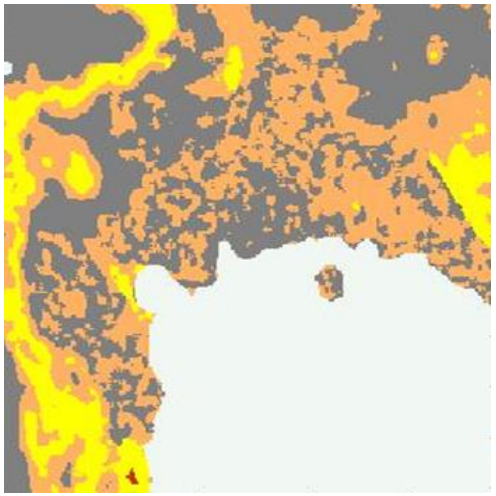
FORCE

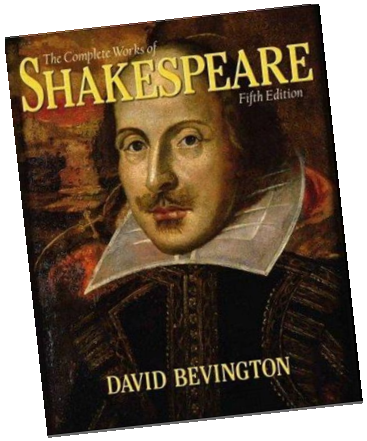
Pre-stack seismic data for interpretation and analysis

Stochastic inversion by matching to pseudo-wells

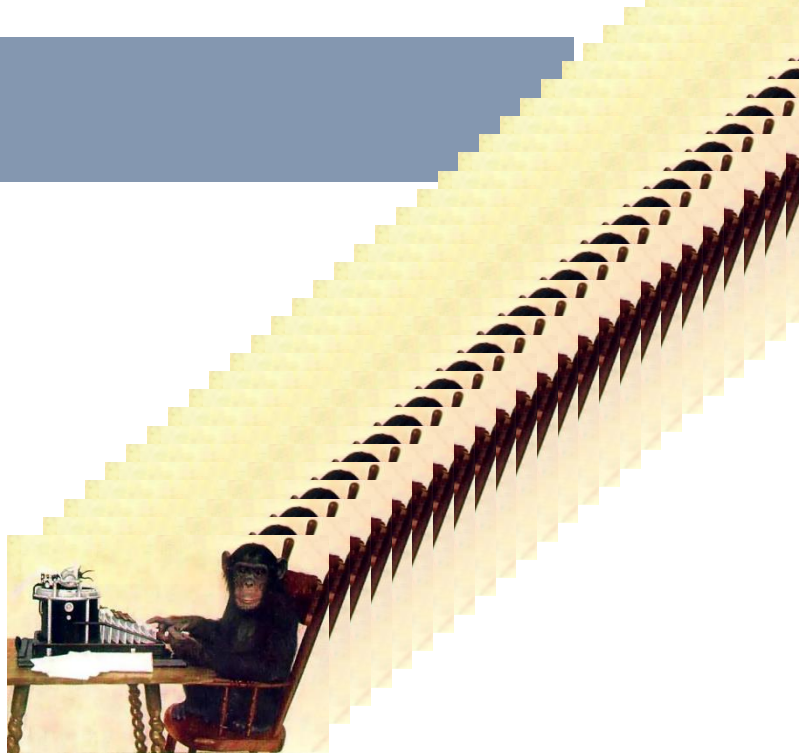
Patrick Connolly

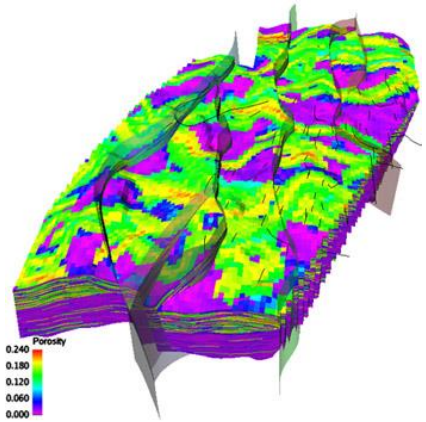


Shakespeare

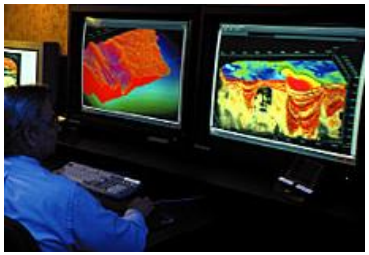


- 884,647 words
- ~6,000,000 characters, 30 values each
- $10^{9,000,000}$ realisations





- 400 x 300 x 50 = 6,000,000 cells
- 30 possible porosity values
- $10^{9,000,000}$ realisations



pseudo Shakespearian phrase matching

data

1	**Now is the winter of our discontent**	model	Richard lll
2	**Now is the winter of our discoteqt**	data	

a geological phrase

Prior: vocabulary & grammar

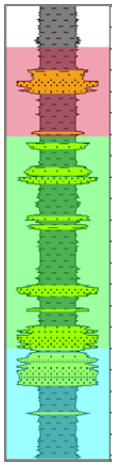
Prior sample:

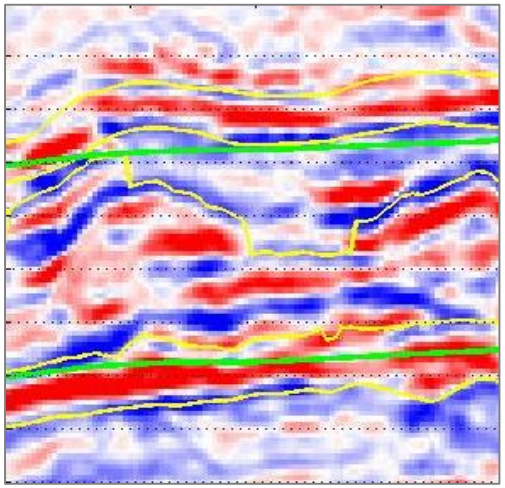
`New if tie waiter pi out disconnect`

Data

Prior: geological context

Prior sample:

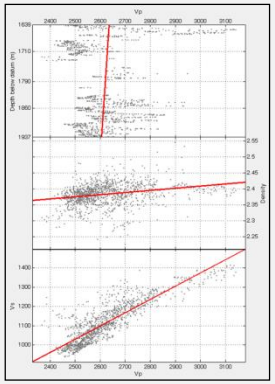




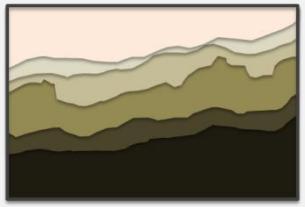
sampling the prior

priors

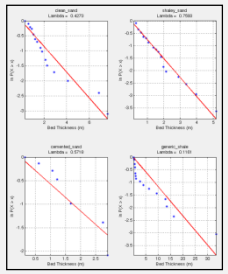
rock property correlations



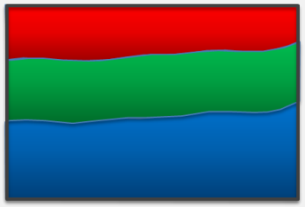
stratigraphy



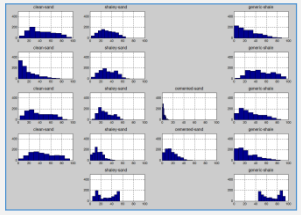
vertical statistics



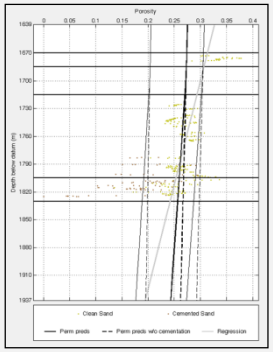
fluid contacts



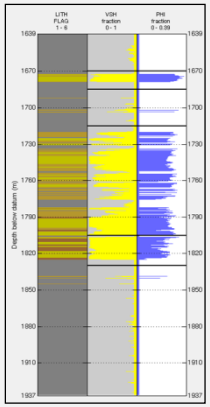
lithofacies probabilities



depth trends

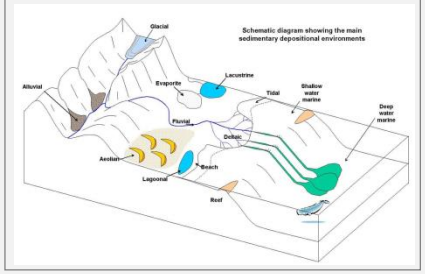


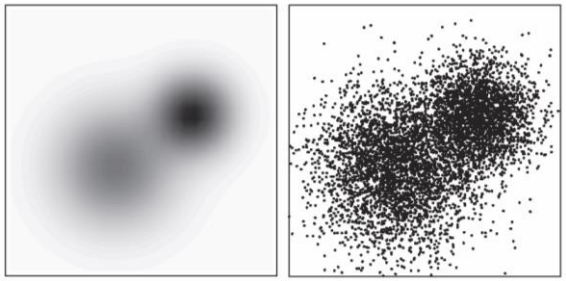
well logs

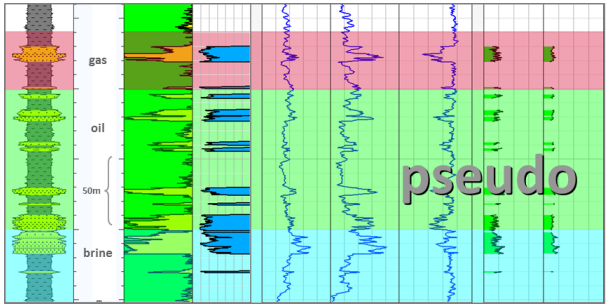


geology

(depositional environment)





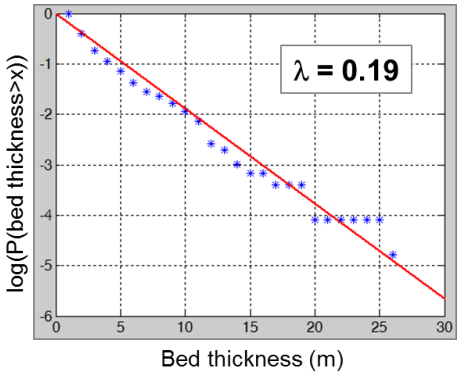


the grammar - vertical statistics

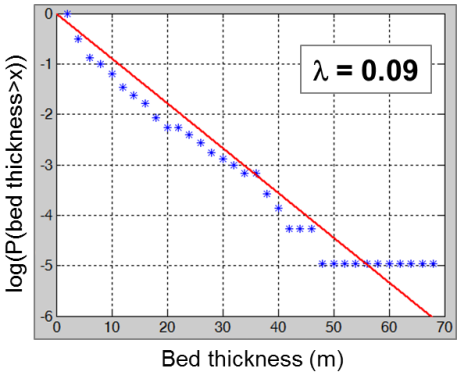
Bed thickness measurements usually fit long-tailed distribution models:

- log-normal
- exponential
- power-law

sand



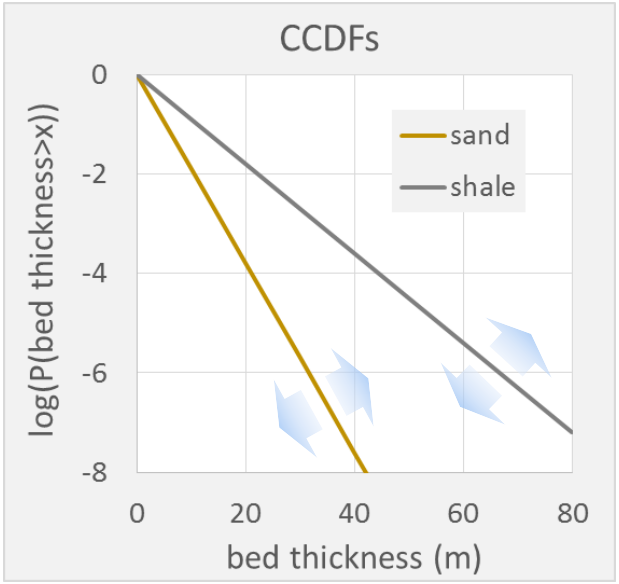
shale



$e^{-\lambda x}$

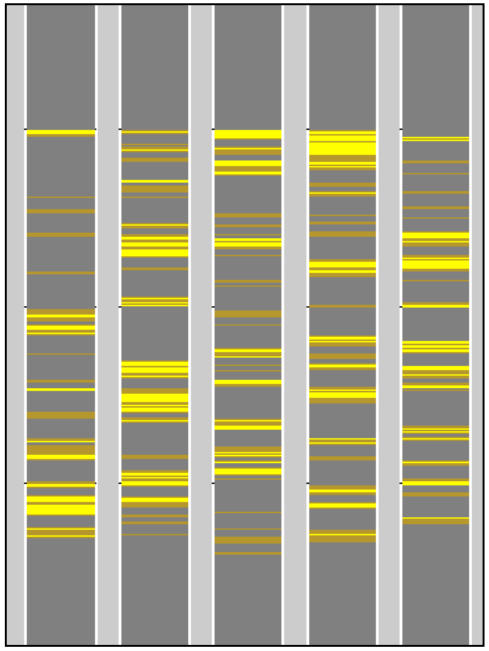
complementary cumulative distribution functions
7 wells composited, offshore Angola

