Synthetic Seismic Validation of Reservoir Models of the Carbonate Gas Fields in Offshore Sarawak, Malaysia*

Alexander David Kayes[1]

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Abstract

From mid-2012, the Sarawak Gas Asset will comprise 20 producing fields accounting for more than 40 Tcf of gas initially in place and supplying more than four Bscf/d to the Malaysian LNG plant at Bintulu. A tool for performing quick and timely health checks of reservoir models is therefore invaluable for providing confidence in model-based volumetric estimates, production forecasting and optimum gas supply planning. In Shell, a synthetic seismic workflow is used for validating carbonate reservoir models against seismic data, effectively "closing the loop" in the integrated reservoir modeling process, which originates with the interpretation of the seismic data.

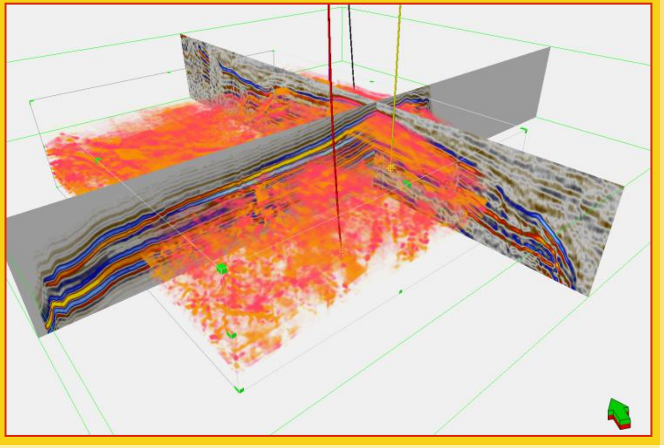
The underlying mechanics of the process is to convert the reservoir properties in the model (primarily porosity) to acoustic rock properties (Vp, Vs, and Density), based on water-wet rock property regressions derived from the available well data. Gassman fluid substitution is then used to convert the predicted acoustic properties to their gas-saturated state. As an initial QC of the model, the predictions of acoustic properties are compared to the measured acoustic logs at the well locations. Synthetics based on these models are subsequently generated by convolving the AI property model with a seismic wavelet extracted from the seismic dataset and compared back to the actual seismic data.

Developing a workflow for validating Sarawak carbonate reservoir models against seismic has come with many benefits. Field examples exist where the technique has been applied as an effective check for internal reservoir architecture. This extends to scrutiny of the lateral and vertical porosity variability away from wells. Furthermore, it is used for constraining the modeling and porosity enhancement that is assigned to karstified networks and in many cases, as a tool for testing dynamic simulations through the incorporation of 4D repeat seismic acquisition results. Given that seismic acoustic impedance drives both porosity and permeability models in the Sarawak carbonate reservoirs, it ultimately impacts the predicted dynamic behavior of these reservoirs. As an early detection tool, this workflow can alert subsurface teams to issues inherent in their interpretation, depth conversion and modeling, which can be addressed in a timely manner to avoid surprises with respect to volumetric estimates, forecasting and well planning, resulting in more efficient management of the gas reserves of offshore Sarawak.

Synthetic Seismic Validation of reservoir models of the carbonate gas fields in offshore Sarawak, Malaysia.

Alexander David Kayes

Sarawak Shell Berhad.



With special thanks to Petronas, Petronas-Carigali and JX Nippon for their permission to publish this material.

Acknowledgements: Colleagues of Shell Malaysia E&P who have contributed to this study.

OUTLINE

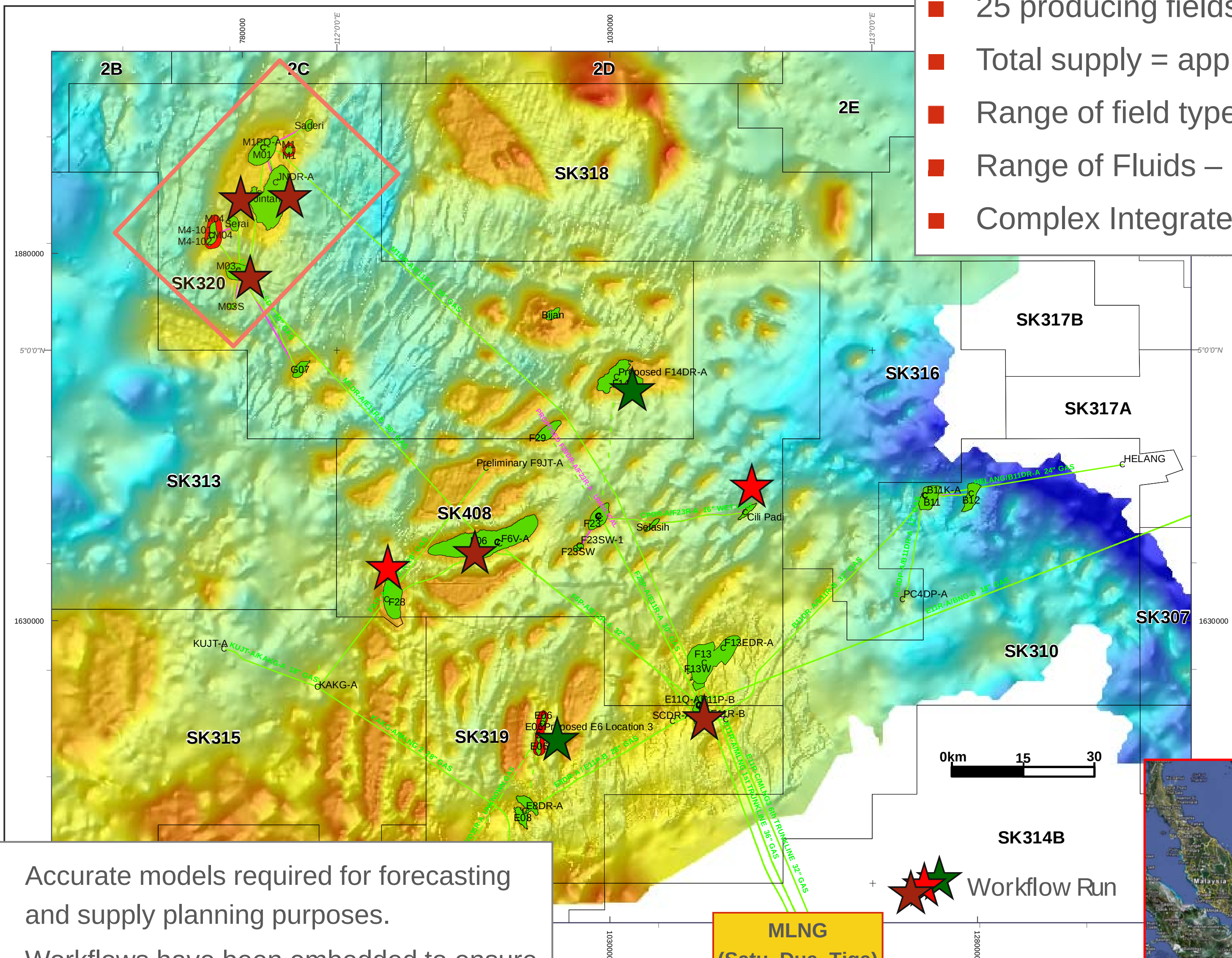
- SARAWAK CARBONATE PLAY:
  - Introduction to Asset Environment
  - Regional Geological Context.

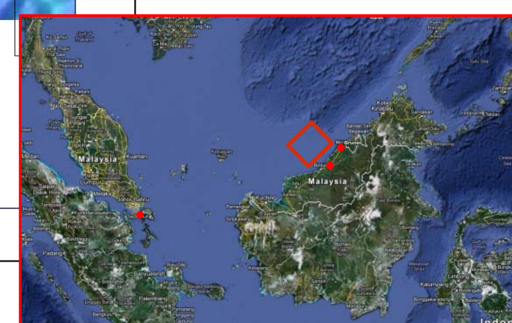
- METHOD:
  - Generalized Modeling Workflow for Sarawak Carbonate fields.
  - Synthetic Seismic Validation Method (SSV).

- CASE HISTORIES:
  - Examples for validating models from Sarawak carbonate fields:
    - Reservoir architecture & vertical porosity variations.
    - Lateral porosity variations.
    - Karst mapping and property assignment.
    - Dynamic simulation results with 4D seismic.

SARAWAK ASSET OVERVIEW

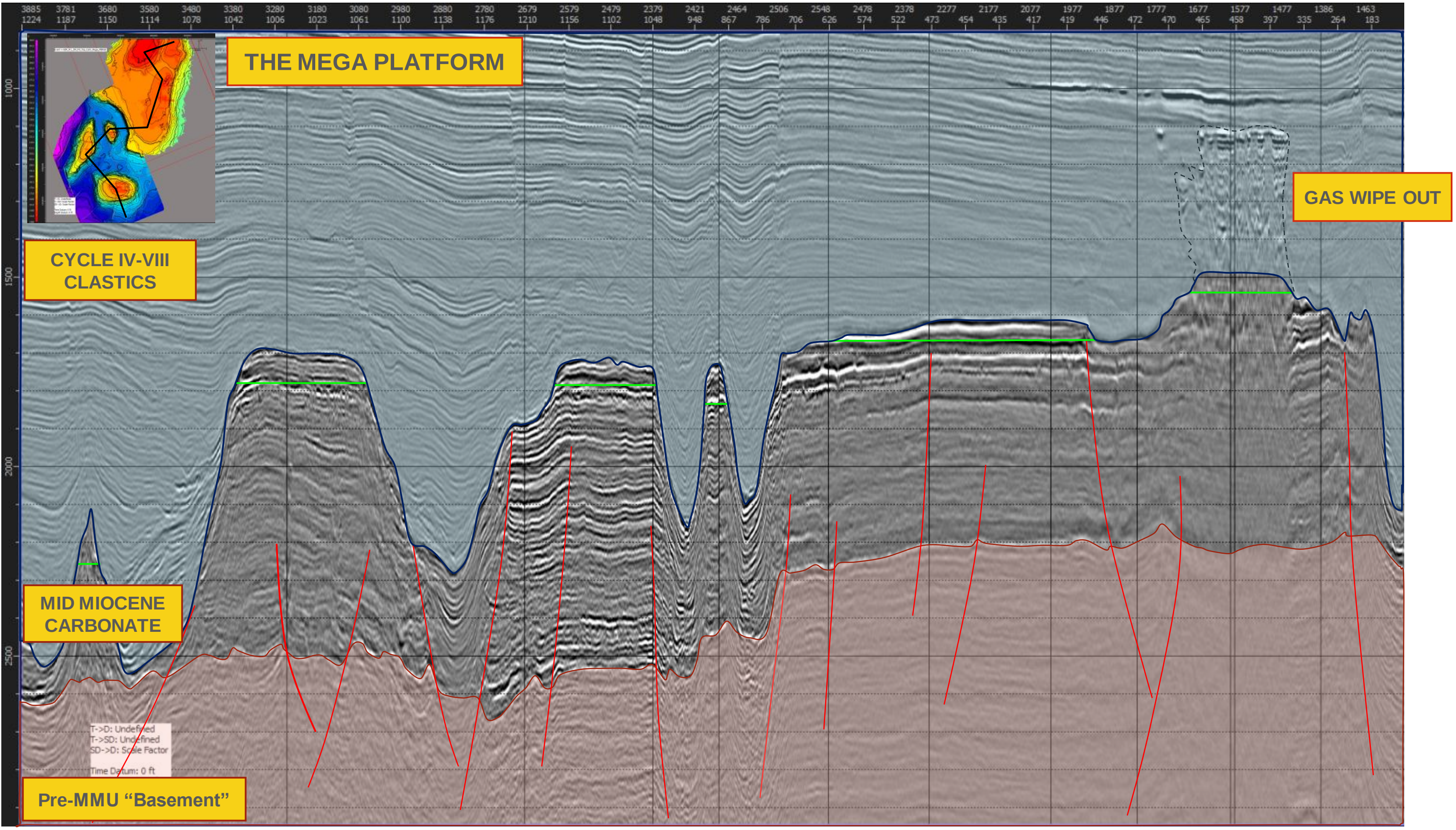
- 25 producing fields (19 Shell operated).
- Total supply = approx 4Bcf/d to MLNG.
- Range of field types, size and maturity.
- Range of Fluids – Mercury, H2S and Co2.
- Complex Integrated Production System.





- Accurate models required for forecasting and supply planning purposes.
- Workflows have been embedded to ensure adequate QC against seismic data.

