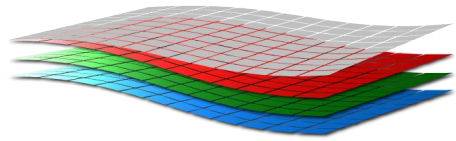


**SPE Luncheon Talk, Perth Chapter
July 7th, 2010**

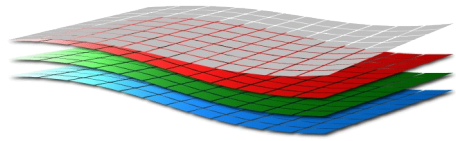
**Beyond Experimental Design:
An Introduction to Stochastic Reservoir
Simulation**

**Dr Andrew Wadsley
Stochastic Simulation Limited**



What I hope to do today:-

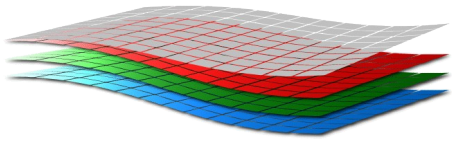
- ❑ Introduce a new way of evaluating reservoir uncertainty through **Stochastic Reservoir Simulation**
- ❑ Illustrate the concepts used
- ❑ Highlight the benefits achieved, and
- ❑ Demonstrate the value of the results.



What is Stochastic Reservoir Simulation ?

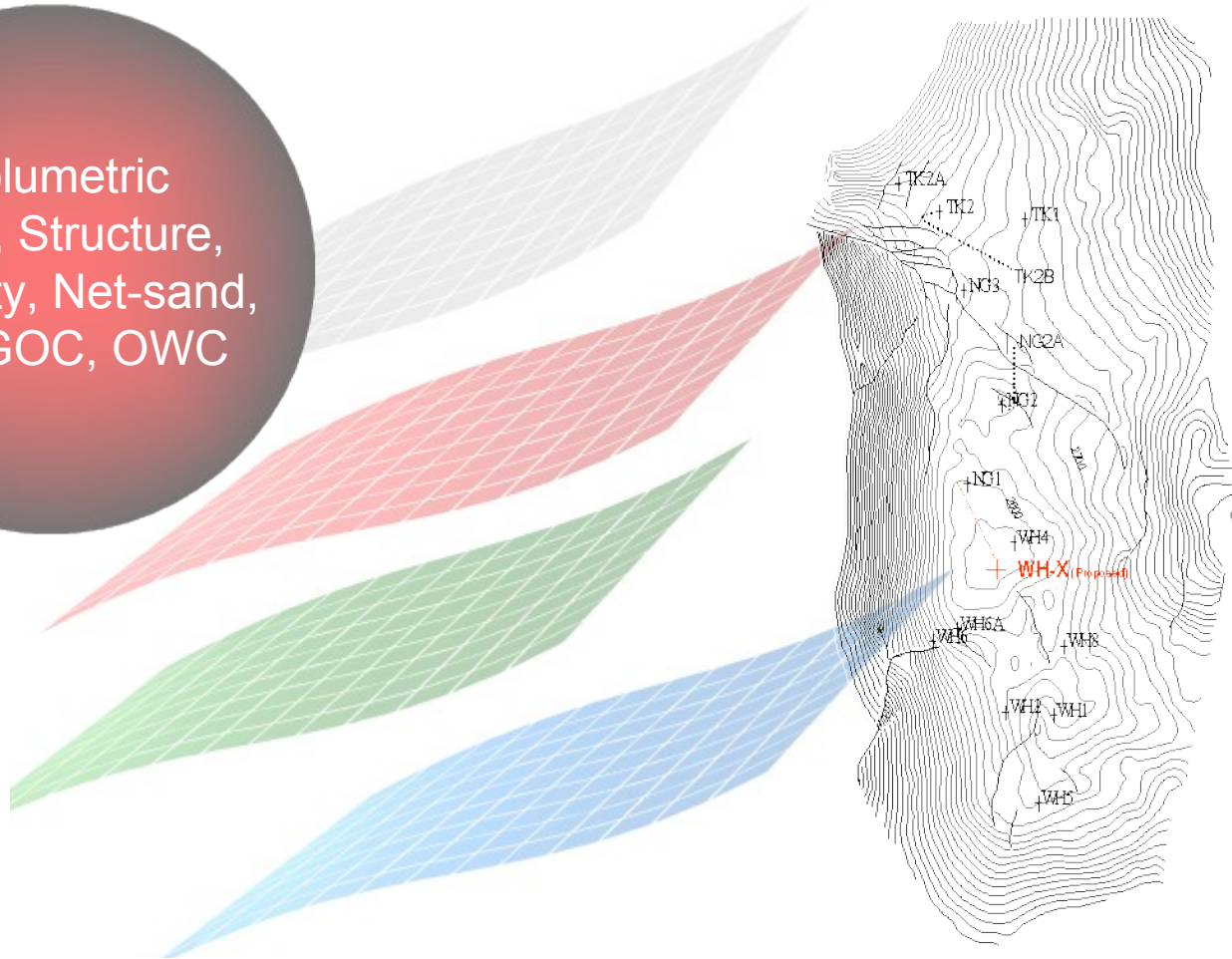
My definition is:-

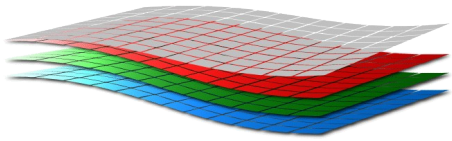
“The use of Monte Carlo simulation using all relevant reservoir parameters (porosity, permeability, fluid contacts, structure, relative permeability, PVT, aquifer size, barriers, etc) to achieve a consistent description of reservoir performance in the presence of uncertainty.”



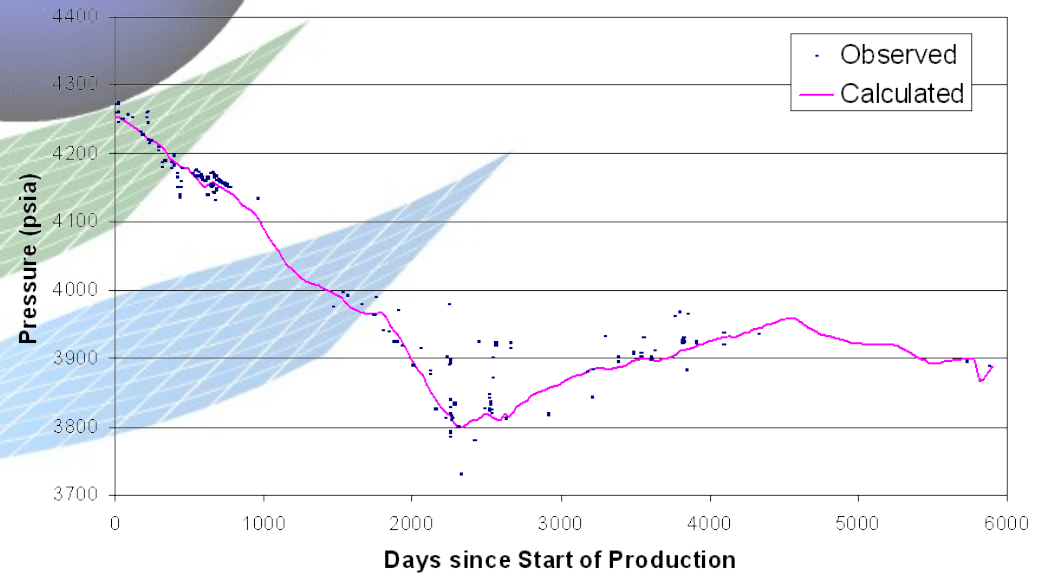
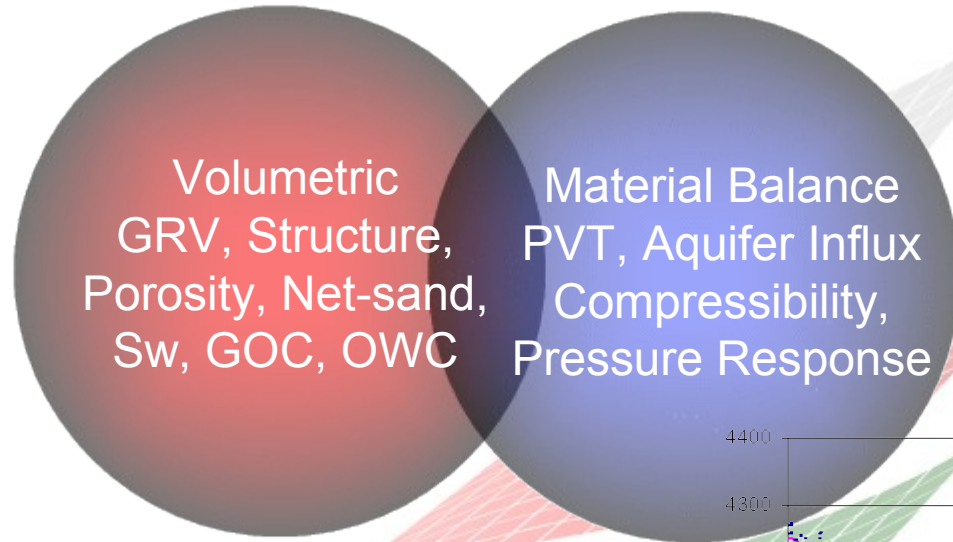
Volumetric Constraints

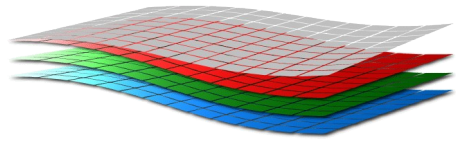
Volumetric
GRV, Structure,
Porosity, Net-sand,
Sw, GOC, OWC



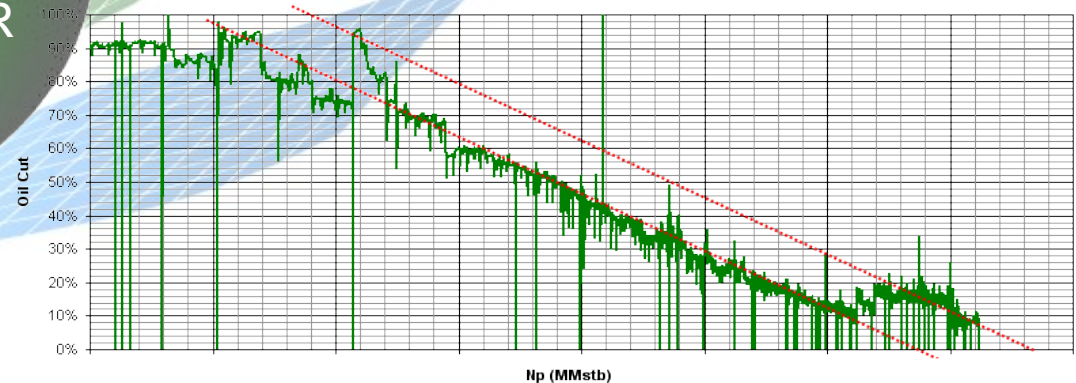
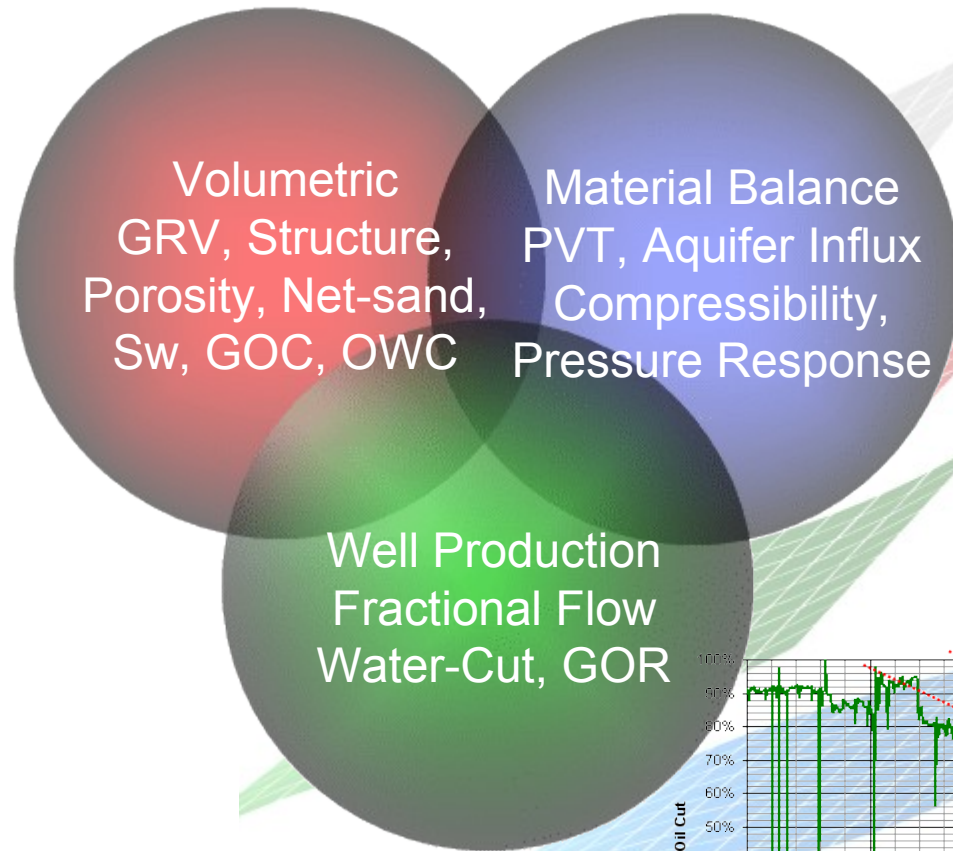


