Improving Petroleum System Analysis with Better Understanding of Seismic Input Uncertainties*

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Abstract

Seismic data serves as the primary Input for basin model construction and petroleum system analysis. The seismic data quality and interpretation directly impact basin model quality through providing inputs regarding a basin's formation depth, geometry, depositional and lithological information. Understanding seismic data and the associated uncertainties will allow for effective incorporation of seismic information into basin models to enhance the model's geologic content and predictive capability.

The scheme employs integrating seismic data within a 3D basin model as the basis of analysis. During the model building process, seismic attributes are extracted and interpreted in order to use these variables to optimize the basin's geologic elements and populate the litho-facies. The seismic sections or cube inserted into the 3D basin model provides visual and dynamic connections between the seismic data and the basin model. This allows for optimization in establishing correlations and interactions between petroleum system components and seismic characteristics.

Uncertainty analysis is performed using the integrated model. The analysis covers the uncertainties of seismic velocity model building, time / depth conversion, amplitude characteristics and their implication on the lithological composition of formations, attribute geometry variations and their impact on the depositional environment. Another topic of interest involves an investigation of the relative magnitude of the seismic input uncertainties and the intrinsic uncertainties in basin model regarding the "trade-off" effect in modeling uncertainties. Some of the uncertainties in seismic data may be so overwhelming that the uncertainties of the exploration are primarily determined by the seismic data, while some uncertainties may have strong correlations with those in basin model such that the overall uncertainties of modeling may be inflated or reduced by these correlations.

Case studies from deepwater basins of the northern margin of South Atlantic area show that this uncertainty analysis influences the selection of modeling methodologies, improves the source rock maturity prediction, provides clearer understanding of hydrocarbon migration patterns, and incorporates estimates of the nature and volume of hydrocarbon accumulations.

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 Chevron Africa and Latin America E&P

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Introduction

- Seismic data serves as the primary Input for basin model construction and petroleum system analysis

- The seismic data quality and interpretation directly impact basin model quality through providing inputs regarding a basin's formation depth, geometry, depositional and lithological information

