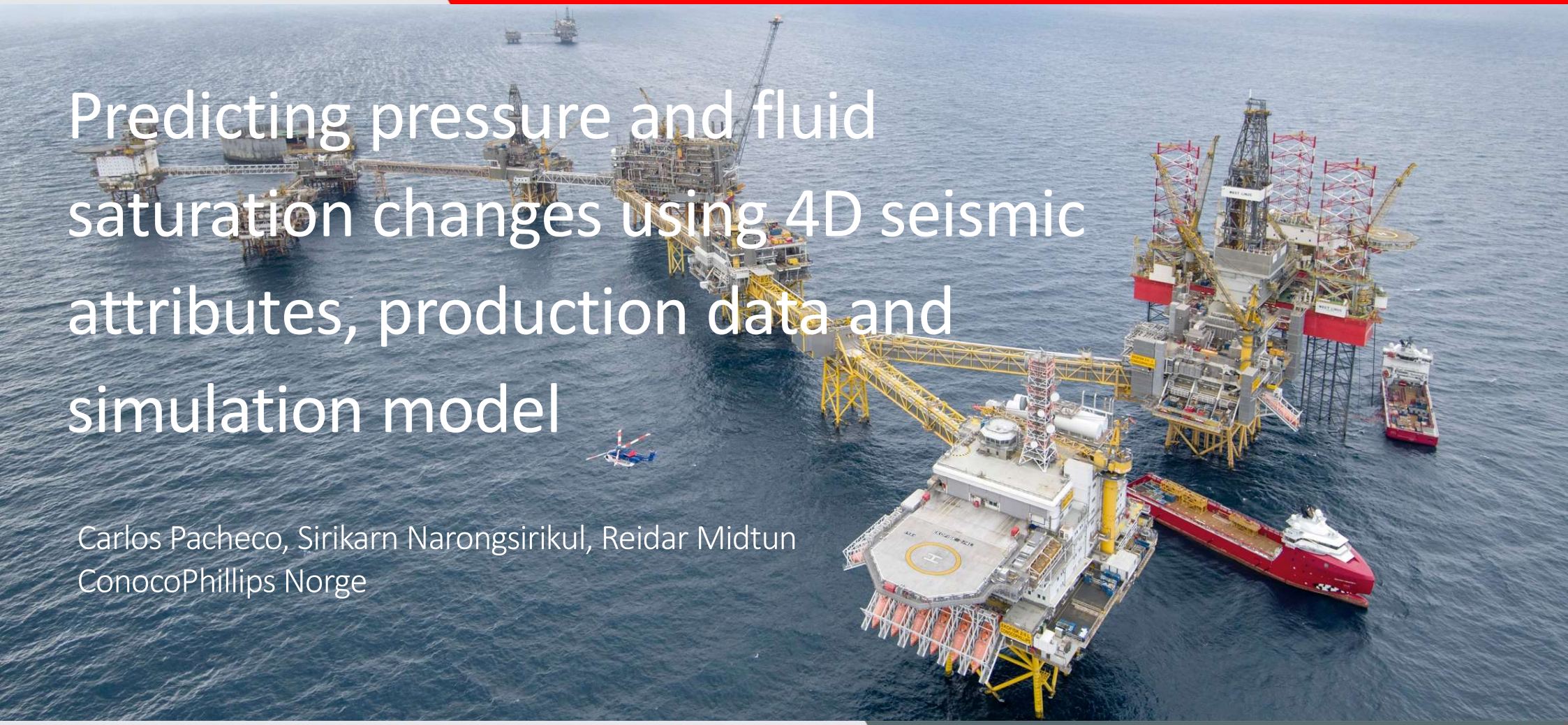
ConocoPhillips

Predicting pressure and fluid saturation changes using 4D seismic attributes, production data and simulation model



Carlos Pacheco, Sirikarn Narongsirikul, Reidar Midtun
ConocoPhillips Norge

February 11, 2019

Cautionary Statement

The following presentation includes forward-looking statements. These statements relate to future events, such as anticipated revenues, earnings, business strategies, competitive position or other aspects of our operations, operating results or the industries or markets in which we operate or participate in general. Actual outcomes and results may differ materially from what is expressed or forecast in such forward-looking statements. These statements are not guarantees of future performance and involve certain risks, uncertainties and assumptions that may prove to be incorrect and are difficult to predict such as oil and gas prices; operational hazards and drilling risks; potential failure to achieve, and potential delays in achieving expected reserves or production levels from existing and future oil and gas development projects; unsuccessful exploratory activities; unexpected cost increases or technical difficulties in constructing, maintaining or modifying company facilities; international monetary conditions and exchange controls; potential liability for remedial actions under existing or future environmental regulations or from pending or future litigation; limited access to capital or significantly higher cost of capital related to illiquidity or uncertainty in the domestic or international financial markets; general domestic and international economic and political conditions, as well as changes in tax, environmental and other laws applicable to ConocoPhillips' business and other economic, business, competitive and/or regulatory factors affecting ConocoPhillips' business generally as set forth in ConocoPhillips' filings with the Securities and Exchange Commission (SEC). We caution you not to place undue reliance on our forward-looking statements, which are only as of the date of this presentation or as otherwise indicated, and we expressly disclaim any responsibility for updating such information.

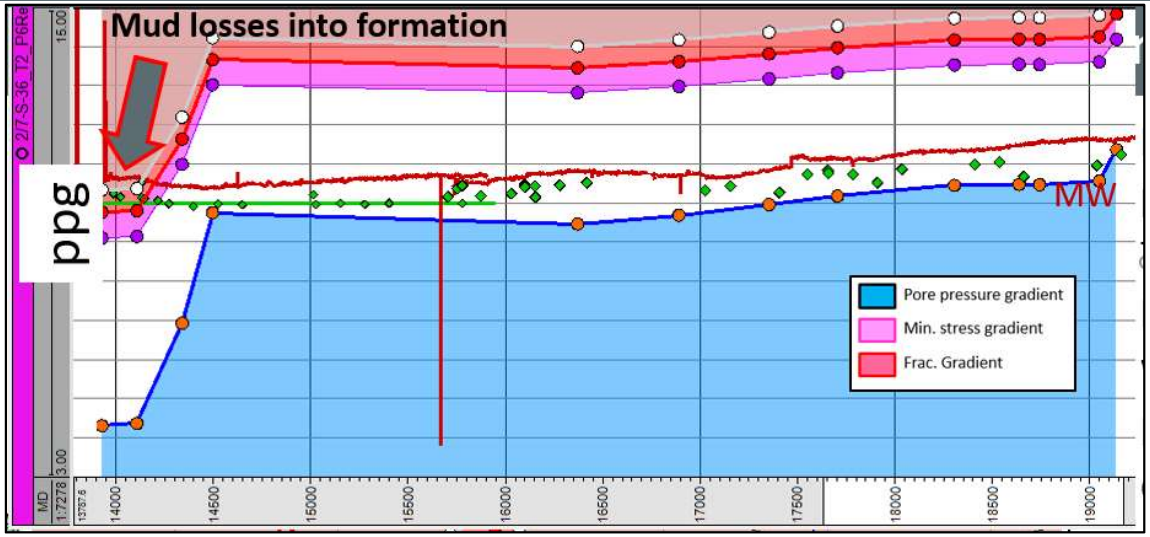
Use of non-GAAP financial information – This presentation may include non-GAAP financial measures, which help facilitate comparison of company operating performance across periods and with peer companies. Any non-GAAP measures included herein will be accompanied by a reconciliation to the nearest corresponding GAAP measure on our website at *www.conocophillips.com/nongaap*.

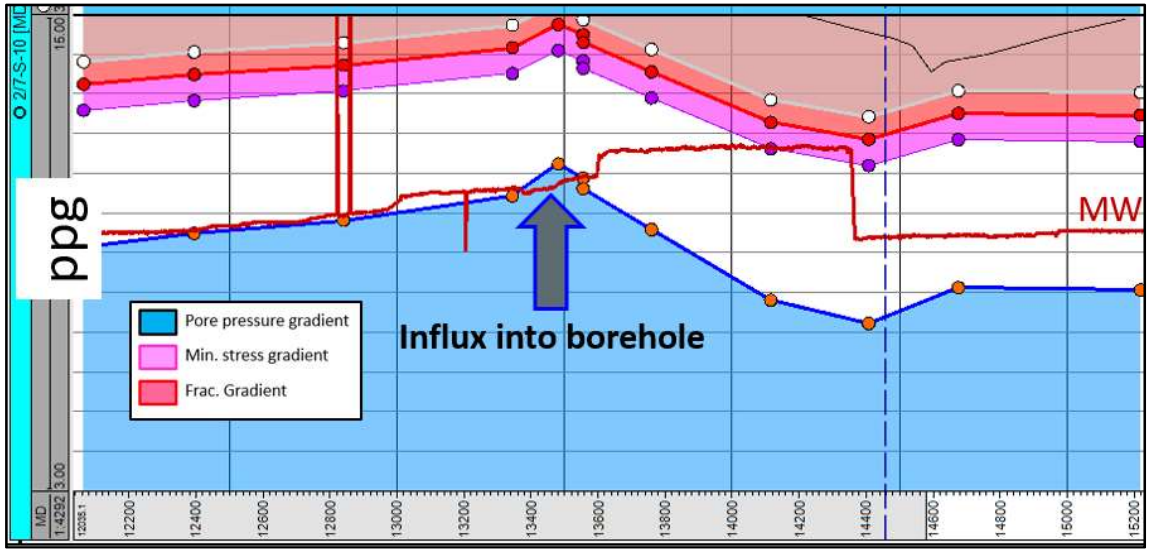
Cautionary Note to U.S. Investors – The SEC permits oil and gas companies, in their filings with the SEC, to disclose only proved, probable and possible reserves. We use the term "resource" in this presentation that the SEC's guidelines prohibit us from including in filings with the SEC. U.S. investors are urged to consider closely the oil and gas disclosures in our Form 10-K and other reports and filings with the SEC. Copies are available from the SEC and from the ConocoPhillips website.