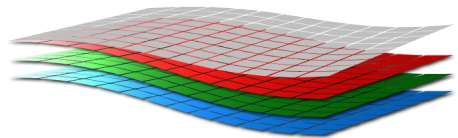
Material Balance Constraints



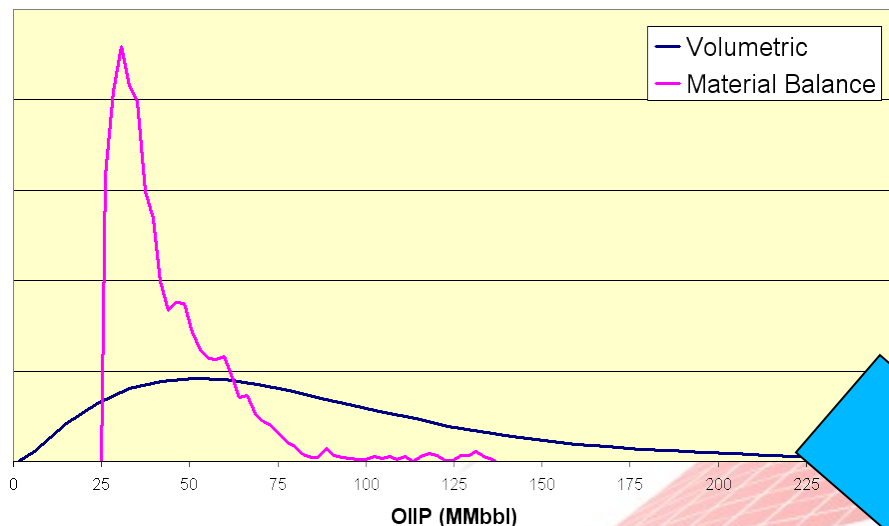


Production / Fractional Flow





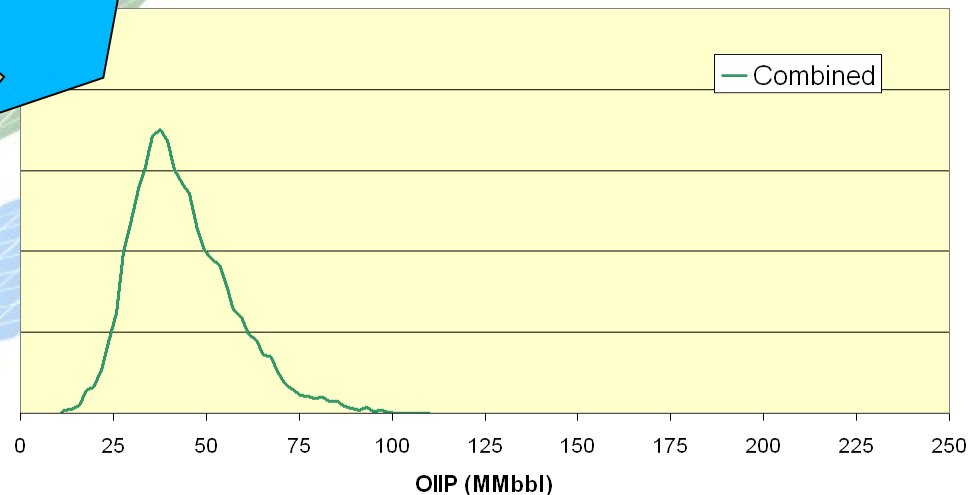
Inconsistent vs Consistent OIIP Estimates

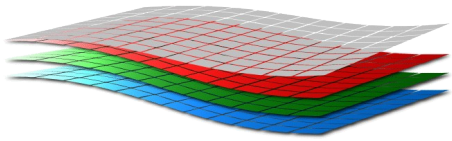


Consistency is achieved using a Markov chain Monte Carlo (MCMC) algorithm

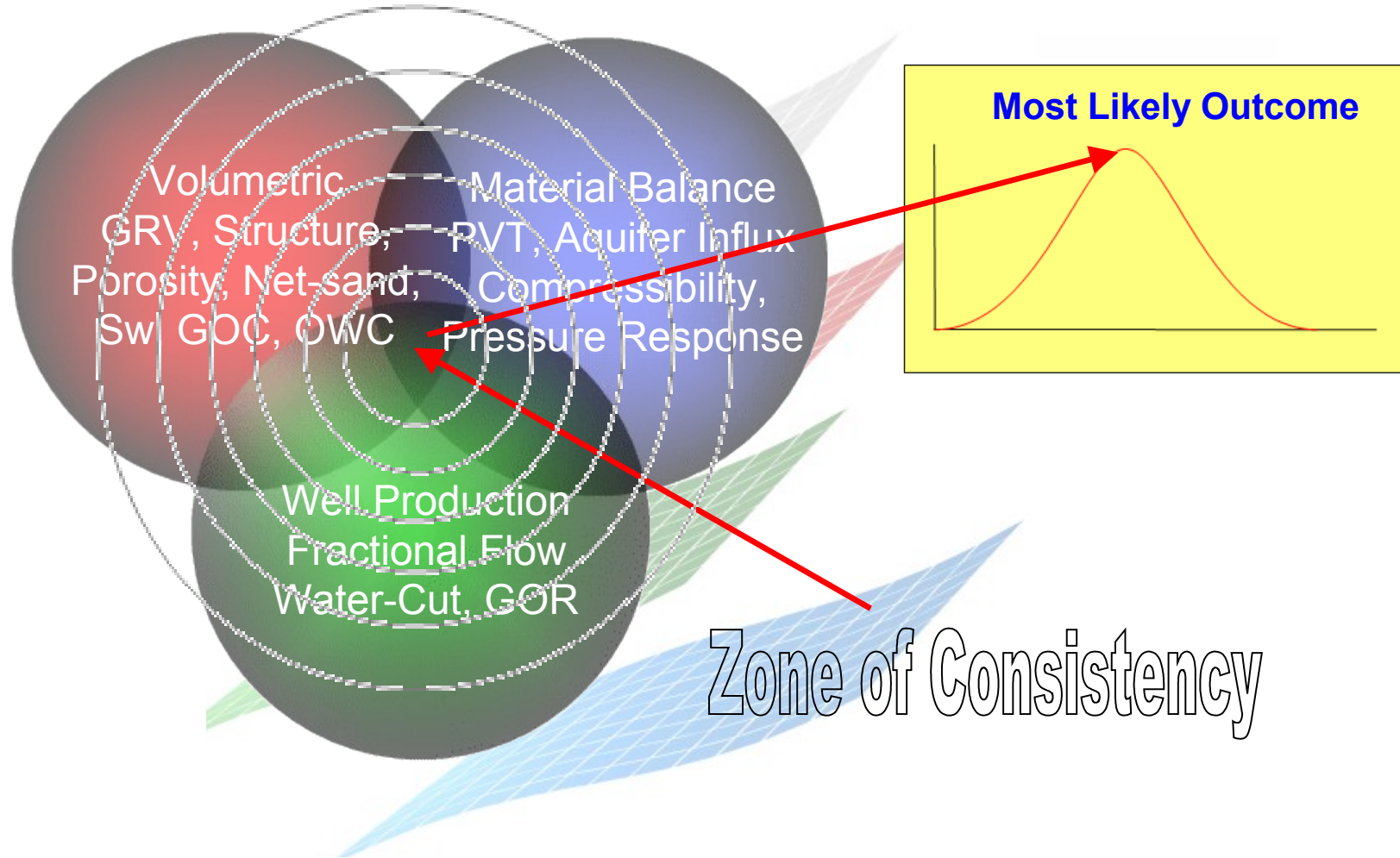
What MCMC does:

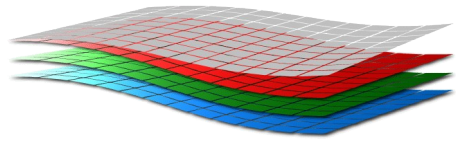
Takes a random walk through the space of reservoir / aquifer parameters and selects those which are consistent (in a probabilistic sense) with both the volumetric and pressure data





Zone of Consistency

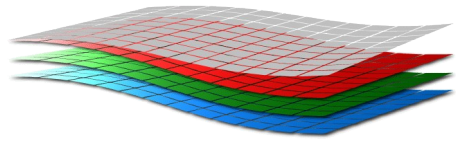




But what is The Elephant In The Room ?

- **WHEN** it comes to history-matching through reservoir simulation ...
- **THE** match may not be representative ... how do we know ?
- **IS** the match a P50 outcome, or something else ?
- **MULTI-million \$** decisions are taken in the face of large reservoir uncertainties which may not have been taken into account in the model

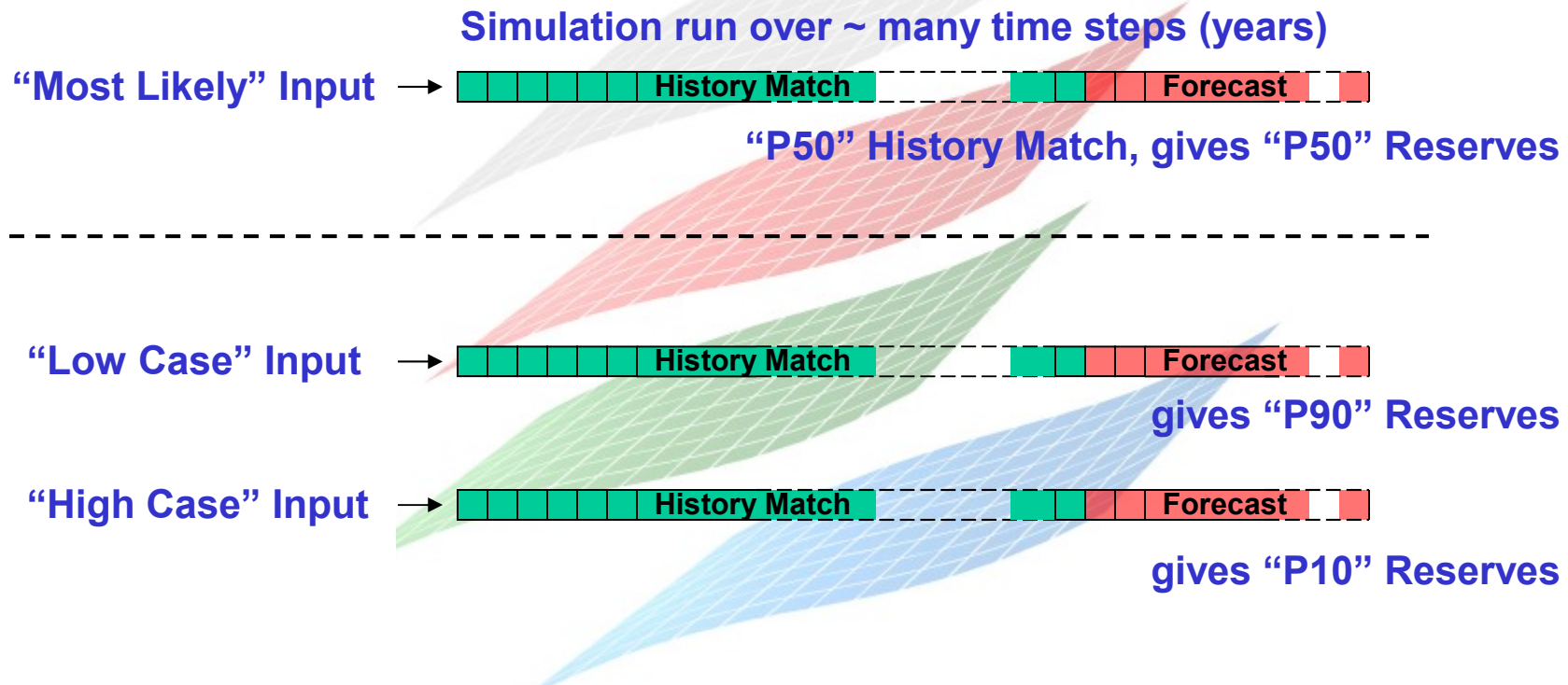




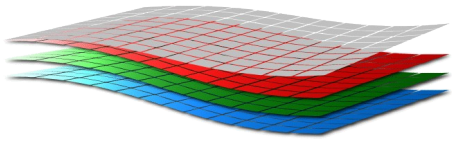
Conventional History-Matching & Forecasting