- Understanding seismic data related uncertainties will allow for effective incorporation of seismic information into basin models to enhance the model's geologic content and predictive capability
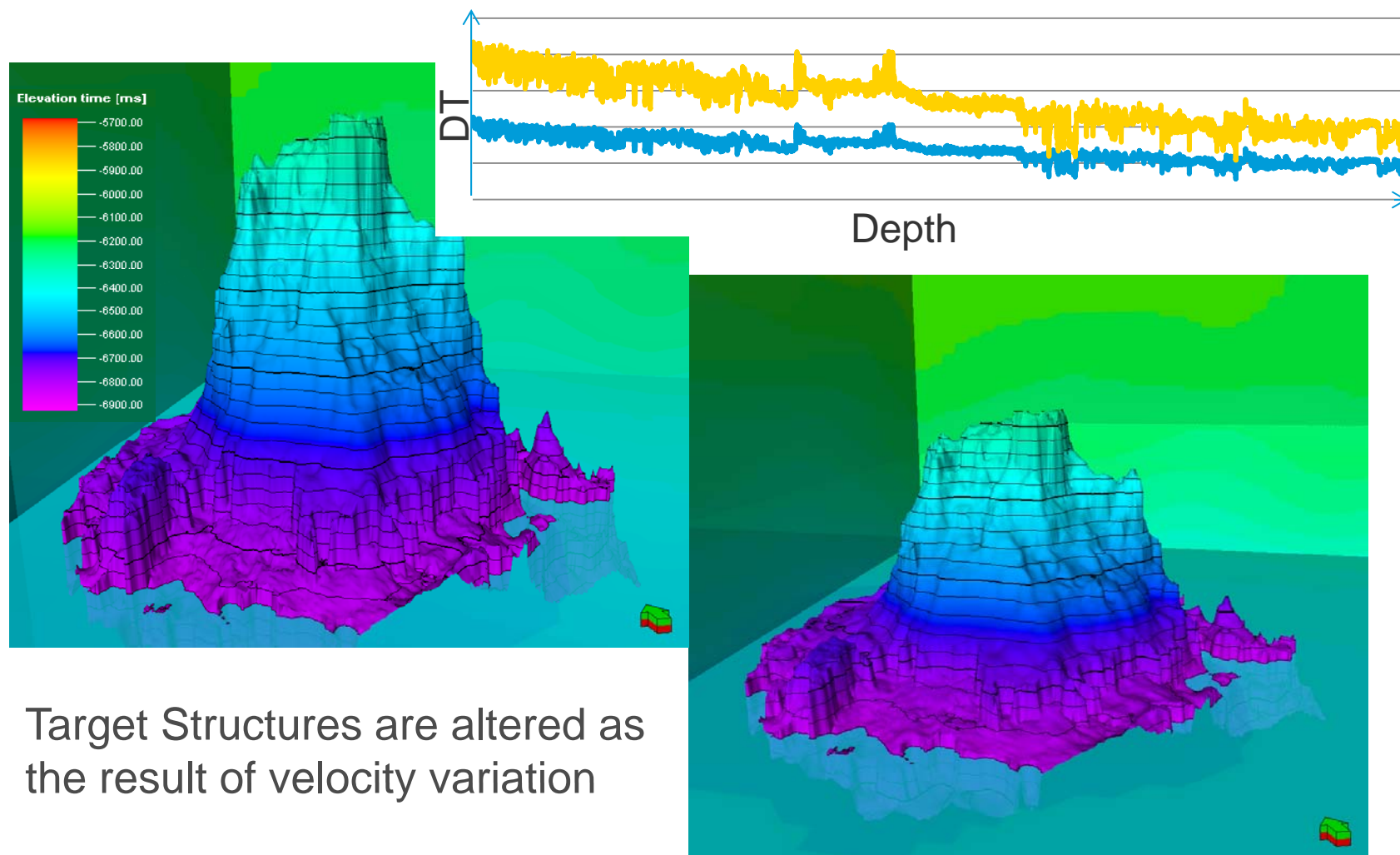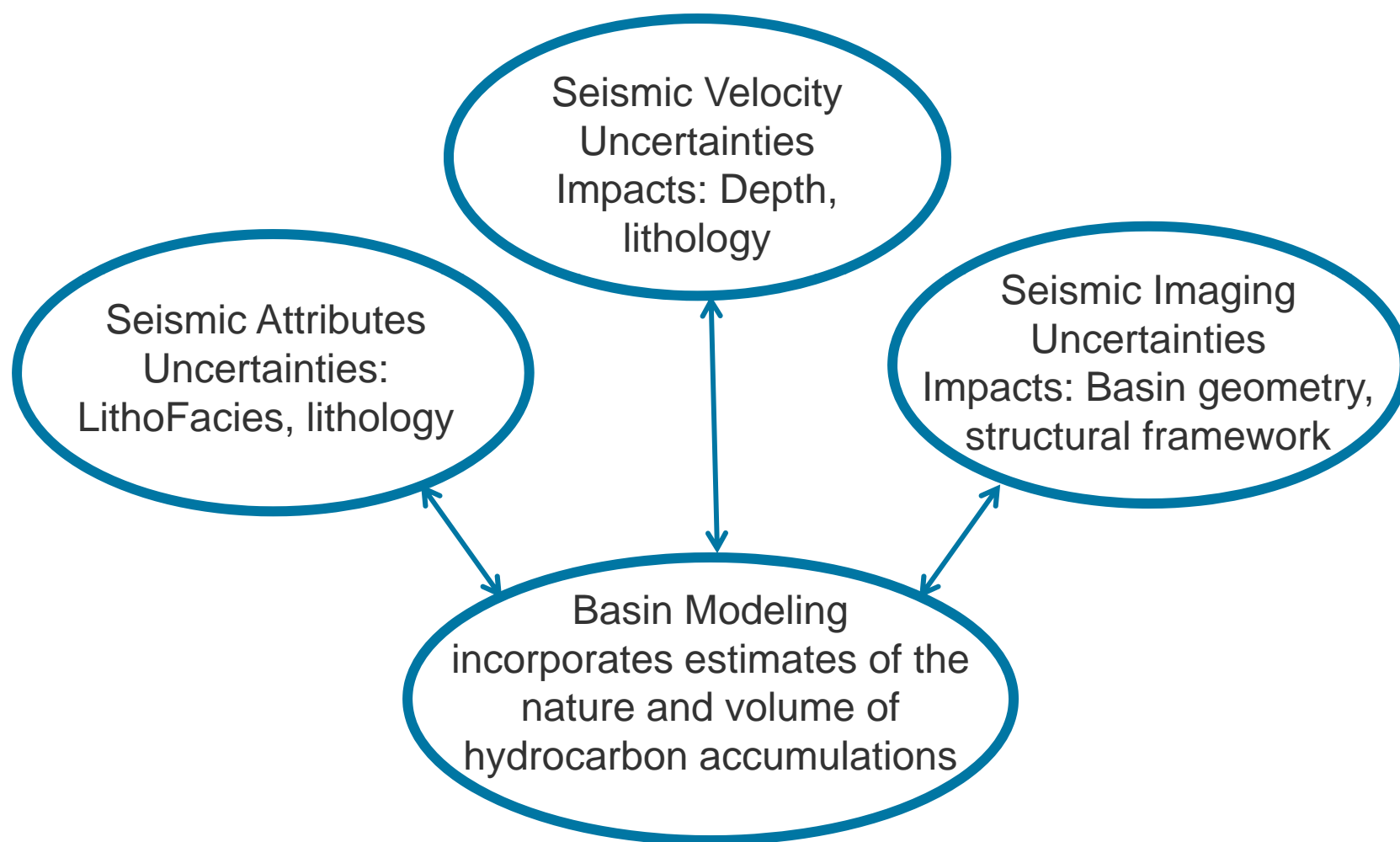
Key Seismic Data Related Uncertainties

- The uncertainties of seismic velocity model building in regarding to time to depth conversion

- The uncertainties of seismic amplitude characteristics and their implication on the lithological composition of formations, attribute geometry variations and their impact on the depositional environment

- The uncertainties of seismic imaging and their impact on basin structural framework and the geometry of the accommodation space