Outline

1. Why use 4D seismic to assist well planning prognosis?
   - Optimize infill target locations with respect to remaining oil
   - Characterize and mitigate drilling reservoir risks related to pressure
2. Chalk sensitivity to pressure and corresponding 4D seismic attributes
   - Chalk Water Weakening Compaction
   - Dry Rock Effective Stress Sensitivity
3. Seismic Assisted Pressure Prognosis Workflow using 4D Rock Physics Inversion & Model
4. 4D Seismic inversion for pressure and fluid change estimates along planned well paths
   - Expected pressure profile
   - Uncertainty: High/Low pressure profiles

Drilling Reservoir challenges: Pressure differential, loss vs influx





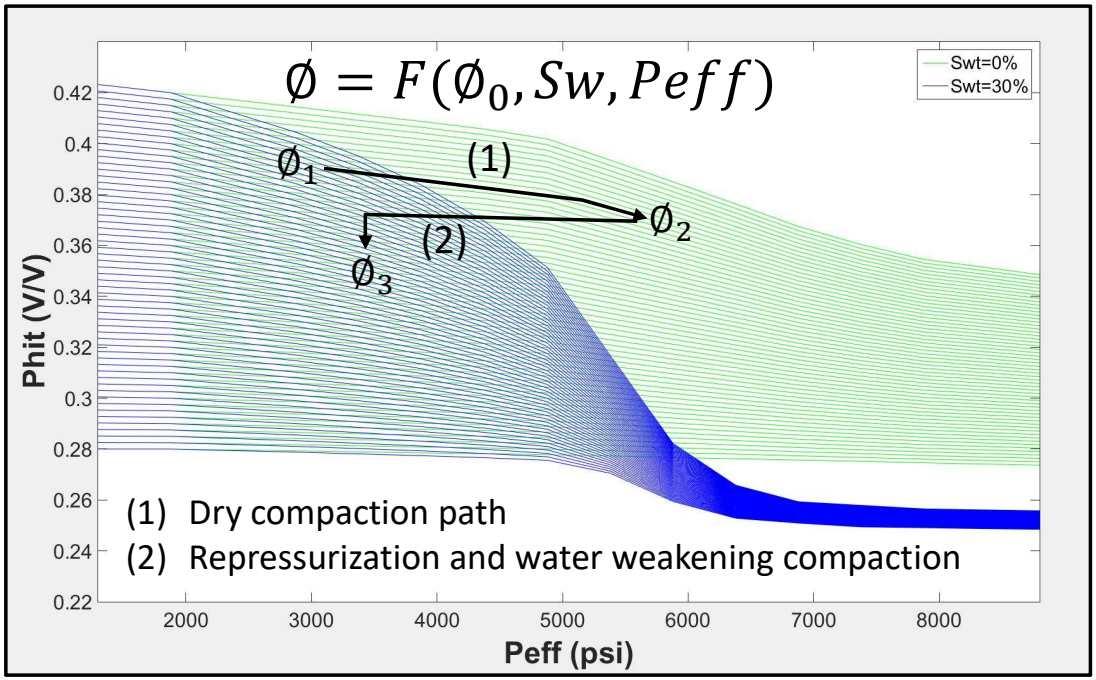
- High Pressure Differential: Due to production and injection PP can vary from ~1000psi to ~7000 psi.
- Experience Rule of Thumb: “we can drill with Pdiff<2500 psi.”
- Modeling: PP+2500 is approximately equal to Fracture propagation pressure and close to breakdown pressure

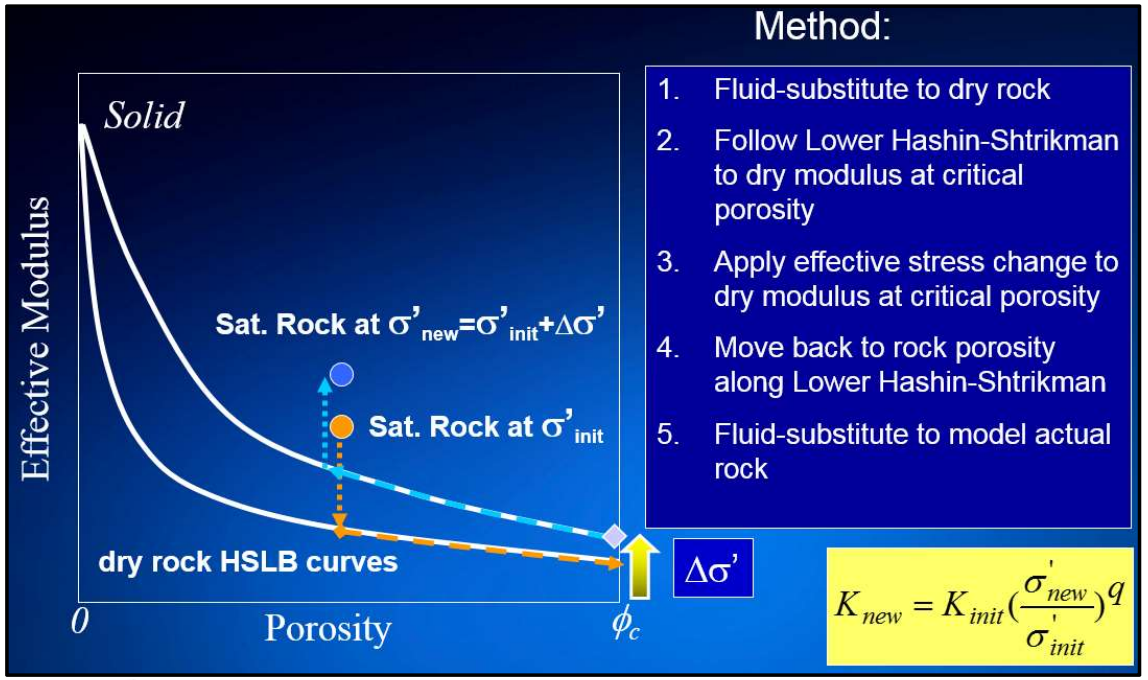
Mitigations:

- Accurate reservoir pressure modeling
- Avoid planning wells with high Press Diff
- Stay within safe window, rule of thumb is good estimation
- *FracCem* to mitigate losses
- Contingency liners for pressure differentials

Pressure Sensitivity of Ekofisk Chalk: Compaction and Dry Rock Contacts

1) Chalk Water Weakening Compaction Curves → ***2) Hertz-Mindlin Dry Rock Effective Pressure Model***

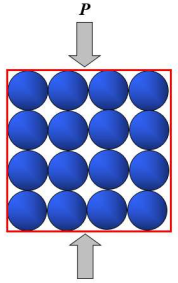




Porosity decreases with both increase in Peff and Sw

$$\left.\begin{aligned}\rho_b &= \rho_b(\emptyset)\\ V_p &= V_p(\emptyset)\end{aligned}\right\} AI$$

$$V_s = V_s(\emptyset)$$



Hertz-Mindlin Contact Theory

Effective Moduli of a packing of spherical grains depend on

- grain properties
- packing geometry
- confining pressure

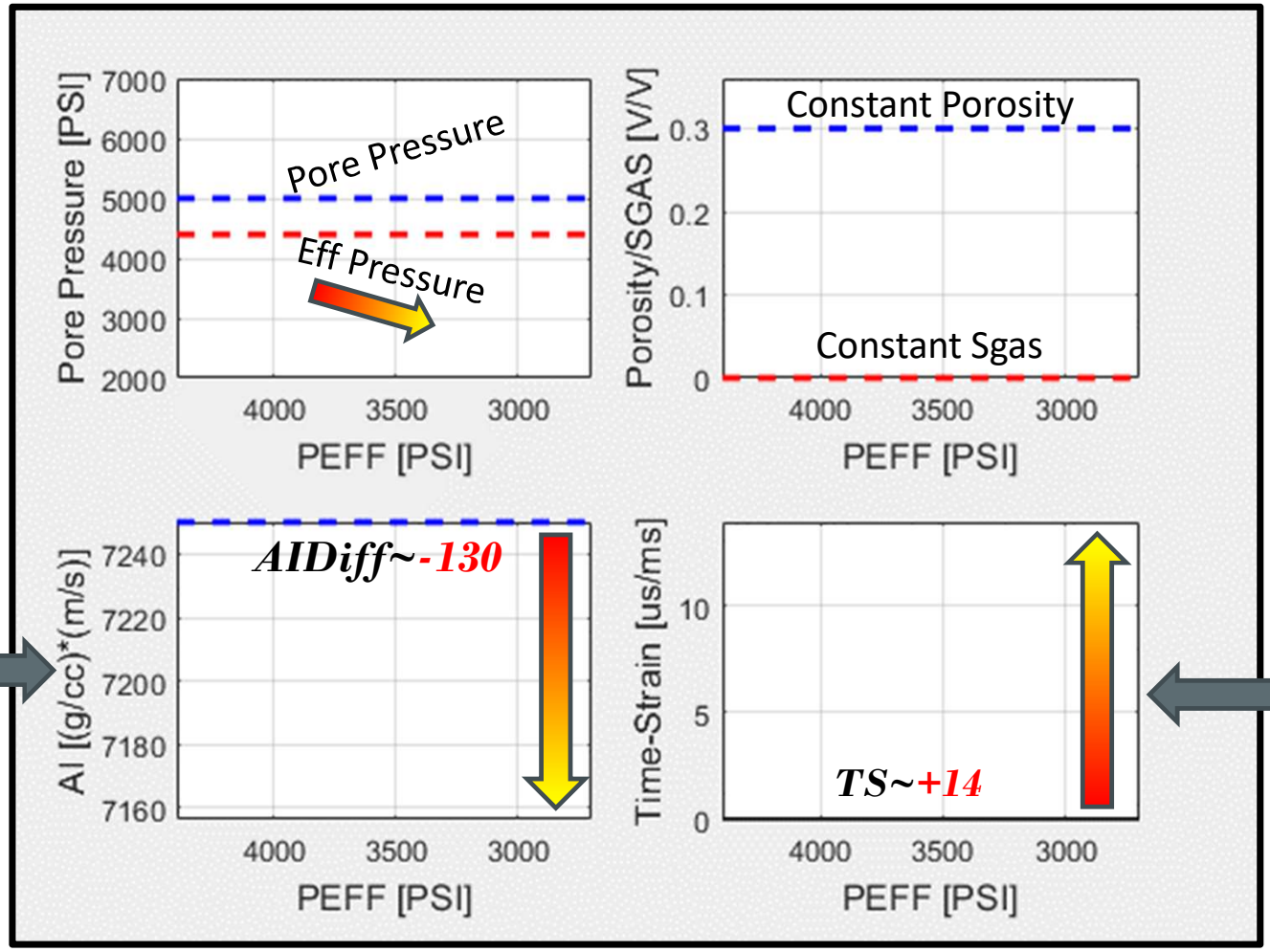
$$V_p = \sqrt{\frac{K + (\frac{4}{3})\mu}{\rho}}$$

$$V_s = \sqrt{\frac{\mu}{\rho}}$$

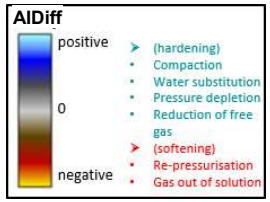
4D Seismic Attributes around Injector A (pressure increase, no fluid sub)