Conventional Approach

The “P50” / Expectation Case

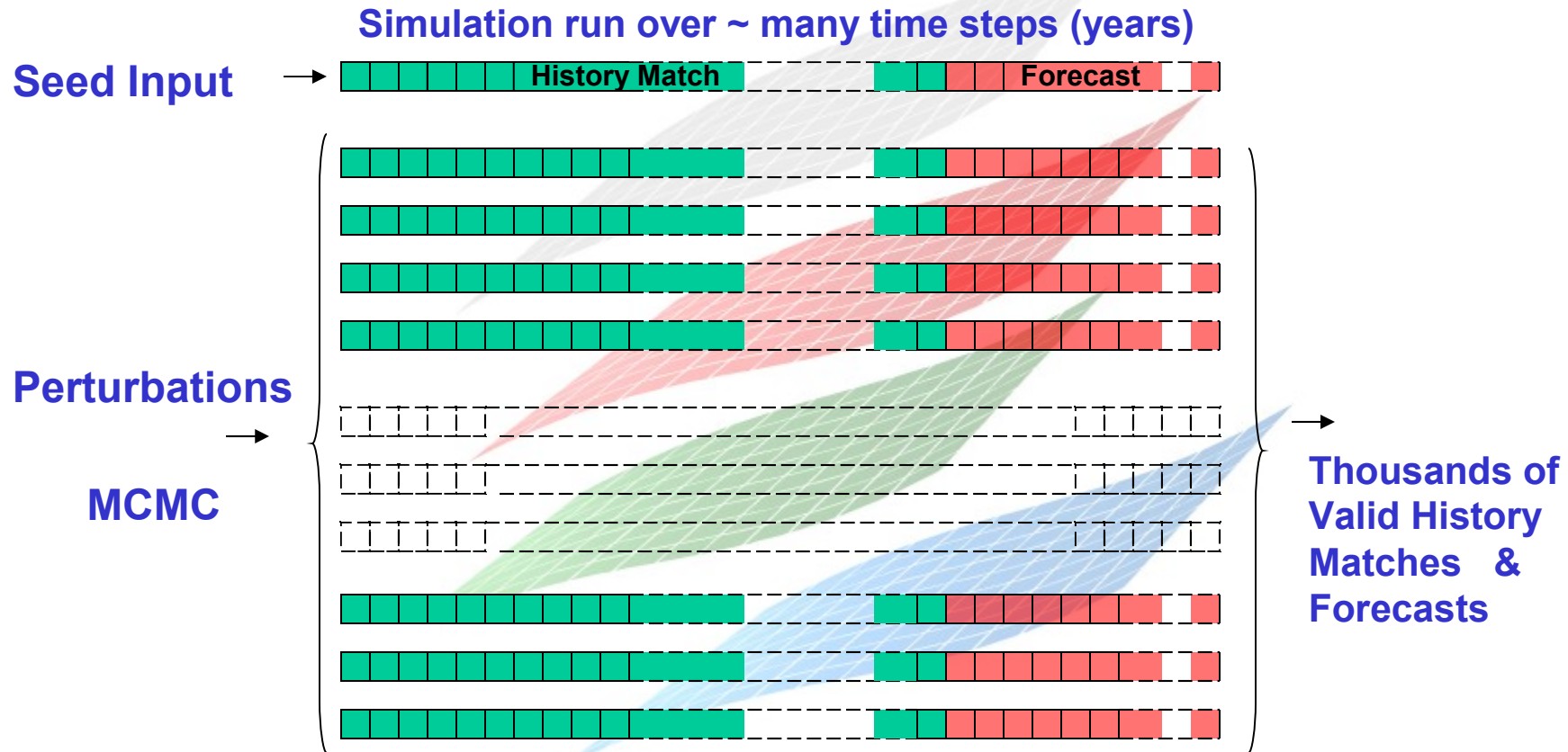


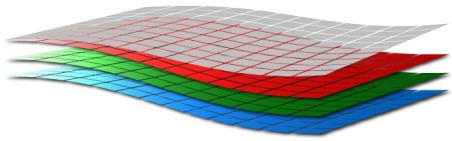
But how often are consistent “P90” & “P10” History Matches actually generated?



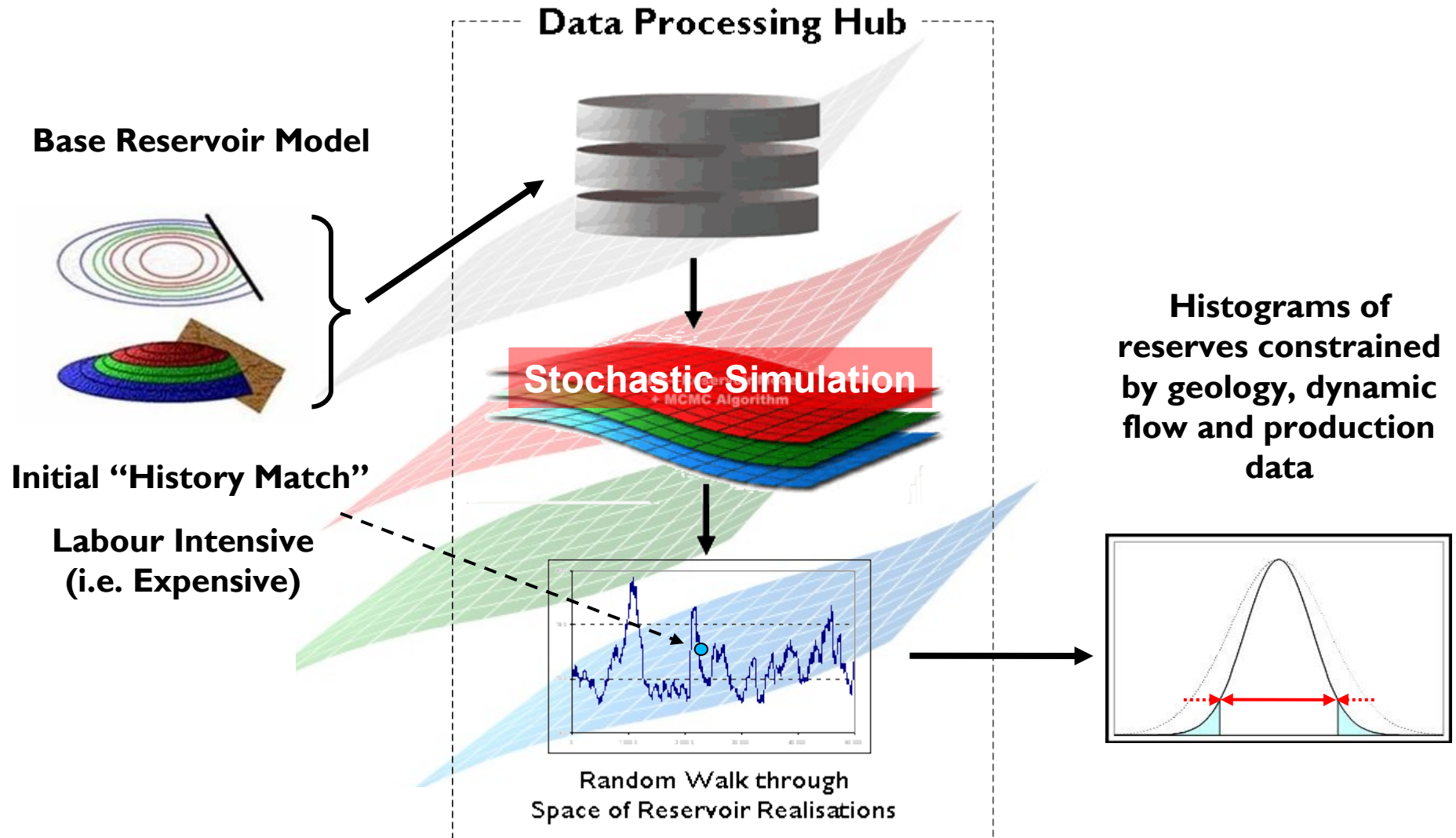
Stochastic History-Matching & Forecasting

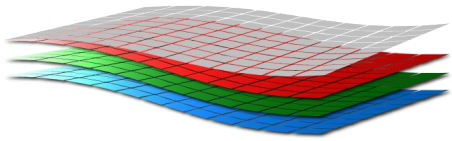
Stochastic Reservoir Simulation Approach



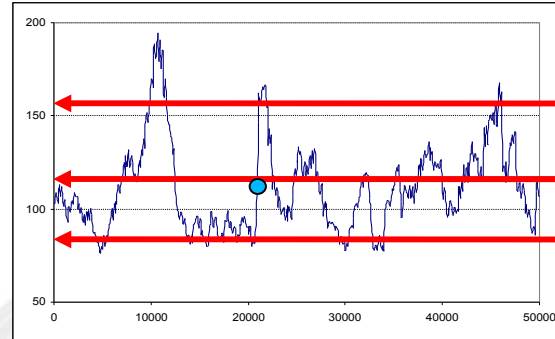


Stochastic Simulation Process





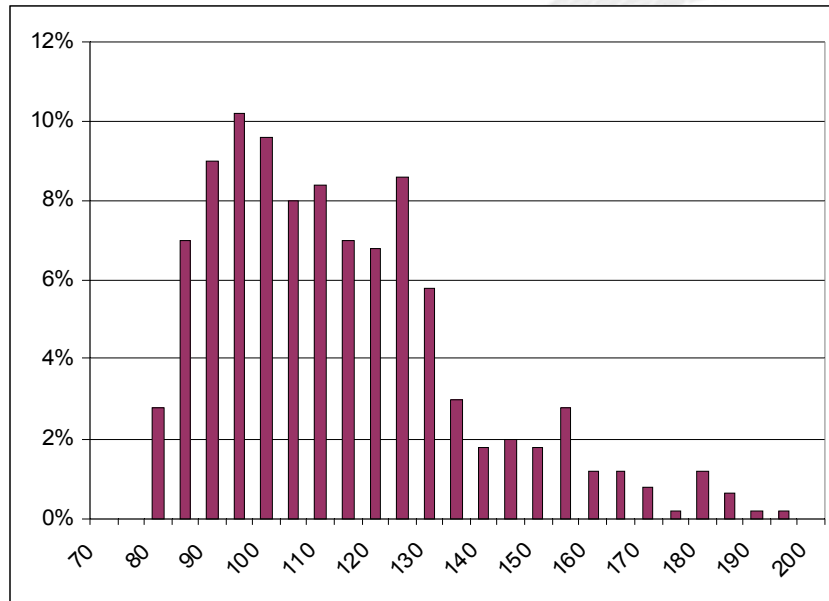
Stochastic Simulation Process - Results



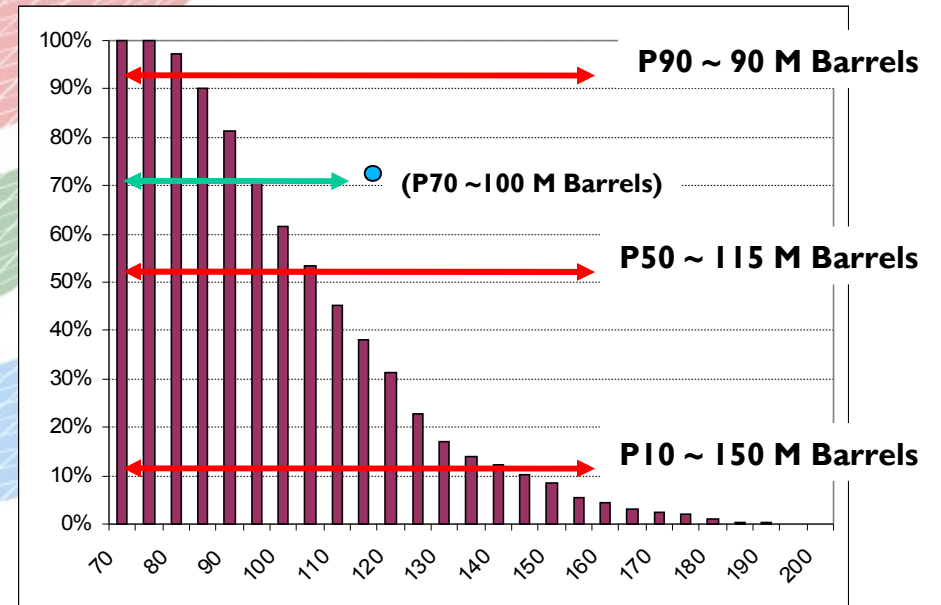
P10 ~ 150 M Barrels

P50 ~ 115 M Barrels

P90 ~ 90 M Barrels



Probability of a Sub-surface Volume being Present



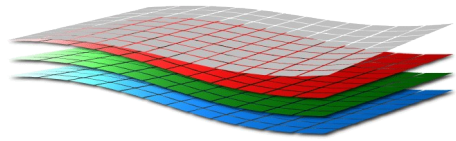
P90 ~ 90 M Barrels

(P70 ~ 100 M Barrels)