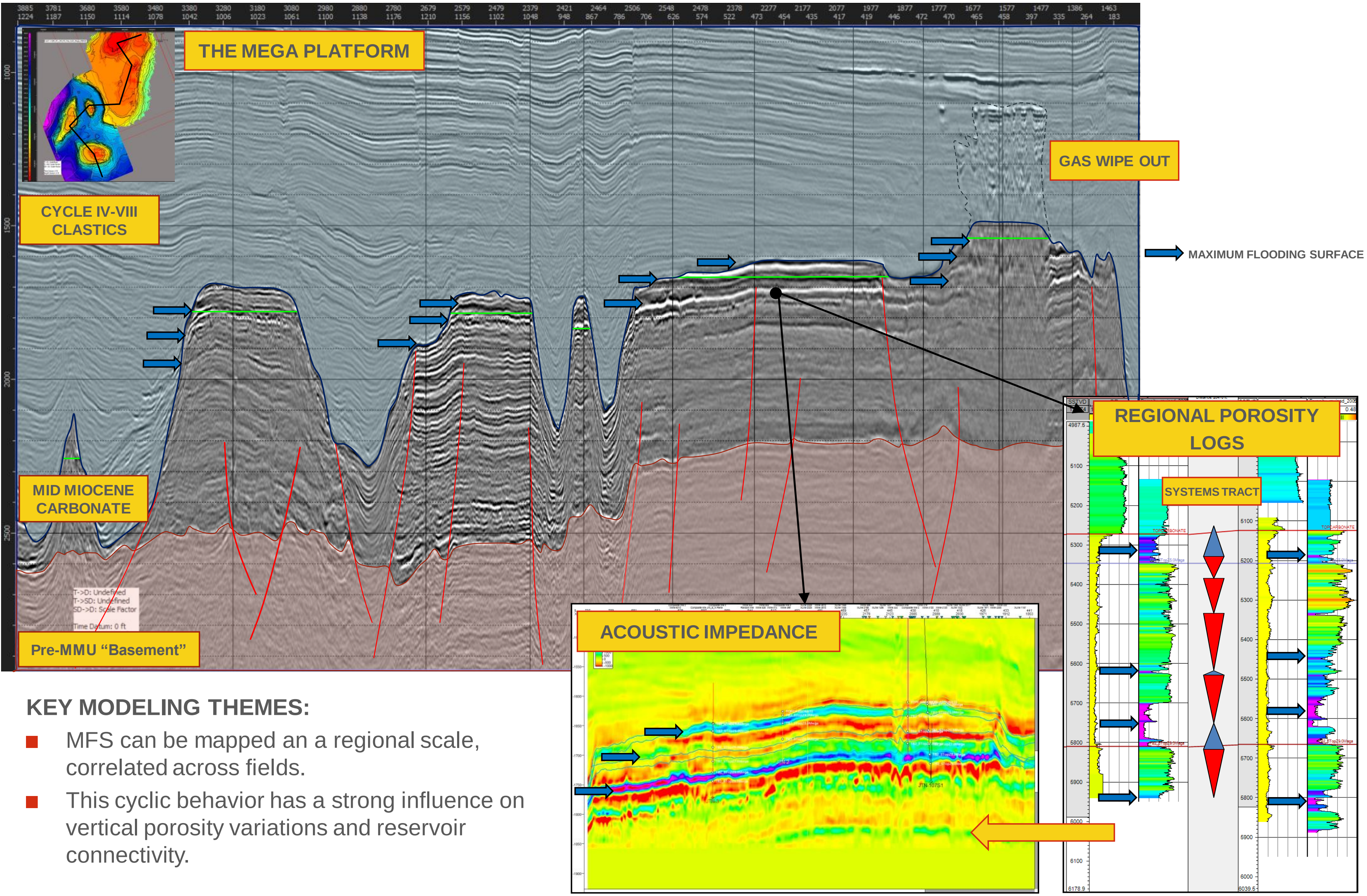
REGIONAL CONTEXT – Central Luconia



KEY MODELING THEMES:

- Miocene Carbonate Reef growth initiated on fault bounded highs.
- Reservoir development and architecture defined by interplay between eustatic sea-level changes and basement tectonic episodes.

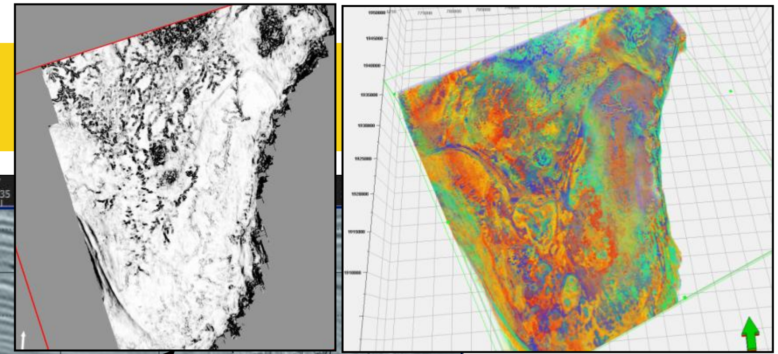
REGIONAL CONTEXT – Central Luconia

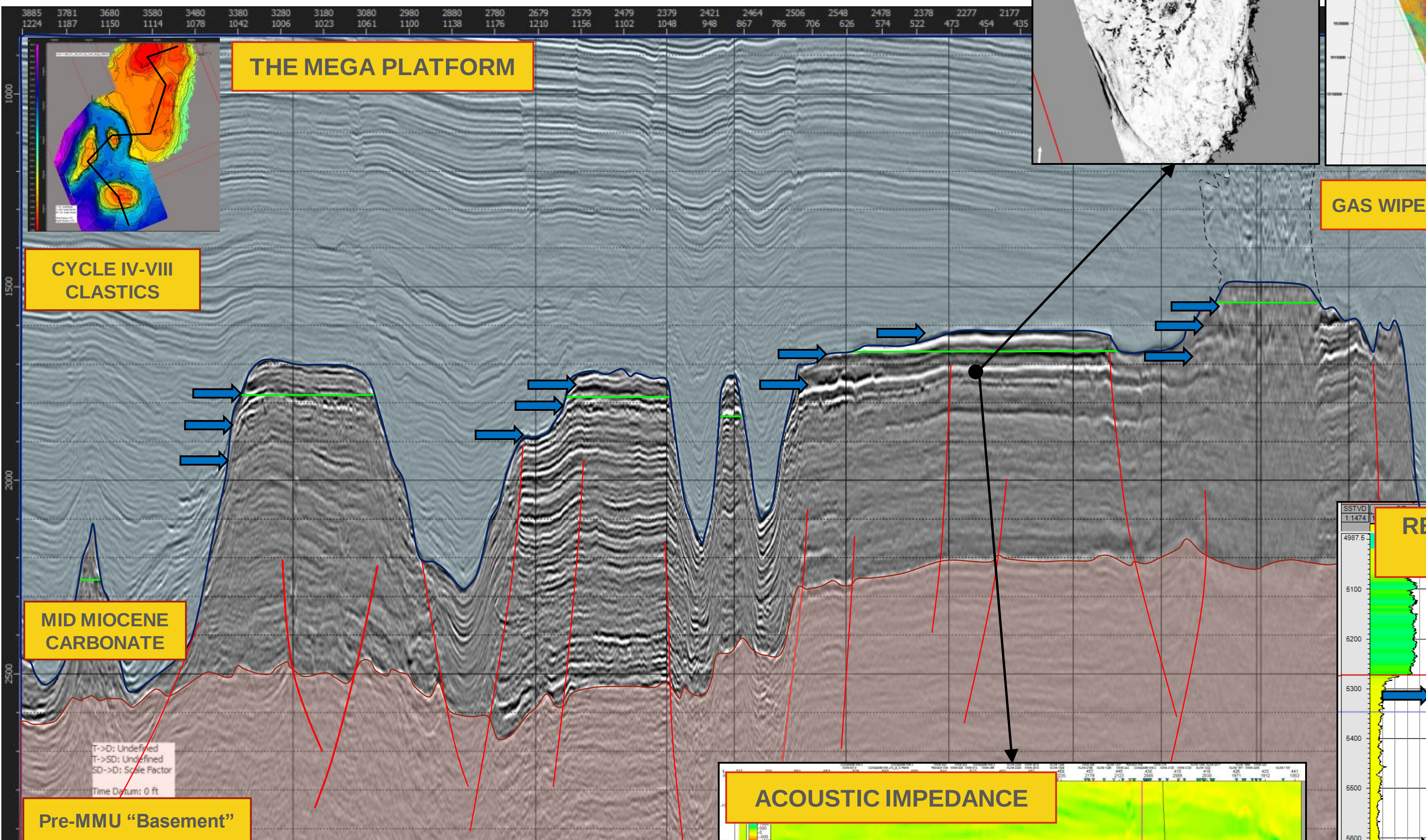


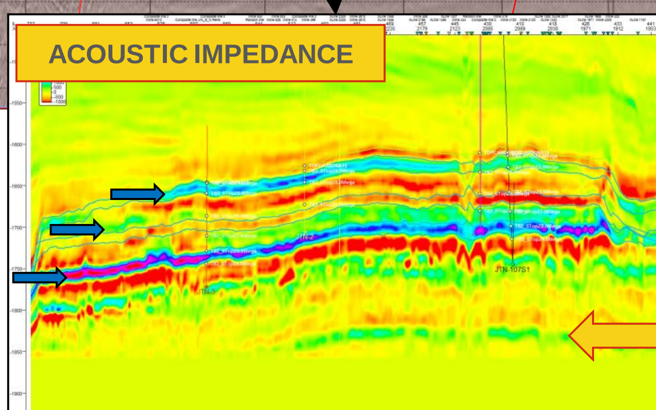
KEY MODELING THEMES:

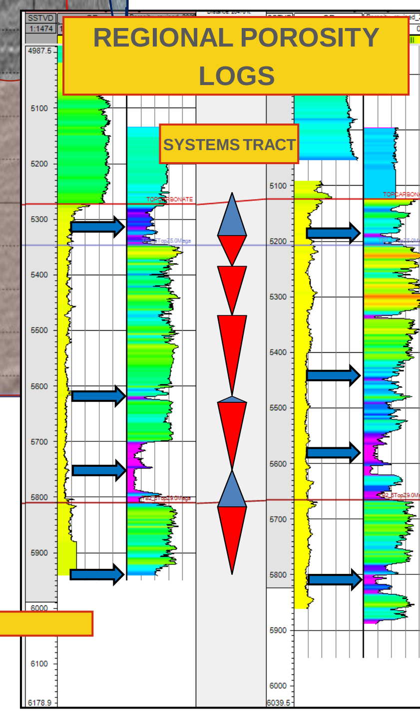
- MFS can be mapped an a regional scale, correlated across fields.
- This cyclic behavior has a strong influence on vertical porosity variations and reservoir connectivity.

REGIONAL CONTEXT – Central Luconia





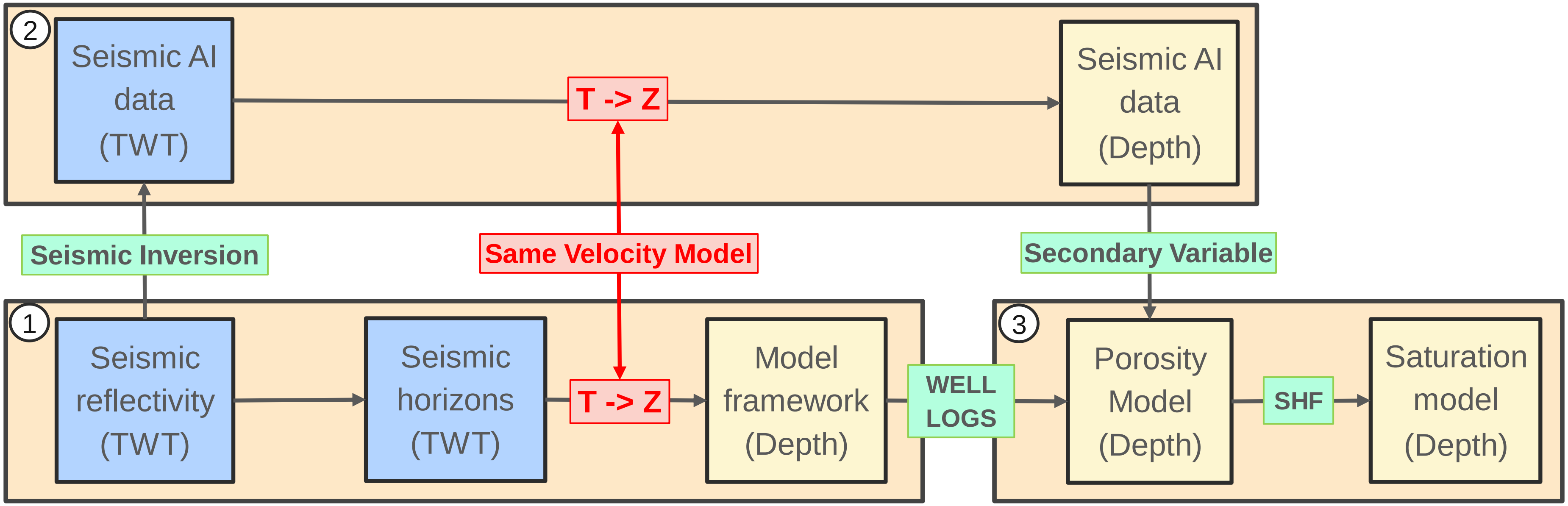




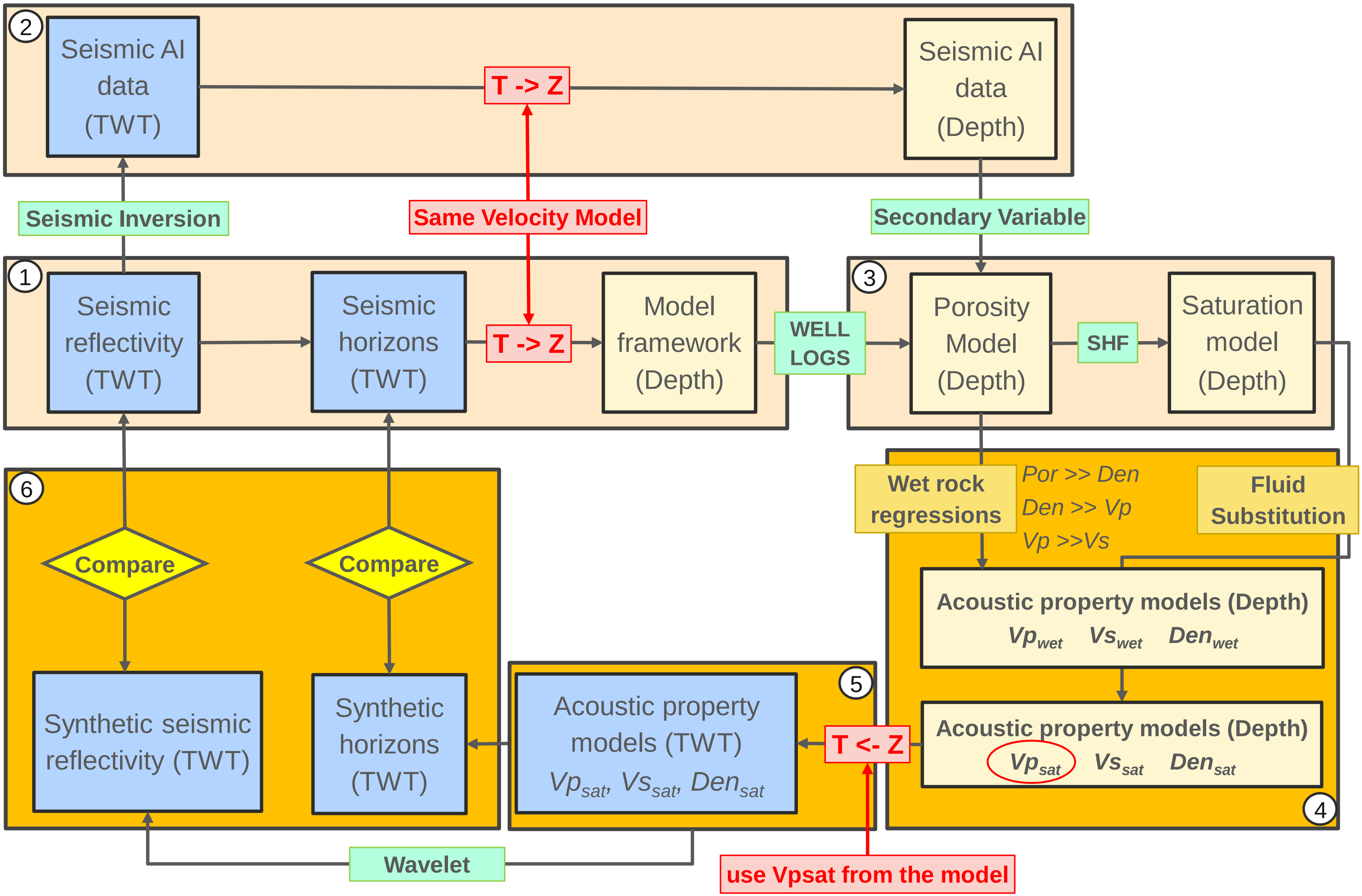
SUBSURFACE/DEVELOPMENT UNCERTAINTIES:

- Porosity Distribution (Horizontal/Vertical).
- Water Breakthrough Timing/Aquifer Behavior.
- Karstification.
- Variable seismic data quality.

