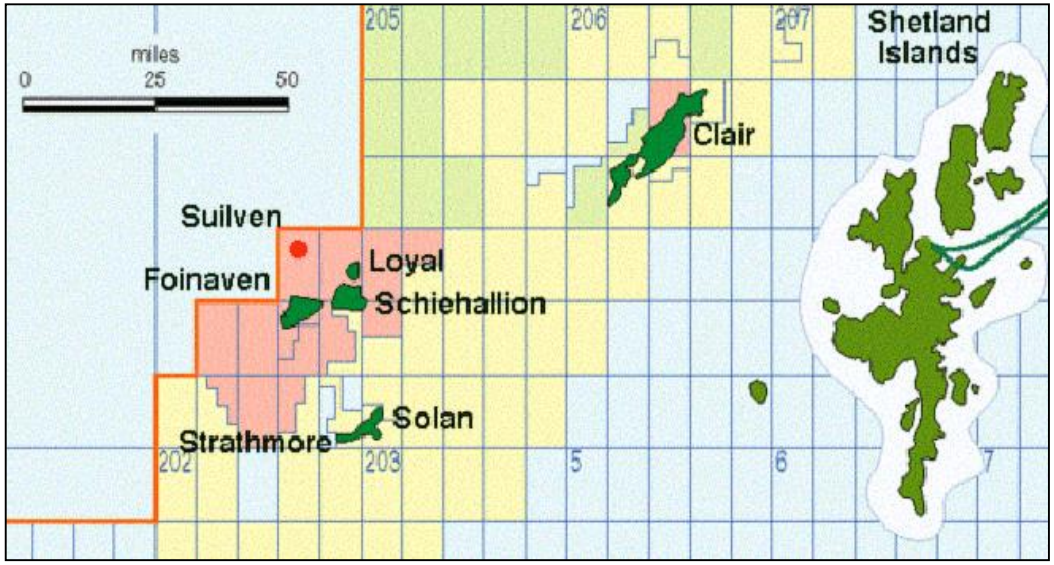
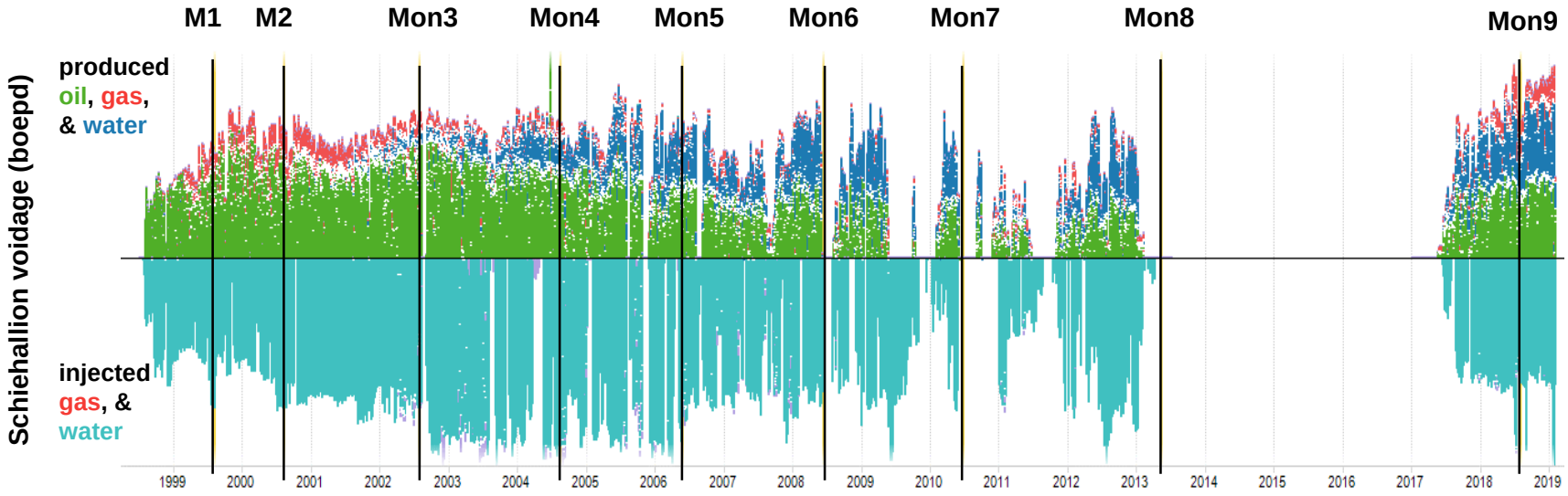


Quad 204 4D – reaching limits

Ewan Laws on behalf of BP's Deepwater Team

9th 4D monitor (2018) Acquisition

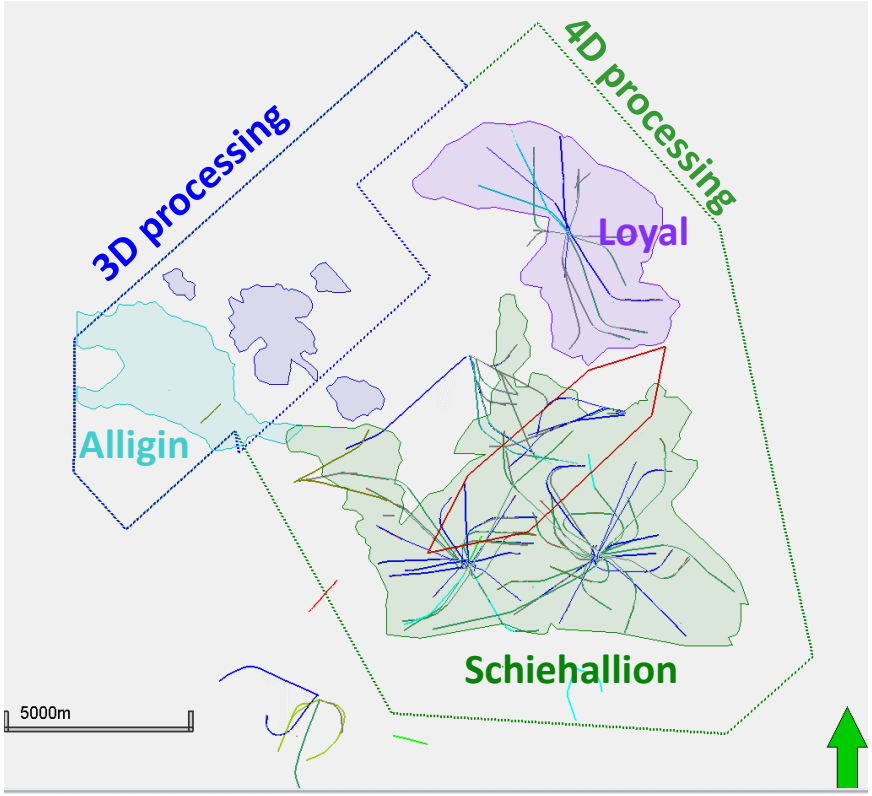
- 9th NATS survey acquired safely & under budget
- Judged risk to tow deep and re-datum using Sentinel® MS paid off
- 84 days from last shot to field-wide map:
  - Acquired 18th July – 12th Aug, H_{rec} 25th Sept, field-wide 4D map 18th Dec