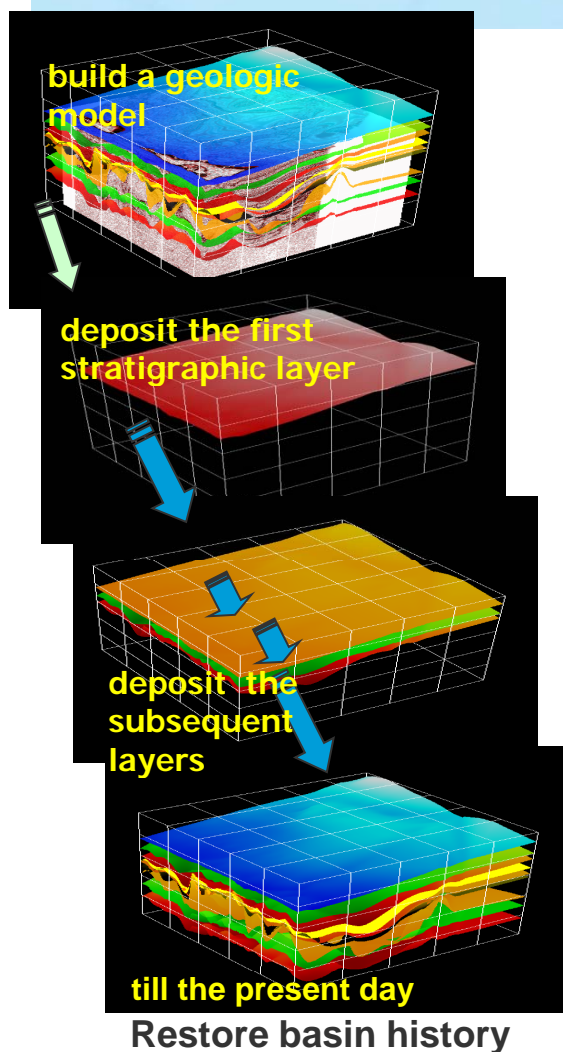# Example of Velocity Uncertainties impacts on Target Zone Structure Geometry

Target Structures are altered as the result of velocity variation

Seismic Uncertainties Basic Elements

Seismic Velocity Uncertainties Impacts: Depth, lithology

Seismic Attributes Uncertainties: LithoFacies, lithology

Seismic Imaging Uncertainties Impacts: Basin geometry, structural framework

Basin Modeling incorporates estimates of the nature and volume of hydrocarbon accumulations

Basin Modeling Uncertainties

- Two types of uncertainties – user input and model intrinsic

- Seismic data impact basin modeling in basin geometry and litho-contents - on source maturity and HC migration

- Detailed geologic data and modeling to reduce uncertainties

- Interaction of seismic data analysis and basin modeling to maximize value of available data
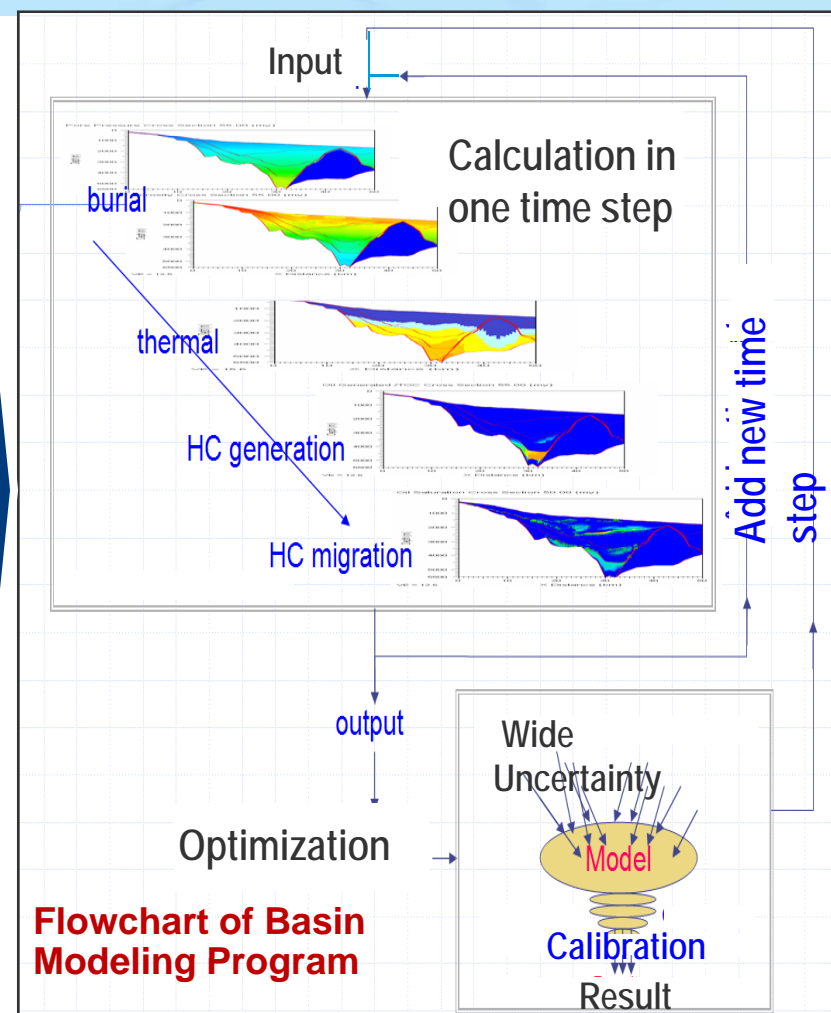
Basin Modeling General Workflows

