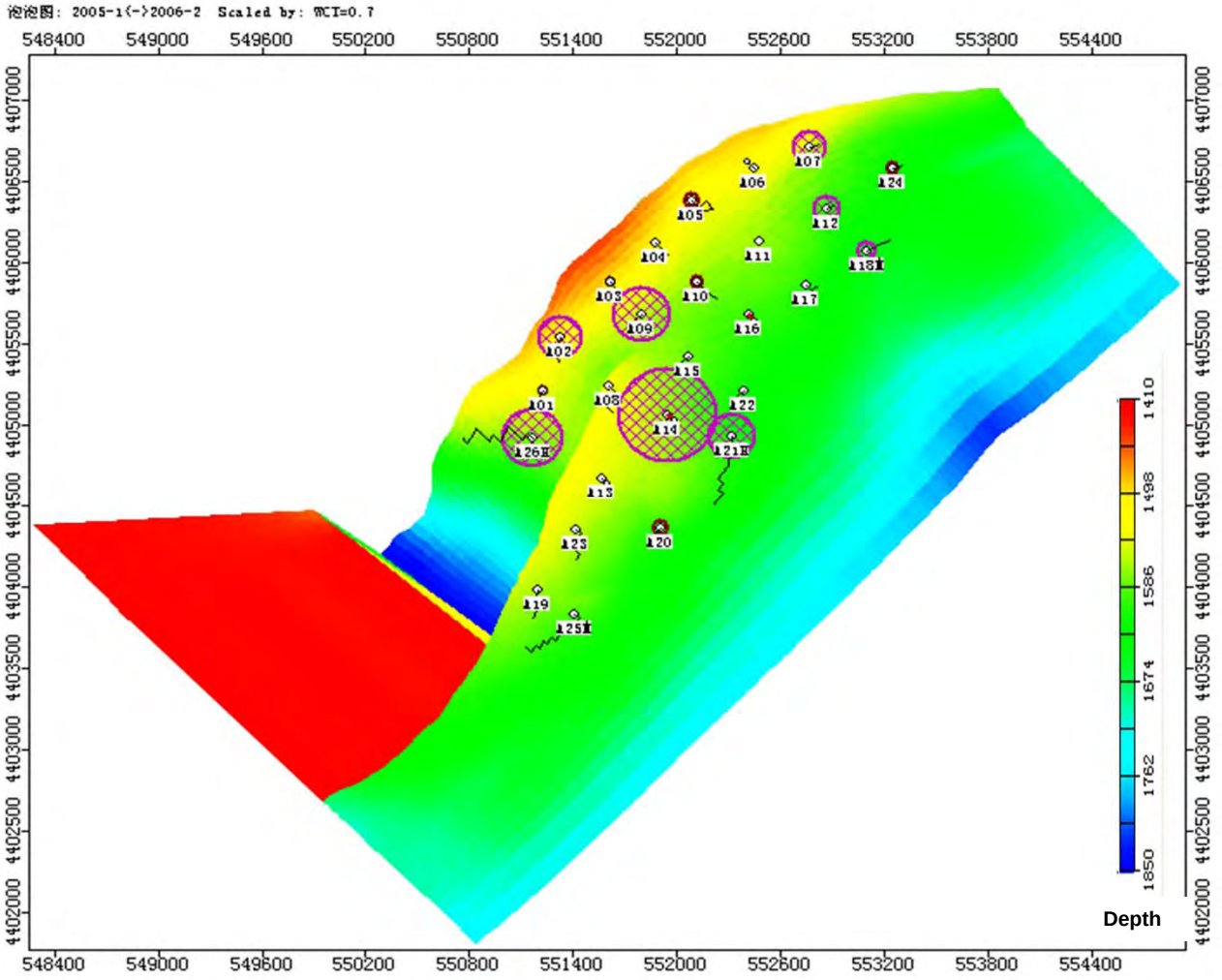
History Matching & Seismic



A procedure for model-based “Close-the-Loop”



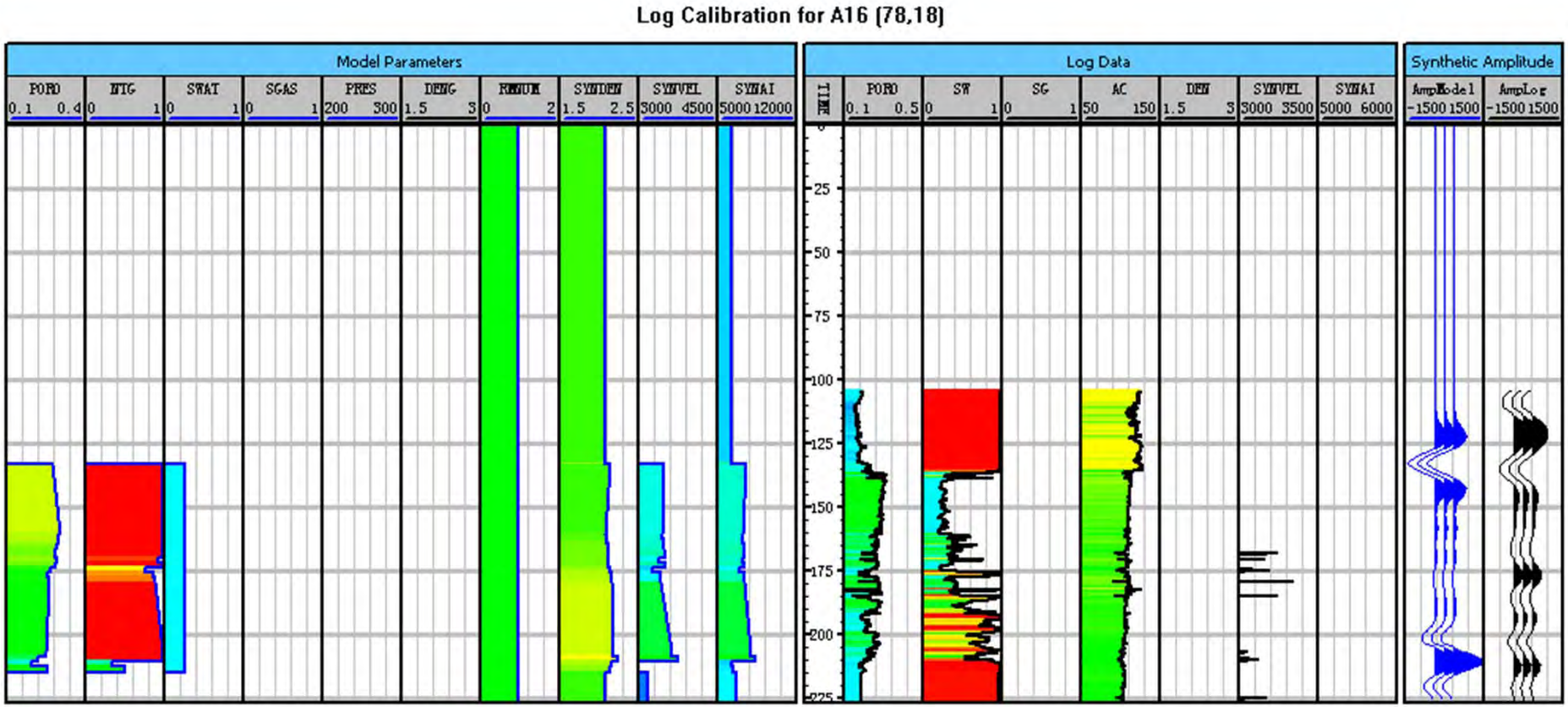
Step 1: History matching review



Higher mismatches in the central areas of the reservoir

Step 2: Rock model & log calibration

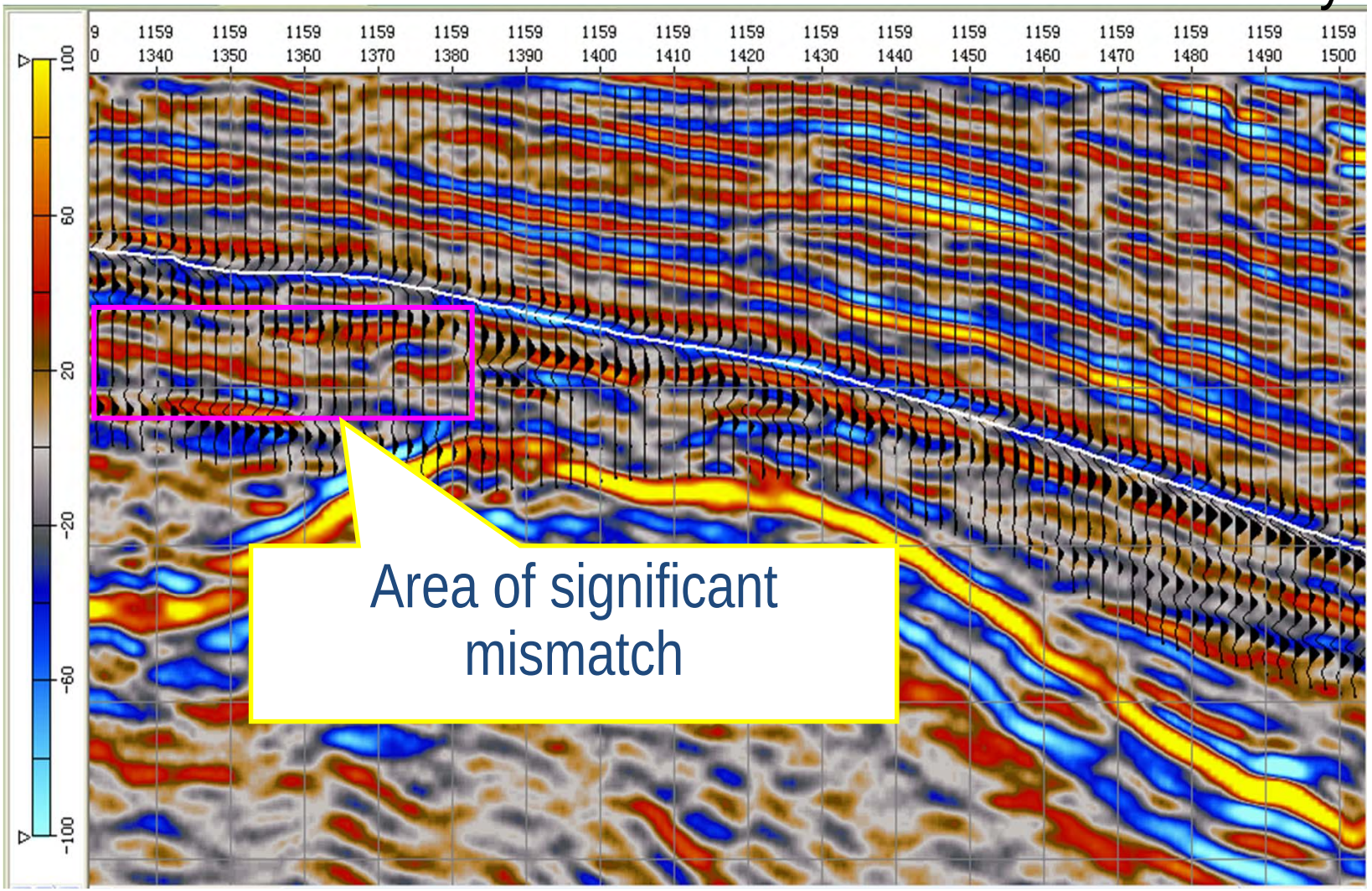
Log Calibration



Find a rock model which builds a relationship between reservoir properties (dynamic and static) and seismic responses.

Step 3: Seismic mismatches

Seismic Consistency



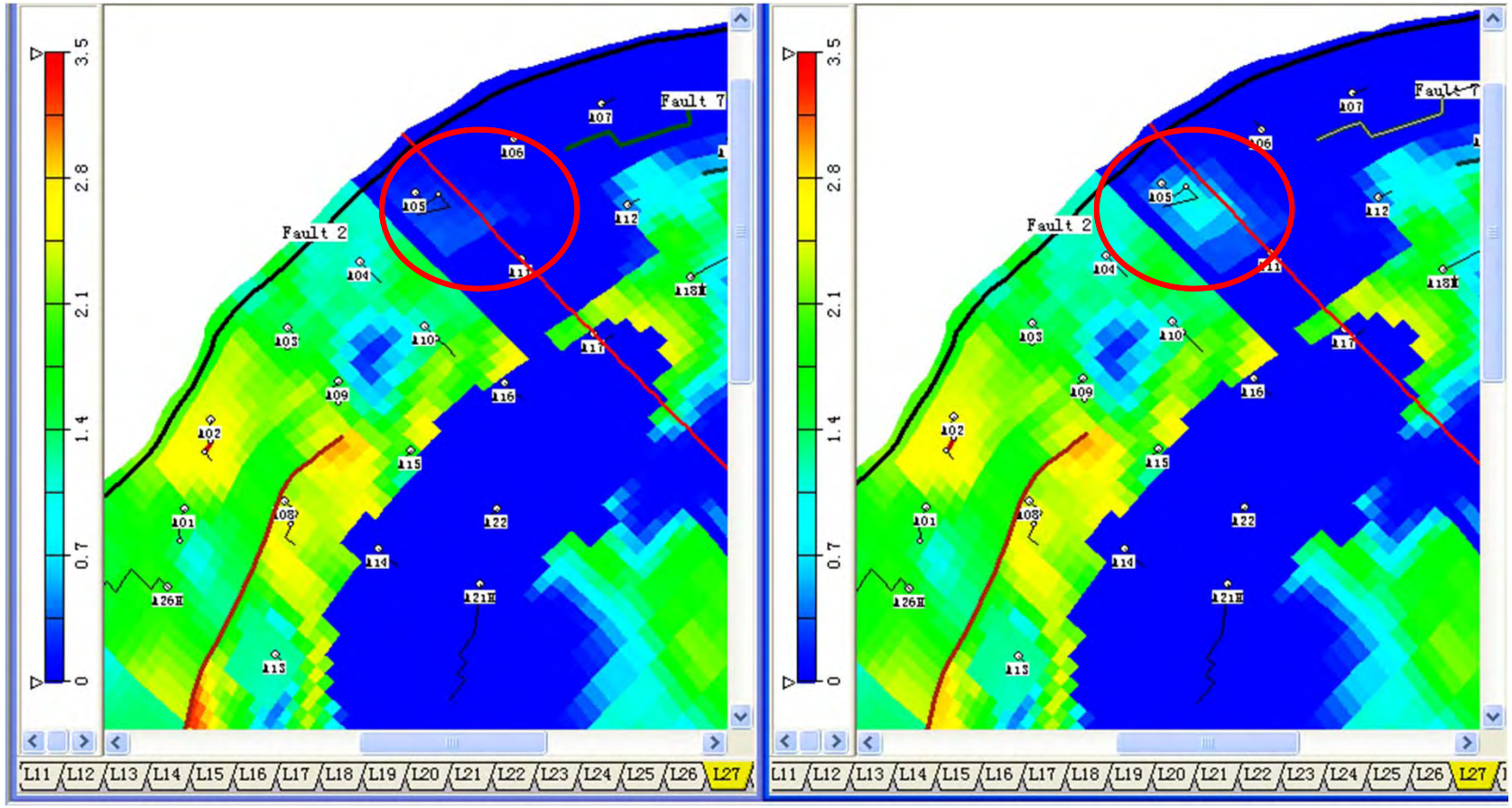
Screen the synthetic seismic with observed for seismic mismatch

