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Close-the-Loop between Geophysics and Reservoir Engineering

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SunRise PetroSolutions Tech, Inc.

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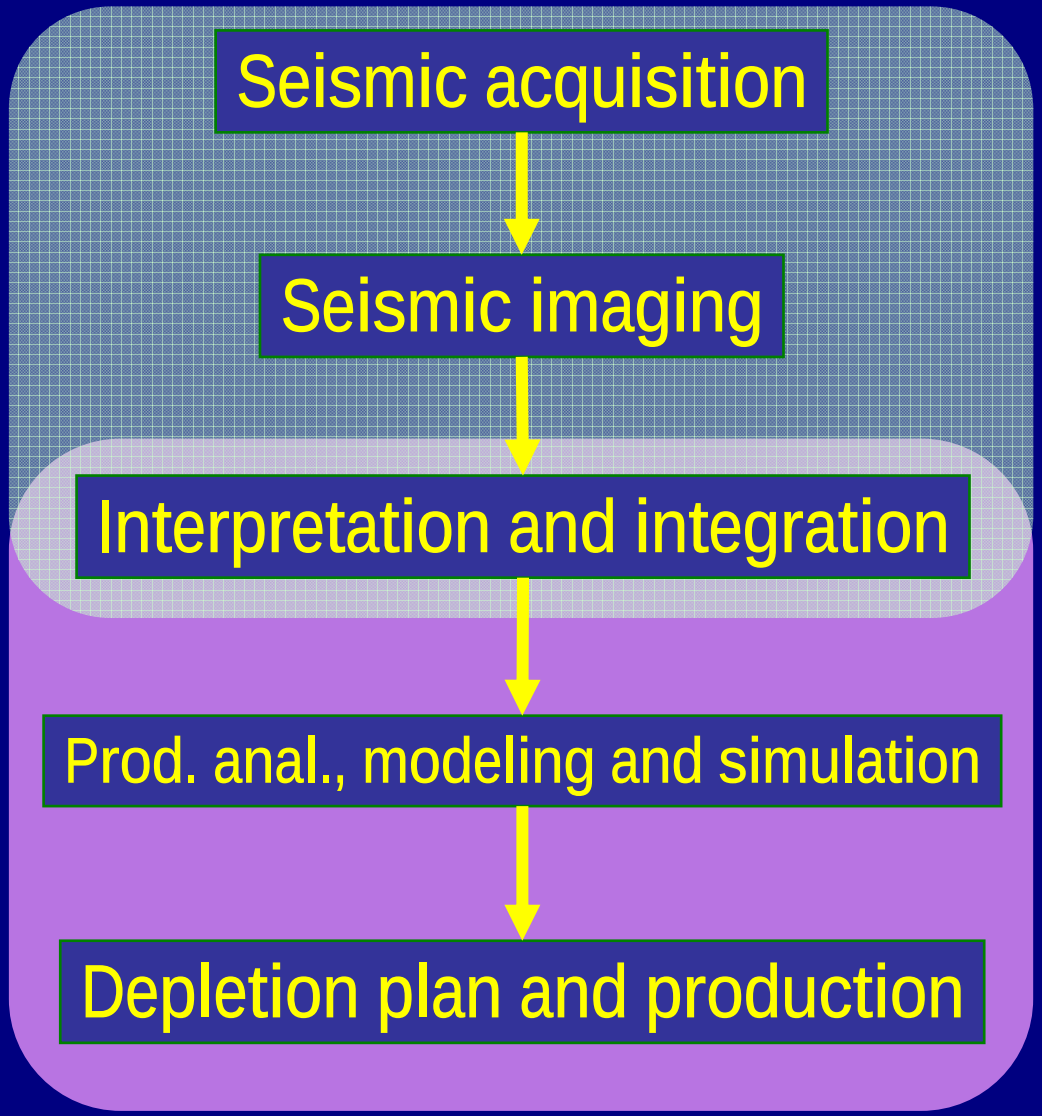
Outline

- Overview
- Close-the-Loop in Data Domain
- Close-the-Loop in Model Domain
- Optimization
- Summary

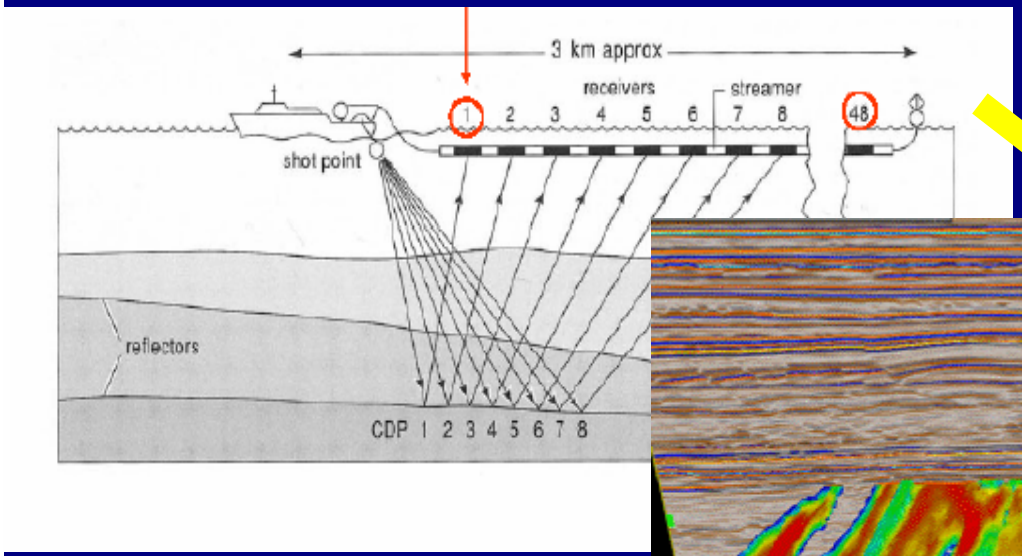
Common industry practice

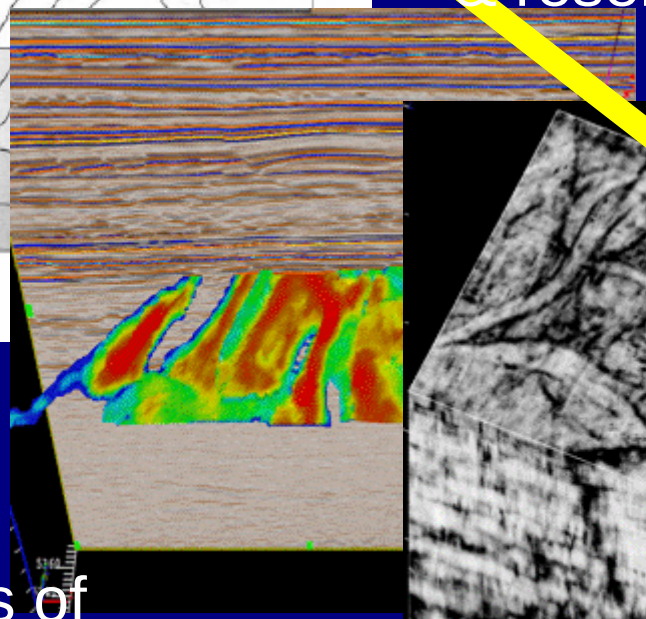


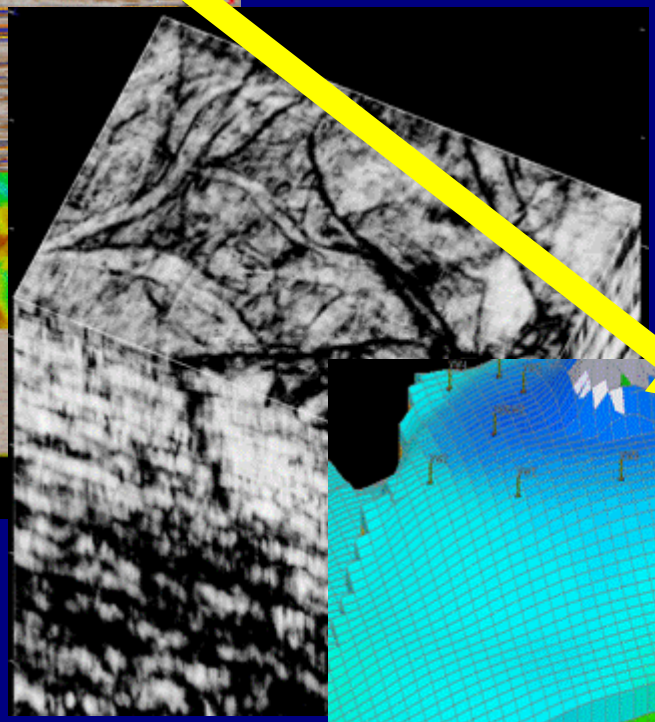
Workflow from seismic to simulation

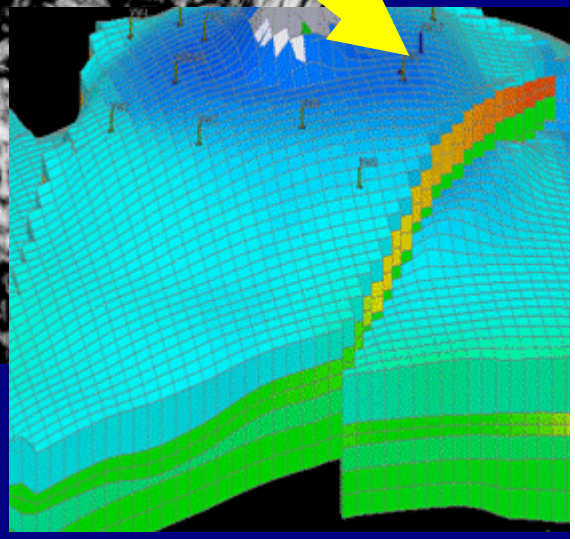
Seismic and Reservoir

Seismic data are collected in multi-dimensions to study spatial features of formation & reservoir.



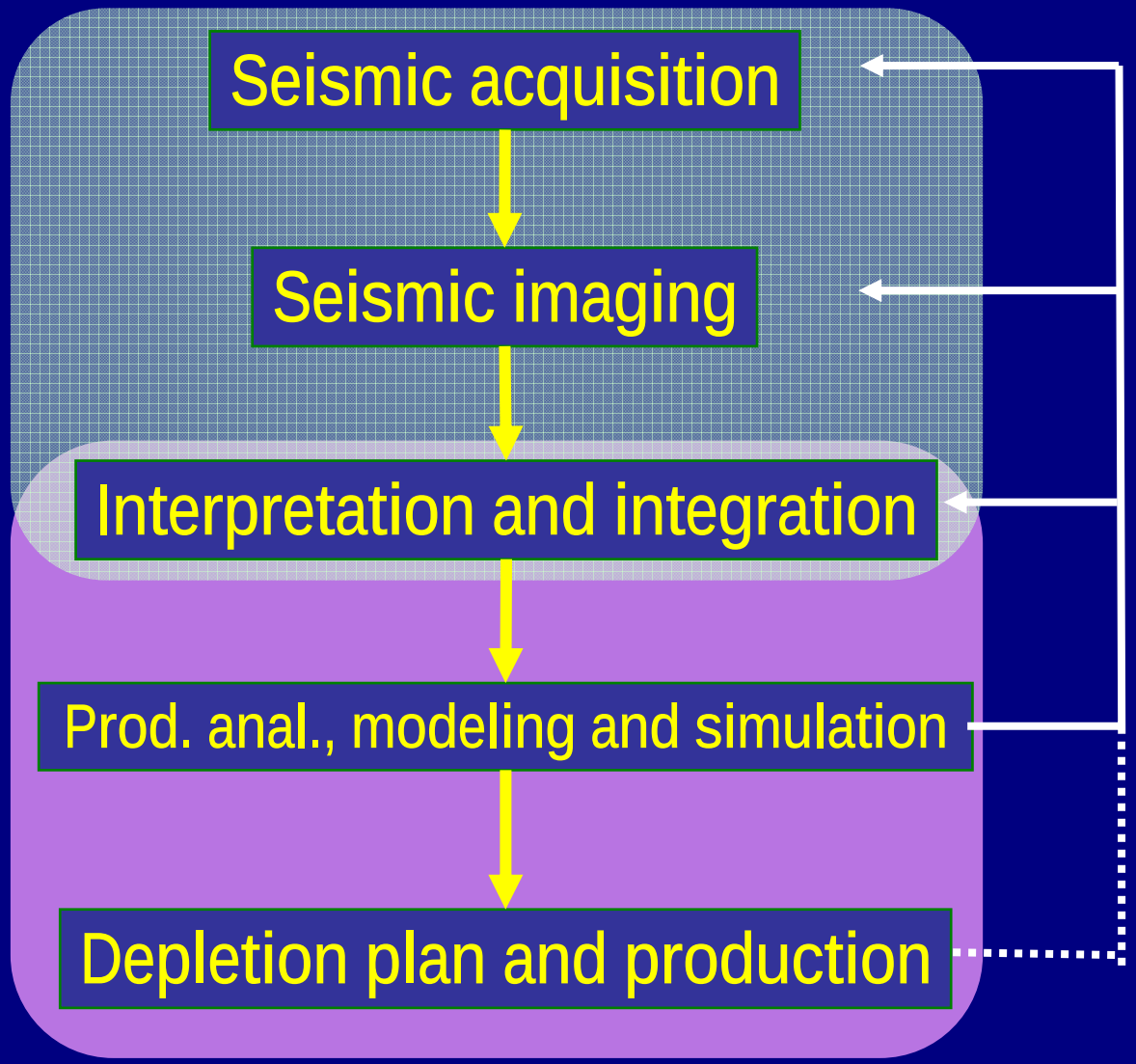






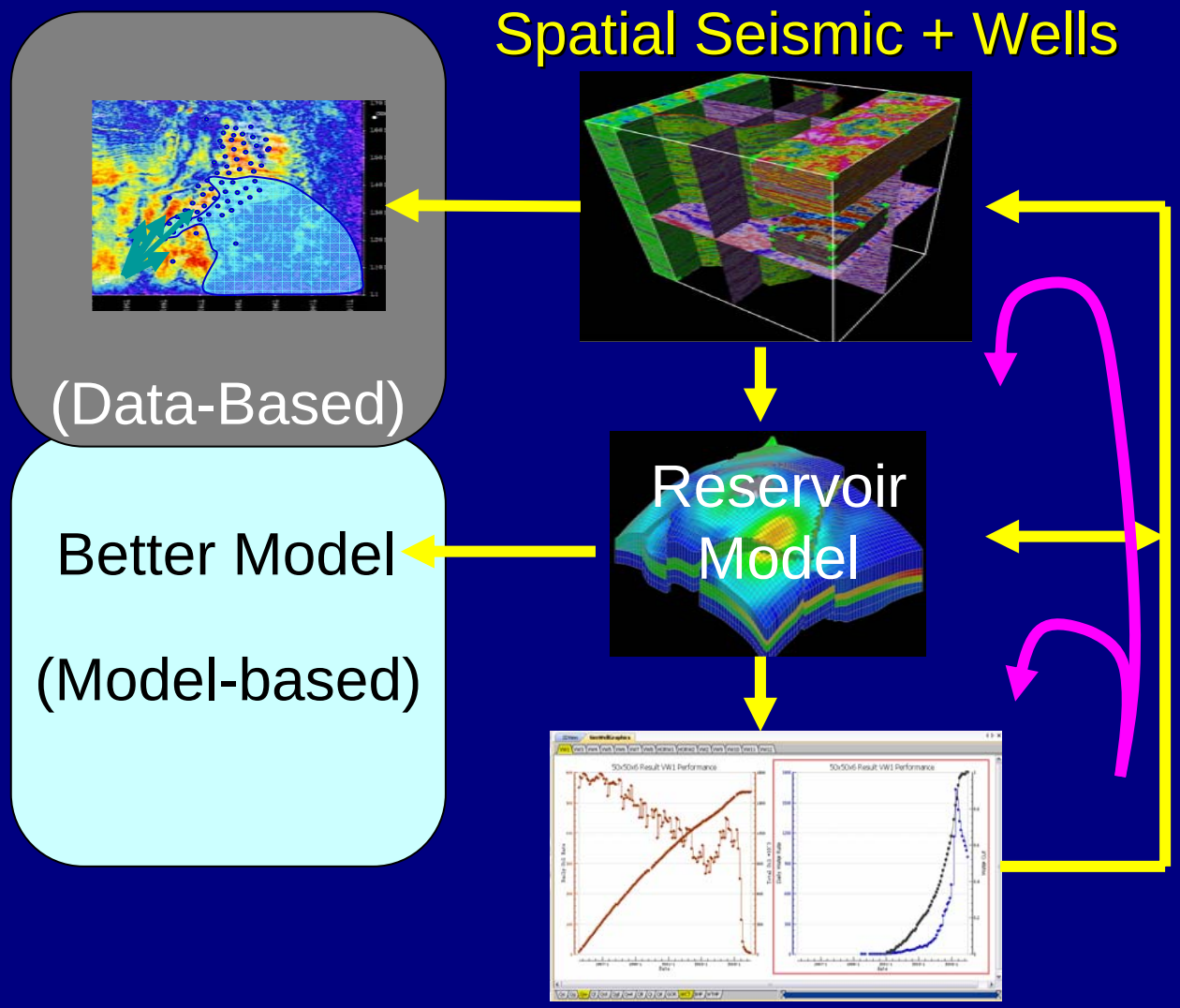
Attributes are metrics of reflection variation spatially, which could be critical indicators of reservoir heterogeneity.