build a geologic model

deposit the first stratigraphic layer

deposit the subsequent layers

till the present day

Restore basin history

Integrates all petroleum system components:

source,
generation,
reservoir,
seals,
trap,
migration &
preservation

within the context of a basin's structural - stratigraphic history

Input

Calculation in one time step

burial

thermal

HC generation

HC migration

Add new time step

output

Optimization

Wide Uncertainty

Model

Calibration

Result

Flowchart of Basin Modeling Program
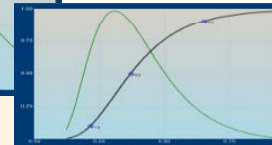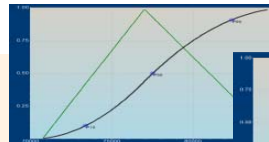
Uncertainties Within Basin Modeling

Geologic Input	Modeling Software
Depth, lithology, age, structural elements, paleo-bathymetry, measurements of pressure, porosity and permeability	Lithology compaction functions and parameters, structural functions, solver, model boundary conditions
Measurements of heat flow, temperature, vitrinite reflectance, apatite fission track, etc. basement compositions, radiogenic heat, rifting characteristics;	Thermal conductivities, heat capacities, solver and boundary conditions
Source rock properties, source rock positions, HC show / discovery observations, fluid flow related rock properties	Kinetics and expulsion functions, migration functions, solvers and boundary conditions
Uncertainty is always part of the geologic input which varies with data availability, quality, and interpretation	*Internal consistency of a modeling program is the key to make the modeling output meaningful*

Basin Model Uncertainty

uncertainty

*ambiguity* → degree of known probability → **risk**
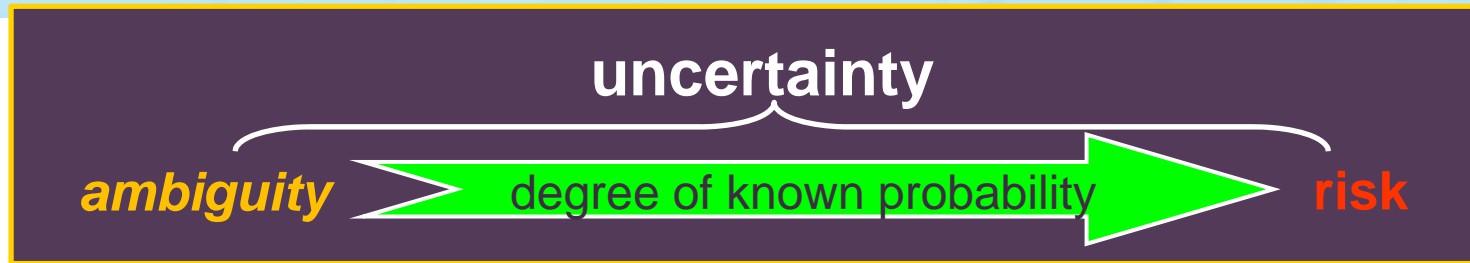
- **Uncertainty:** the predictability nature of an event

- **Risk:** the potential for realization of a consequence of an event.

- **Uncertainty** and **Risk:** closely related and can be distinguished by the degree of known probabilities. An event under risk can be seen as a special case of the event under uncertainty with precisely known probabilities