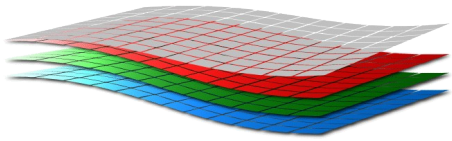
P50 ~ 115 M Barrels

P10 ~ 150 M Barrels

Probability of Exceeding a Particular Sub-surface Volume



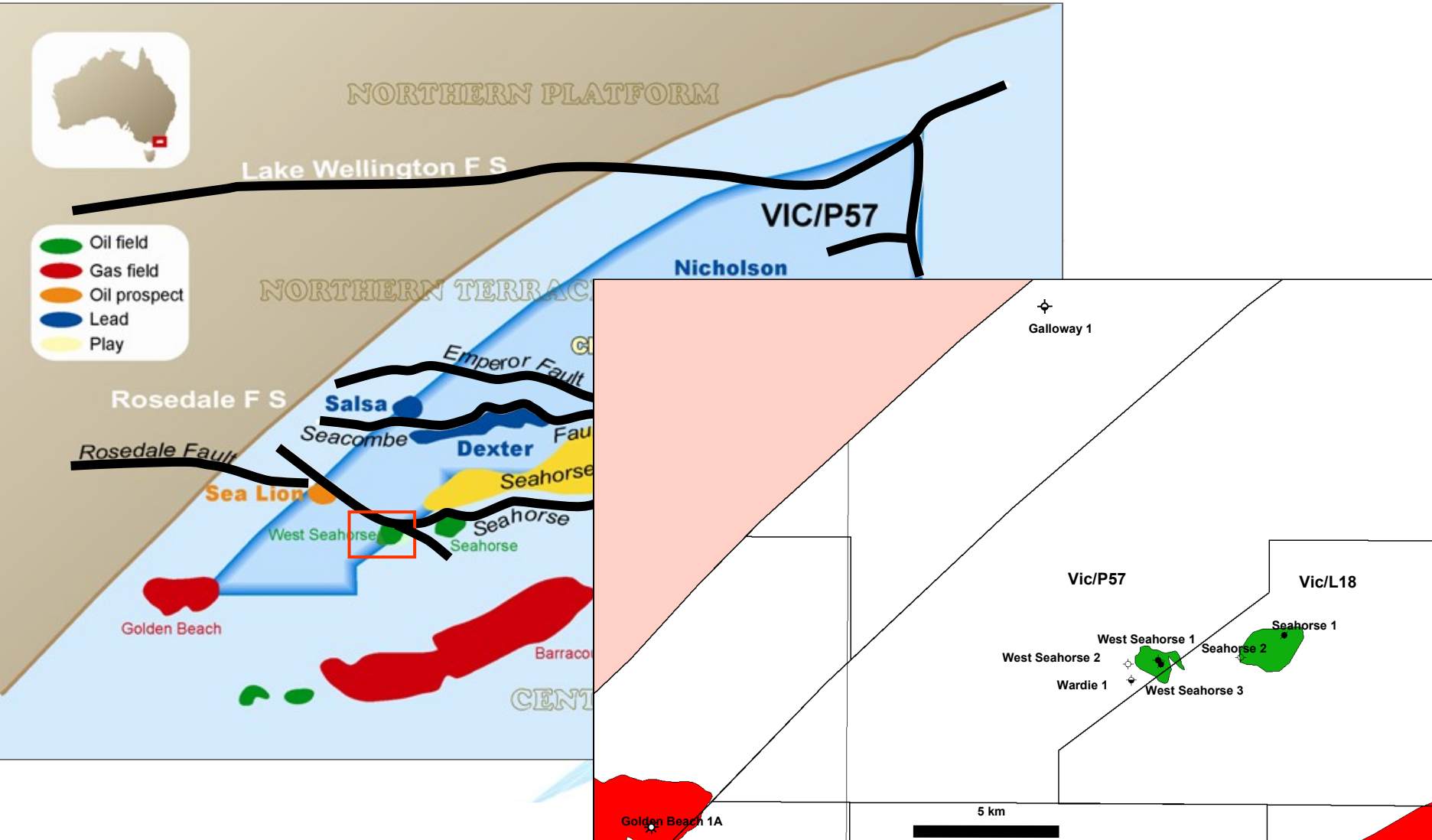
- ❶ **Currently, small to medium simulations running on a single core generate approximately 1000~2000 realisations / hour**
- ❷ **Parallelisation on a 4 core high performance “blade” realise almost linear speed-up to approx. 5000 realisations / hour**
- ❸ **24 hours of computing generates ~ 50,000 realisations, each of which is a valid history-match or reservoir forecast**
- ❹ **This simulation speed is sufficiently fast to enable the working reservoir engineer timely and efficient turnaround of stochastic simulation solutions.**

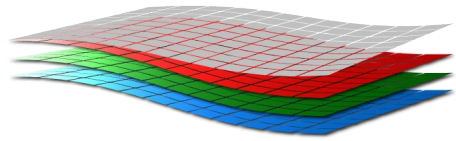


Case Study: West Seahorse



- Oil field
- Gas field
- Oil prospect
- Lead
- Play



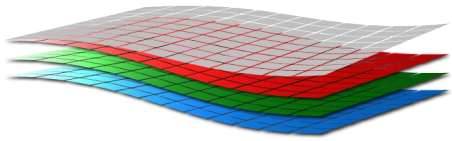


Case Study: West Seahorse

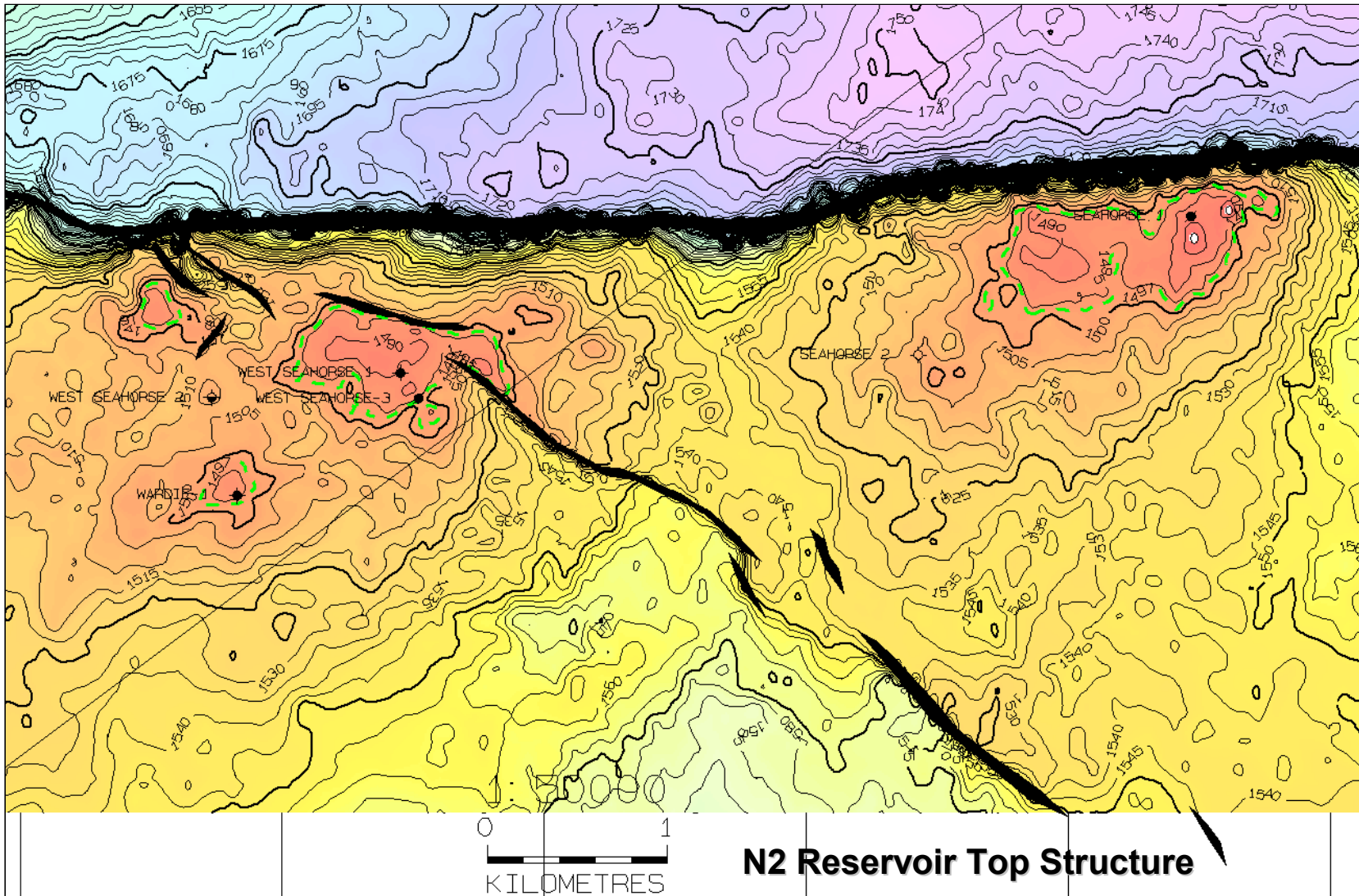
Case Study: West Seahorse Field, Gippsland Basin, Australia

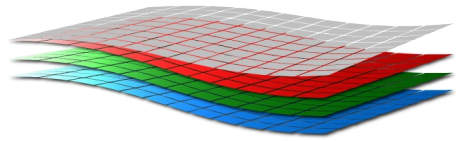


- **West Seahorse Owned and Operated by 3DOil Limited**
- **A development option is to tie the field into the nearby Barracouta Production platform operated by Esso Australia and owned by Esso/BHP Billiton**
- **Use of the SRE was one component of the due diligence that Esso is undertaking with respect to recoverable reserves in the West Seahorse Field.**
- **The study was undertaken on behalf of 3DOil and is part of ongoing reservoir simulation services provided by SSL**

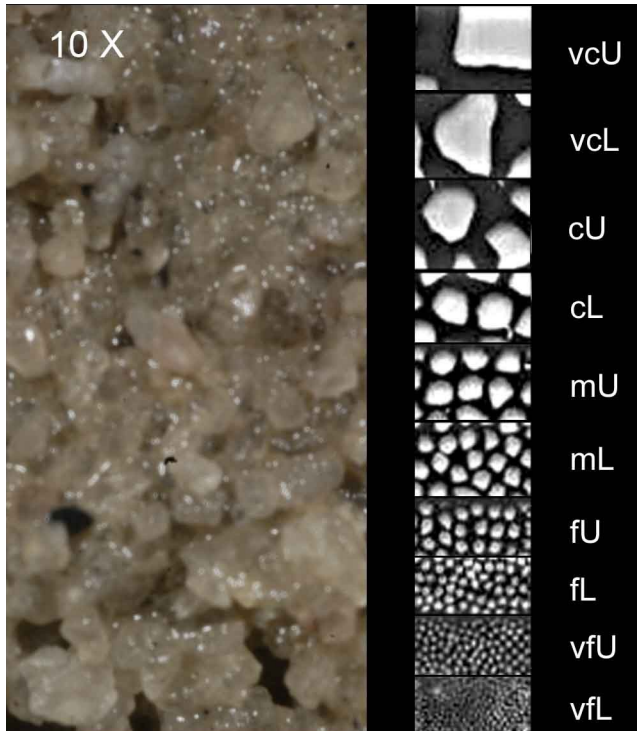


Case Study: West Seahorse

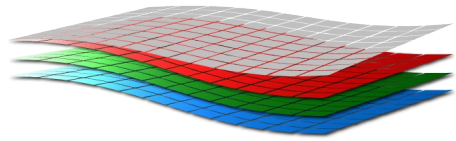




Reservoir Issues

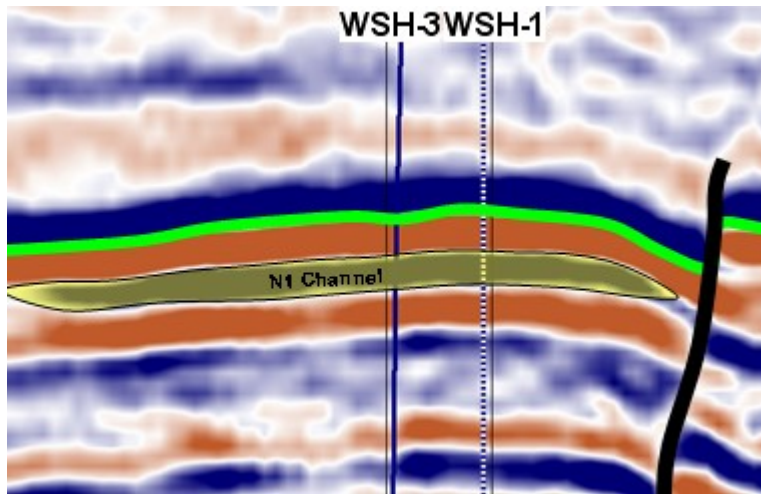


- **Lack of Core Data**
- **Poor Control on Permeability and Spatial Variation in Permeability**
- **No SCAL data or Relative Permeability**
- **Uncertainties in PVT properties including oil formation volume factor and viscosity**
- **Logs not good hydrocarbon indicators due to fresh / variable salinity**