New workflow: Close-the-Loop



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

Close-the-Loop Schemes

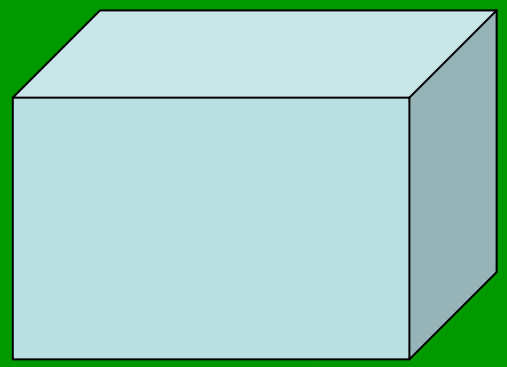


Seismic data can be 3D, 4D, prestack & multicomponent

“Close-the-Loop” Methodologies

Data-based

Material balance



Solve for

Hydrocarbon in Place

Drive Mechanism

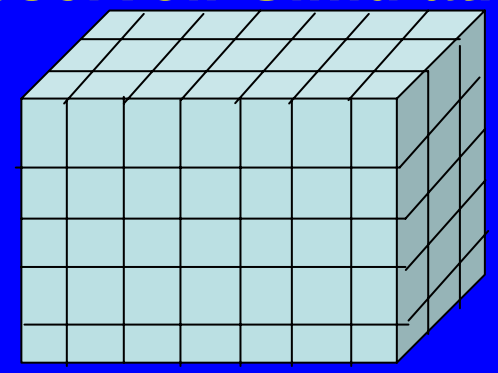
Connectivity

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

Optimization

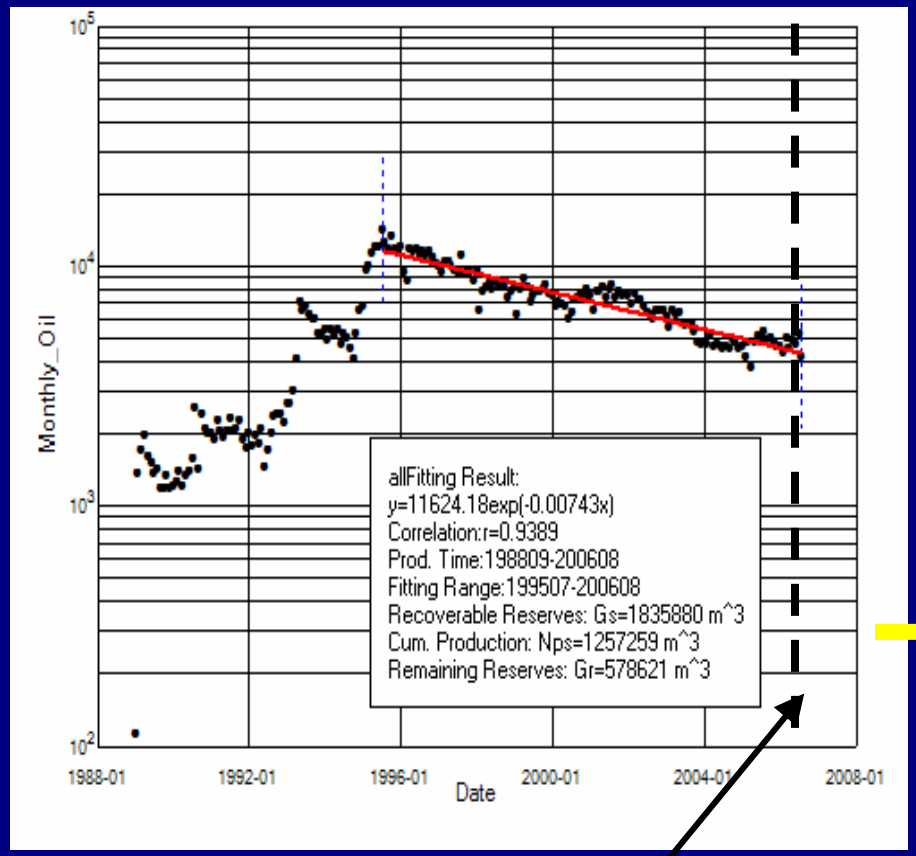
- Use of historical production data
- Use of seismic data
- Use simplified model constrained by seismic for history matching
- Optimize production system to arrest decline

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

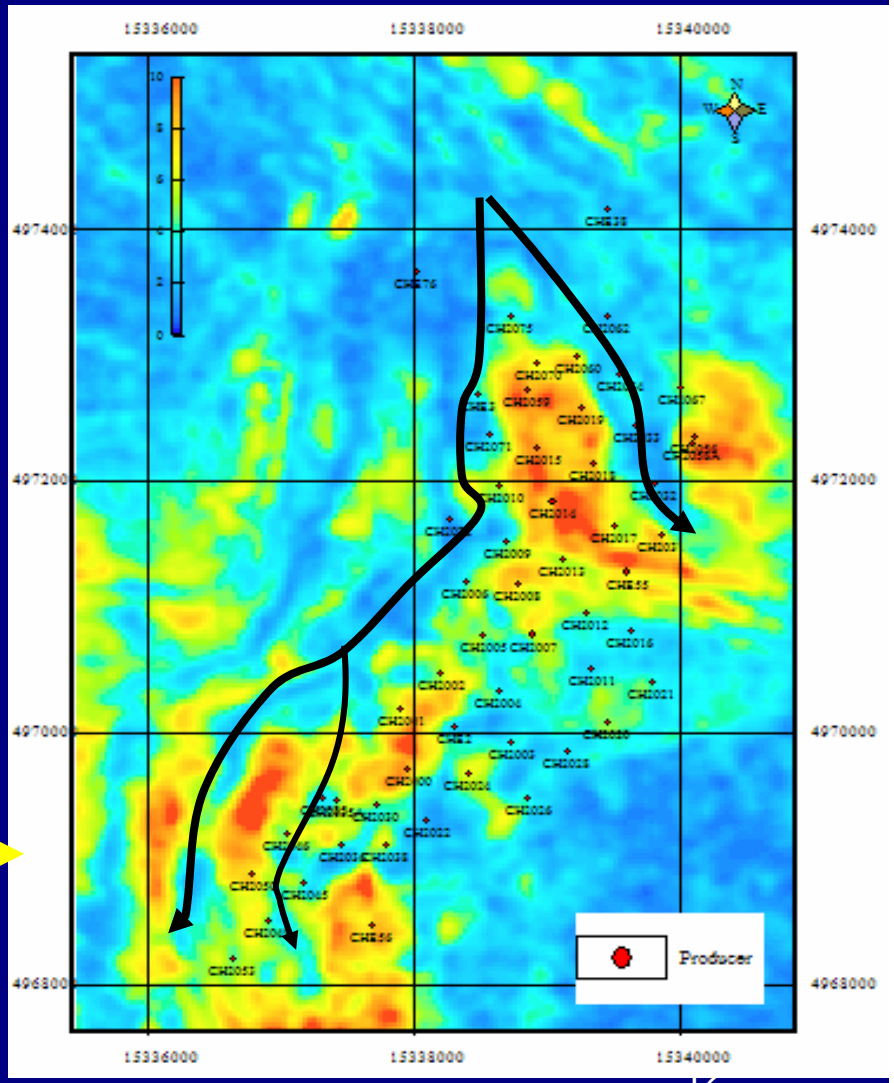
How to interpret the seismic attribute?