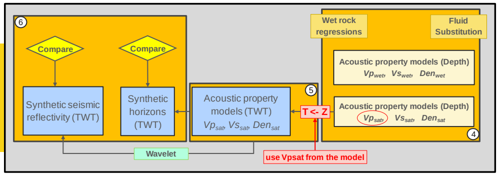
GENERALISED WORKFLOW (STATIC MODEL)

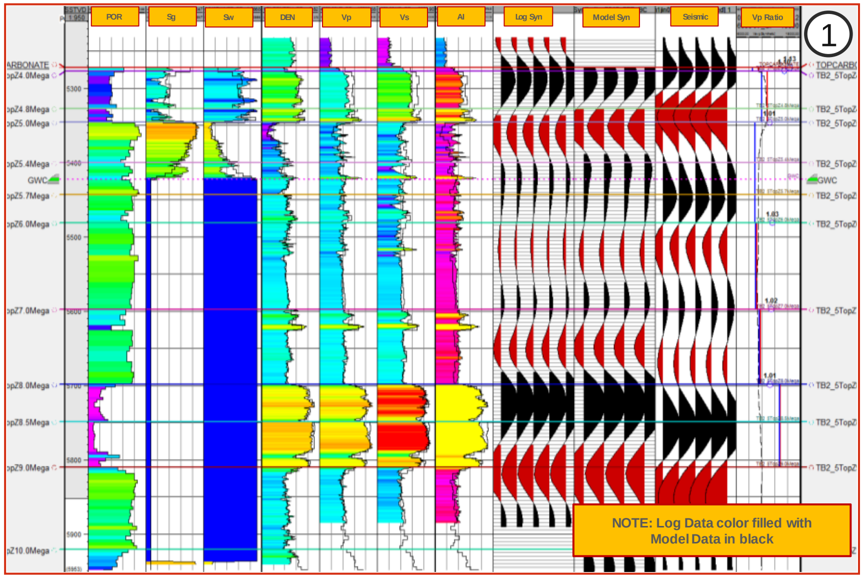


GENERALISED WORKFLOW (SSV)



1D & 2D QC TOOLS – SHELL PLUG-IN



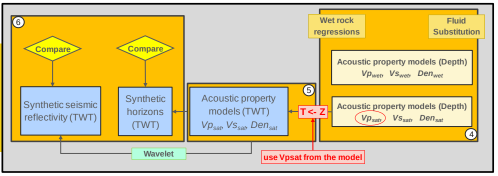


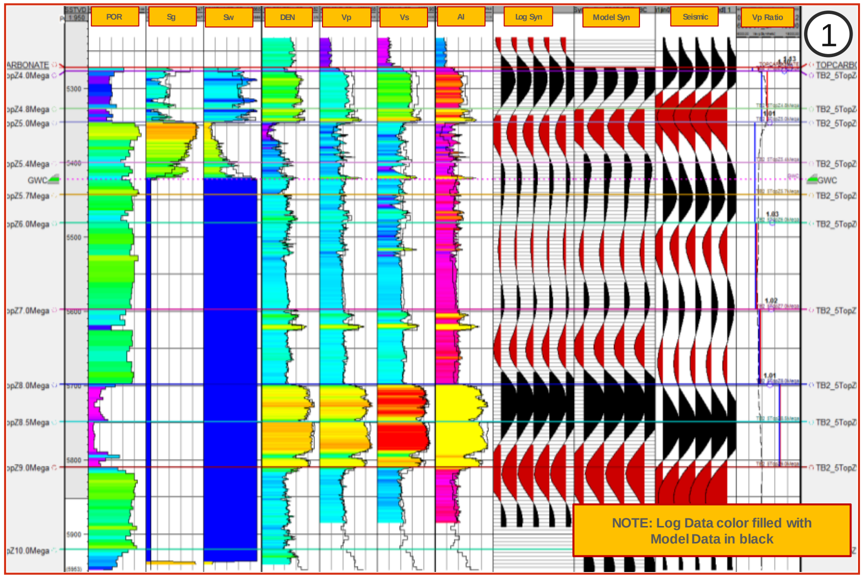
TWT CONVERSION (Vpsat from Model)

ROCK3D SYNTHETIC GENERATION

- **Single Platform** Petrel Plug-in Solutions (SHELL)
  - ROCK3D >> ROCK3D SYNTHETICS
  - SEISMIC COMPARATOR
  - **Rapid model QC and iterative updating.**
- QC Steps at 1D Well Scale **>>** 2D X-Section and Map View **>>** 3D rapid scan volume scale.

1D & 2D QC TOOLS – SHELL PLUG-IN





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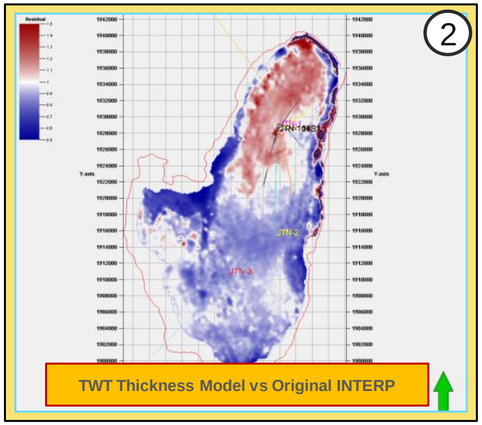
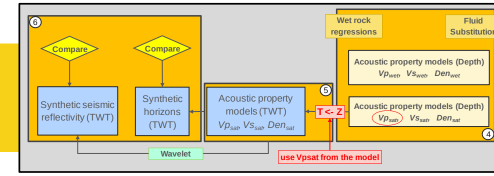
TWT CONVERSION (Vpsat from Model)

ROCK3D SYNTHETIC GENERATION

COMPARE TWT THICKNESS





1D & 2D QC TOOLS – SHELL PLUG-IN

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  - ROCK3D >> ROCK3D SYNTHETICS
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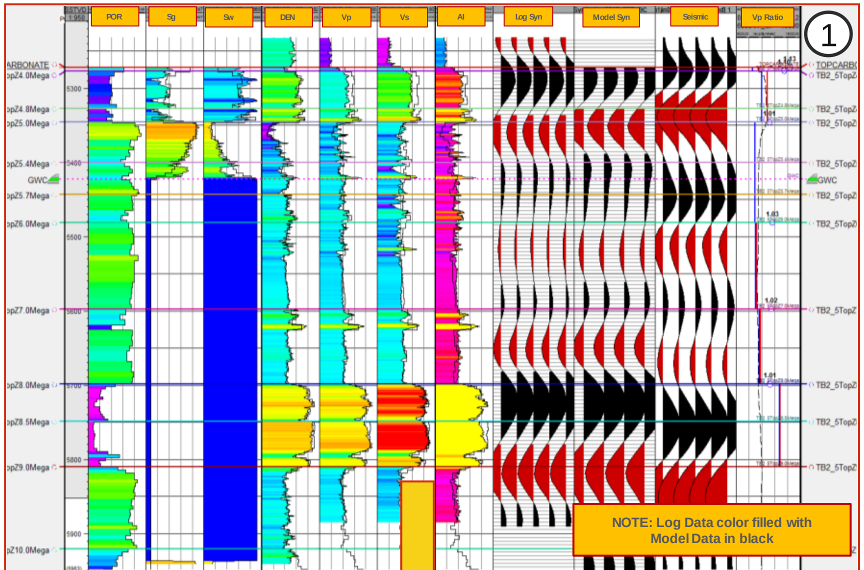
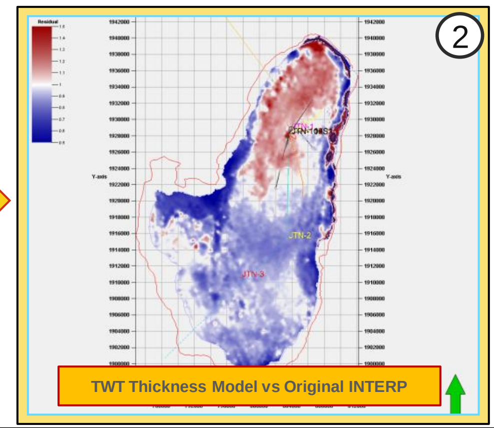
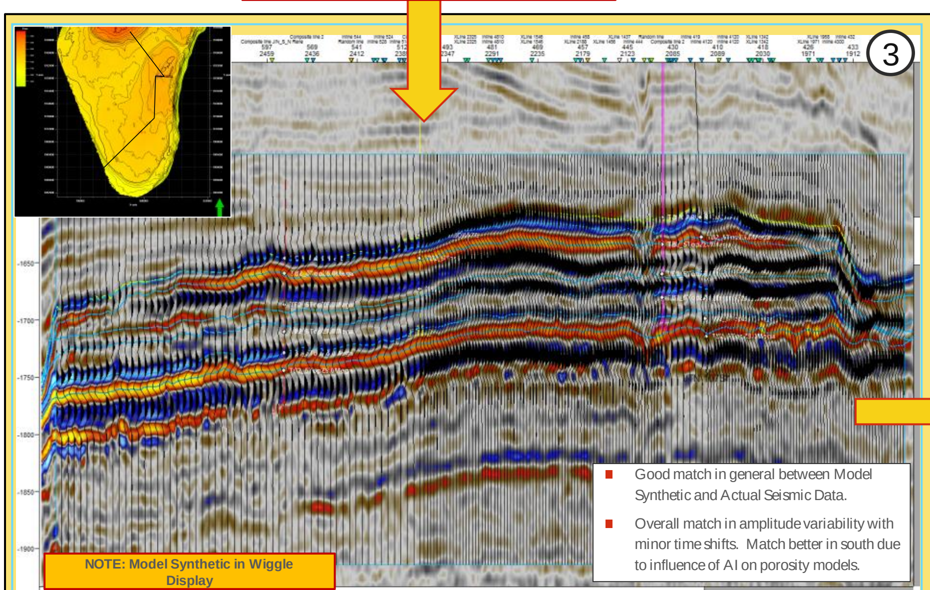


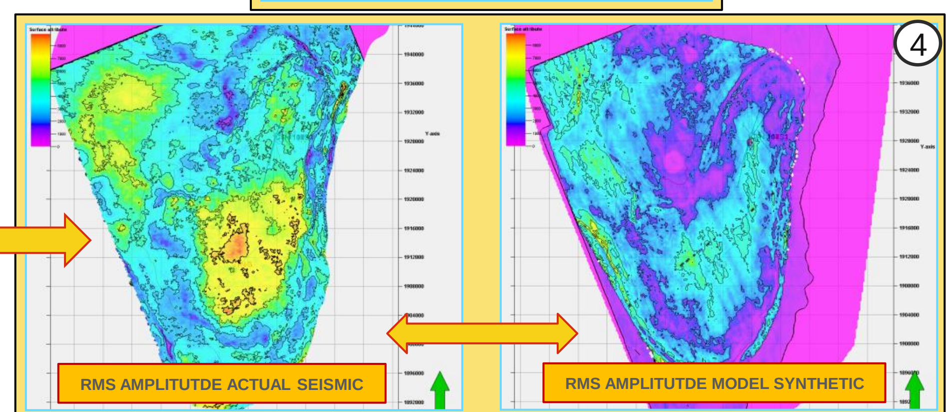
TWT CONVERSION (Vpsat from Model)