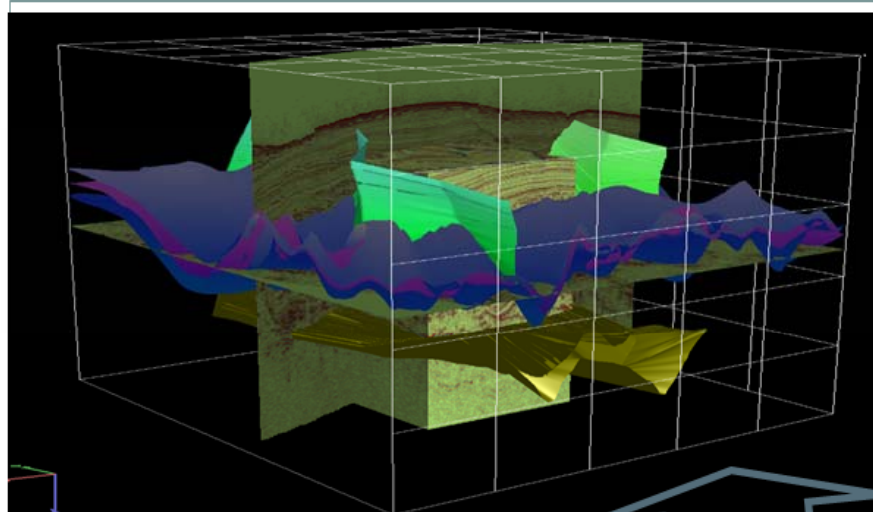- **Two main tasks** in evaluating HC charge risks:
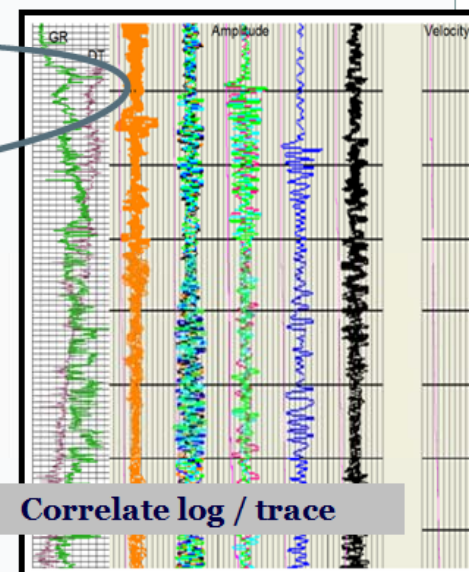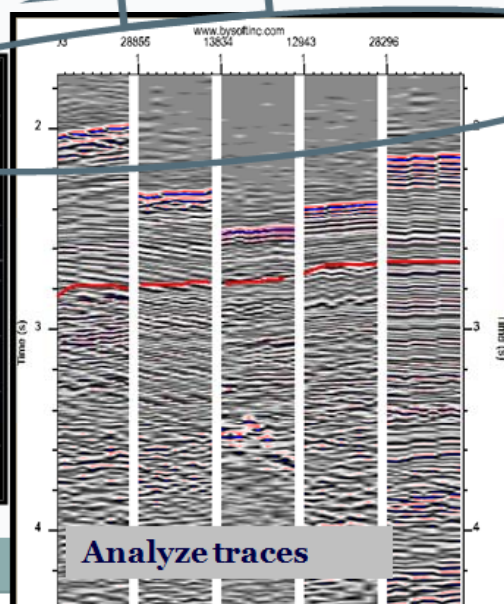
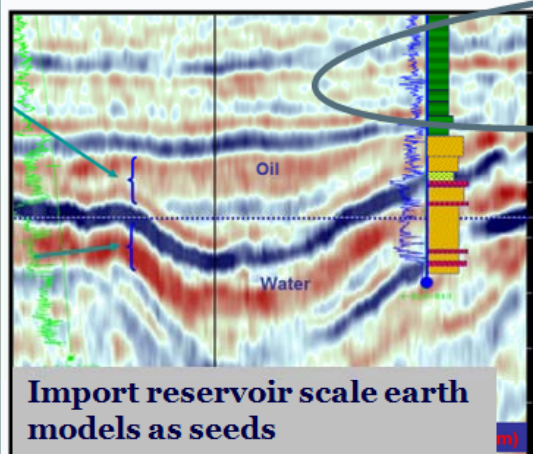   - **Quantify key uncertainties:**
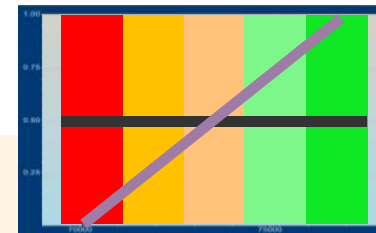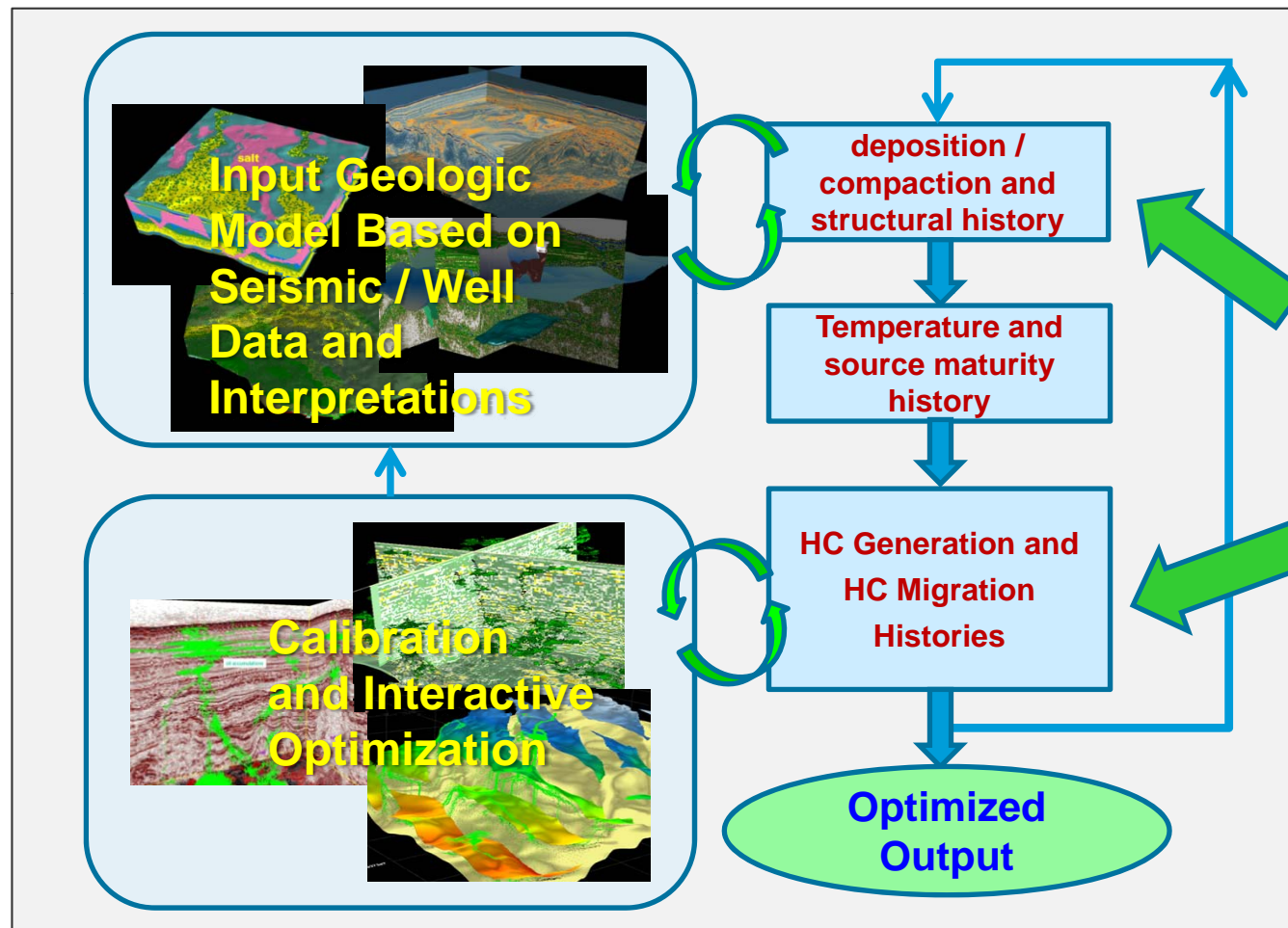
    - **Compute probabilities:**
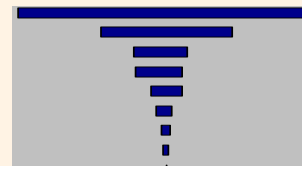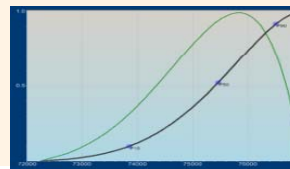
Basin Modeling Uncertainty Derived from Seismic and Well Data Inputs