1. How has the water moved?
2. Where is the potential spatially?



Seismic acquired

Amplitude along reservoir



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

Screening attributes with prod. data

↓

Semi-quantitative analysis

↓

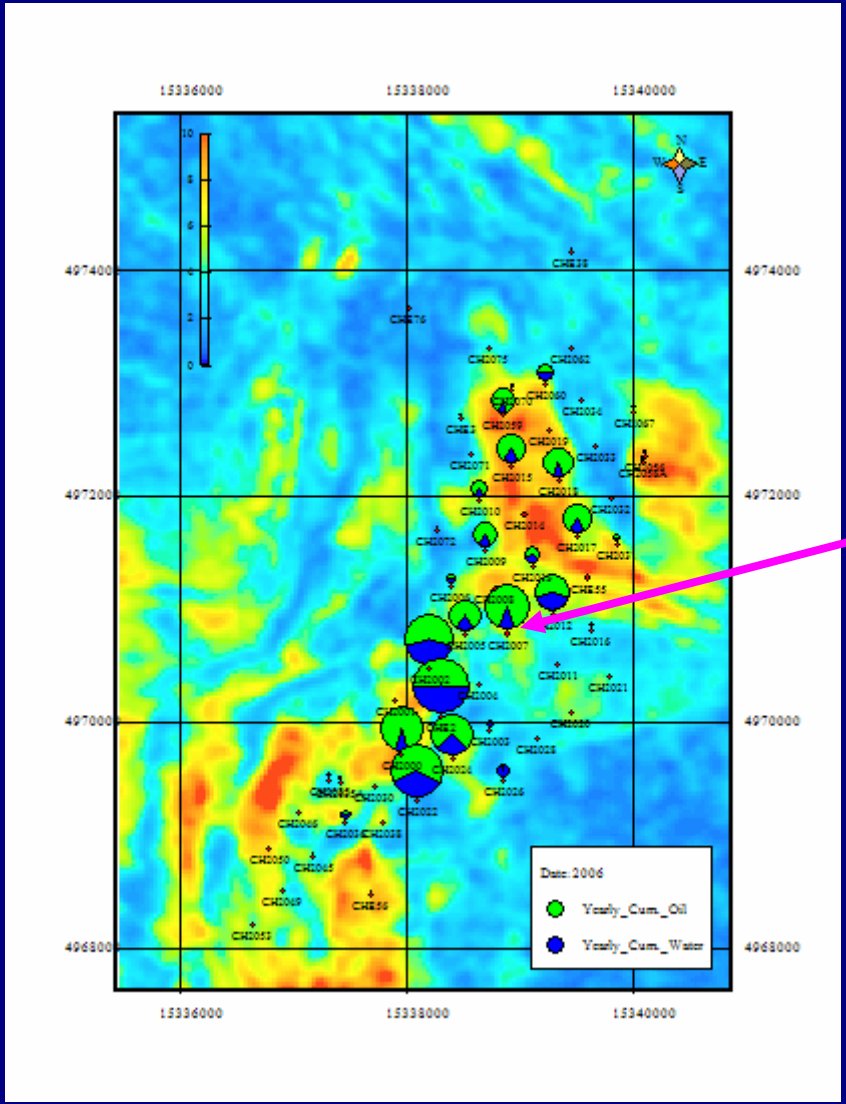
Filtering with volumetric

↓

Interpretation of potentials

Production data + Seismic → Interpretation

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

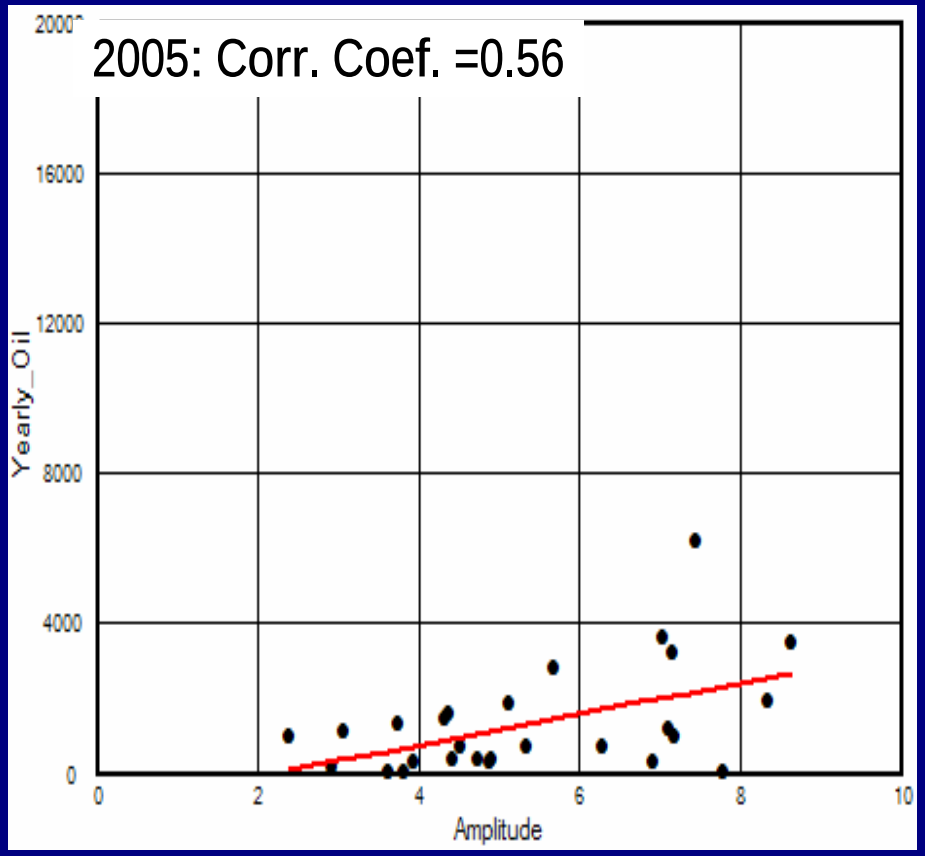


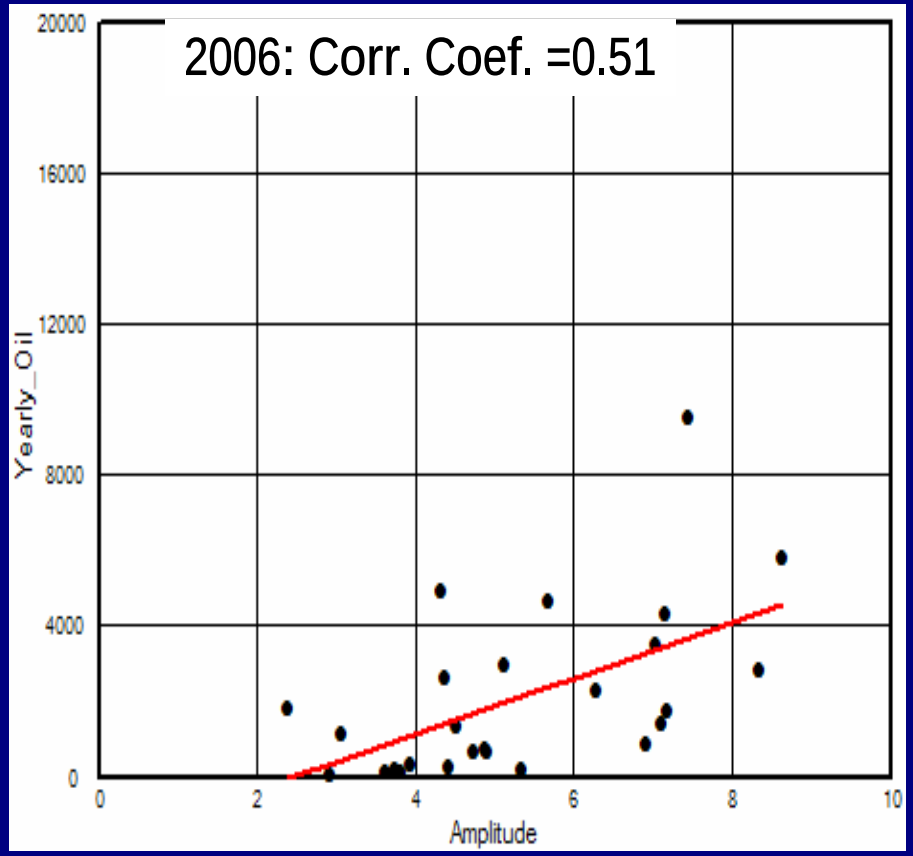
Cum Oil & Water

Reproc. Amplitude

Seismic attribute and production data patterns consistent

Step 2: Quantified relationship



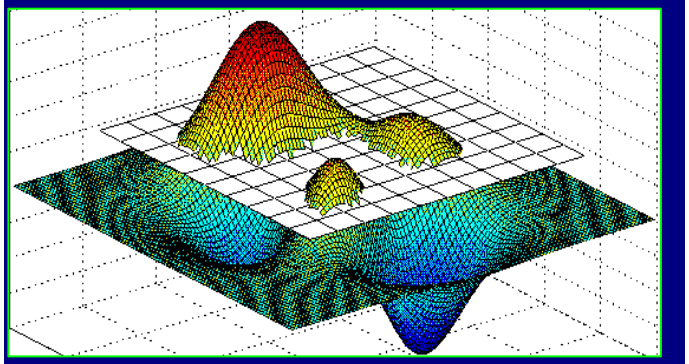


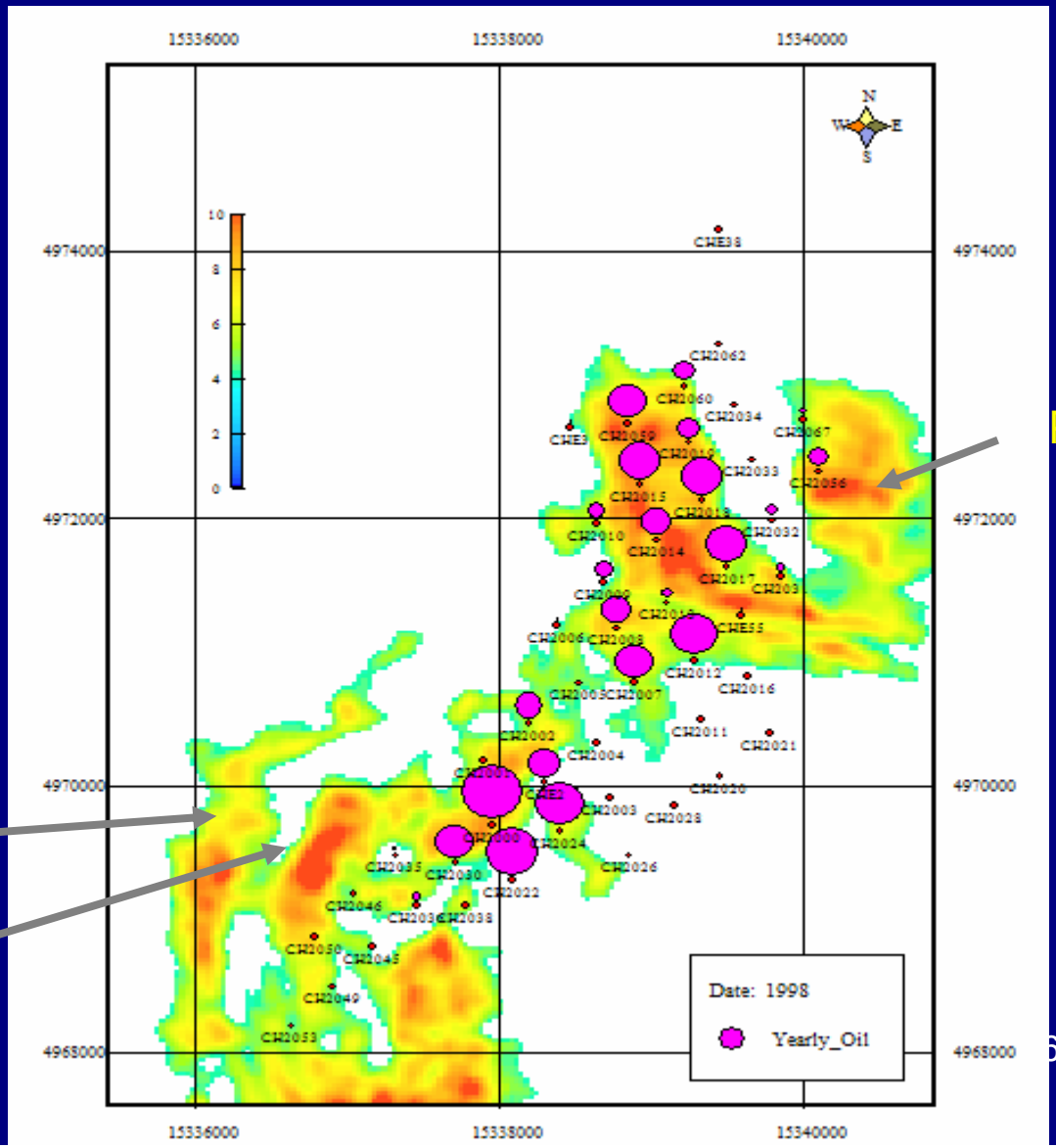
Favorable correlation indicates consistency of seismic attribute and production data

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

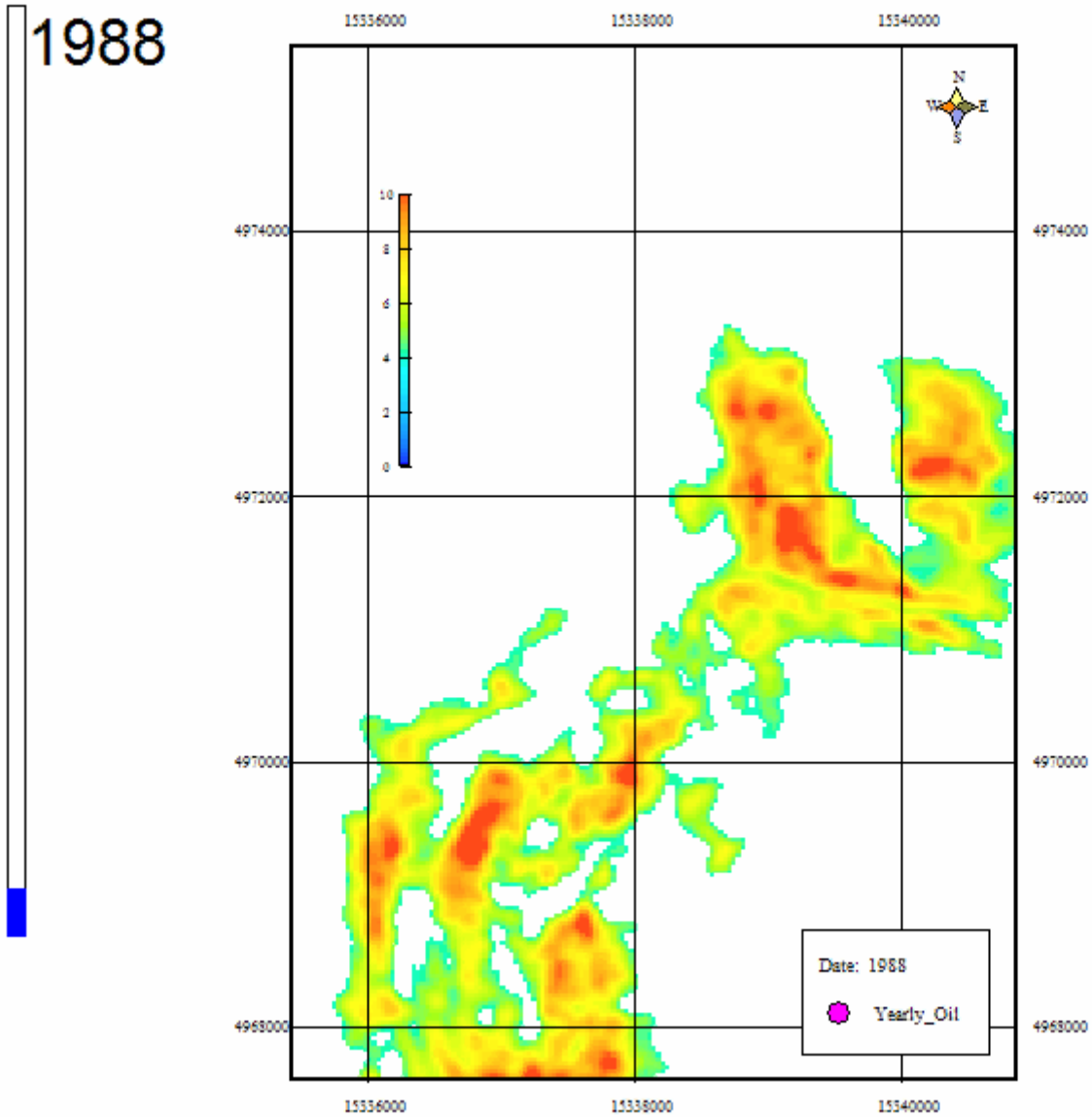




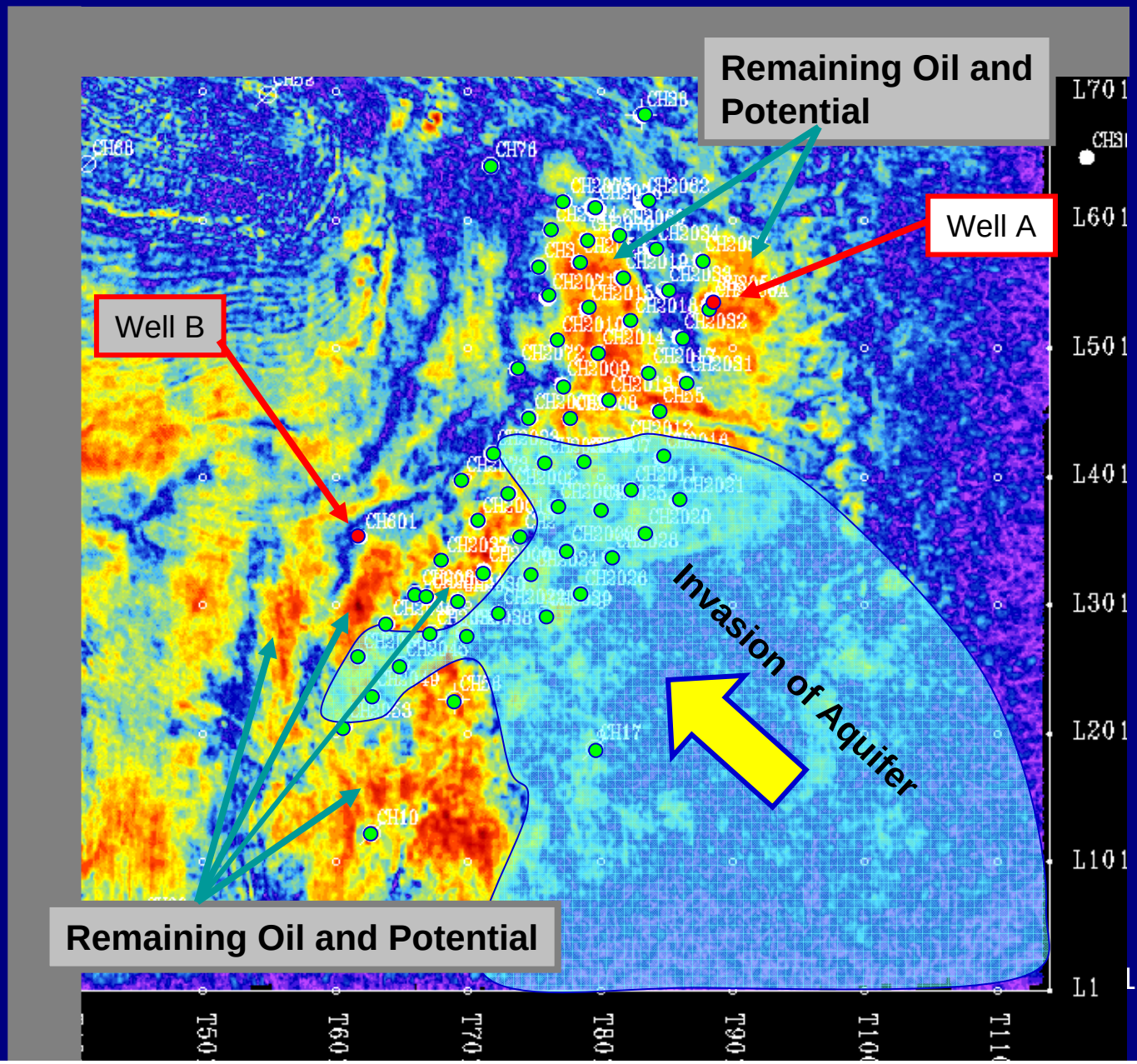
Potentials

Potentials

Revalidation with production data



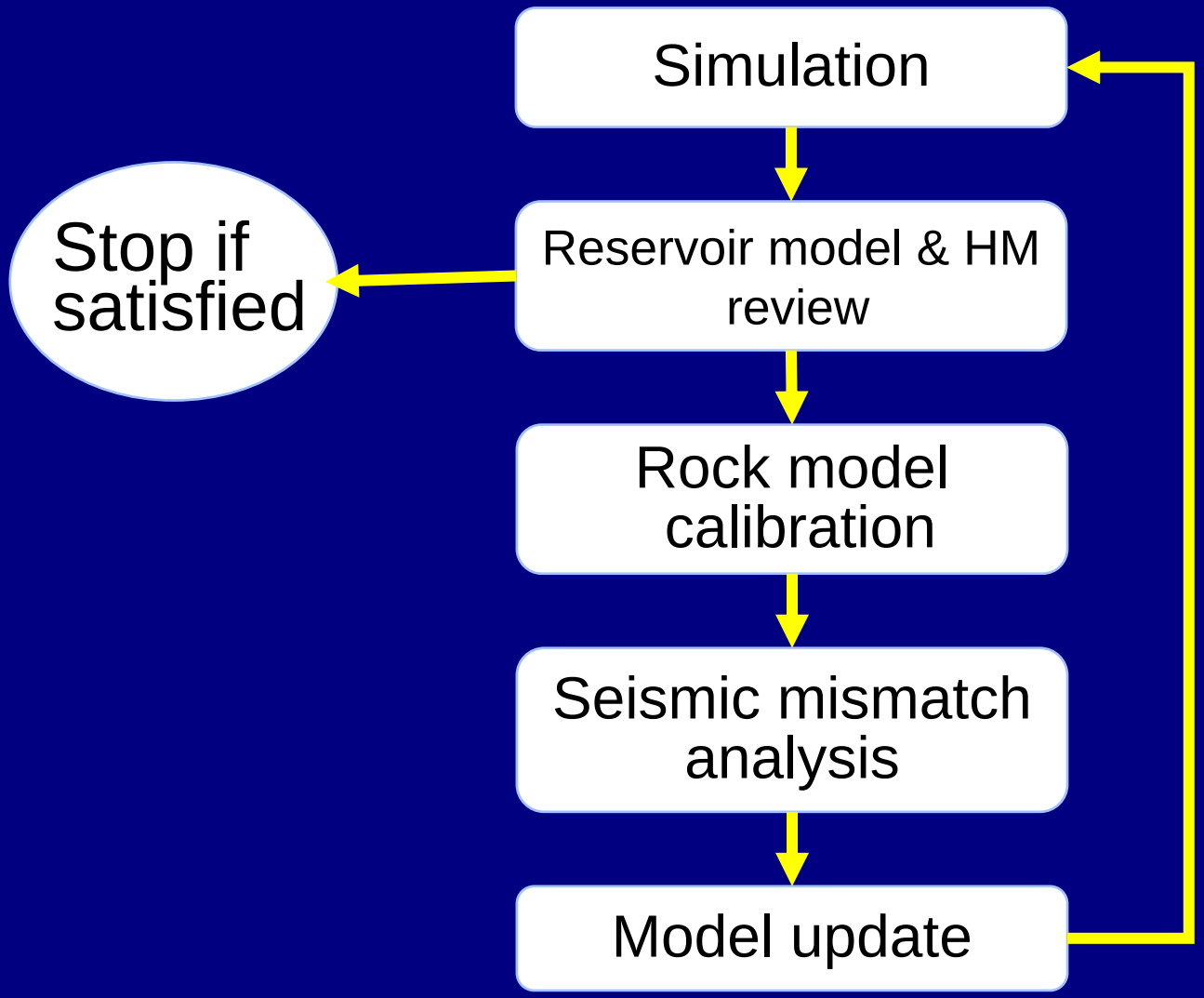
Step 4: Remaining potential and aquifer movement