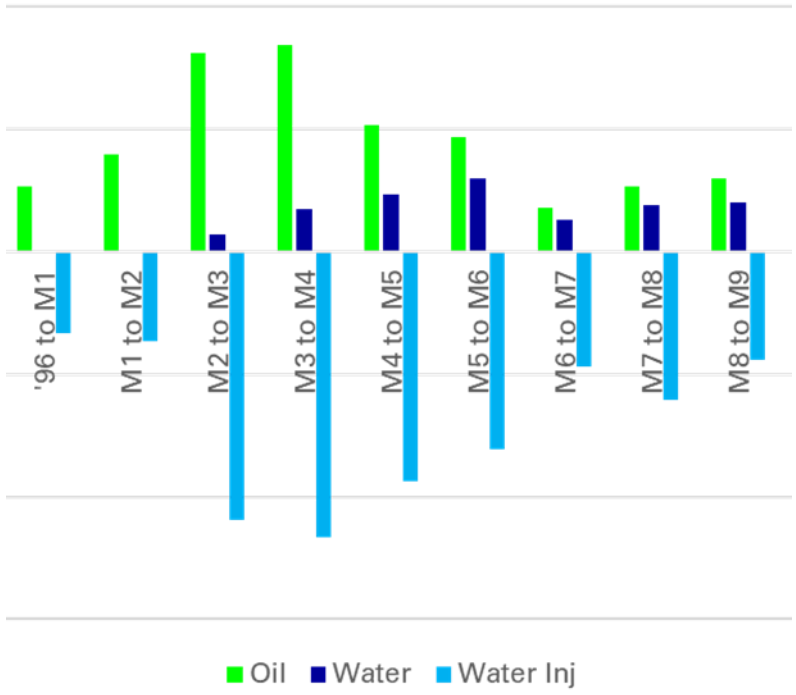
From Thomas Harpley

WoS fields, seismic surveys and reservoir flux

Mon9 acquisition = 238km² full-fold



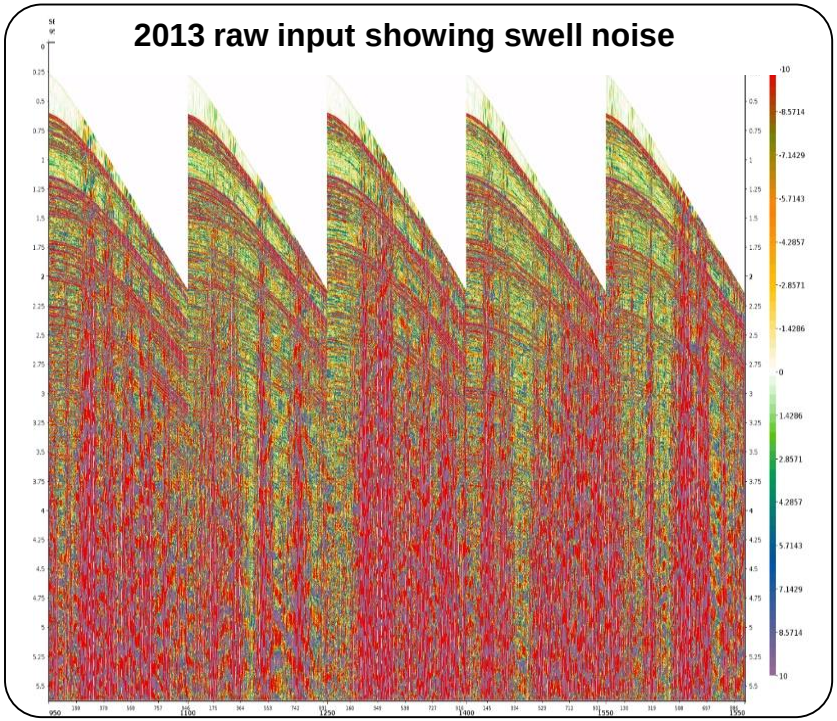
flux between 4D surveys (reservoir bbls)



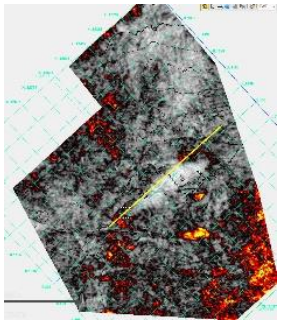
What have we got and what have we done to it?

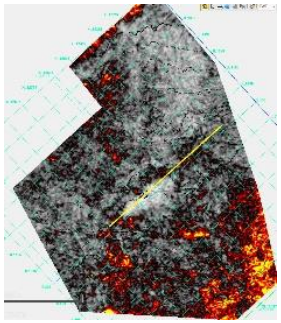
- Tech limit 4D NATS acquisition
  - Dual sensor deep-tow (18m) cables re-datumed to 8m using H_{rec}
- Technical limit 4D processing
  - De-bubble, 3D MWD, SRME and RADON,
  - TTI high res tomo, specular migration, pair-wise binning.
  - Q + destretch

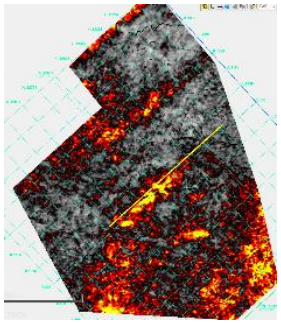
2013 raw input showing swell noise

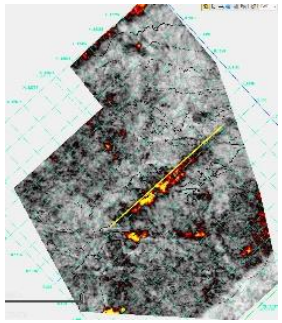


Seismic quality is linked to acquisition


1999-1996

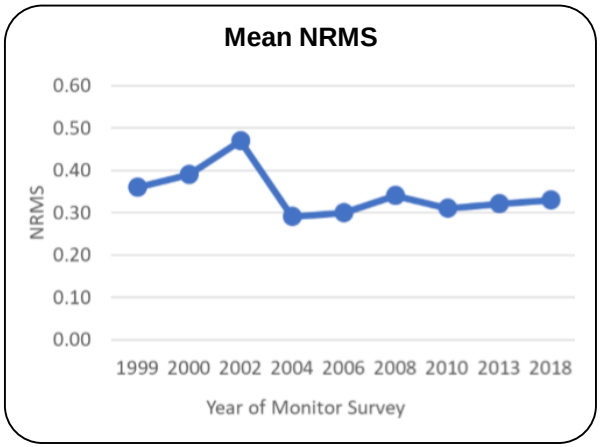

2000-1996

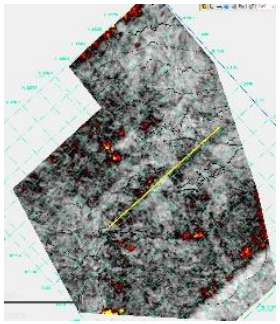

2002-1996

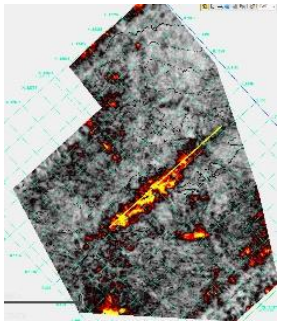

2004-1996

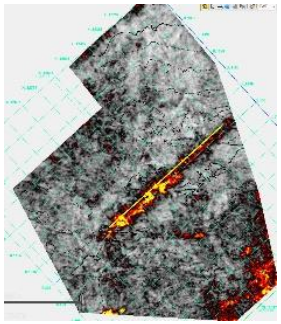
"repeat 3Ds"