Seismic Attributes and Velocity Analysis May Provide Litho-facies Control for Basin Modeling But Also Introduces Uncertainties

Import reservoir scale earth models as seeds

Analyze traces

Correlate log / trace

Interaction of Seismic Data and Basin Modeling

Input Geologic Model Based on Seismic / Well Data and Interpretations

Calibration and Interactive Optimization

deposition / compaction and structural history

Temperature and source maturity history

HC Generation and HC Migration Histories
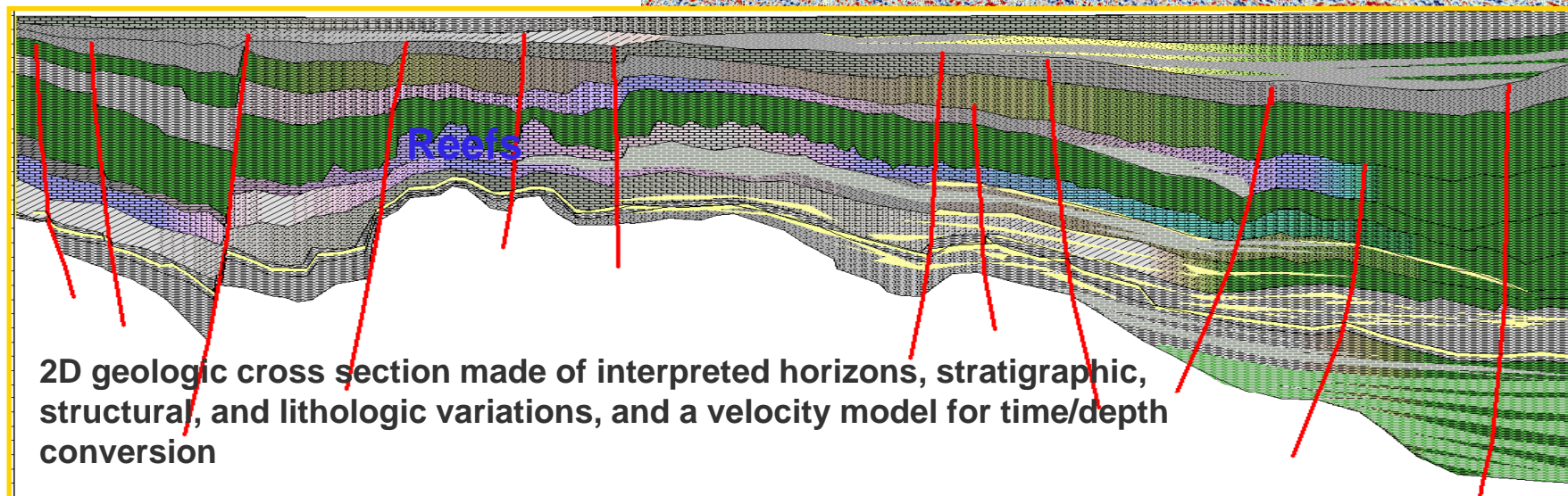
Optimized Output

Interaction of seismic data and basin modeling occurred in two processes of basin modeling to improve petroleum system analysis quality