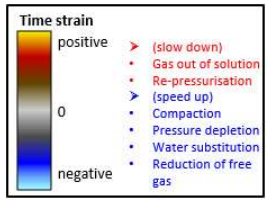
$$\Delta Press > 0$$
$$\Delta Sg = 0$$
$$\Delta Sw = 0$$
$$\Delta \phi = 0$$

Dynamic Simulation Model Properties



Acoustic Softening





Slow down or positive time delay

ConocoPhillips

4D Seismic Attributes around a producer well (pressure depletion)

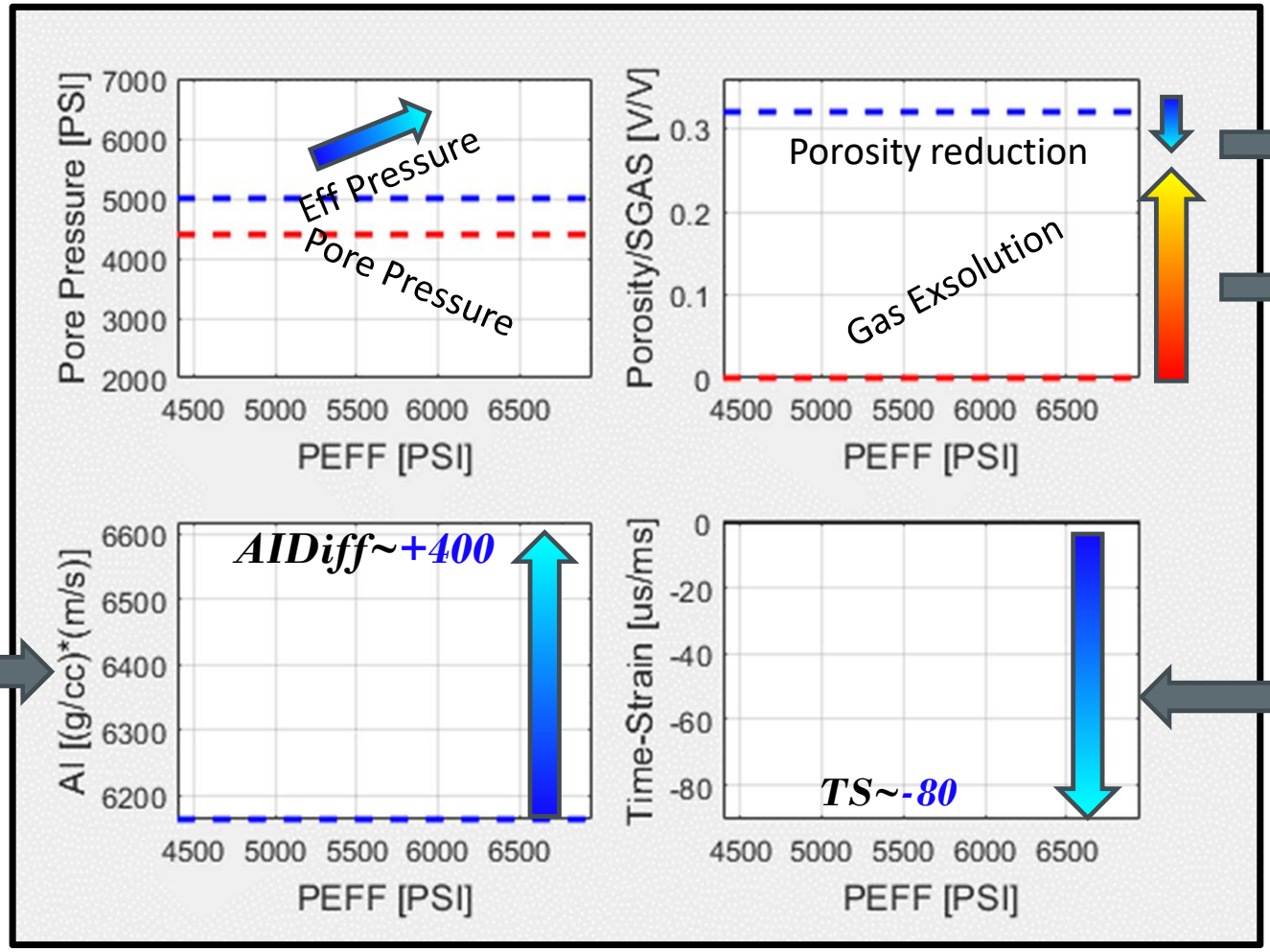
$\Delta Press < 0$

$\Delta Sg > 0$

$\Delta Pbub < 0$

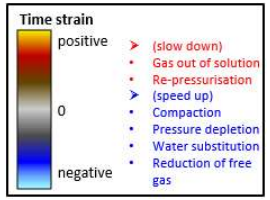
$\Delta \phi < 0$

Dynamic Simulation Model Properties

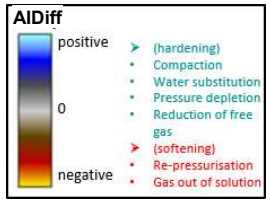


Porosity decrease because depletion

Gas increase as pressures sink lower than bubble point



Acoustic Hardening

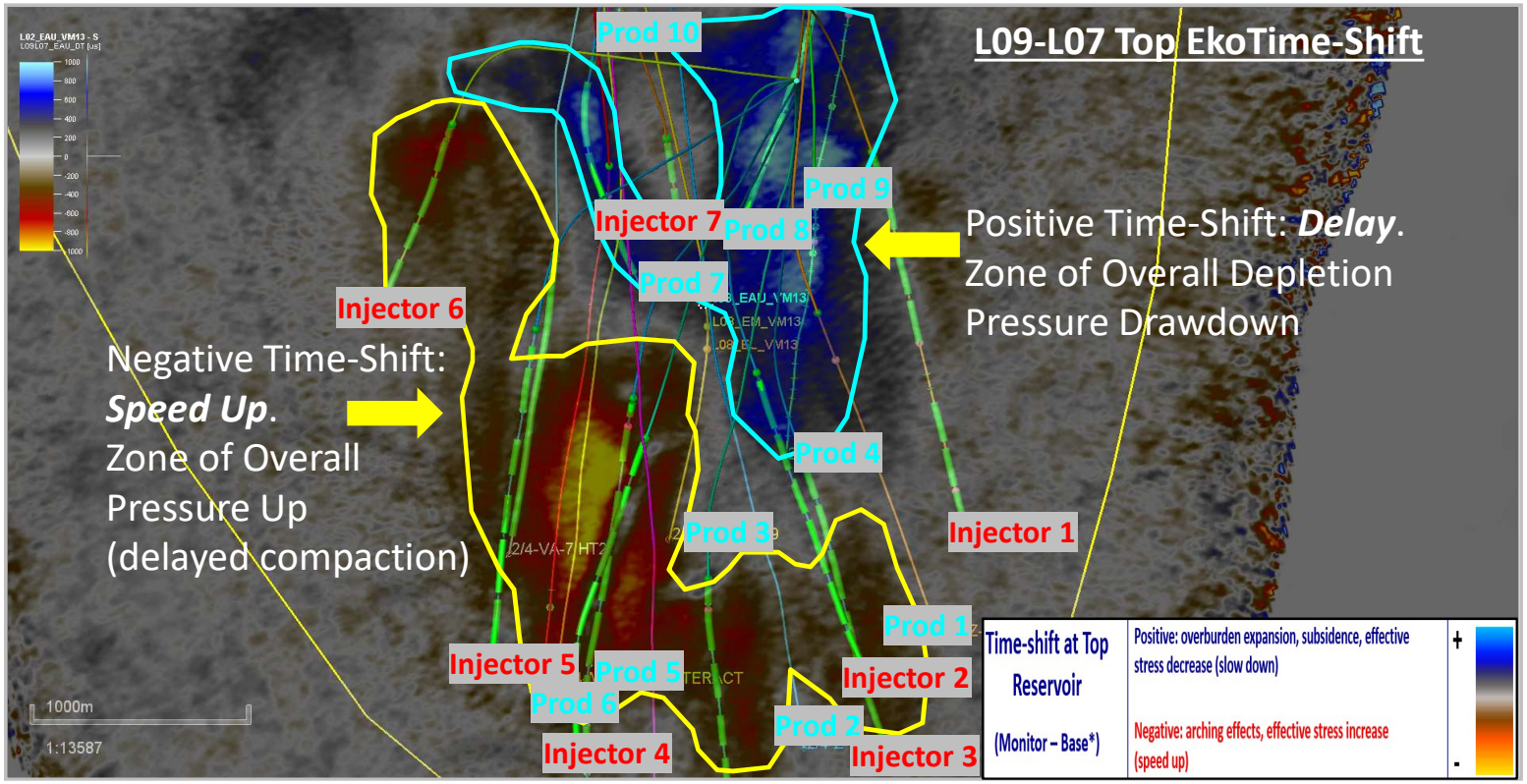


Speed up or negative time delay

Overall Reservoir Pressure Regime from Top Ekofisk Time-Shift

A positive (+) Time-Shift indicates a relative stretching (slow-down) of the overburden in response to overall reservoir depletion/compaction