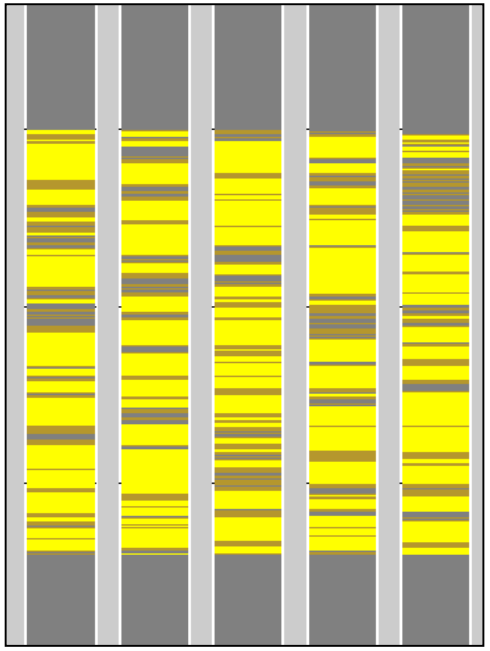
controlling net-to-gross



clean sand	shaley-sand	shale
2.0	2.0	0.2

clean sand	shaley-sand	shale
0.2	2.0	2.0





low net-to-gross

high net-to-gross

Shale

Shaley sand

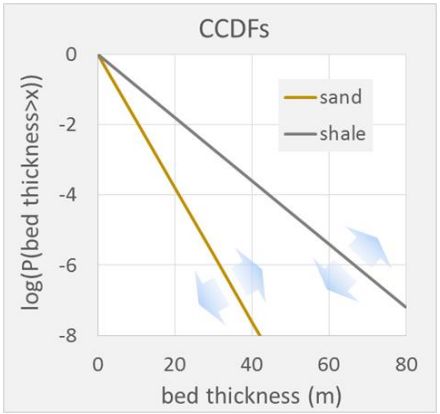
Sand

continuous-time Markov chain

Next lithology from transition probability matrix

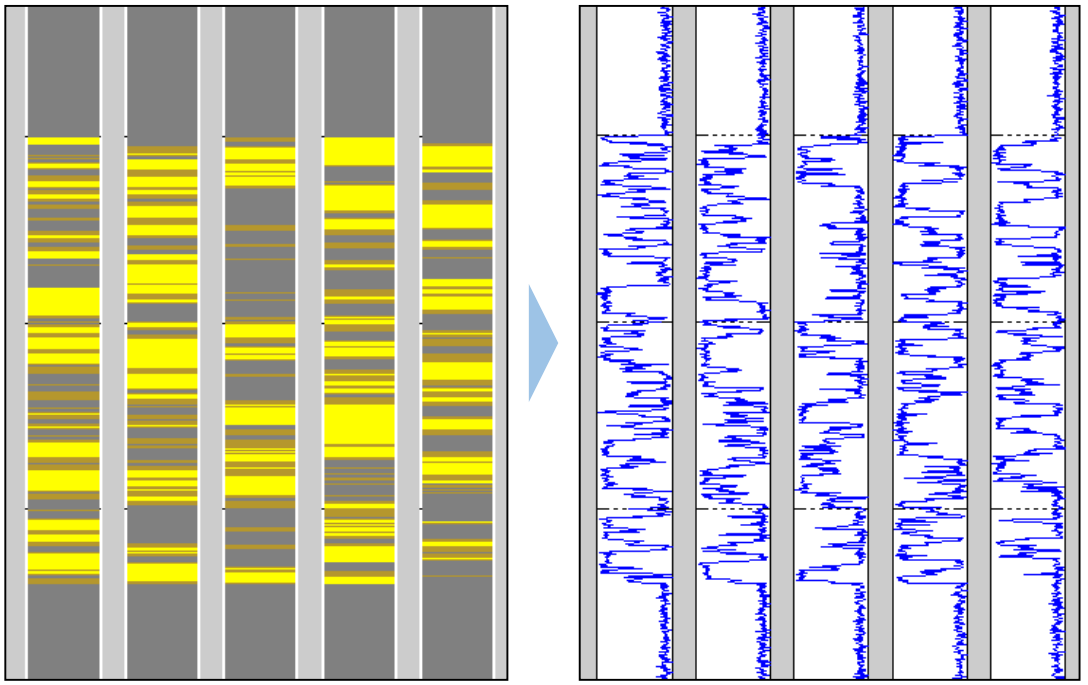
	ss	sh-ss	sh
clean sand	0	1	0
shaley-sand	0.5	0	0.5
shale	0	1	0