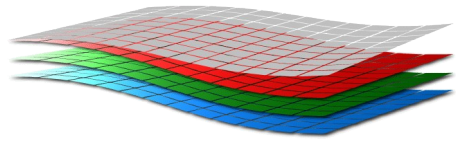


Case Study: West Seahorse

Approach to Reservoir Uncertainty

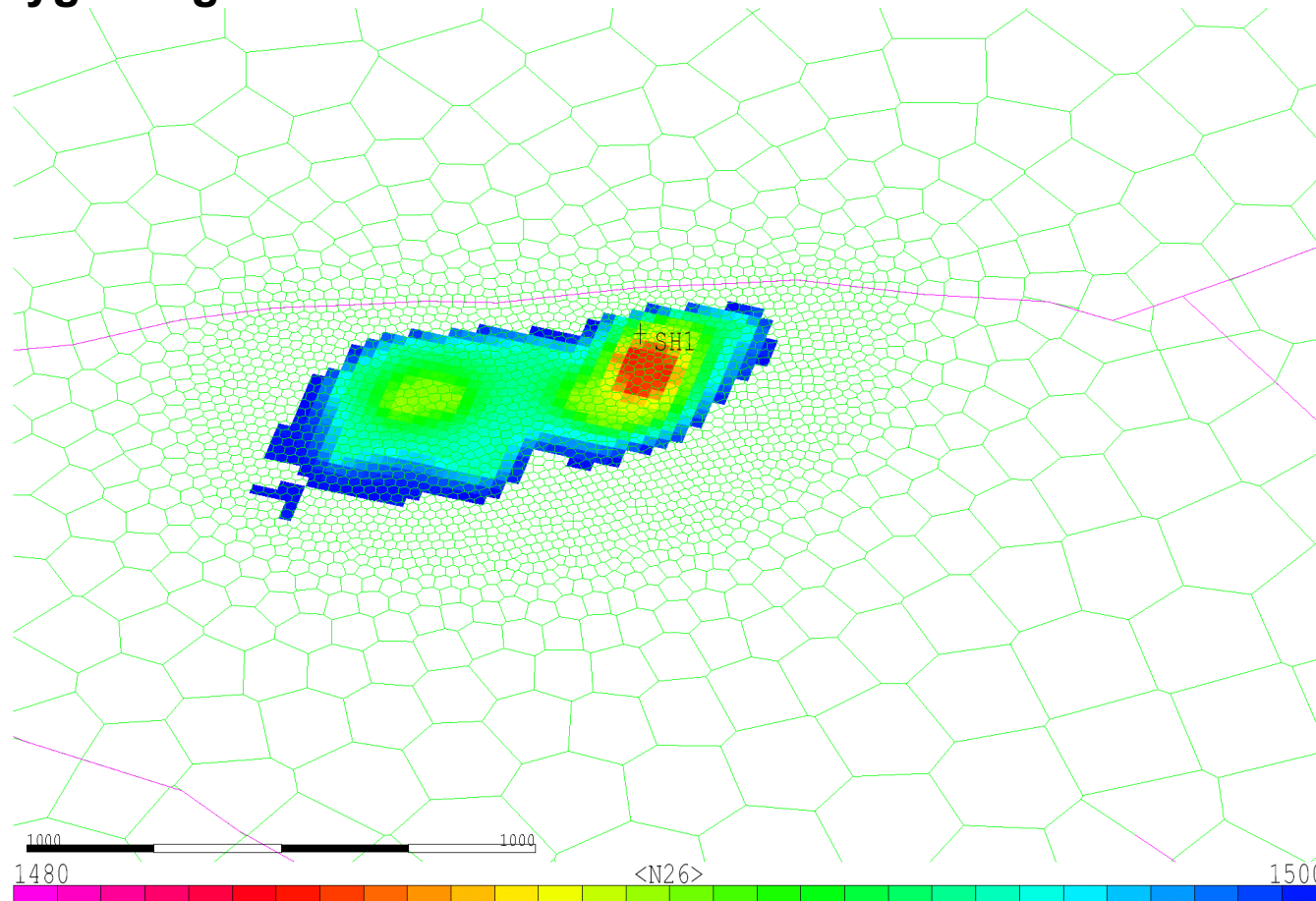


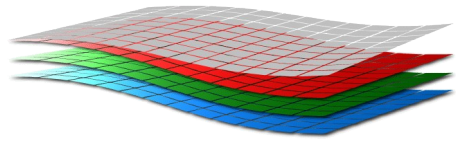
- **History-match nearby Seahorse Field**
- **Oil the same in the N2.6 sand, with similar OWC to the West Seahorse Field**
- **Use Seahorse as an Analogue Reservoir**
- **Carry out stochastic simulation of the West Seahorse Field using *prior* distributions of parameters based on the Seahorse Field**



Case Study: West Seahorse

- **Detail showing elevation of N2.6 sand above OWC**
 - polygonal grid used to reduce number of active cells in model





Case Study: West Seahorse

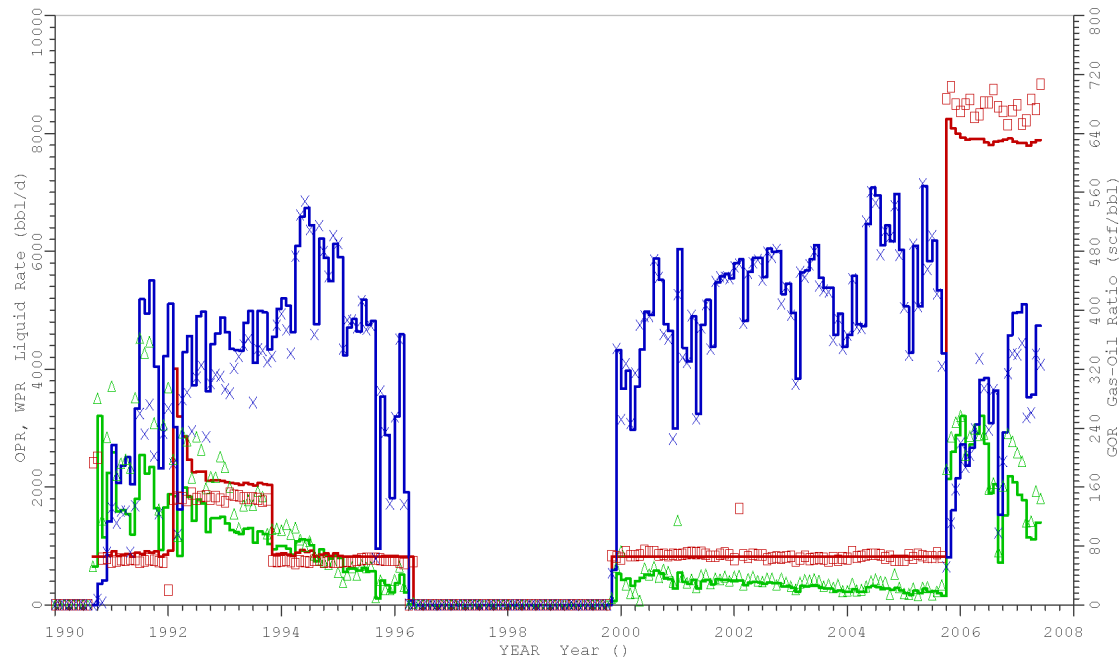
Conventional history-match – good fit to late time data

Seahorse-1

Match to Observed Production

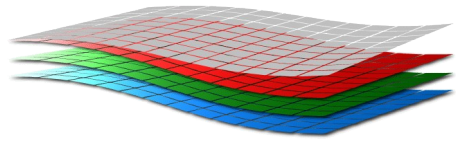
Permeability: N1 = 700 mD, N2.6 = 2000 mD

— FIELD OPR n126p
— FIELD GOR n126p
— FIELD WFR n126p
△ FIELD OPR sh1_n26
□ FIELD GOR sh1_n26
× FIELD WFR sh1_n26



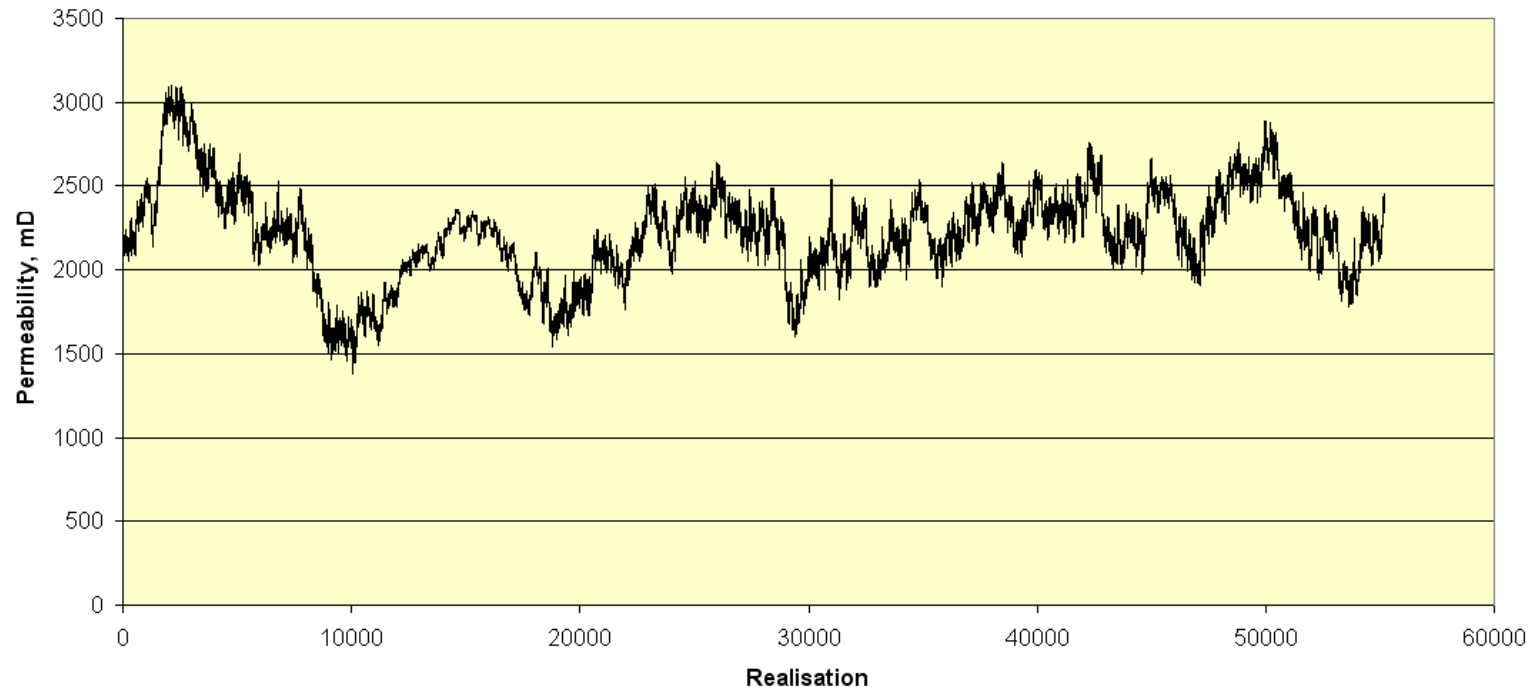
Is this a one-off match and merely an outlier ?

What confidence is there that this model is applicable to West Seahorse ?

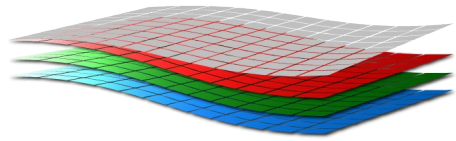


Case Study: West Seahorse

Markov Chain of History-Match Permeability

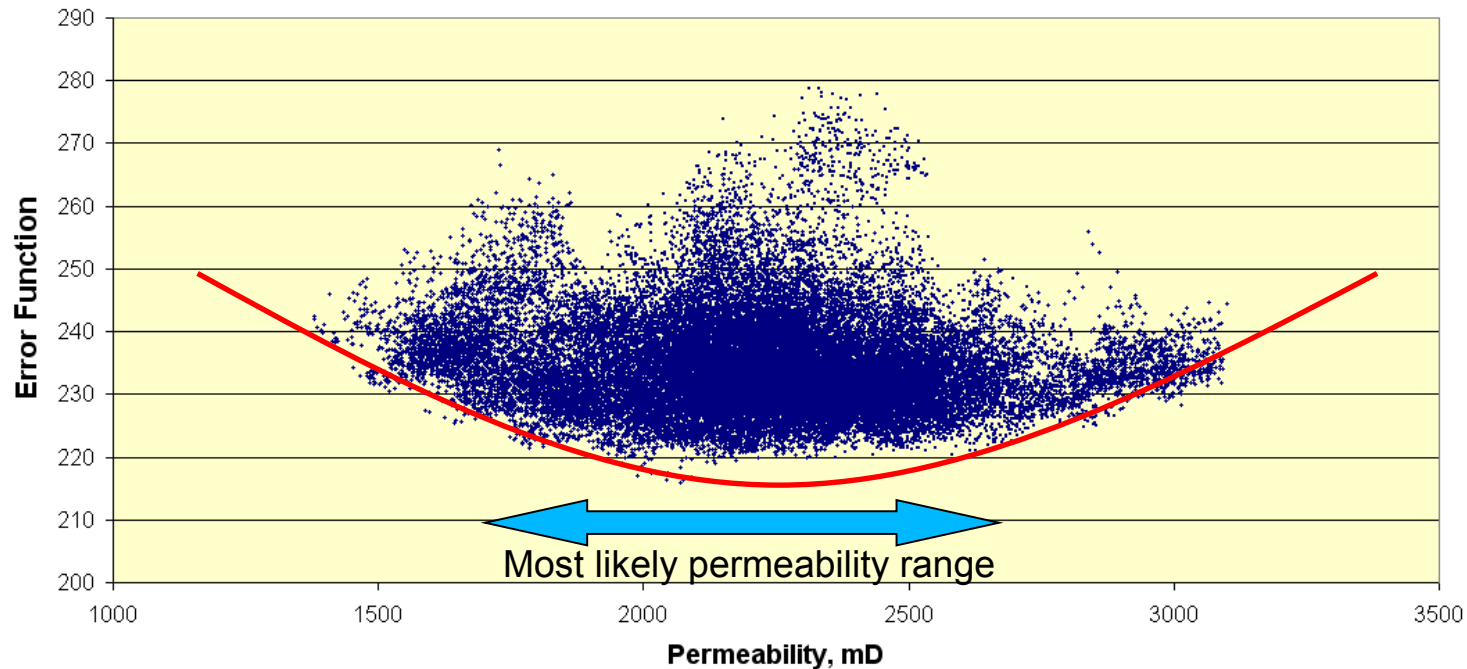


- Simulated over 55,000 realisations of Seahorse N2.6 sand using stochastic simulation
- Matching horizontal permeability, kv:kh ratio, immobile water saturation and variation in OWC