Reservoir Pore Pressure Up (+)



Reservoir Pore Pressure Down (-)

A negative (-) Time-Shift indicates a tightening (speed-up) of the overburden in response to overall reservoir pressuring up (delayed compaction)

"Simplified" Workflow for Pressure Prognosis using 4D Seismic, Wells & Model

Pressure, saturations, porosity, GOR, etc. at baseline date

VP, VS, Density

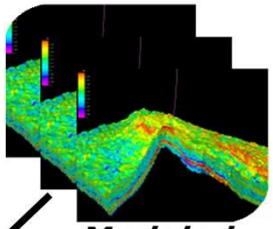
AIDiff, Time-Strain

History Match Reference Model

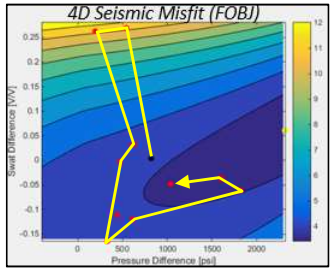
$\{P_1, Sw_1, Sg_1, \emptyset_1, Pbub_1, Temp_1\}$

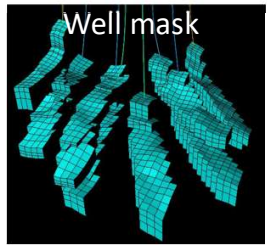
Rock Physics Modelling

4D Seismic Modeling

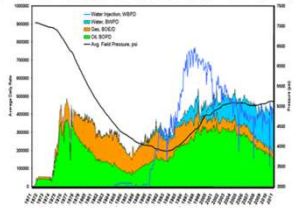


Modeled Seismic Data



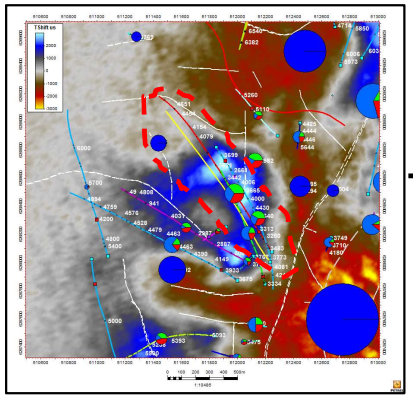


Observed Production Data



Modelled 4D Seismic

Top Reservoir DT with Cumm Volumes and RFT's

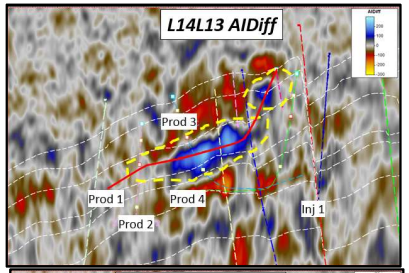


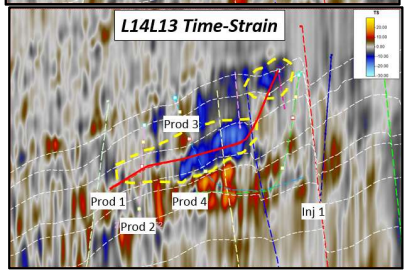
Constraints

Rock Physics Inversion (Minimize Misfit)