Bed thickness from exponential distribution



lambda values

clean sand	shaley-sand	shale
0.95	1.53	0.23



lithofacies

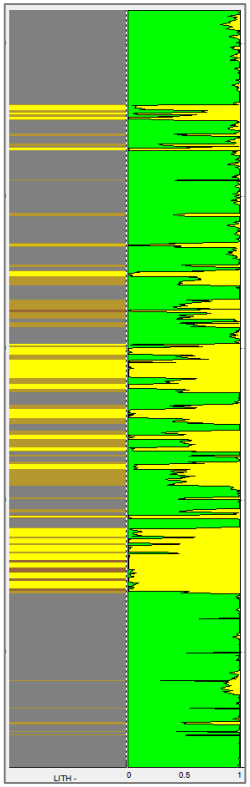
Vsh

Shale

Shaley sand

Sand

pseudo-well rock physics



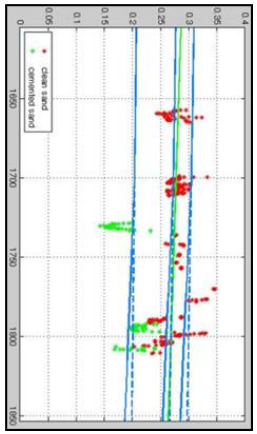
lithofacies

shale volume

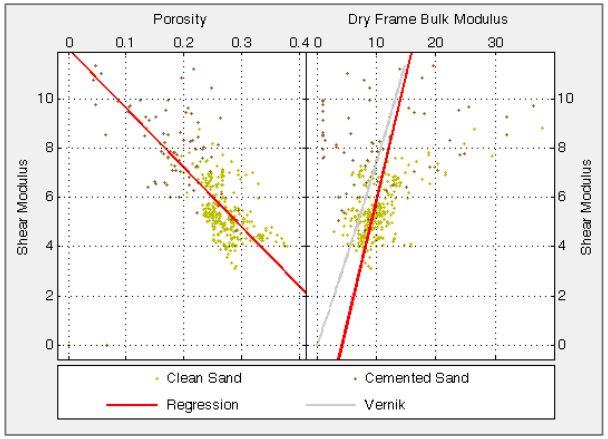
sands

shales

model sands and shales separately

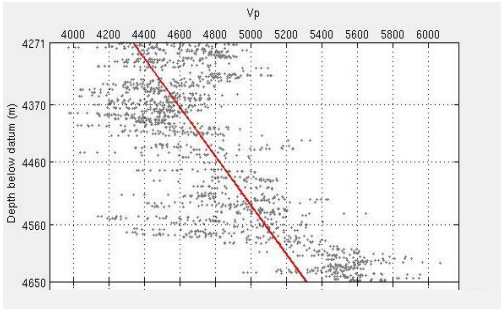


phi depth trend

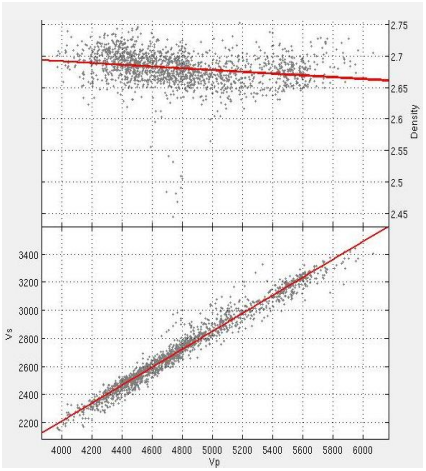


phi / μ and μ / K correlations

recombine for shaley-sands



Vp depth trend



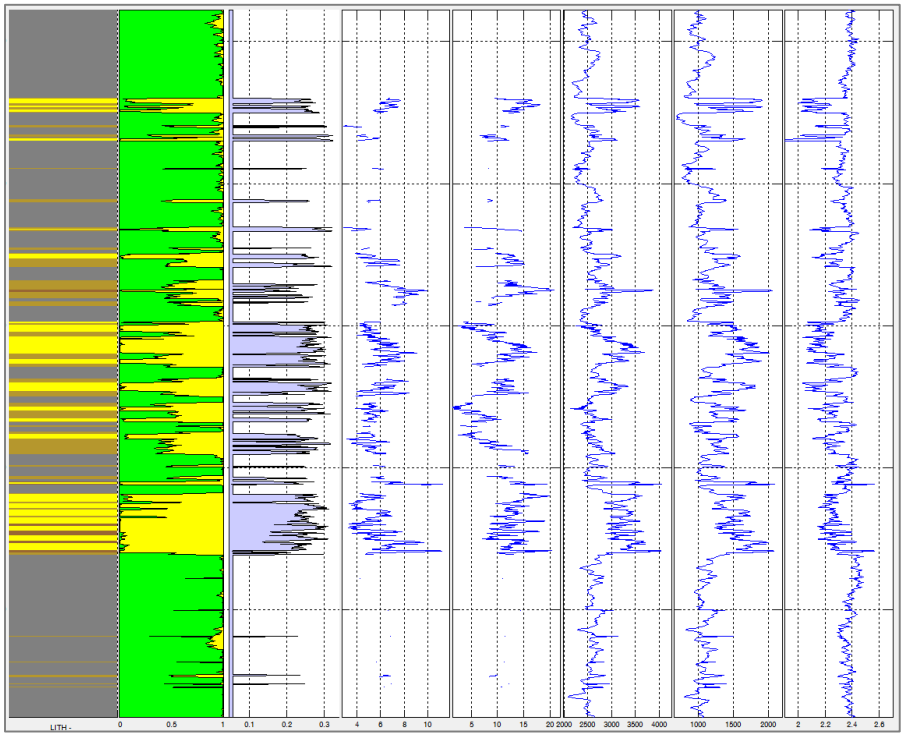
Vp / Vs and Vp / ρ correlations

Gassmann fluid substitution

deterministic or stochastic fluid contacts

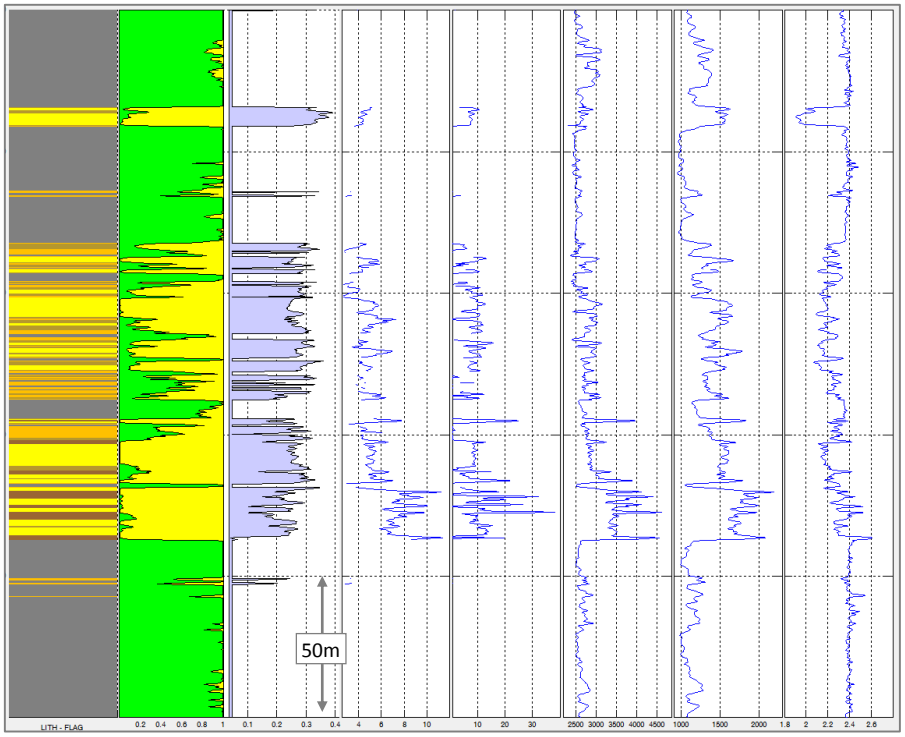
pseudo/real comparison

pseudo-well



lithofacies | shale volume | porosity | shear modulus | dry-frame modulus | Vp | Vs | bulk density

real well

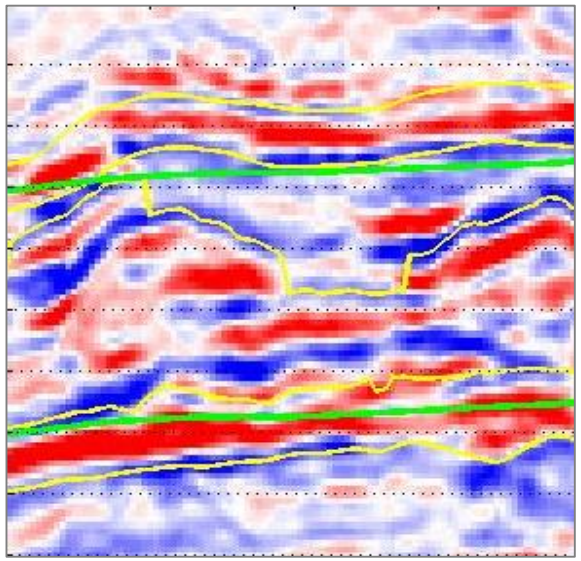


lithofacies | shale volume | porosity | shear modulus | dry-frame modulus | Vp | Vs | bulk density

matching

For each trace generate large number of pseudo-wells (~2000)

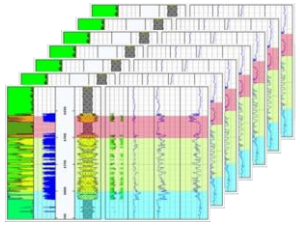
Match and select the best-match pseudo-wells (~30)



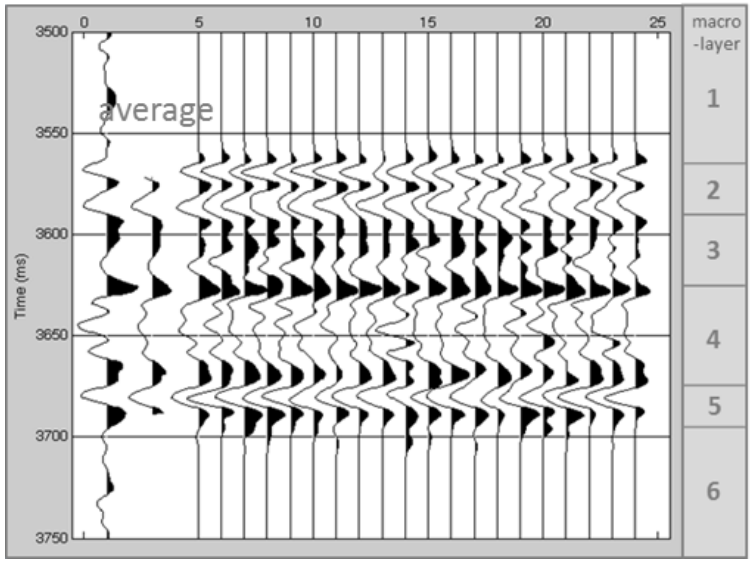
gradient CI

Horizons define macro-layers and fluid contacts.

