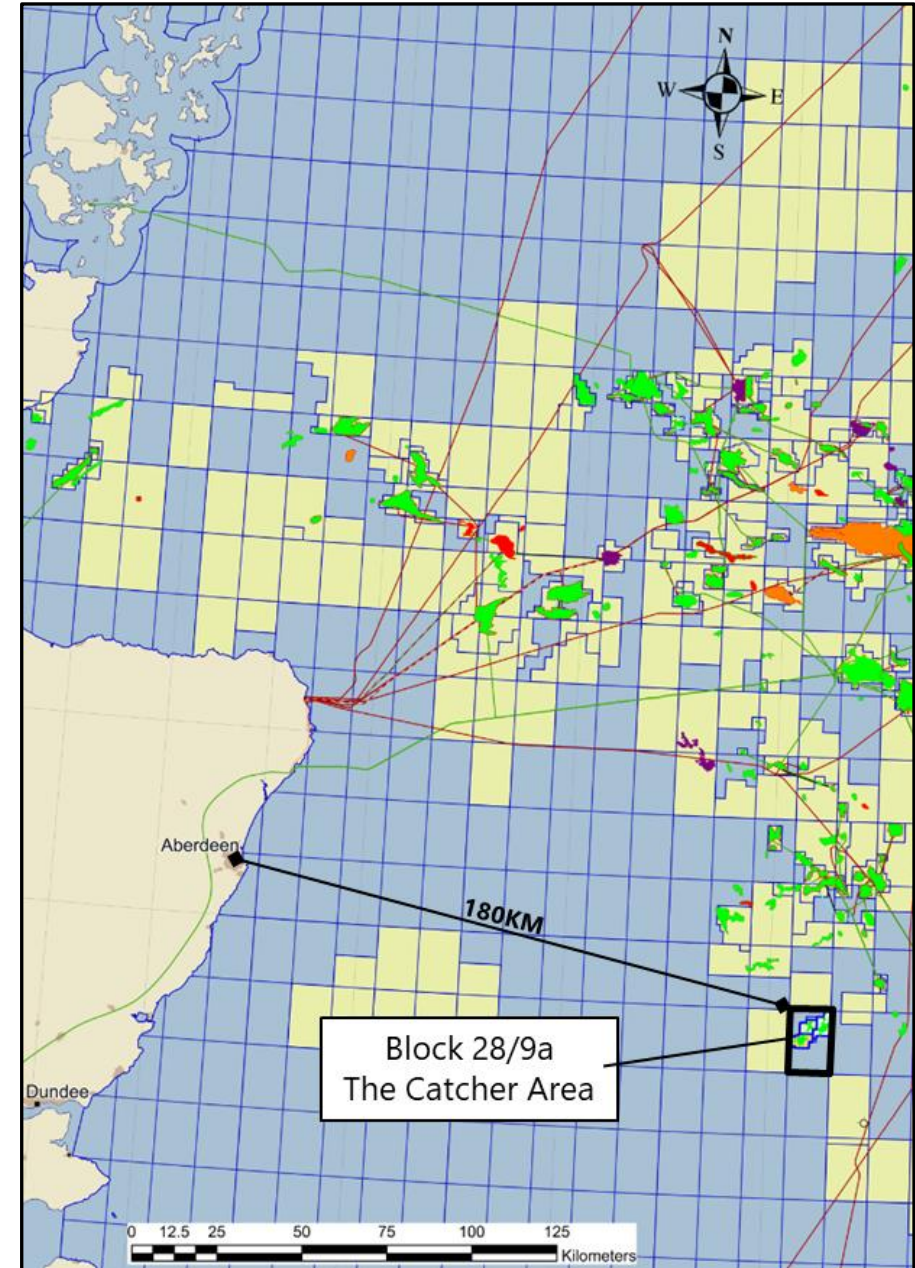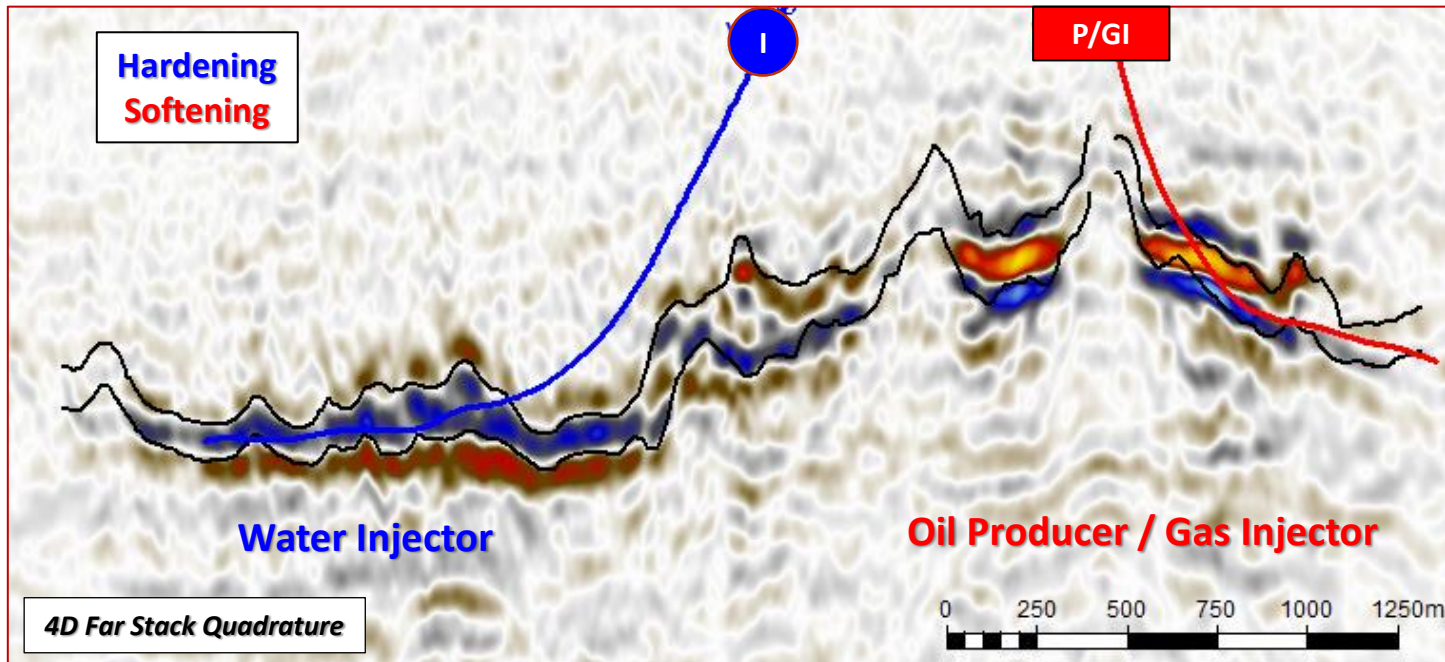# 4D Seismic in the Catcher Area

**Shining a new light on reservoir management
in complex injectite sands**

**Gary Marsden, Matt Gibson, Andy Miles,
& Vikash Kumar (Harbour Energy)**

*Sean Tian, Gustavo Corte & Colin MacBeth
(Edinburgh Time Lapse Project)*

Seismic2022

Organiser SPE

Supported by PESGB

**SEISMIC 2022 AND BEYOND - THE CONTINUING
ROLE OF SEISMIC IN THE ENERGY INDUSTRY**

4-5 MAY 2022

Catcher 4D - Presentation Outline

- **Introduction to the Catcher area**
  - 4D applicability
  - pre-survey Sim2Seis / 4D justification
  - acquisition & processing
- **4D data examples & qualitative observations**
  - waterflood movement
  - gas injection monitoring
  - fluid contacts
- **Qualitative → quantitative progress …**

The Catcher Area ...
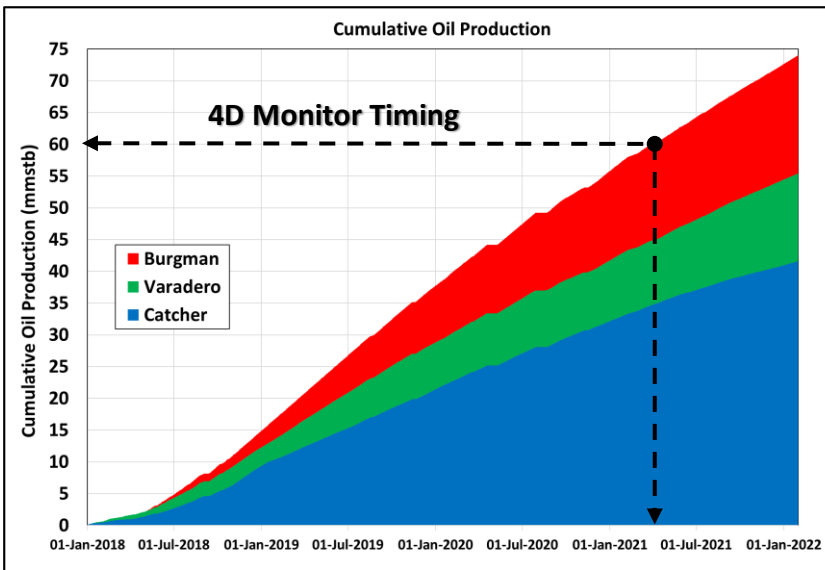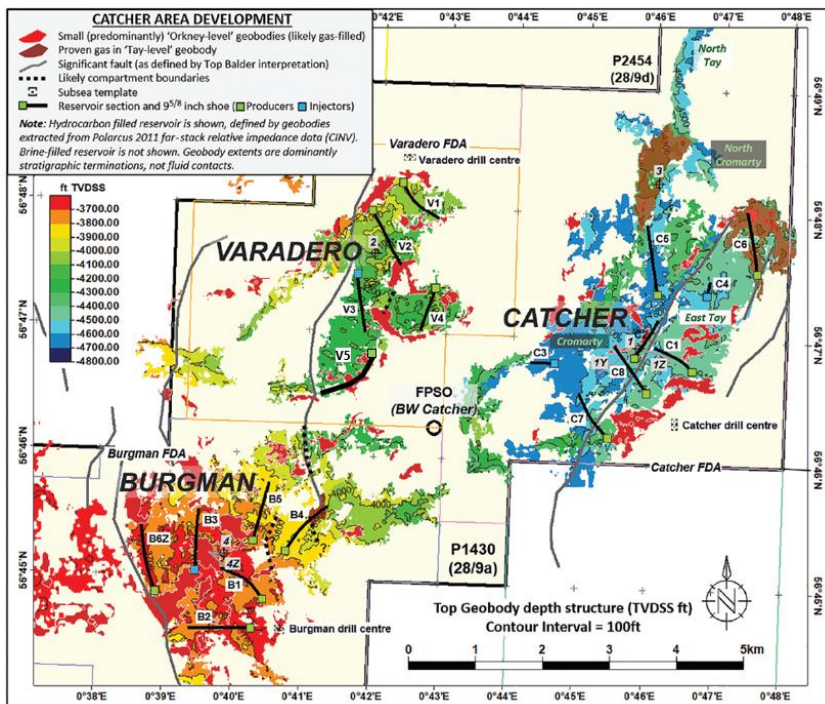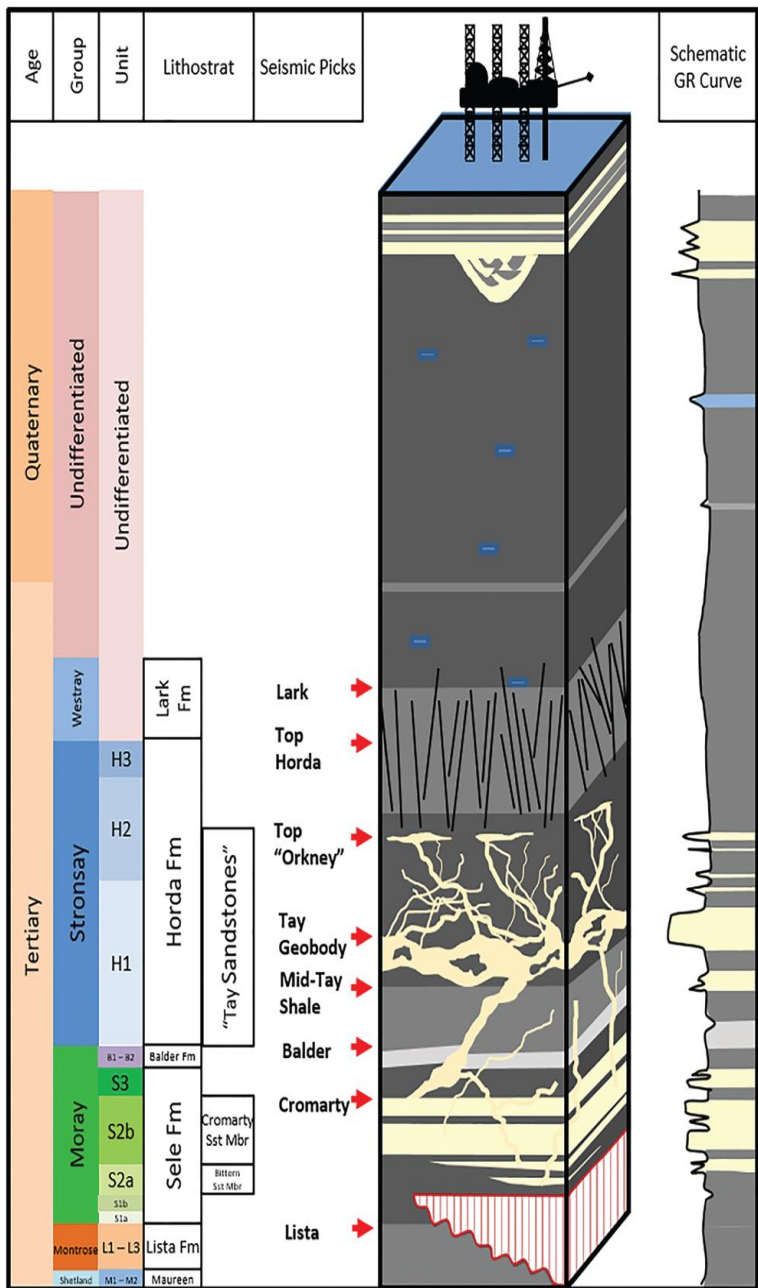
Reservoir