Compute 4D Seismic Misfit

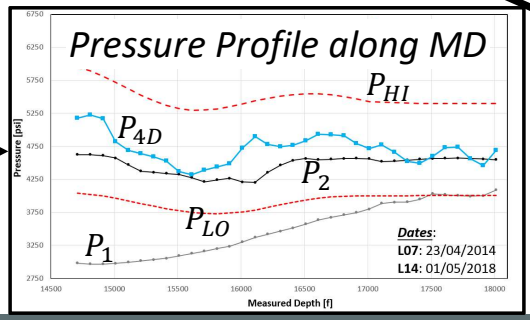
Observed 4D Seismic





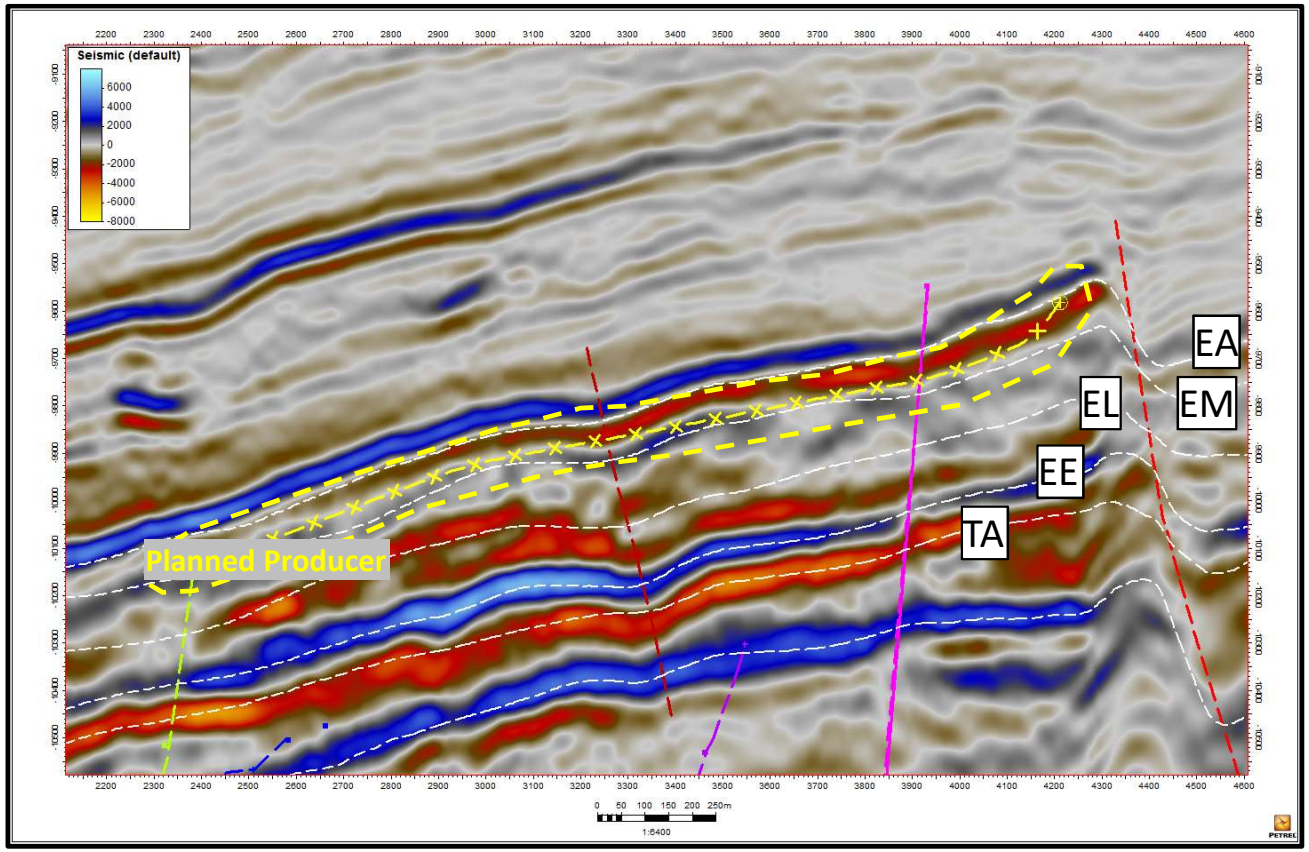
ΔPress
ΔSwat
ΔSgas

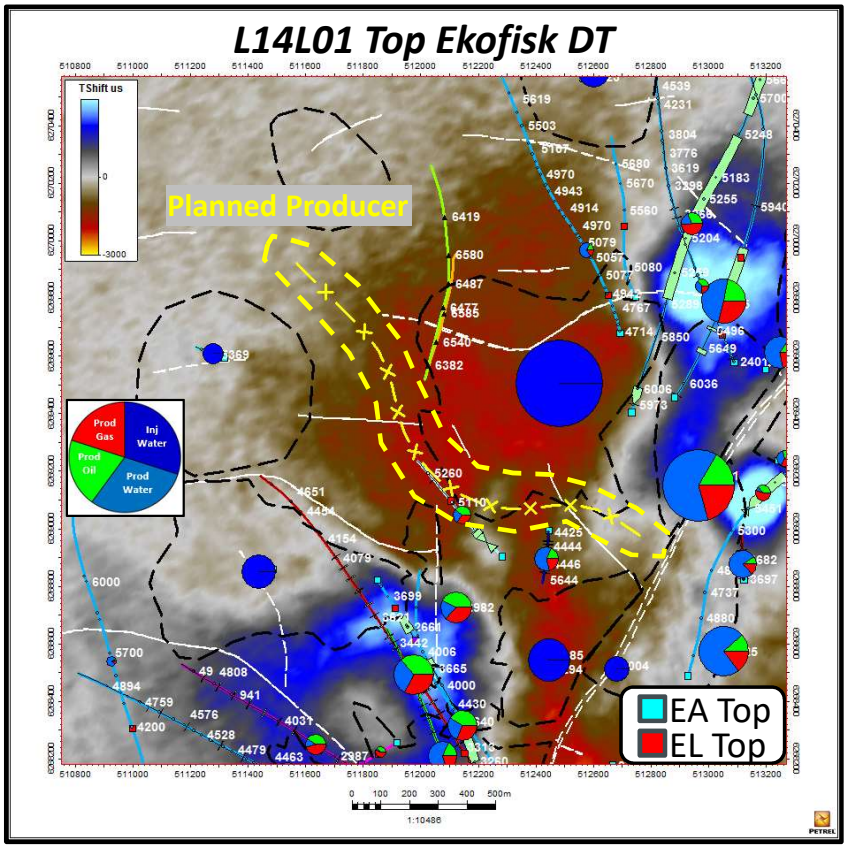
$P_{2(4D)} = P_1 + \Delta P_{4D}$



ConocoPhillips

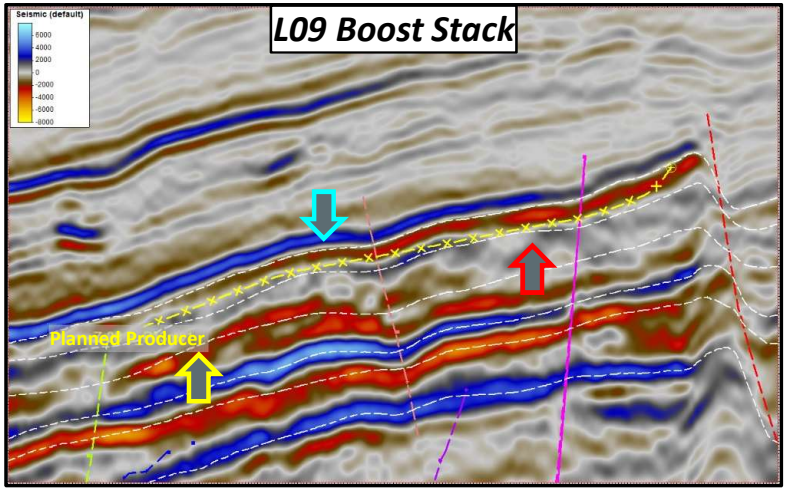
Planned Producer 4D Prognosis : Well Location on Seismic and Overall Setting

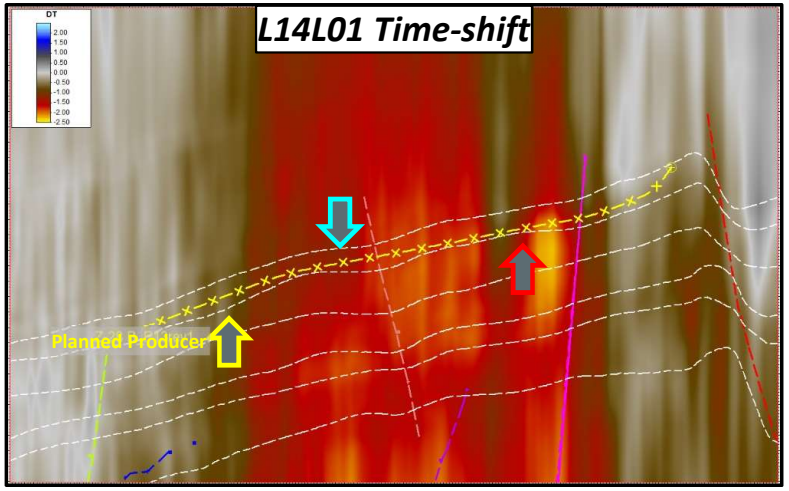


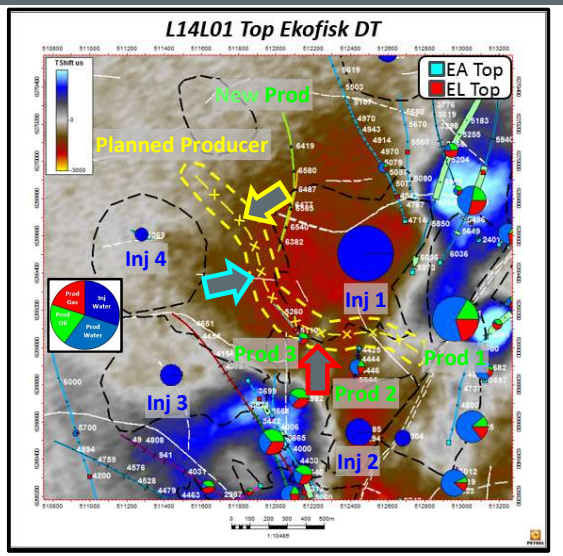


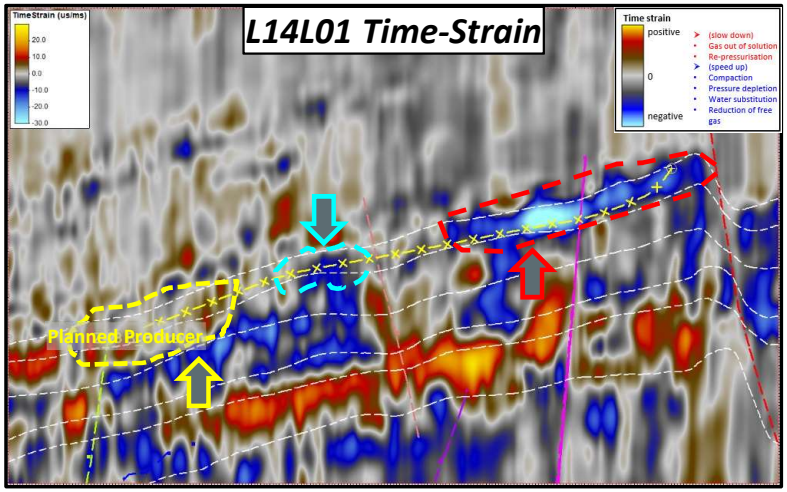
RFT pressure points are white annotations. EA Fm water front polygons are dashed black polygons.
Produced and injected volumes per well in the period shown as pie/slice charts on middle perforation

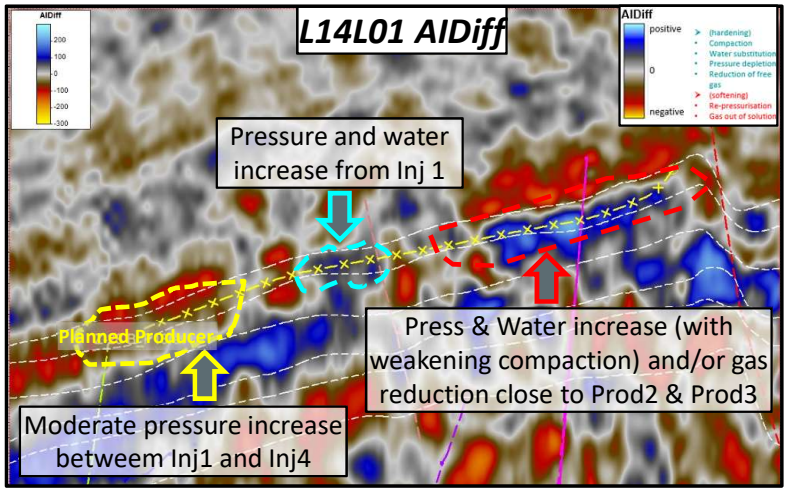
Planned Producer 4D Prognosis: Summary of 4D Attributes along planned well path