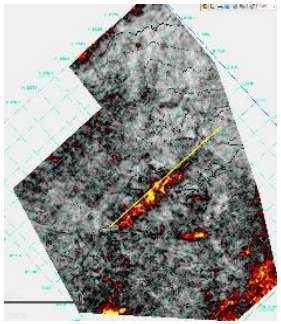
Source matching

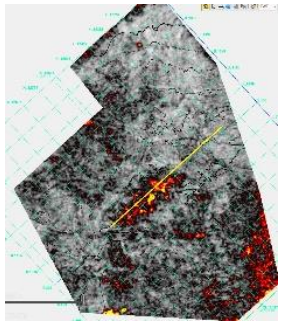



2006-1996


2008-1996


2010-1996


2013-1996


2018-1996

Source & receiver matching, overlapping cables to avoid infill

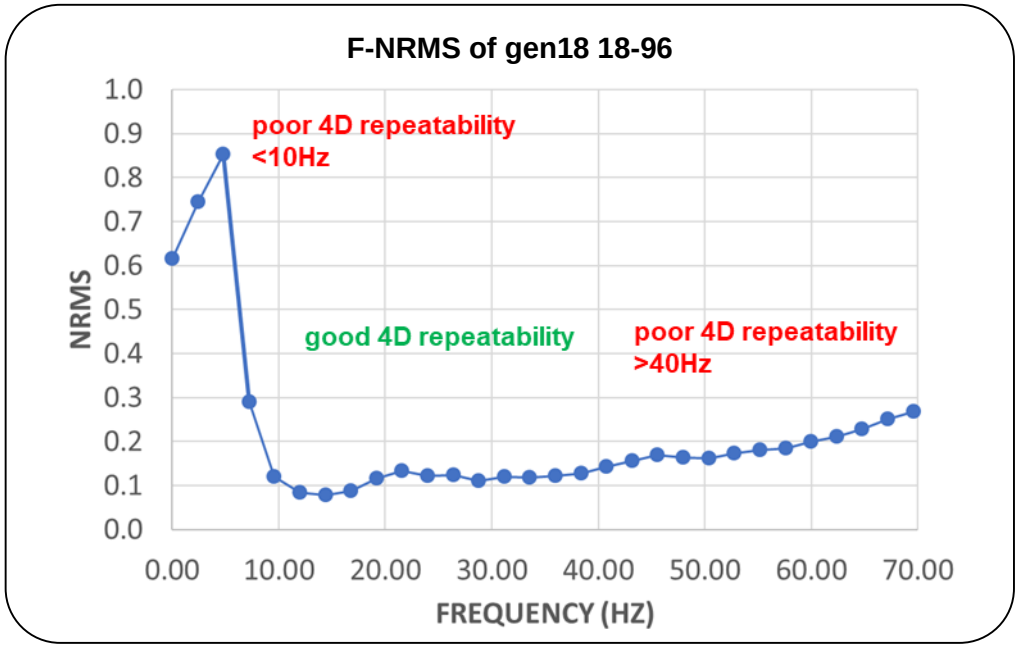
- Deep tow dual-sensor
- Overlapped large spread for future re-baseline

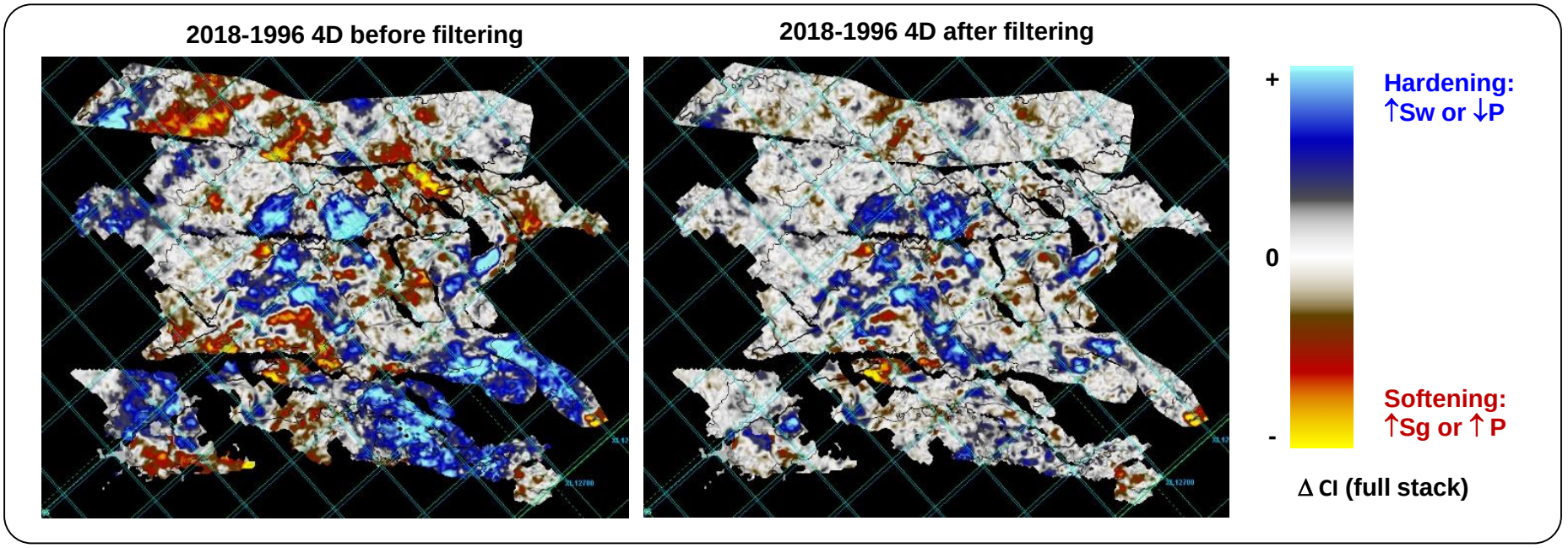
NRMSE maps, black-grey = good, red-orange =bad. Blue = no undershoot

From Dan Davies

4D improvements after F-NRMS analysis

- Frequency-dependent NRMS analysis led to a decision to apply a low-cut filter





From Alistair Robertshaw and Lifeng Wang

“Licence to operate”

OneNote for pragmatic, evergreen knowledge capture: Our “Geophysical ISD”

Quad-wide 3D seismic atlas systematically records who interpreted what, when and why.