- Eocene age Tay / Cromarty injectite sands
  - ~ gross thickness < 60ft (tuning)
  - ~ 35% porosity
  - ~ 2 - 10 Darcy permeability
  - ~ 25º - 31º API oil

- Complex architecture
  - Main geobodies are seismically defined
  - Numerous sub-seismic sands in all wells
  - Well connected
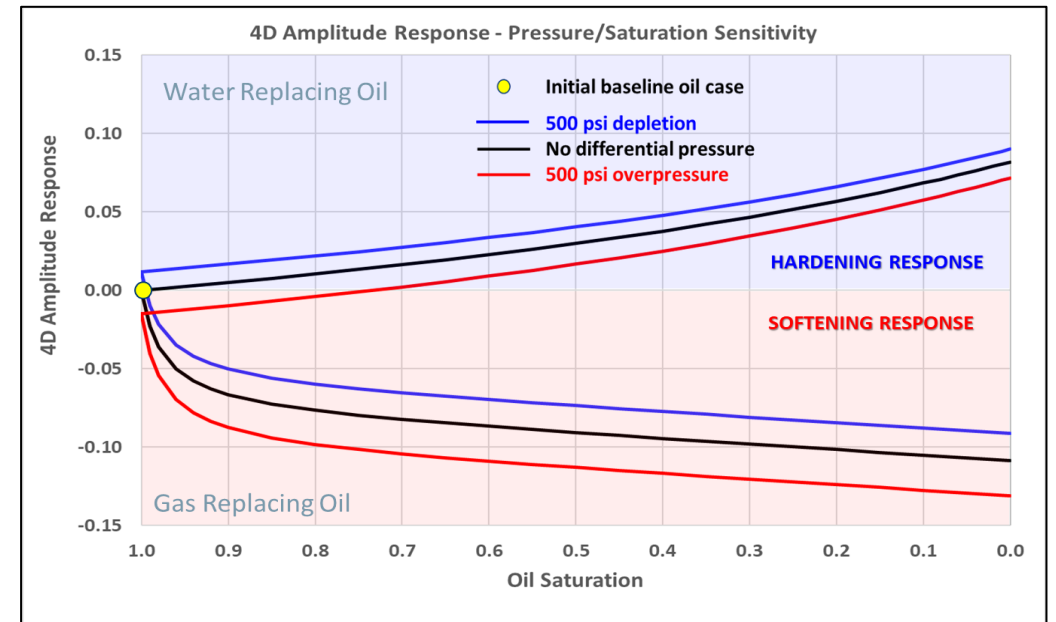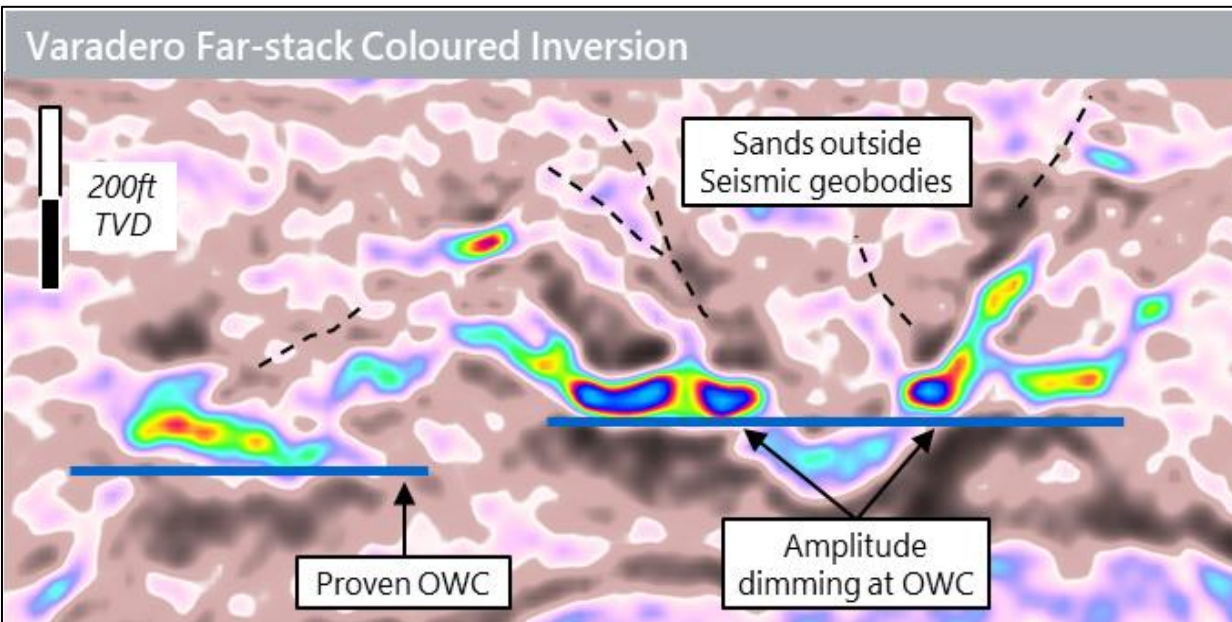
Field Development

- 3 producing fields
  - Catcher, Varadero & Burgman

- 19 development wells
  - Catcher (8), Varadero (5), Burgman (6)

- First oil - December 2017
  - ~ 74 MMstb produced by end-2021
  - ~ 60 MMstb produced at April 2021 (4D monitor)

- Volumetrics
  - 366 MMstb STOIIP

Catcher 4D Applicability ... Geophysical Perspective

Synthetic Gathers

				In Situ	Brine 100%	Oil 80%	Gas 90%
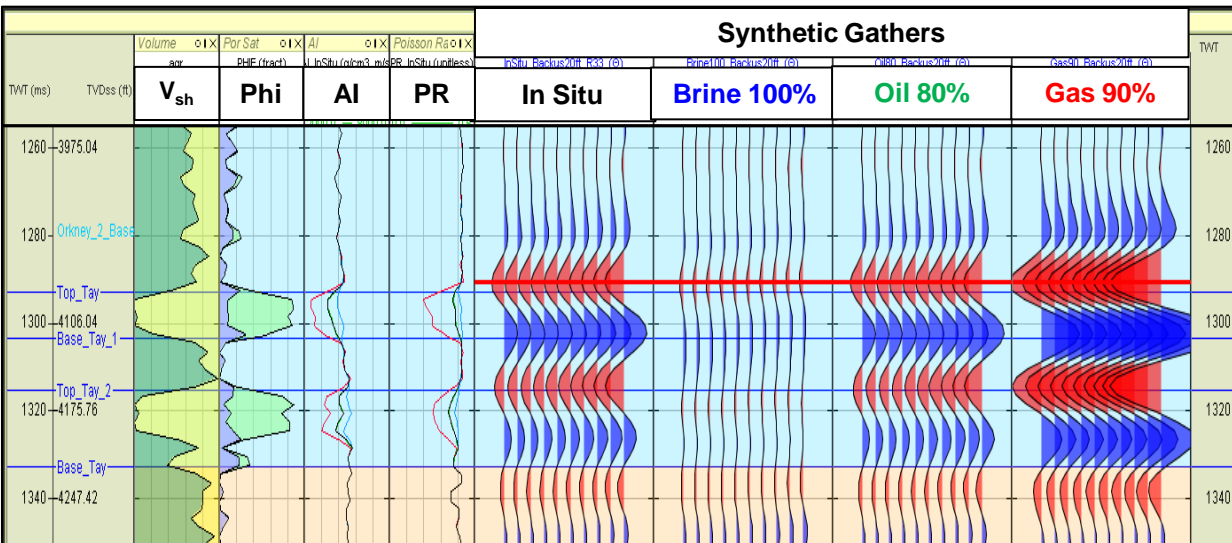
Seismic Response

- Low impedance reservoir
  - typically Class III AvO response
  - sensitive to fluid / saturation : brine sands are weak / transparent

- Far stack CI is primary dataset for interpretation
  - GOC's and OWC's can be seismically defined / inferred

- Pressure sensitivity evaluated by laboratory study
  - sensitivity limited by small reservoir pressure changes (+/-500 psi)
  - results in a weak 4D pressure response

Varadero Far-stack Coloured Inversion

200ft TVD

Sands outside Seismic geobodies

Proven OWC

Amplitude dimming at OWC

4D Amplitude Response - Pressure/Saturation Sensitivity

Water Replacing Oil
- Initial baseline oil case
- 500 psi depletion
- No differential pressure
- 500 psi overpressure