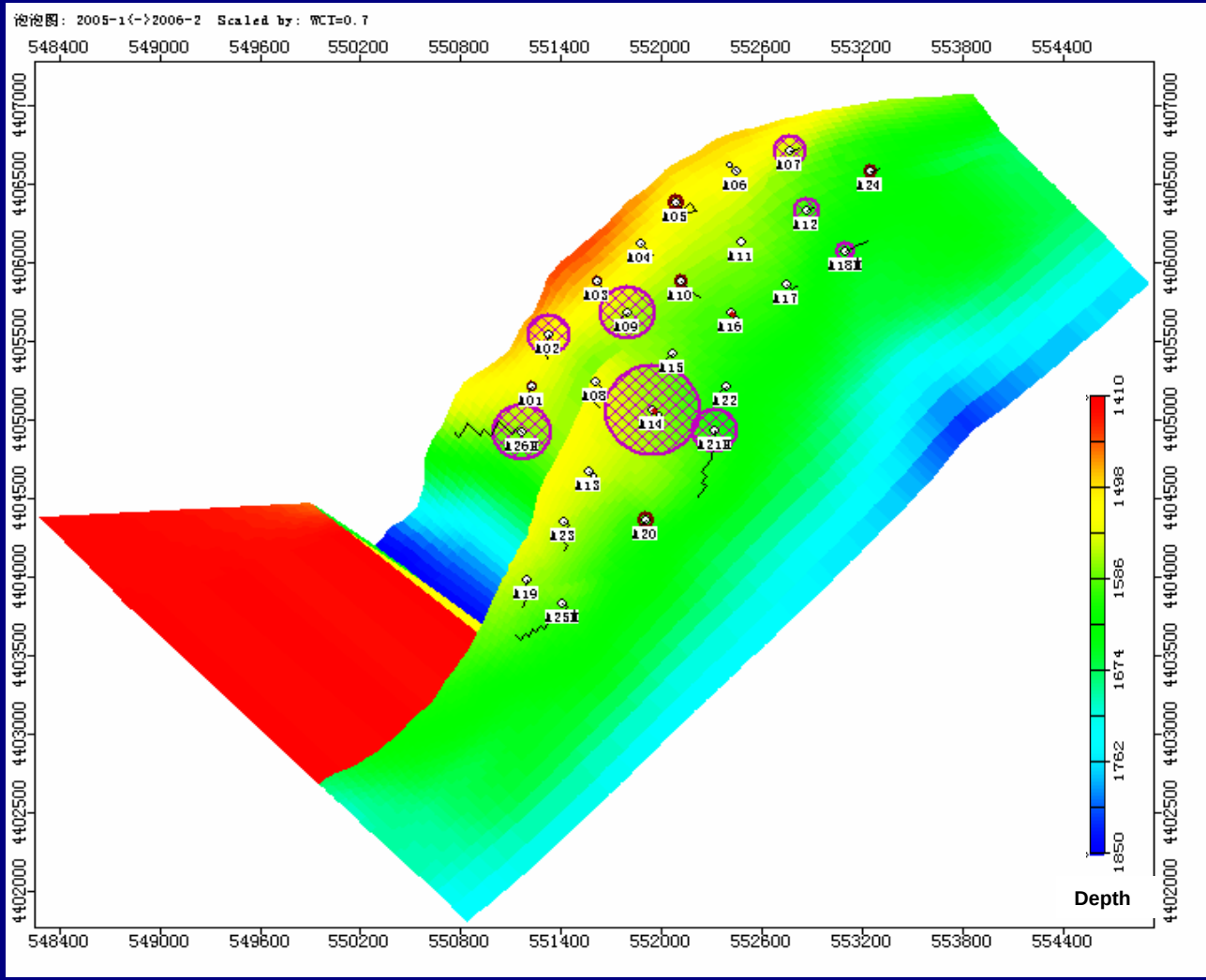
Model-based "Close-the-Loop" example: Field background