# Interaction of Seismic Data and Basin Modeling to Reduce Uncertainty

Reefs
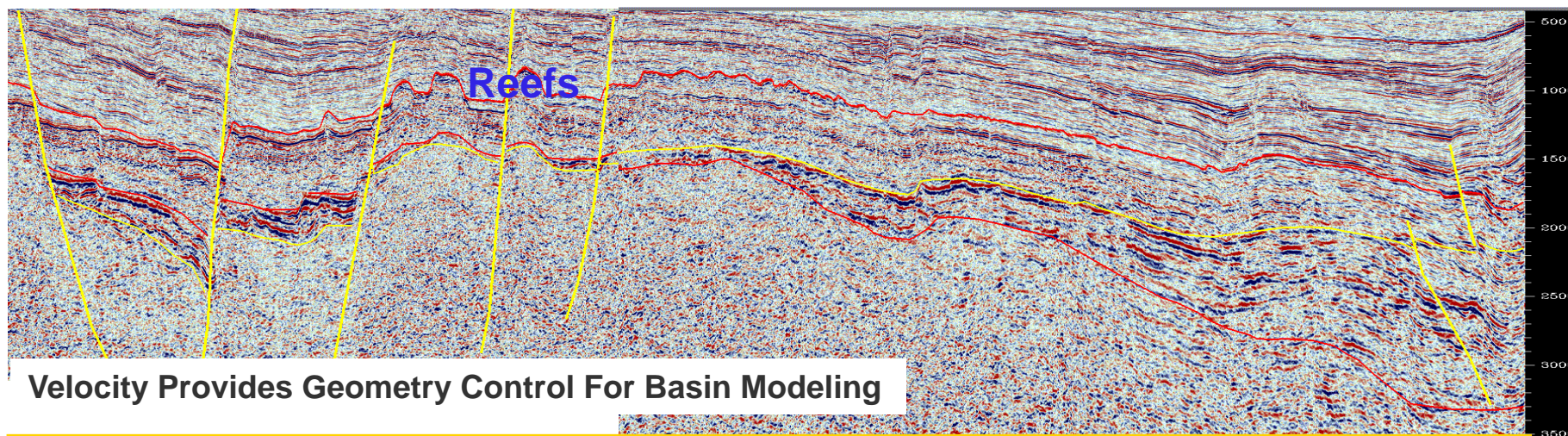
**Velocity Provides Geometry Control For Basin Modeling**

Reefs

2D geologic cross section made of interpreted horizons, stratigraphic, structural, and lithologic variations, and a velocity model for time/depth conversion

Optimized High Resolution Basin Modeling

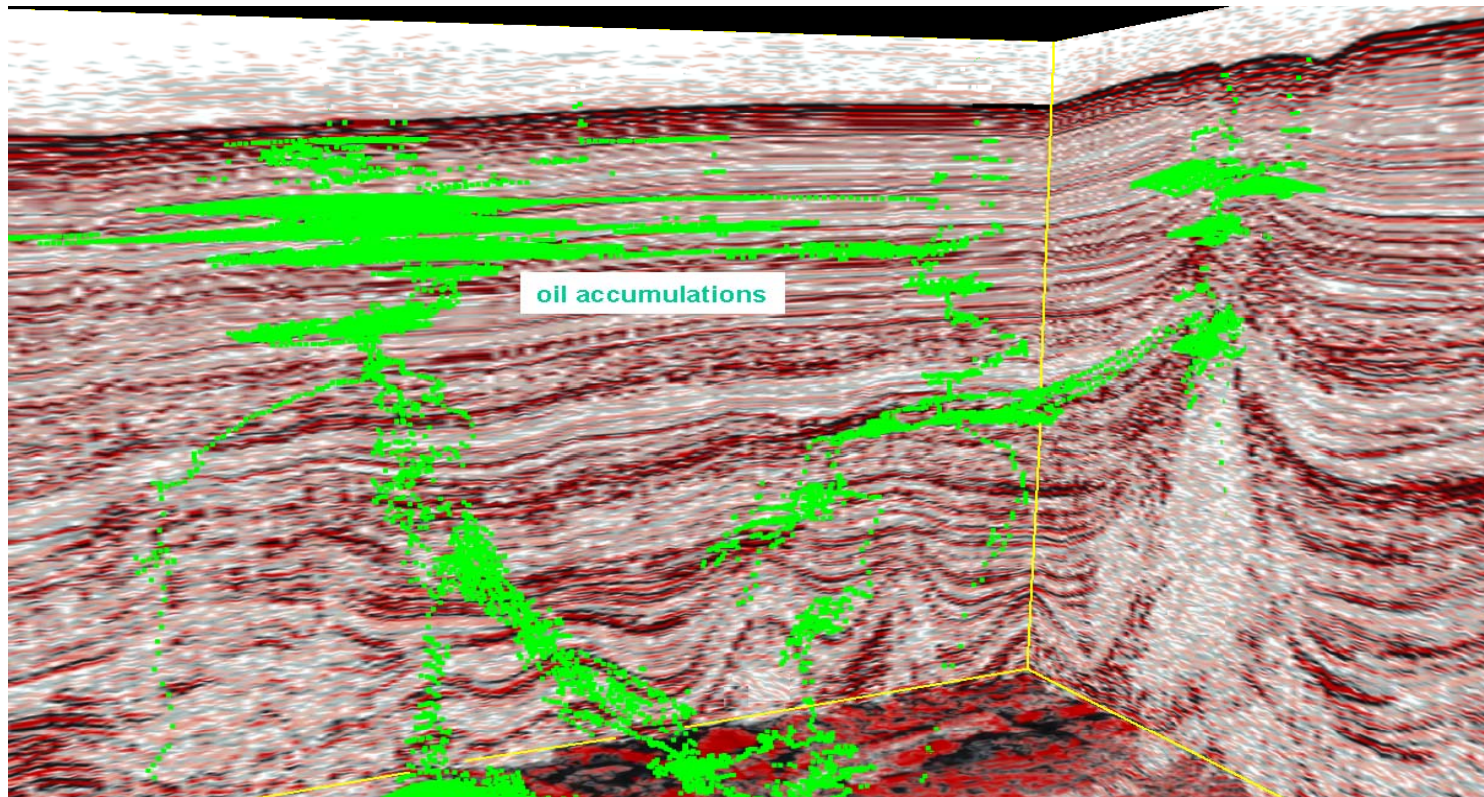Basin model based on 2D seismic data
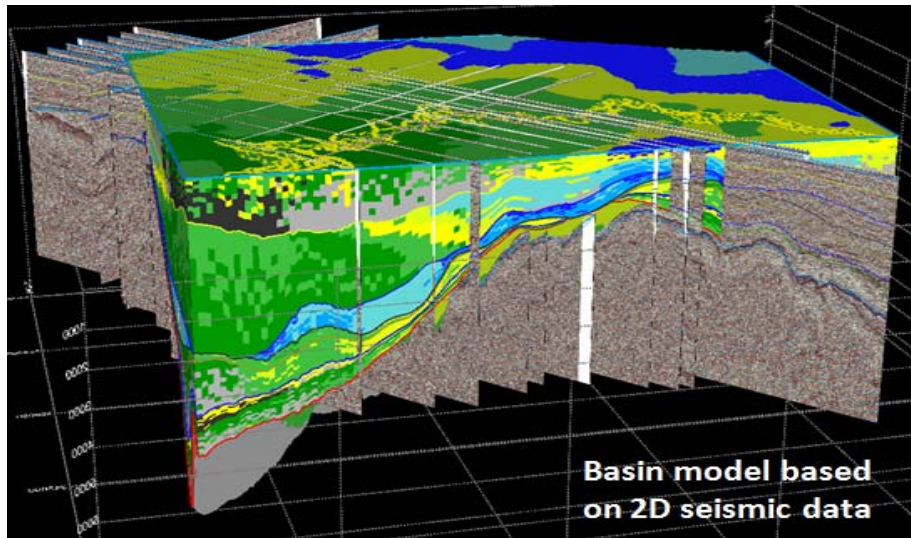
Intervention and interpretation necessary to make seismic information more geologic and valuable