HARDENING RESPONSE

SOFTENING RESPONSE

Gas Replacing Oil

Oil Saturation

4D Amplitude Response

- Elastic properties of reservoir are favourable for imaging a 4D response
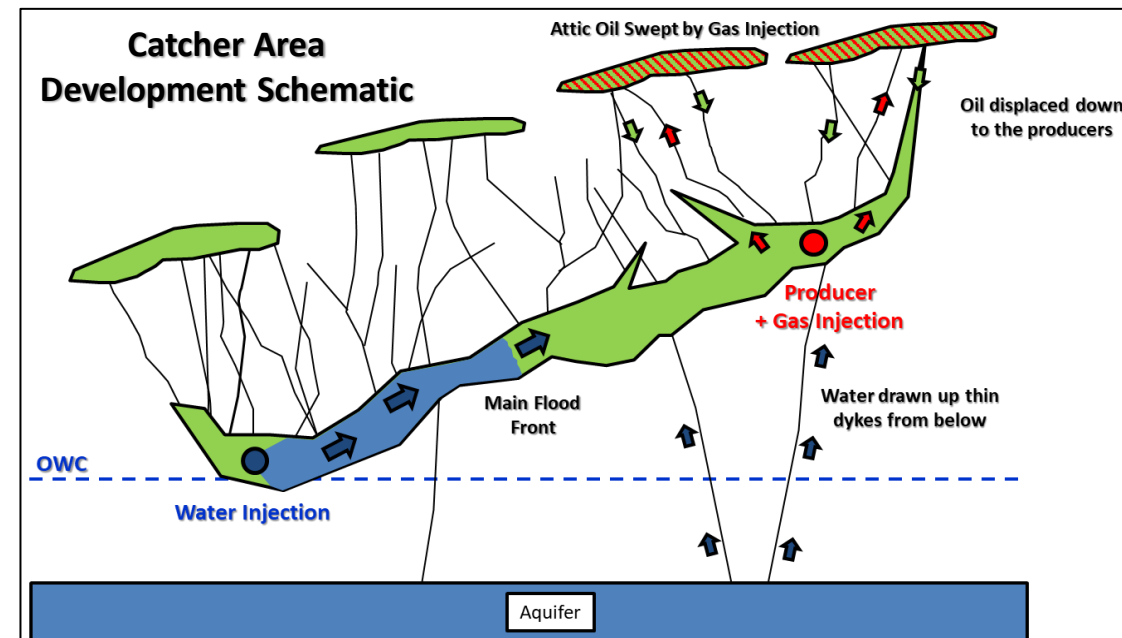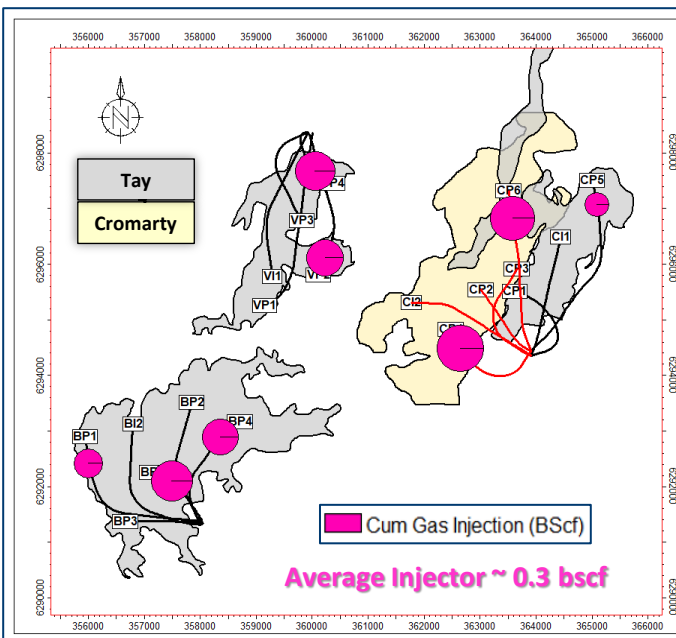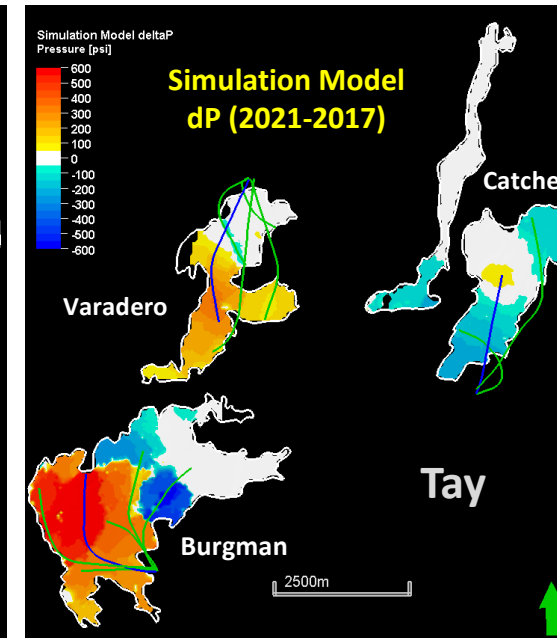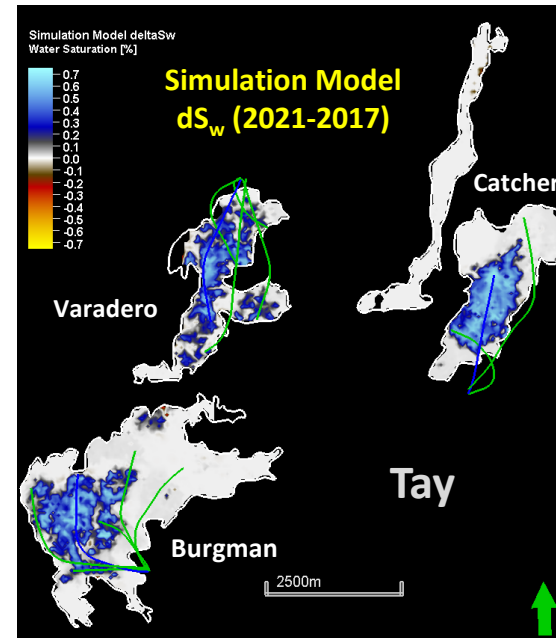- 4D response is likely to be saturation dominated ...

4

Catcher 4D Applicability ... Field Development Perspective

Average Injector ~ 20 MMbbl
Average Producer ~ 4.5 MMstb

Legend:
- Cum Oil Production (MMstb)
- Cum Water Production (MMbbls)
- Cum Water Injection (MMbbls)

Simulation Model deltaSw
Water Saturation [%]

Simulation Model dS$_w$ (2021-2017)

Varadero — Catcher — Tay — Burgman

2500m

Simulation Model deltaP
Pressure [psi]

Simulation Model dP (2021-2017)

Varadero — Catcher — Tay — Burgman
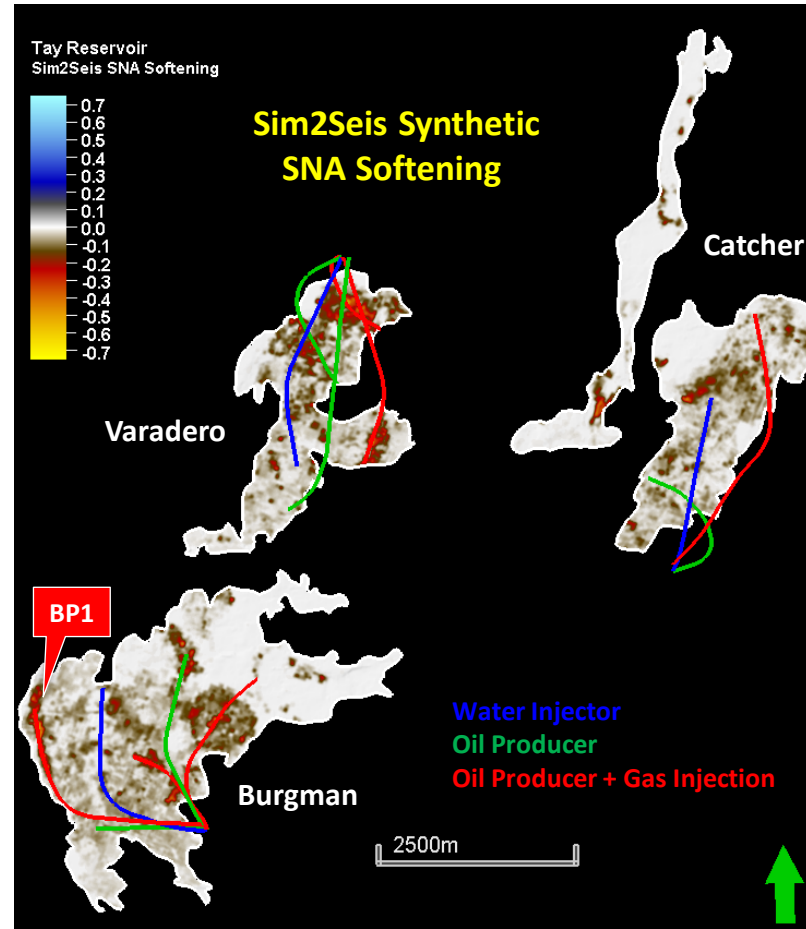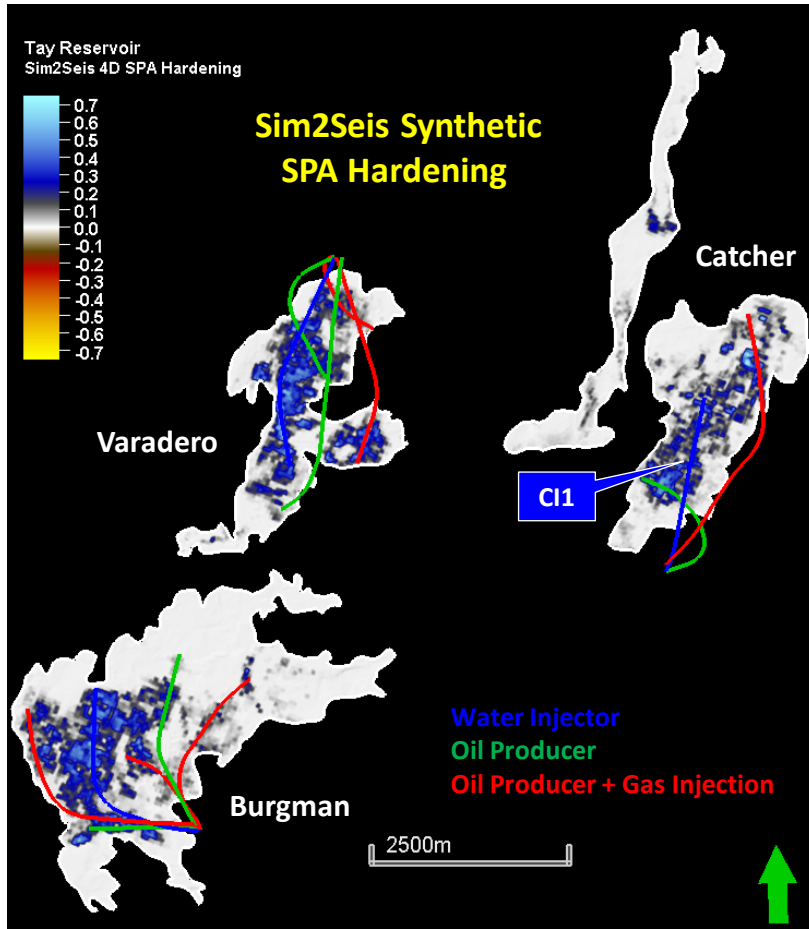
2500m

Field Development

- 4 water injectors
  - sweep & pressure support
- 15 oil producers
  - 8 with intermittent gas injection
  - GI deployed through gas lift system
- Simulation pressure change
  - relatively small ~ +/- 500psi

Average Injector ~ 0.3 bscf

Legend:
- Cum Gas Injection (BScf)

Catcher Area Development Schematic

- Attic Oil Swept by Gas Injection
- Oil displaced down to the producers
- Producer + Gas Injection
- Main Flood Front
- Water drawn up thin dykes from below
- OWC
- Water Injection
- Aquifer

Key 4D Questions

- Can flood front be tracked ?
- Can injected gas be tracked ?
- Can contact changes be observed ?

5
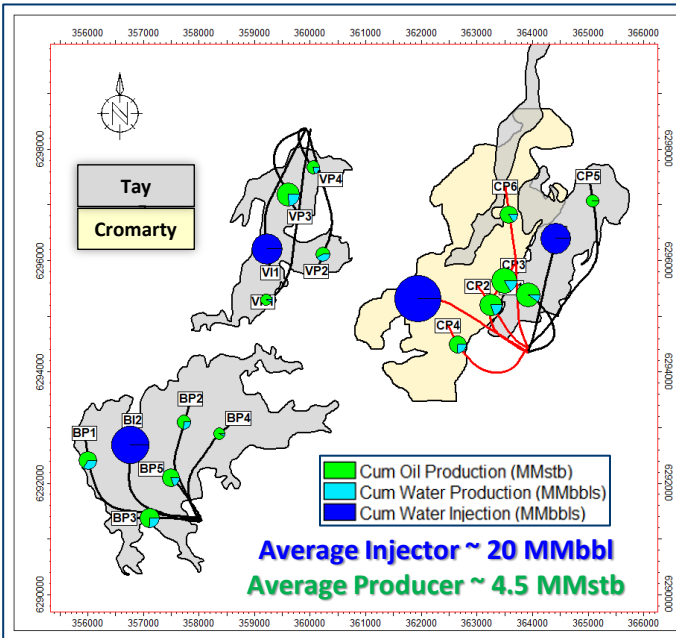
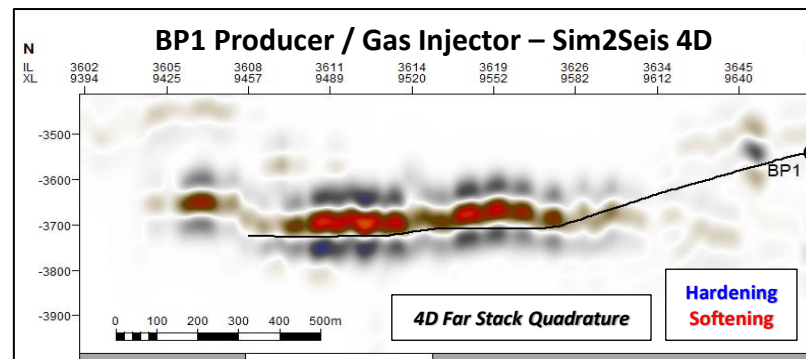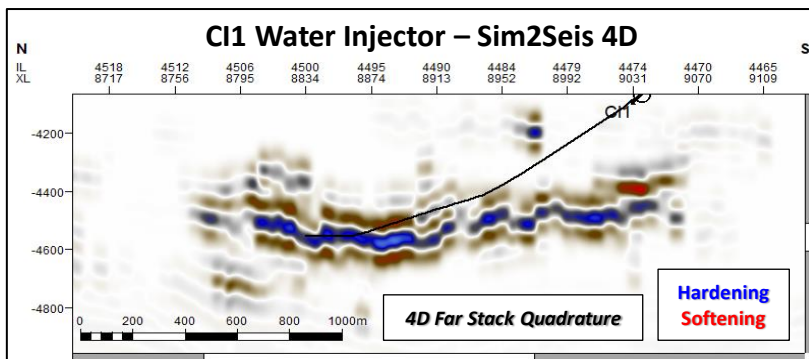# Catcher Sim2Seis Evaluation / Pre-Survey Justification