ROCK3D SYNTHETIC GENERATION

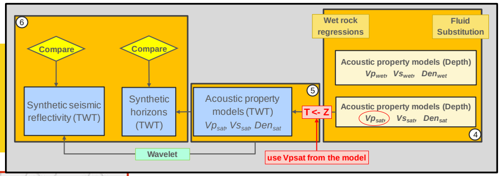
COMPARE TWT THICKNESS and RMS AMPLITUDE

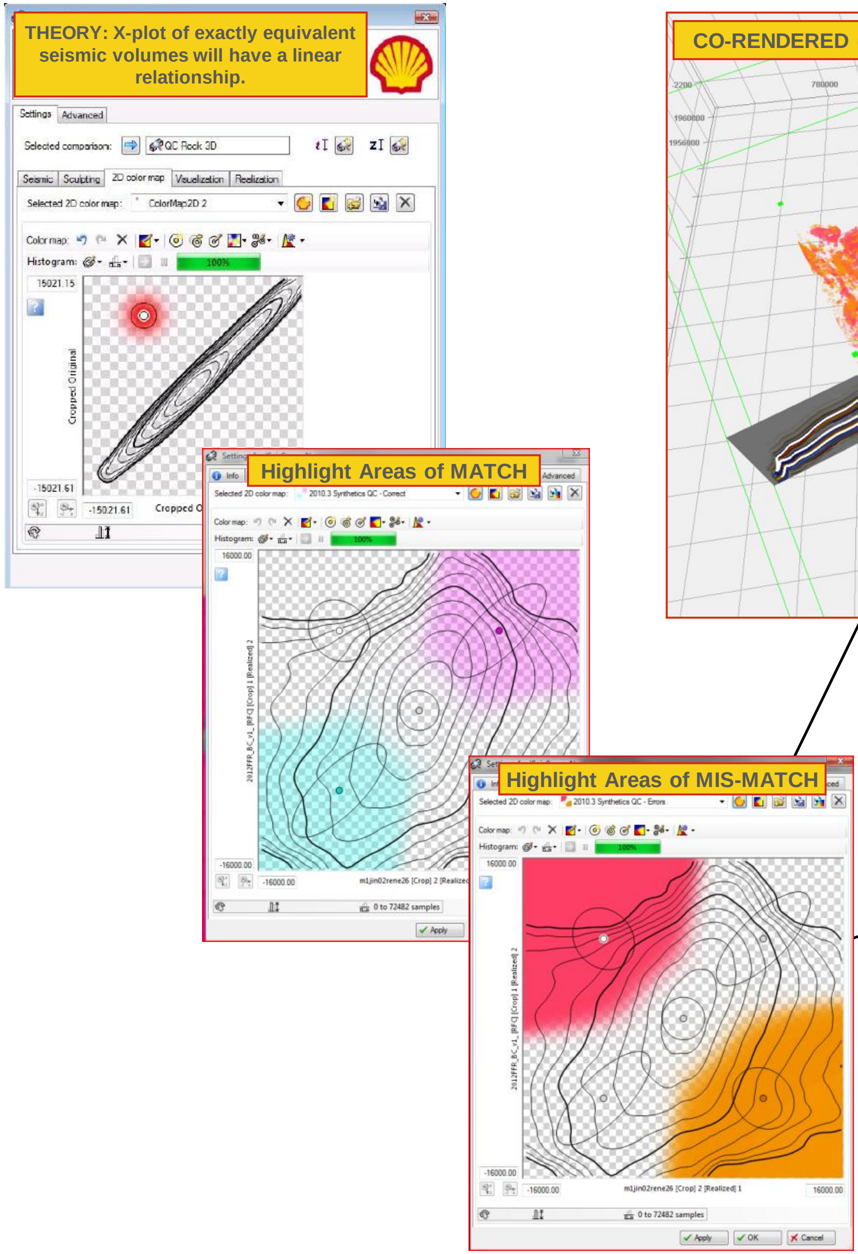


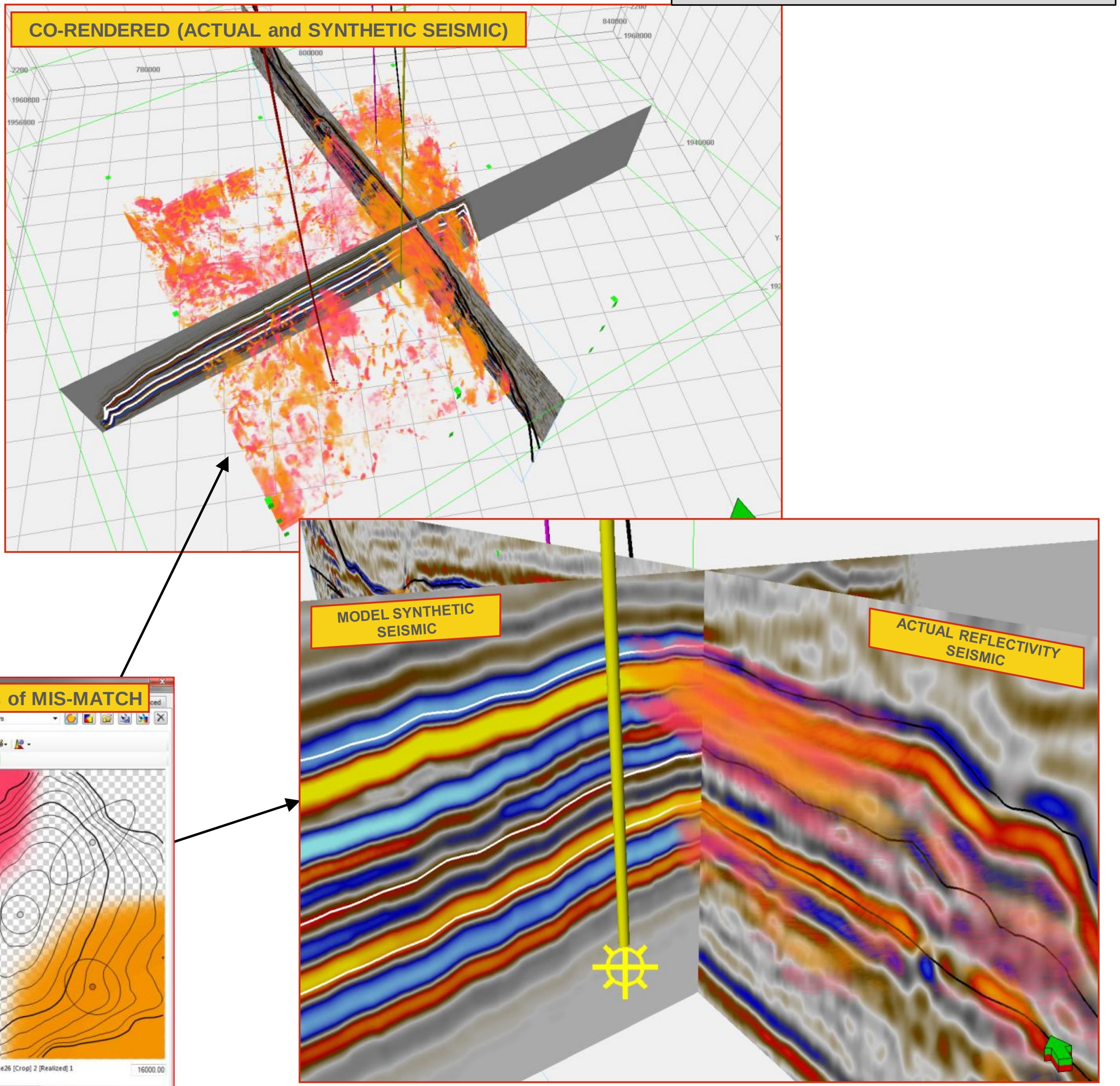




3D QC TOOLS – SHELL PLUG-IN



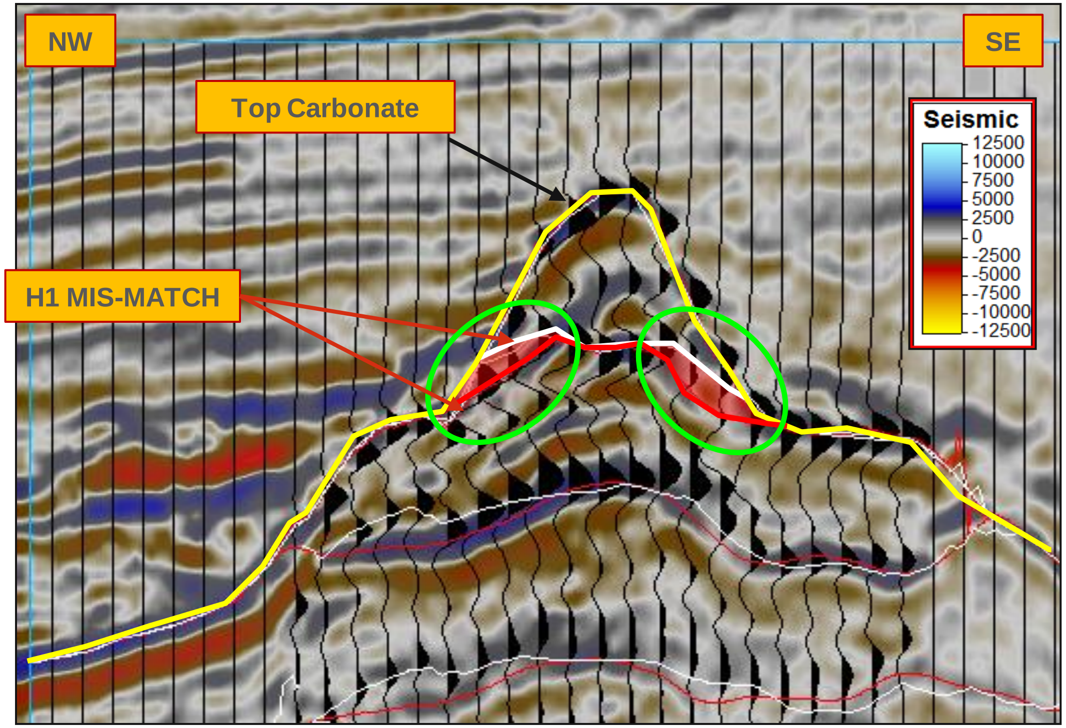




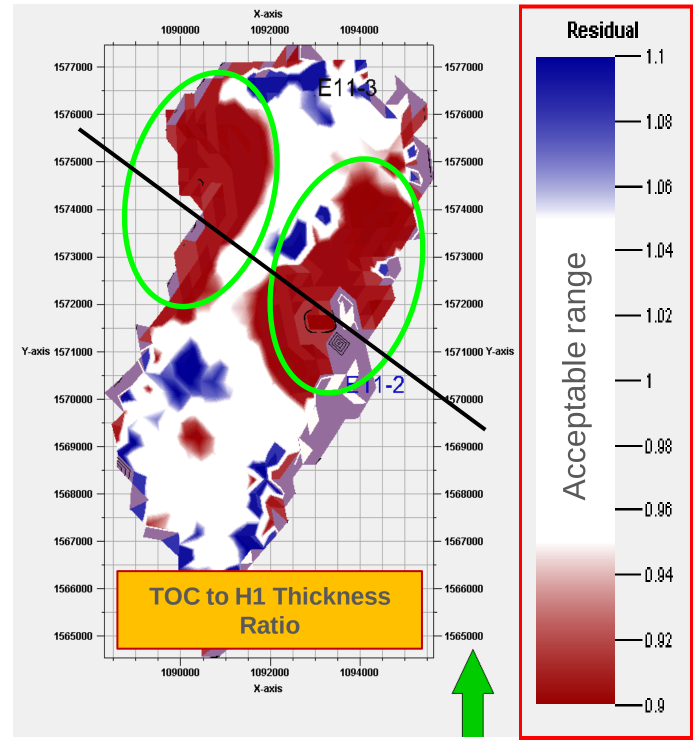
CASE STUDIES

Field Examples from Sarawak Luconia Carbonate Play.

FIELD A - INTERNAL ZONE ARCHITECTURE



Actual seismic (coloured) vs. synthetic seismic (wiggles) TWT
Red line = interpretation horizon ; White line = model horizon



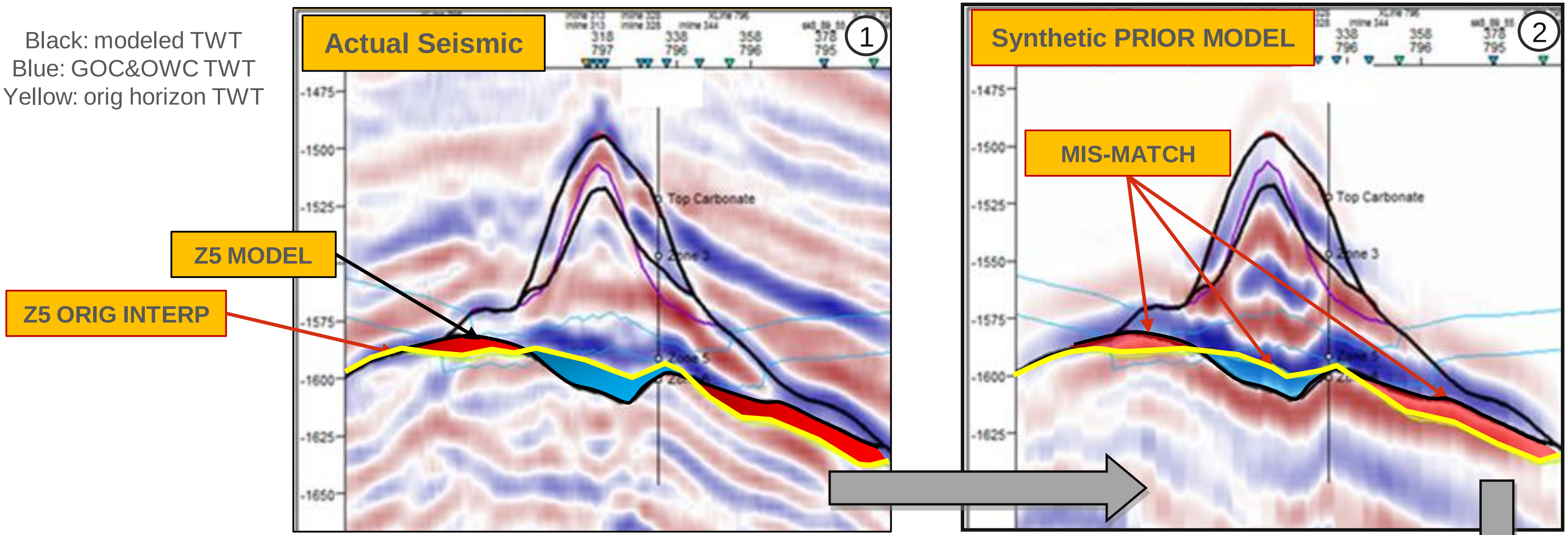
Synthetic versus actual time thickness ratio between Top Carbonate & H1.