- 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 model

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



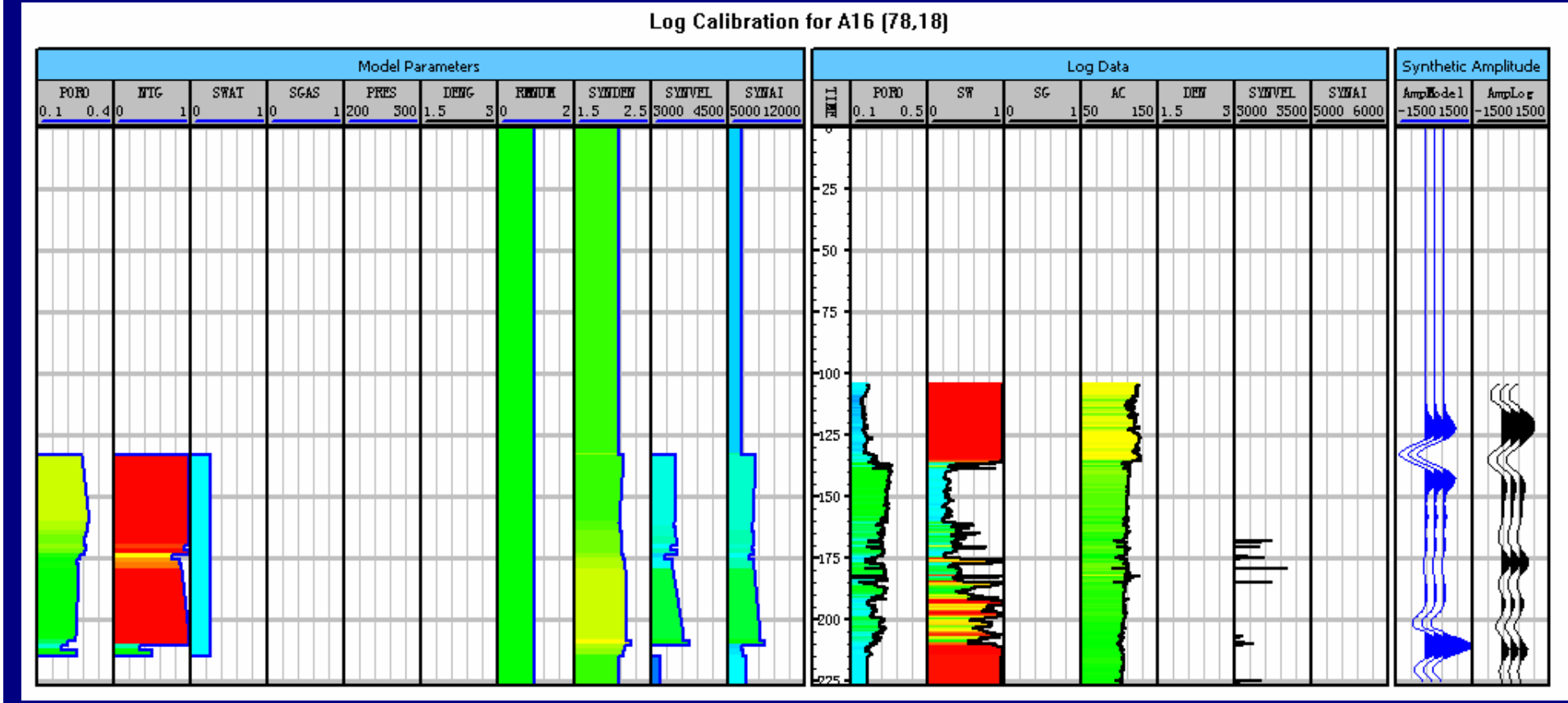
Step 1: History matching review



Higher mismatches in the central areas of the reservoir

Step 2: Rock model & log calibration

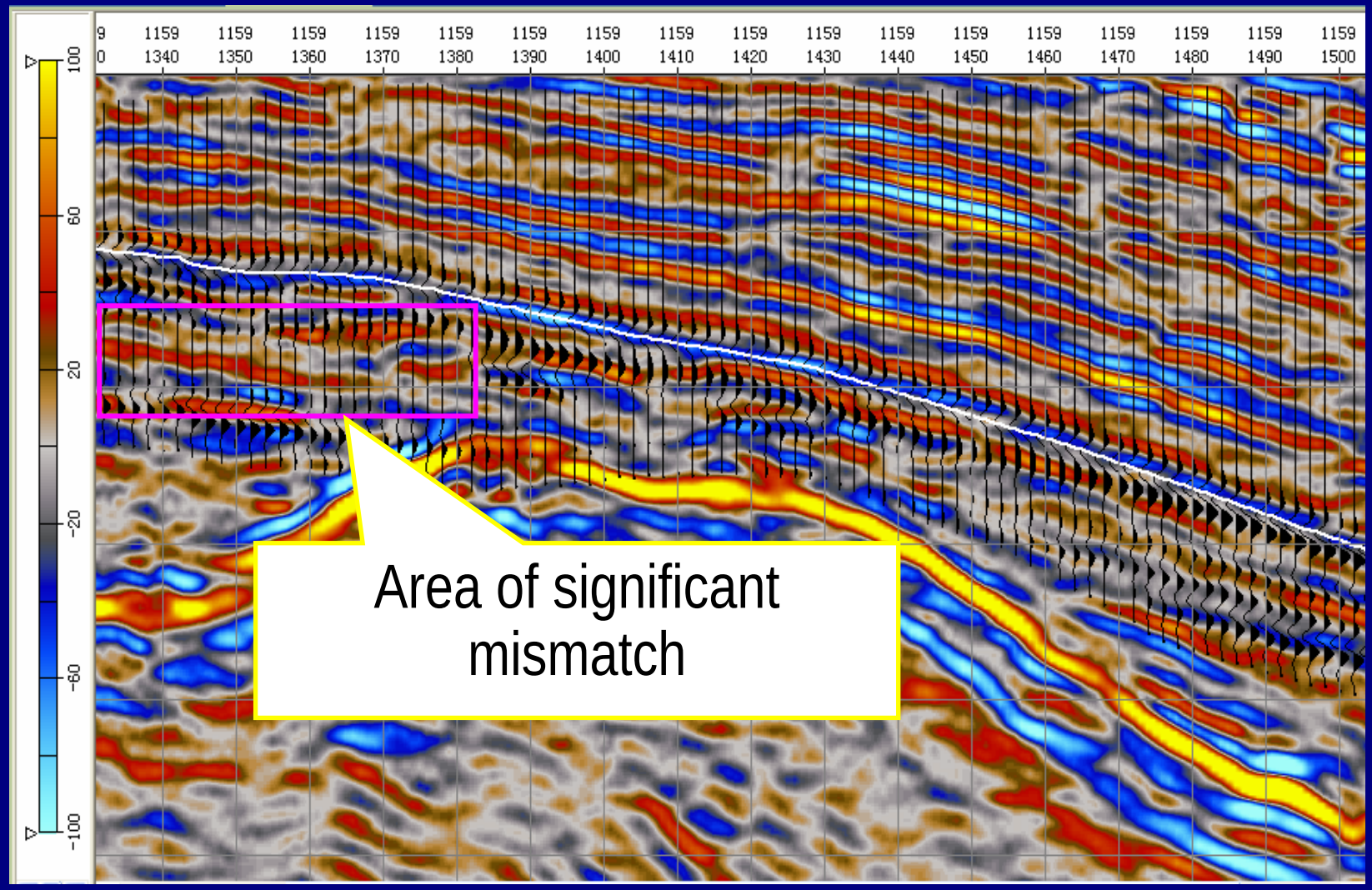
Log Calibration



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

Step 3: Seismic mismatches

Seismic Consistency

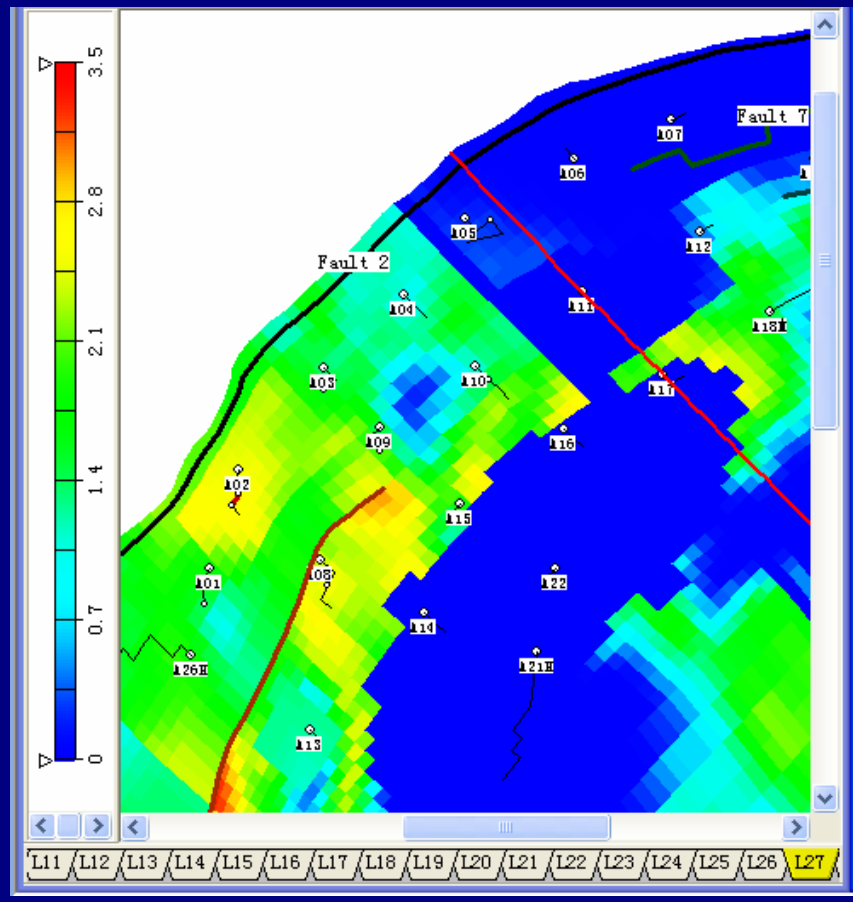


Screen the synthetic seismic with observed for seismic mismatch

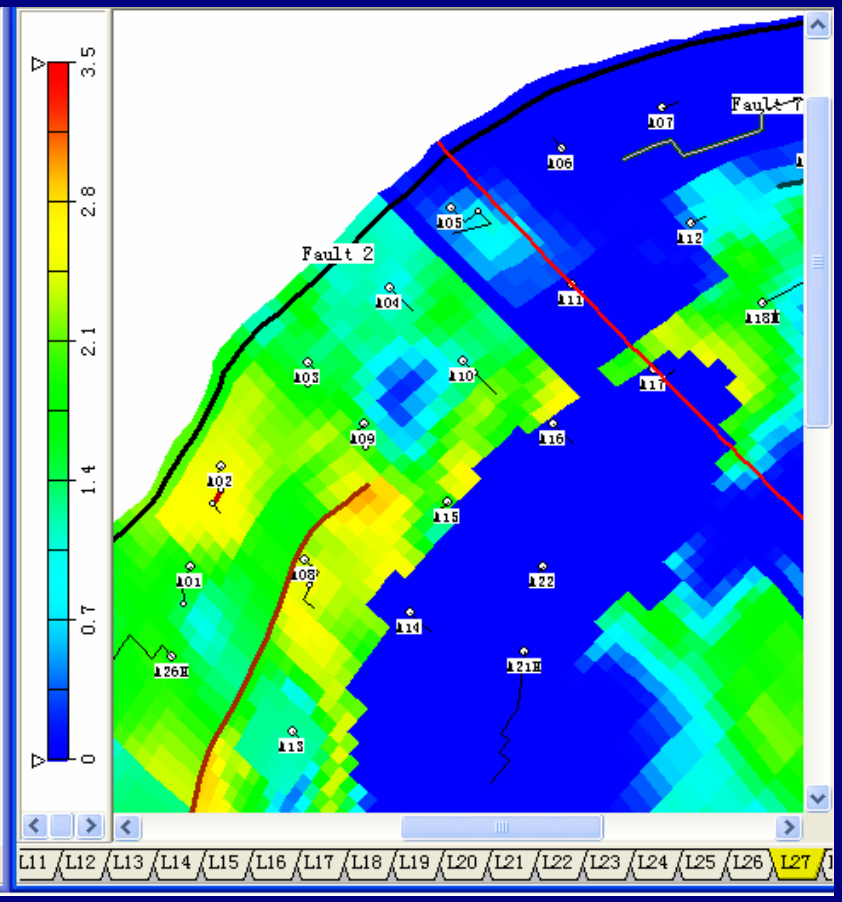
Step 4: Model updating