Step 4: Model updating

Thickness modification

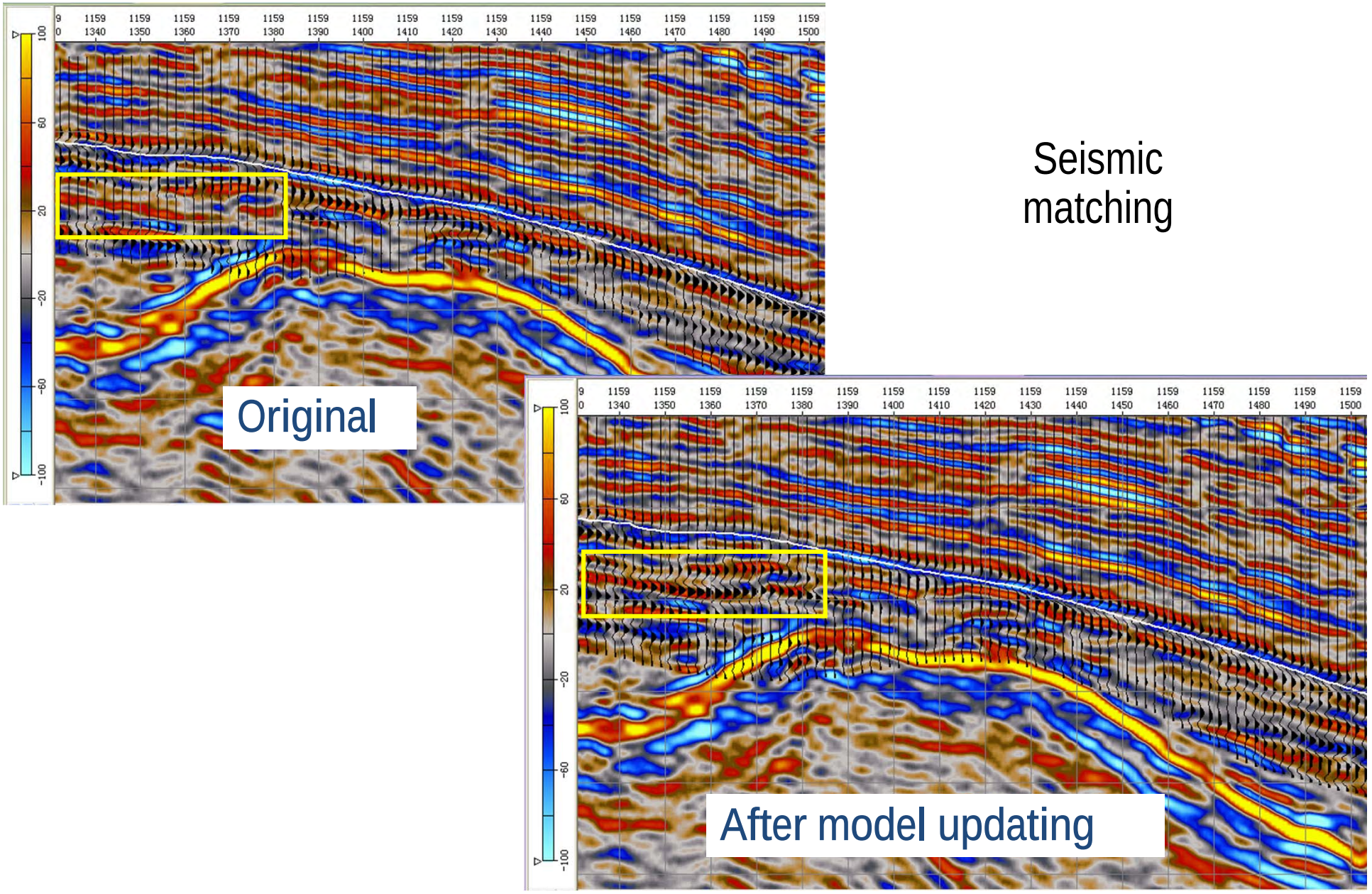
Original model

New Model



Modify the reservoir according to seismic mismatch

Seismic comparison

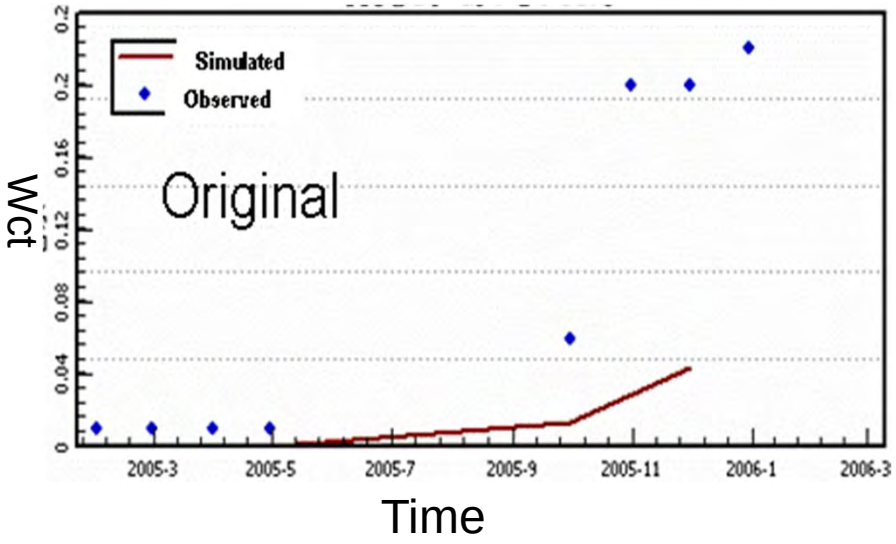


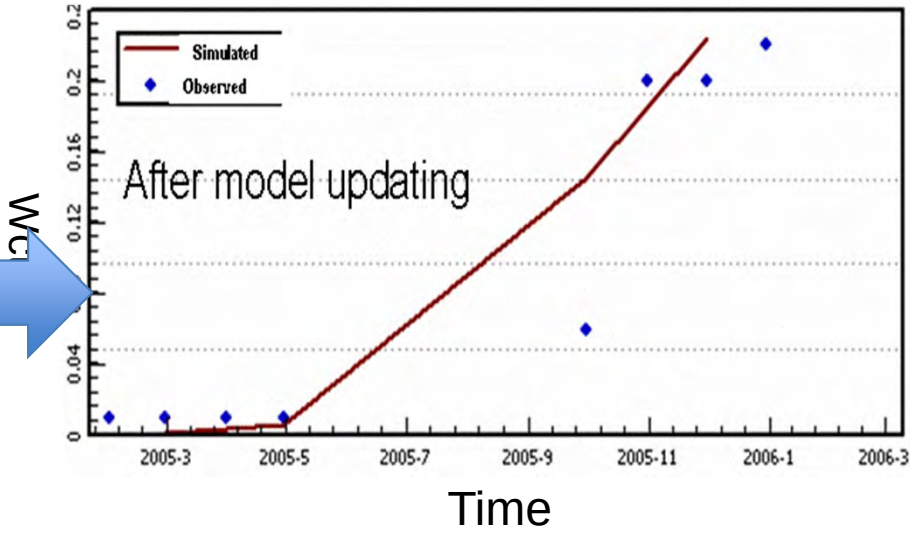
Seismic matching

History matching

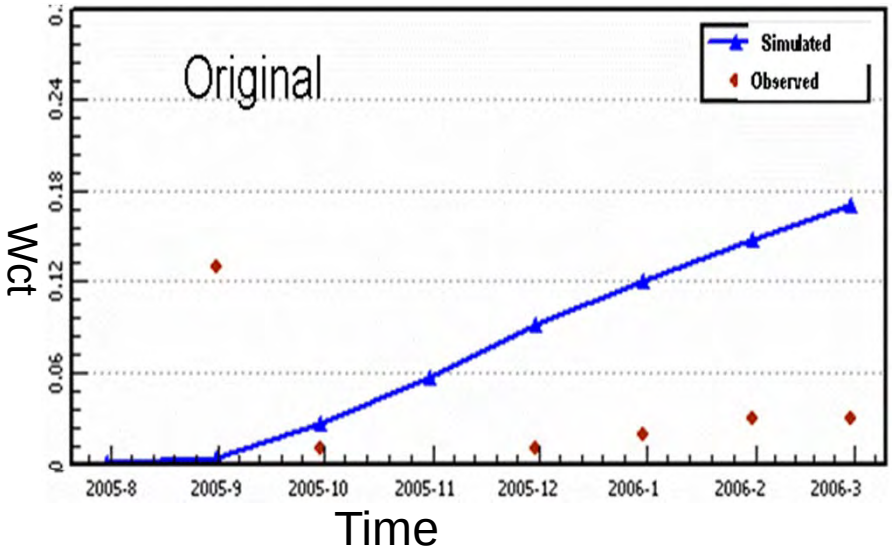
Water-Cut

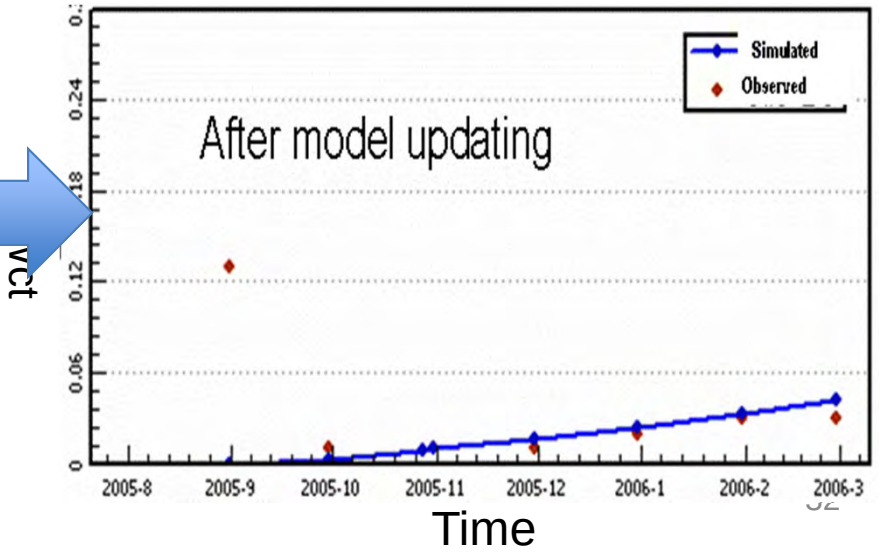
Well A09



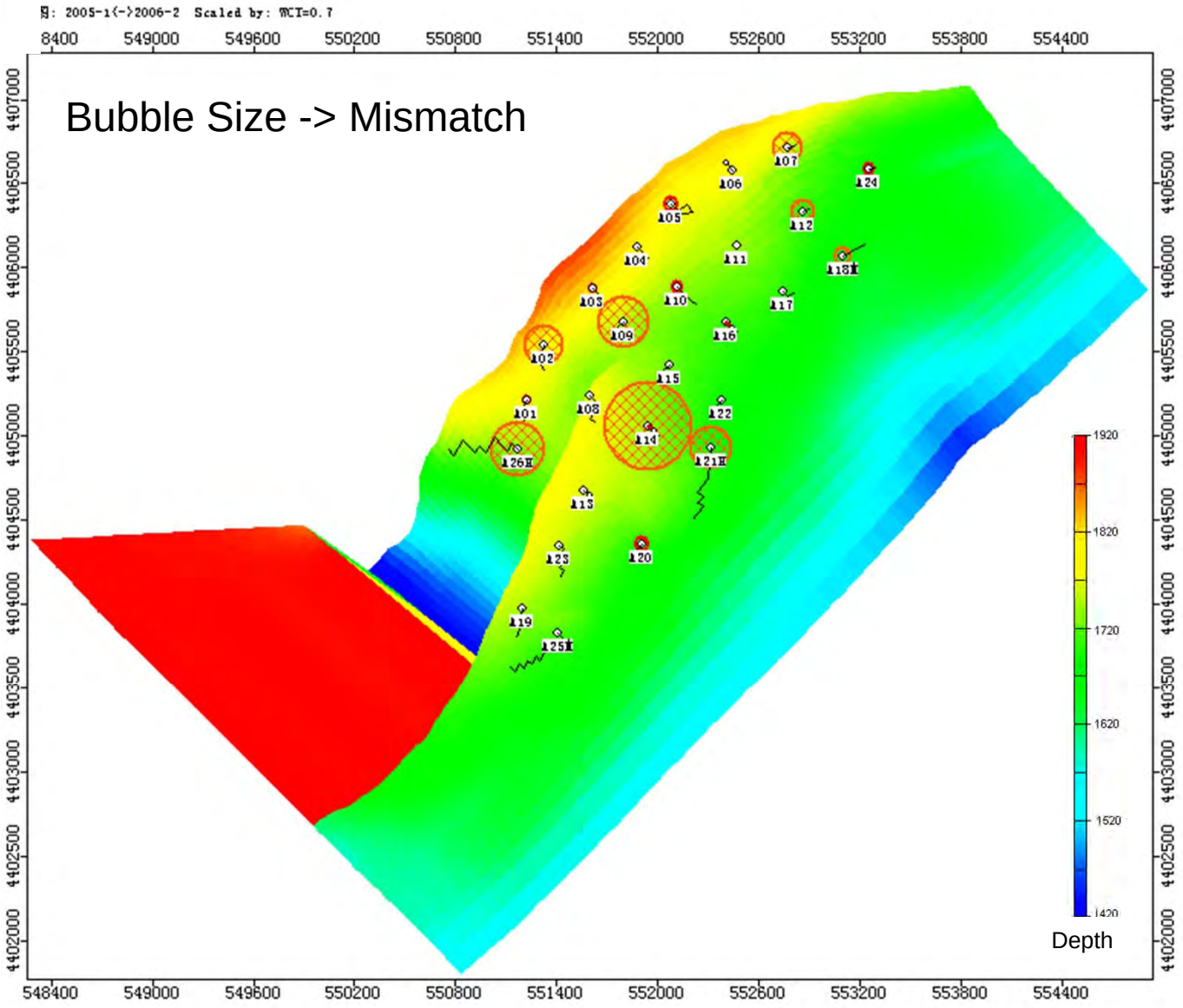


Well A26X

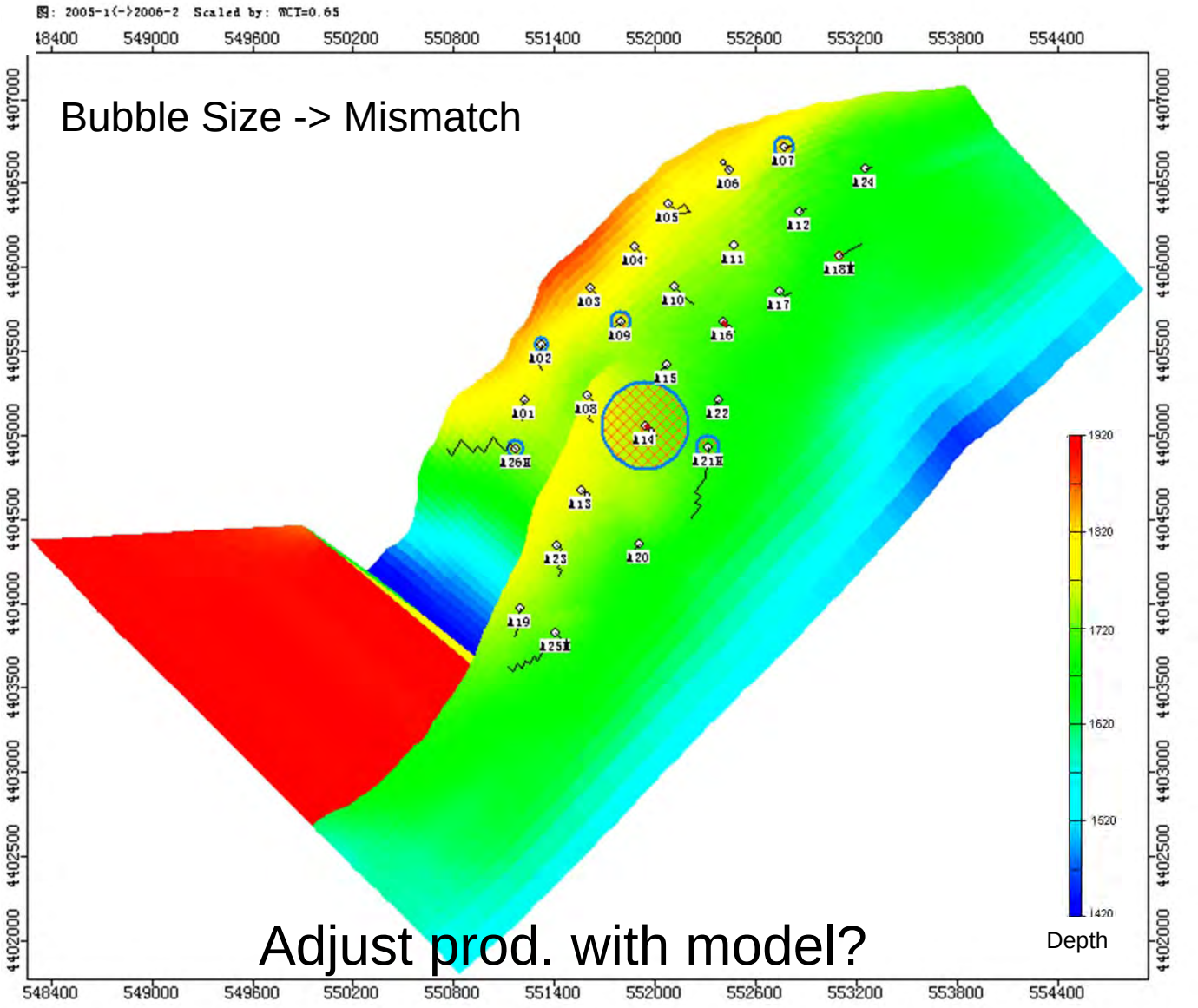




History matching before updating: water-cut

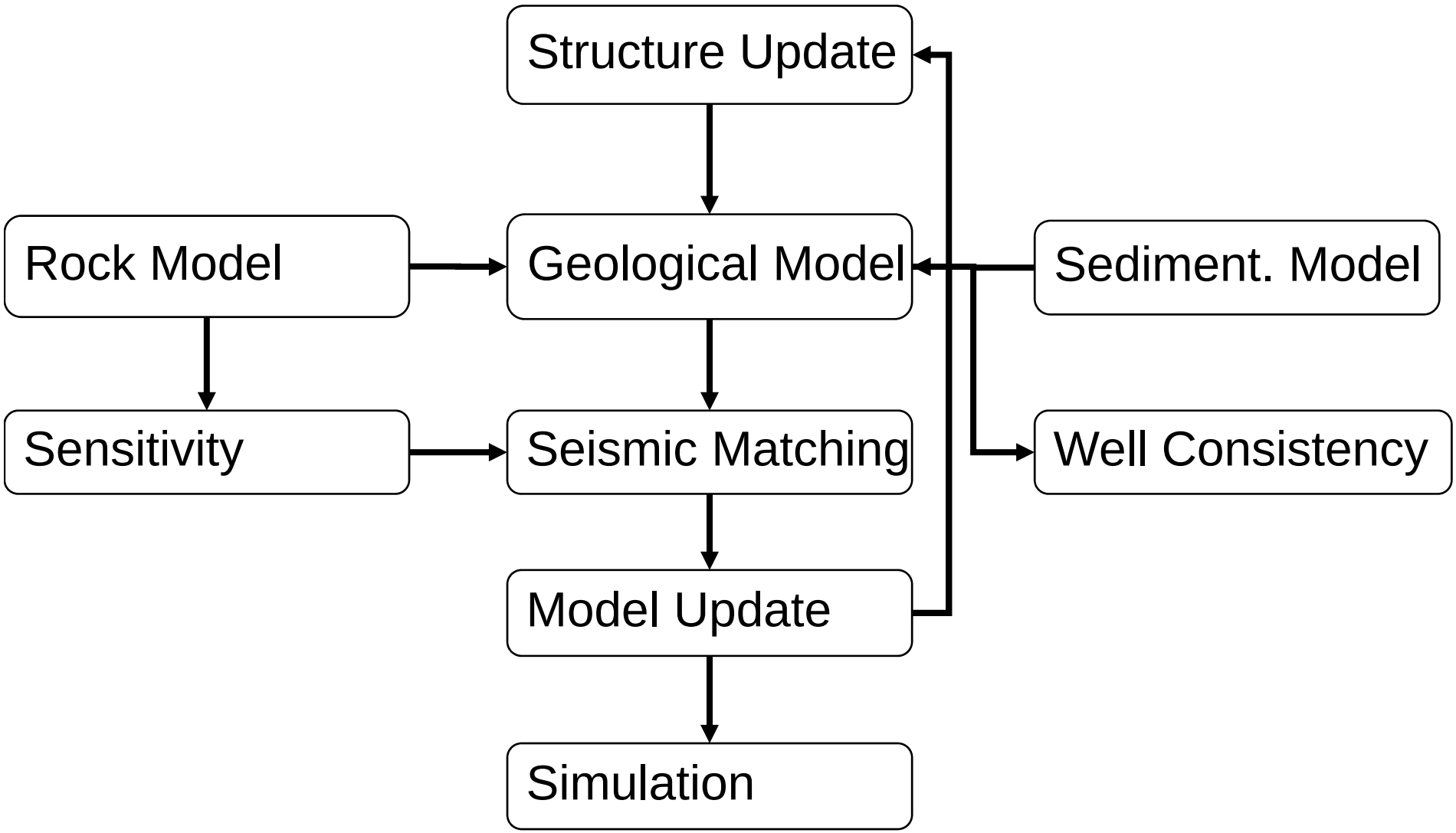


History matching after updating: water-cut

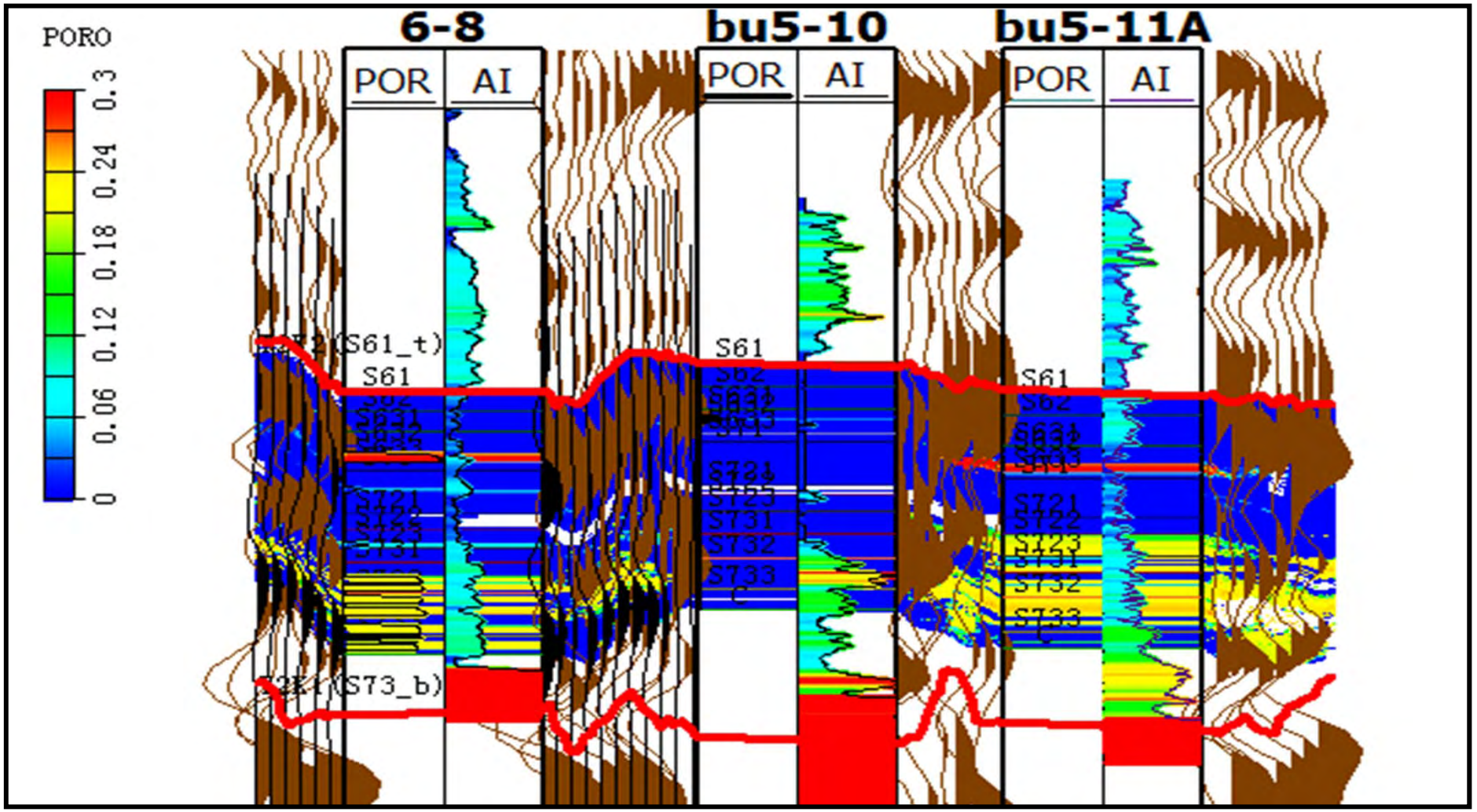


Model-based “Close-the-Loop” example 2: Field background

- **Mature field**
  - **More than 30 year production**
  - **2010 seismic**
  - **More than 200 wells**
- **Reasonable seismic data**
- **Goal: update or diagnose geological model using seismic**

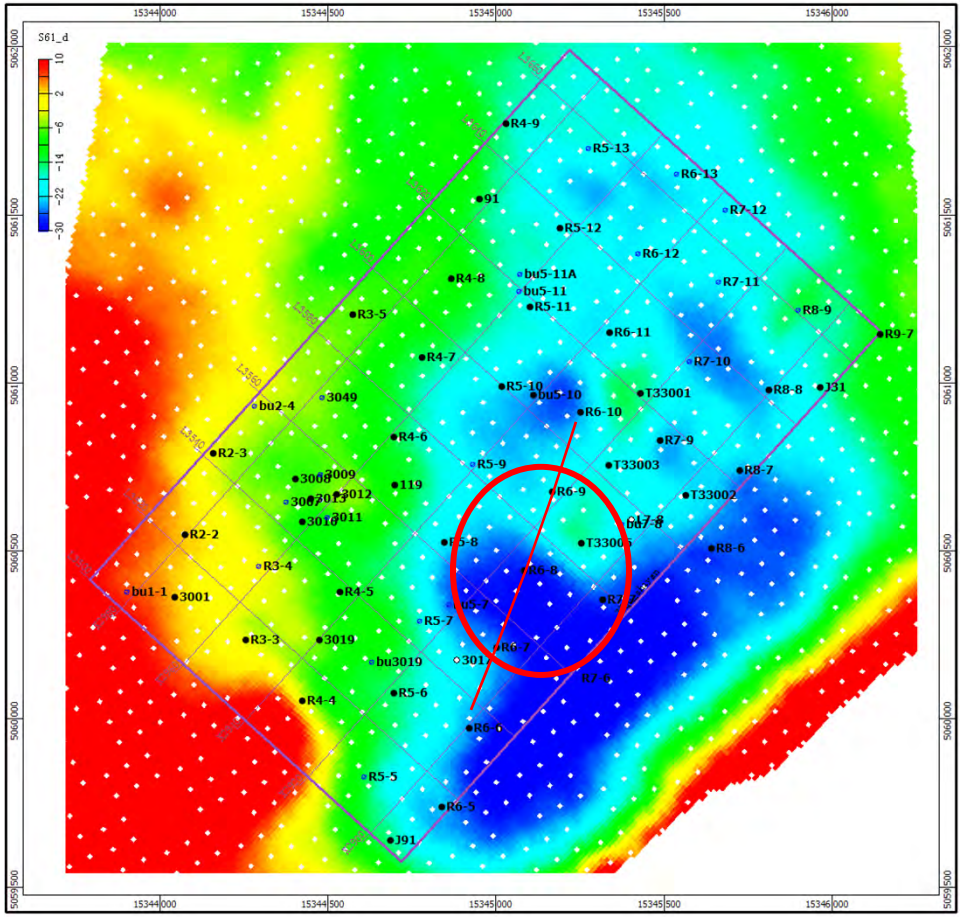

Structure Update
Rock Model
Geological Model
Sediment. Model
Sensitivity
Seismic Matching
Well Consistency
Model Update
Simulation

Step 1: Structure Check & Update

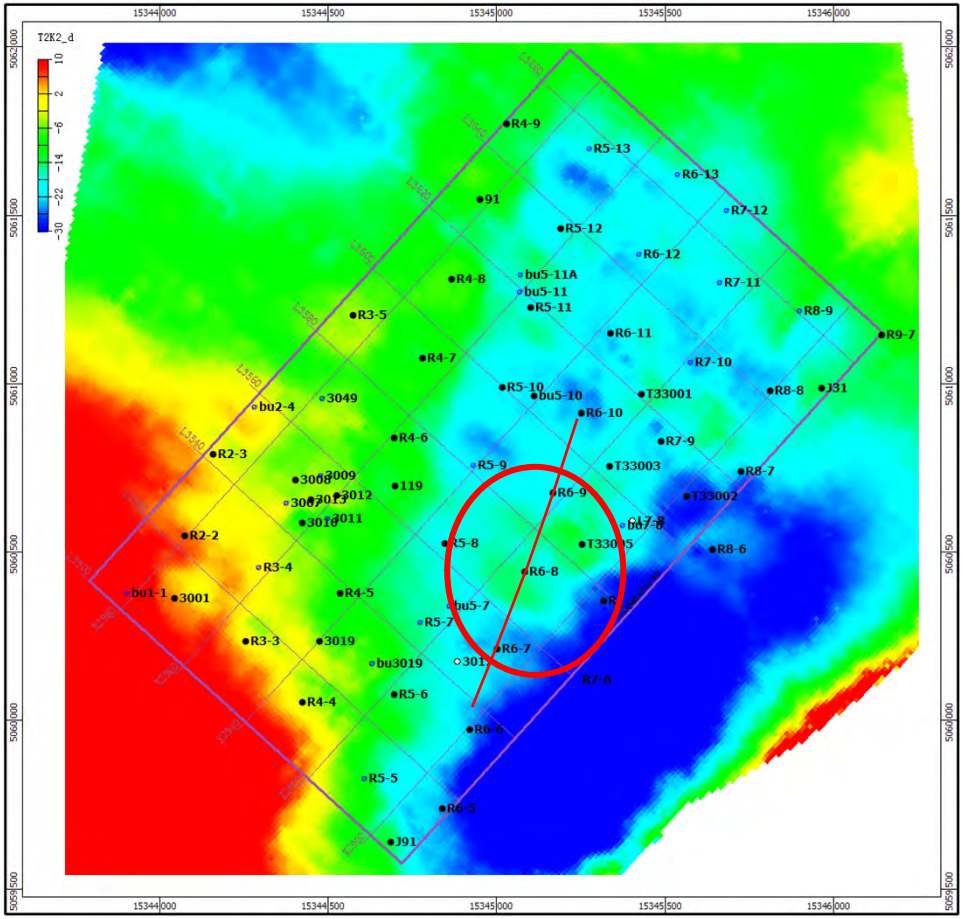


Step 1: Structure Check & Update

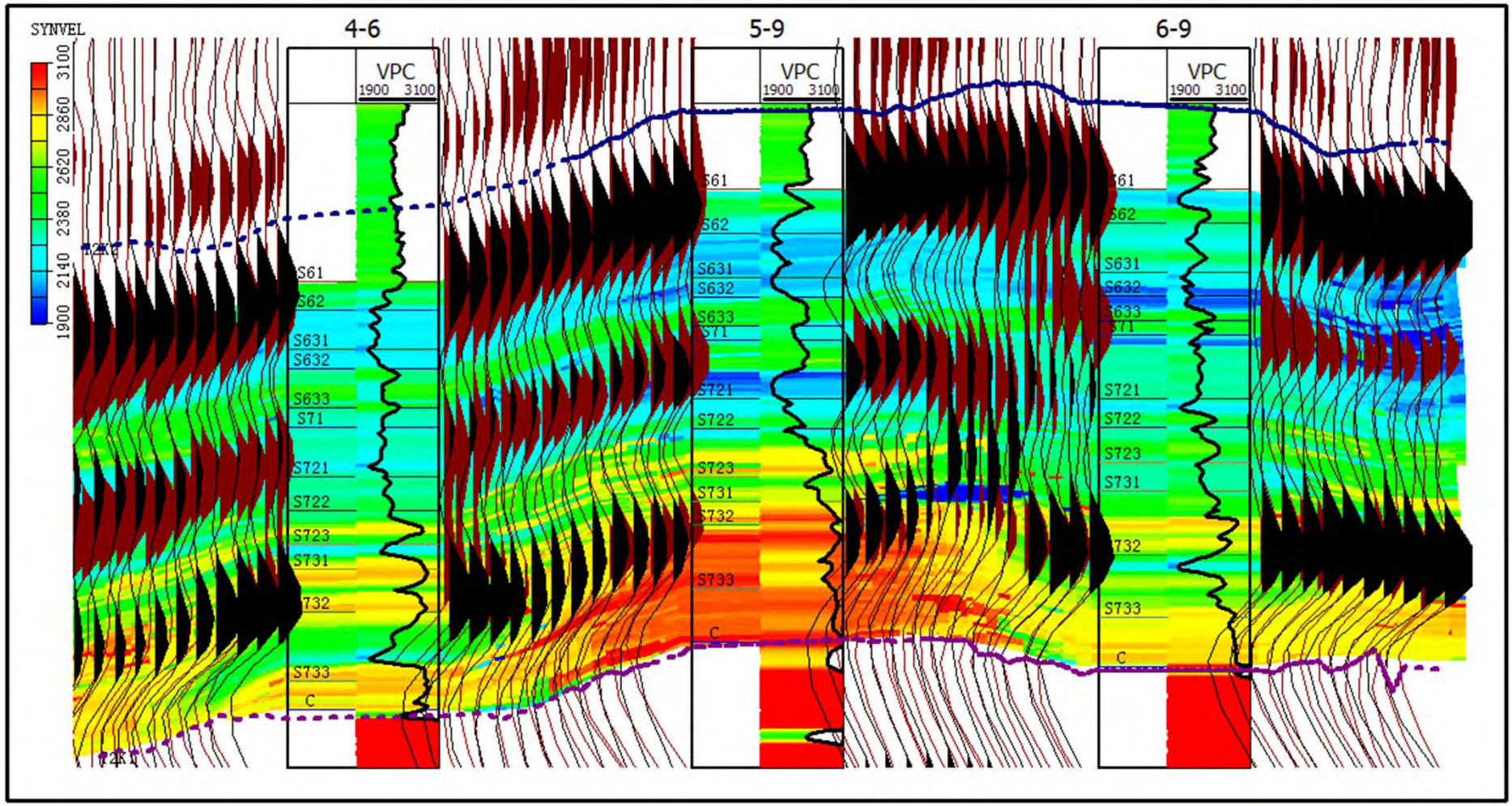
Original Top



Updated Top



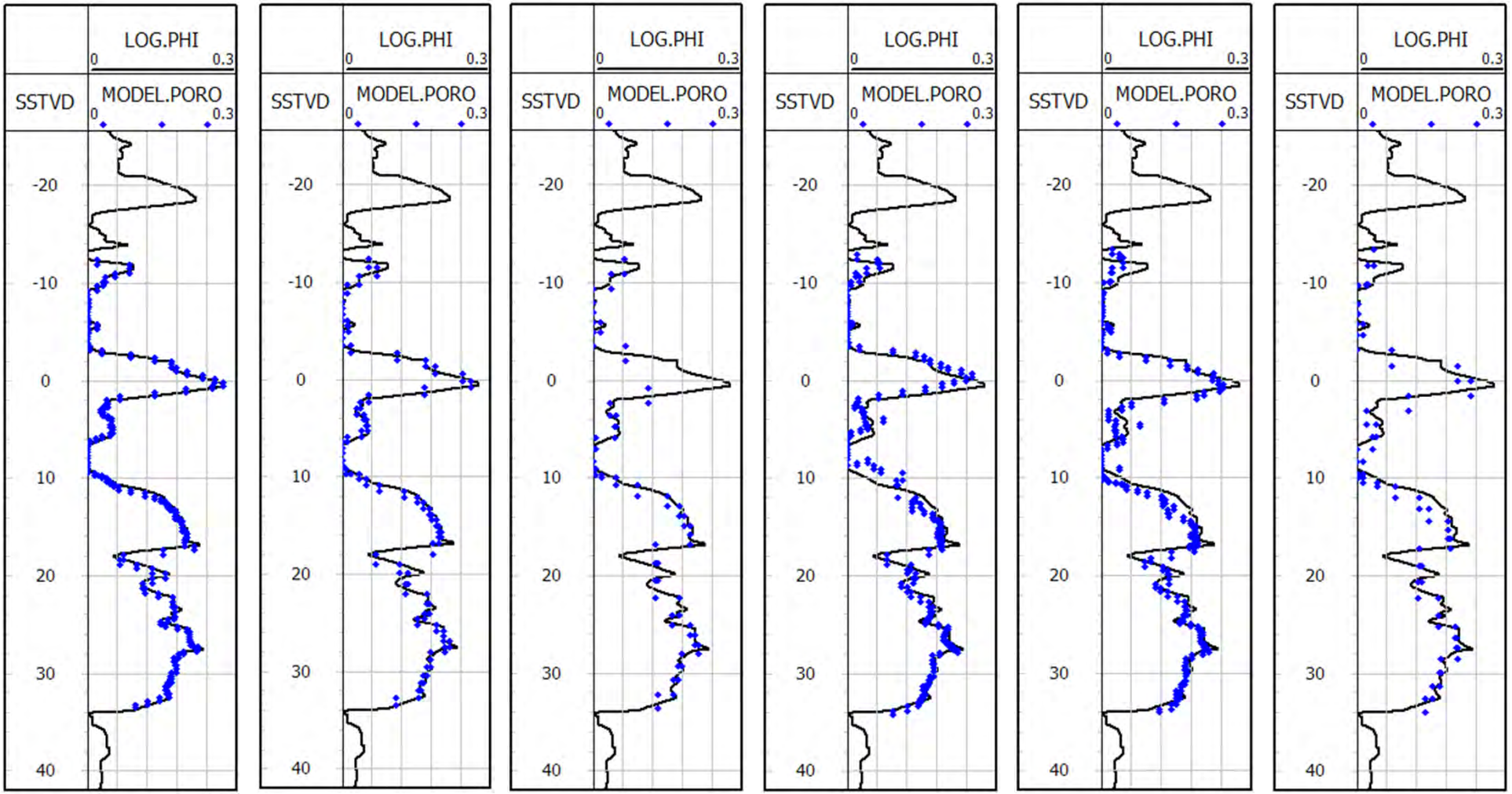
Step 1: Structure Check & Update



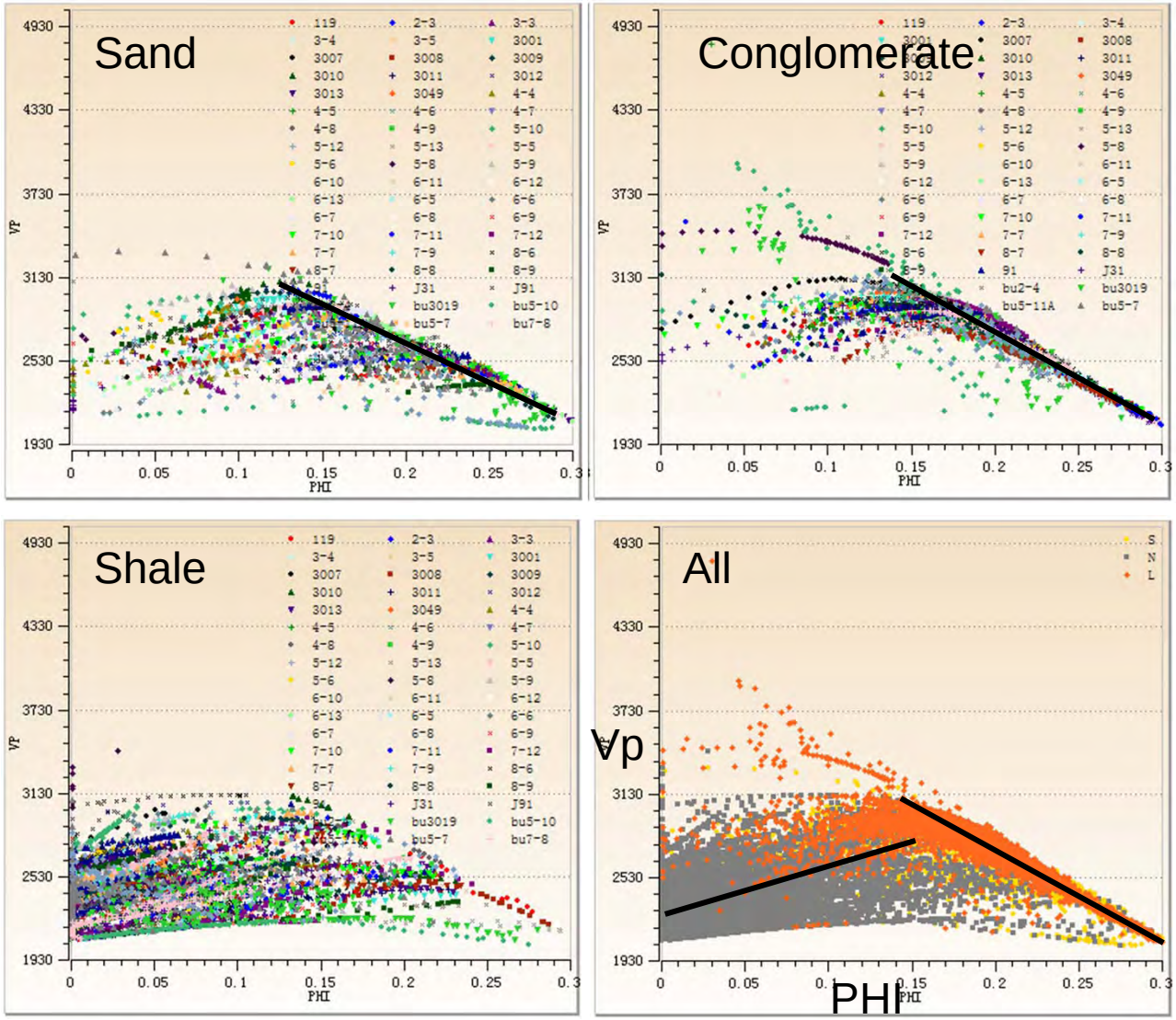
Step 2: Well Consistency

W119

12.5m×12.5m×0.5 | 12.5m×12.5m×1 | 12.5m×12.5m×2 | 25m×25m×0.5 | 50m×50m×0.5 | 50m×50m×2