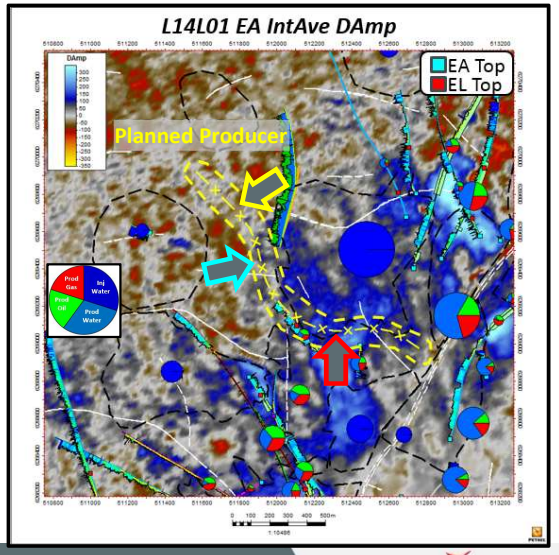






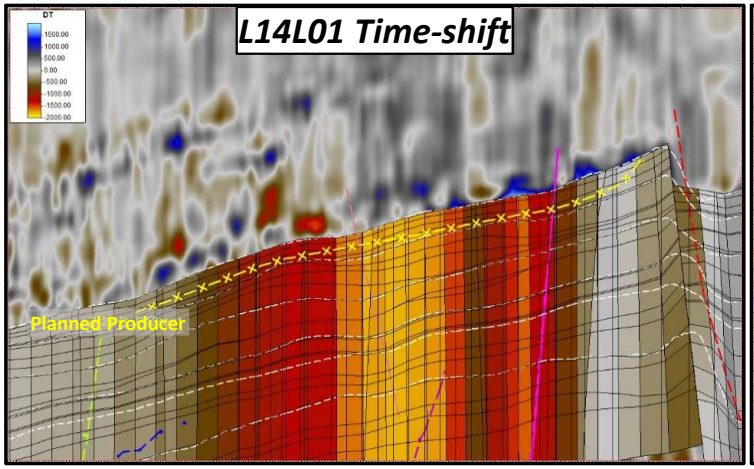


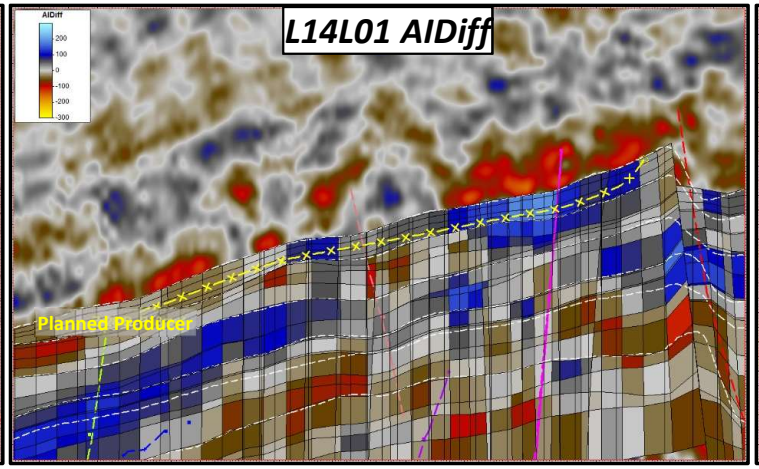


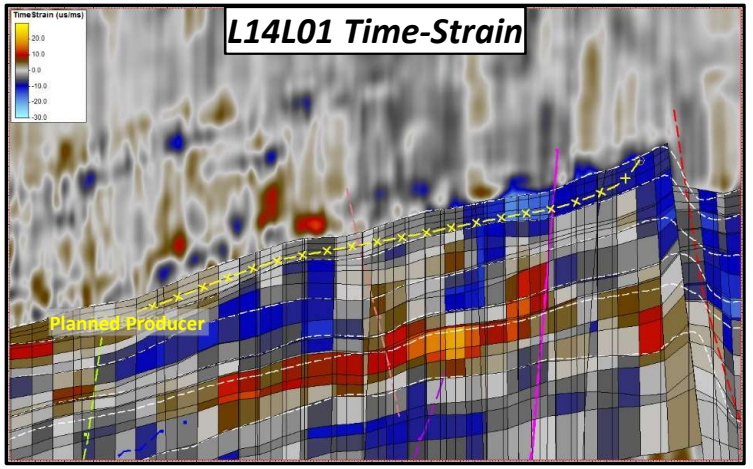


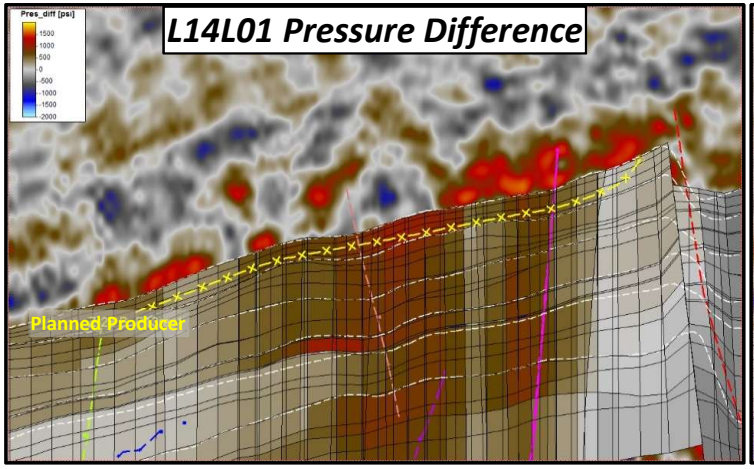
ConocoPhillips

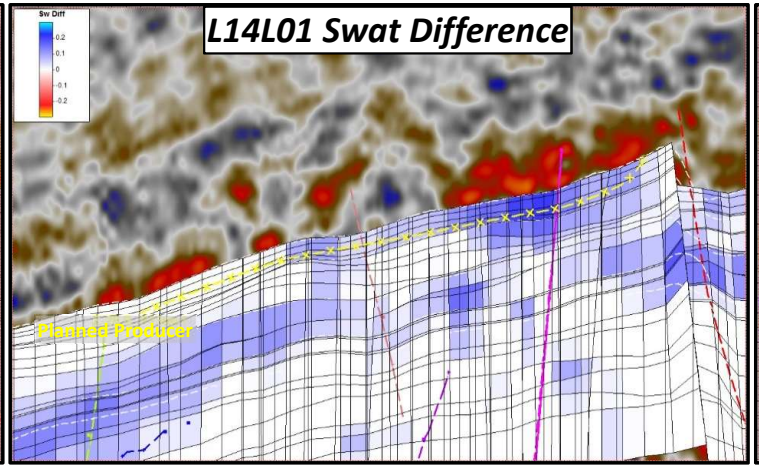
Planned Producer: Upscaled 4D Seismic and Flow Model Property Changes