Thickness modification

Original model

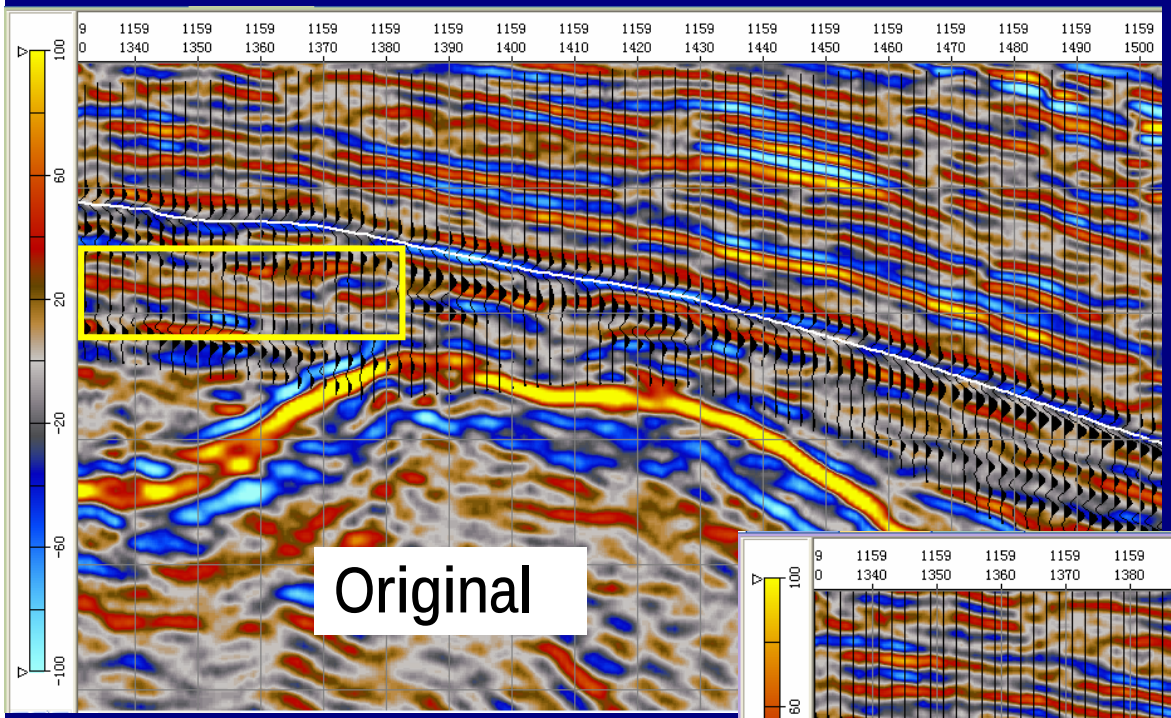


New Model

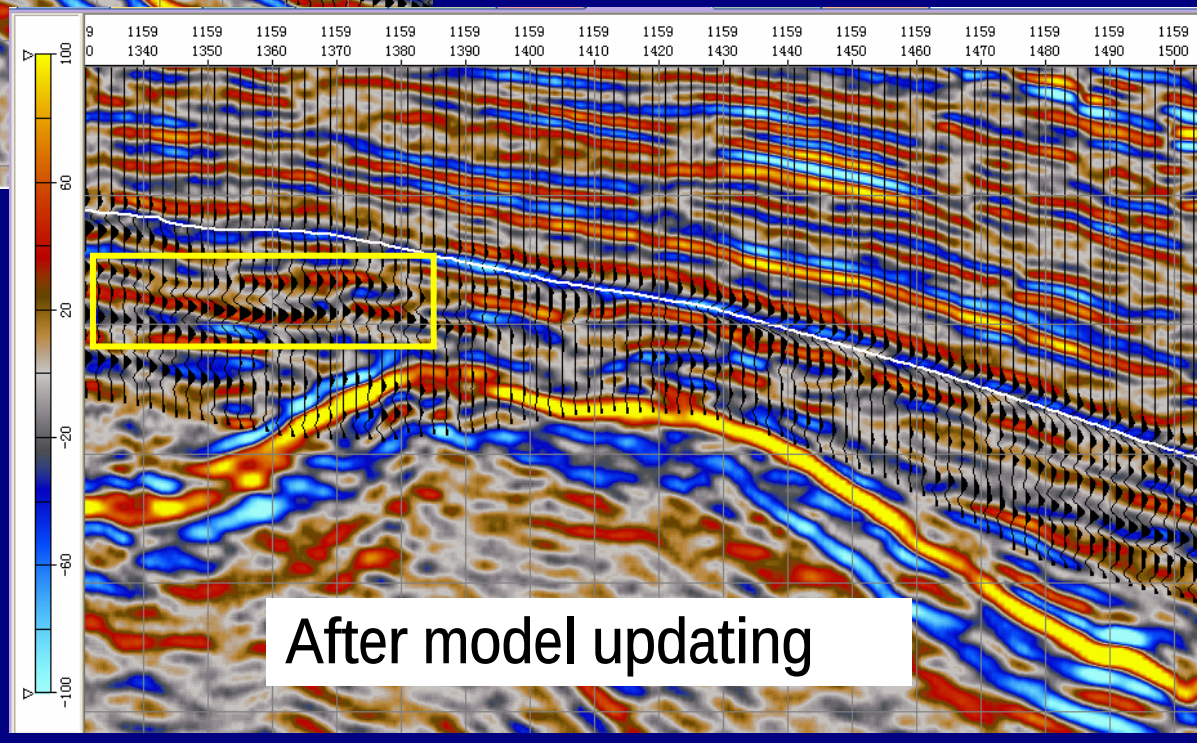


Modify the reservoir according to seismic mismatch

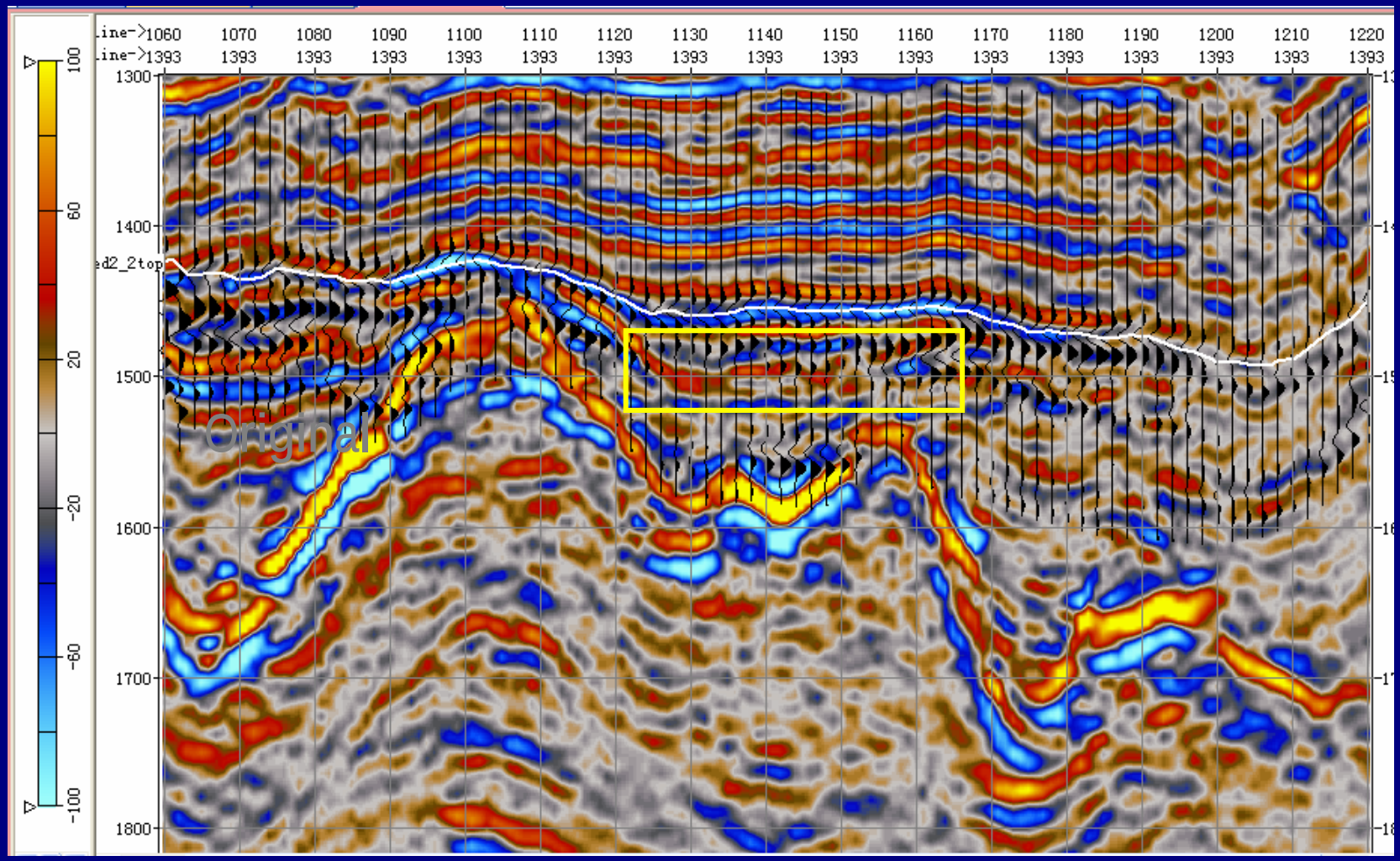
Seismic comparison



Seismic matching



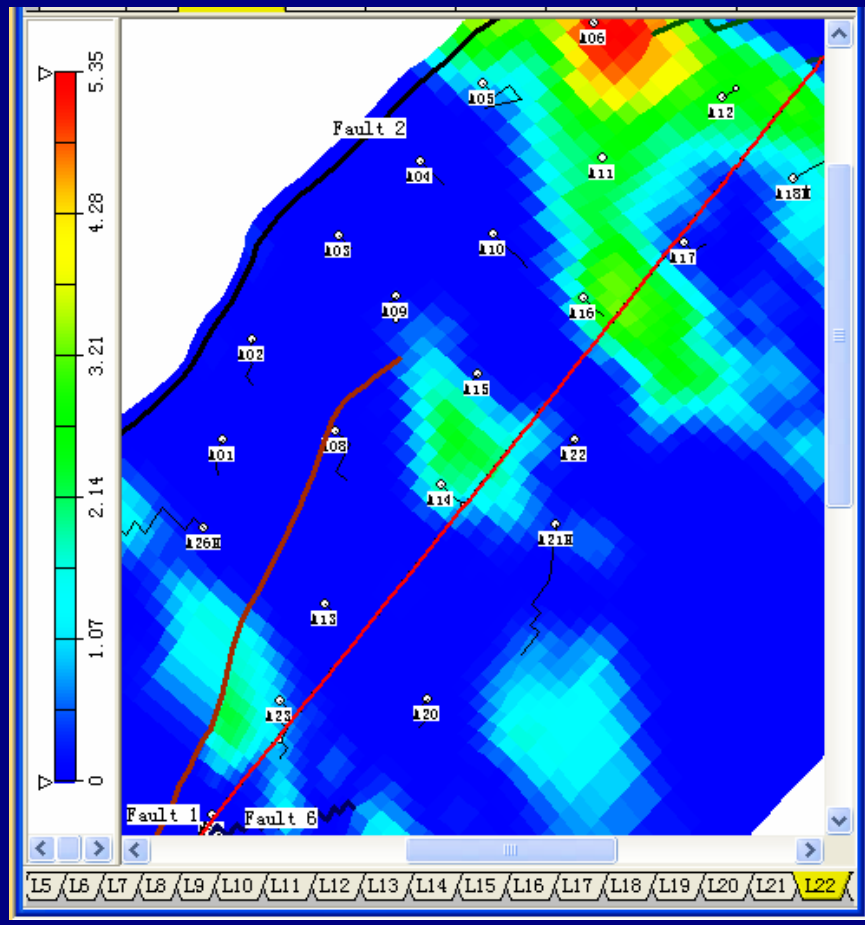
Step 3: Seismic Mismatches



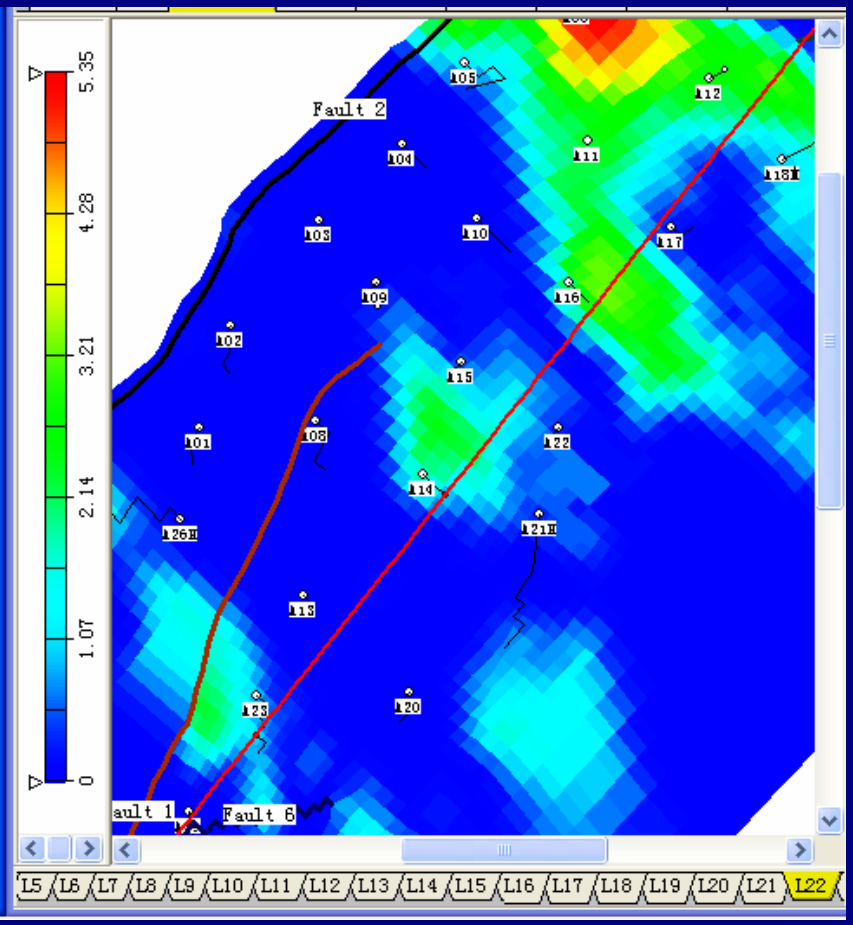
Step 4: Model Updating

Thickness of model

Original

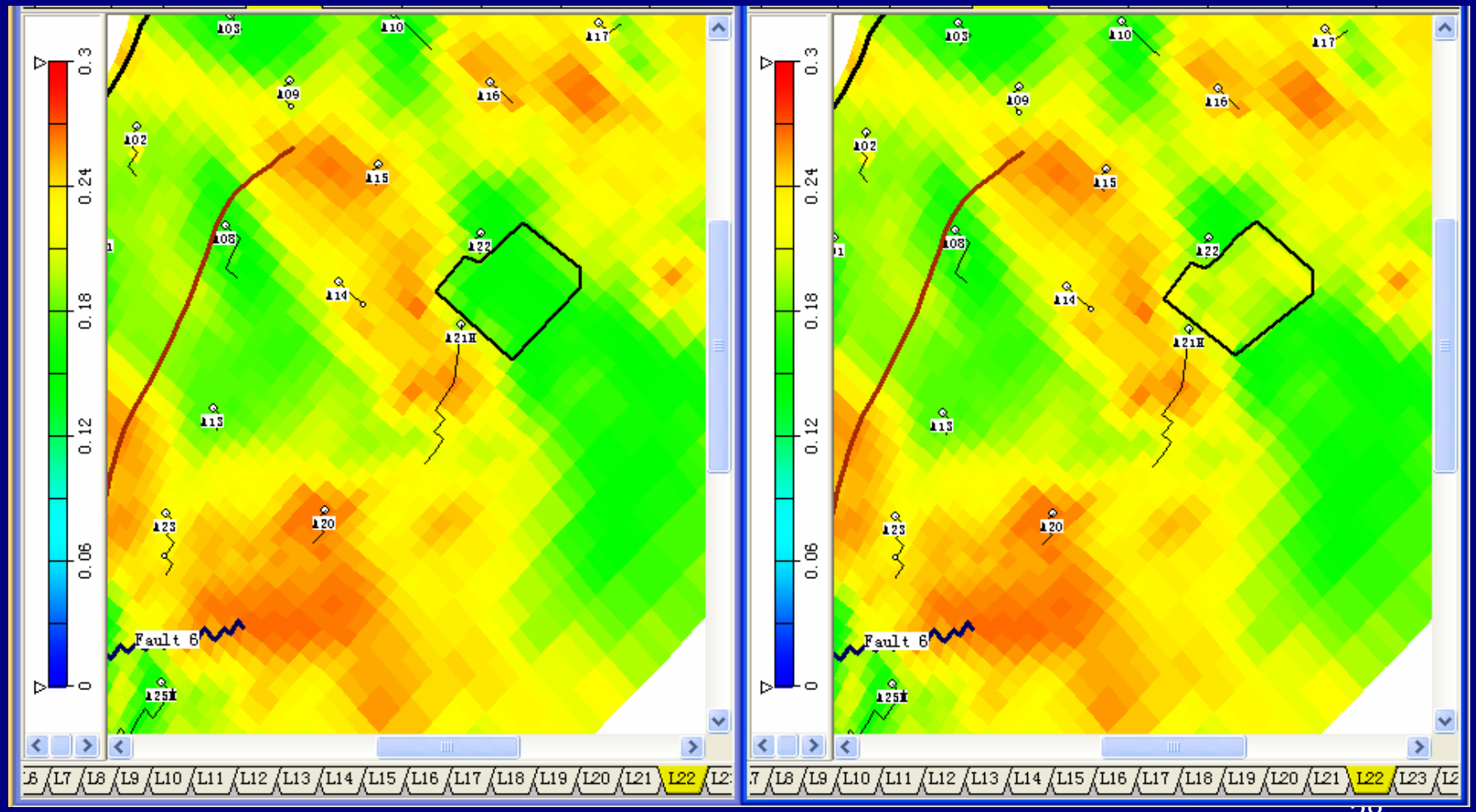


new

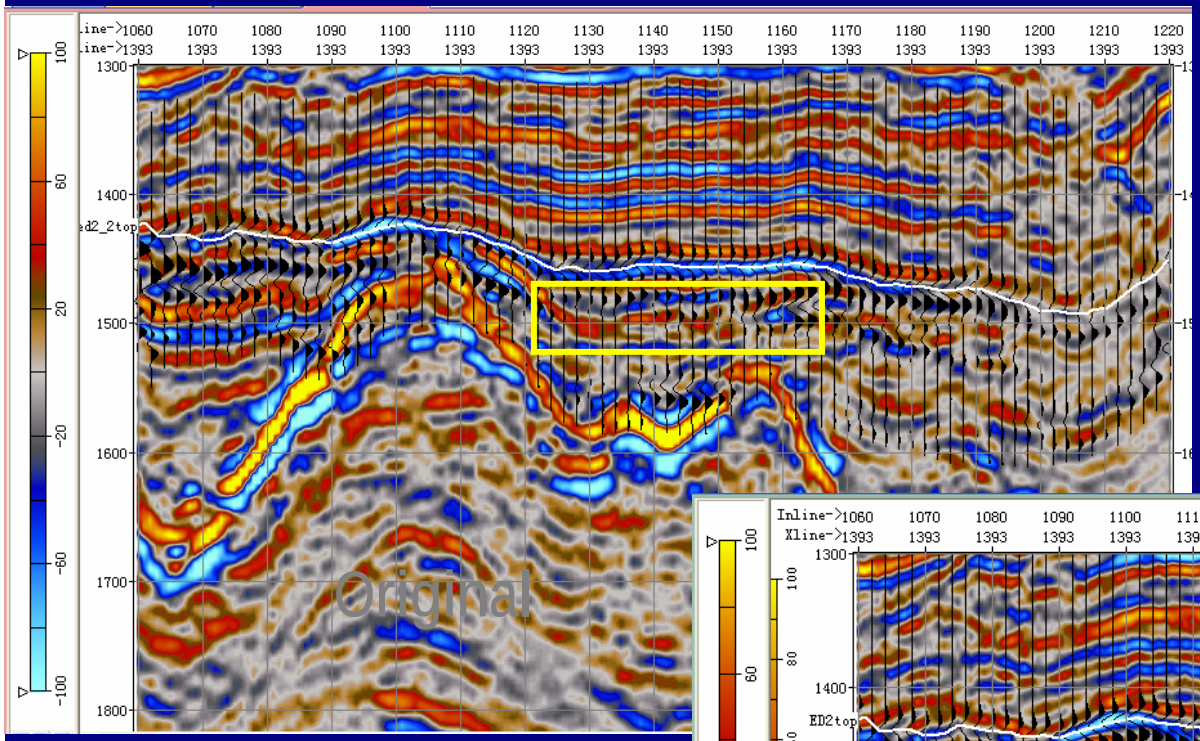


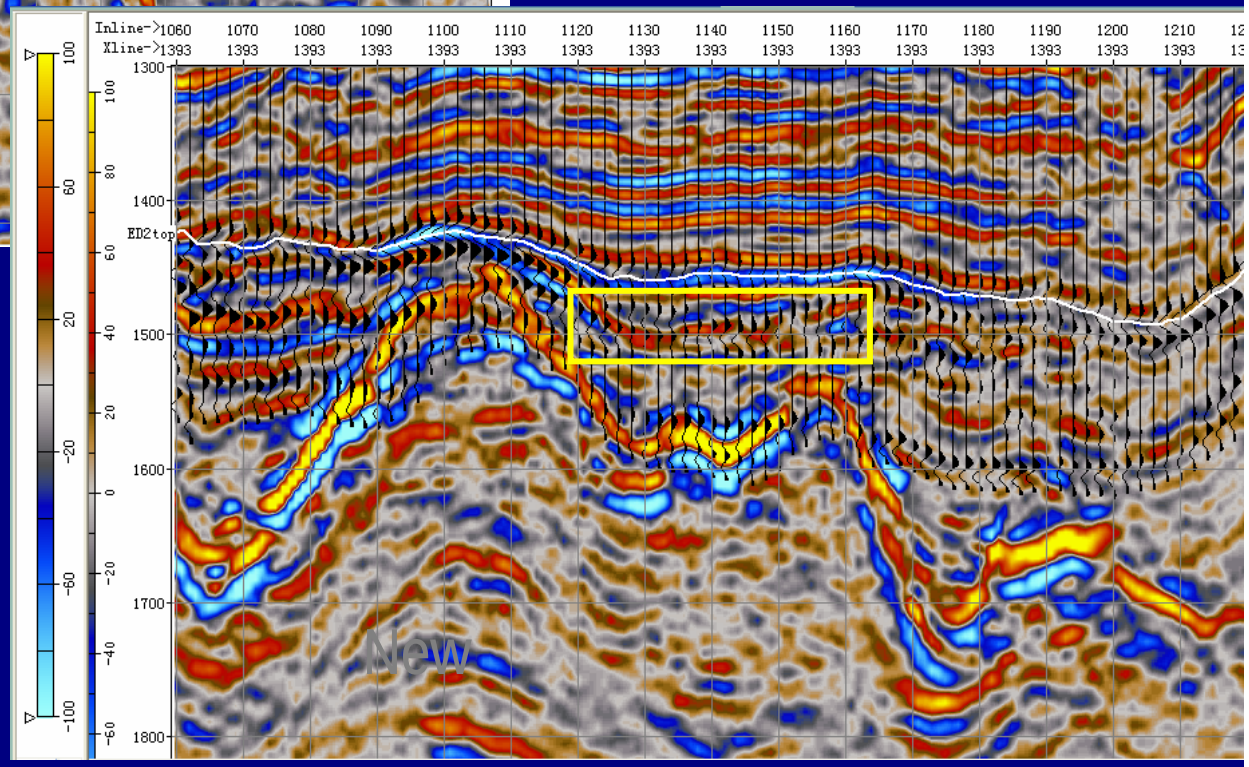
Updating constraining by prod. and seismic