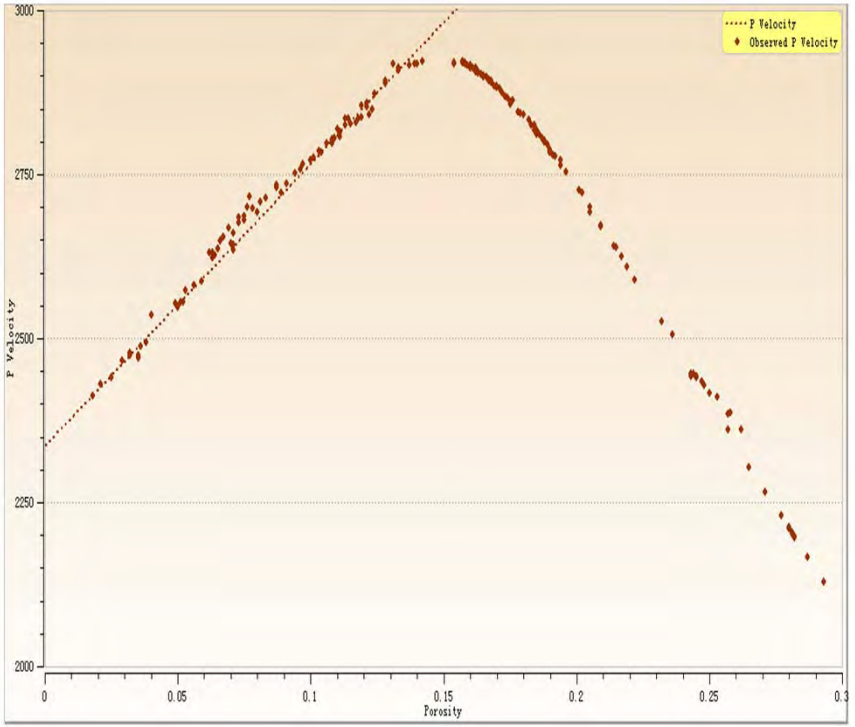


Step 3: Rock Model

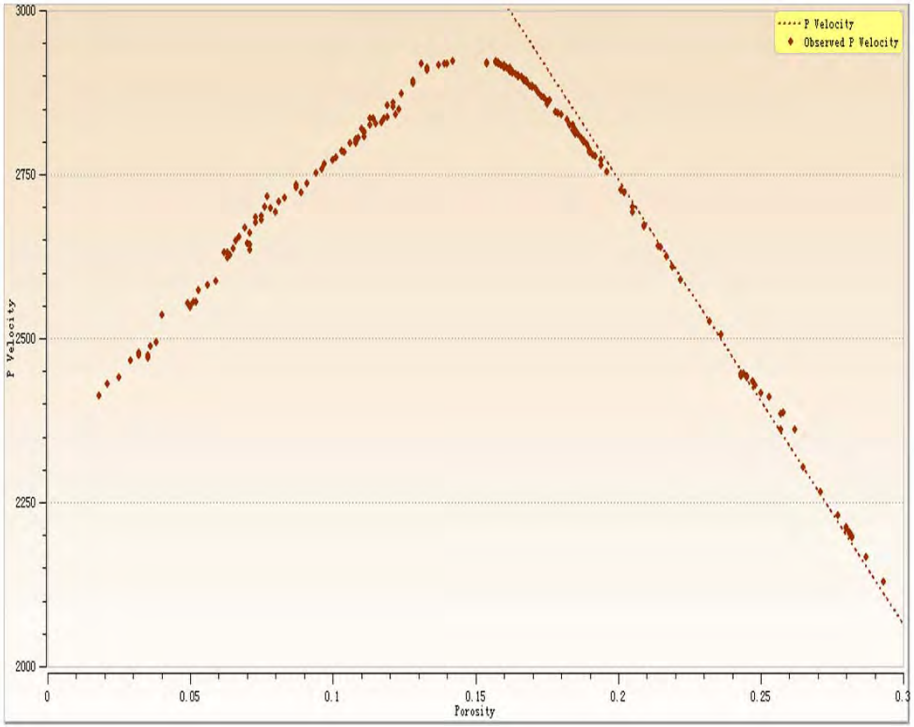


Step 3: Rock Model

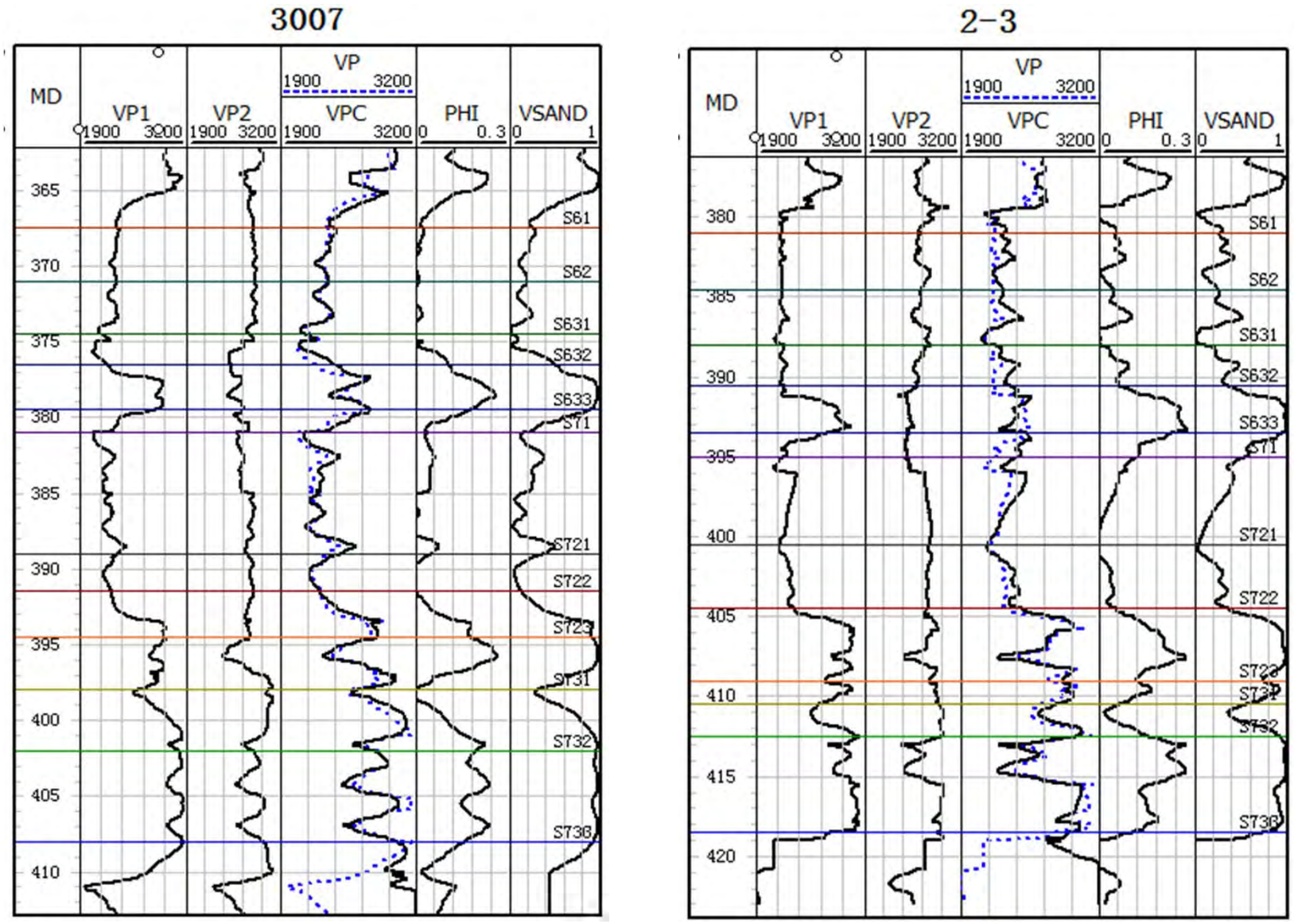
Template 1



Template 2



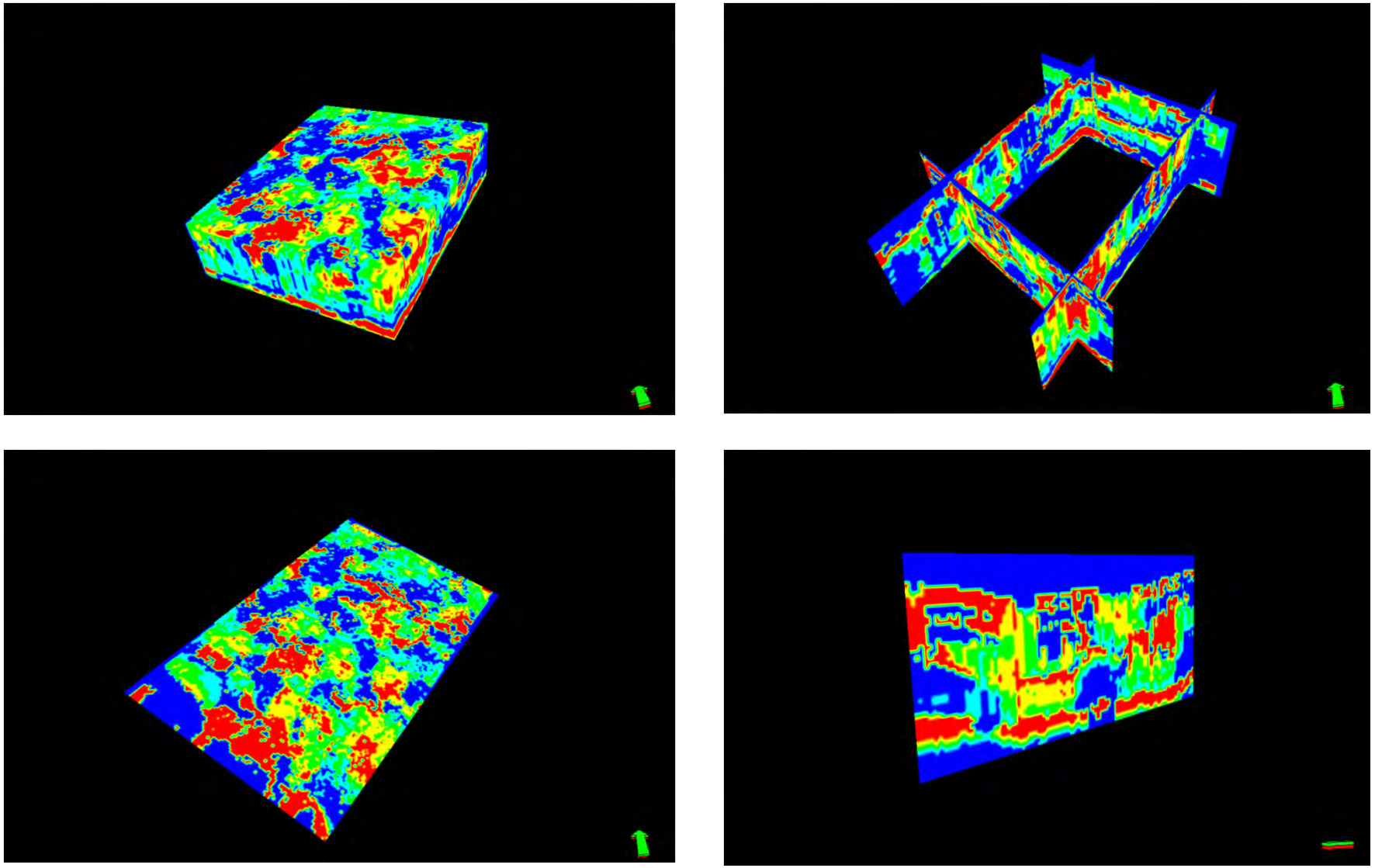
Step 3a: Rock Model-Validation



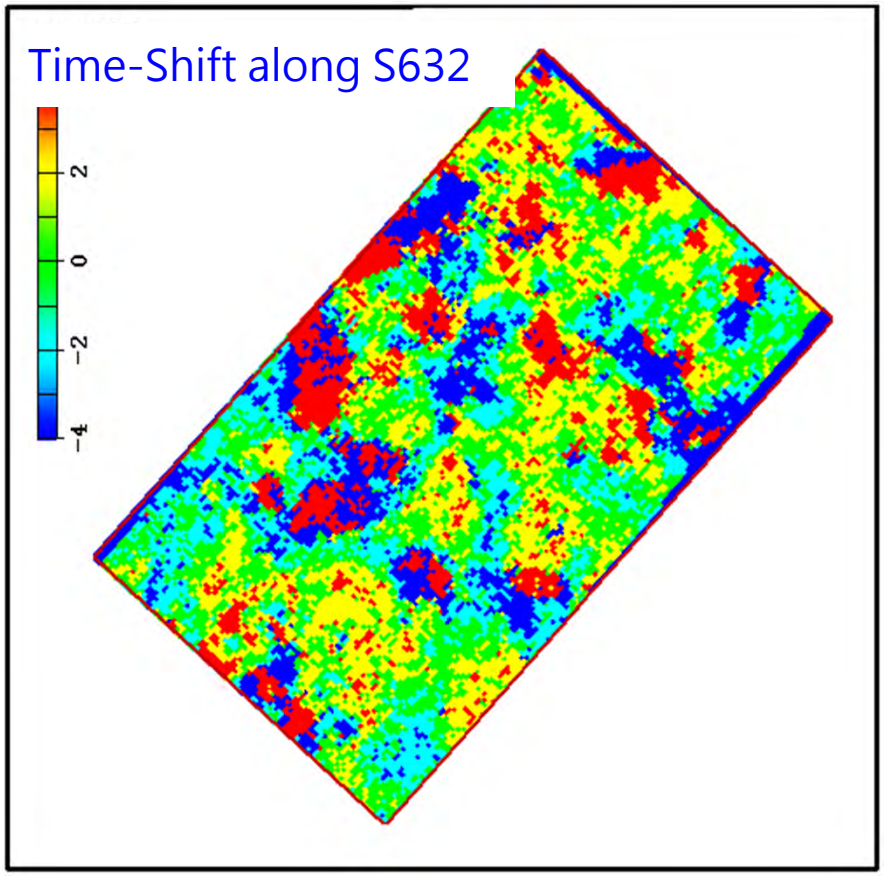
Error Analysis

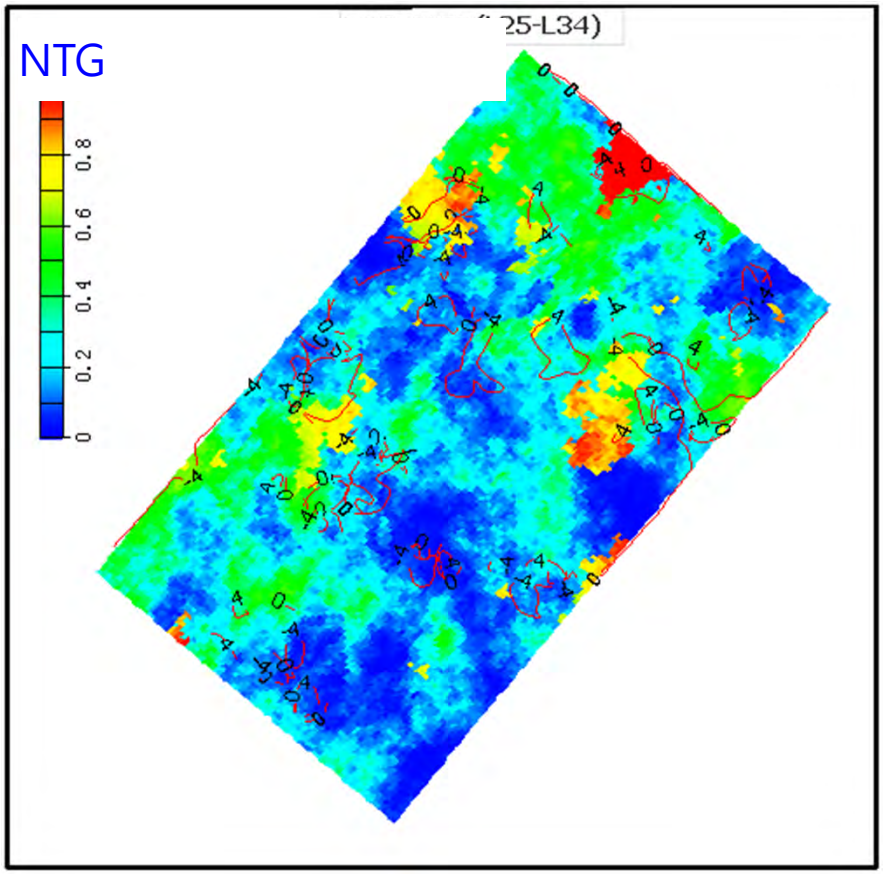
Well	True Tr. Time (ms)	Synthetic Tr. Time (ms)	Difference (ms)
4-7	36.16219	35.92061	0.24158
5-10	36.6594	37.295	-0.63559
5-12	36.97477	37.15802	-0.18325
7-10	35.72214	35.63342	0.088722
7-12	31.50602	30.86014	0.645885
3007	32.69672	32.35389	0.342842
3010	33.49424	33.74509	-0.25085
T33001	32.95722	33.09006	-0.13284
T33003	33.57714	34.05234	-0.4752
bu2-4	28.60338	27.92846	0.674921

Step 4: Time-Shift of Mismatch between Synthetic and Observed



Step 5: Model Update





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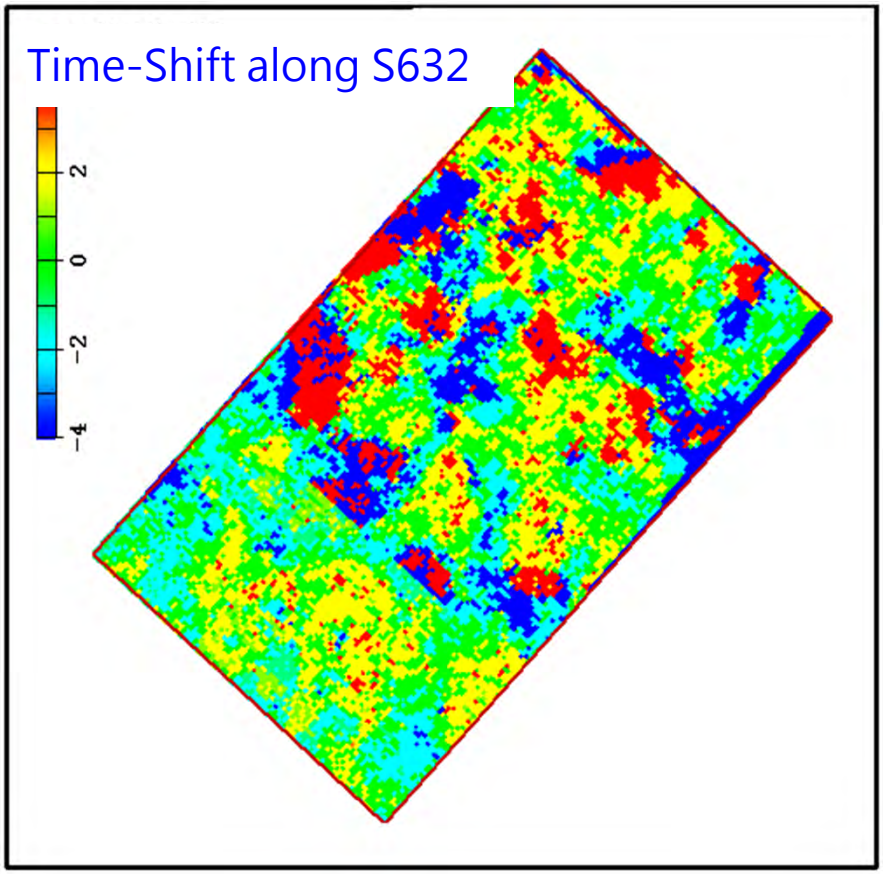
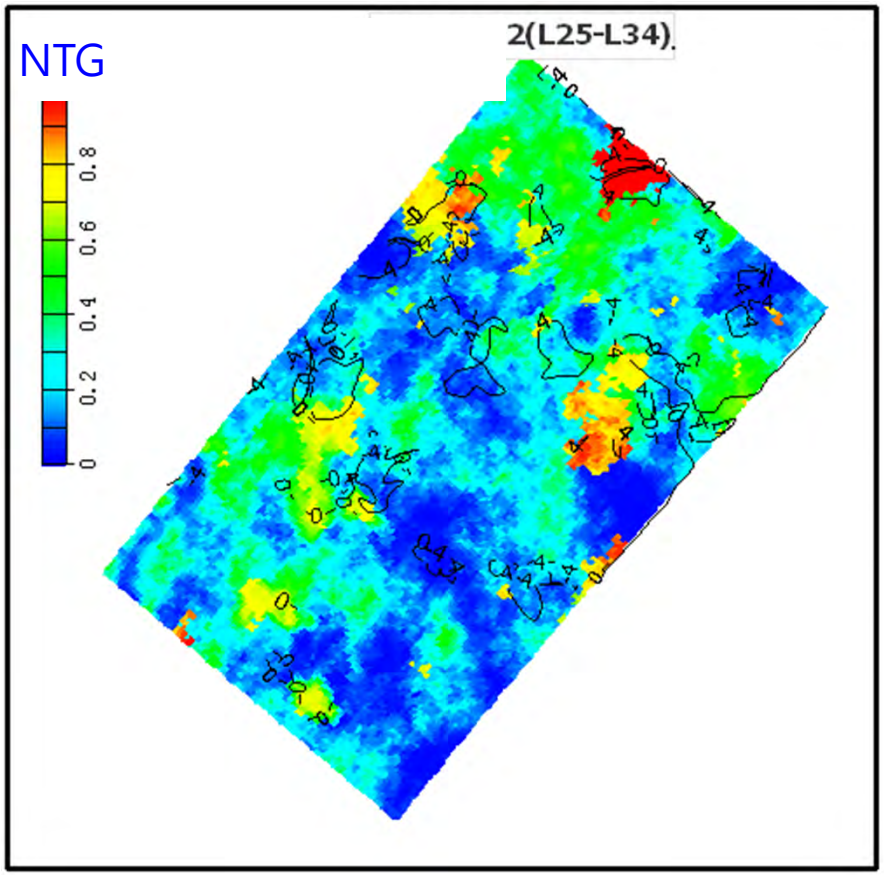
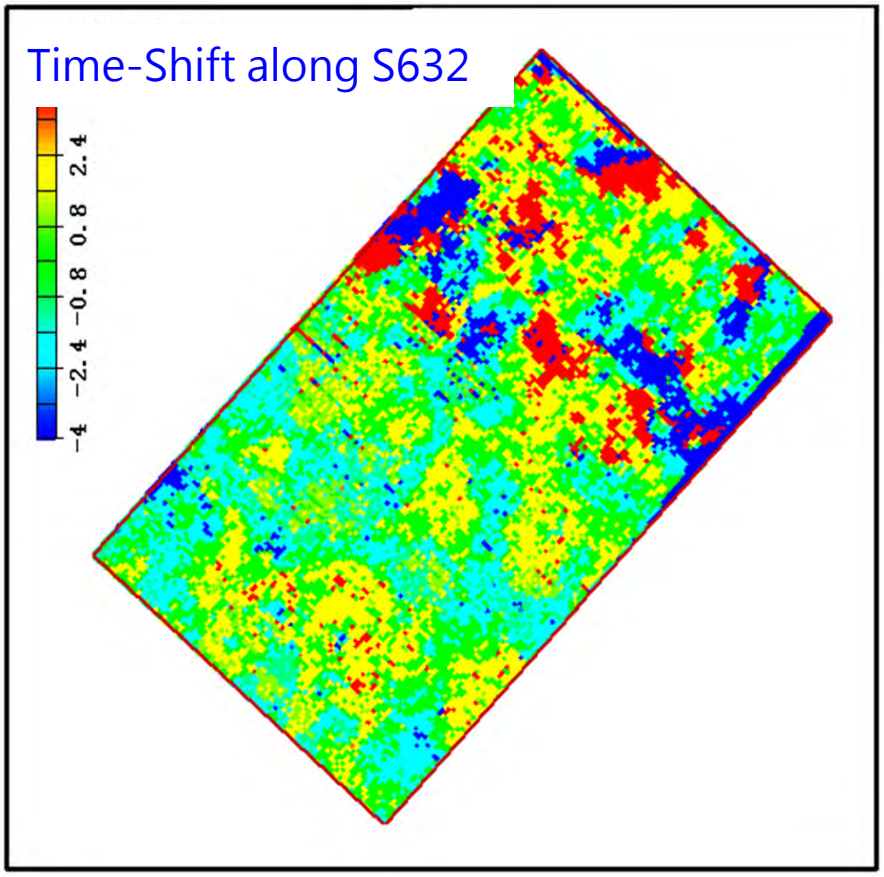
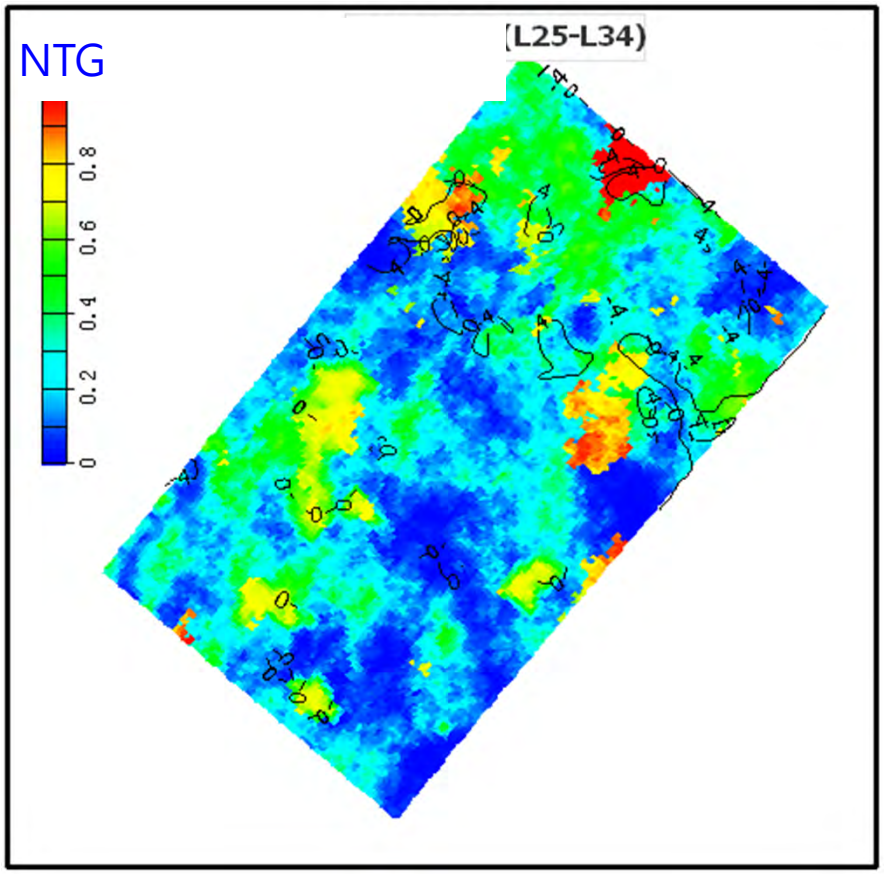