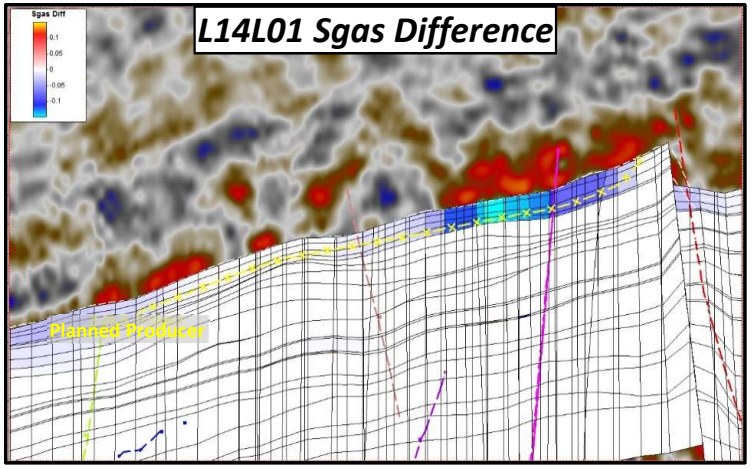






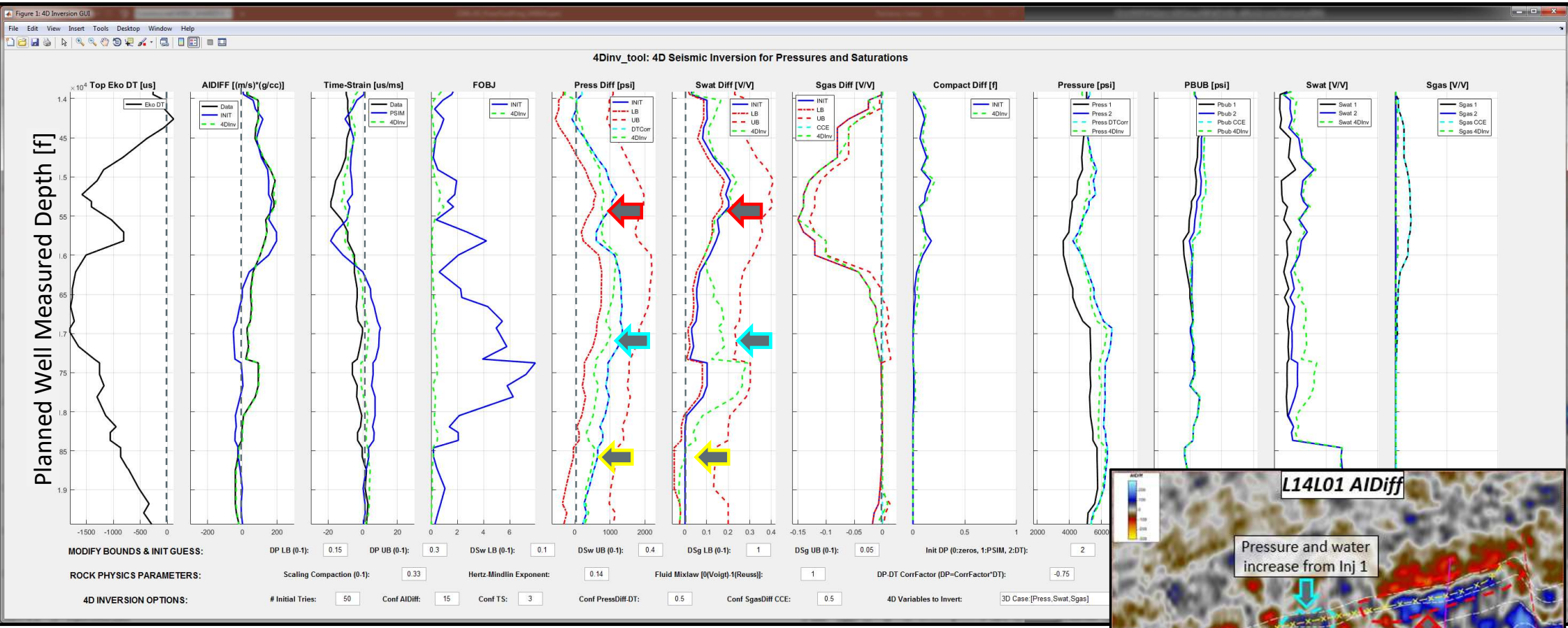






Planned Producer : 4D Seismic Inversion App along wellpath measured depth

Absolute Reservoir Properties

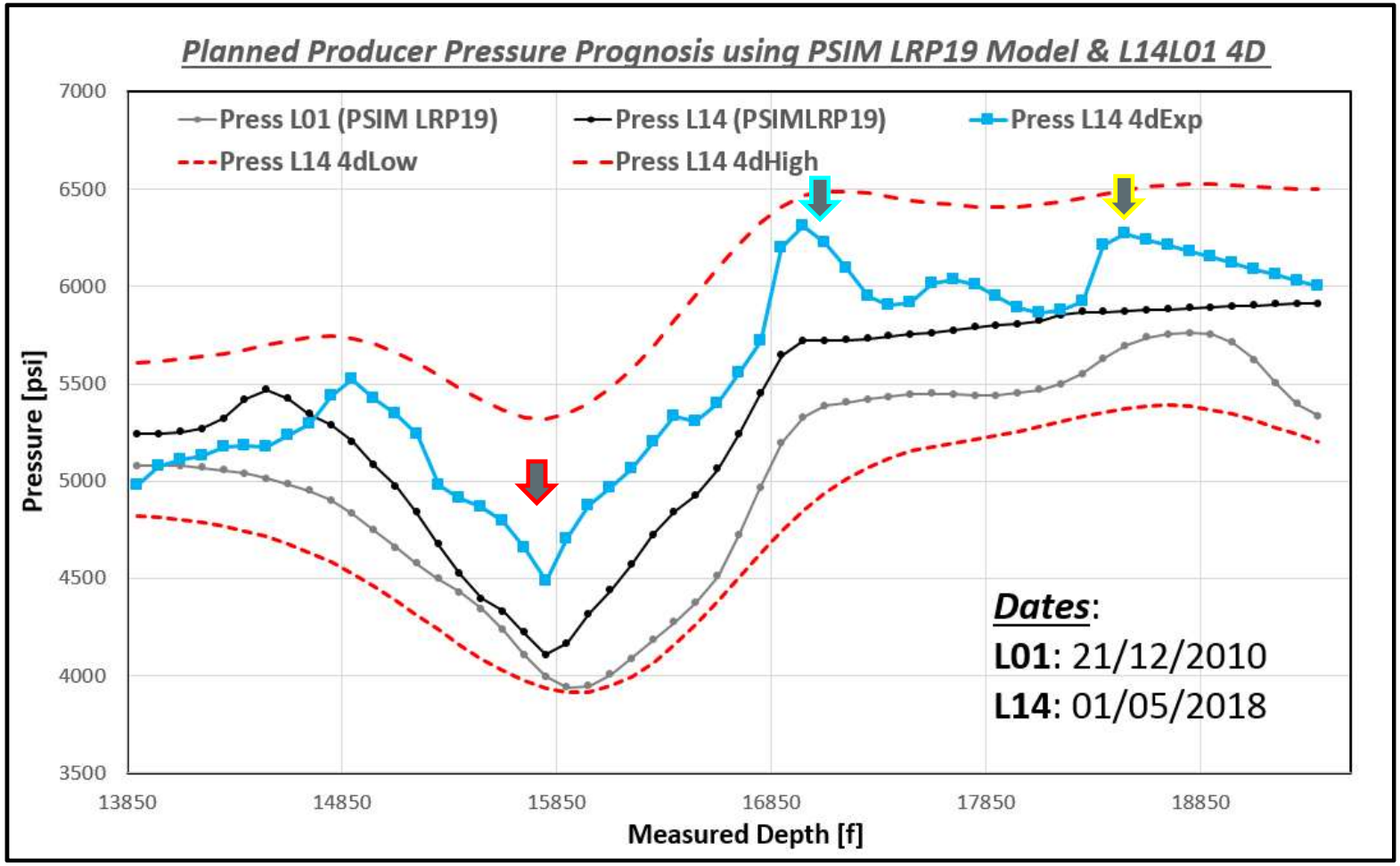


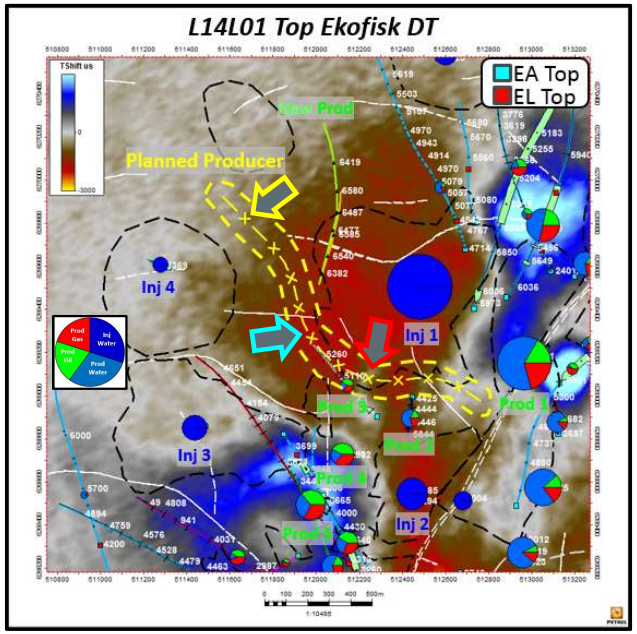
4D Seismic Attributes

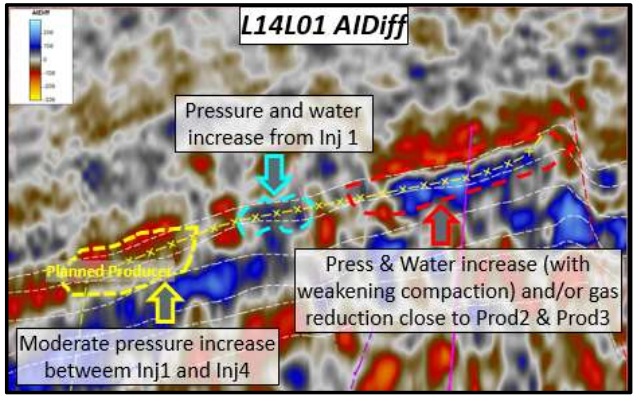
Misfit Function

Inverted Reservoir Property Changes

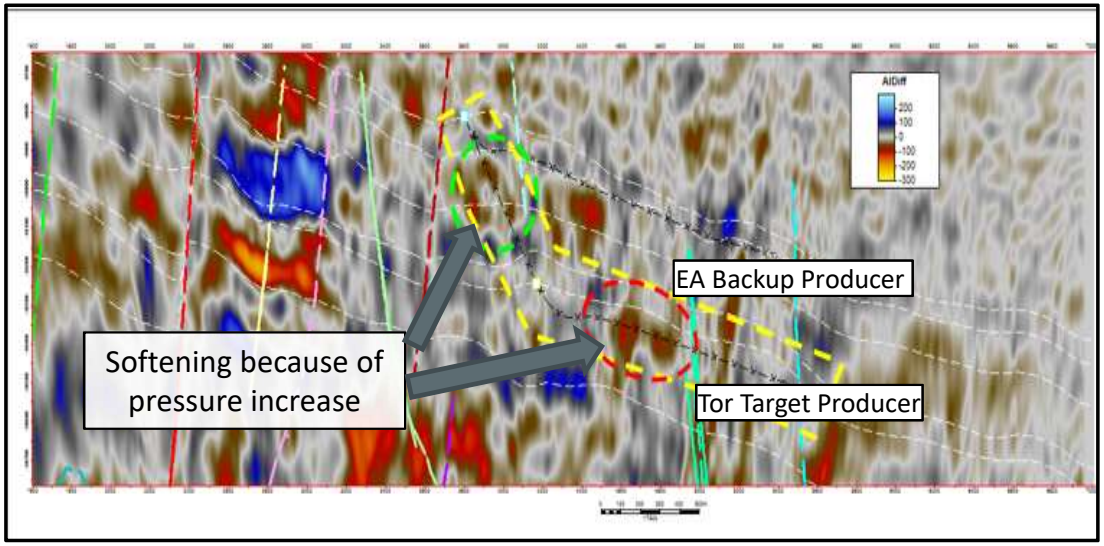
Planned Producer Example: Integrated Model and 4D Seismic Pressure Prognosis