Tay Reservoir
Sim2Seis 4D SPA Hardening

Sim2Seis Synthetic
SPA Hardening

Varadero

Catcher

CI1

Water Injector
Oil Producer
Oil Producer + Gas Injection

Burgman

2500m

Tay Reservoir
Sim2Seis SNA Softening

Sim2Seis Synthetic
SNA Softening

Varadero

Catcher

BP1

Water Injector
Oil Producer
Oil Producer + Gas Injection

Burgman

2500m

Sim2Seis Evaluation

- Can flood front be tracked ? ☑
- Can injected gas be tracked ? ☑
- Can contact changes be observed ? ☑

Value of Information Assessment

- Improved infill drilling decisions
  - target definition, risk reduction, optimisation
- Improved reservoir management decisions
  - balance & distribution of water / gas injection
- Improved resource assessment
  - definition of connectivity and HC contacts
- Satellite development opportunities
  - main field learnings & 3D broadband dataset

→ VOI >> Seismic Cost

CI1 Water Injector – Sim2Seis 4D

4D Far Stack Quadrature

Hardening
Softening

BP1 Producer / Gas Injector – Sim2Seis 4D

4D Far Stack Quadrature

Hardening
Softening

Catcher Seismic Acquisition & Processing

2011 Baseline

Polarcus Nadia

Polarcus Samur

2017 First Oil

2021 Monitor

PGS Hyperion

NRMS Repeatability Tracking

Processing Step
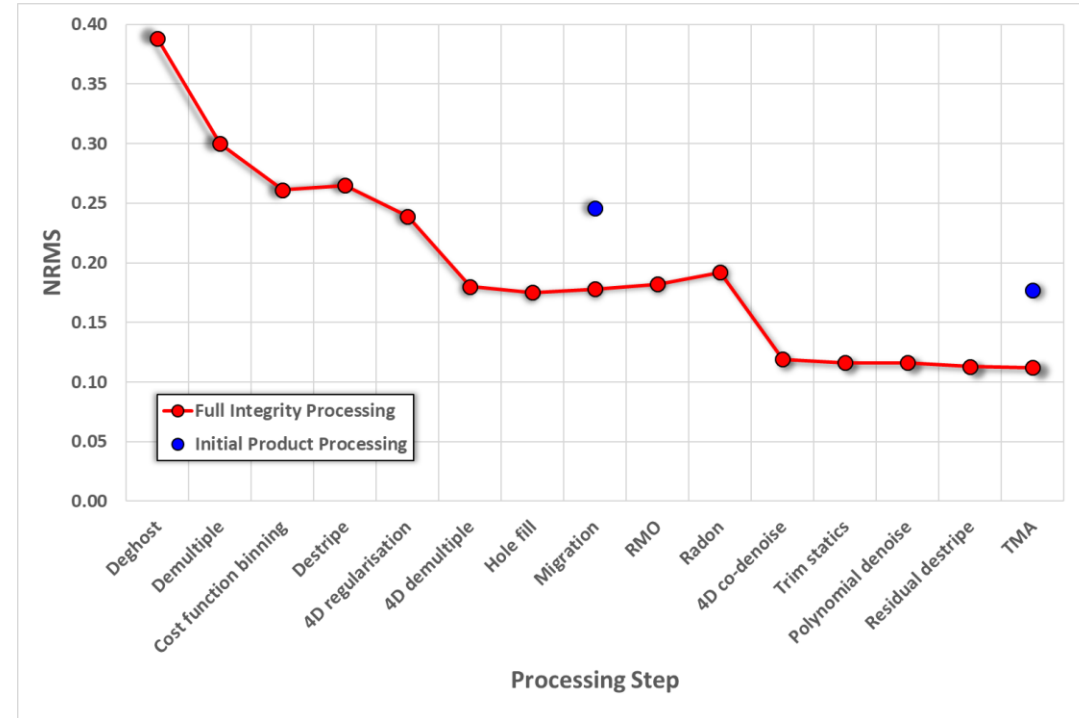
Baseline Acquisition ...
- July - October 2011
- Towed streamer survey
- 8 x 5100m streamers
- 75m separation
- Survey duration - 90 days

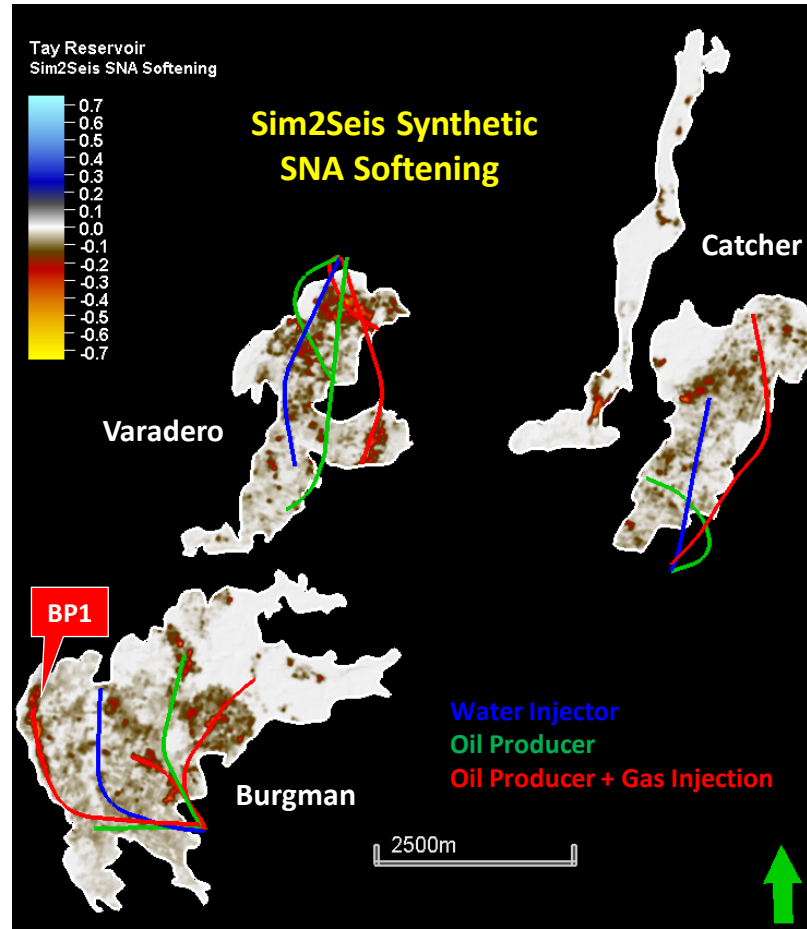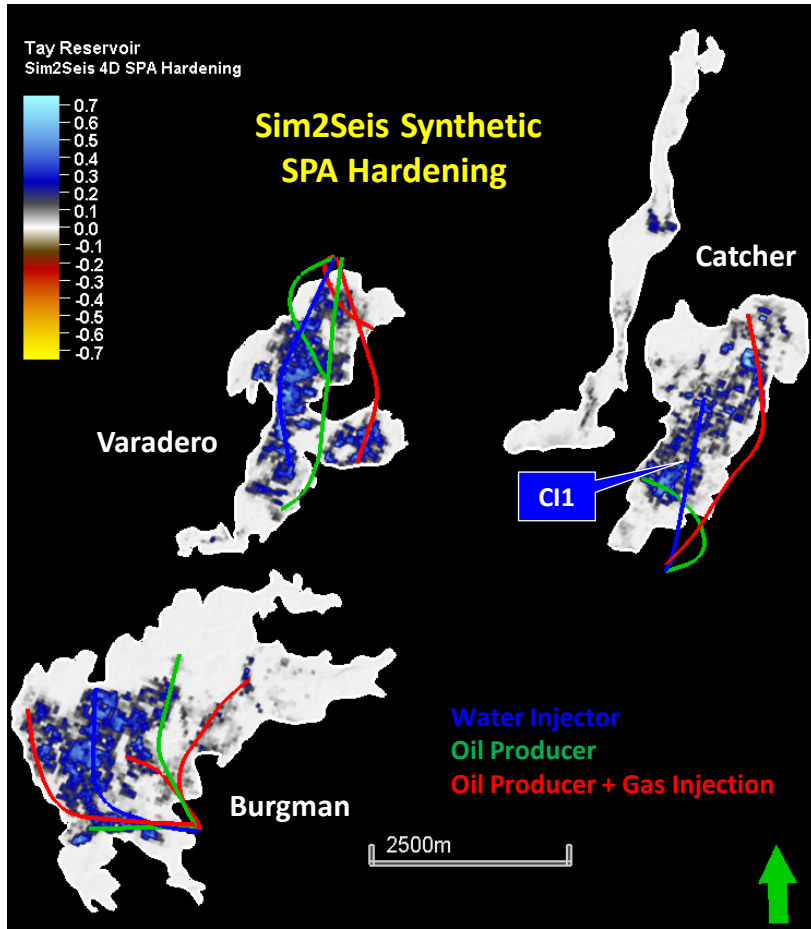**Monitor Acquisition ...**
- April - May 2021
- Towed streamer survey
- 12 x 6000m streamers
- 75m separation
- Survey duration - 33 days

4D Seismic Processing ...
- Reprocessed baseline data ahead of monitor acquisition
- Processing flows ready to run immediately on monitor data
- Initial product processing (CGG) completed July 2021
  - **- 4D initial product processing < 6 weeks**
  - **- 4D results available ~ 3months from first shot**
- Full integrity processing (CGG) completed January 2022
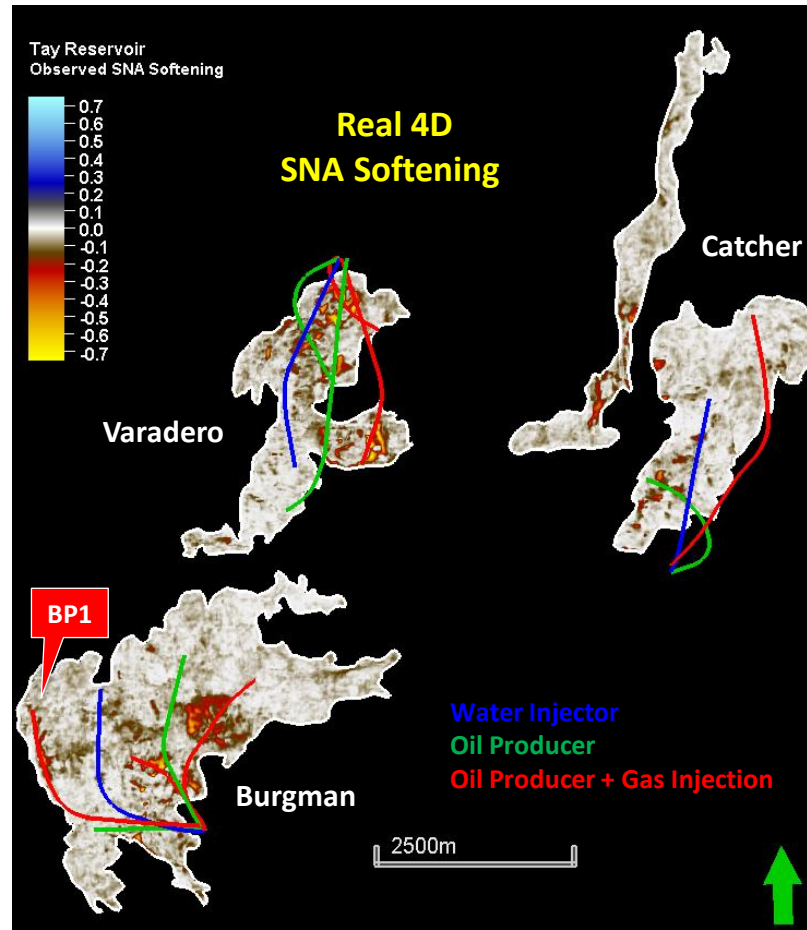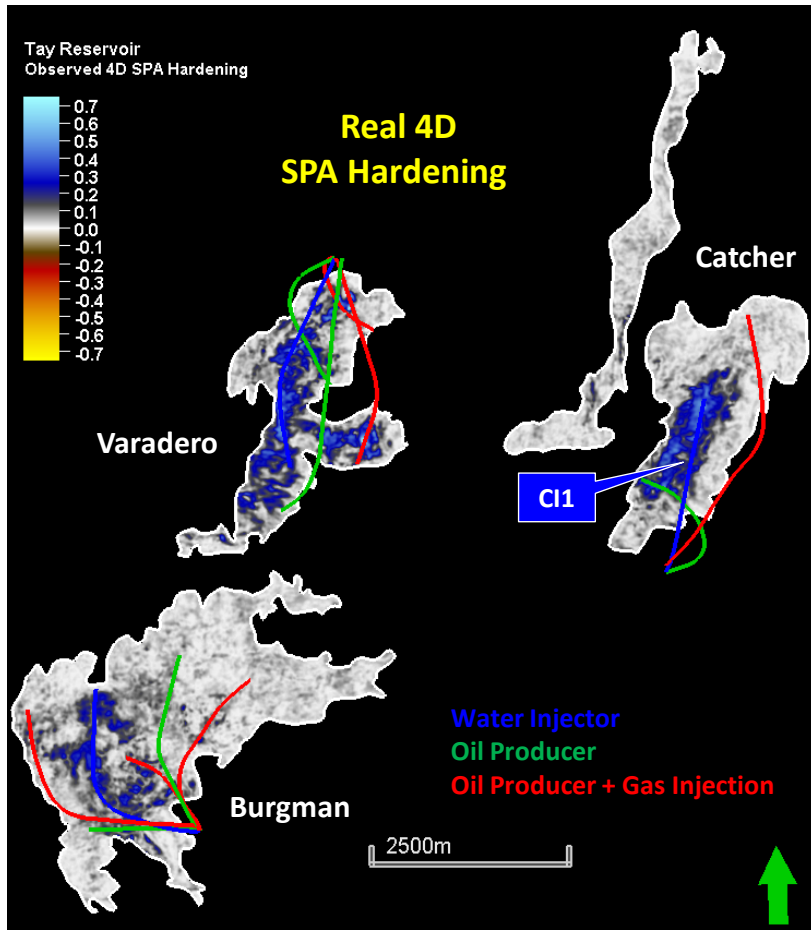
Catcher Sim2Seis 4D Seismic Response