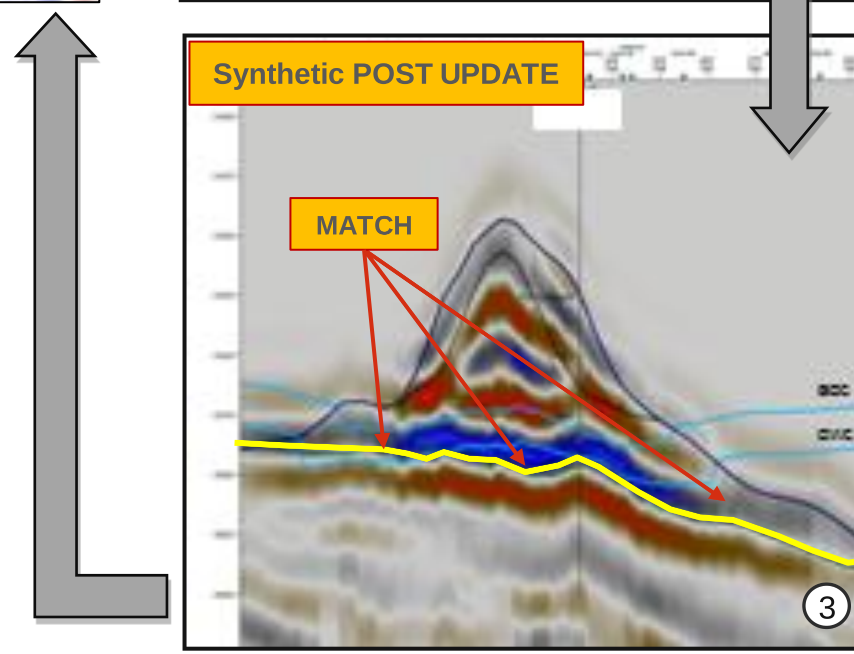
Red = modelled time thickness
< actual time thickness

- Discrepancies could be due to either:
  - Incorrect framework model
  - Incorrect porosity model
  - Incorrect Porosity-Vp regression.
- Incorrect framework model will impact GIIP estimates and dynamic behaviour of baffle zones etc.

FIELD B - INTERNAL ZONE ARCHITECTURE

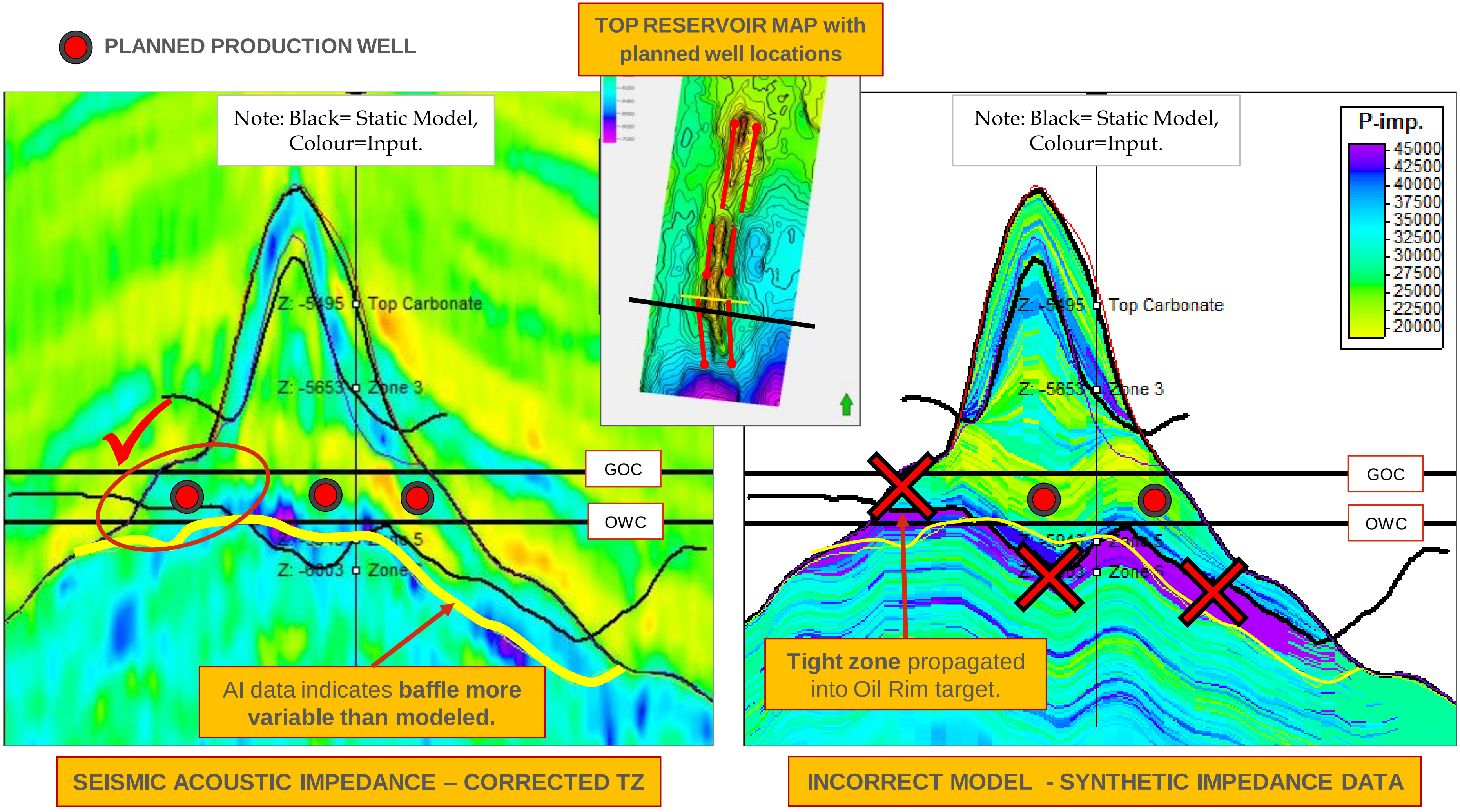
PRE-DEVELOPMENT





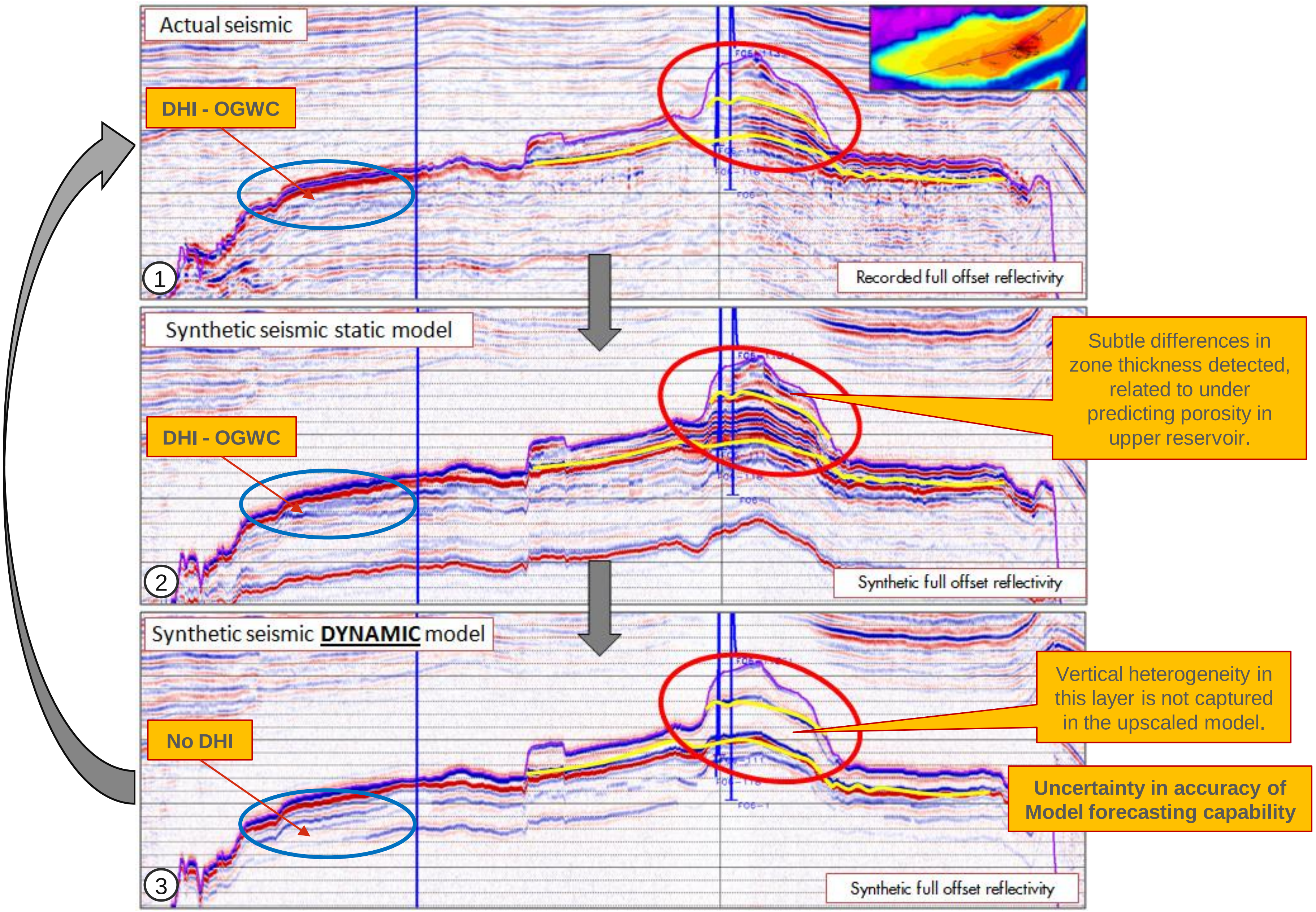
- Error with original velocity model has been detected.
- The error highlighted by difference in modelled and original marker (Z5) marking top of a field wide tight layer.
- Positioning of this layering scheme with respect to OWC critical to assessment of development concept.

DEVELOPMENT PLANNING (OLD VS. UPDATED MODEL)

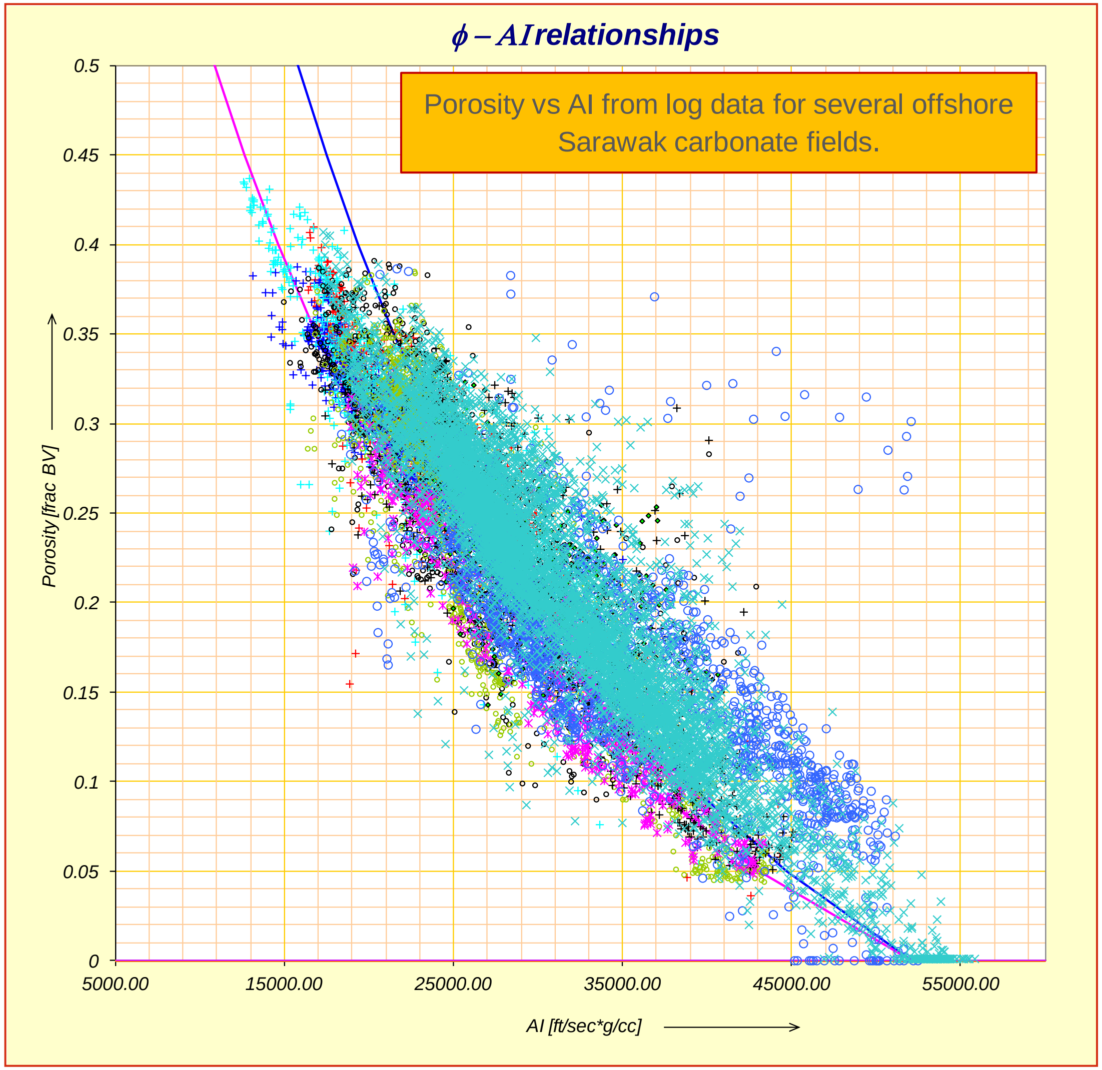


- The errors have been identified and corrected. This leads to improved model based predictions for well performance.
- Better risk mitigation, optimal well placement and development concept screening.