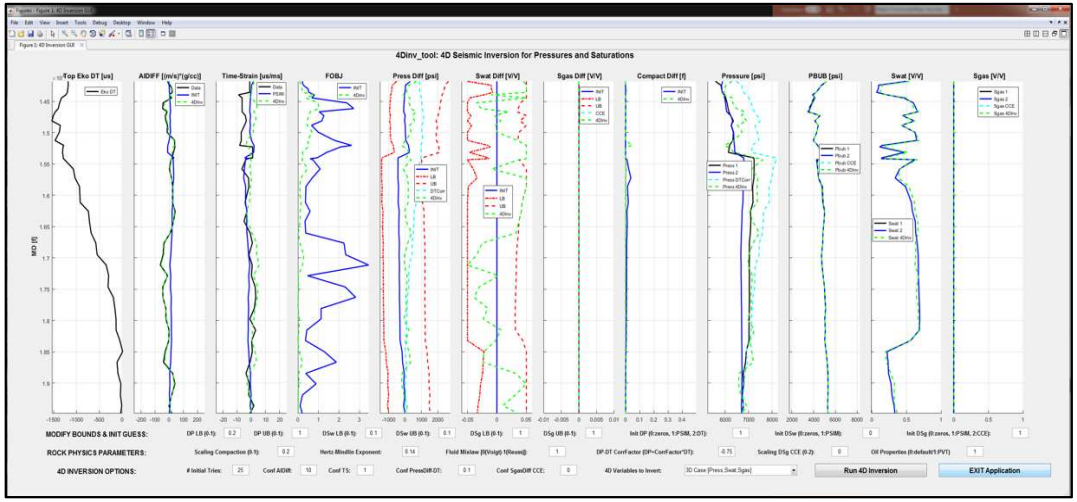


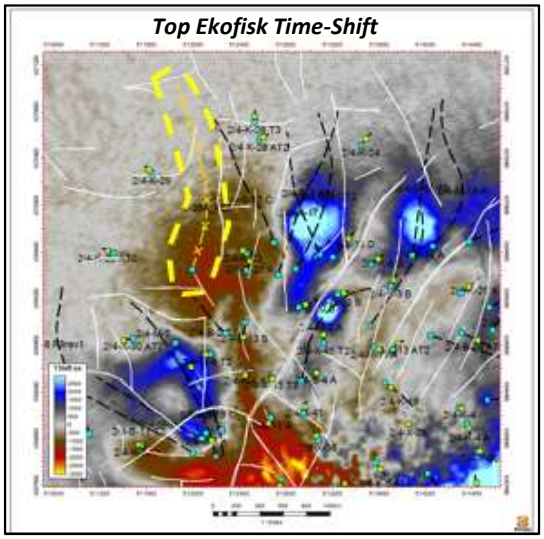


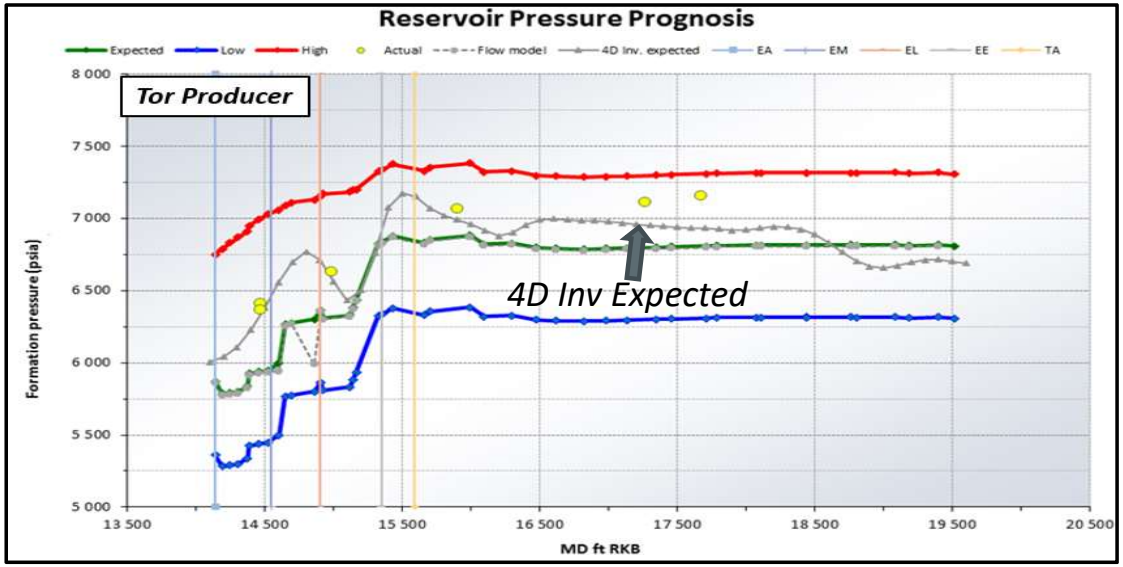


Pressure Prognosis Post Well Results: Tor Fm Well in NW Region

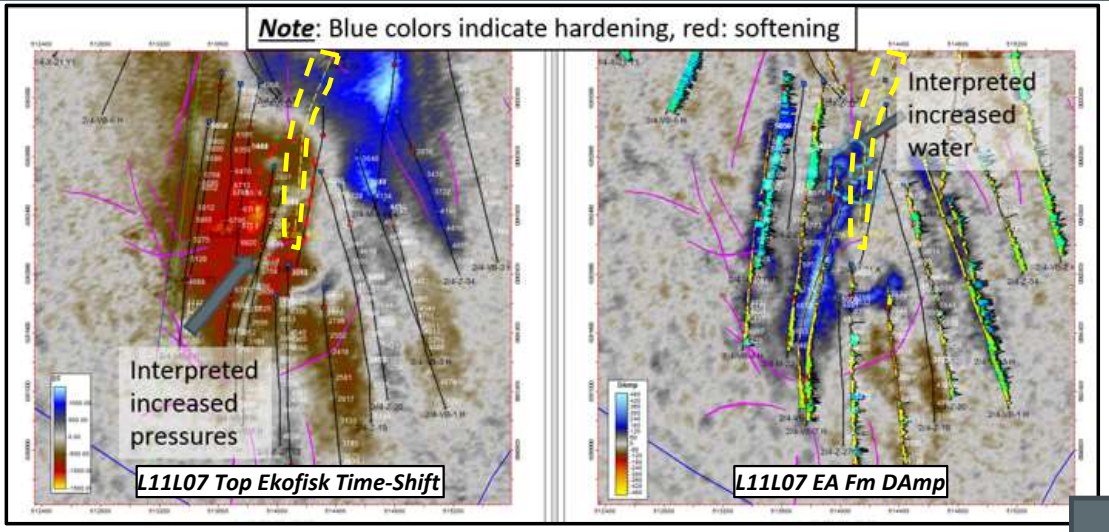


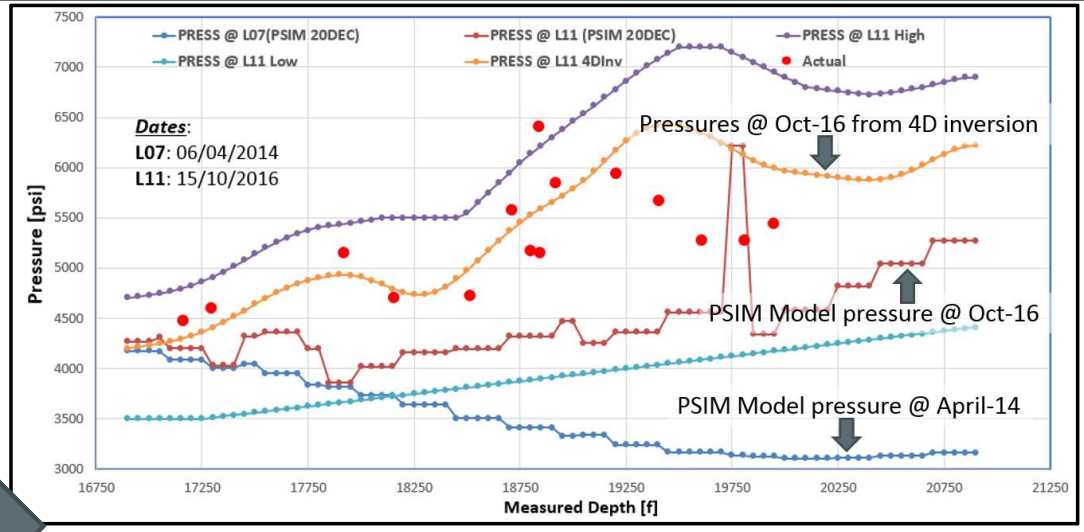


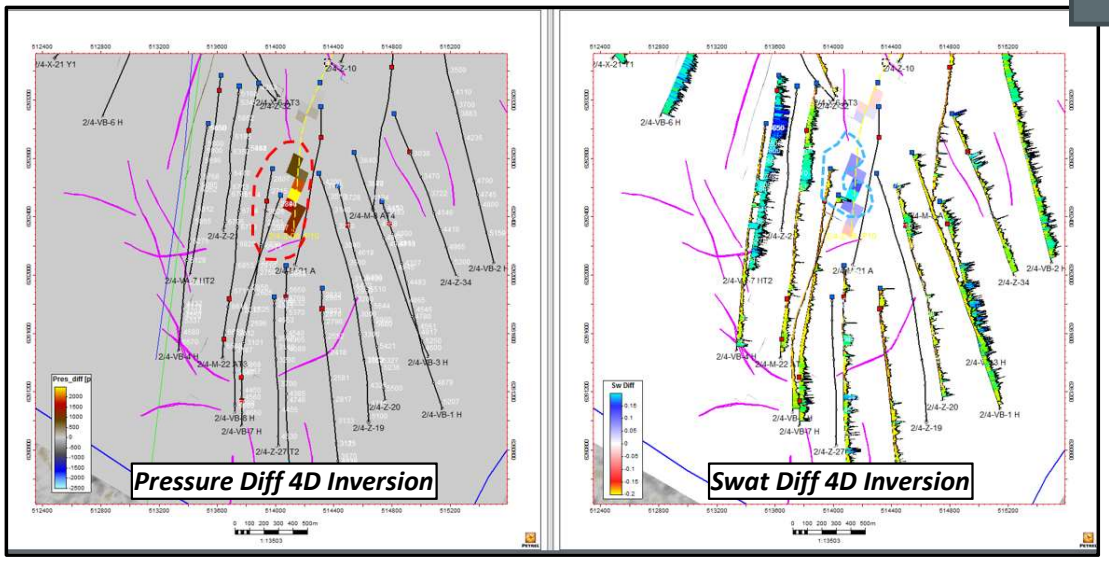


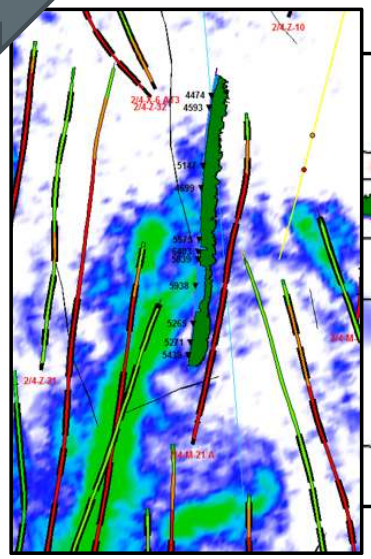


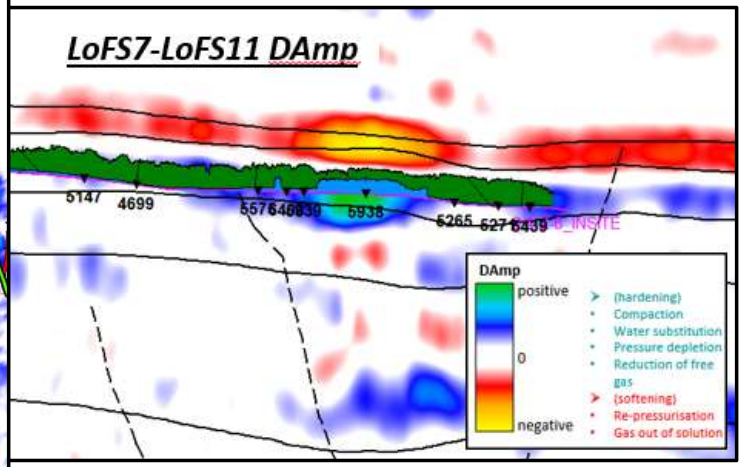
Pressure Prognosis Post Well Results: EA Fm Producer approaching injectors











Conclusions

- Seismic 4D data attributes have been incorporated routinely in the evaluation of infill well locations and their pressure profiles

- The 4D seismic inversion methodology along planned well paths provides a quick and interactive way of assessing both the 4D seismic attributes and the simulation model

- Pressure prognosis uncertainty and low/high case scenarios can be estimated by integrating simulation model results and the different solutions obtained by modifying the local constraints and bounds on the 4D inversion

- Caveat: Rock Physics Inversion is both non-linear and non-unique.
  - Need to constrain solution space
  - Include additional data such as AVO or seismic angle dependent elastic properties

Acknowledgements

- PL018 Partnership
  - ConocoPhillips Skandinavia AS
  - Total E&P Norge AS
  - ENI Norge AS
  - Equinor AS
  - Petoro AS

- Colleagues at ConocoPhillips
  (too many to mention)