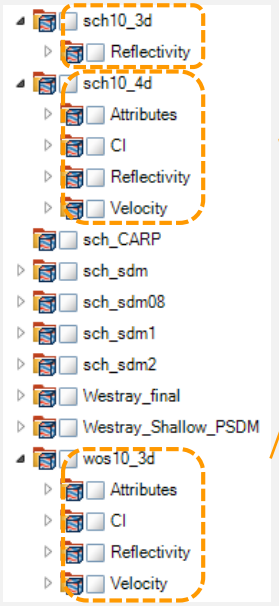
4D seismic atlas systematically records maps and sections, commoditising interpretation for other disciplines

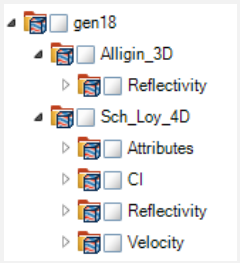
4D anomaly dashboard captures reservoir physics and history match quality

Res Man dashboard (from REs) provides well data needed for, and optimised for, 4D integration

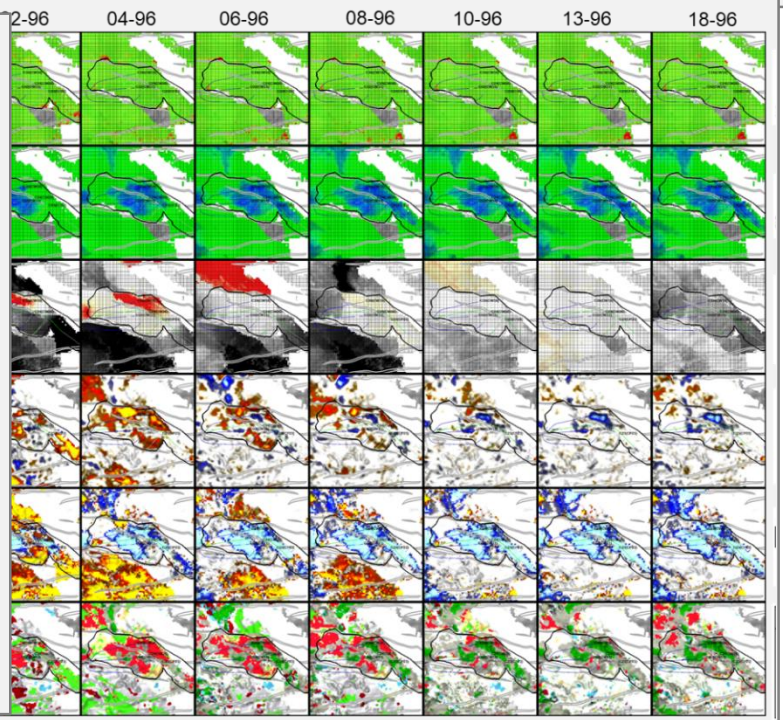
Simulator-to-seismic qc of anomalies and model

Studio data simplification of seismic data volumes





- 1,000 out of 2,800 historic volumes deleted to-date.
- 36,000 historic seismic horizons to follow…



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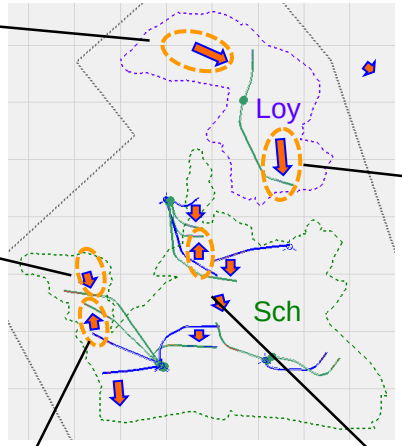
Examples of Mon9 early successes

Insights into performance of some new waterfloods

North Loyal T35 (example follows)

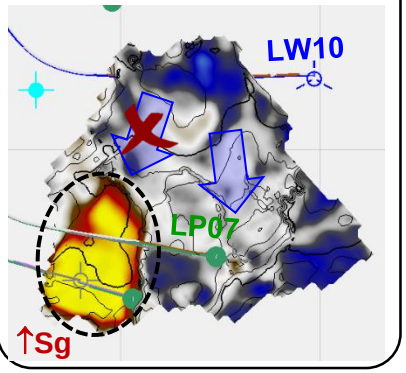
North Claw T34 (example follows)