Porosity



Seismic comparison

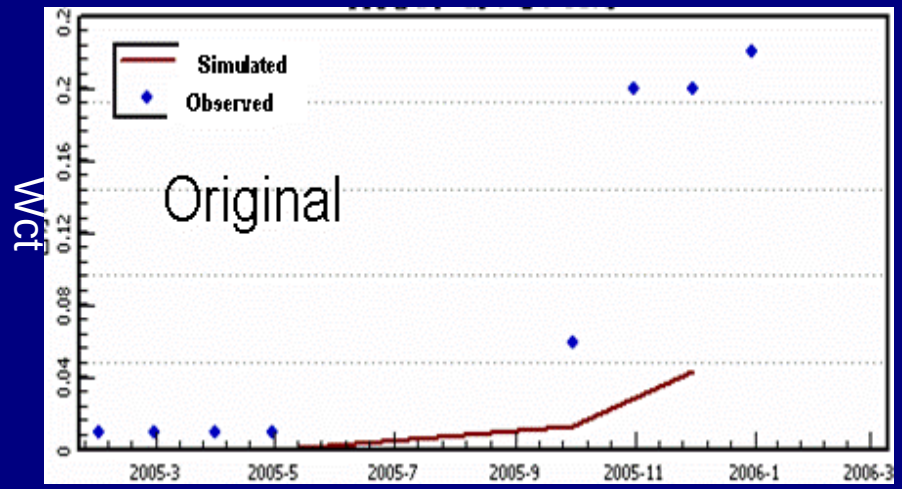


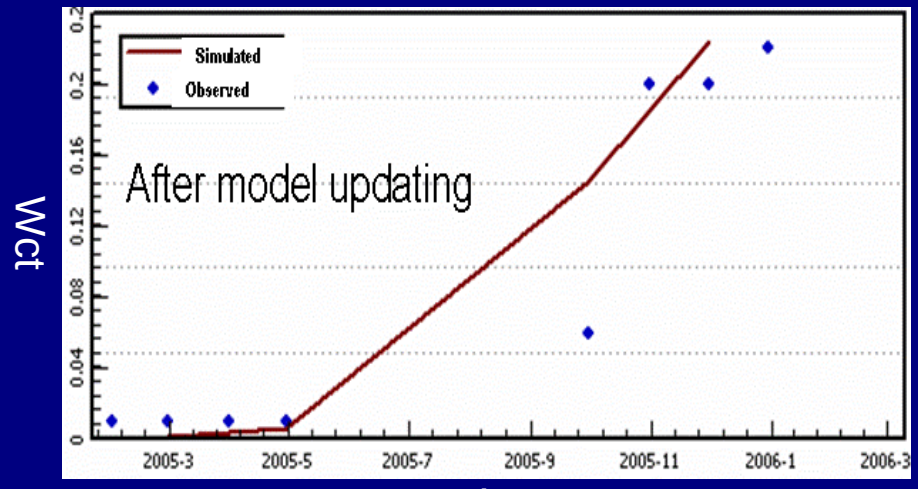


History matching

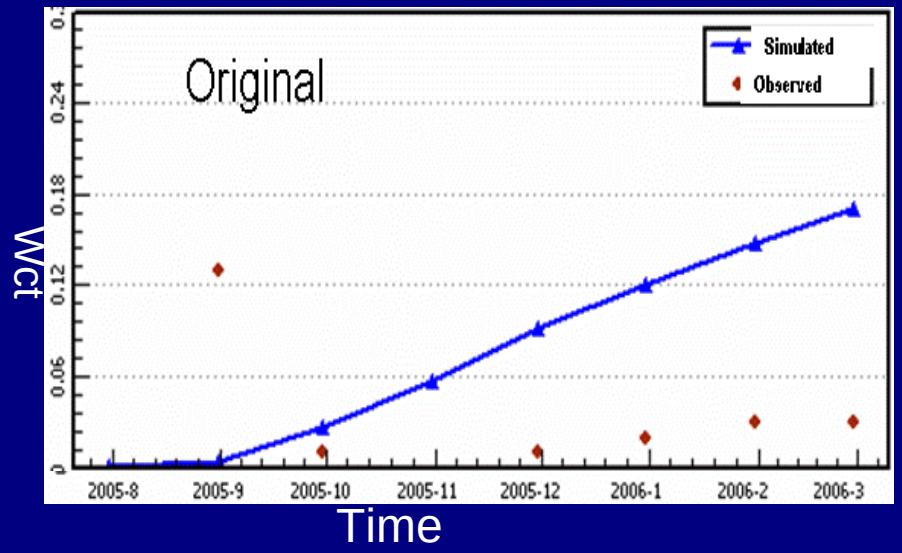
Water-Cut

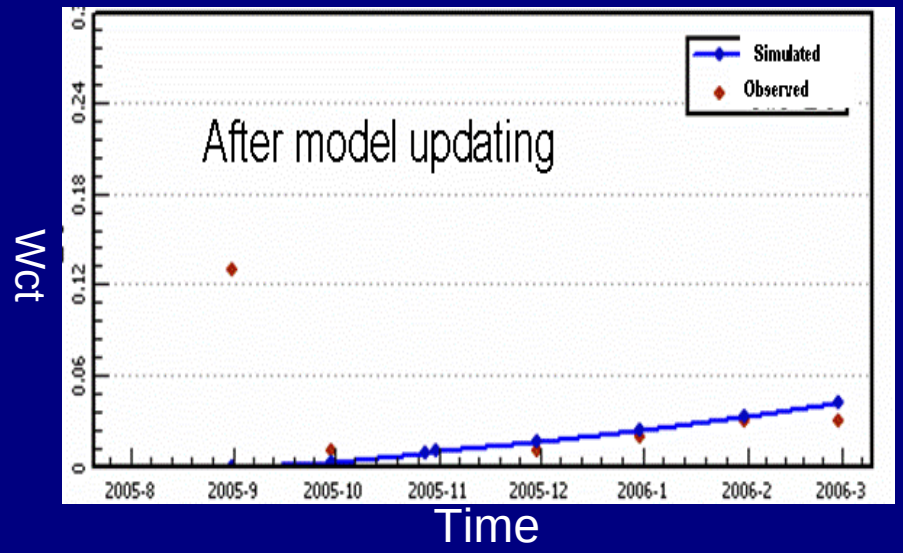
Well A09



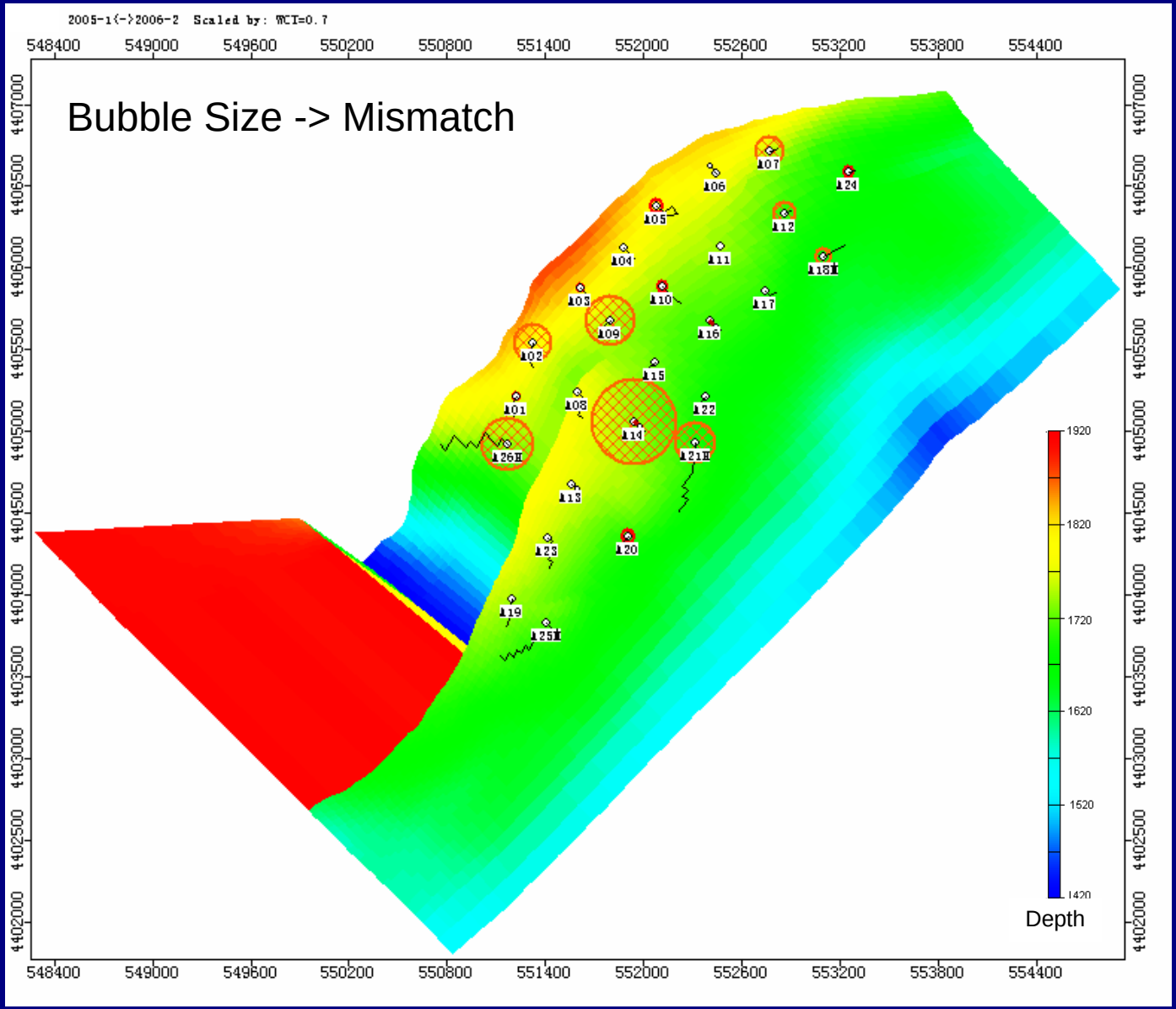


Well A26X

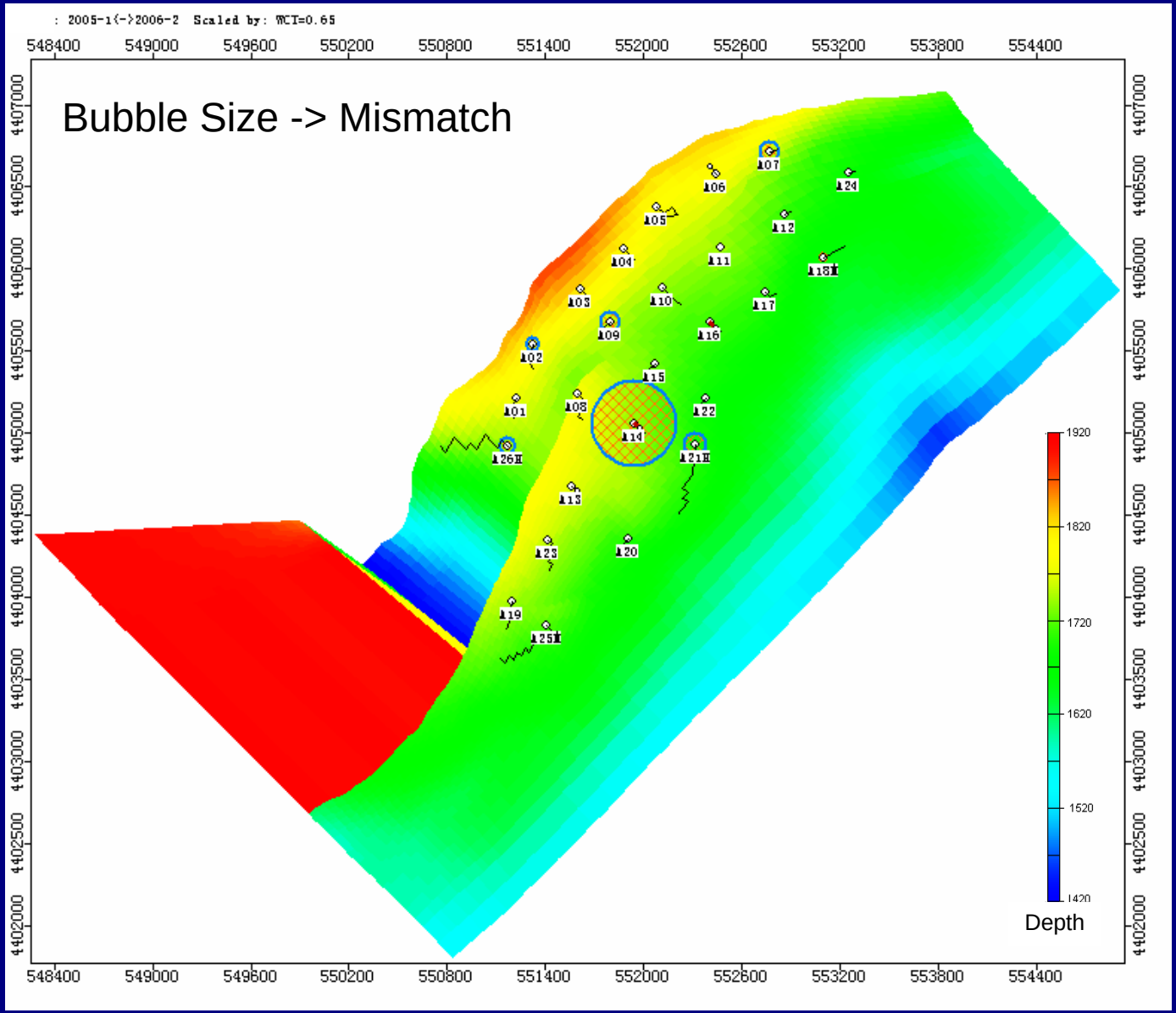




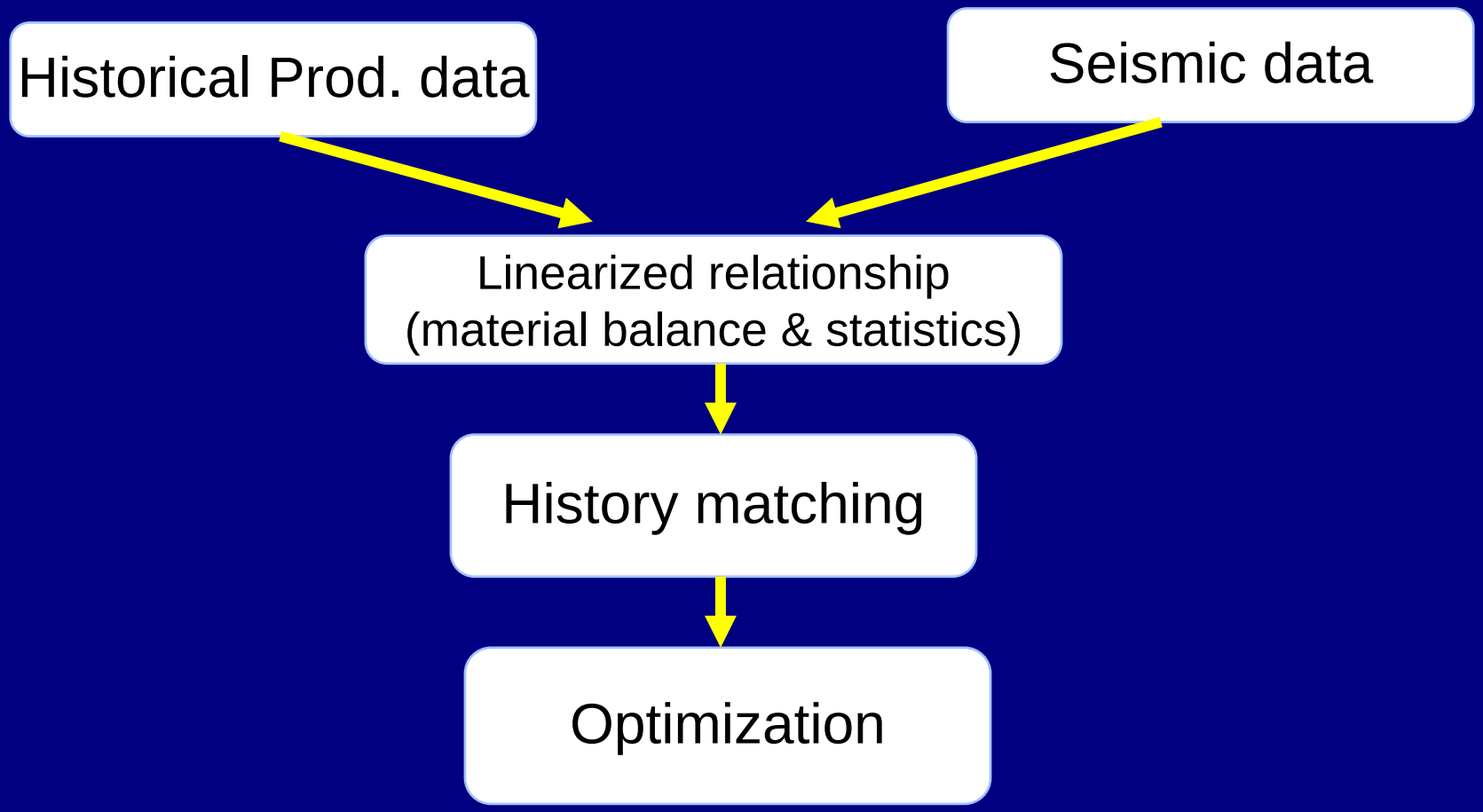
History matching before updating: water-cut



History matching after updating: water-cut



A procedure for waterflooding optimization



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*'

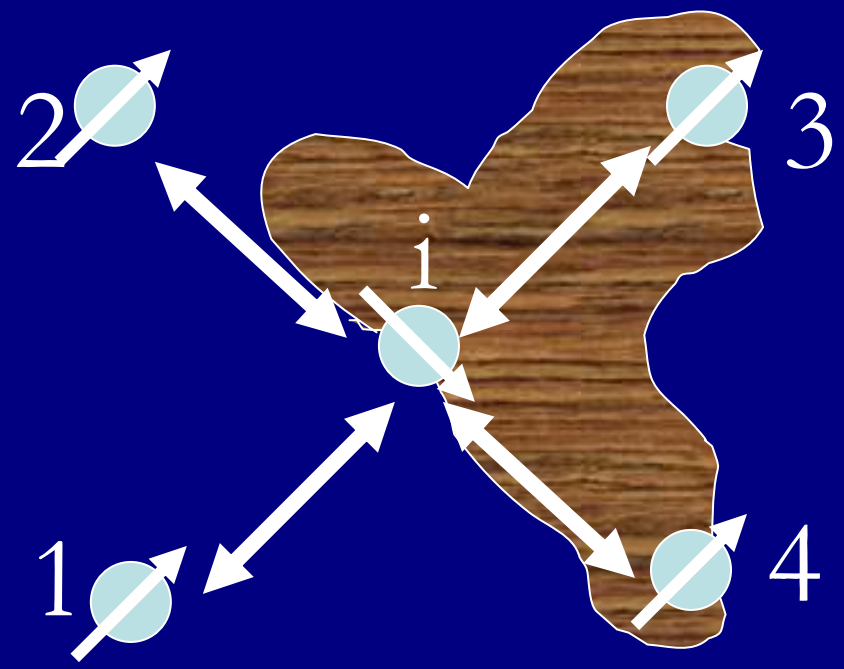
$\hat{q}_j$ modeled liquid production rate, RB/D

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

Single well water-cut fitting with power law

↓

Perturb injection rate for injectors

↓

Computing Q_o $Q_o = Q_l(t) * [1 - Wct(t)]$

↓

Objective function evaluation - max($\sum_{i=1}^{N} Q_{oi}$)