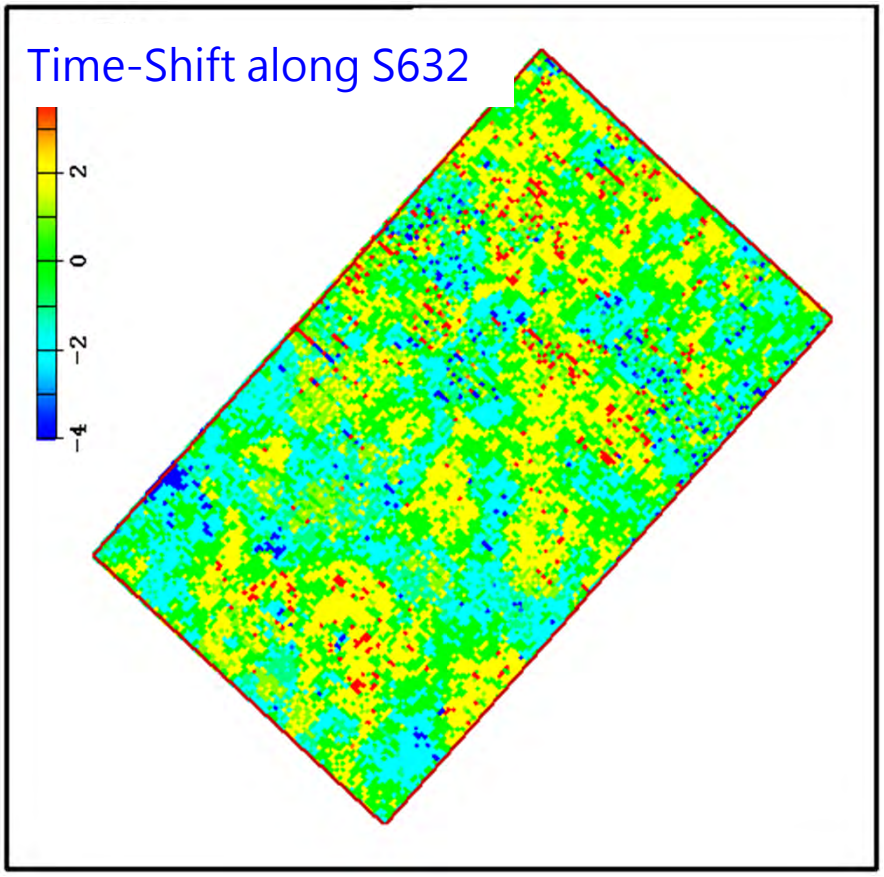


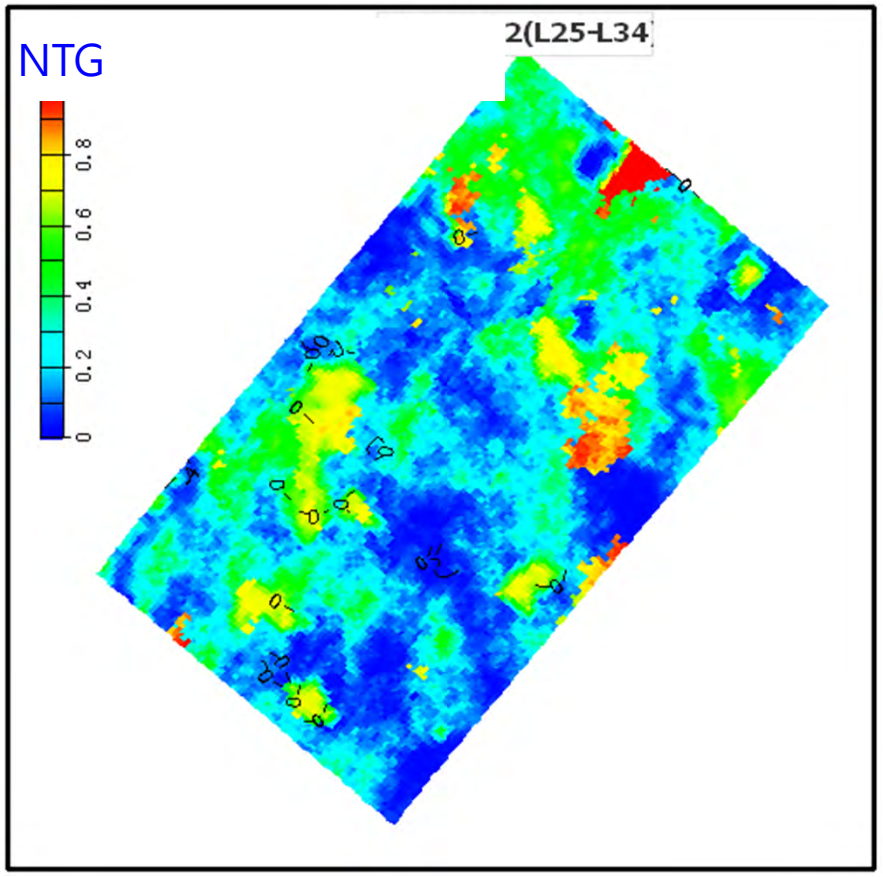
Step 5: Model Update



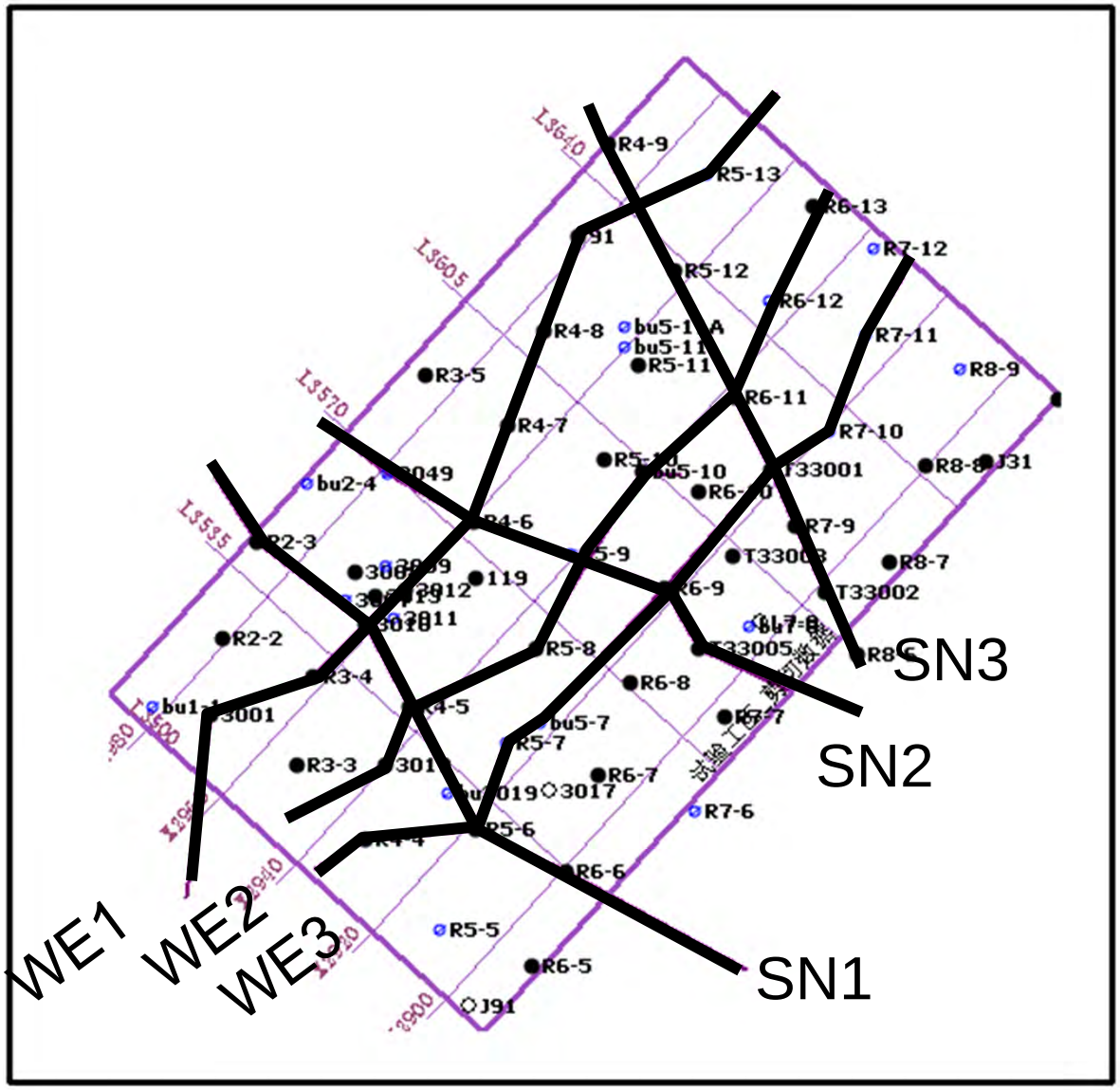


Step 5: Model Update



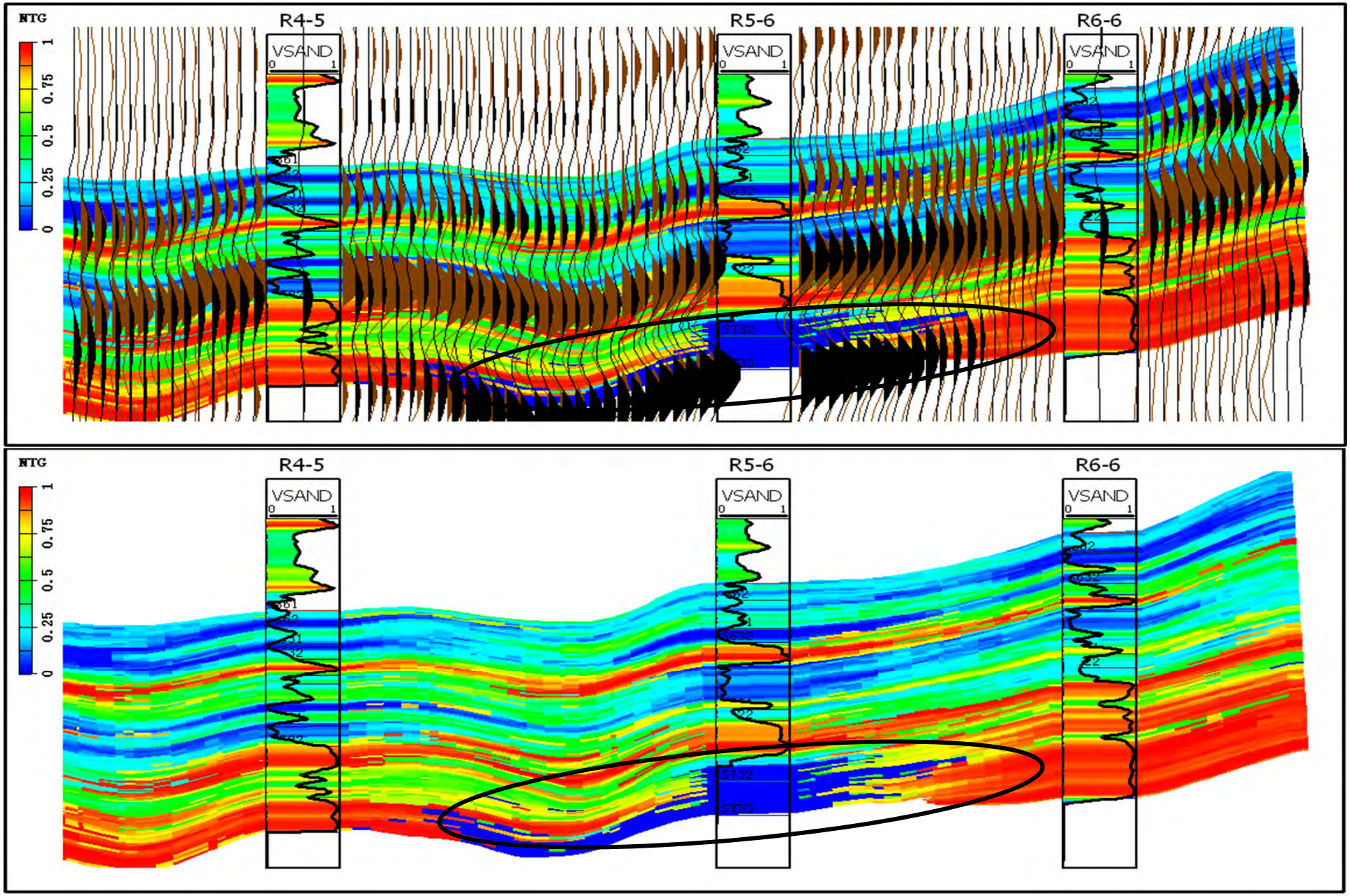


Step 6: Seismic Matching

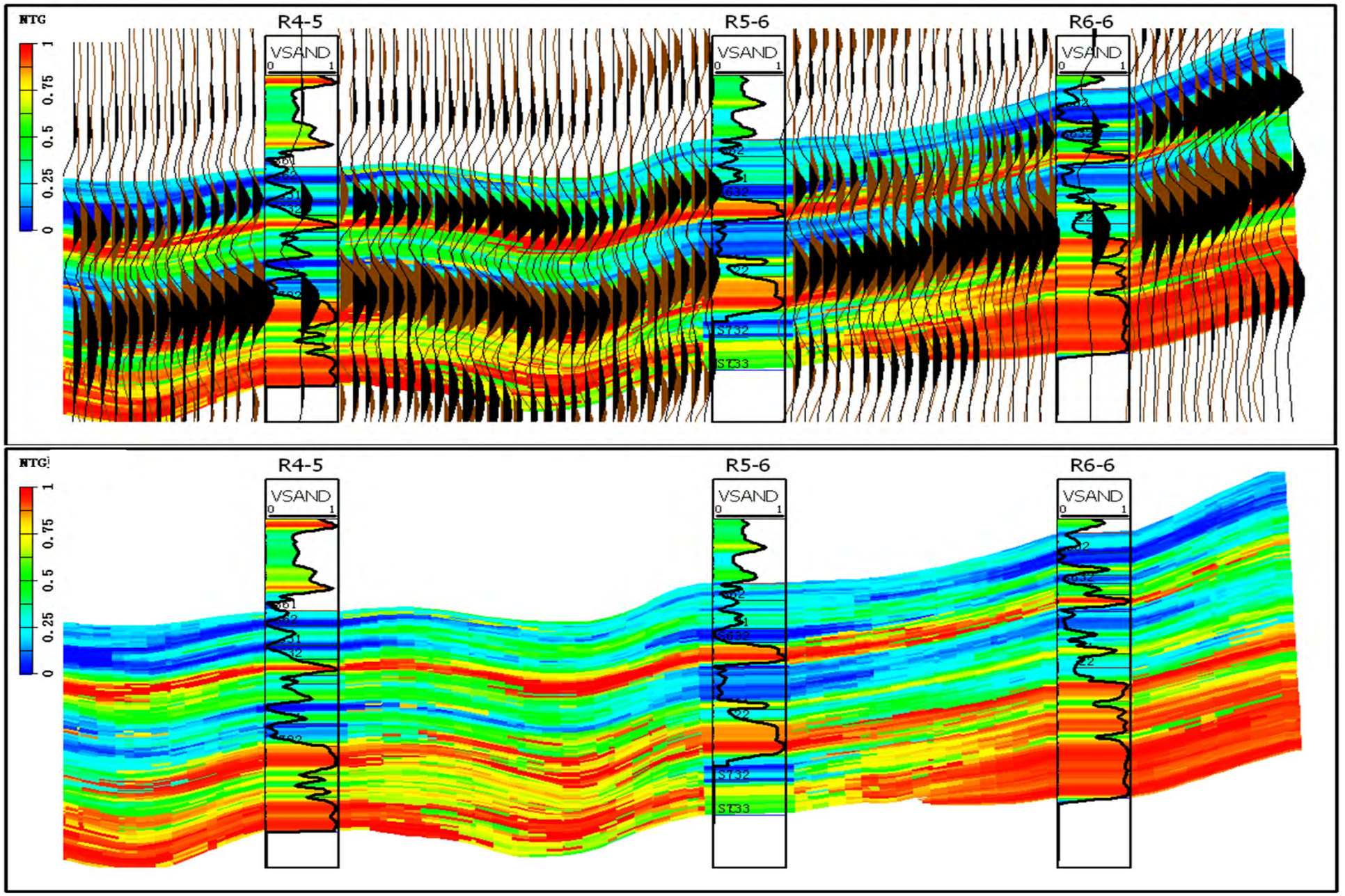


Exit

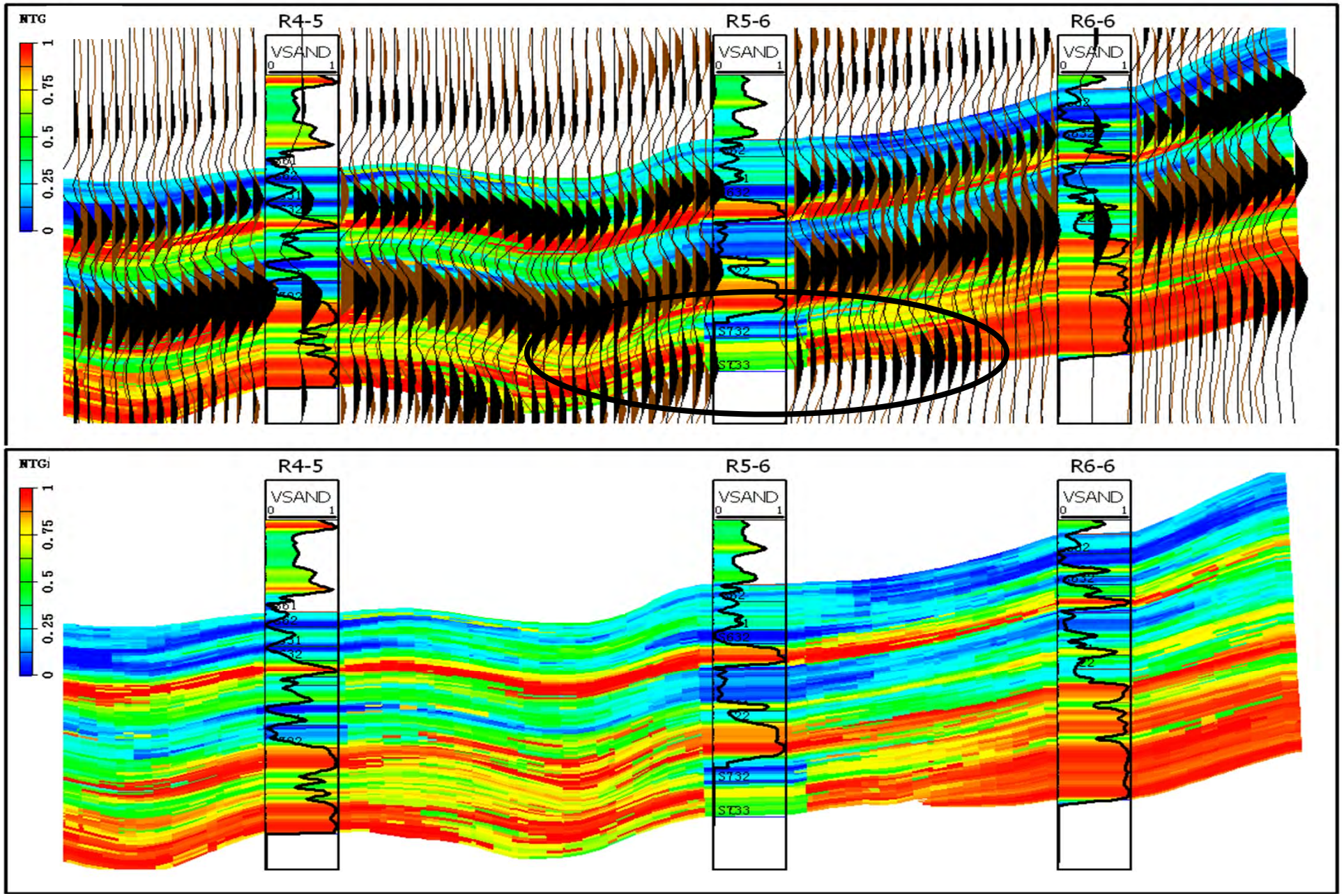
Step 6: Seismic Matching



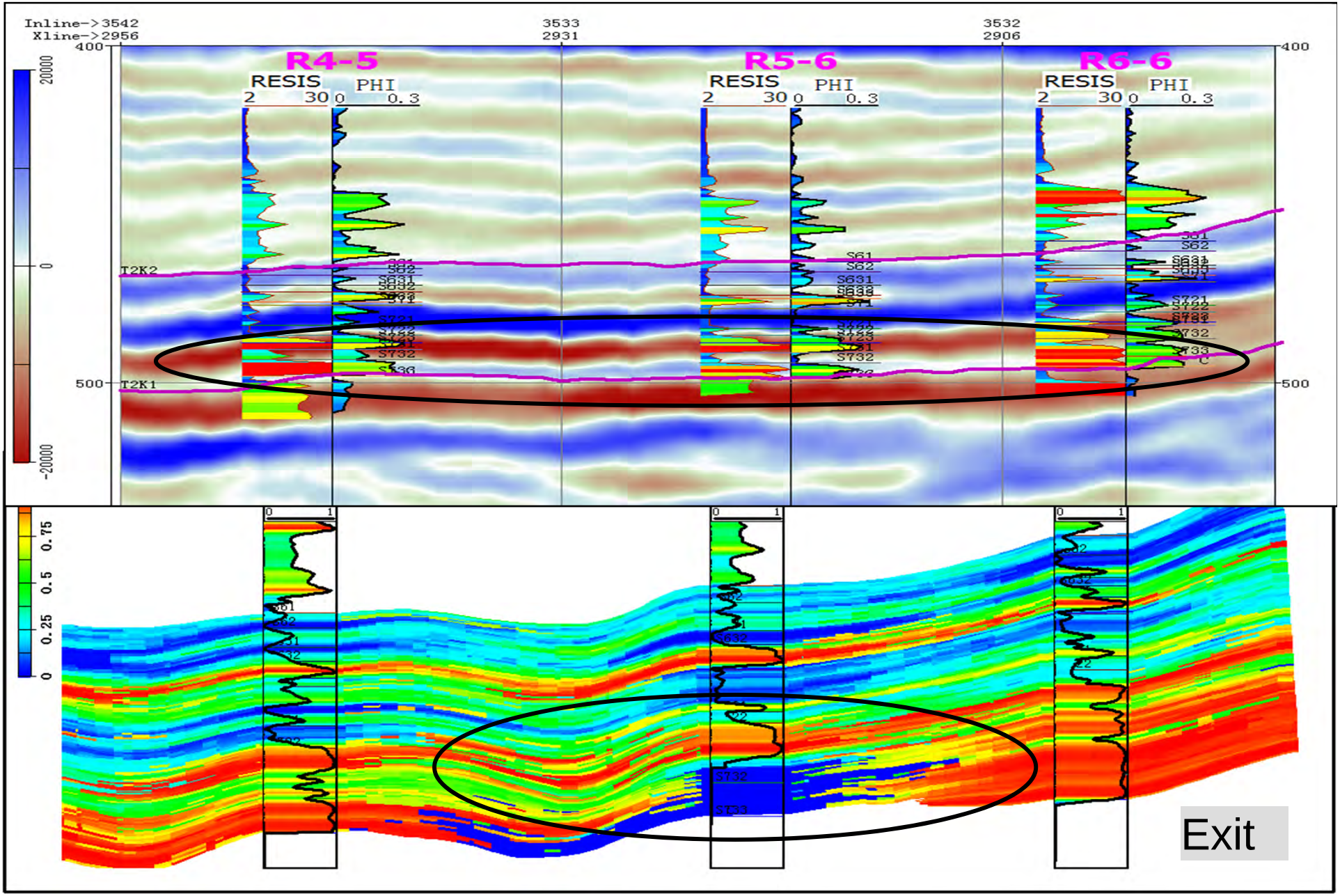
Step 6: Seismic Matching



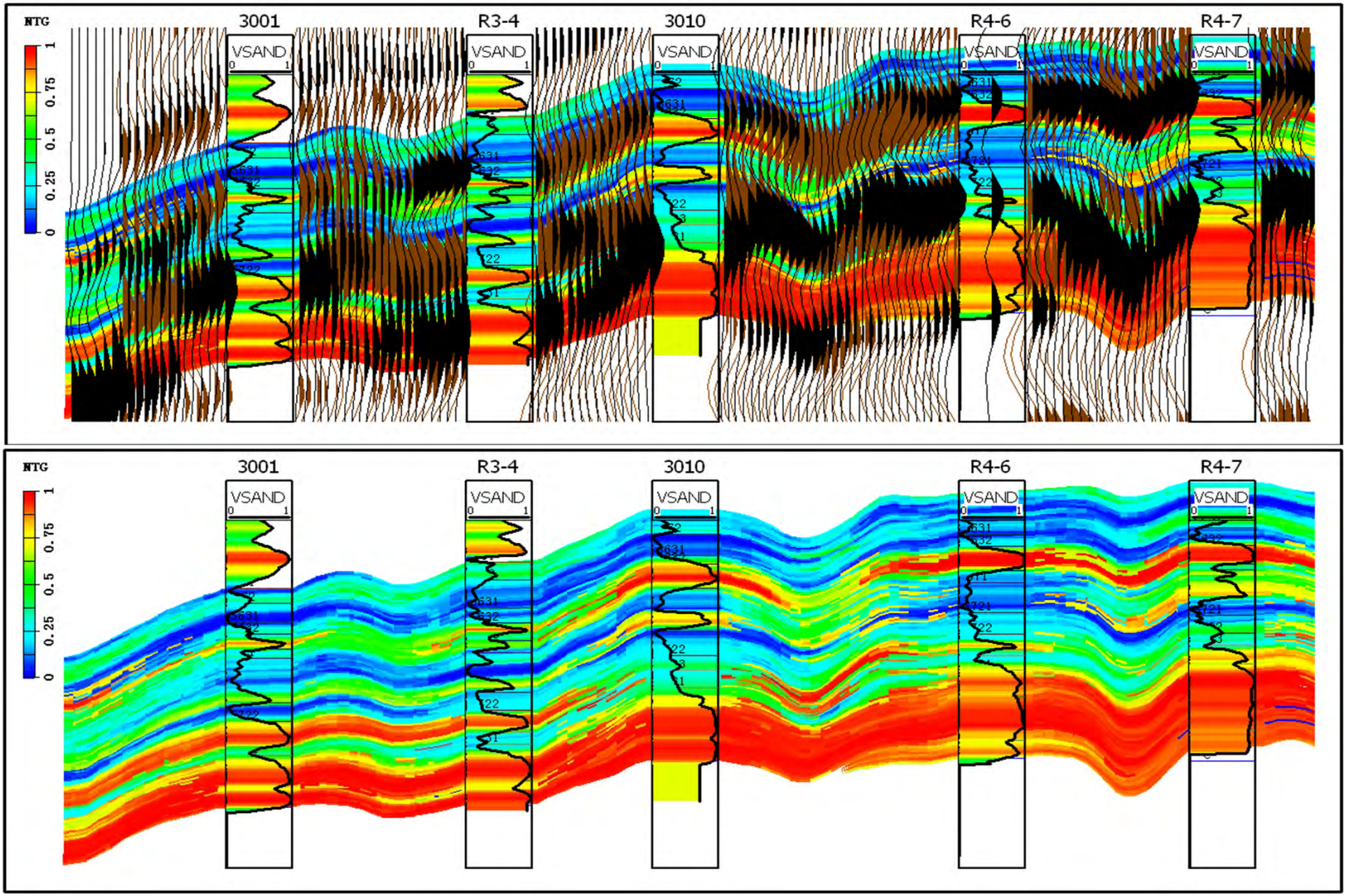
Step 6: Seismic Matching



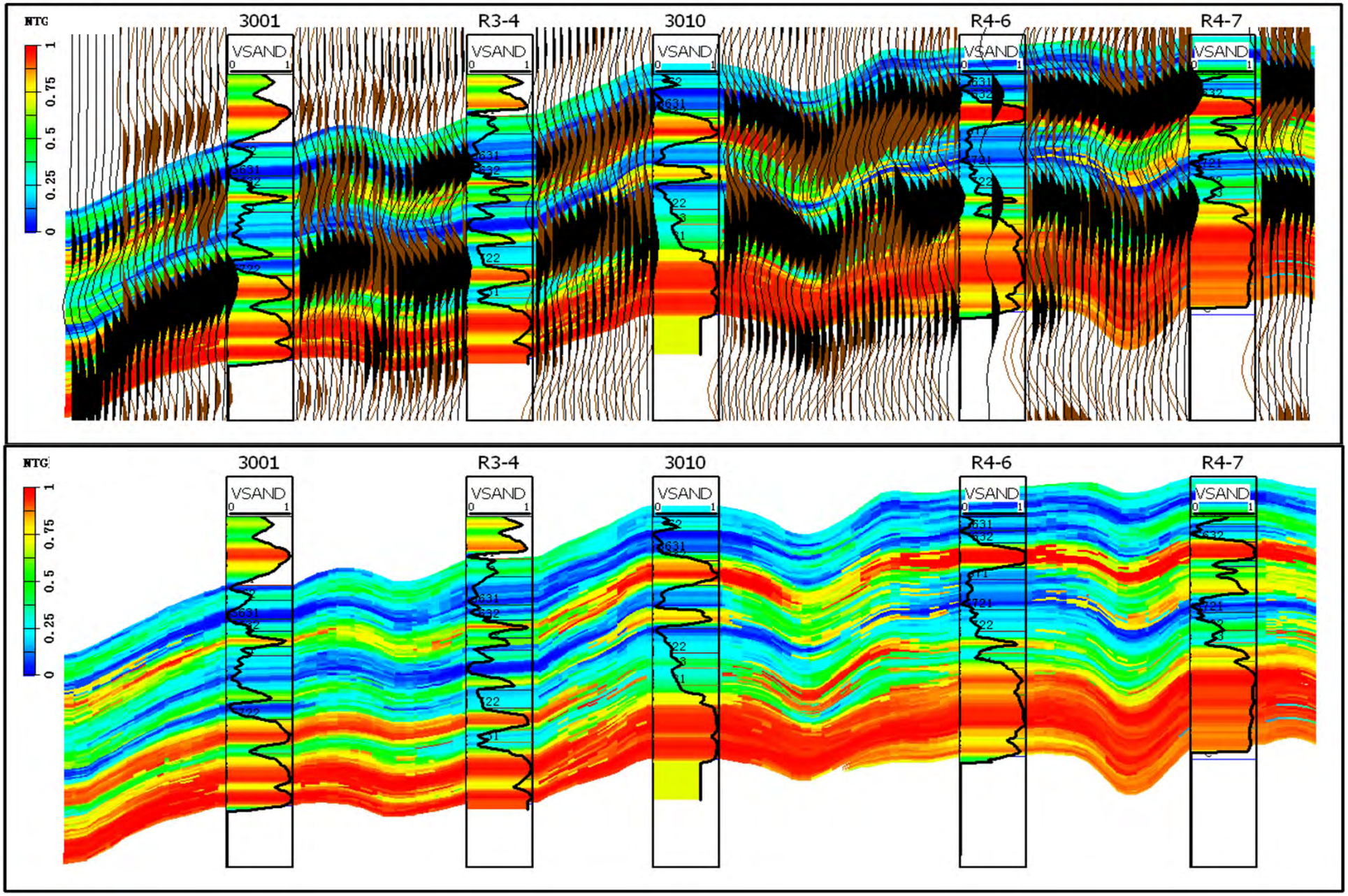
Step 6: Seismic Matching



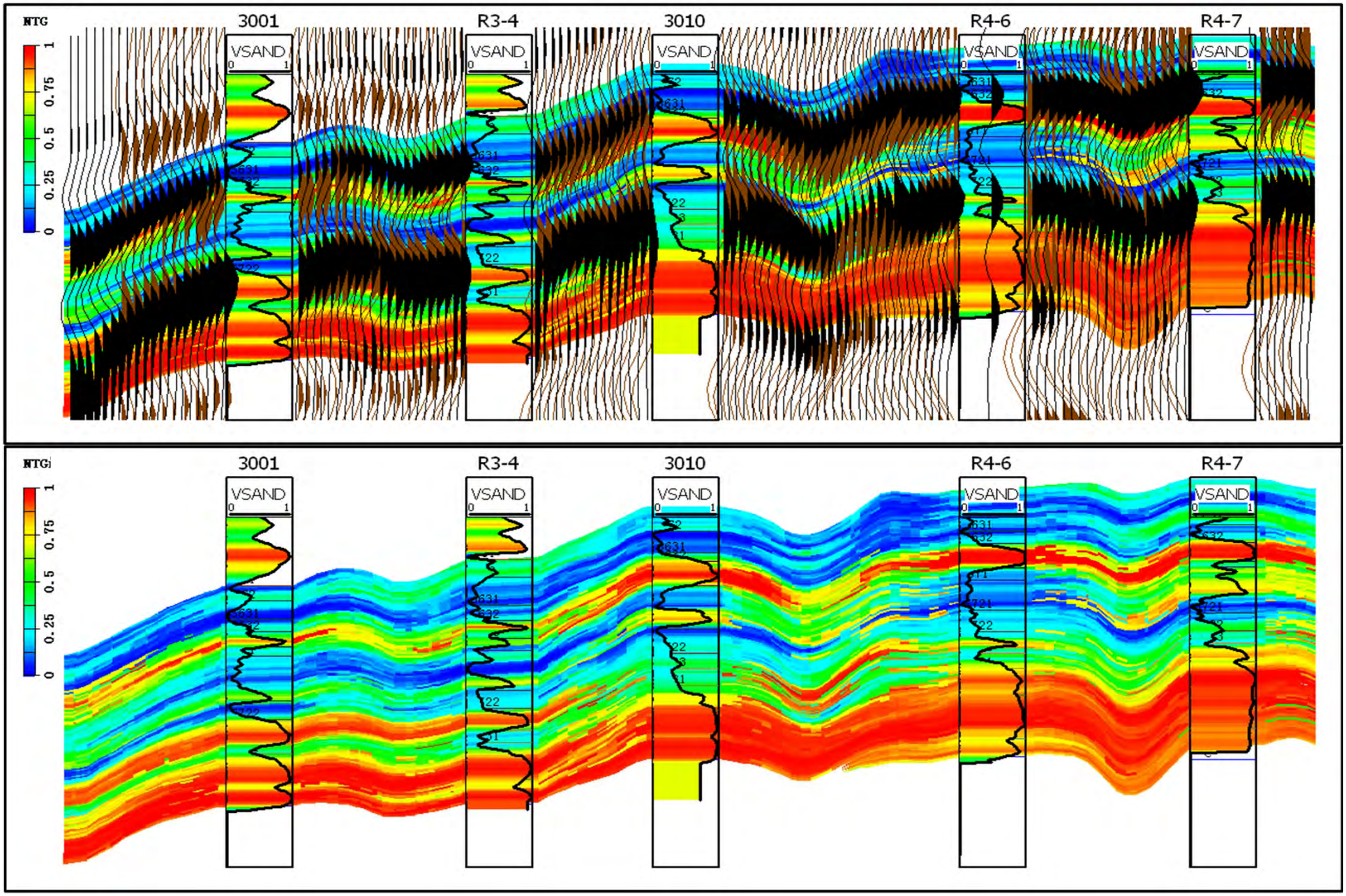
Step 6: Seismic Matching



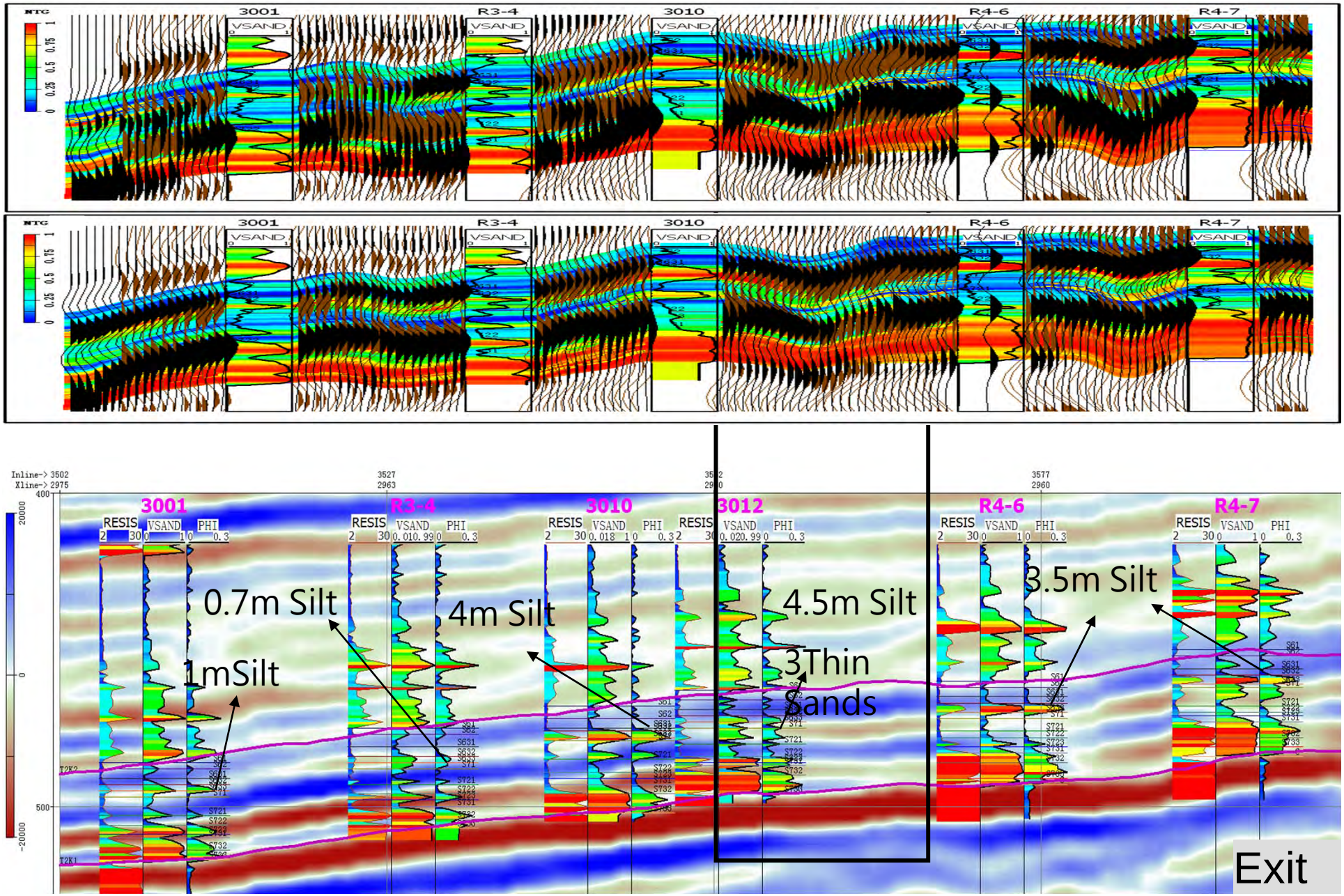
Step 6: Seismic Matching