Tay Reservoir
Sim2Seis 4D SPA Hardening

Sim2Seis Synthetic SPA Hardening

Catcher

Varadero

CI1

Burgman

Water Injector
Oil Producer
Oil Producer + Gas Injection

2500m

Tay Reservoir
Sim2Seis SNA Softening

Sim2Seis Synthetic SNA Softening

Catcher

Varadero

BP1

Burgman

Water Injector
Oil Producer
Oil Producer + Gas Injection

2500m

Sim2Seis Evaluation

- Can flood front be tracked ? ☑
- Can injected gas be tracked ? ☑
- Can contact changes be observed ? ☑

CI1 Water Injector – Sim2Seis 4D

Hardening
Softening

4D Far Stack Quadrature

BP1 Producer / Gas Injector – Sim2Seis 4D

Hardening
Softening

4D Far Stack Quadrature

Catcher Real 4D Seismic Response

Real 4D
- Can flood front be tracked ? ☑
- Can injected gas be tracked ? ☑
- Can contact changes be observed ? ☑

Initial Observations
- **Waterflood** generally in line with pre-survey model but with key differences …
  - Varadero more swept than expected
  - Catcher & Burgman less swept than expected

- **Gas distribution** generally in agreement …
 - injection is occurring along full wellbore
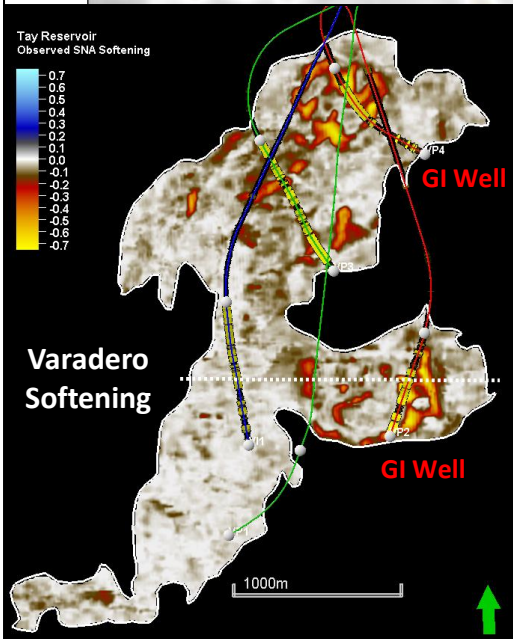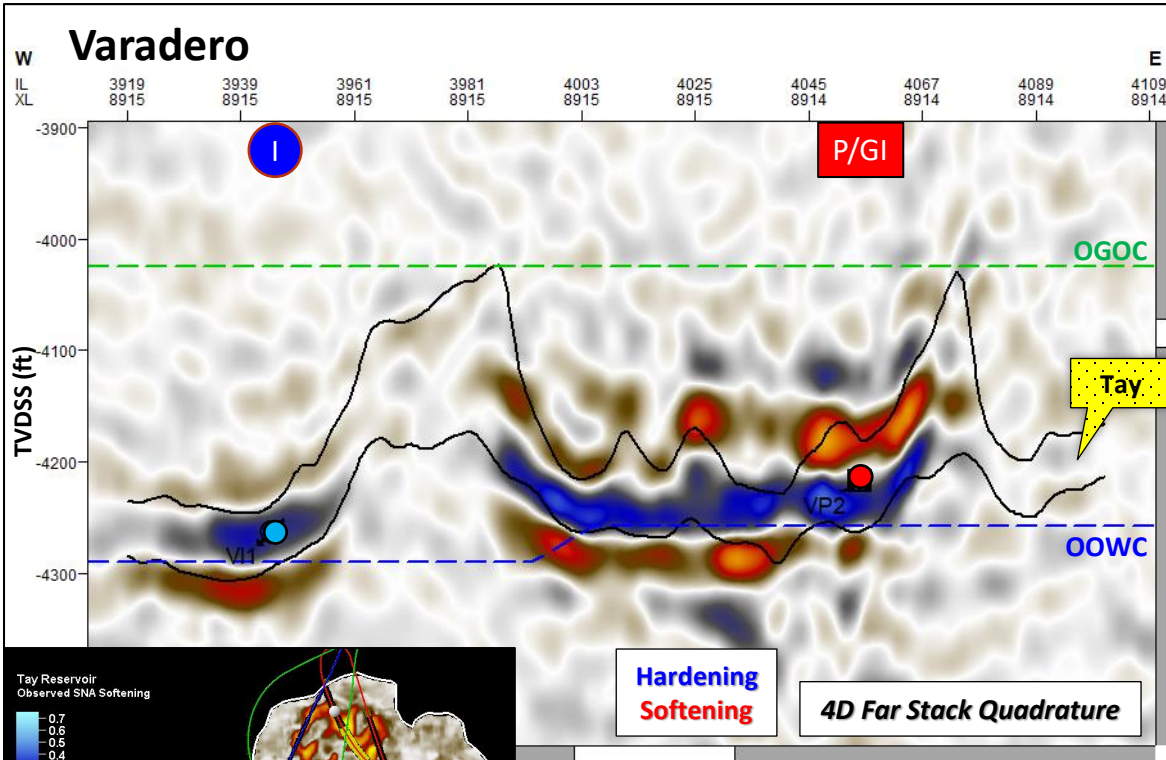 - alignment with local structure
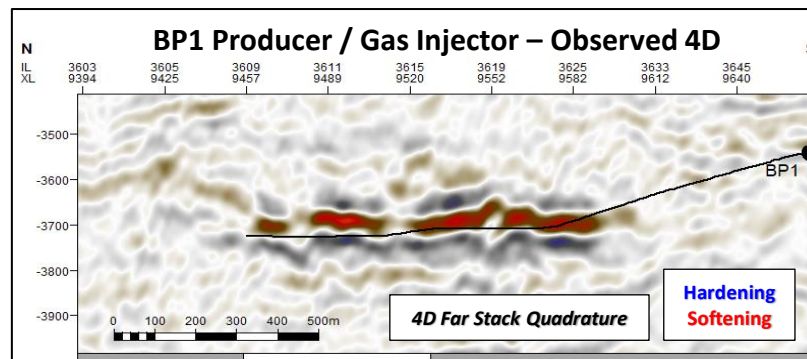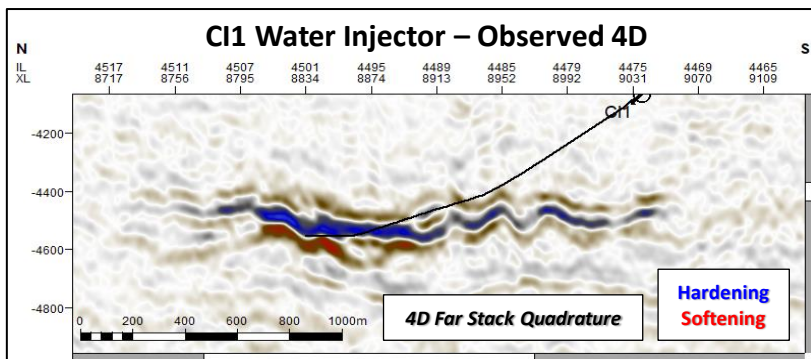
Catcher 4D Seismic - Hardening Examples
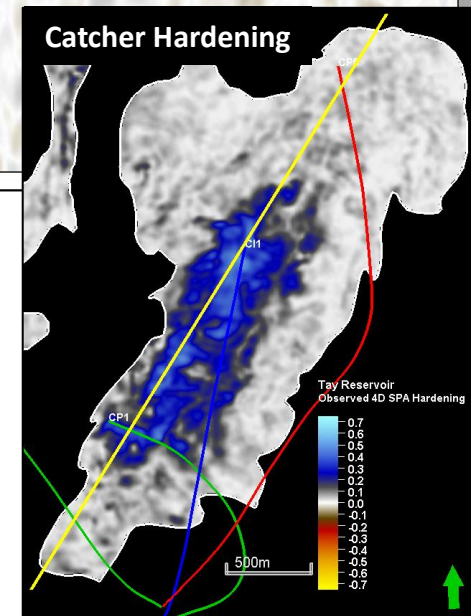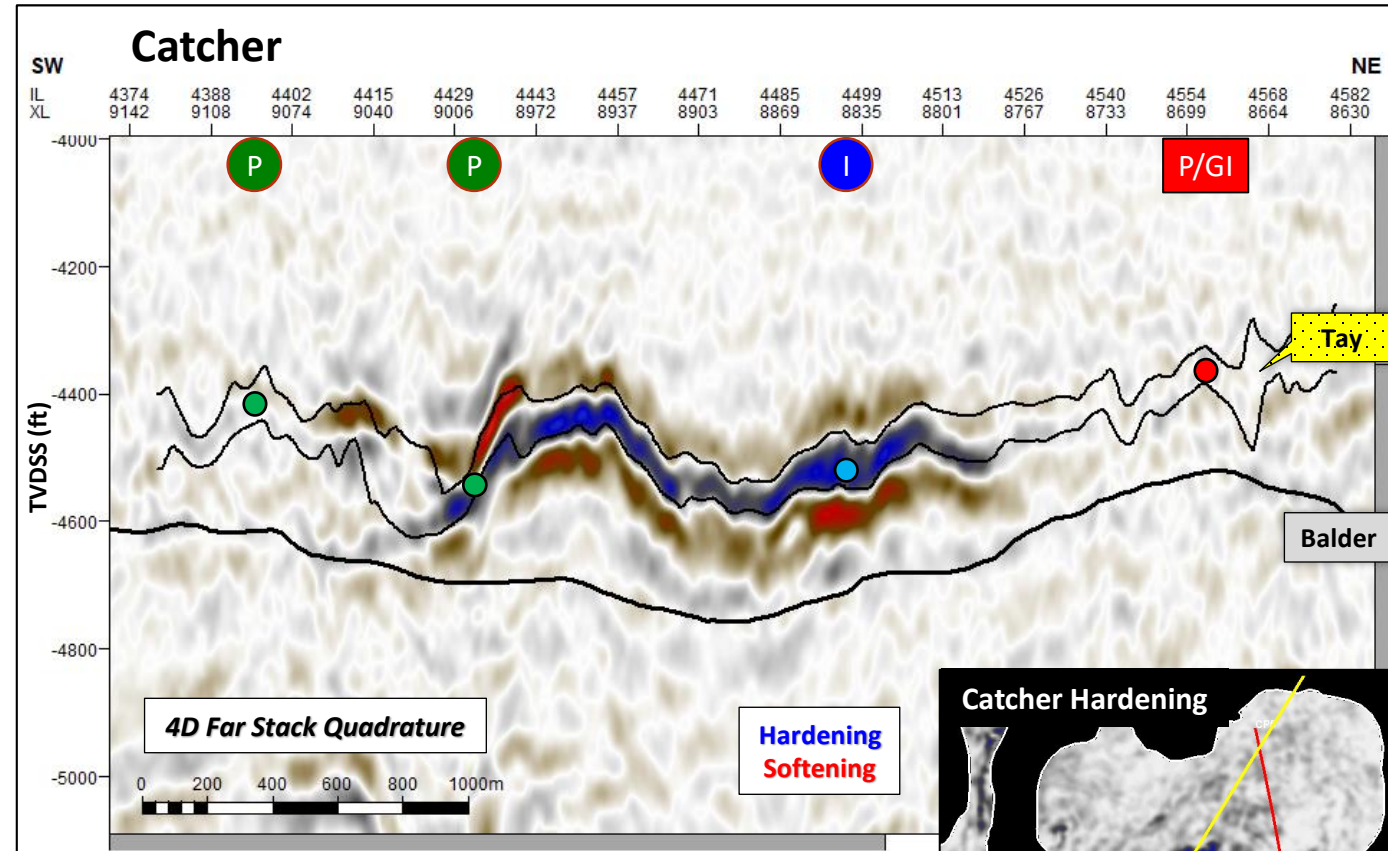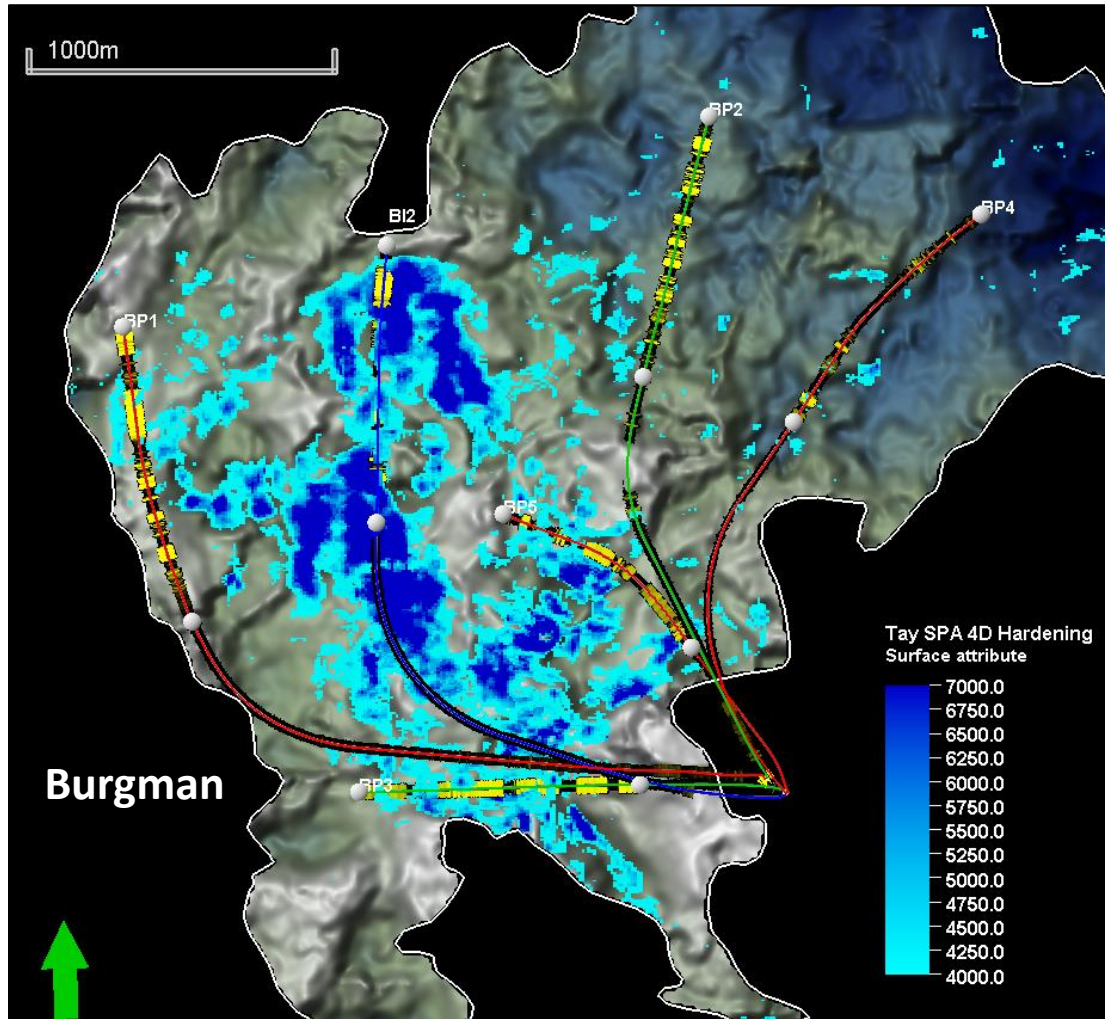
- Good vertical sweep near water injectors ... gravity segregation to base geobody further away
- Strong alignment between inferred water movement and basal structure / discontinuities
- Good evidence of solution gas segregating into local attics