FIELD C: LAYERING ARCHITECTURE AND UPSCALING

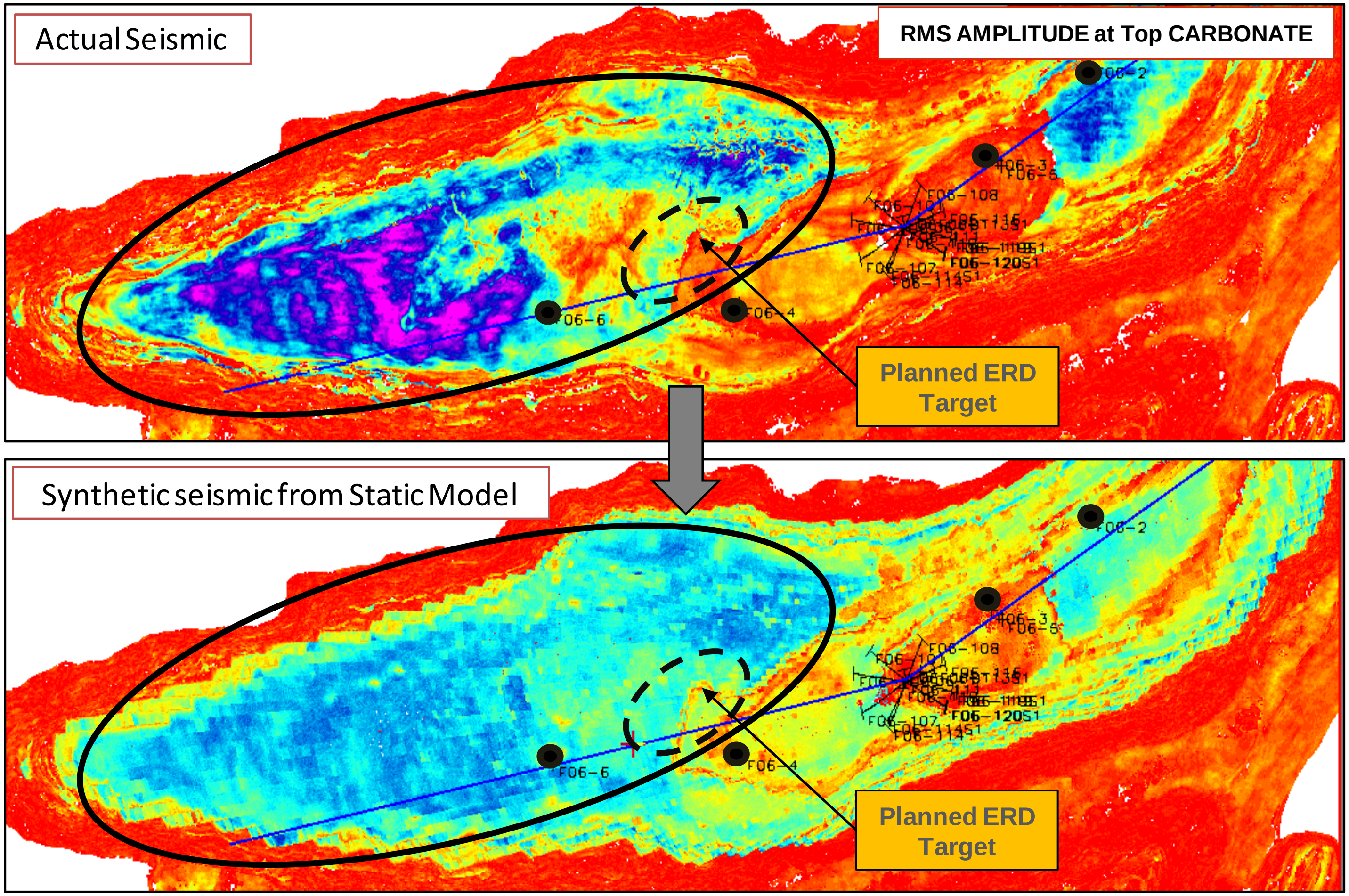


POROSITY PREDICTION IN SARAWAK CARBONATES



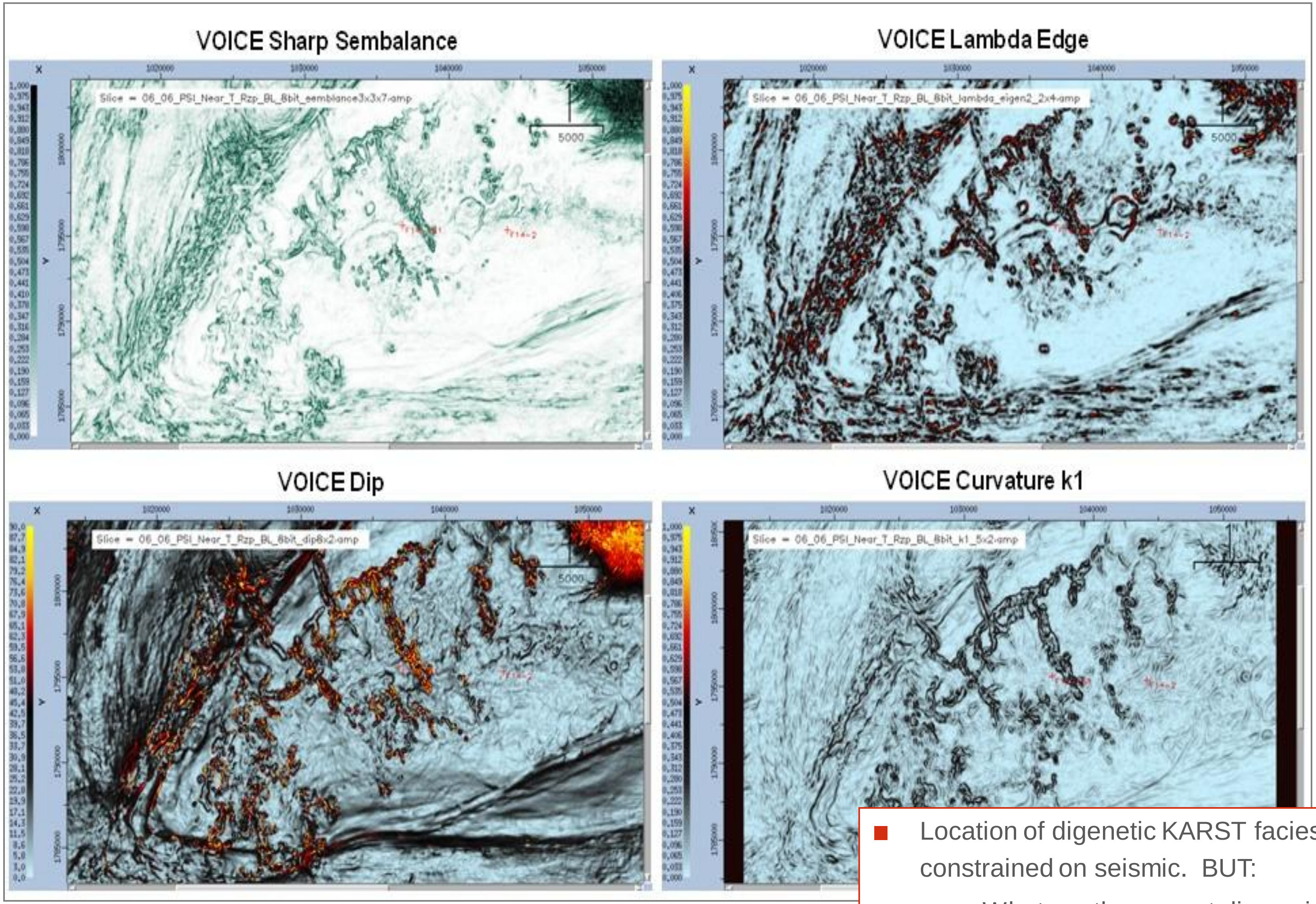
- To predict lateral porosity variations, we assume a relationship between porosity & AI.
- This relationship is poor at the log scale and core scale measurement, evidence suggests that it is reasonably good at the seismic scale.
- Therefore seismic AI data is used as a secondary variable to constrain porosity in our models.
- UNCERTAINTIES:
  - AI Processing (LFM and ULFM).
  - Absolute vs. Relative AI Data.
  - Seismic Data Quality.
  - Impact of gridding algorithm and geostatistical parameters.

FIELD C: LATERAL POROSITY VARIATIONS IN MODELS



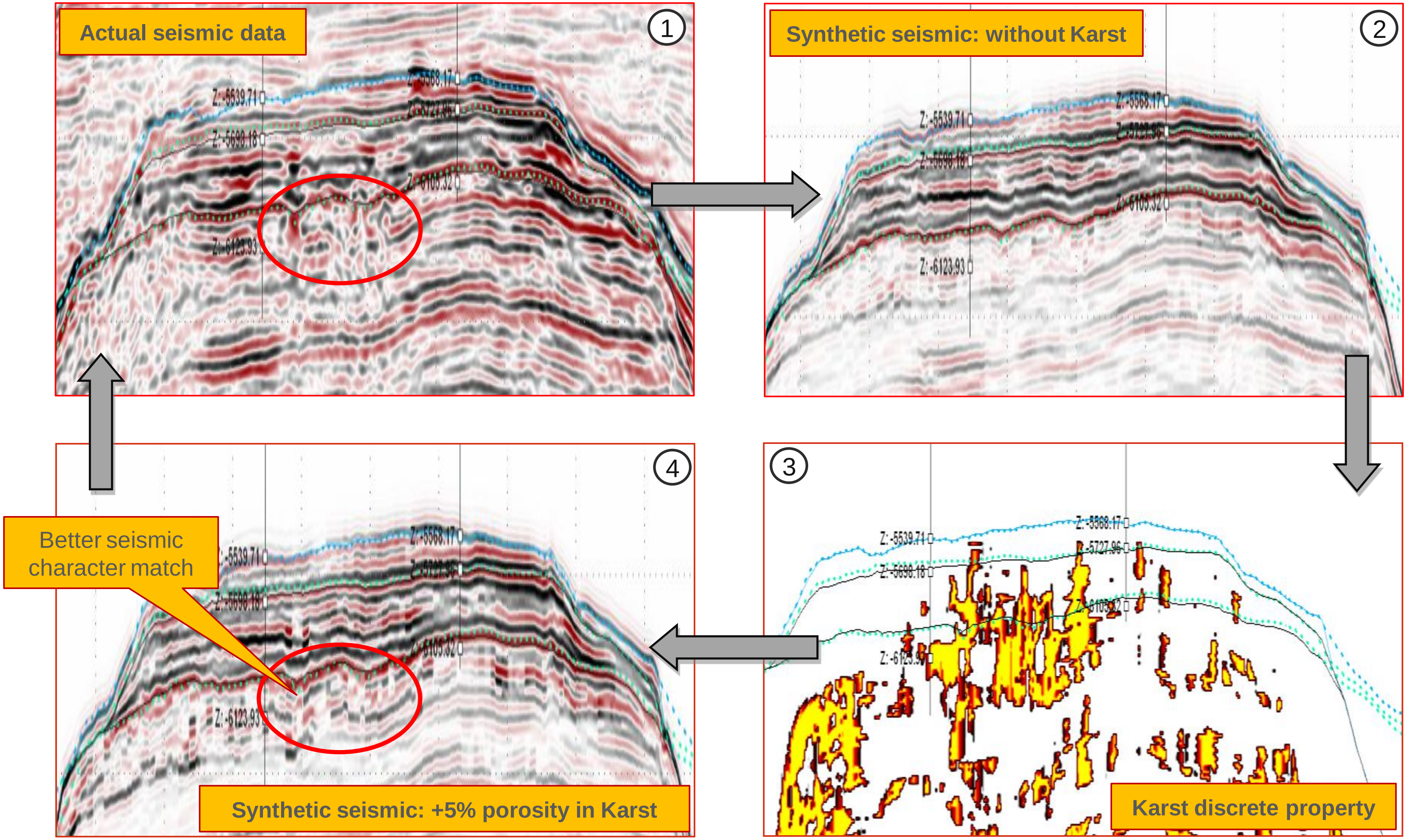
- Overall match between synthetic and actual RMS amplitudes trends are reasonable. What constitutes a good match is field specific, dependent of various factors.
- Workflow highlights potential uncertainty in porosity prediction away from well control, impacting infill well target analysis. Model QC workflows are valuable INTEGRATION tools.

MODEL THEME: VALIDATING KARST PROPERTIES



- Location of digenetic KARST facies are well constrained on seismic. BUT:
  - What are the correct dimensions to model?
  - What are the correct properties to assign?