Direct comparison of seismic and HC migration modeling helps optimization of model input and result

Oil migration with seismic attribute guided litho-facies
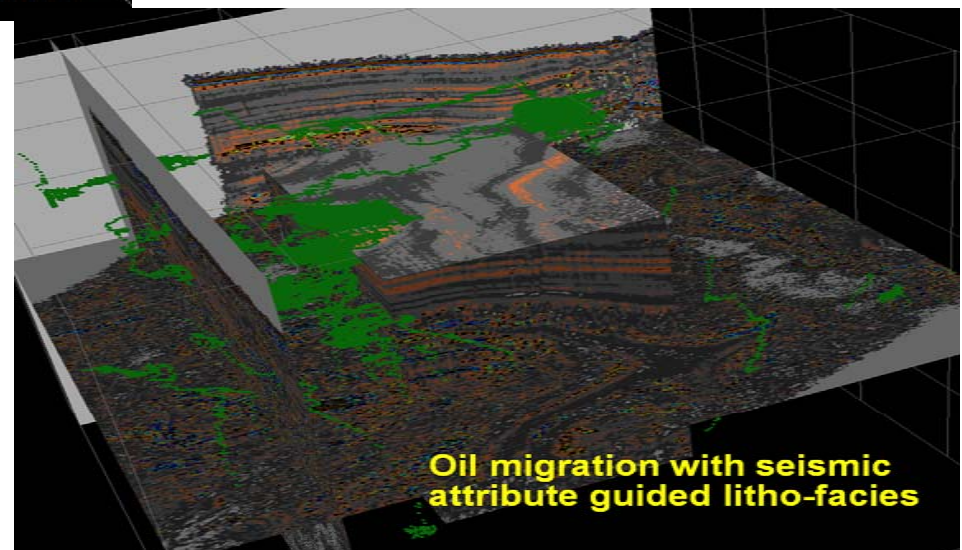
Optimized HC Migration Prediction

HC migration is impacted by the interaction of the driving pressure and resistance pressure determined by different lithology properties and geo-structures (folds and faults etc). Seismic interpretation and velocity model provide these boundary conditions

Conclusions

- Depths and structures in a basin model are affected by the seismic velocity and its lateral variation

- Depth data in a basin model may be a feedback to improve the velocity model with reasonable litho-facies interpretations

- Understanding seismic data and the associated uncertainties will allow for effective incorporation of seismic information into basin models to enhance the model's geologic content and predictive capability

- Seismic uncertainty analysis influences the selection of modeling methodologies, improves the source rock maturity prediction, provides clearer understanding of hydrocarbon migration patterns, and incorporates estimates of the nature and volume of hydrocarbon accumulations.