Catcher 4D Seismic - Softening Examples
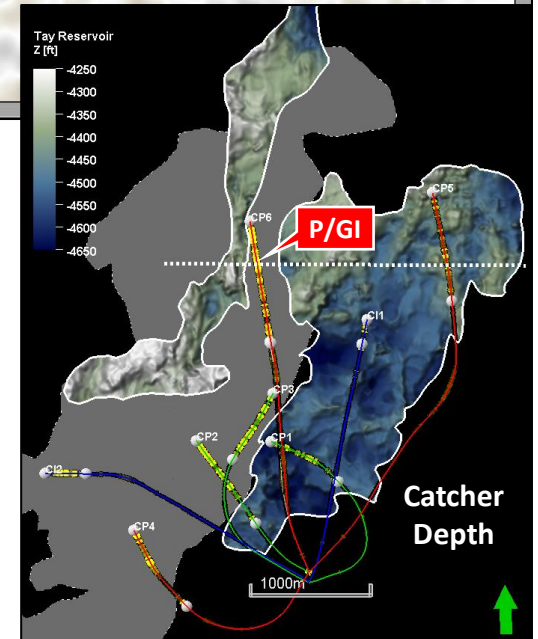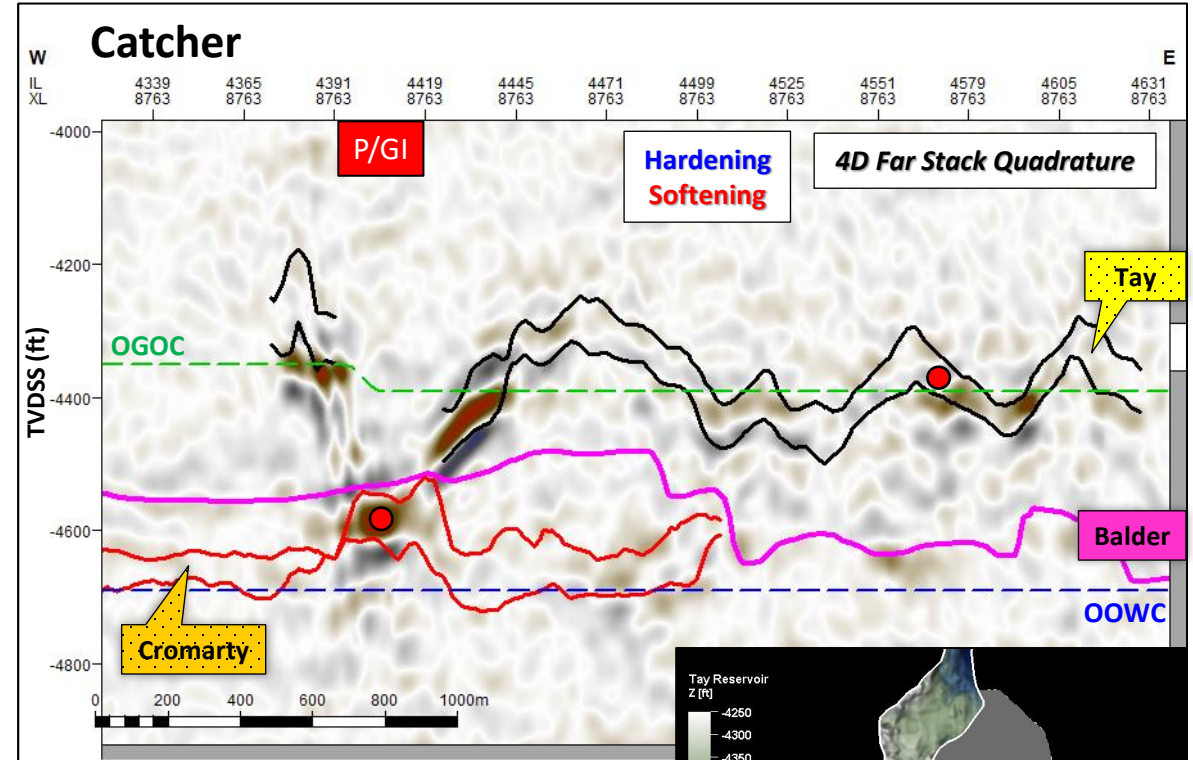
- Good evidence that injected gas is filling local structural highs
  - Confident that gas is propagating along the full wellbore

- Migrating gas illuminates previously low visibility sands
  - Confidence in prior tentative connectivity
 - Confirmation of locally different gas/oil contacts