Macro-layers matched independently



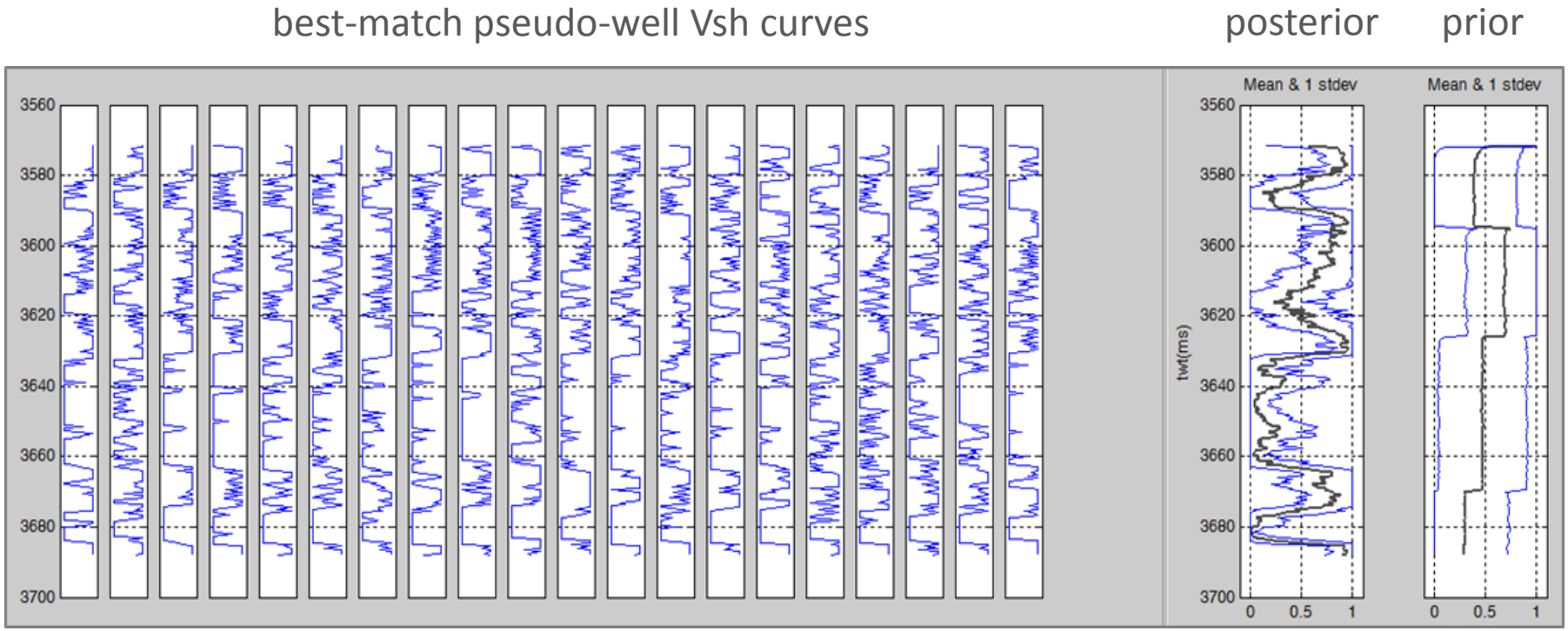
synthetics from filtered EEI curves



seismic trace

best-match pseudo-well synthetics

property estimation



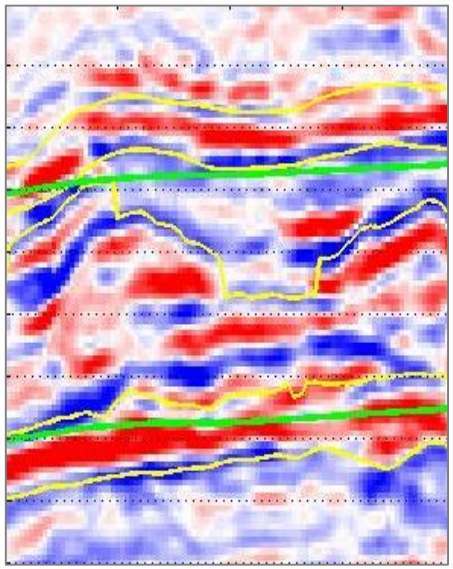
Posterior = mean & variance of best-match Vsh curves

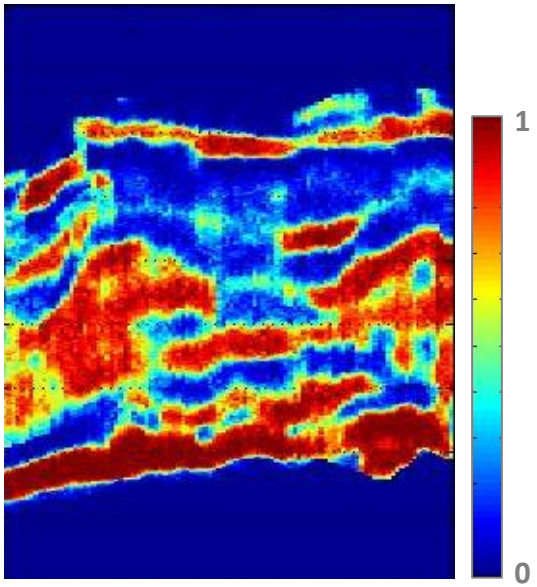
Prior = mean & variance of all Vsh curves

Highly transparent process

results – Angola, B18

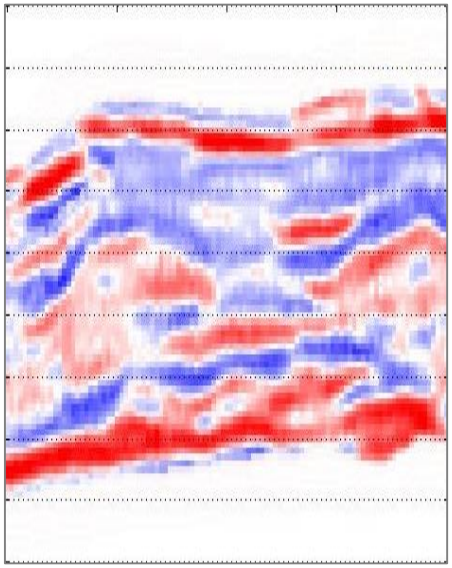
gradient CI

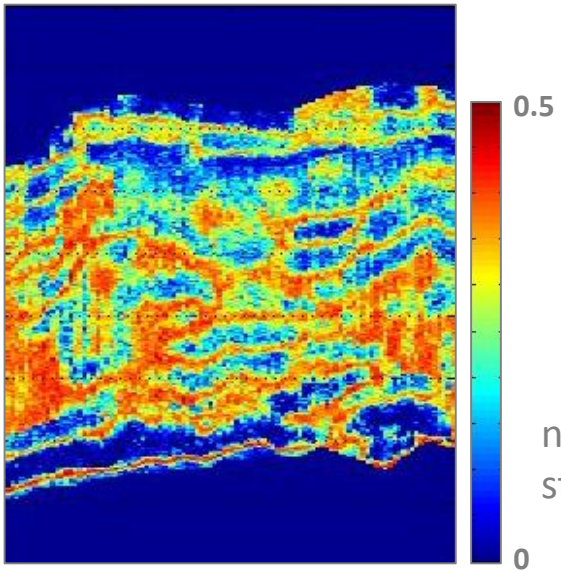




net-to-gross mean

modelled gradient CI (average of pseudo-well synthetics)