FIELD D - VALIDATING KARST PROPERTIES

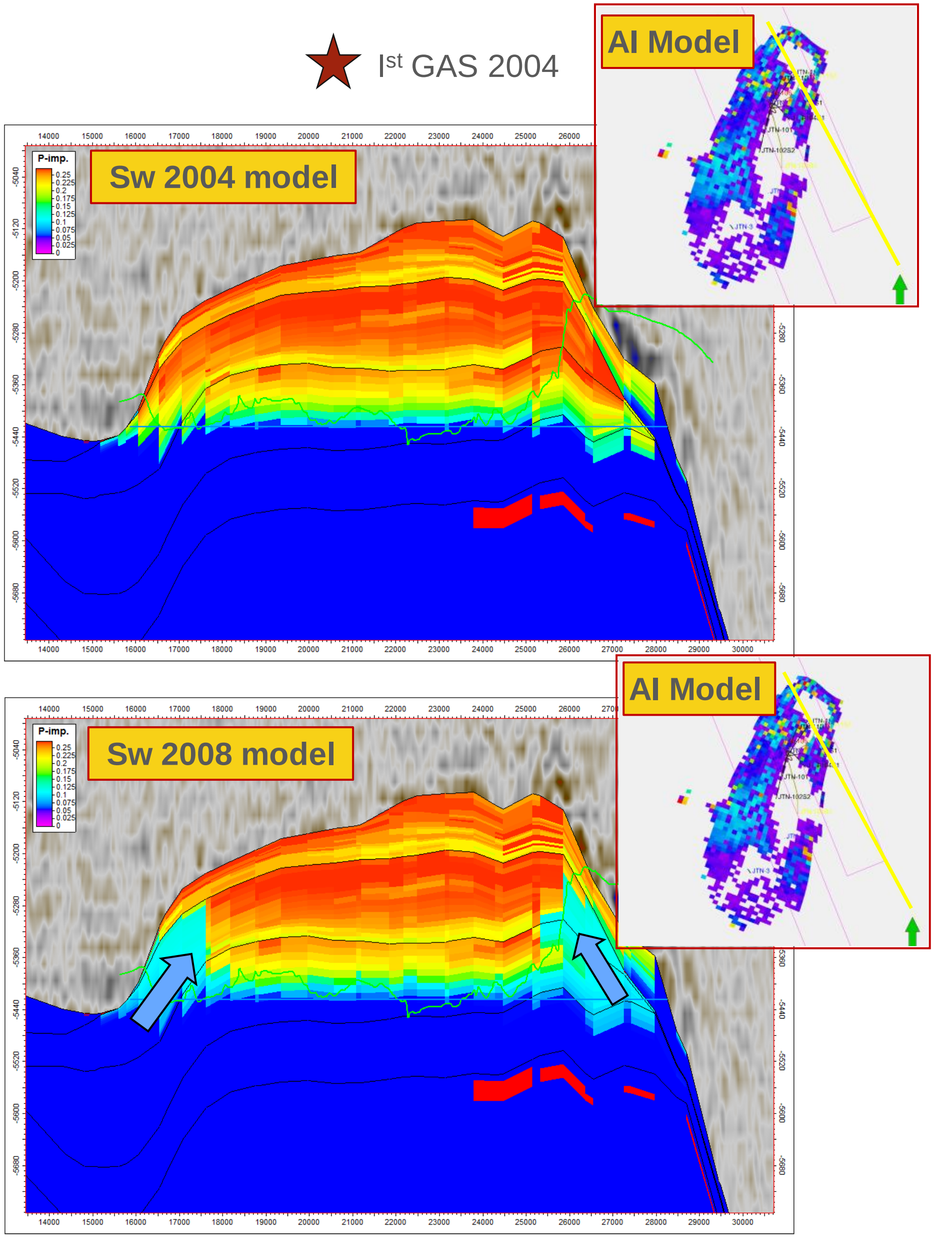


- Using an iterative approach, the most optimal property is assigned that gives closest match to actual seismic character associated with a diagenetic karst facies.

FIELD E: DYNAMIC SIMULATION COMPARED TO 4D SIGNAL

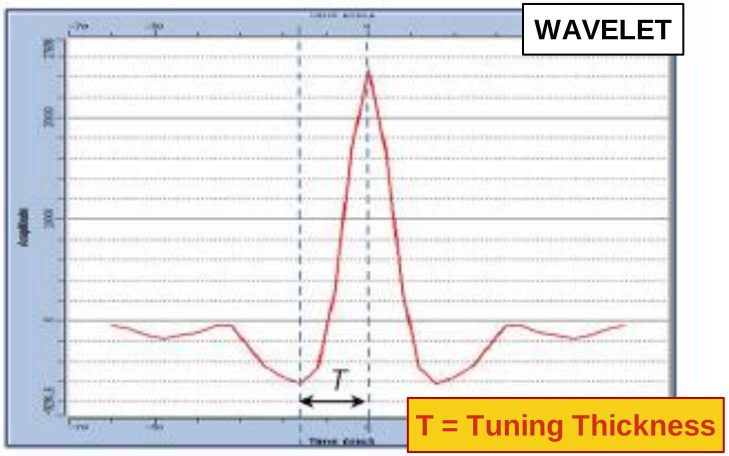
- Timing of water breakthrough is a key challenge and subsurface uncertainty.
- Time-step Saturation Models can be compared to equivalent Time-Lapse Seismic volumes.

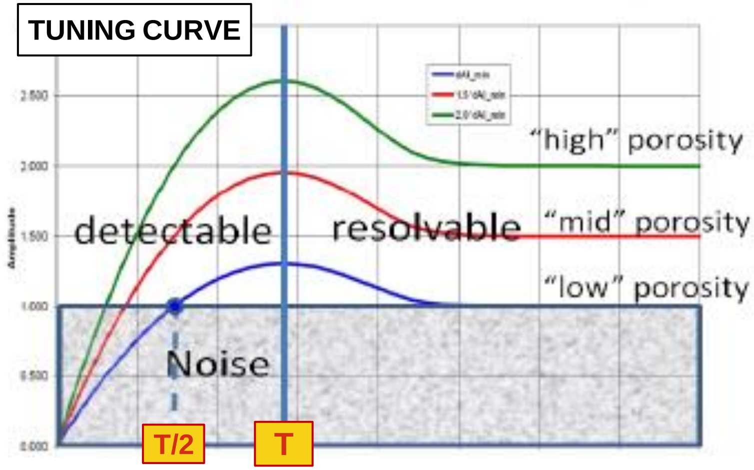
- The % AI change from the models are compared to acquired 4D signal (difference).
- Mismatch between AI difference vs 4D signal indicates where water movement is not properly constrained.



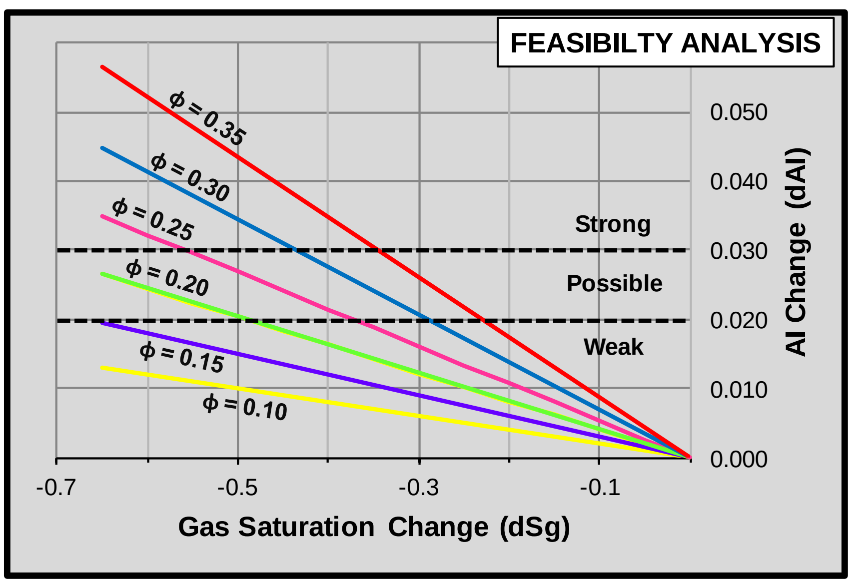
FILTERING FOR DETECTABLE 4D SIGNAL – SARAWAK HISTORY

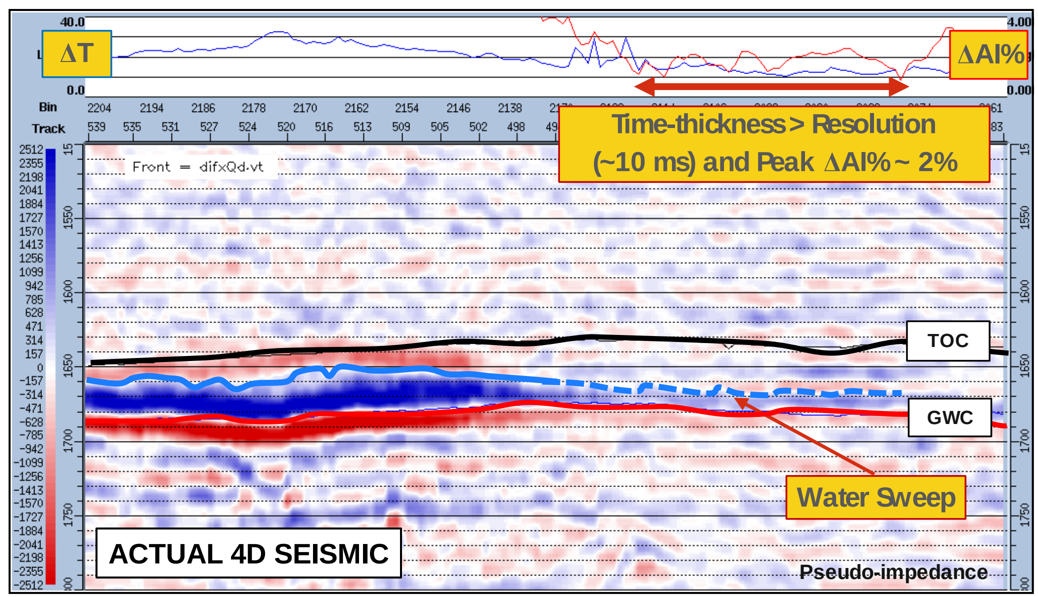
1. MINIMUM SWEEP THICKNESS





2. MINIMUM AI CHANGE (Sg CHANGE)





FILTERING FOR DETECTABLE 4D SIGNAL – SARAWAK HISTORY

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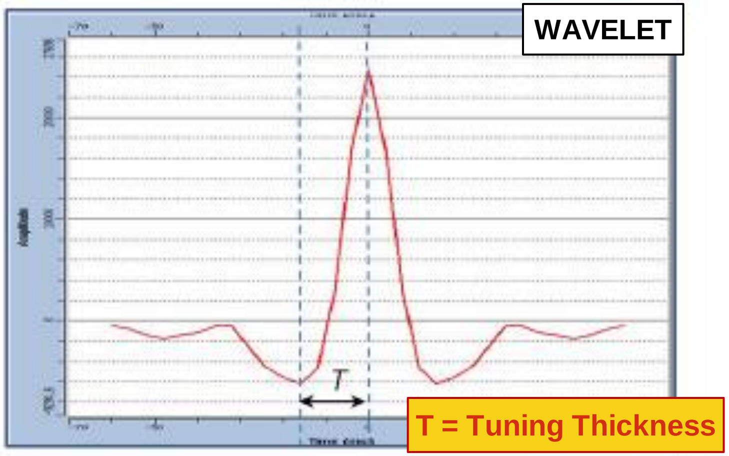
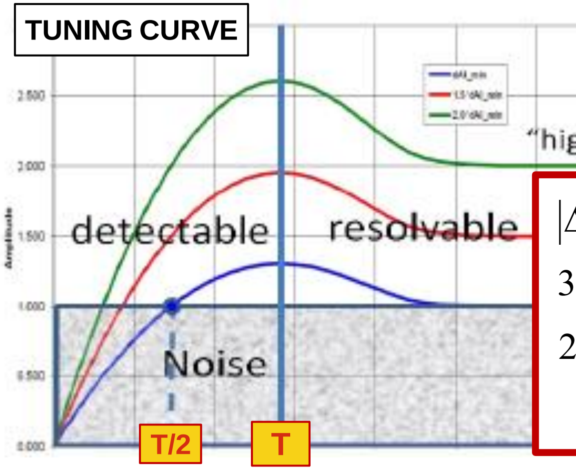




FIELD E:
MIN SWEEP approx 33ft

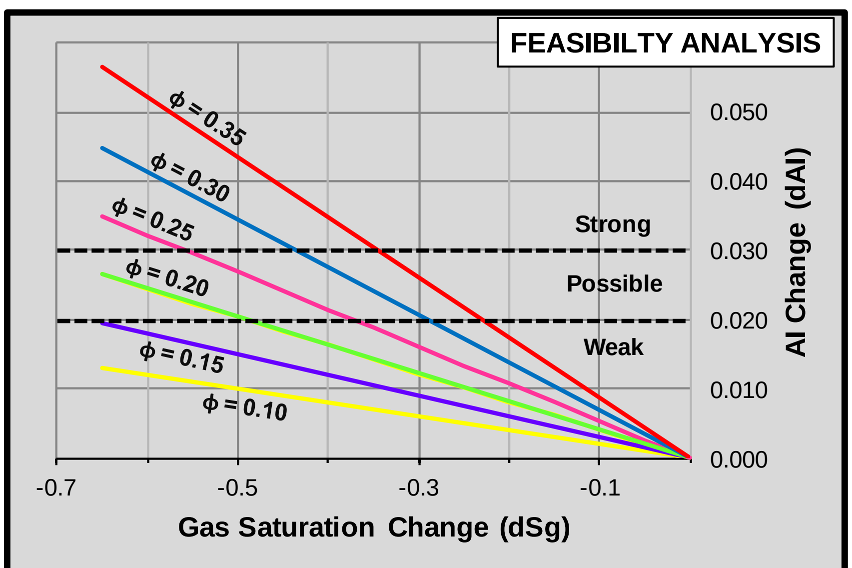
$$|\Delta AI\%| > 3\% \quad \rightarrow strong$$