Catcher 4D Seismic - Contact Movement Example
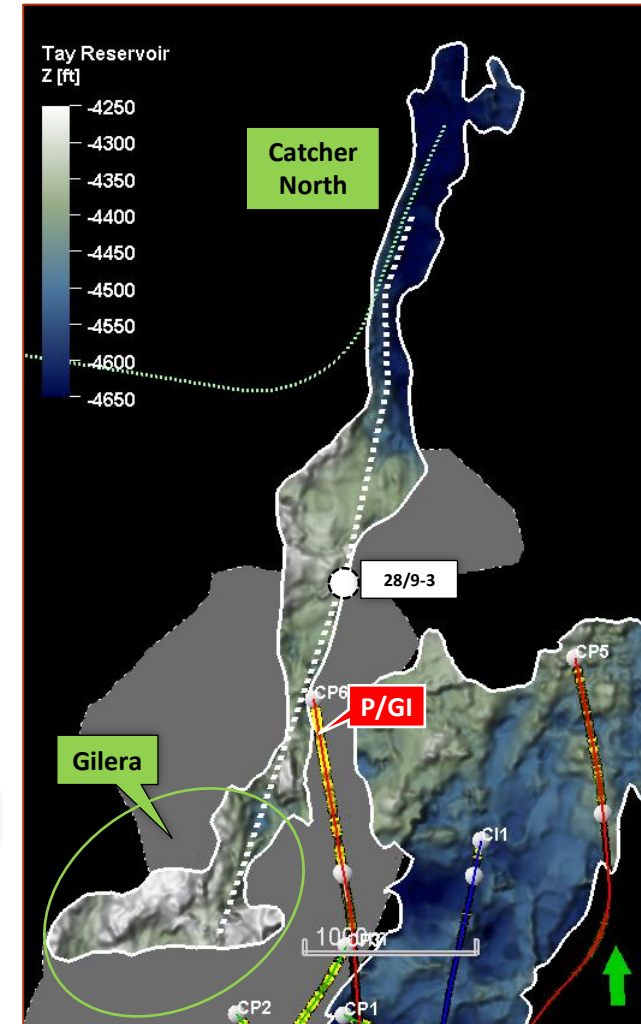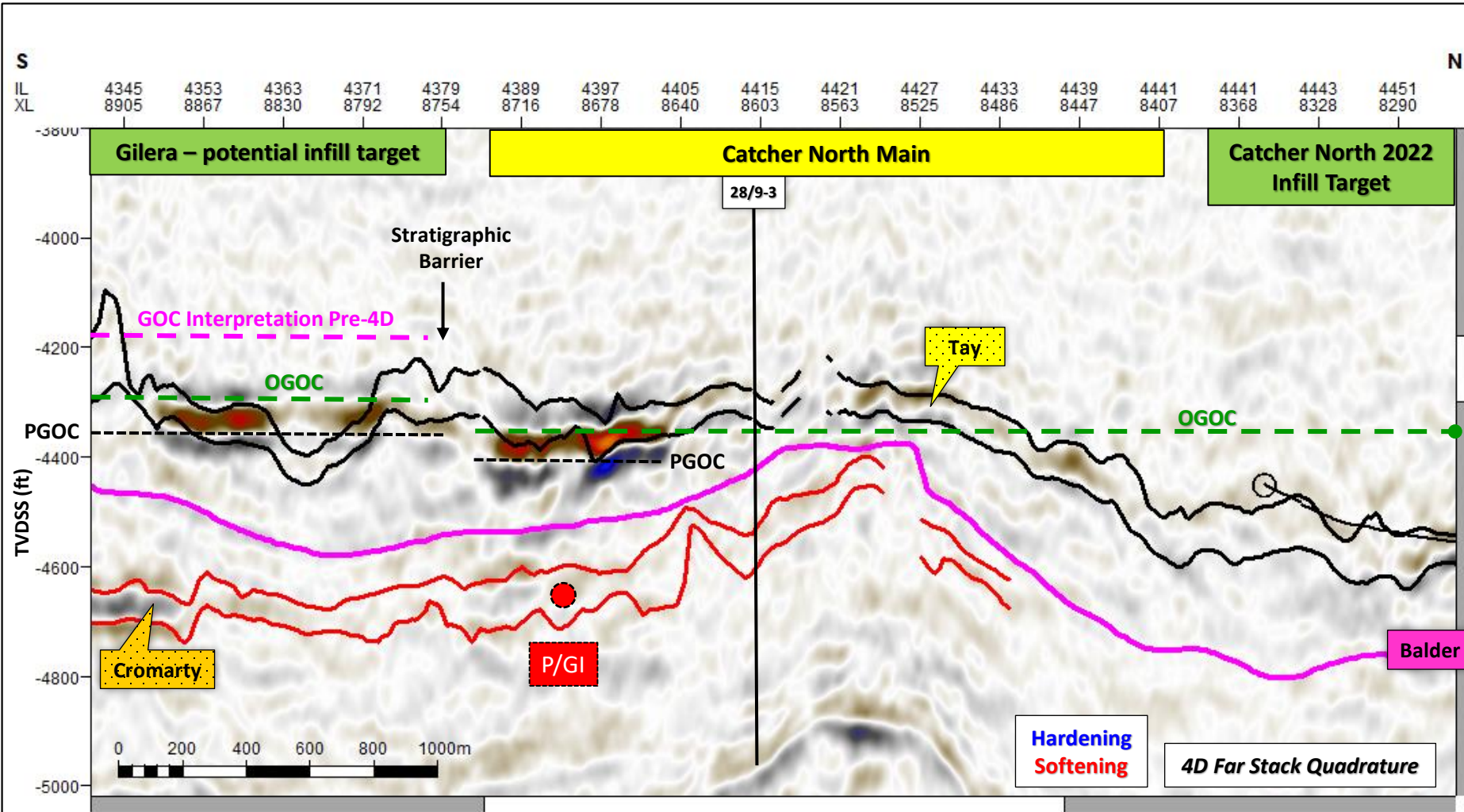
- GOC in Gilera was originally interpreted to be shallower than the main area → potential oil infill target
- 4D confirms difference in GOC between Gilera & Catcher North but demonstrates Gilera OGOC is deeper than prognosed
- 4D also infers that gas has migrated into Gilera and displaced oil ... mitigated drilling of non-viable infill target
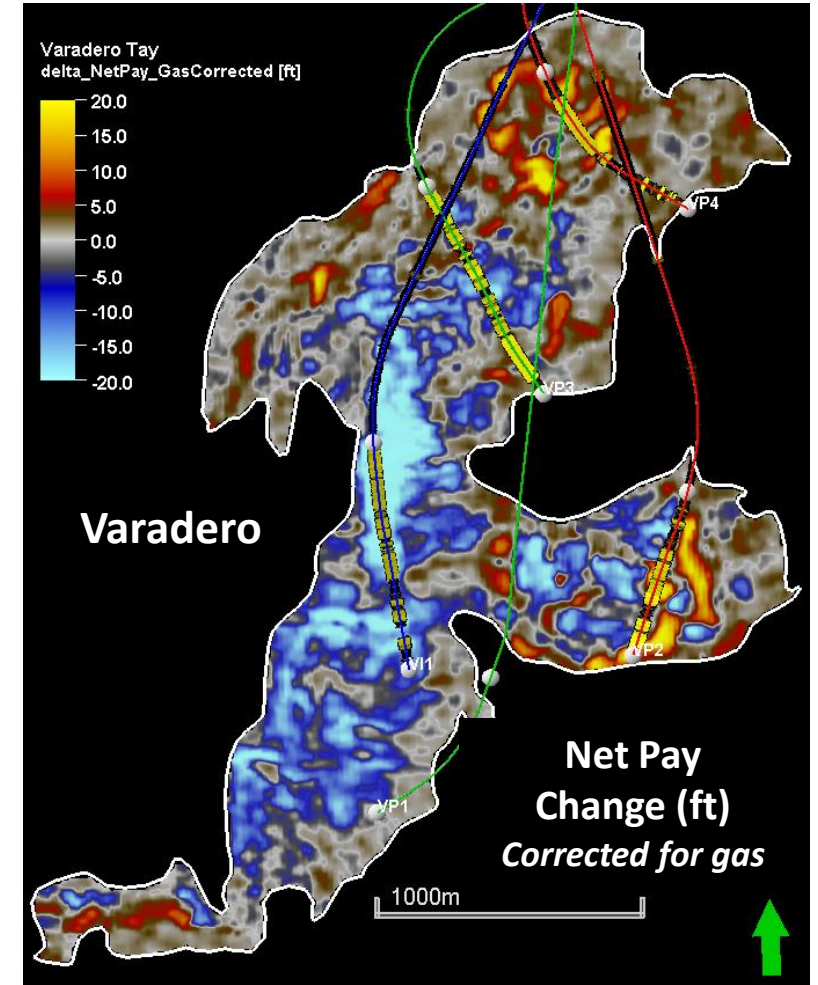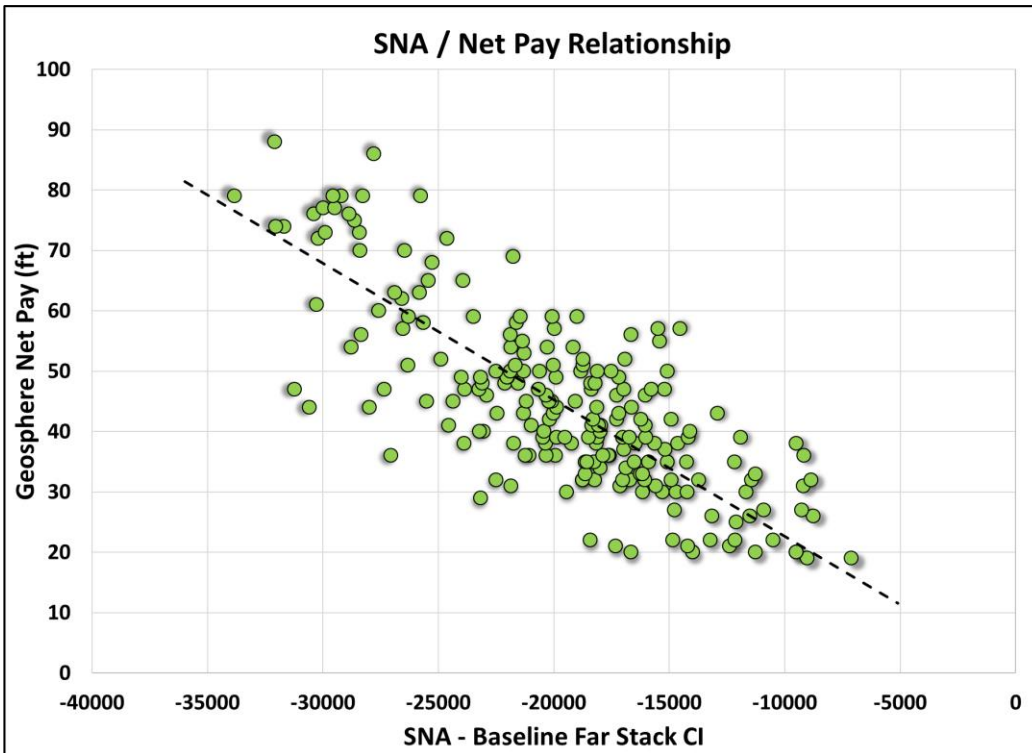
12

Semi-Quantitative Interpretation : Net Pay Change

Far Stack CI Data
→ SNA Attribute
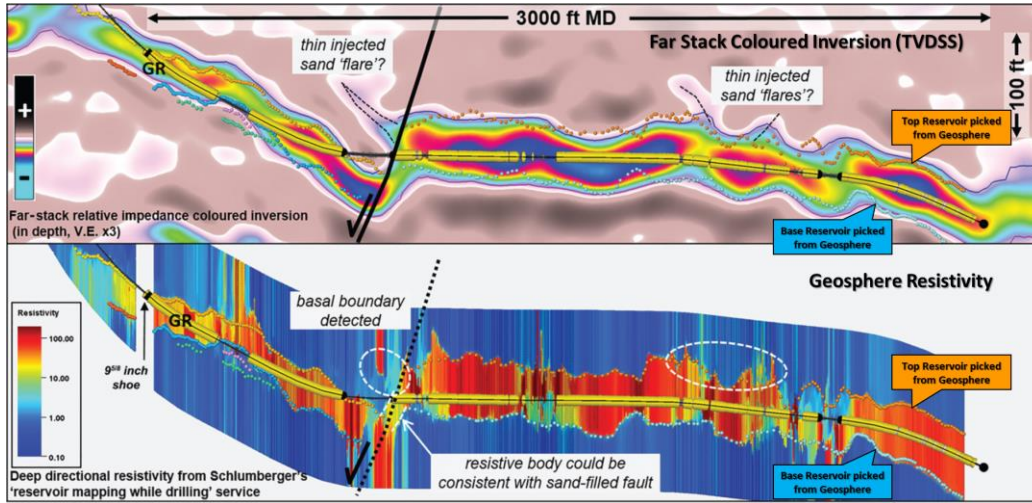
Geosphere
Resistivity
→ Net Pay Estimate
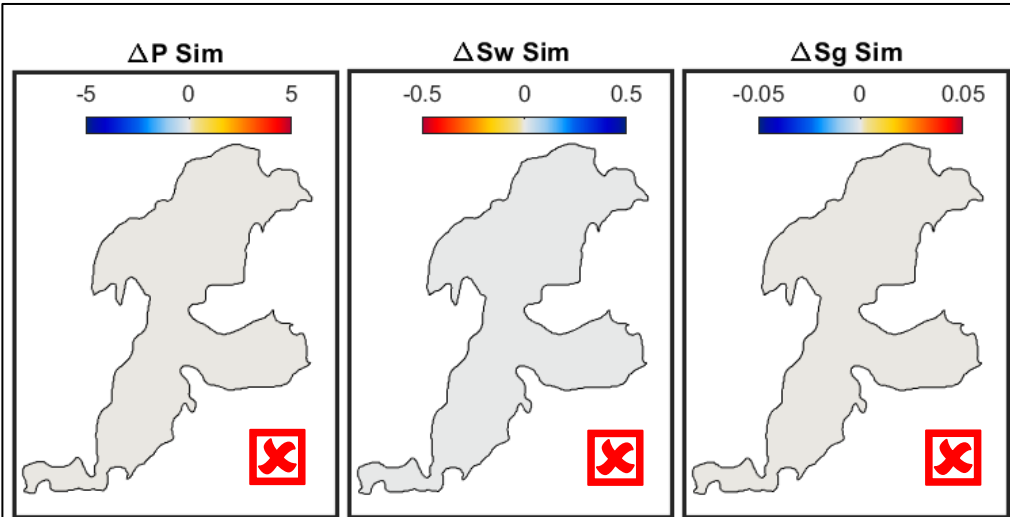
SNA / Net Pay
Relationship

- SNA relationship used to estimate Baseline Net Pay (ft)
- Same relationship used to estimate Monitor Net Pay (ft)
- Difference provides estimate of net pay change (ft)
  - -ve where pay has reduced (primarily water replacing oil)
  - +ve where pay has increased (primarily gas injection)