Step 6: Seismic Matching

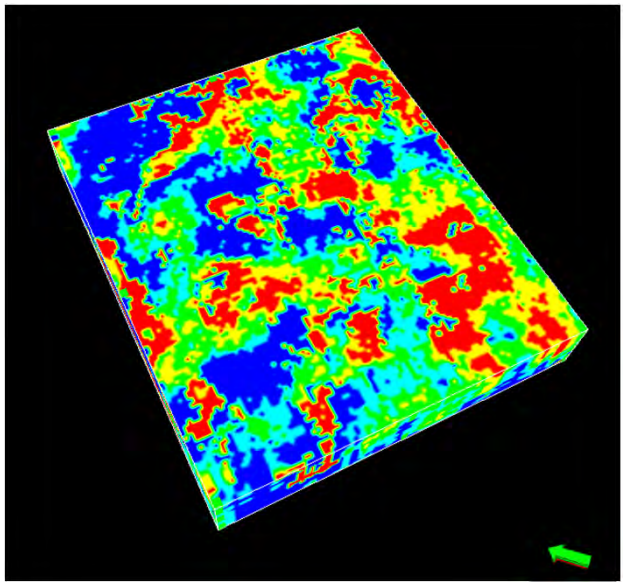


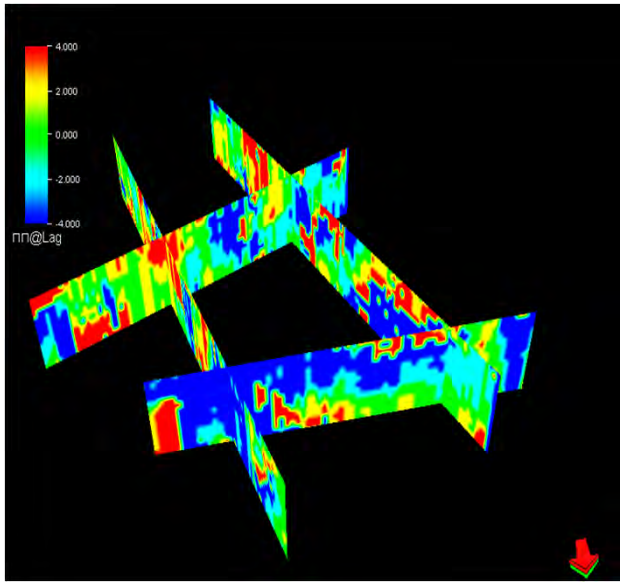
Step 6: Seismic Matching



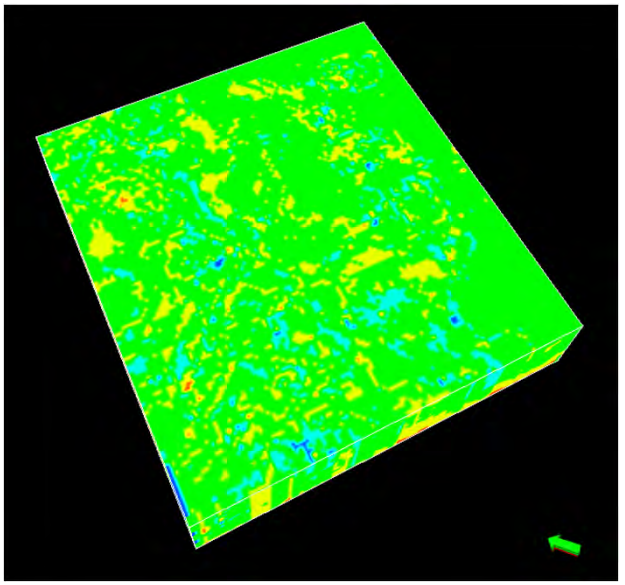
Step 7: Comparison of before and after model update

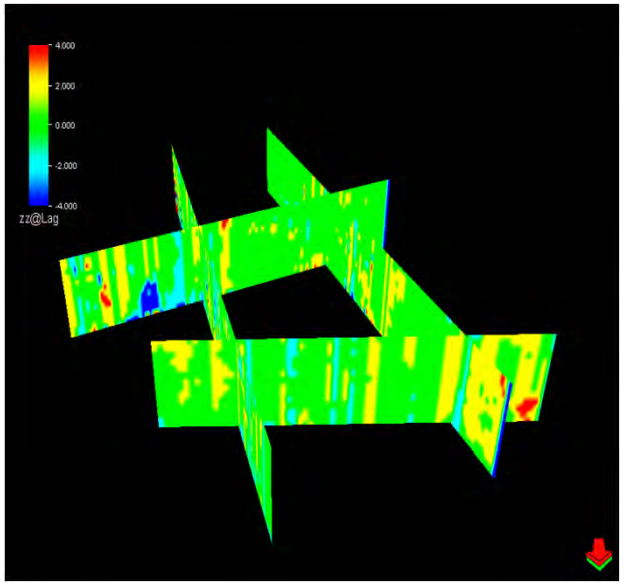
Before





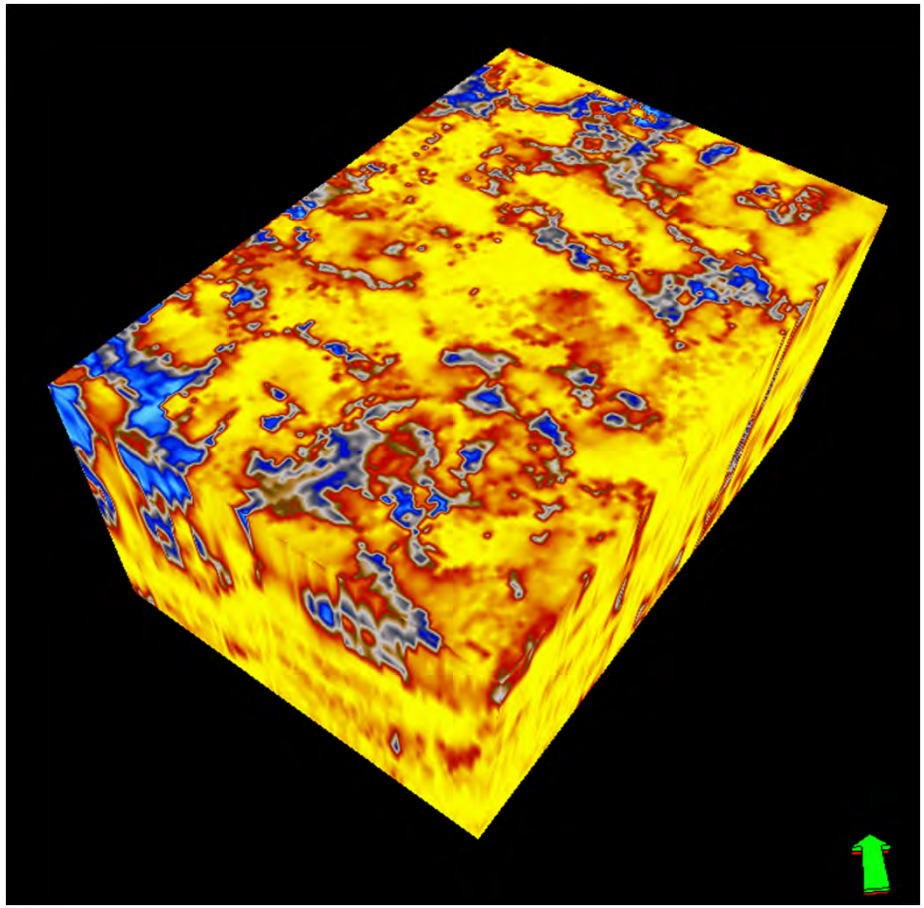
After



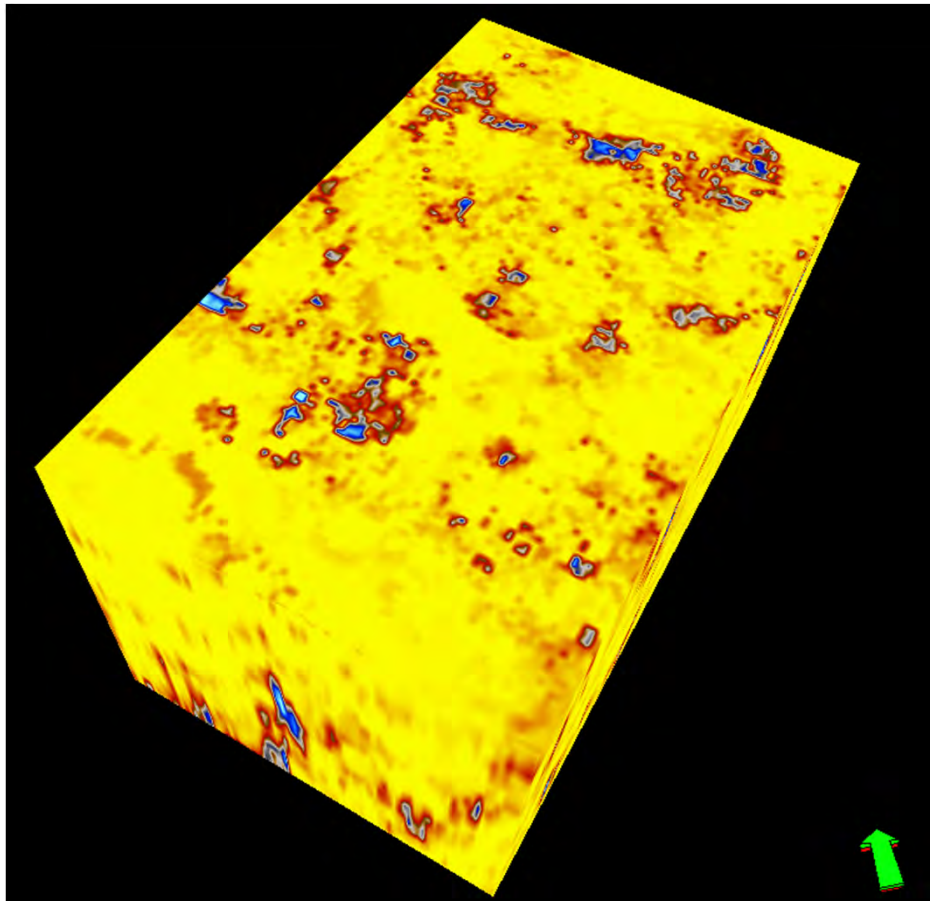


Step 7: Comparison of before and after model update

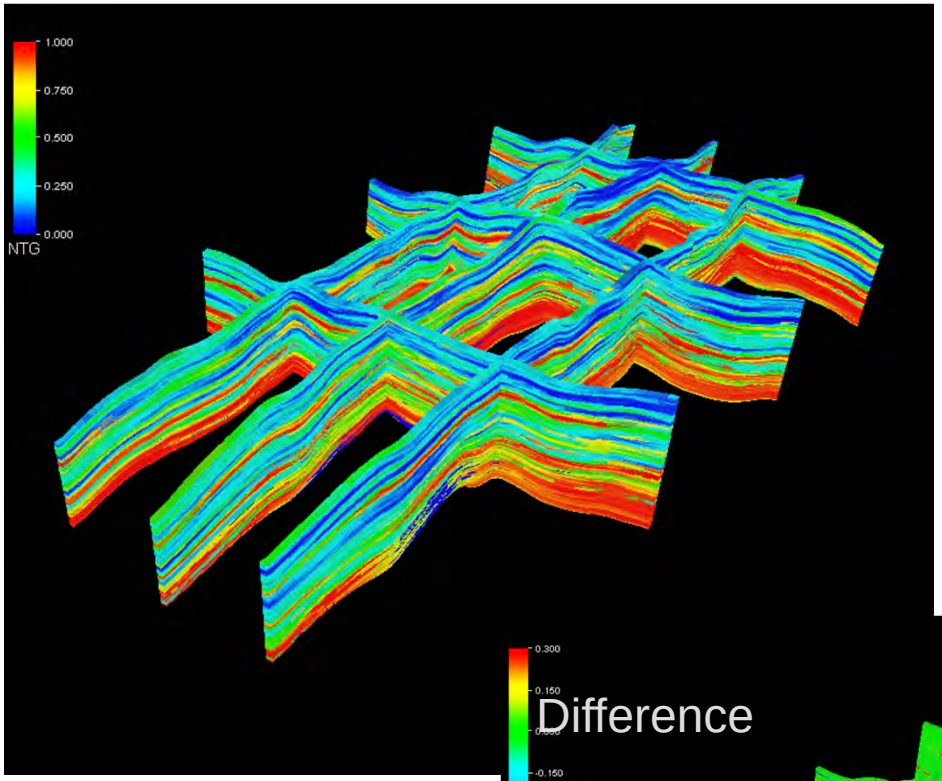
Corr. Before

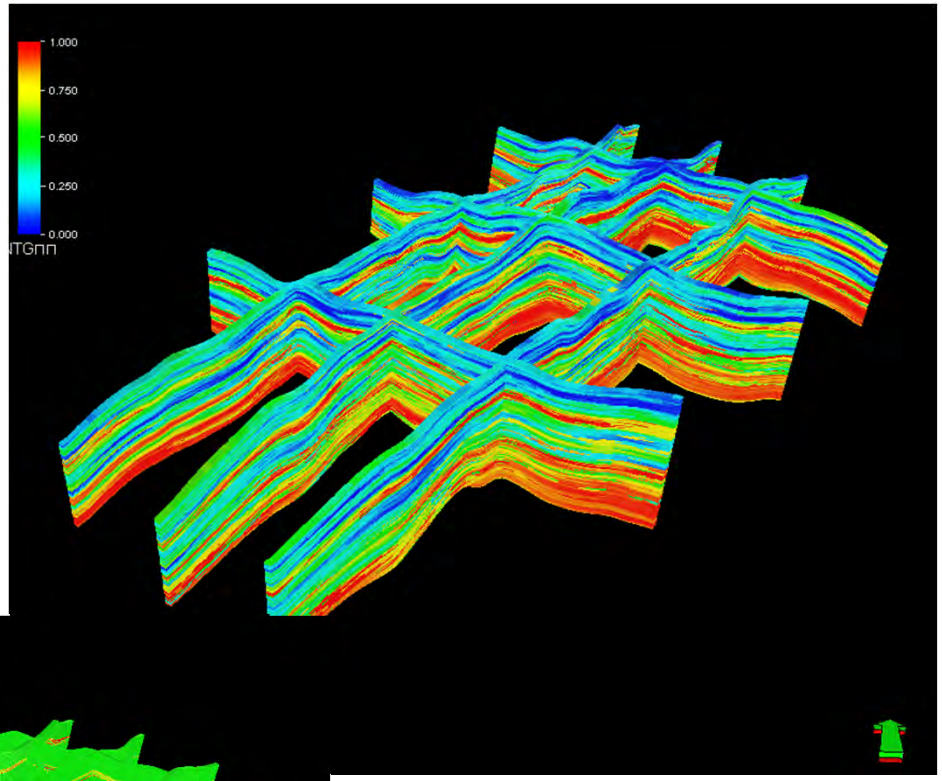


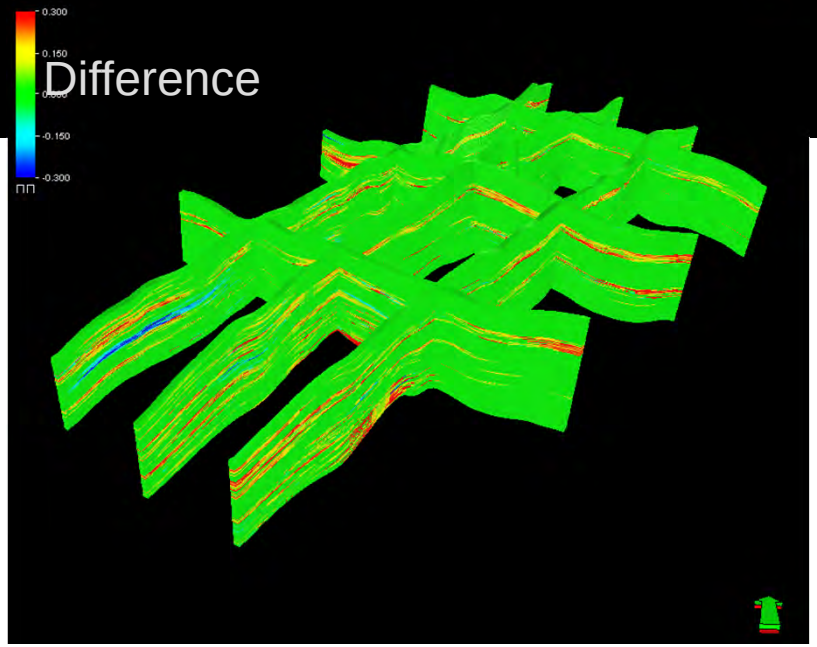
Corr. After



Step 7: Comparison of before and after model update



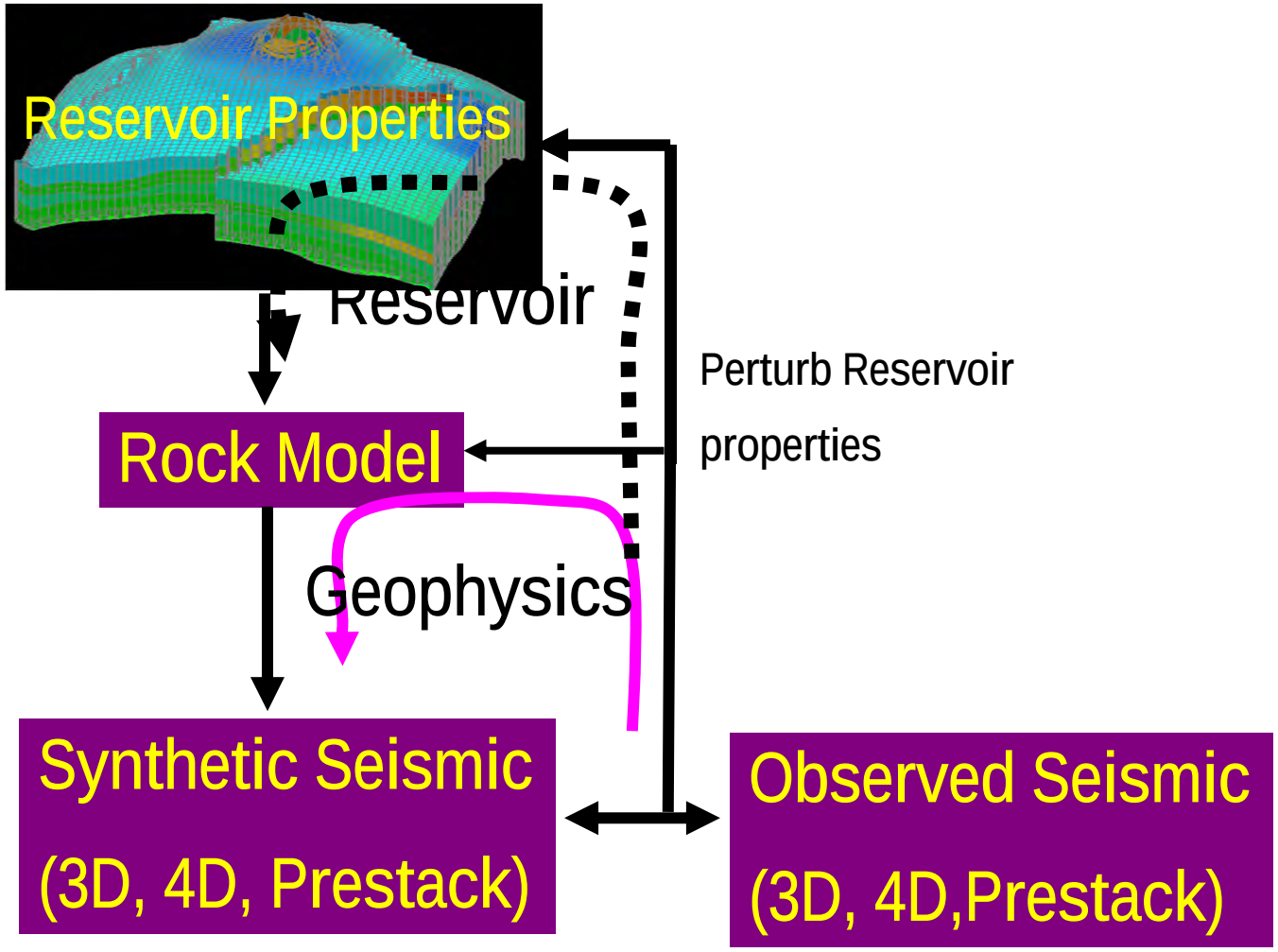




New model for optimize prod.