Map of new waterfloods for Mon9



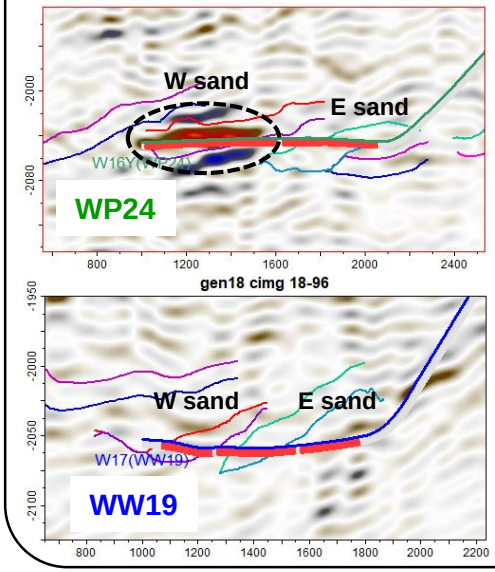
South Loyal T31
LP12 barrier identified

18-13 4D map

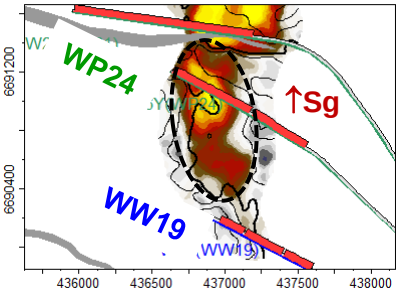


South Claw T34 conformance investigation triggered

18-96 4D sections

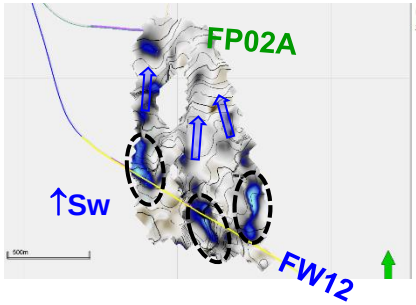


18-96 4D map
W sand

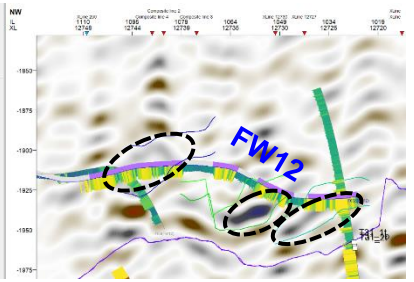


NWAD T34 FW12 injection conformance confirmed

18-13 4D map



18-13 4D section



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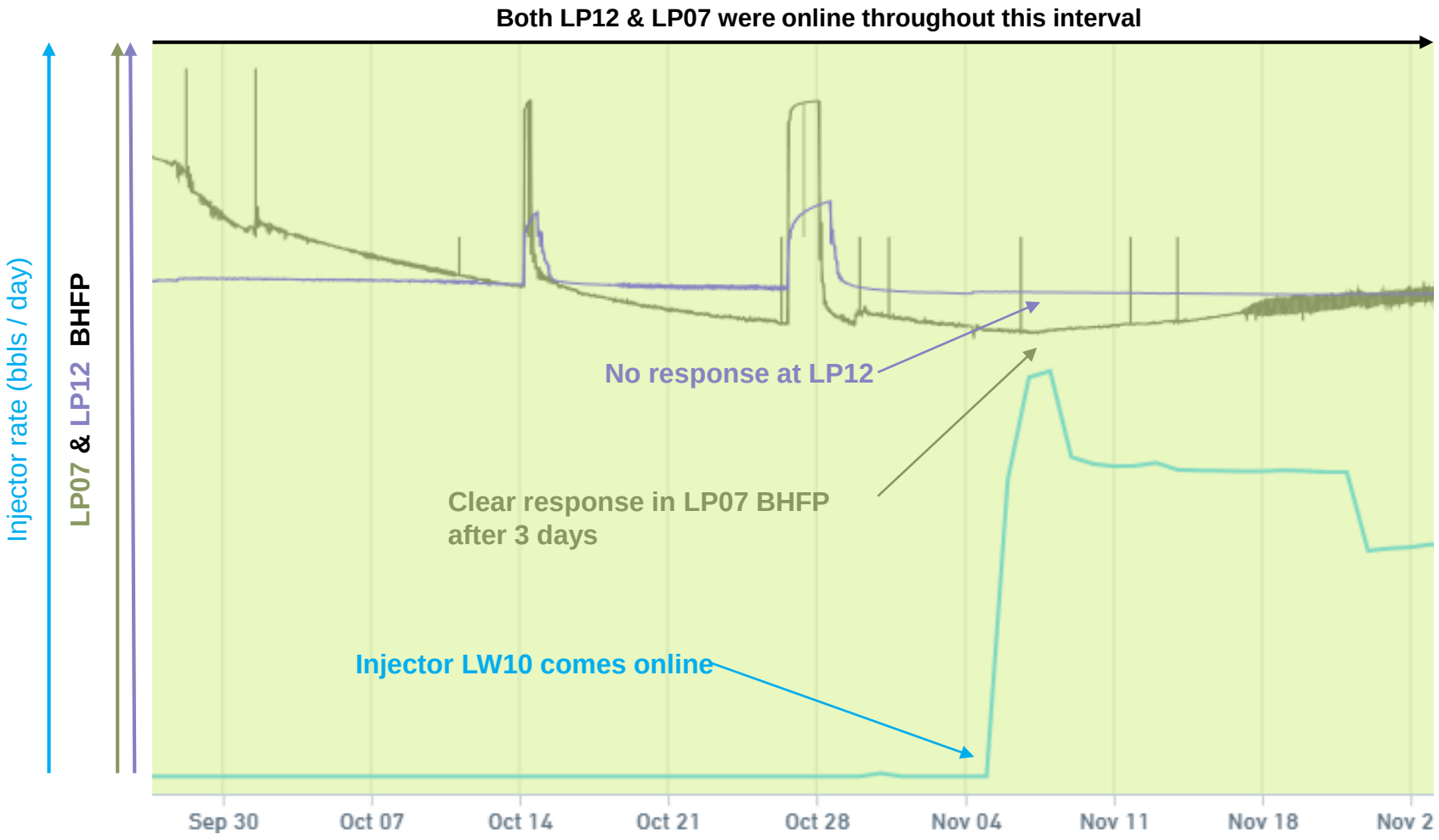
South Loyal T31 Interference data



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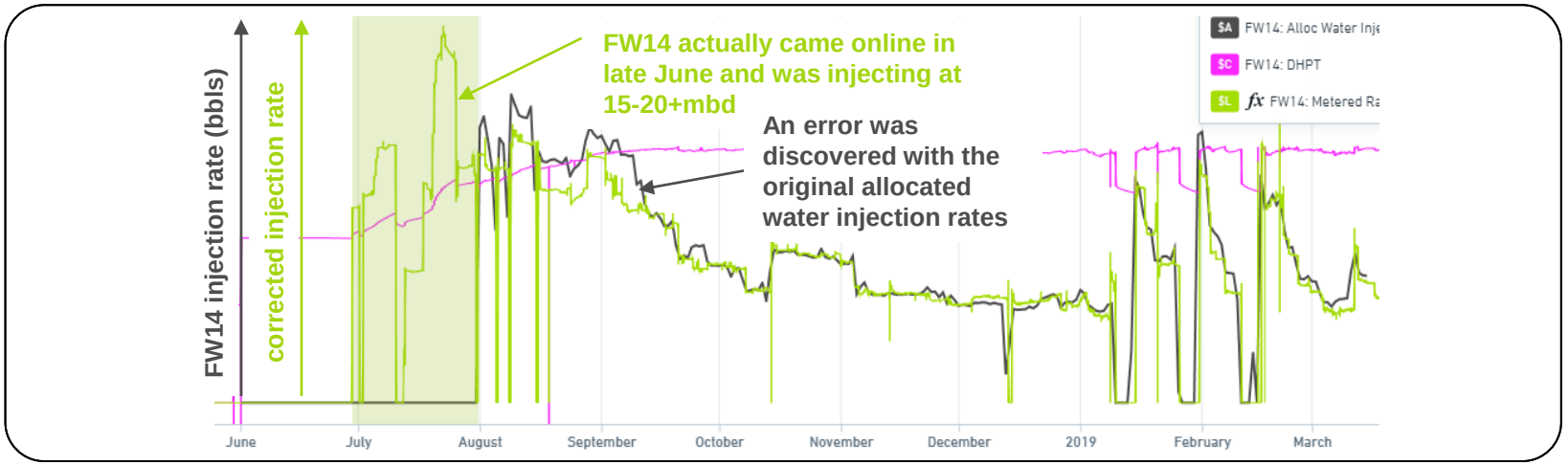
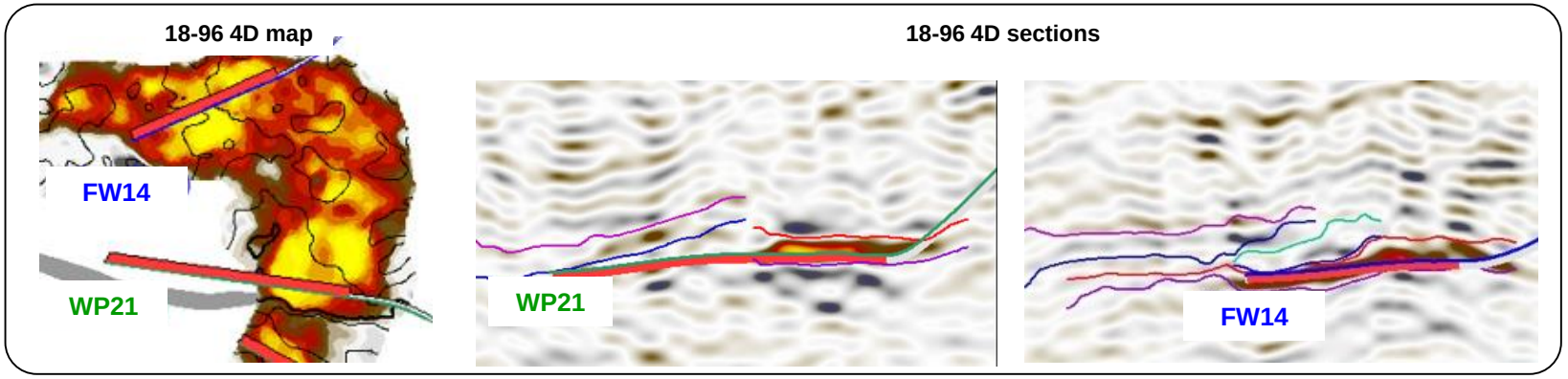
From Ross Walder

North Claw 2018 4D

- What do you think the cause of the 4D anomaly is?
- widespread softening initially interpreted as Sg
- a surprise given relatively little production