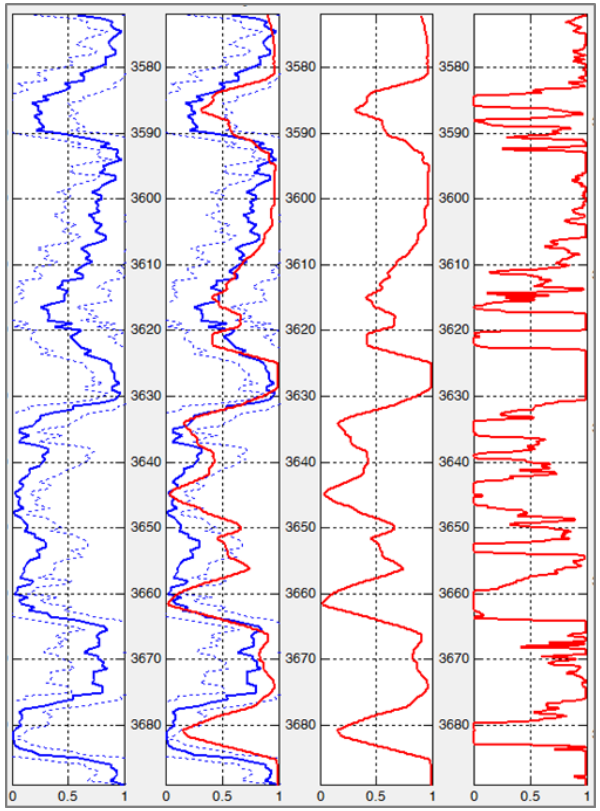




net-to-gross standard deviation

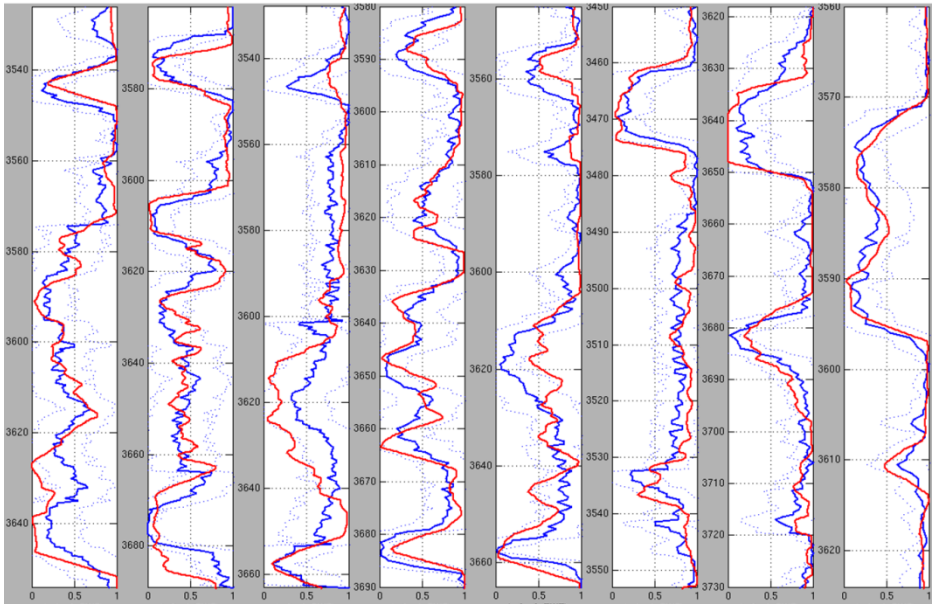
validation

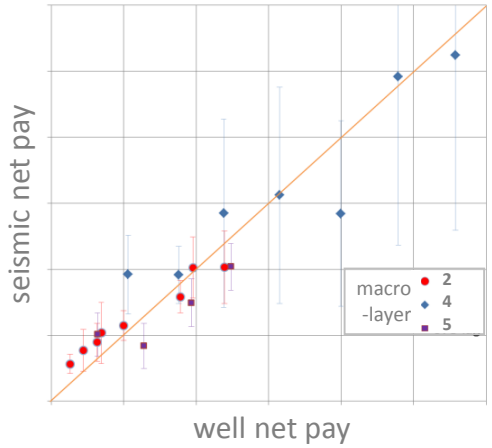
blind well tie



estimate | overlay | smoothed well data | well data

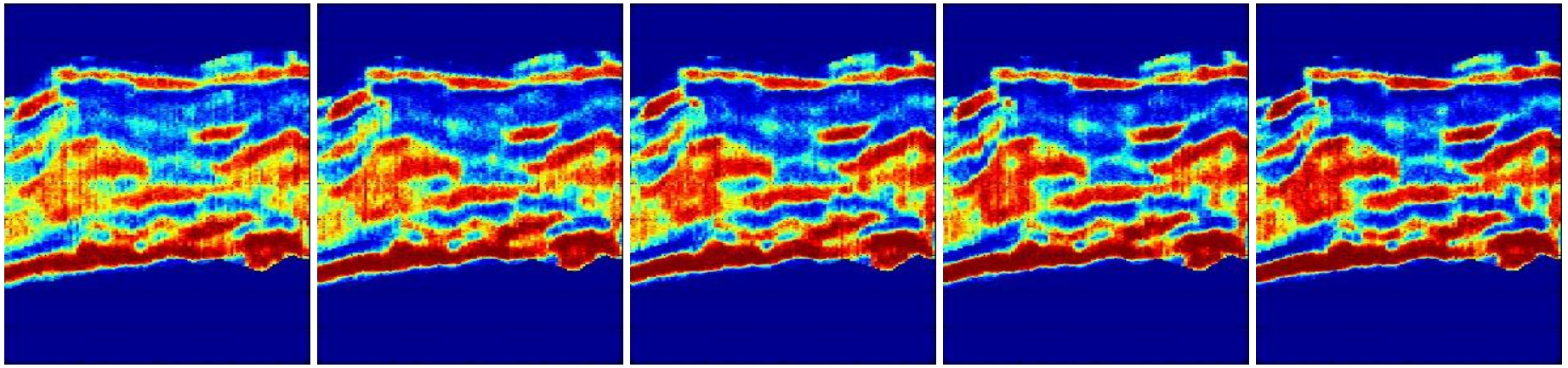
calibration well ← blind wells →





scalable and highly parallelisable

Scalable, by changing pseudo-well count …



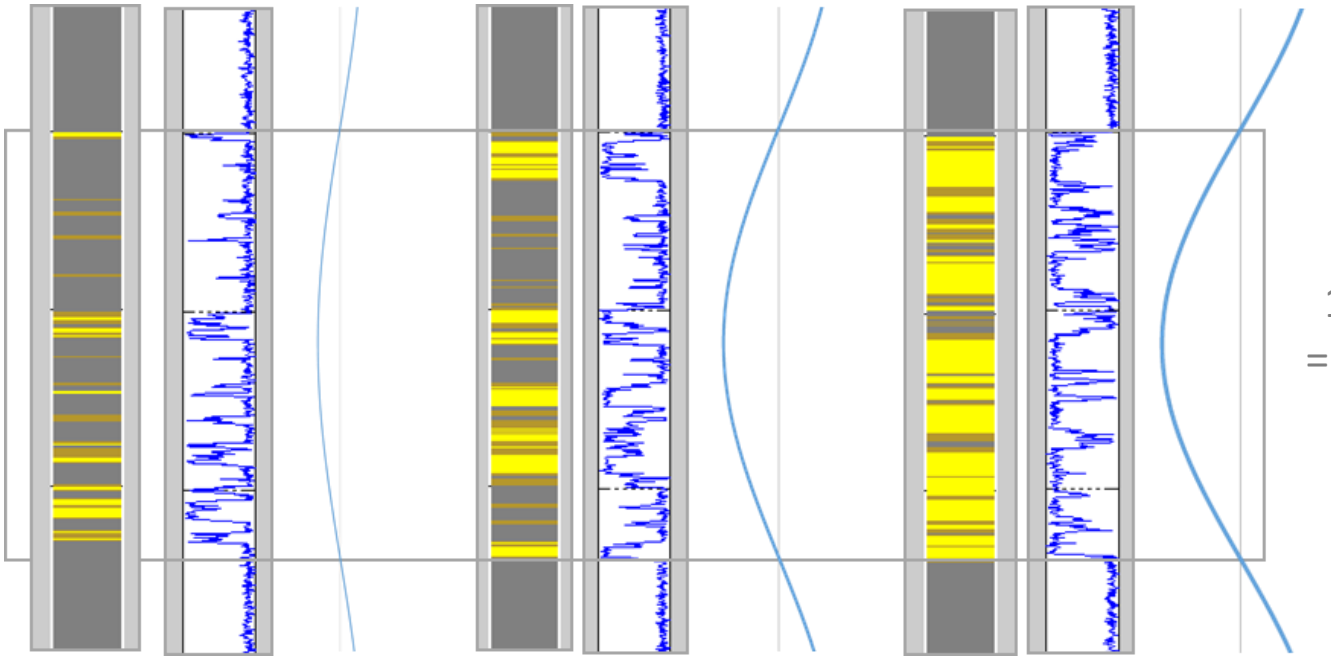