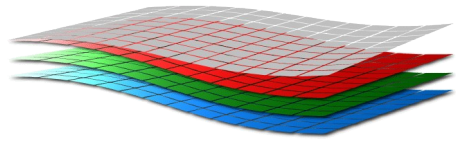


Case Study: West Seahorse

Permeability vs History-Match Error Function

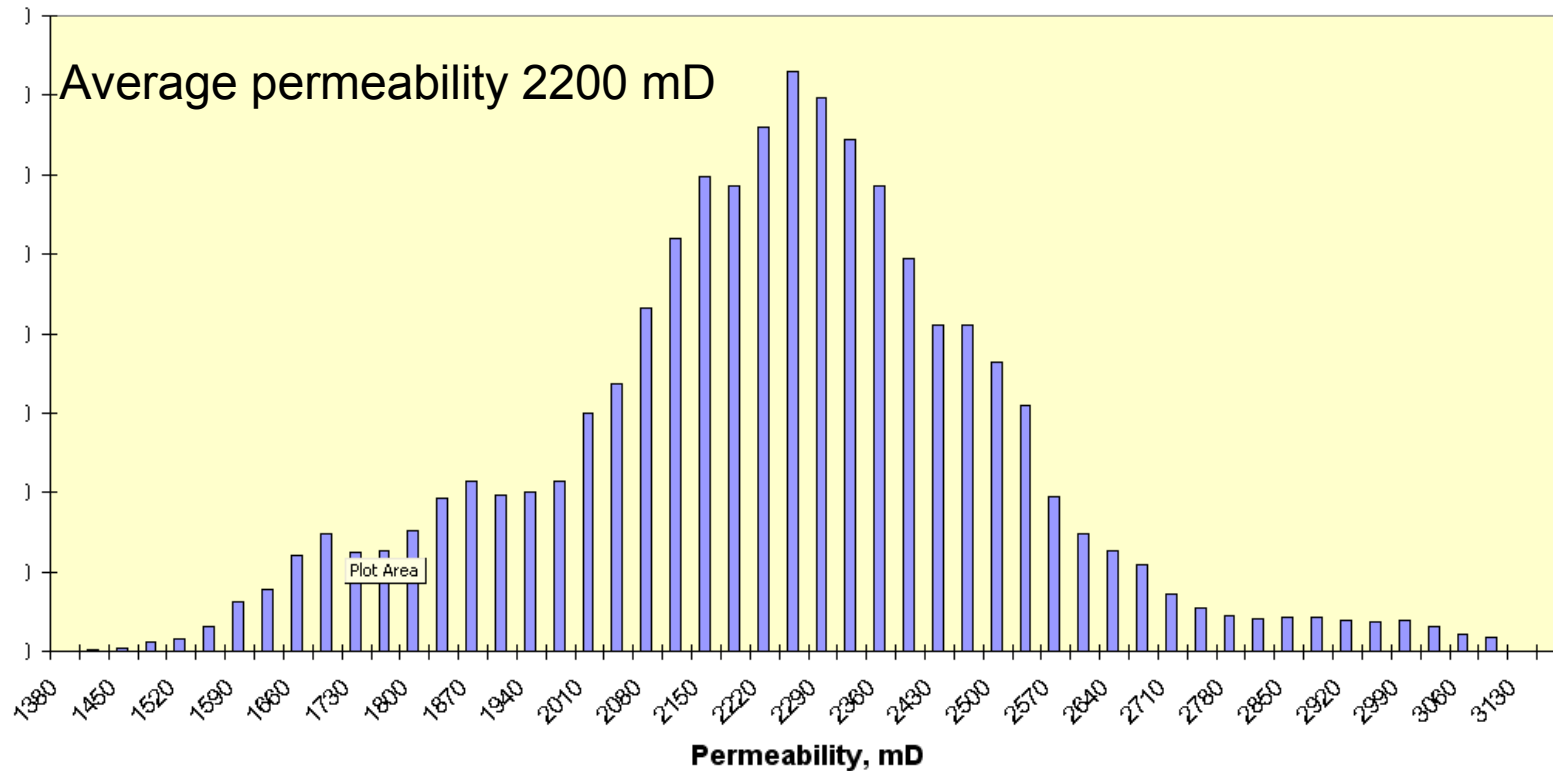


- The “Error Function” measures the difference between (normalised) calculated well rates and observed well rates

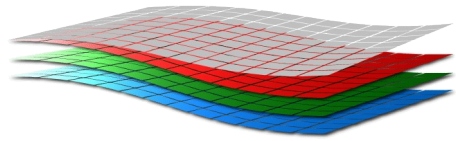


Case Study: West Seahorse

Histogram of History-Match Permeability

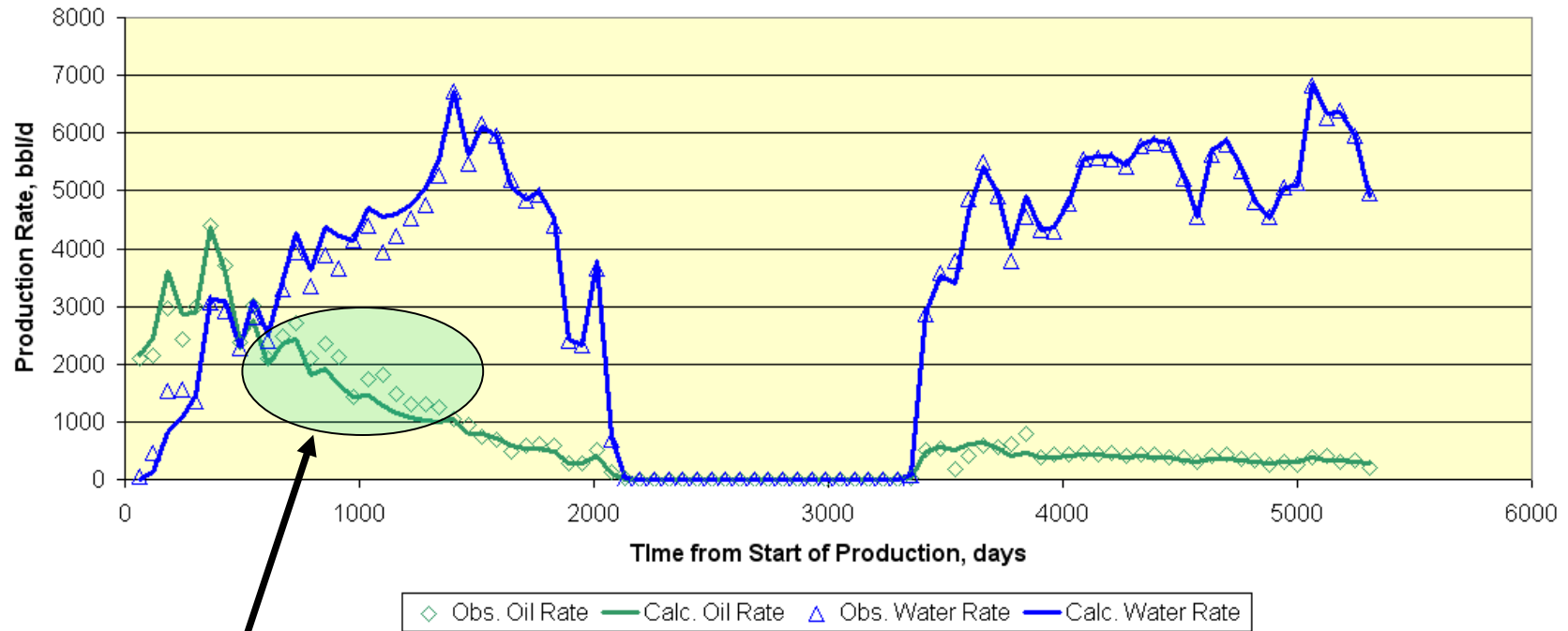


- **Stochastic simulation confirmed the permeability was in range 1500mD to 3000mD**



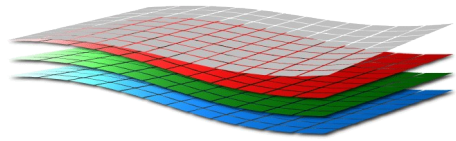
Case Study: West Seahorse

N2.6 Sand History-Match for One Realisation



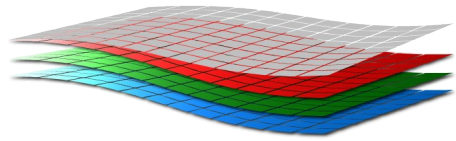
Some Commingled Production from N1 Sand

- **Stochastic simulation consistently achieved a better history match than conventional history-matching techniques, and quicker**



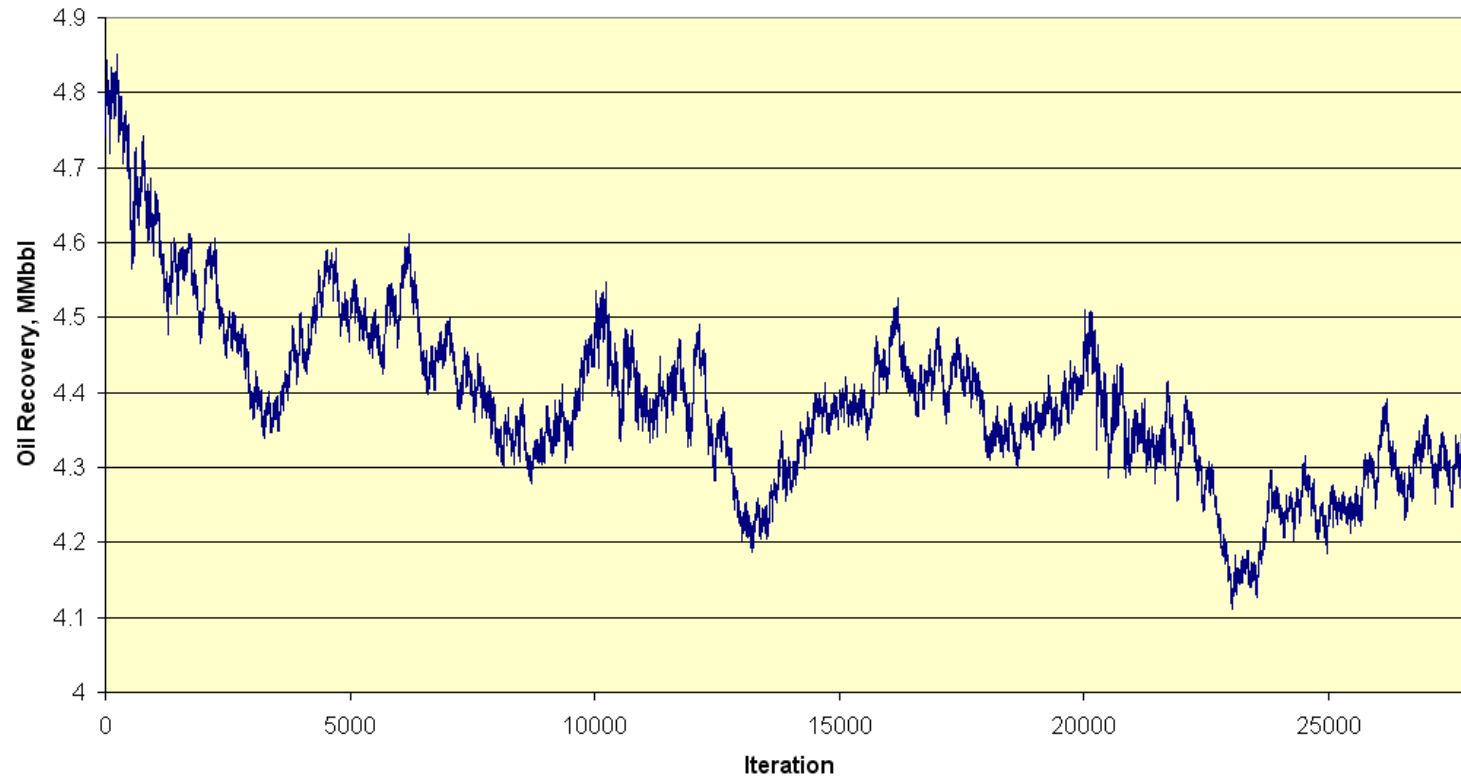
Major Sensitivities included in Stochastic Simulation of West Seahorse Reserves Analysis