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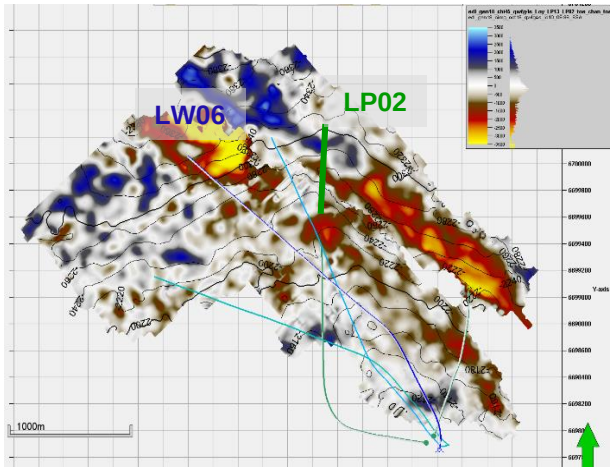
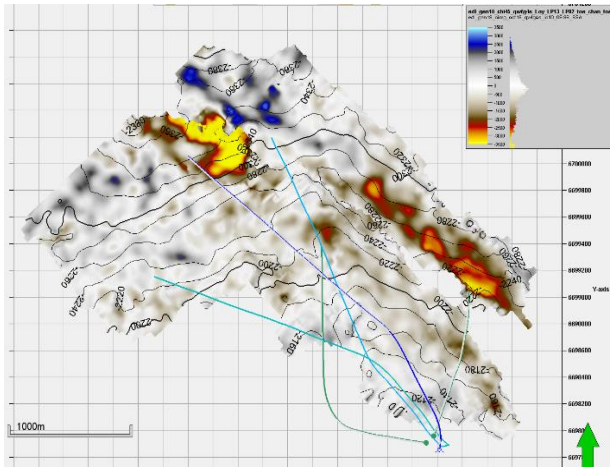
From Cat Owen

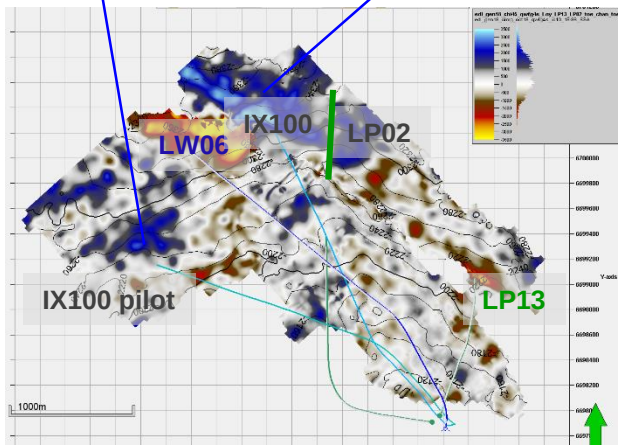
Examples of Q204 4D limitations

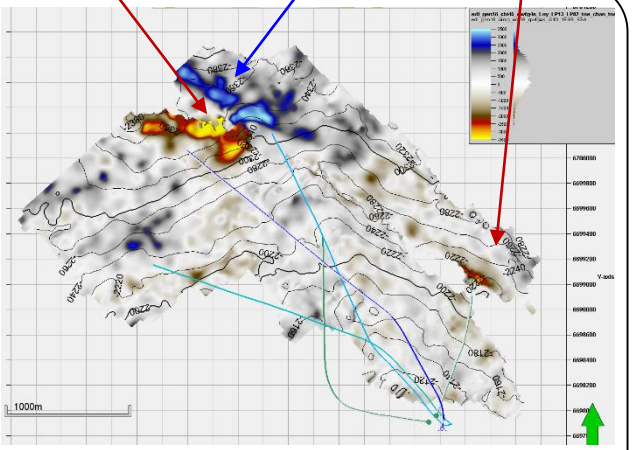
Integration with recent well results on N Loyal

08-96 full stack difference maps (identical maps, different colour bar)









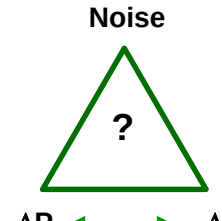
White covers amplitudes+/-1000

White covers amplitudes+/-2000

18-96 full stack difference maps (identical maps, different colour bar)

- Gas production leads to compositional change in remaining oil with $\downarrow P_{bubble}$

Challenge of noisy data and strong 4D pressure response



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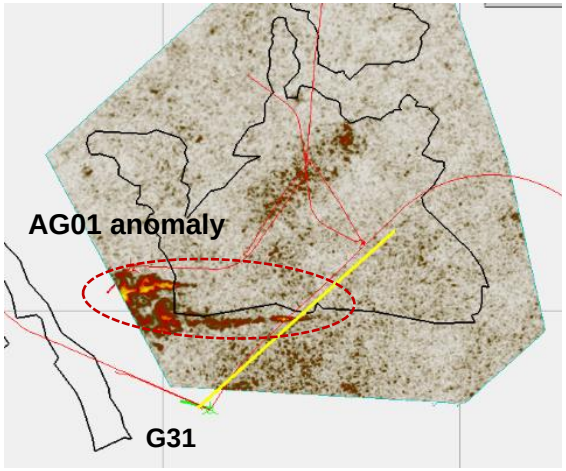
Timeshifts

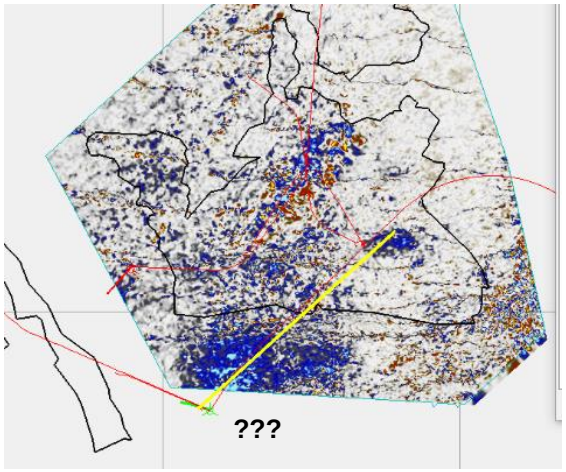
- Workflow prioritised amplitude-based analyses ahead of time shifts
- Are we missing a trick with ΔT?
- Focus on gas disposal wells south of Schiehallion

18-96 full stack amplitude



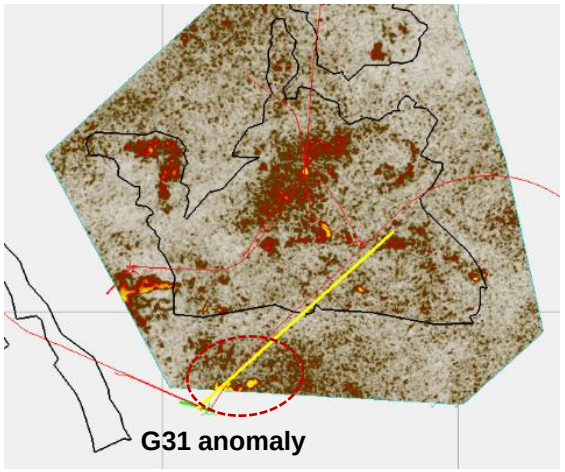
Min Amp in 150ms window
Reservoir layer 1