200 500 1000 2000 3000

pseudo-wells per trace

- 1D, hence highly parallelisable
- Continuity demonstrates algorithmic stability

low frequencies

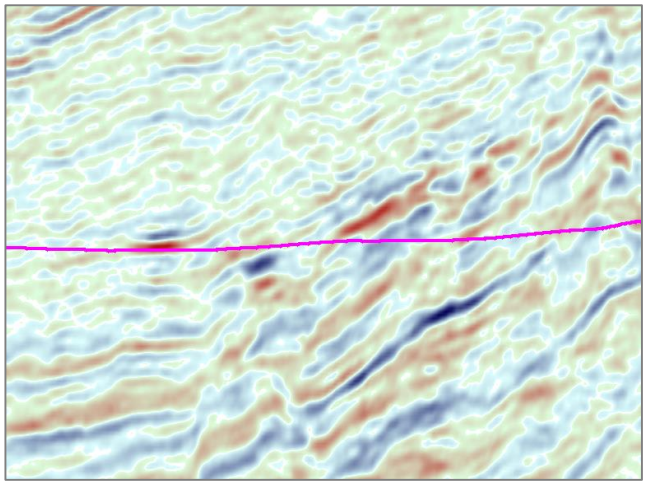
Low frequencies are implicitly constrained
by prior range of sand/shale proportions.



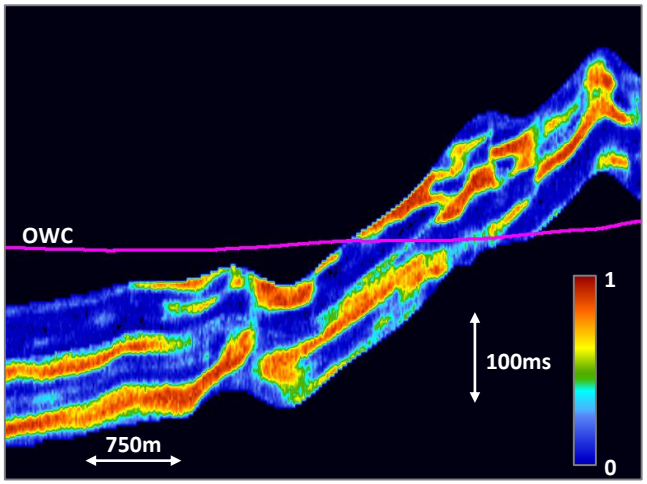
115ms
= 4.4 Hz

If net-to-gross is unknown then low frequencies are
unconstrained – which may well be the right answer.