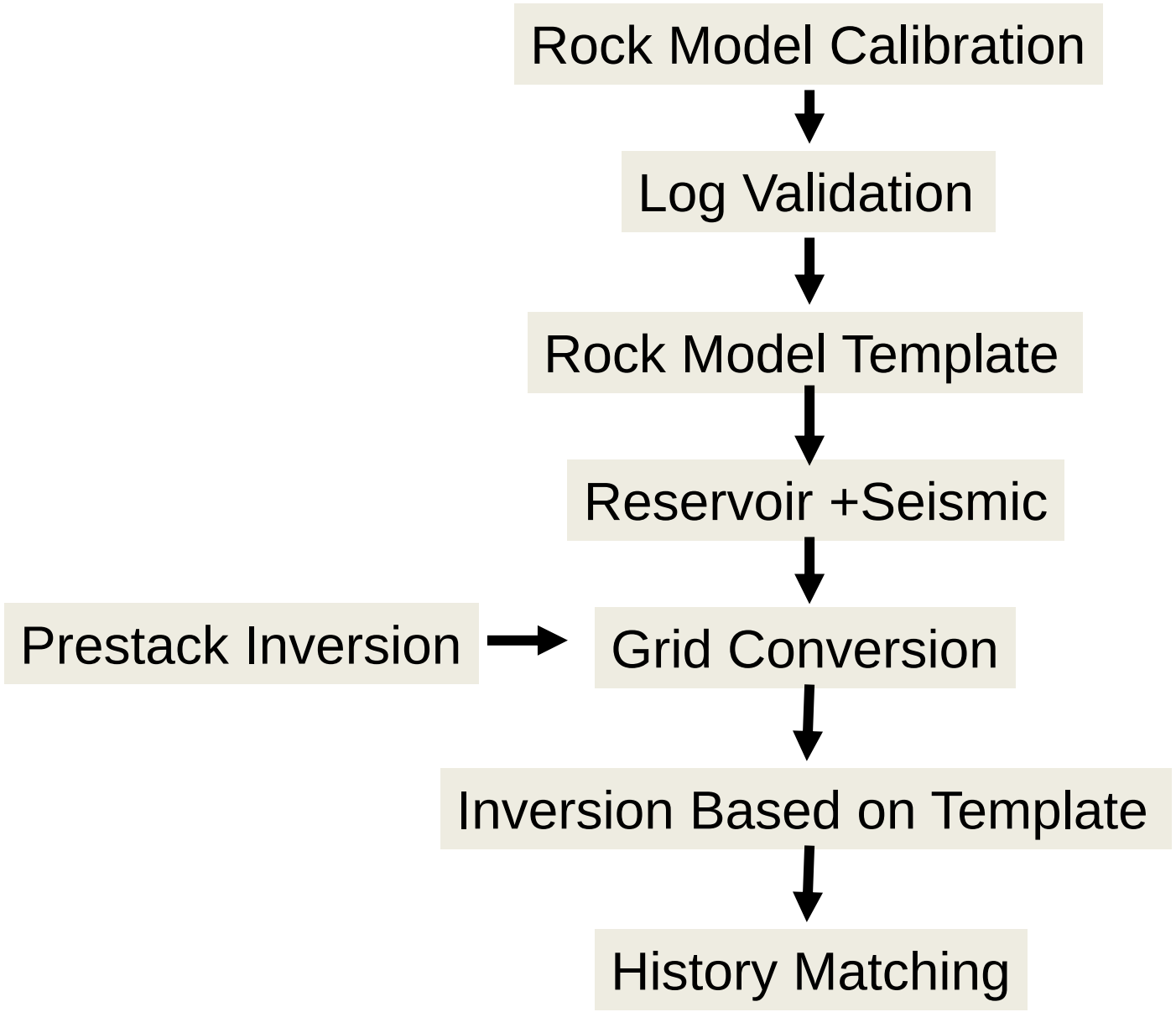
Model-based “Close-the-Loop” example 3:

Seismic Inversion in Reservoir Domain

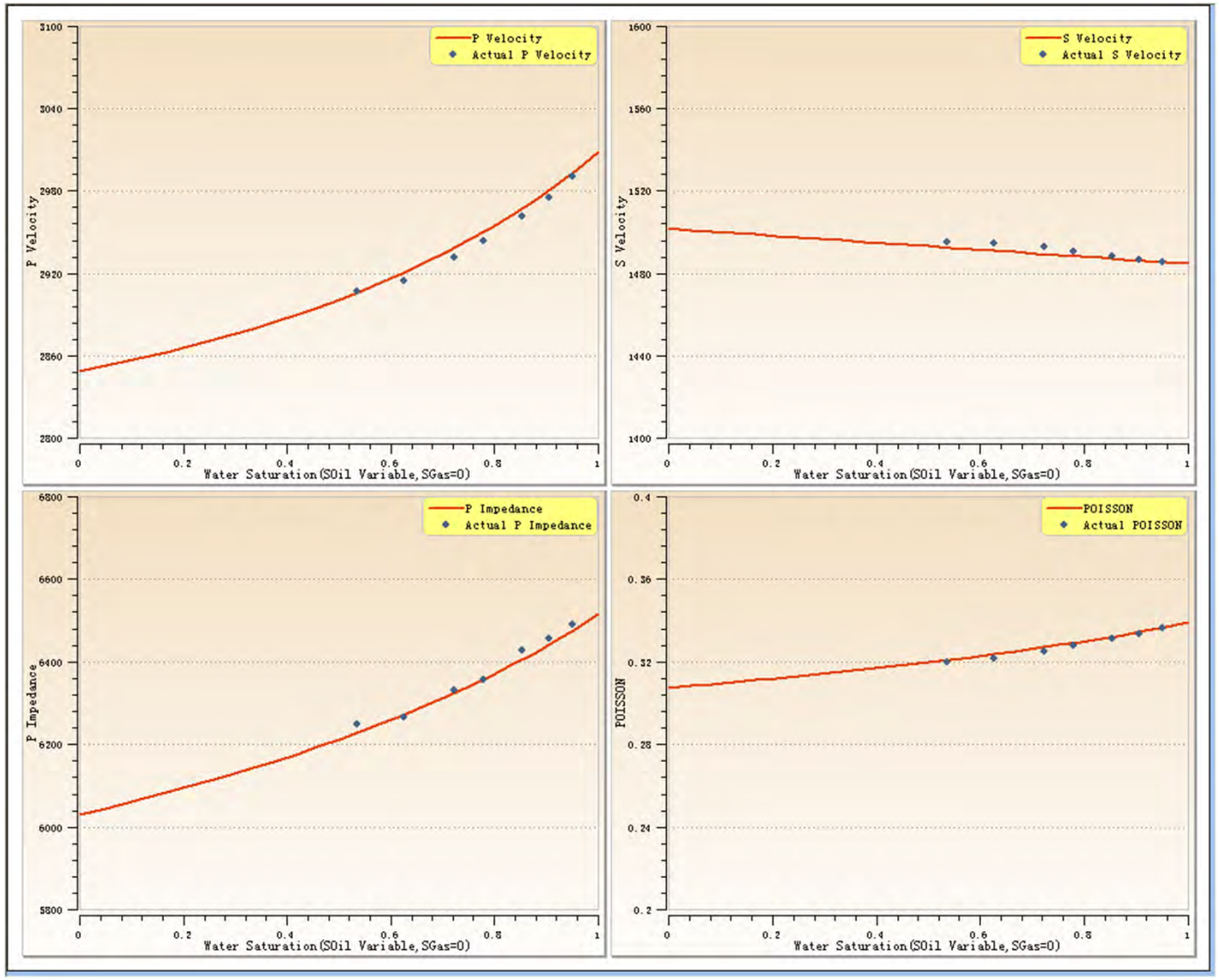


Background

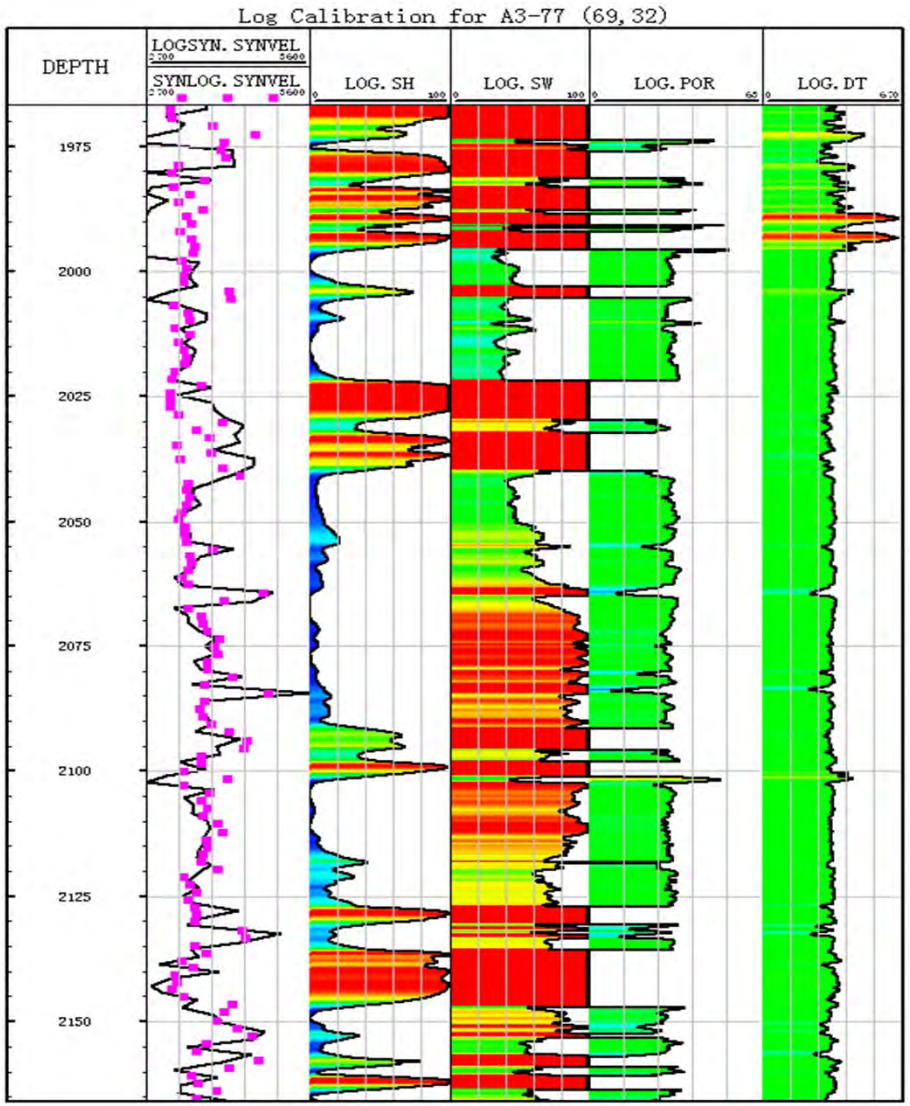
- Field: producing more than 40 years (1965)
- New 3D seismic acquired (2007)
- Reservoir model available
- Goal: fluid analysis, HM & model updating using existing data

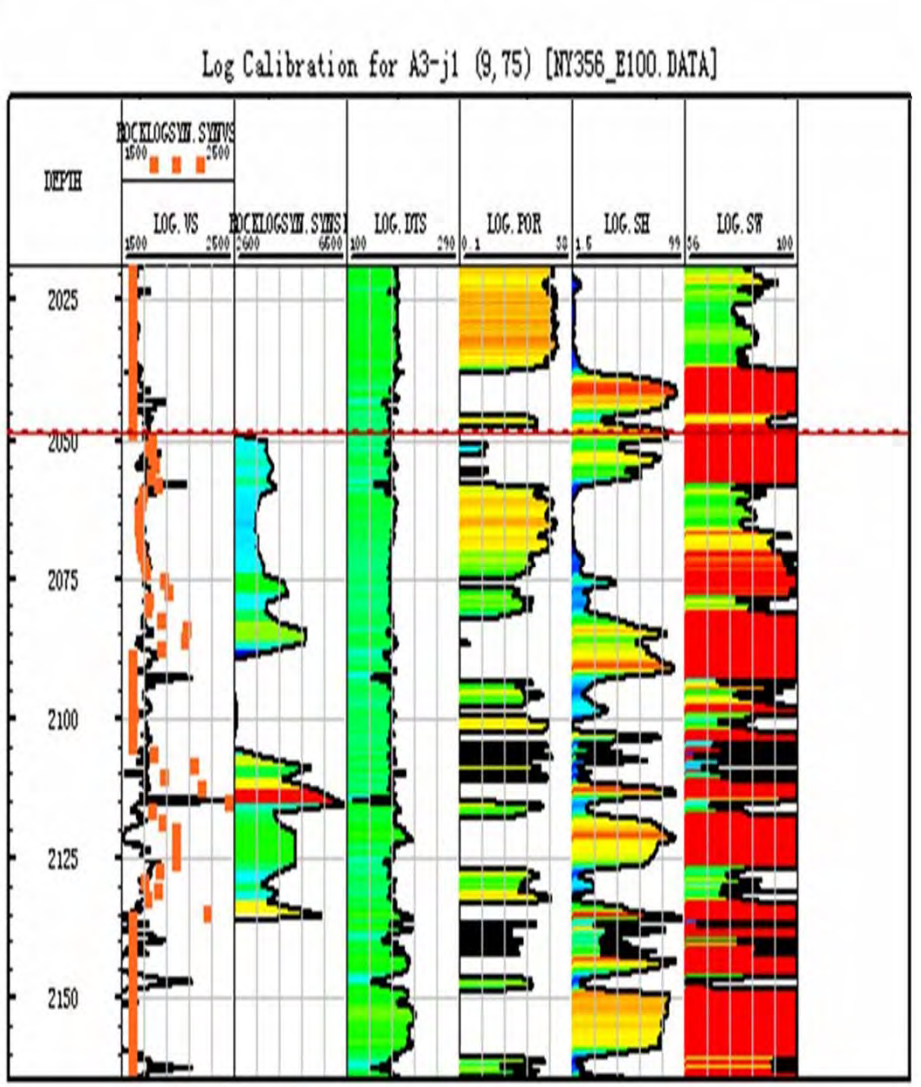

Rock Model Calibration
Log Validation
Rock Model Template
Reservoir +Seismic
Prestack Inversion
Grid Conversion
Inversion Based on Template
History Matching