- **Horizontal and Vertical Permeability for N1 and N2.6 reservoirs**
- **Porosity Sensitivity for N1 and N2.6 reservoirs**
- **Variation in Oil-Water Contacts**
- **Flexing Top Structure tied to Well Depth**
- **Sensitivity to Residual Oil Saturation, Immobile Water Saturation and End-point Water Relative Permeability**
- **Total of 13 major sensitivities analysed simultaneously**

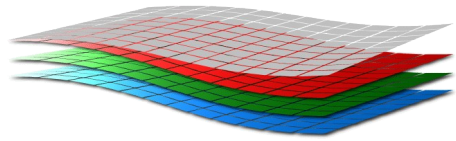


Case Study: West Seahorse

Fragment of Stochastic Simulation of Oil Recovery

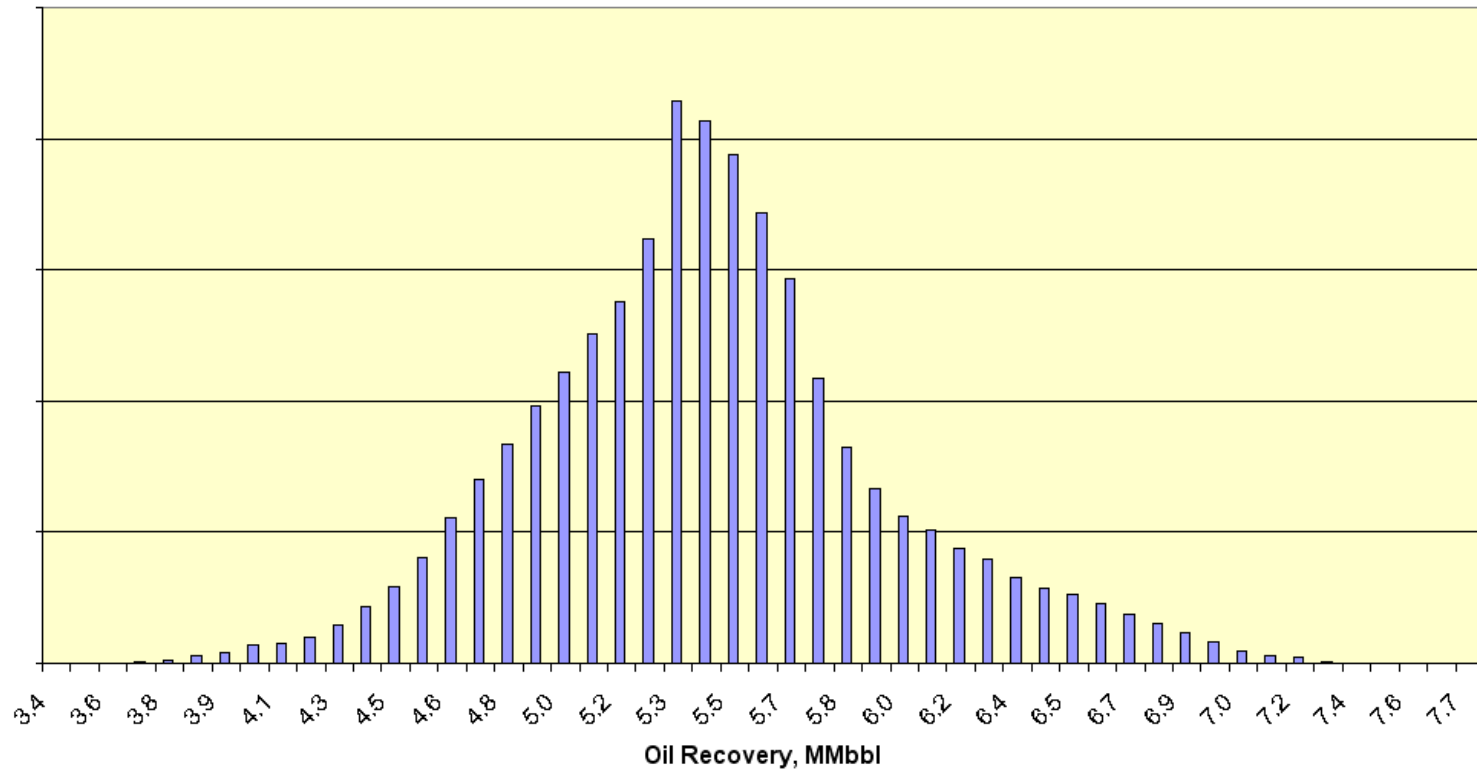


- Part of greater than 160,000 stochastic realisations of West Seahorse Field

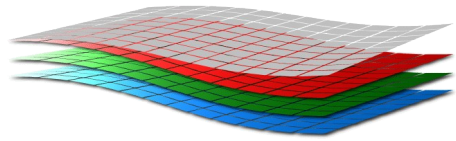


Case Study: West Seahorse

Oil Recovery at 7 Years

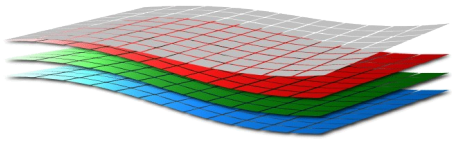


- **Histogram of Oil Recovery based on Stochastic Simulation of West Seahorse Field**



2nd Case Study uses stochastic simulation to differentiate between reservoir alternatives:

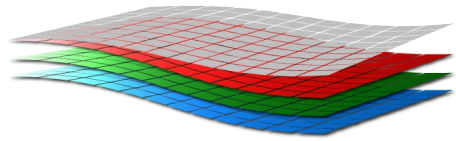
- **Thin oil column**
- **Seismic resolution comparable with oil column height**
- **Difficult to history-match due to commingled production**
- **Well control is inlet pressure to separator – allocation to wells is achieved through calibrated tubing-flow and gas-lift tables**
- **History match using:-**
 - **Vertical & horizontal permeability**
 - **Elevation of OWC**
 - **Top structure**



Case Study: Thin Oil column

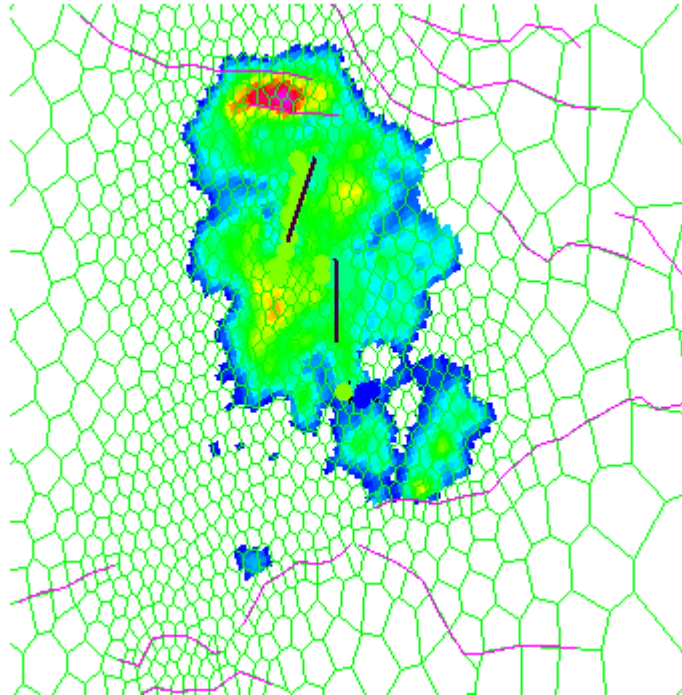


• Conventional History Match

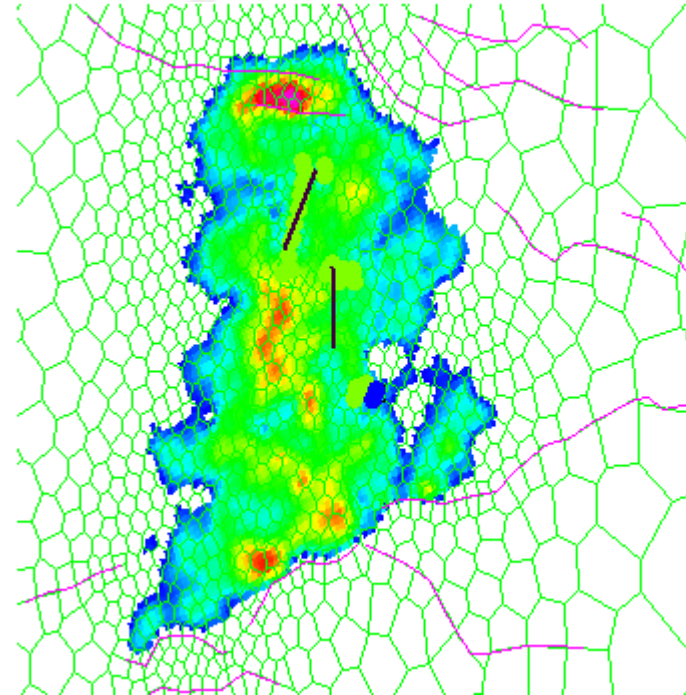


Case Study: Thin Oil column

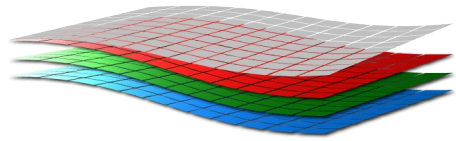
Downside Case



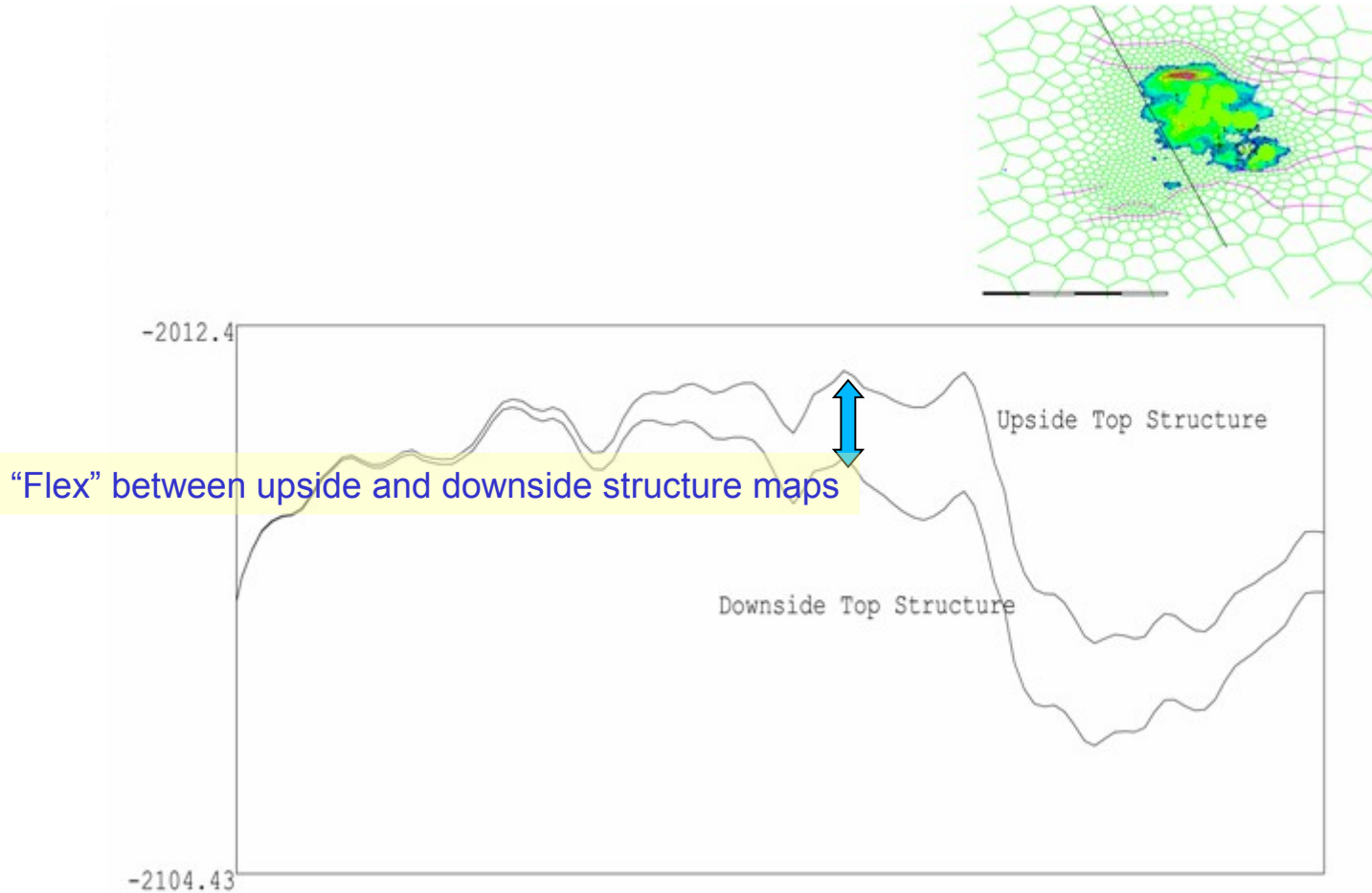
Upside Case



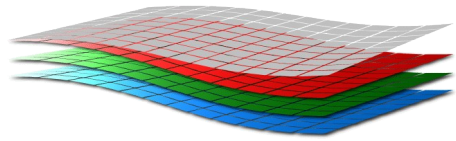
- **Conventional History-Match cannot distinguish between downside and upside cases**