gen18 18-96 ΔT



(surface is below amplitude anomalies)
Blue where 18 surface is deeper than 96

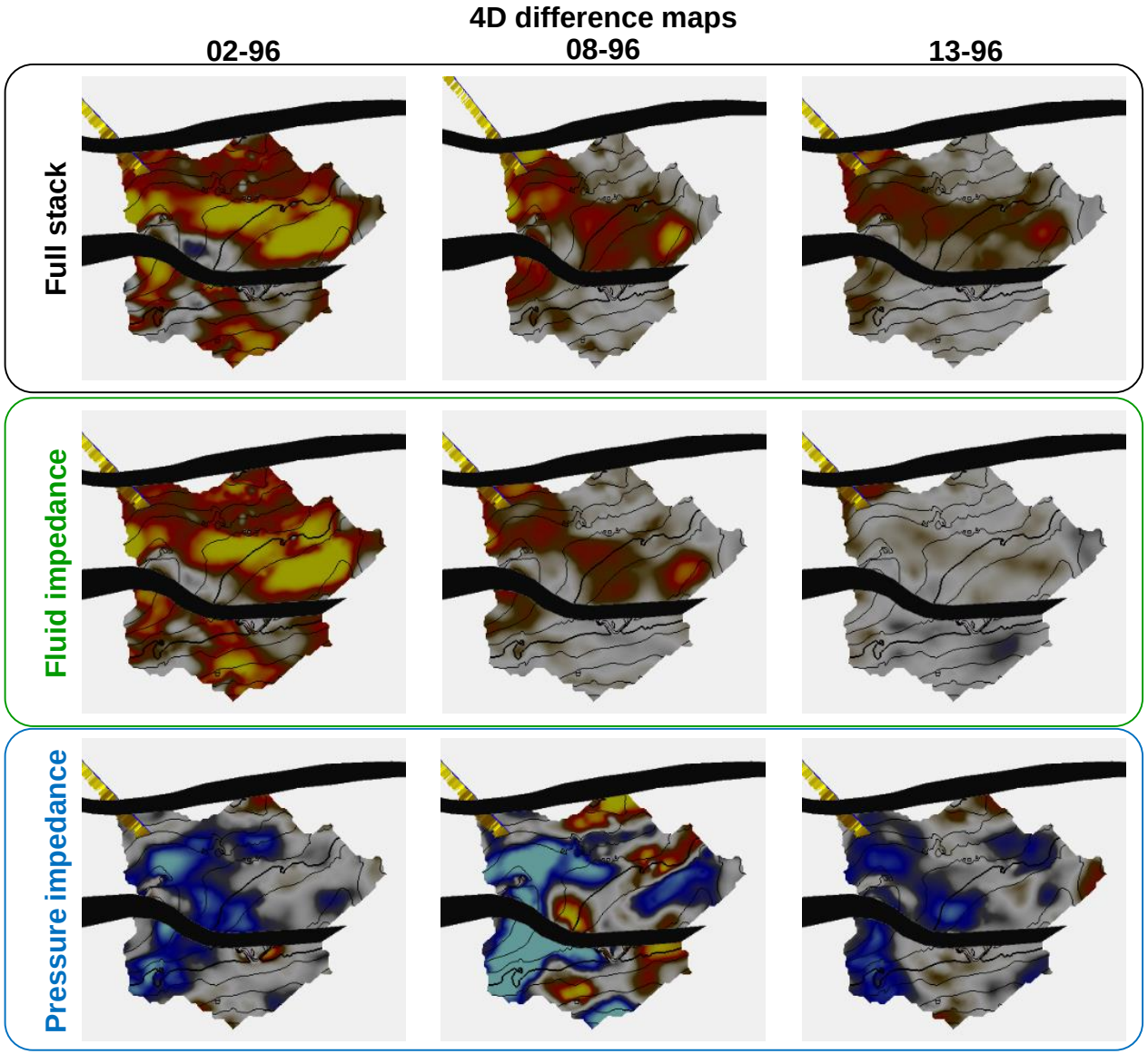
18-96 full stack amplitude



Min Amp in window
Reservoir layer 2

4D AVO does not work…

- Isolated water injector, stopped injecting before Mon1 in 1999
- Only 1.8mmb injected
- P↑ anomaly seen on Mon1
- Anomaly fades away over subsequent monitors.
- 4D full stack working as expected
- 4D Fluid and Pressure AVO projections useless



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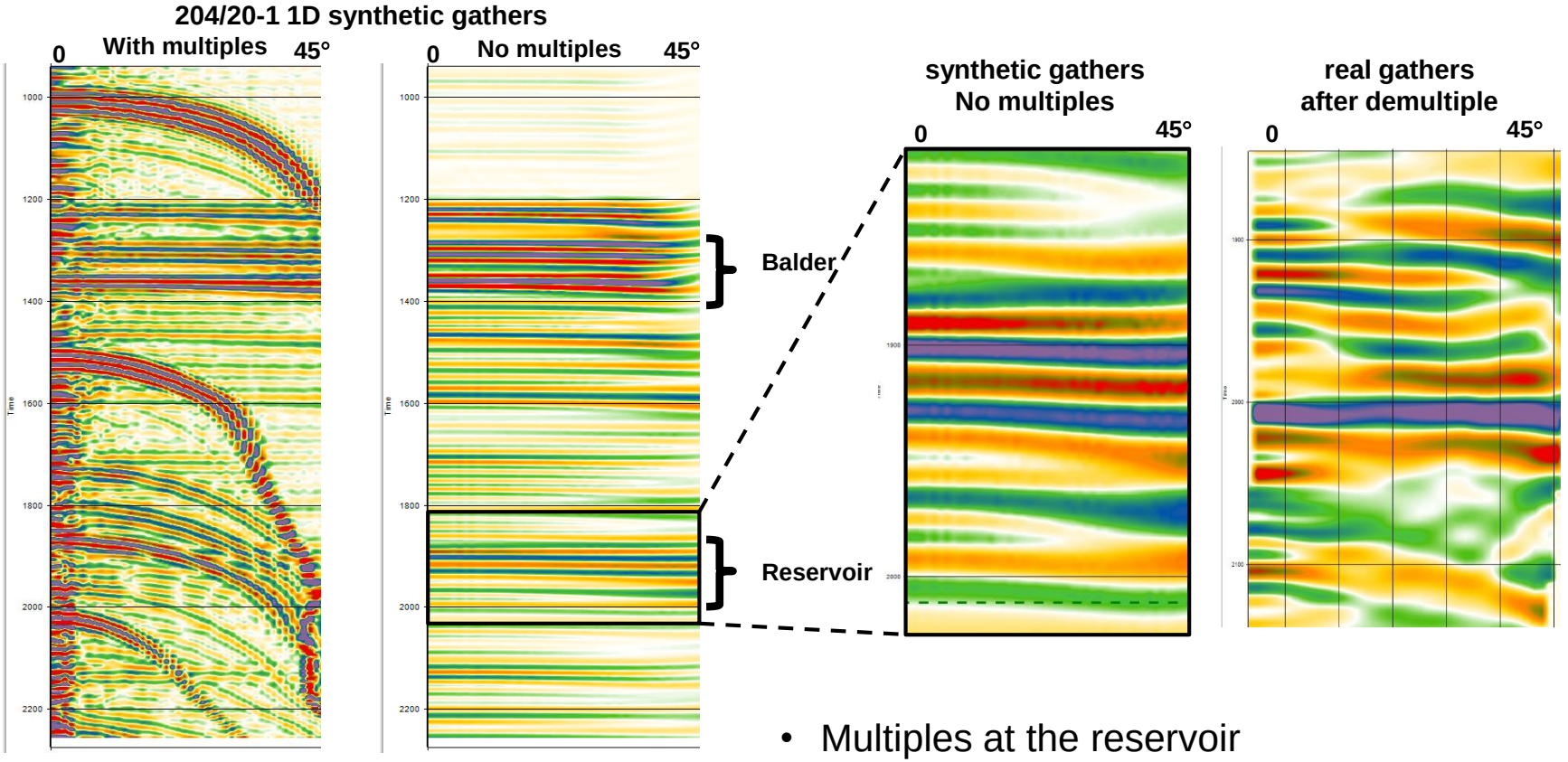
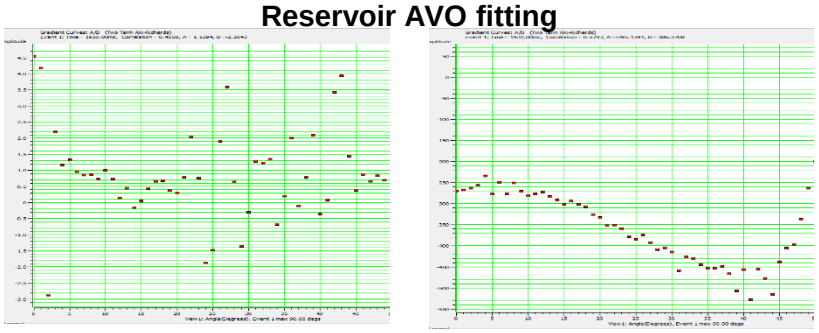
From Lifeng Wang