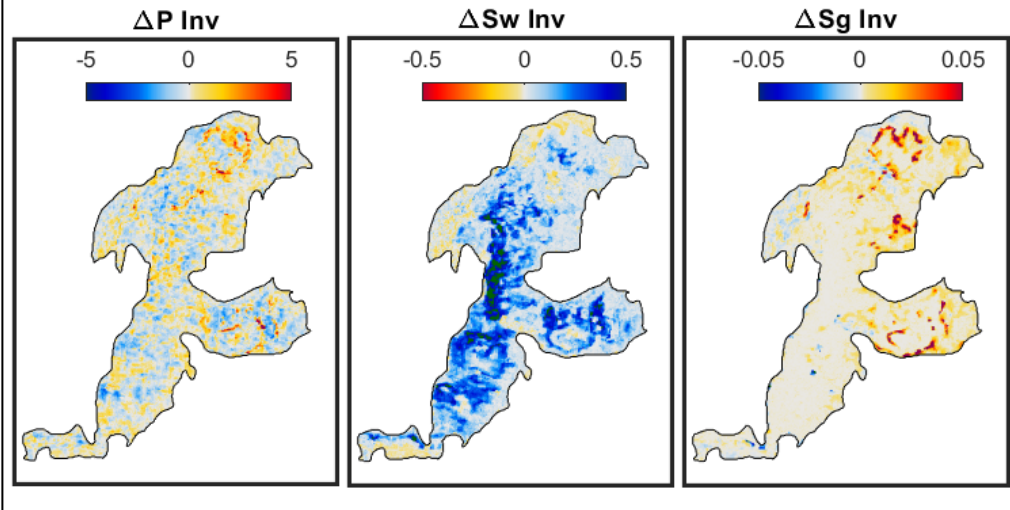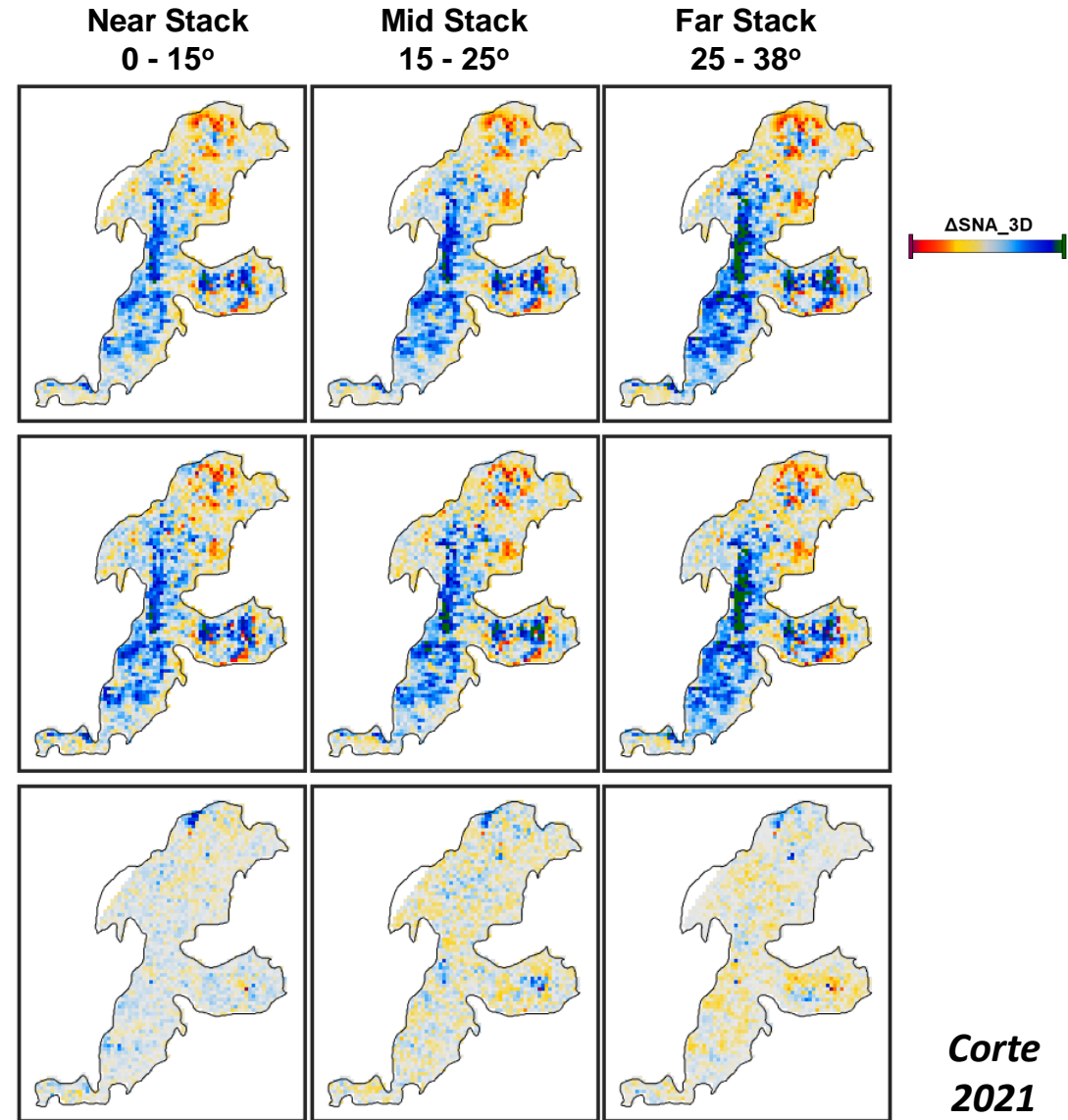# Quantitative Interpretation : Saturation / Pressure Inversion

Corte 2021

- Bayesian inversion approach (developed by ETLP) used to invert 4D angle stack maps into pressure, water and gas saturation changes
- Can selectively incorporate weighted a-priori information from simulation models ...
- No Prior - reasonable ΔS_w & ΔS_g results but weak pressure signal in 4D response produces noisy, incoherent ΔP inversion

Quantitative Interpretation : Saturation / Pressure Inversion
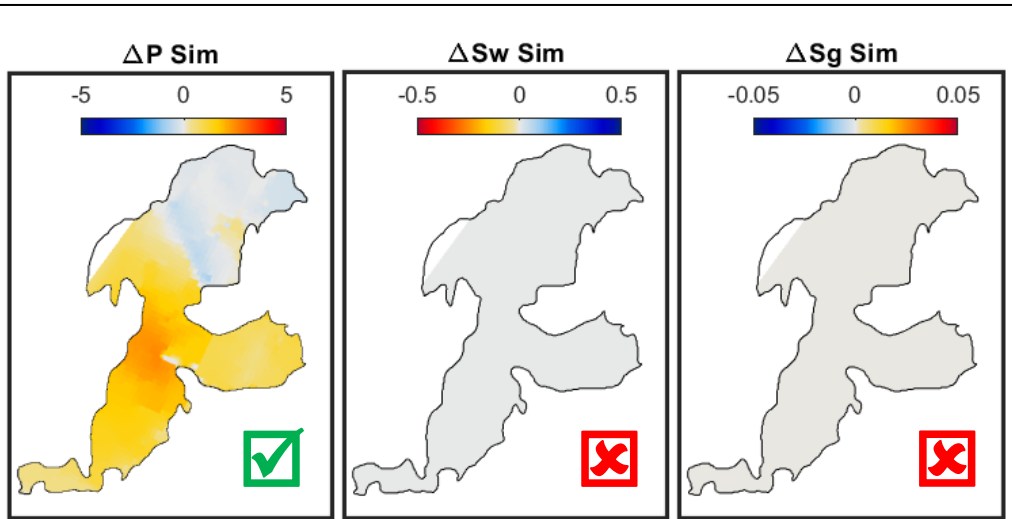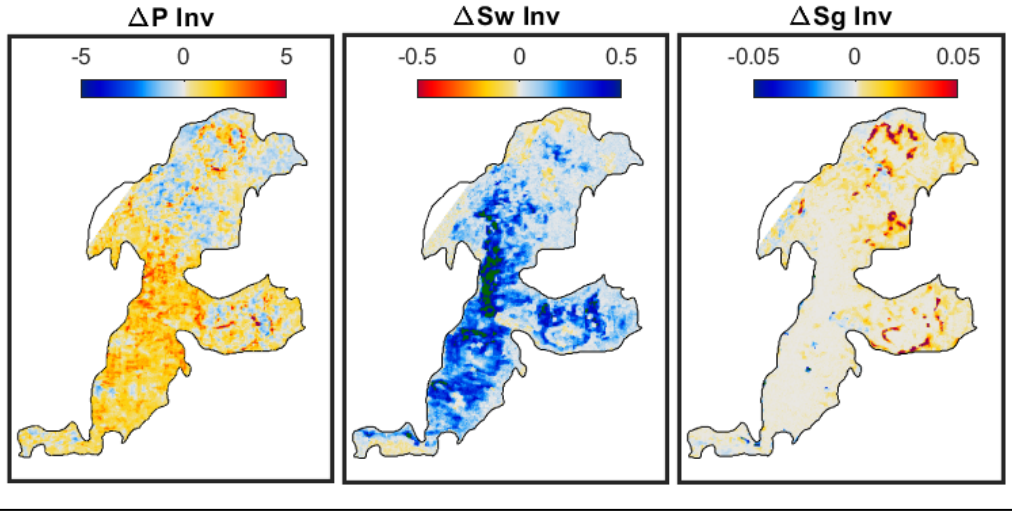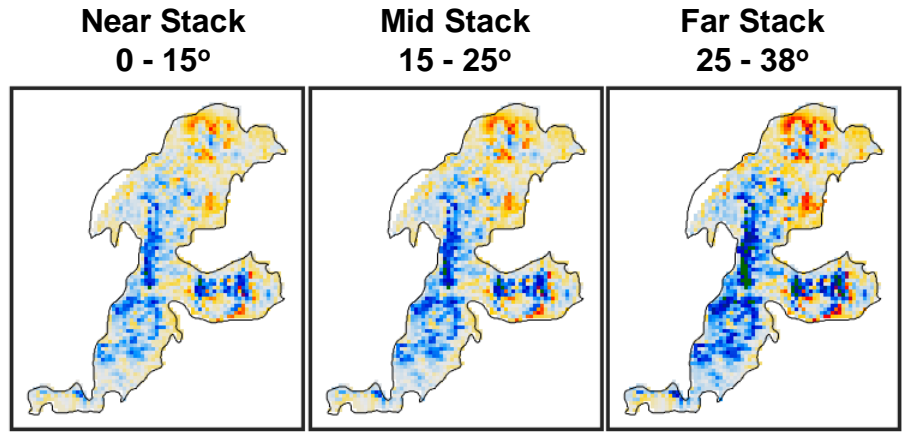

Weak Pressure Prior
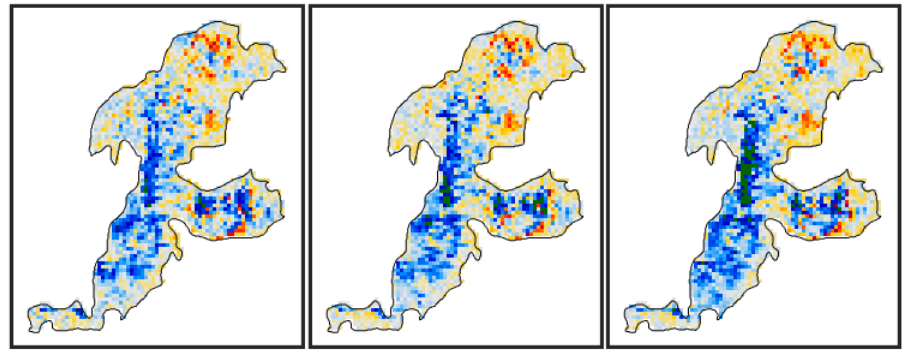
Corte 2021

- Bayesian inversion approach (developed by ETLP) used to invert 4D angle stack maps into pressure, water and gas saturation changes
- Can selectively incorporate weighted a-priori information from simulation models …
- Weak pressure prior - pressure increase invokes a weak softening response / inverted ΔSw increases by up to ~ 15% to compensate

Catcher 4D Seismic Summary ...

4D seismic has already demonstrated significant value ...

- Improved reservoir management through understanding of fluid movement, connectivity & flow pathways
- Facilitated identification, de-risking and / or elimination of future infill wells
- Demonstrated success of gas injection project and optimised future potential
- STOIIP refinement through fluid contact corrections and improved confidence in sub-seismic sand volume

4D seismic will continue to deliver future value ...

- Incorporation of 4D observations / QI products is guiding new phase of modelling and history matching
- 3D imaging improvements derived from monitor broadband processing / diffraction imaging

Thank you …

Acknowledgements …

- Significant support from the entire Catcher subsurface and asset team
- Acquisition and processing QC personnel
- CGG subsurface imaging team
- Edinburgh Time Lapse Project
- Guidance and support from the Catcher Area Development JV partners

Thanks to TGS for permission to show 4D results based on Polarcus 2011 multiclient baseline acquisition … TGS