Step1:Rock model Calibration



Step 2: Well log synthetic using templates - Validation

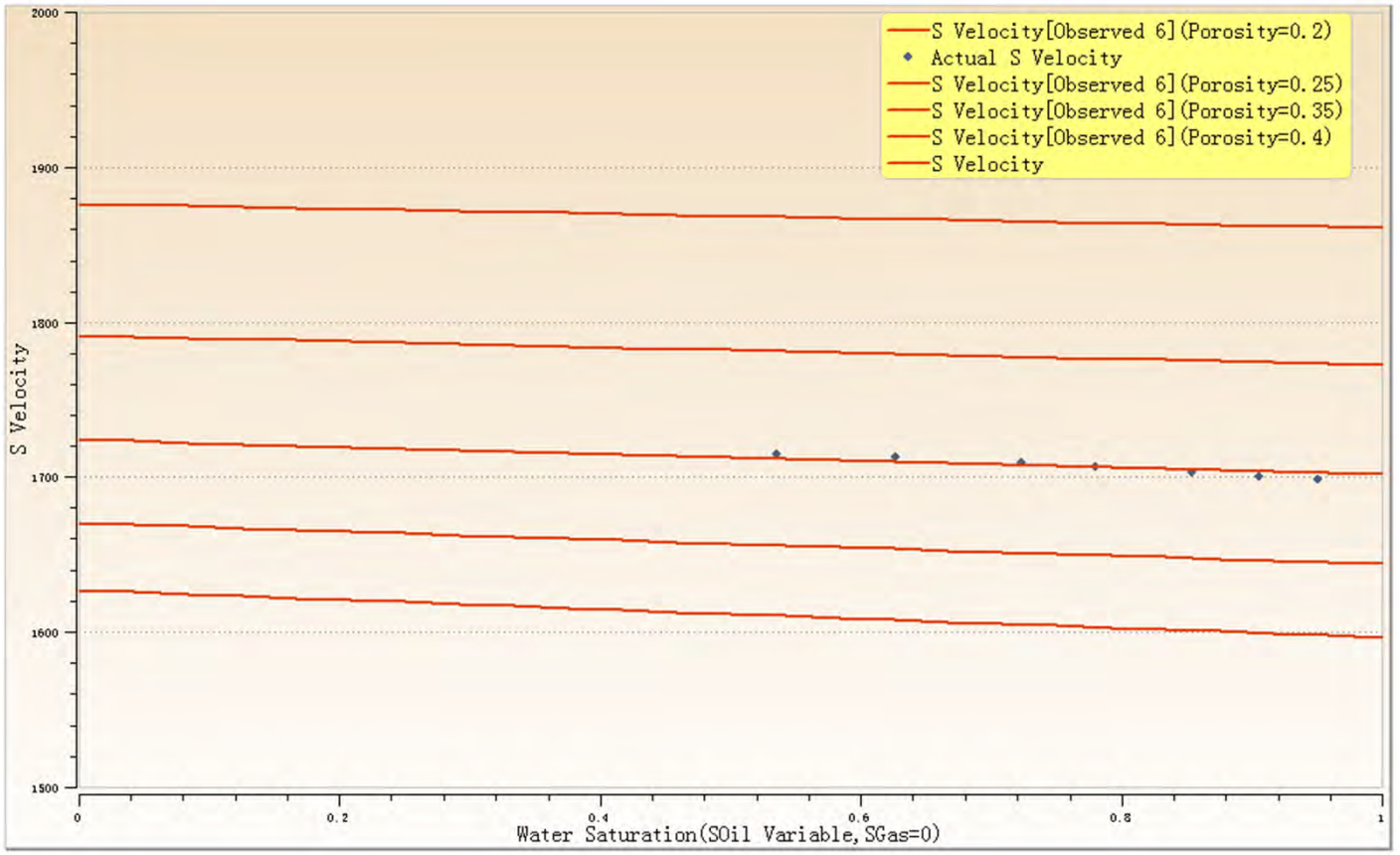




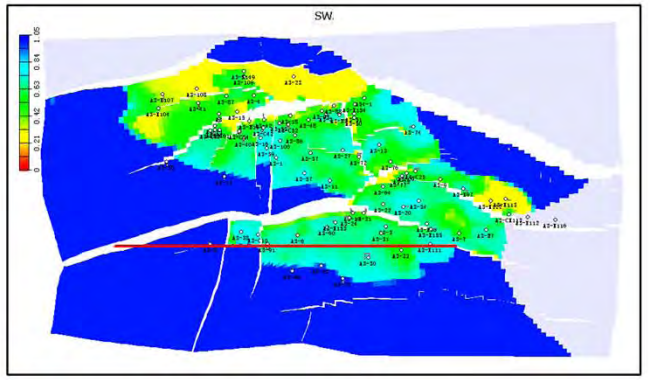
VP: A3-77

VS: A3-j1

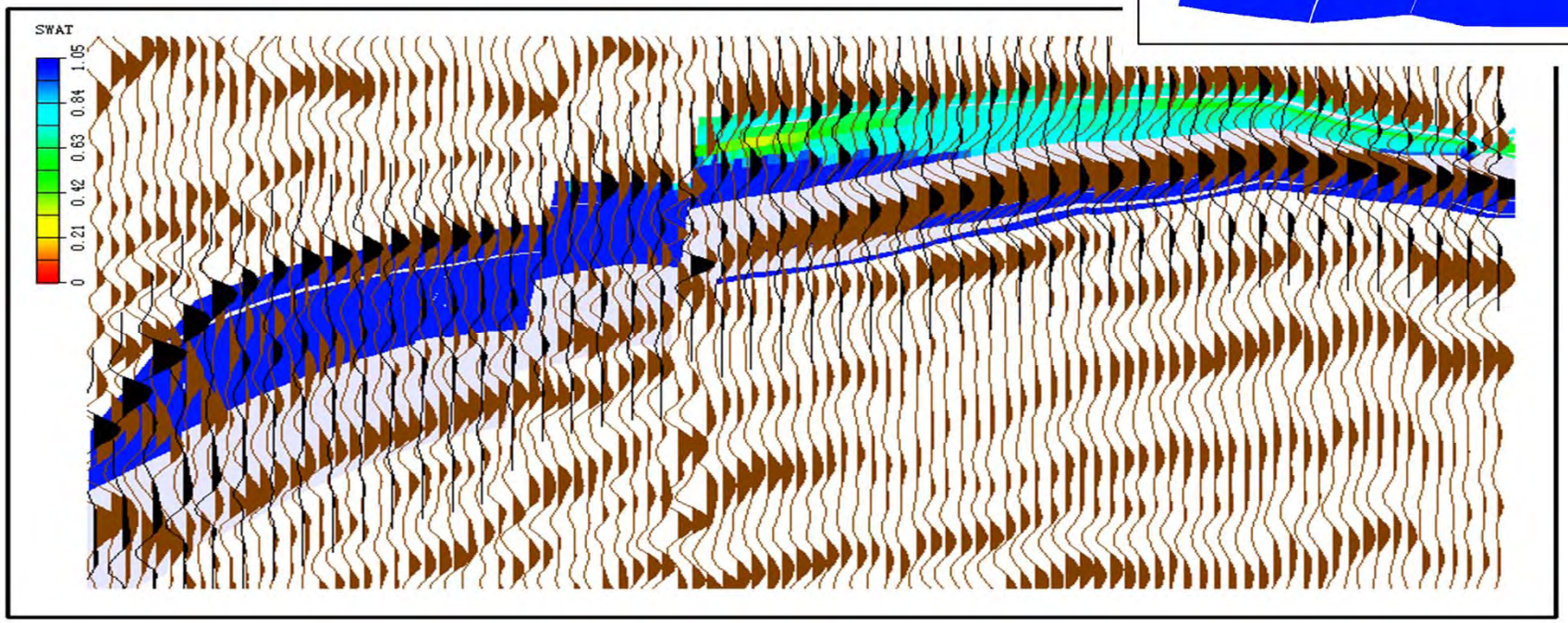
Step 3: Rock model template



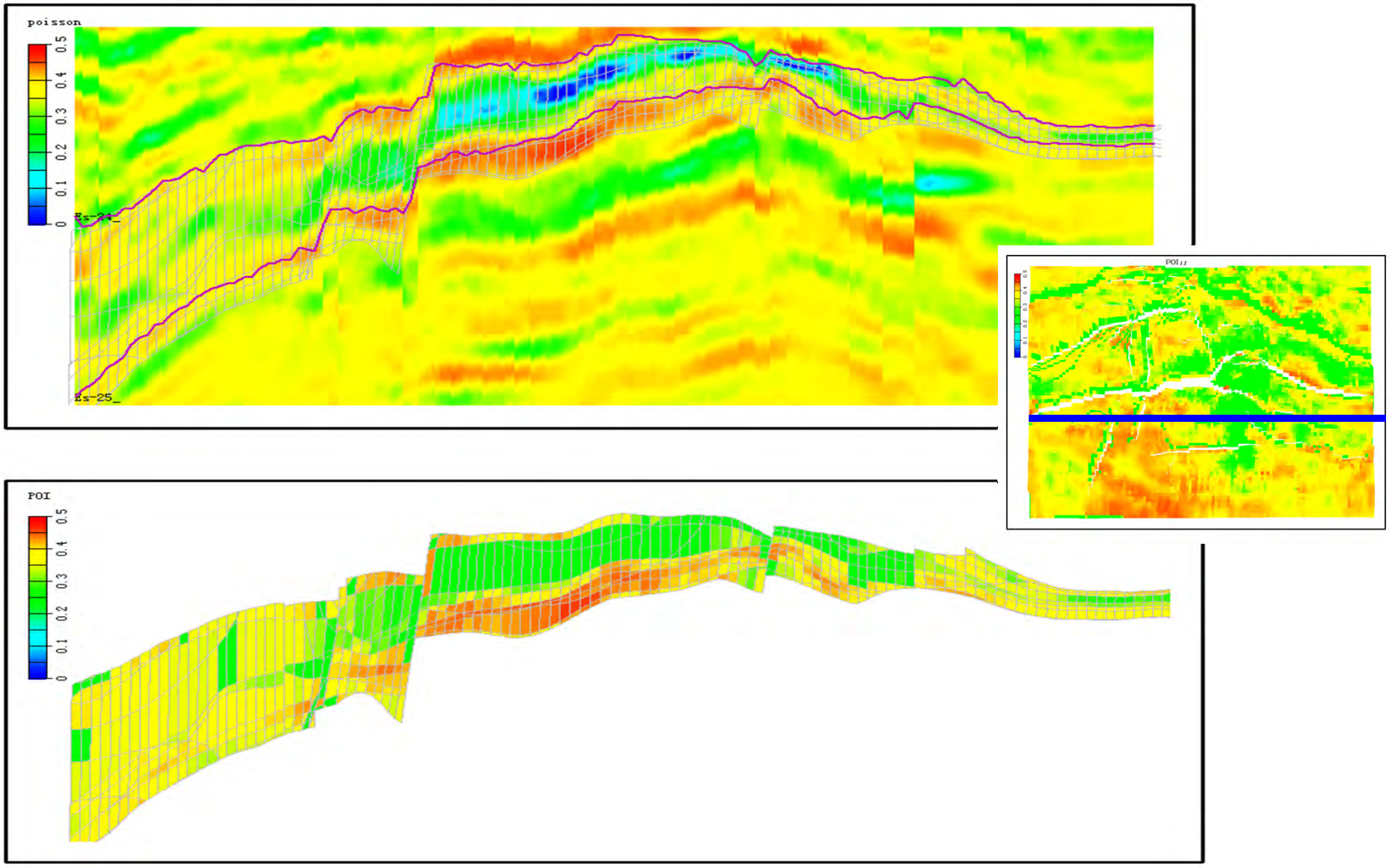
Step 4: Seismic & Reservoir Analysis



Sw-Seismic+synthetic tie

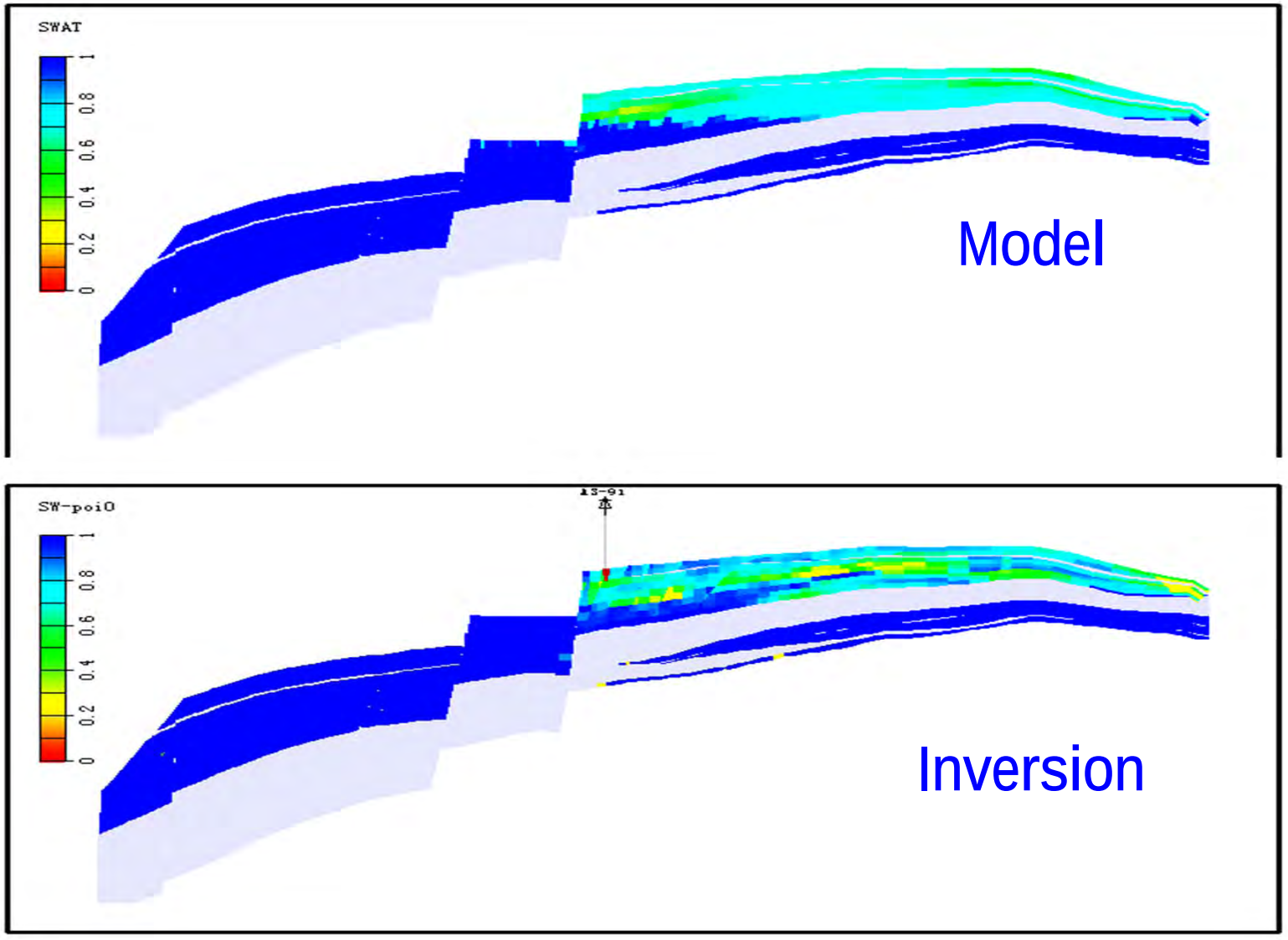


Step 5: Grid Mapping



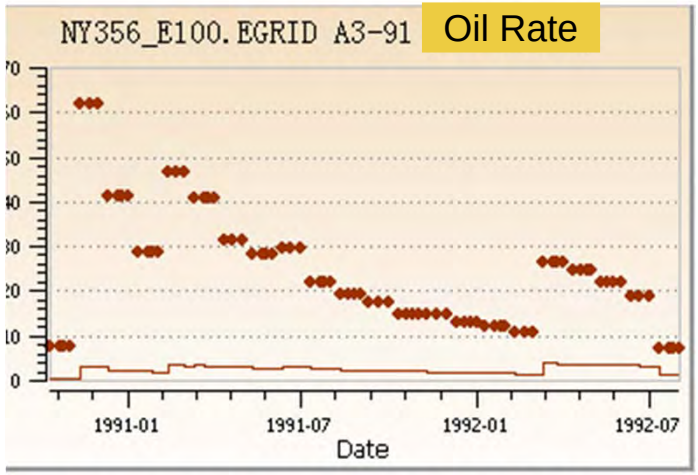
Grid conversion for Poisson's ratio

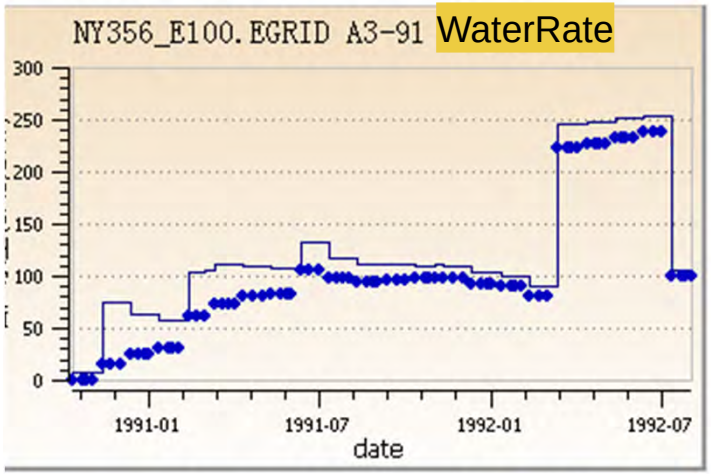
Step 6: Template inversion

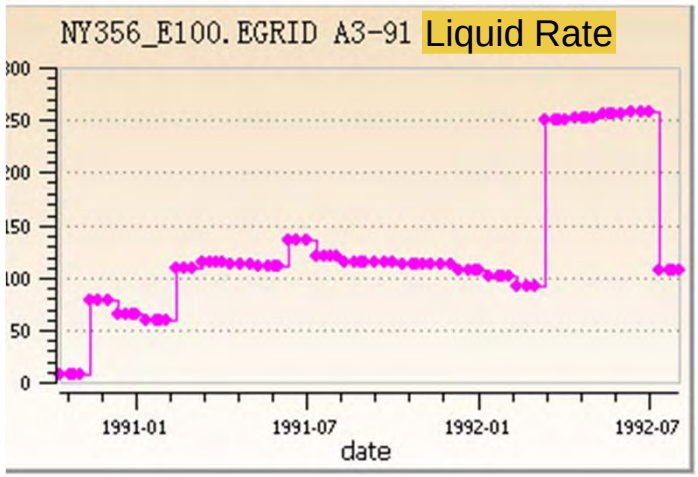


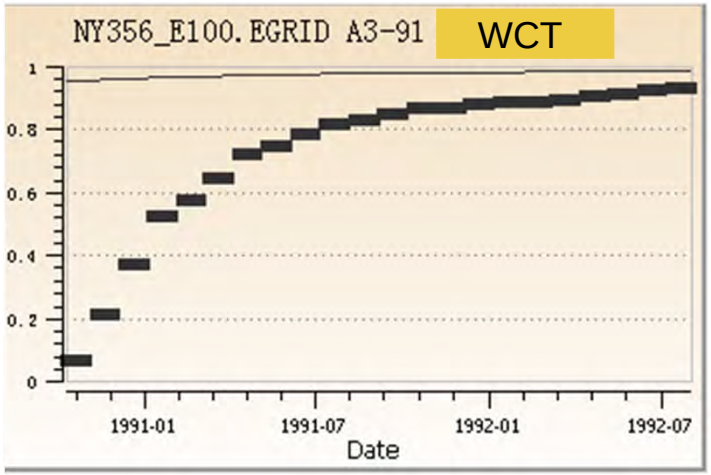
Sw inversion from Poisson's ratio

Step 7: Seismic constrained HM



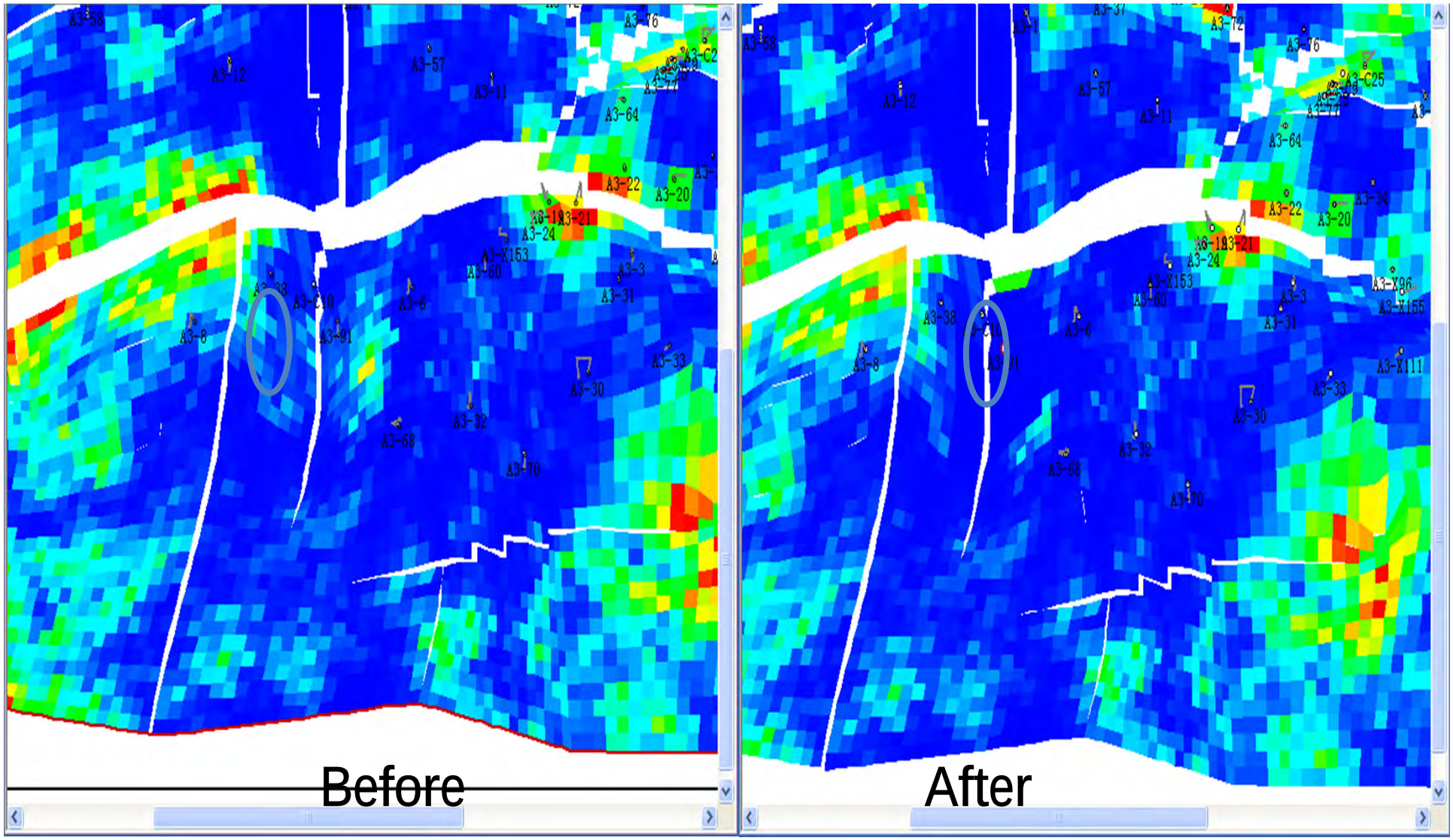






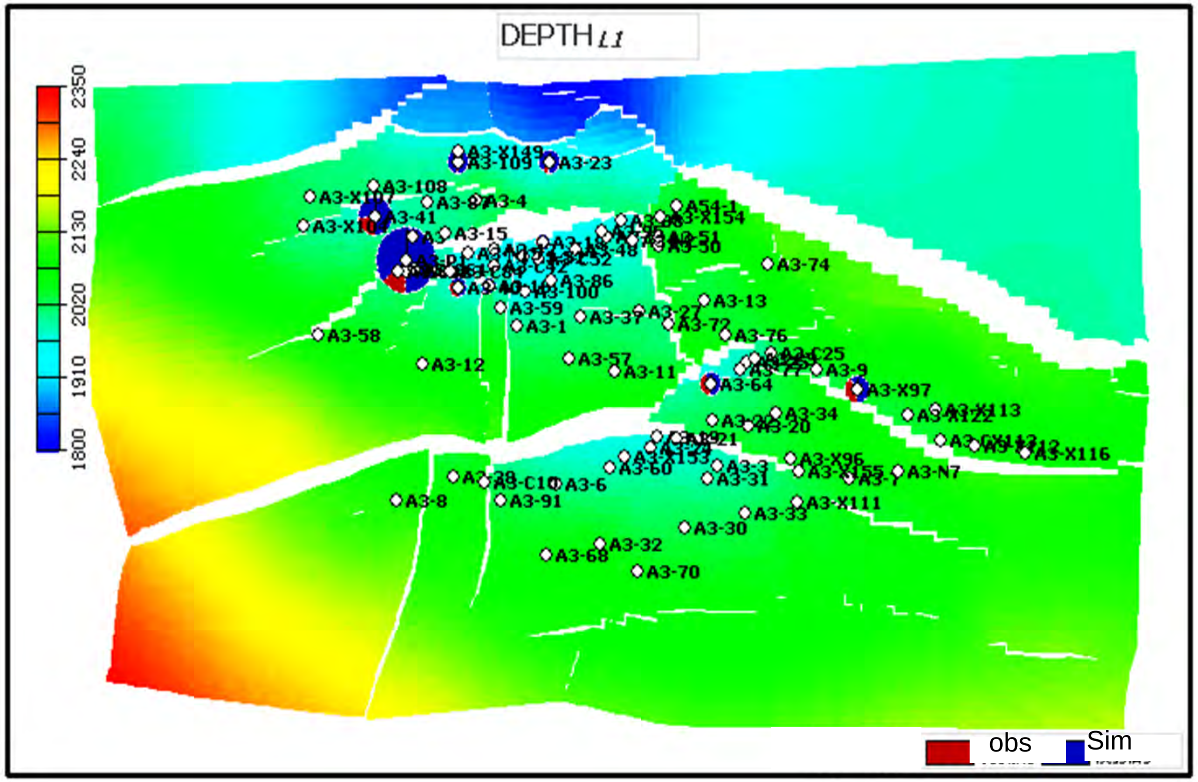
Water invasion earlier

Model Updating: Perm

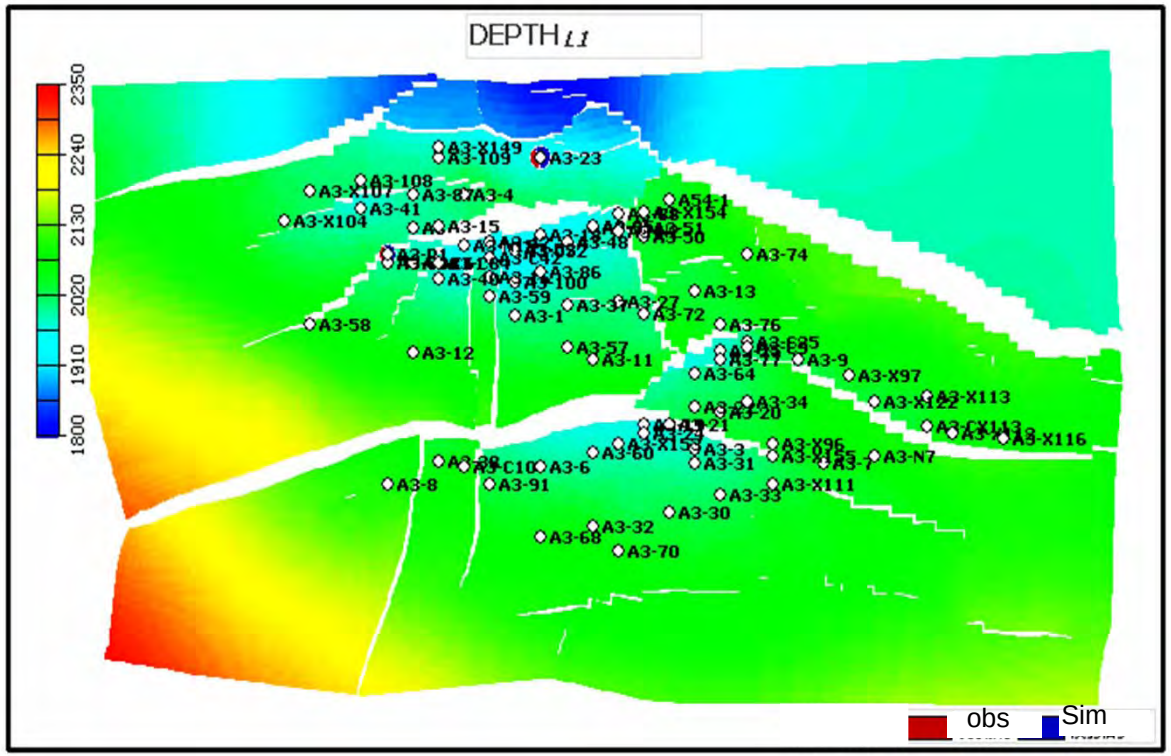


Perm – Layer 2

HM - Before


DEPTH
2350
2240
2130
2020
1910
1800
A3-X149
A3-109
A3-23
A3-108
A3-X107
A3-41
A3-15
A3-4
A54-1
A3-X154
A3-74
A3-13
A3-59
A3-1
A3-37
A3-27
A3-72
A3-58
A3-76
A3-12
A3-57
A3-11
A3-64
A3-9
A3-X97
A3-34
A3-20
A3-X113
A3-X116
A3-60
A3-31
A3-N7
A3-6
A3-8
A3-91
A3-X111
A3-33
A3-30
A3-32
A3-68
A3-70
A3-86
A3-100
obs
Sim

HM - After


DEPTH
2350
2240
2130
2020
1910
1800
A3-X149
A3-103
A3-23
A3-108
A3-X107
A3-87
A3-4
A3-41
A3-X104
A3-15
A3-48
A3-30
A3-74
A3-86
A3-100
A3-59
A3-13
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A3-1
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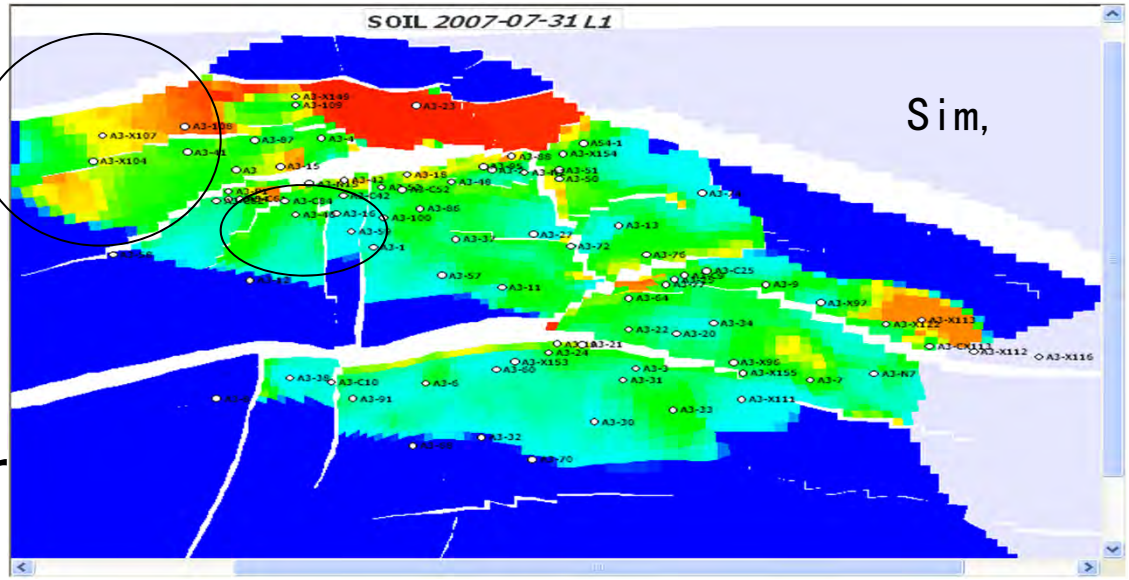
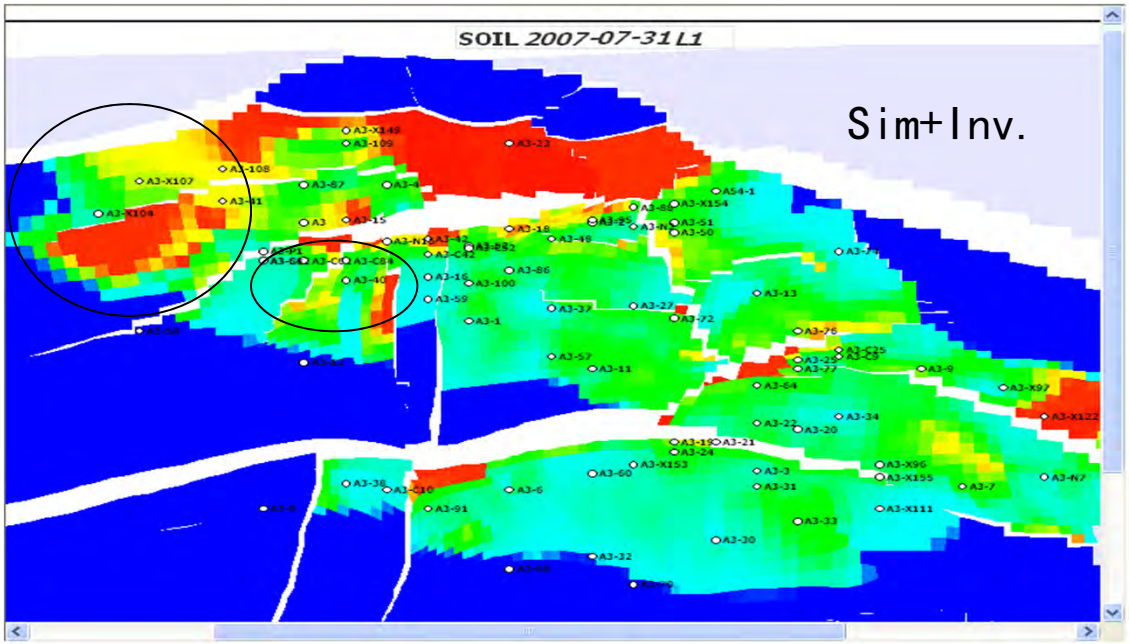
A3-11
A3-9
A3-64
A3-X97
A3-X113
A3-34
A3-20
A3-X122
A3-X116
A3-X96
A3-3
A3-60
A3-31
A3-N7
A3-C10
A3-6
A3-8
A3-91
A3-X111
A3-33
A3-30
A3-32
A3-68
A3-70
obs
Sim

Comparison

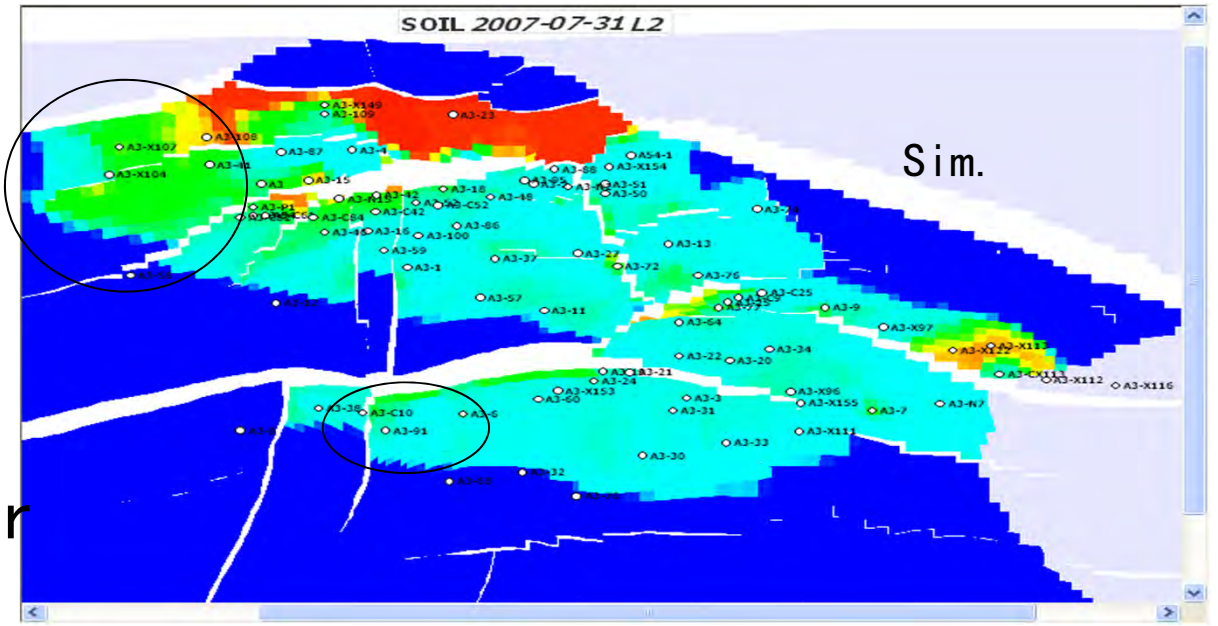
Top Layer



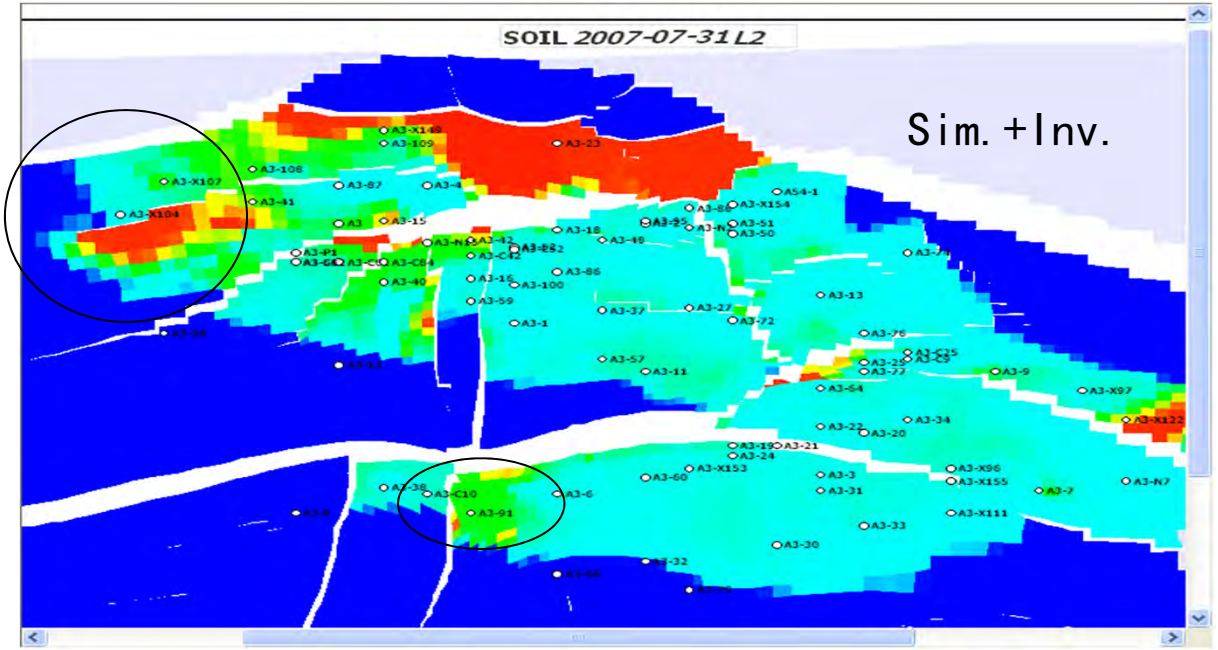


Comparison

Lower Layer



Direct adjust using result. and where to adjust



Optimization of Production

Linearization of producer-injector relationship

$$\hat{q}_j(t) = \lambda_{0j} + \sum_{i=1}^{I} \lambda_{ij} i_i(t), \; j = 1,2,\ldots,N$$