Synthetic and real gathers





- Multiples at the reservoir
- Multiples amplitudes > primaries amplitude
- Strong near offset (angle) multiples
- AVO not working to a degree that can be relied upon for 4D

From Lifeng Wang

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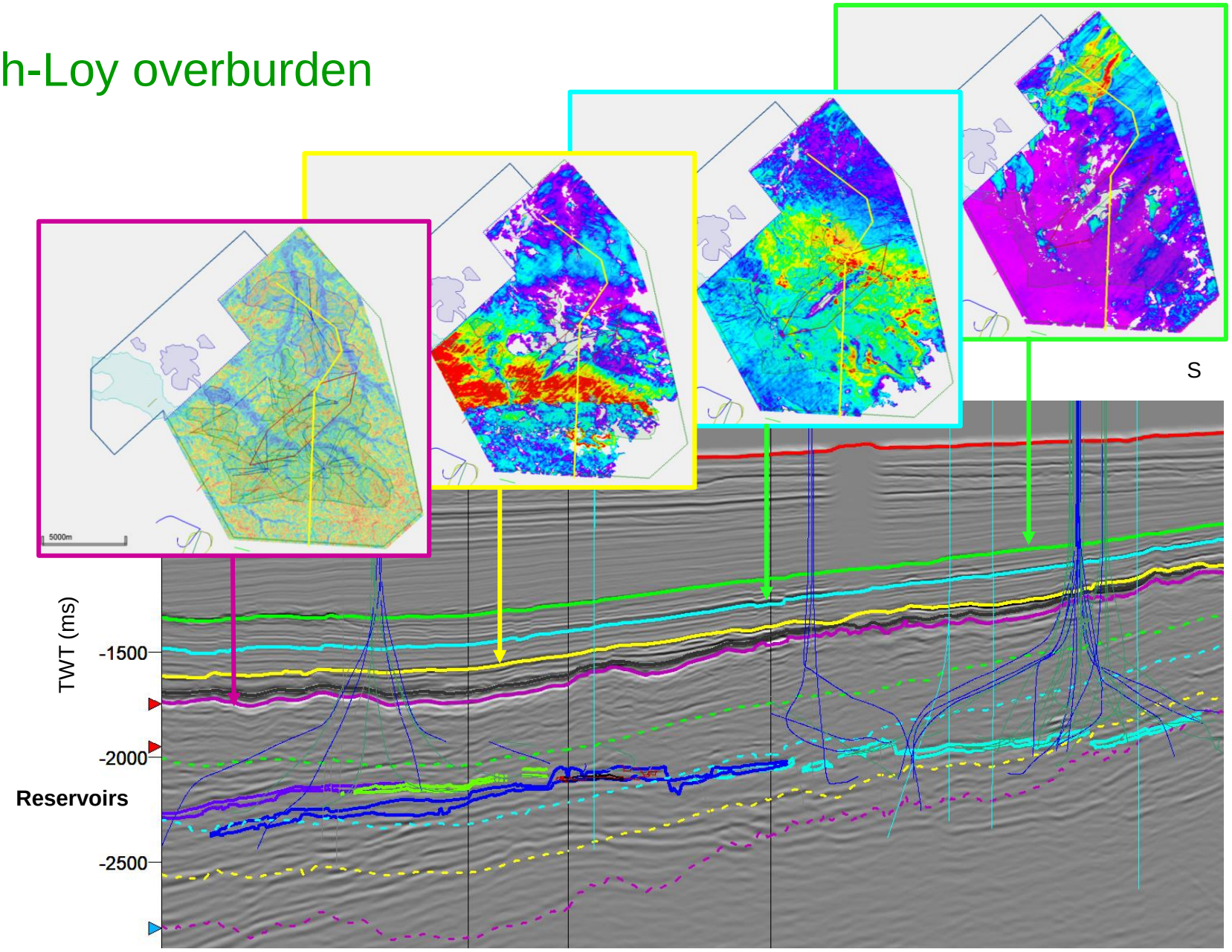
Sch-Loy overburden



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Schiehallion FFM Update 2019

- A complex dataset is being integrated with the model update using Sim2Seis.
- History Match work aims to start simple and introduce more complexity later if required.
- Identify priority areas for matching on the Schiehallion field in conjunction with Geomodeller and Reservoir Engineer

Example of record of anomalies and match

		Year									
		M1	M2	M3	M4	M5	M6	M7	M8	M9	
		99	00	02	04	06	08	10	13	18	Comments
Segment 1 South East	S1SE_T31U_CW16_S118				P↑	P↑	P↑	P↑			Unable to model pressure up based on current rock properties - Ak/Amu
	S1SE_T31U_CW16_H124					Sw↑	Sw↑	Sw↑	Sw↑	Sw↑	Good match - potentially too much water but good matching mechanism.
	S1SE_T31U_CP05_S105	Sg↑	Sg↑	Sg↑	Sg↑						Good match to initial gas break out.
	S1SE_T31U_CW11_S103	P↑									Unable to mirror pressure up signal - dominated by hardening. Could be due to rock properties. Potential modelling required.
	S1SE_T31U_CW11_H121					Sw↑	Sw↑	Sw↑	Sw↑	Sw↑	Initially water saturation signal exists where a pressure up signal dominates in the data.

Signal Present + Matches

Signal in Model but not in Seismic

Signal in Seismic but not in Model

From Matt Le Good

Lessons reinforced by current team

- 9th survey means evolution, not revolution
- ✓ Critical insights into new waterfloods
- Organisation and documentation rigor is crucial
- ✗ 4D AVO still doesn't work on Q204 NATS data
  - Incremental improvements to NATS acquisition and processing are insufficient
  - This is work we should have the confidence to stop until there's a step-change in data quality
- ✗ Timeshifts don't currently add value on Q204 data
- ✗ Noisy 4D data continue to soak up interpreter time.
  - ✓ Sim2Seis with nine monitors helps
- ✓ Modern integration software has made this possible

Acknowledgements

- Schiehallion and Loyal JV partners for permissions to publish

- BP colleagues for contributions and discussions including:
  - Dan Davies (Seismic Delivery Team)
  - Thomas Harpley, Debbie Lee, Nandini Nagra, Cat Owen, Alistair Robertshaw, Lifeng Wang, Ross Walder (Reservoir Management Team)
  - Pham Huu Hau, Matt Le Good, Emma Nesbit (Upstream Technology)
- CGG for safely and successfully acquiring and processing our data
- Brian Lynch and DGI