Not converged

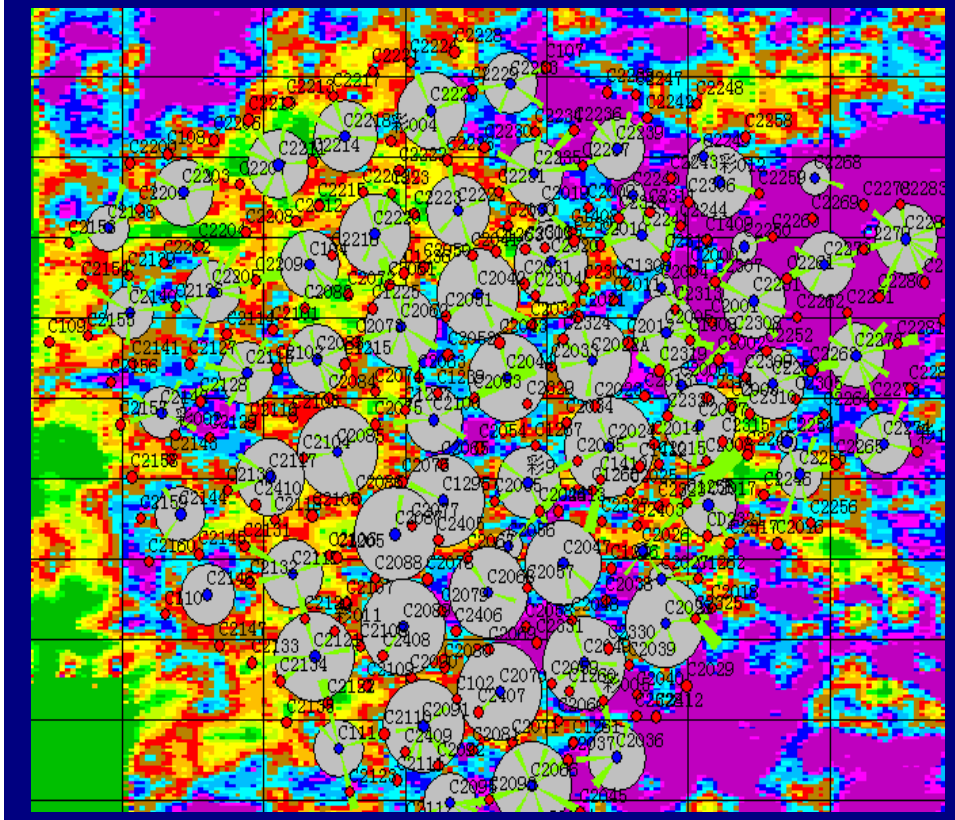
↓

Optimized

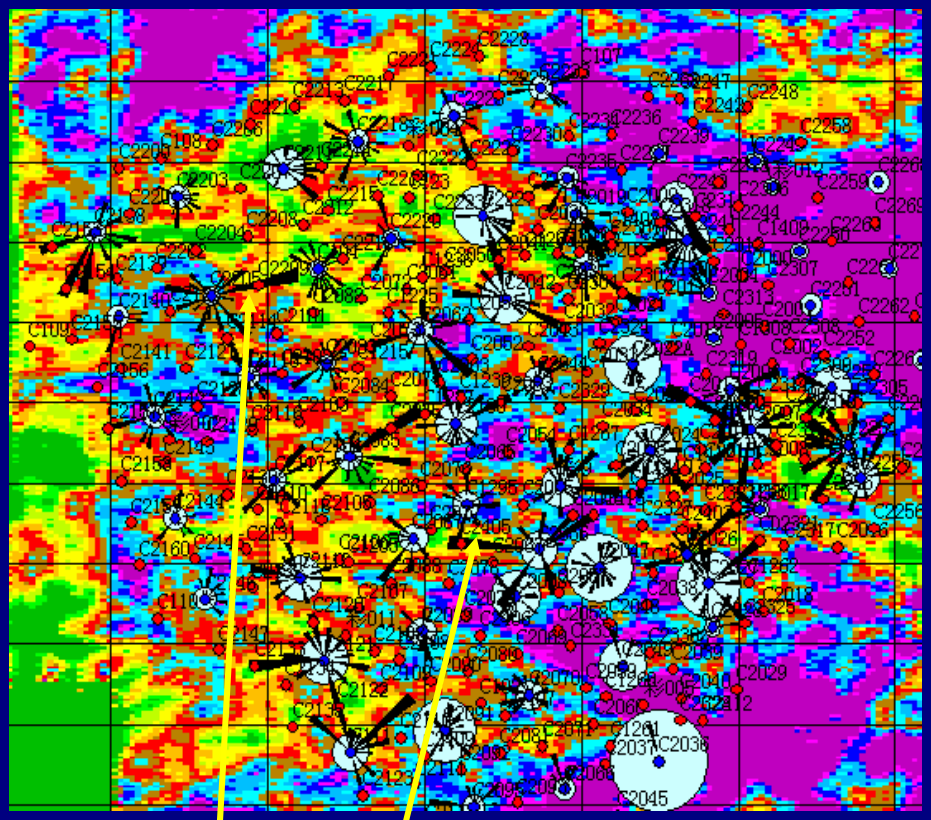
A case study

Difference from 1990, 2001 legacy surveys after reprocessing

Pattern before optimization

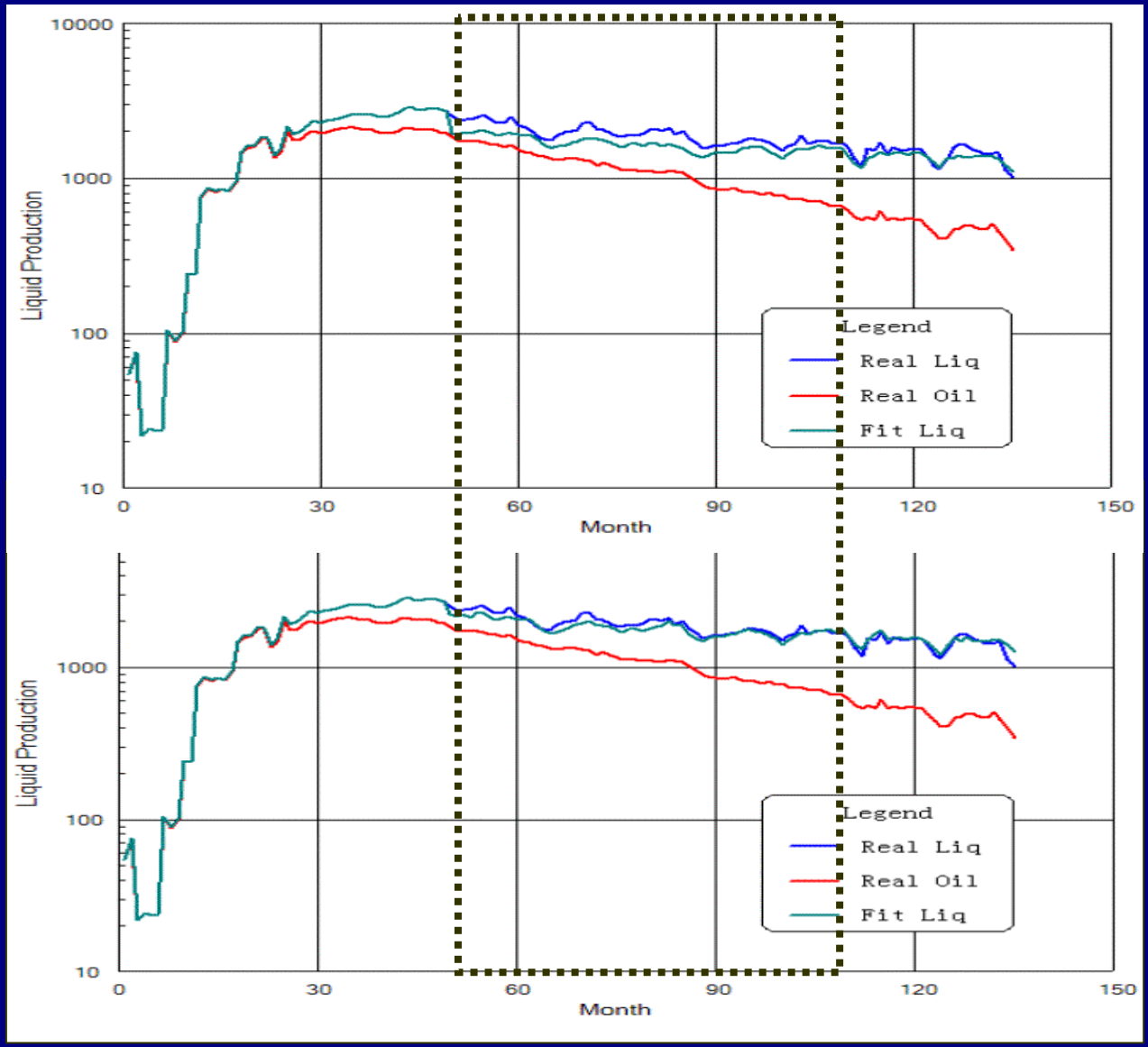


Pattern after optimization



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

• Production history matching



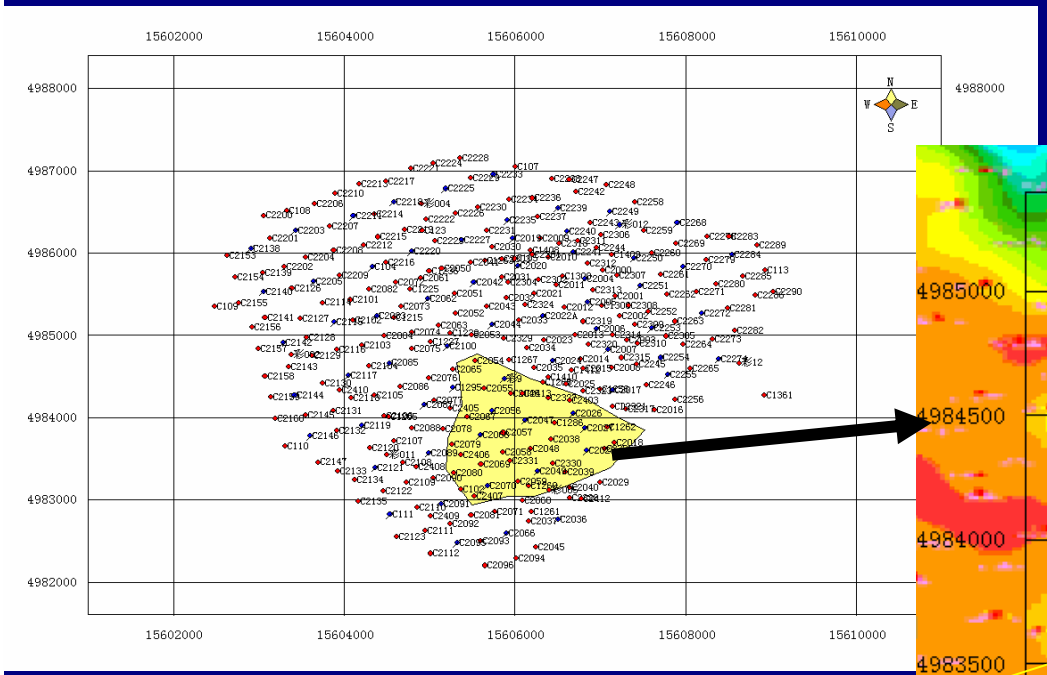
Without seismic
Err.=10.5%

With seismic
Err. =5.6%

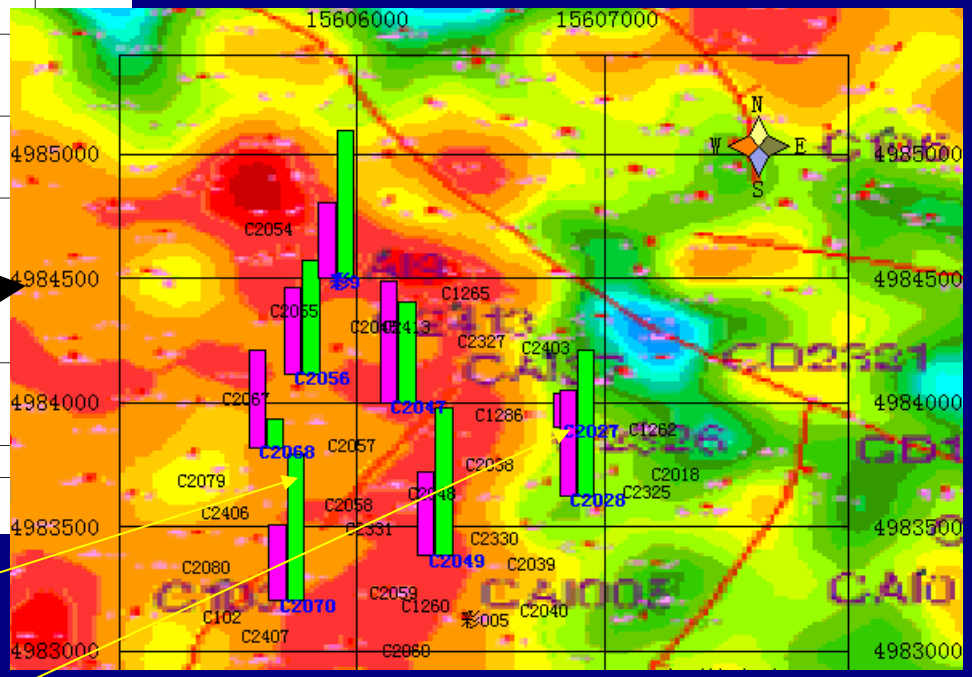
Seismic constraint improves the history matching (Liquid in cubic meters).

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

Pilot Area



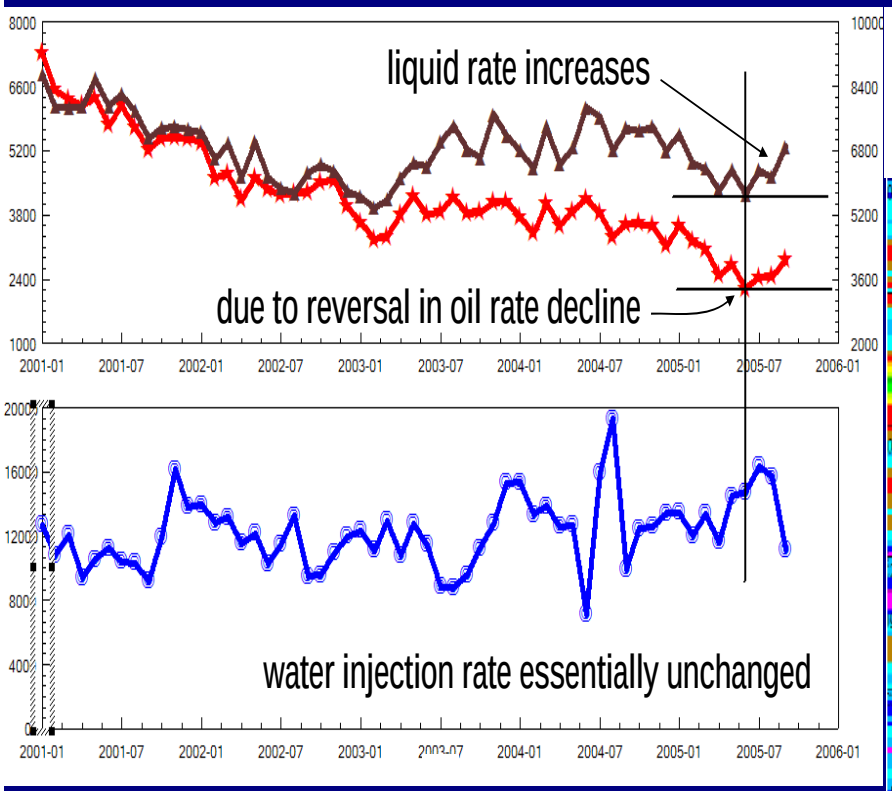
Injection Rate Change

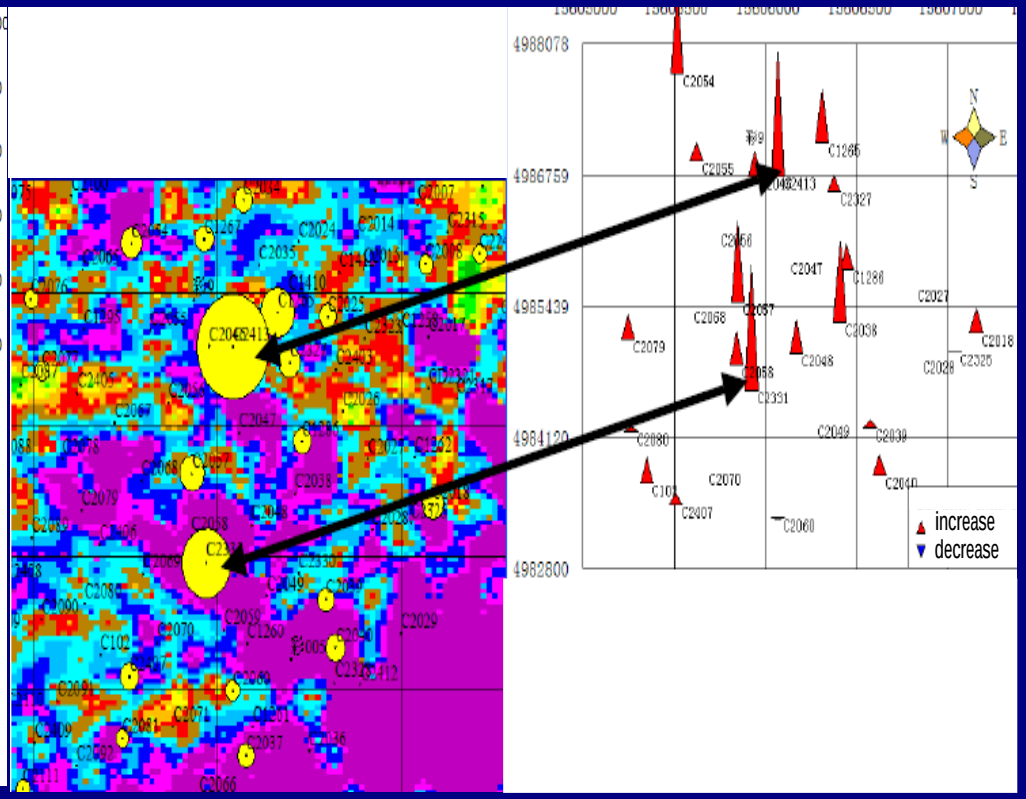


Optimized

History

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





Predicted Result

Summary

- Through close-the-loop in data domain, seismic data can be used to identify potentials in producing field.
- By close-the-loop in model domain, seismic data can help to update the reservoir model.
- It is feasible to use seismic data for production optimization

Road Ahead

- More robust tool for close-the-loop, and tools to 'interact' all data for seismic and production data interpretation
- Possibility for looping back to geological model
- Automatic and interactive tools

Thank you!

Questions?