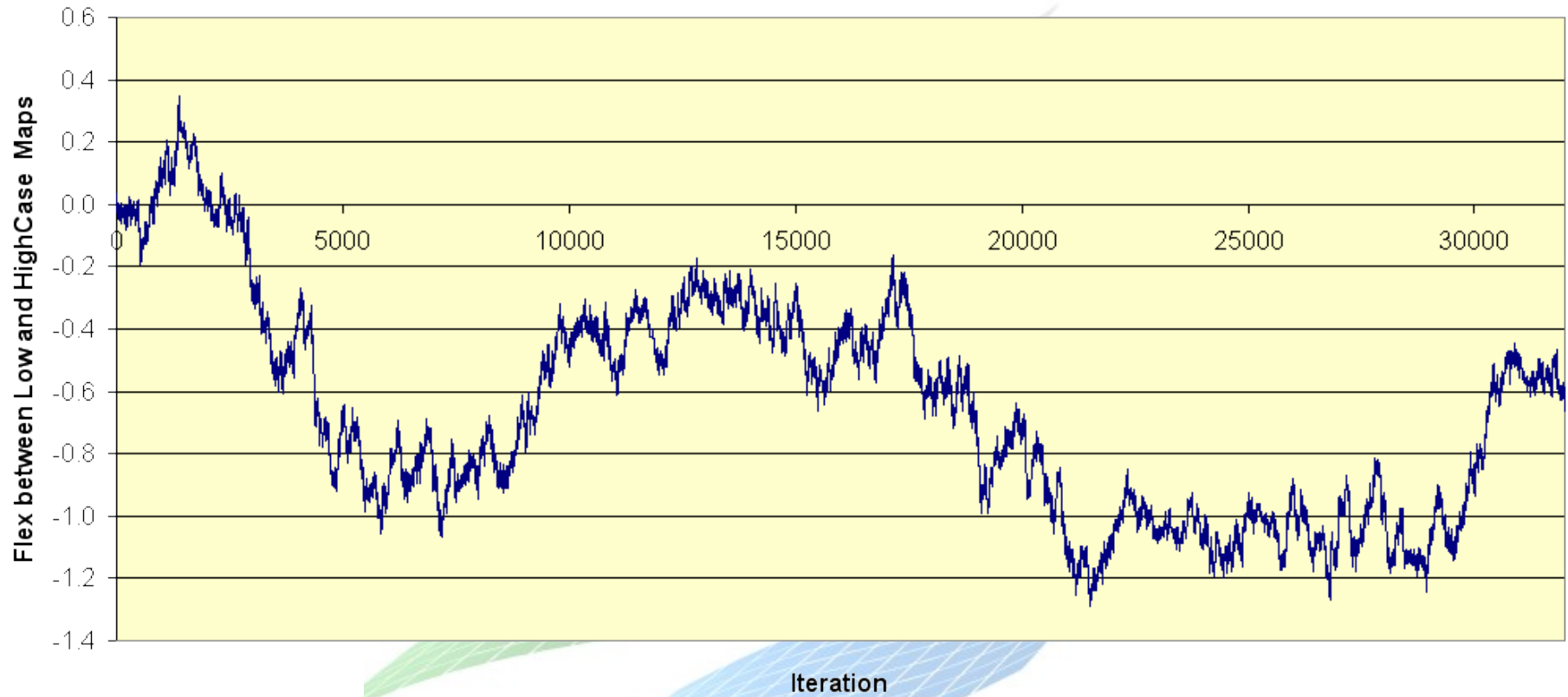
Case Study: Thin Oil column



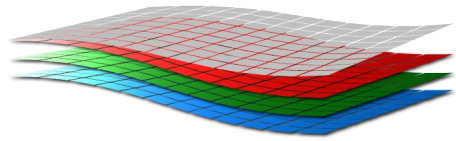
- Section showing upside and downside top structure



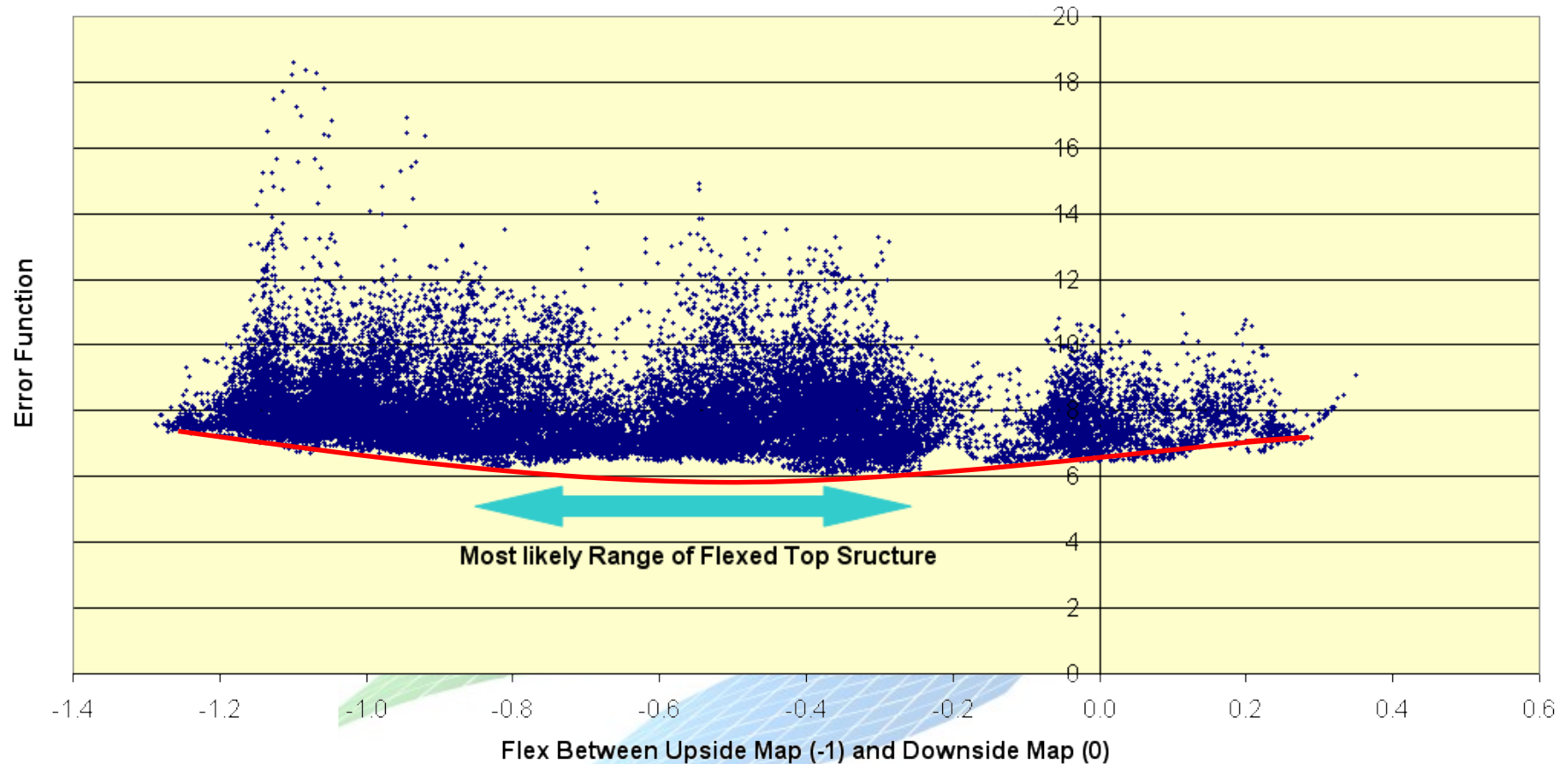
Case Study: Thin Oil column



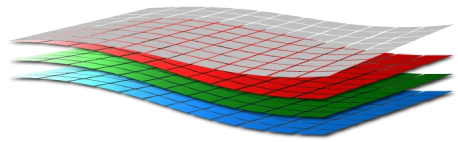
- **Stochastic Simulation showing degree of flexing between Upside Case (-1) and Downside Case (0)**



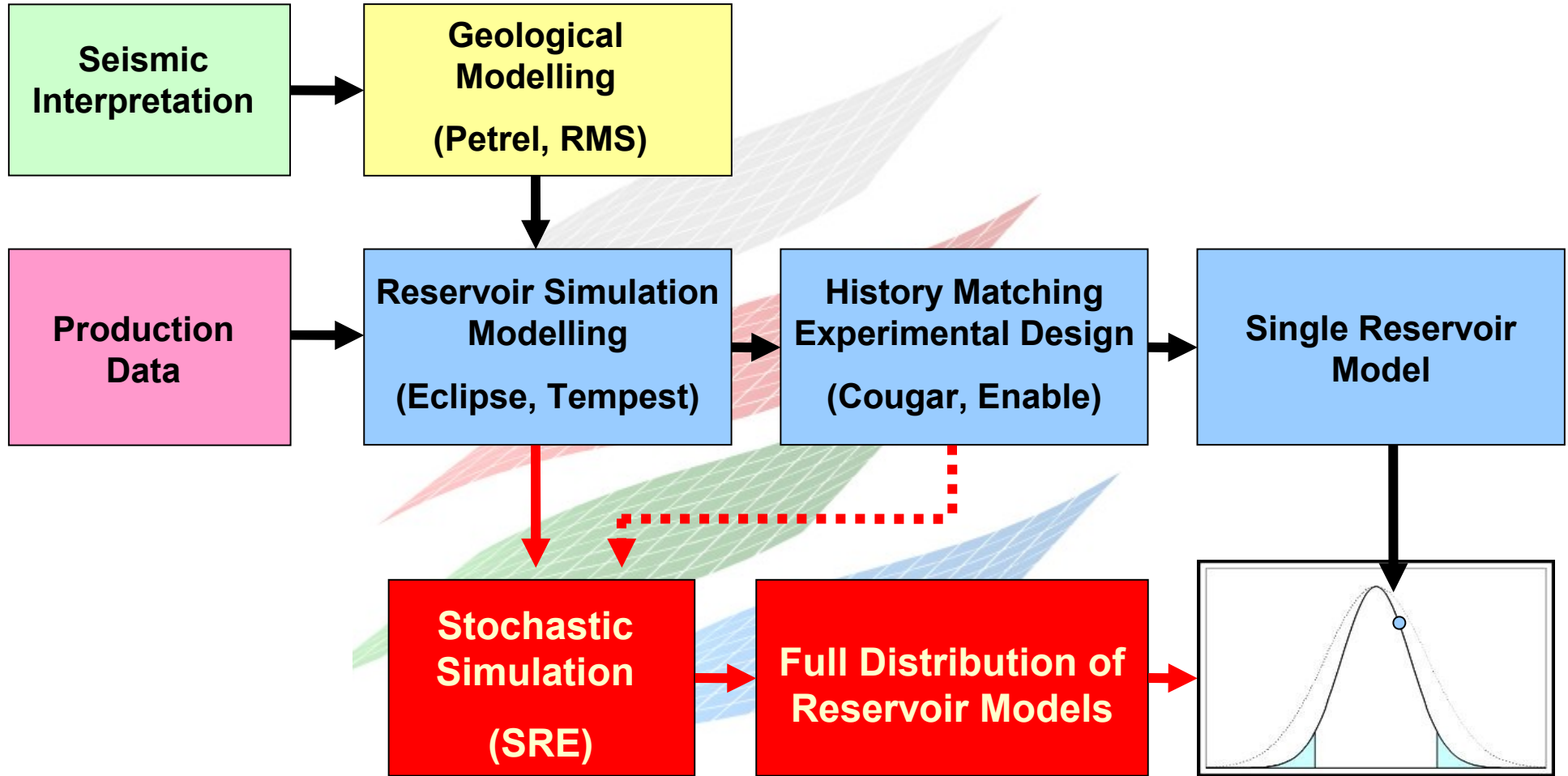
Case Study: Thin Oil column

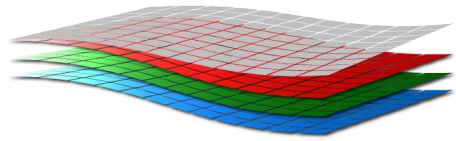


- **Most likely top structure is biased towards upside case**
This study is still in progress ...



Stochastic Simulation Workflow





Conclusion

Thankyou for your attention. I trust that the objectives of the presentation have been achieved. That is

- ✓ **Introduced a new way of evaluating reservoir uncertainty though **Stochastic Reservoir Simulation****
- ✓ **Illustrated the concepts used**
- ✓ **Highlighted the benefits achieved, and**
- ✓ **Demonstrated the value of the results.**

Thank you