λ_{ij} the weighting or 'connectivity' factor between injector '*i*' and producer '*j*'

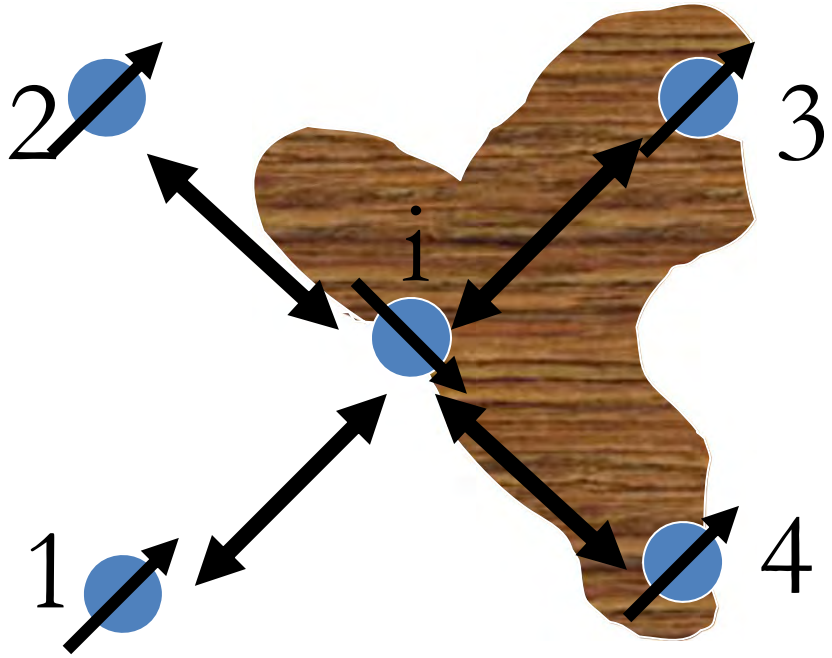
$\hat{q}_j$ modeled liquid production rate, RB/D

i_i observed injection rate, RB/D

Albertoni (2002)

Use of seismic for injector-producer relationship

- Method
  - Use seismic spatial attributes, such as time-lapse seismic difference
  - Calculate the relationship of injector-producer pairs
  - Use the relationship to constrain the weight factor determination (turns into a non-linear problem)



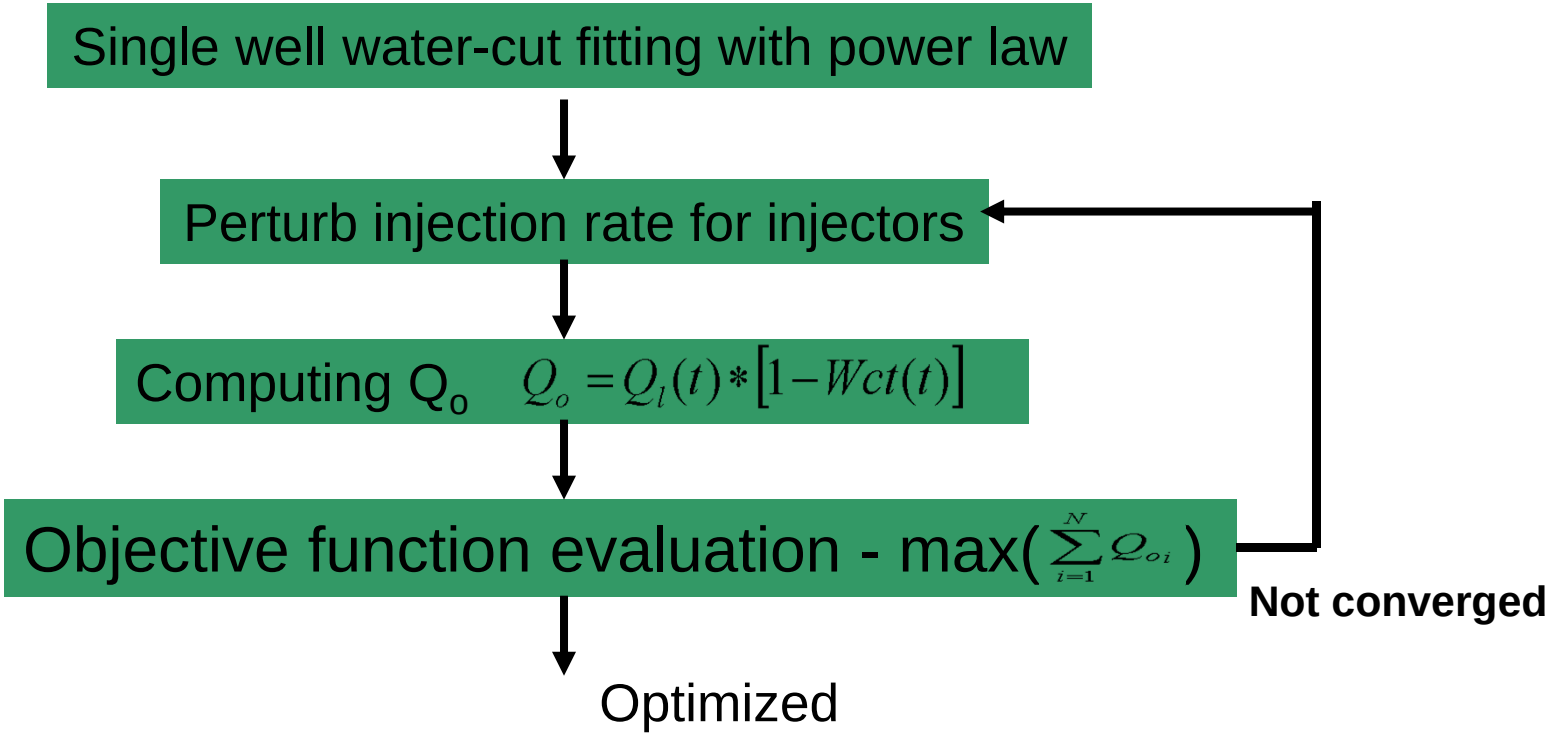
$$\lambda_{i3} > \lambda_{i4} > \lambda_{i2}, \lambda_{i1}$$

Optimization of waterflooding

- Procedure for optimization

$Q=\lambda I$ Given Q, I ⇒ λ Connectivity Computing

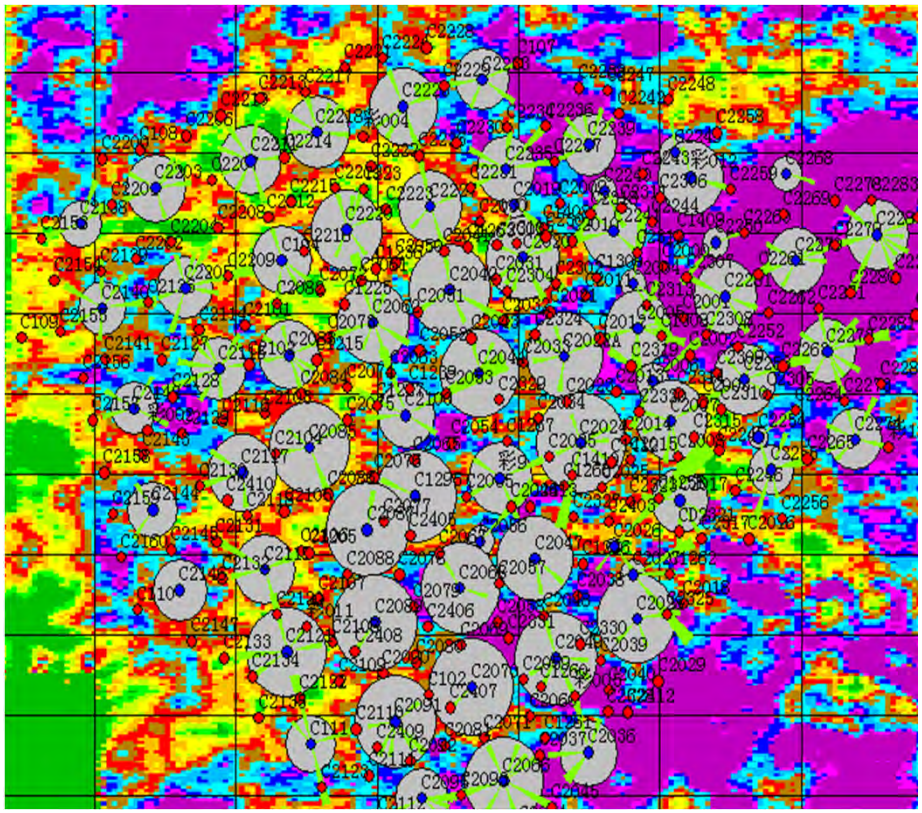
$Q=\lambda I$ Given λ, Perturb I ⇒ Maximizing Q



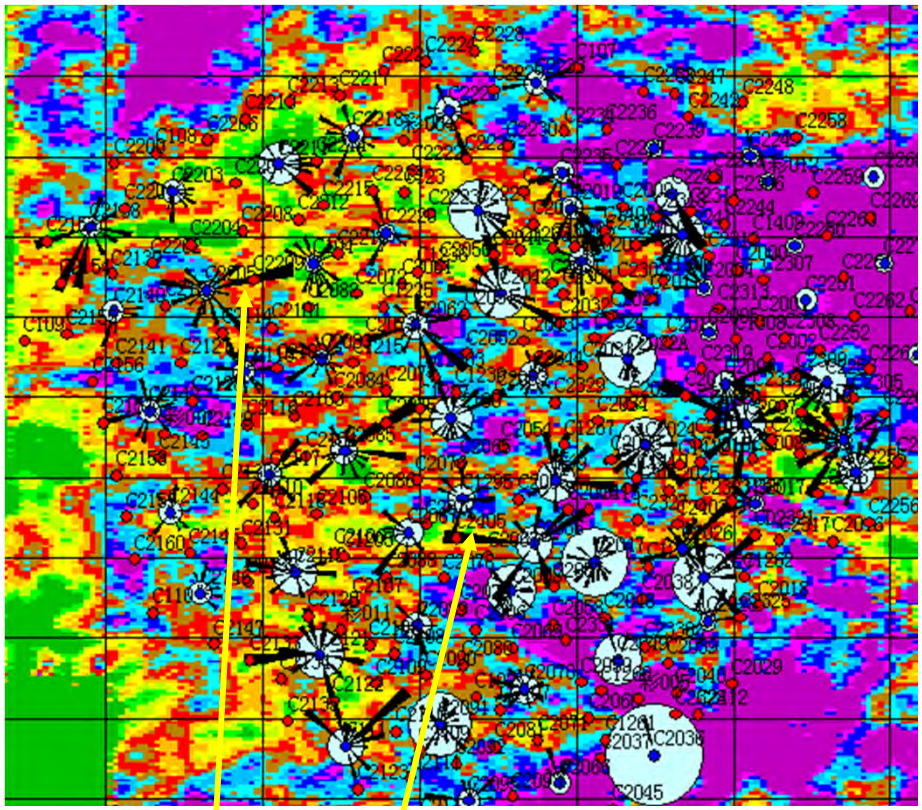
A case study

Difference from 1990, 2001 legacy surveys after reprocessing

Pattern before optimization

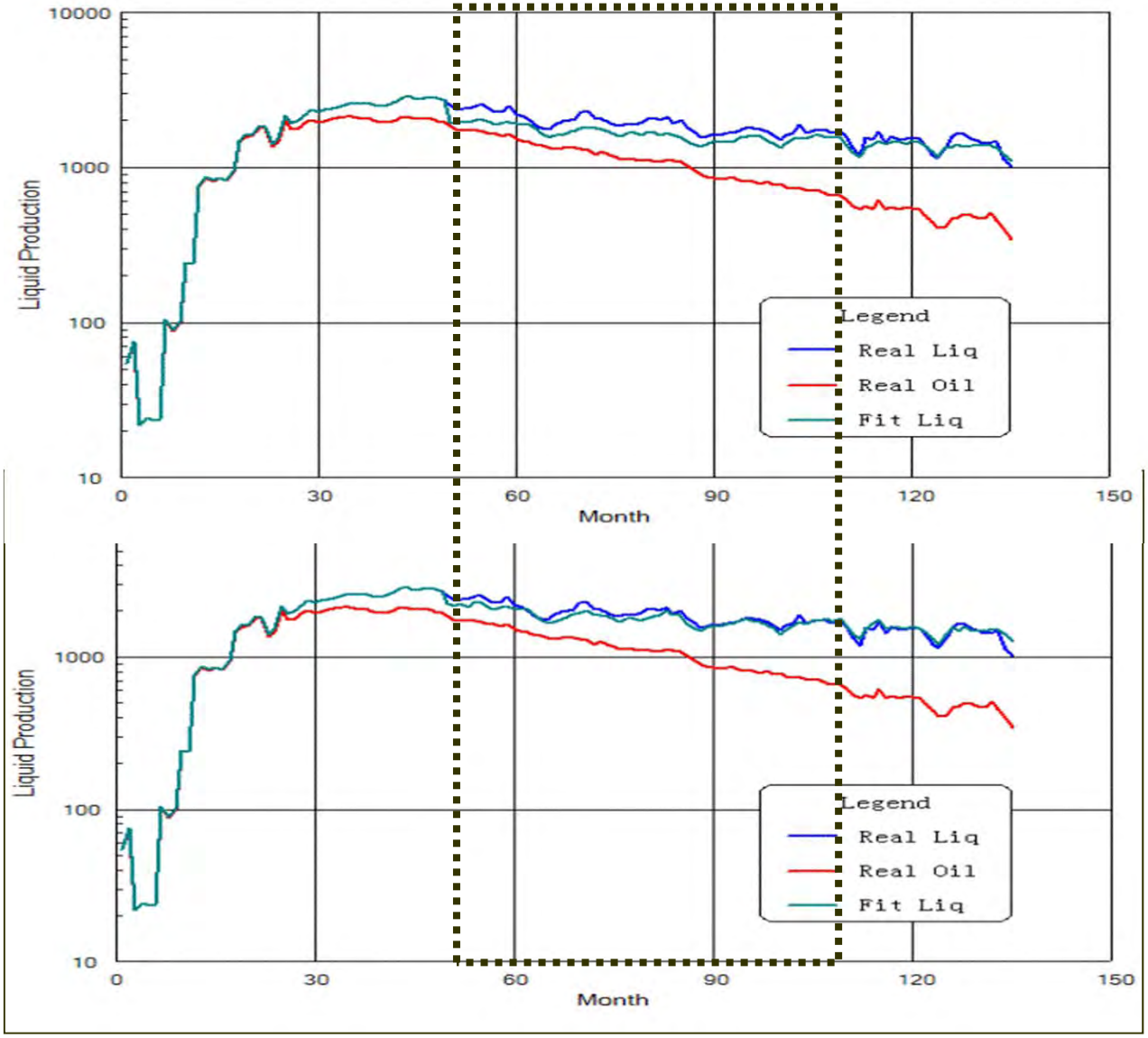


Pattern after optimization



Optimization generates a new injection rate distribution by constraining the process using the seismic difference attribute.

- Production history matching



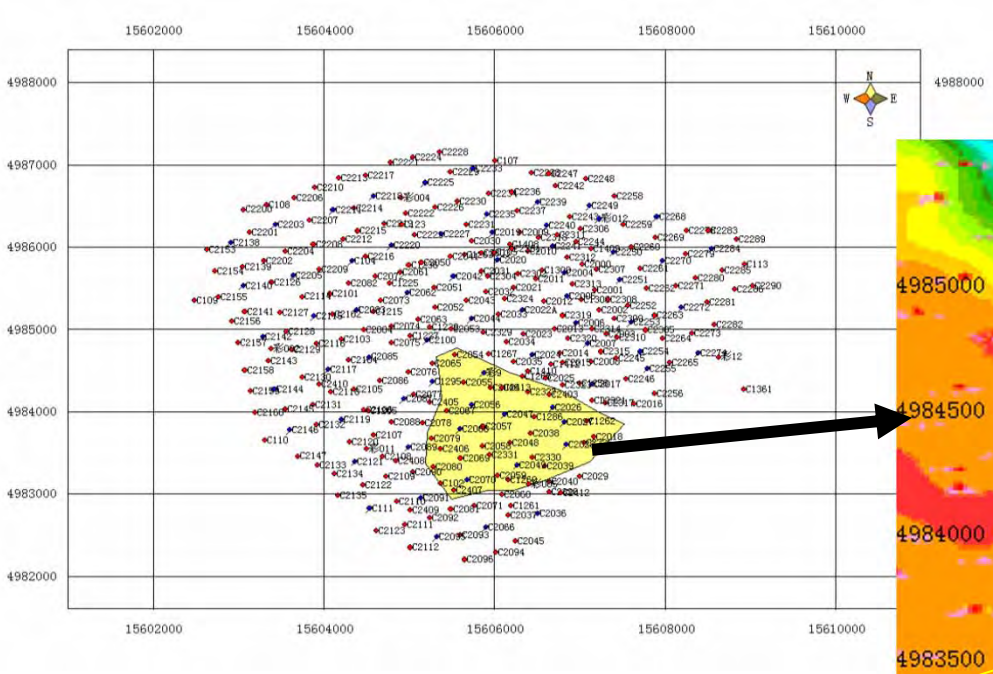
Without seismic
Err.=10.5%

With seismic
Err. =5.6%

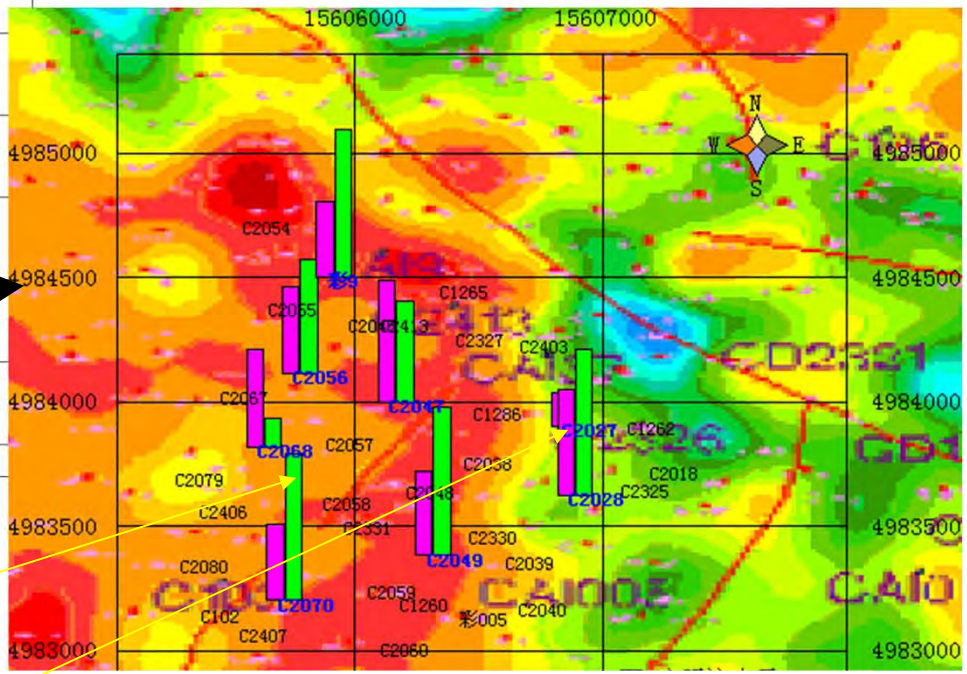
Seismic constraint improves the history matching (Liquid in cubic meters).

- **Pilot implementation**
  - Injection unchanged outside the pilot area
  - Only perturb the injection rate inside the pilot area
  - No other enhancement schemes applied

Pilot Area



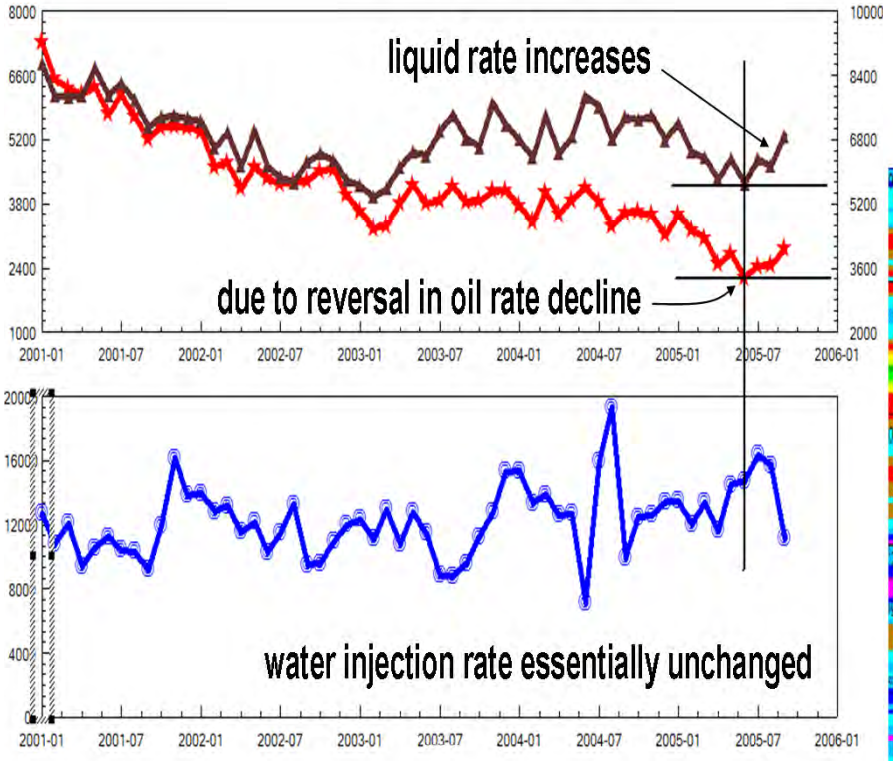
Injection Rate Change

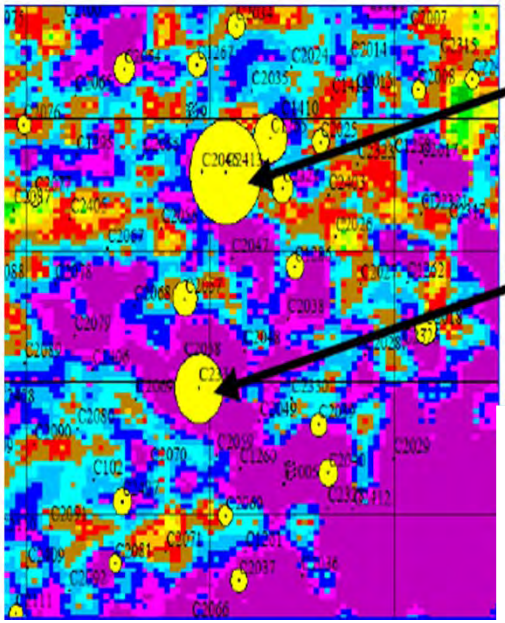


Optimized

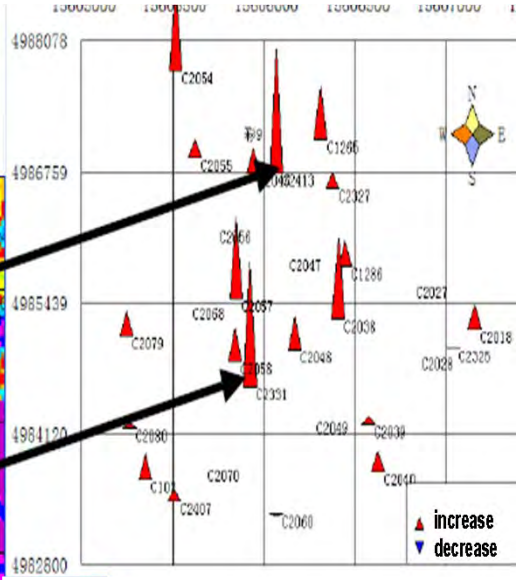
History

- Pilot implementation result
  - Cumulative oil production increase of 7000 barrels
  - Performance followed up for 3 months





Predicted



Result

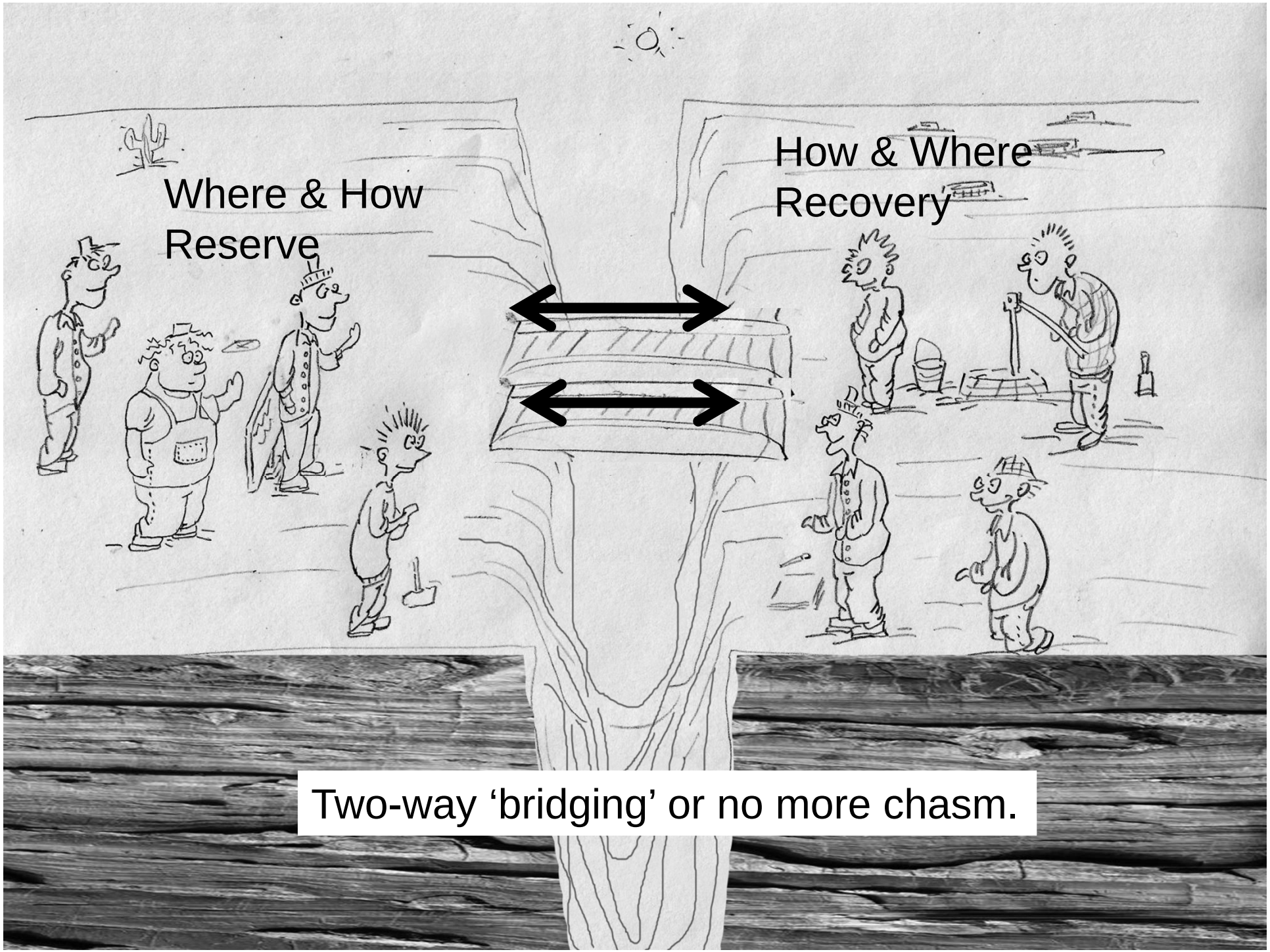
Adjust on operation parameters

Summary

- Through ‘bridging’ in data domain, seismic data can be used to identify potentials in producing field for production adjustment.
- By ‘bridging’ in model domain, seismic data can help to update the reservoir model for further model based production optimization.
- It is feasible to use seismic data for production optimization.

Road Ahead

- More robust tool for ‘bridging’, and tools to ‘interact’ with all data for seismic and production data interpretation
- Possibility for looping back to geological modeling
- Automatic and interactive tools


Where & How
Reserve
How & Where
Recovery
Two-way ‘bridging’ or no more chasm.

Thank you!
Questions?

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