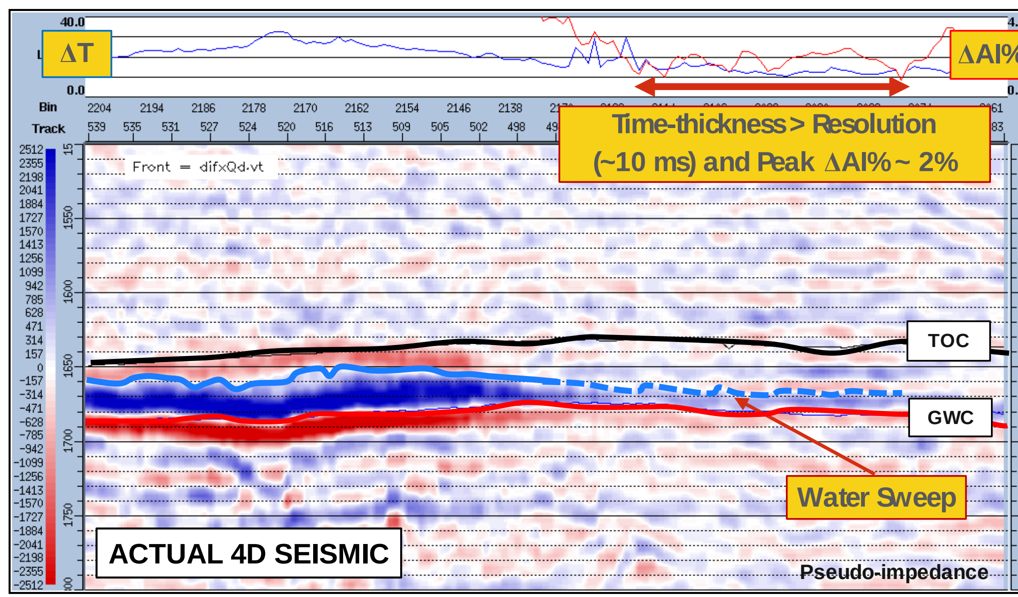
$$3\% > |\Delta AI\%| > 2\% \quad \rightarrow possible$$

$$2\% > |\Delta AI\%| \quad \rightarrow weak$$

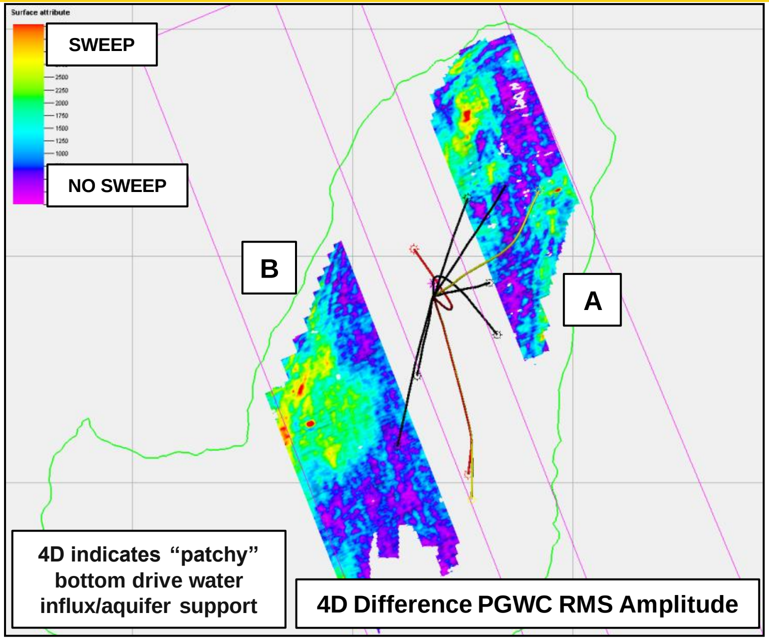
Screening criteria

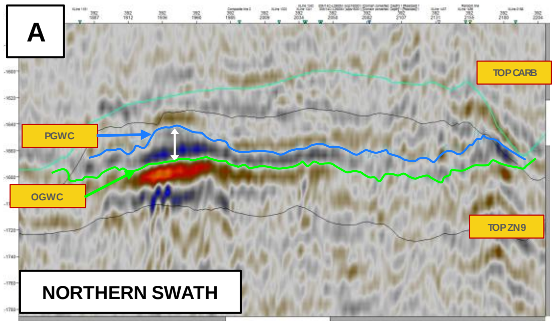
2. MINIMUM AI CHANGE (Sg CHANGE)

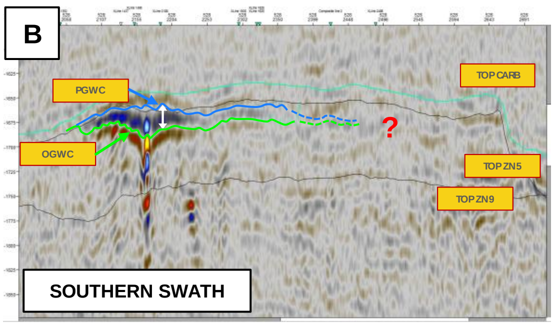


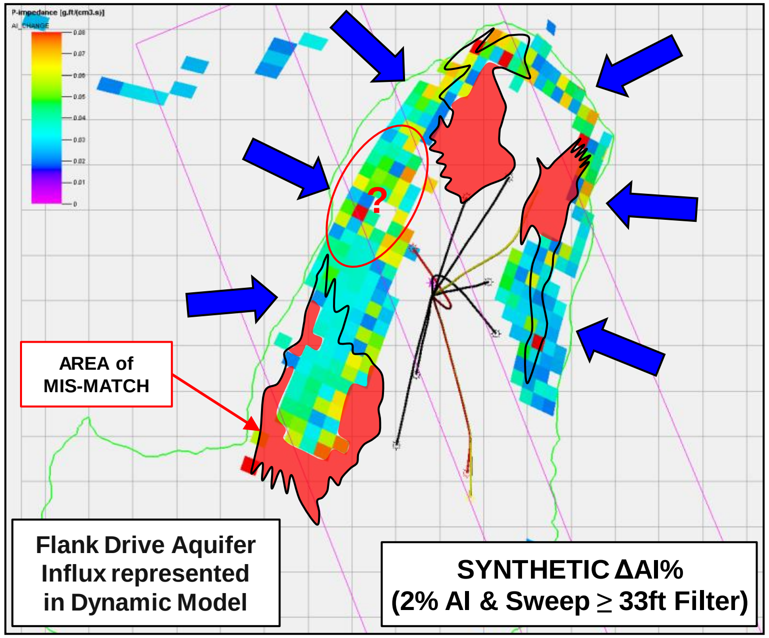


FIELD E: DYNAMIC SIMULATION COMPARED TO 4D SIGNAL



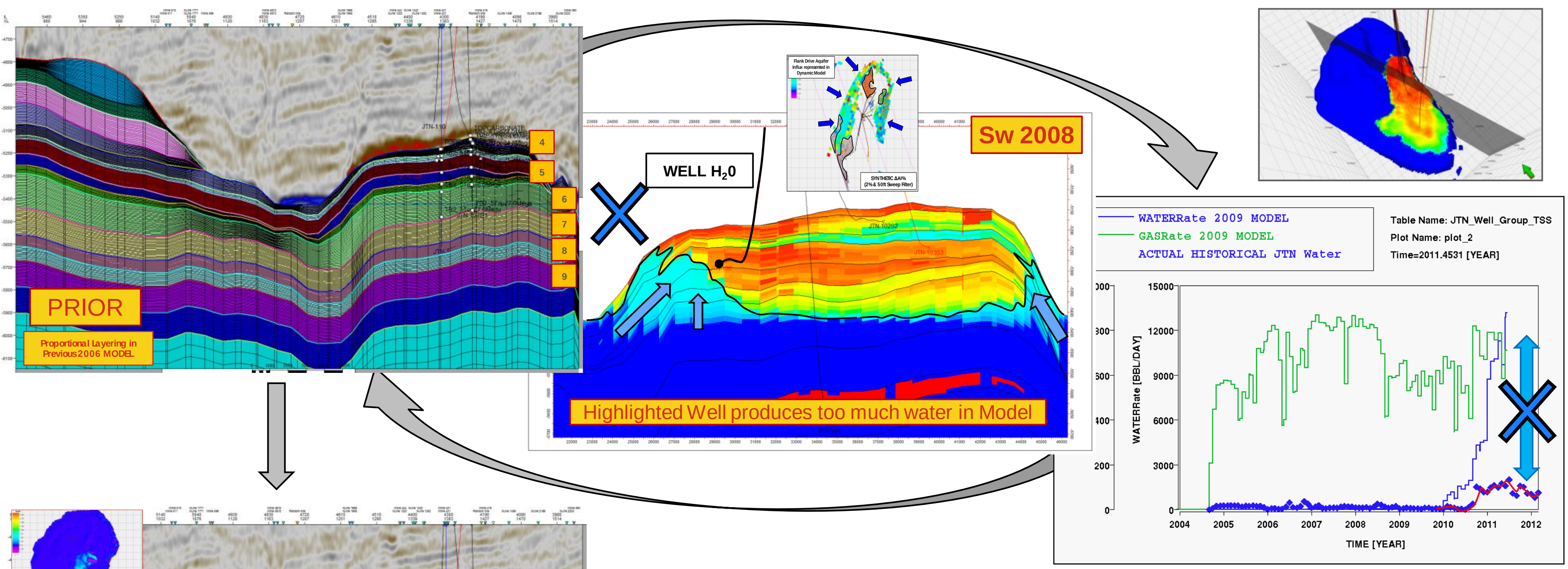


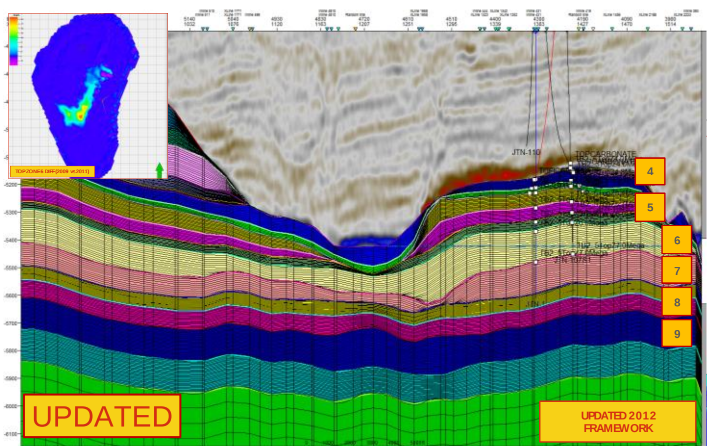


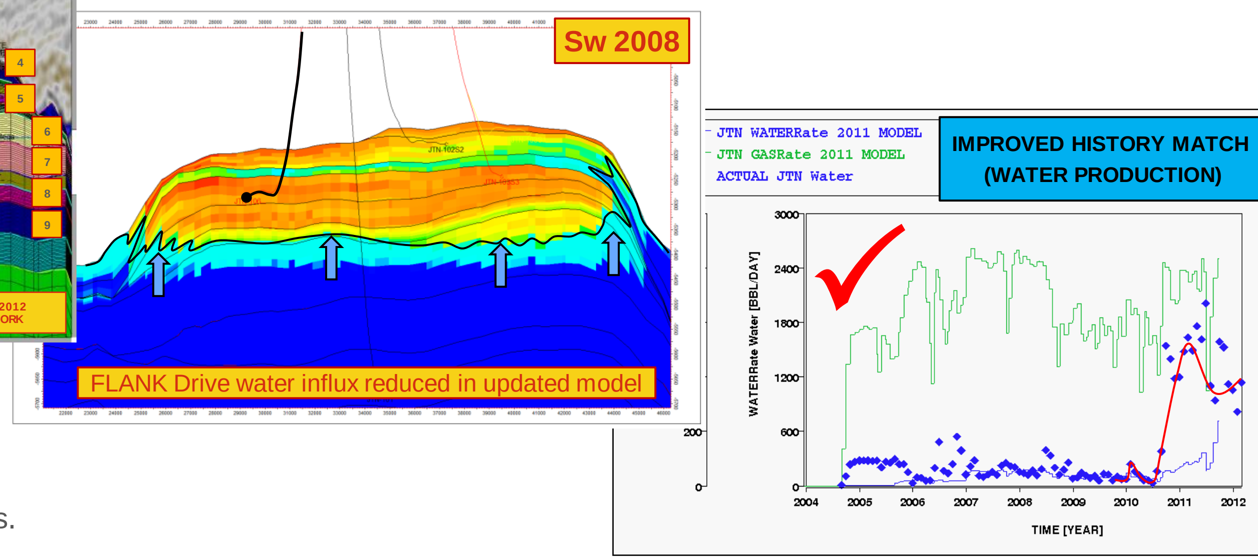


- Enhanced use of 4D seismic in dynamic simulations and constraining of water breakthrough predictions.
  - 4D data points towards "patchy" bottom drive aquifer influx.
  - Previous dynamic model predicts a general flank drive driven water encroachment.
- A 2% ΔAI and minimum height above contact (33ft) filter is applied to the synthetic AI model, to match minimum 4D signal that can be detected.
- Areas of mis-match between 4D signal and modeled AI change are easily highlighted.

FIELD E: COMPARISON BETWEEN PRIOR AND UPDATED MODELS







- Framework updated based on 4D Seismic mismatch, incorporating revised geological and reservoir engineering understanding.
- Effective close-the-loop between disciplines.

CONCLUSIONS

- **Synthetic Seismic Validation:**
  - Encourages Geo-Modellers to ‘think seismic’ and Geophysicists to ‘think geology’.
  - **Early Detection Tool** alerting subsurface teams to issues in modeling approach/strategy and provides easy tool for **Iterative Model Updating**.
  - Tool for **integration** between disciplines. Shorter modelling cycle times.

- **Key Leanings:**
  - The technique promotes a better understanding of the relevance of seismic amplitude variations on a subsurface model.
  - Internal reservoir architecture & layer thickness can be quickly checked through to upscaled model.
  - Use of AI data as secondary variable to constrain porosity distribution in models produces good match to seismic amplitudes.
  - Porosity enhancement in features, which are interpreted as karst, produces reasonable match to seismic data character.
  - 4D synthetic seismic validations of dynamic simulations against available 4D seismic data can be used as an additional history matching parameter.

FIELD EXAMPLES courtesy of:

- FIELD A by **Khairun Niza Baharaldin**
- FIELD B by **Kenneth Boey**
- FIELD C by **Paul Hague**
- FIELD D by **Yee Shuh Wen**
- FIELD E by **Alexander David Kayes**

PLUG, for further information please attend:

- **Yee Shuh Wen** paper on “A decade of 4D seismic monitoring of carbonate reservoirs in offshore Sarawak, Malaysia”, Wednesday 19th September.