simultaneous inversion

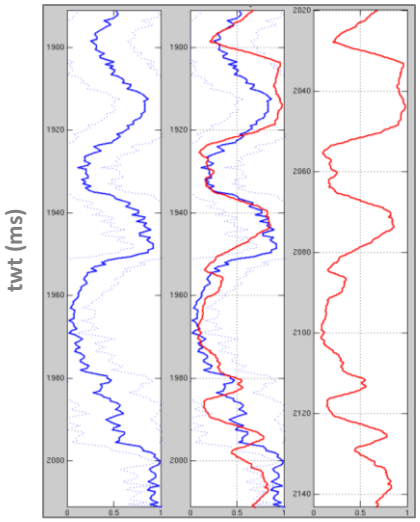


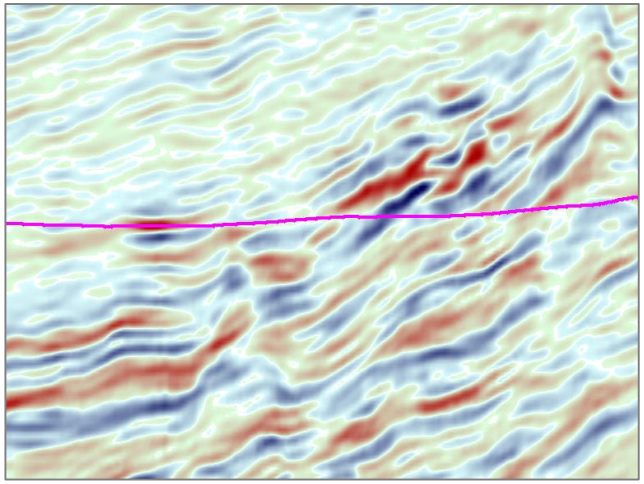
full stack CI



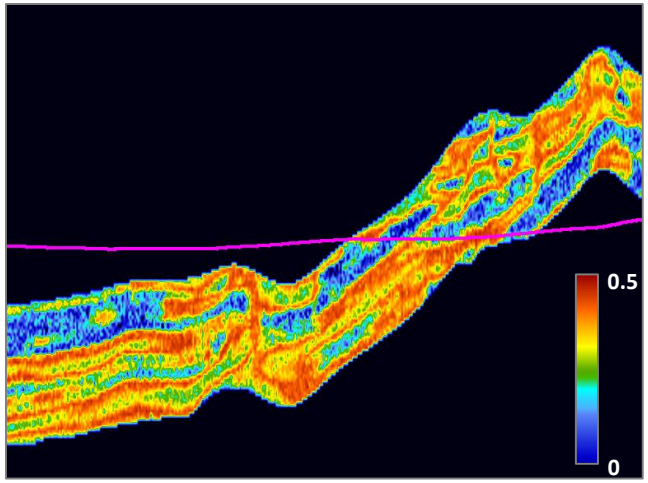
net-to-gross; mean

blind well tie





gradient CI

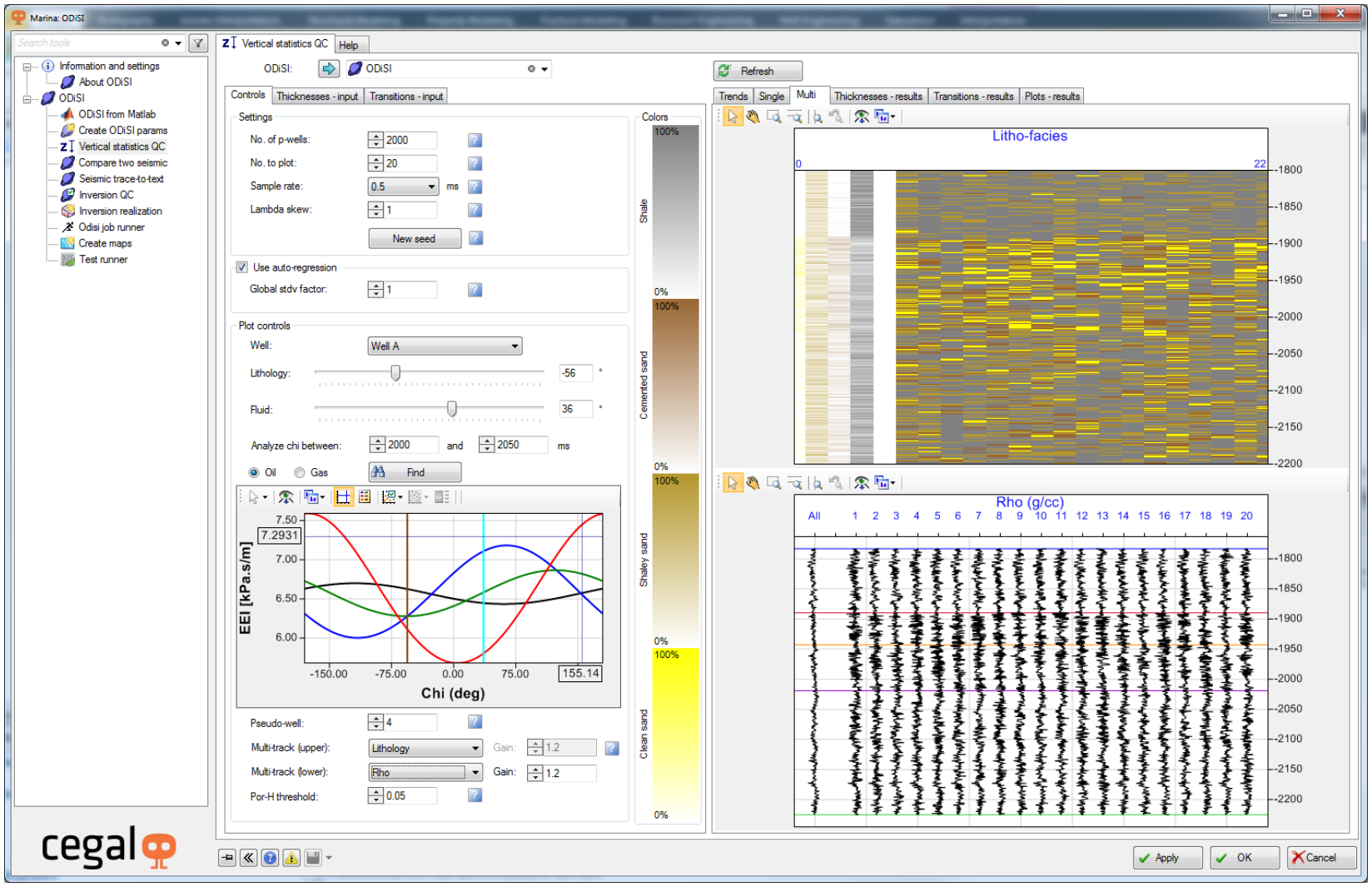


net-to-gross; standard deviation

Simultaneous inversion of two angle stacks; two synthetics from each pseudo-well.

Schiehallion Field, West-of-Shetlands

commercialisation



lateral correlation

Can we improve selection by considering context?

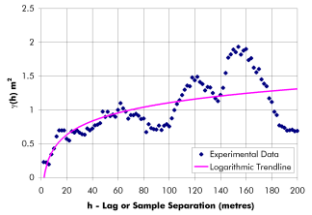
The Winter's Tale

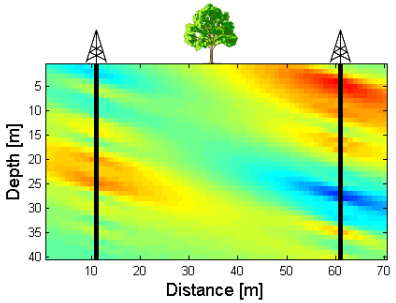
Antigonus
… I never saw
The heavens so dim by day. A savage clamour!
Well may I get aboard! This is the chase:
I am gone for ever.

[Exit, pursued by a bear]

[Enter a Shepherd]
Old Shepherd. I would there were no age between sixteen and three-and-twenty, or that youth would sleep out the rest; for there is nothing in the between but getting wenches with child, wronging the ancientry, stealing, fighting—Hark you now! Would any but these boiled brains of nineteen and two-and-twenty hunt this weather?

Geostatistics

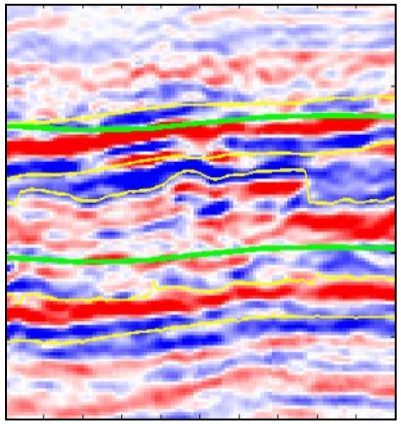


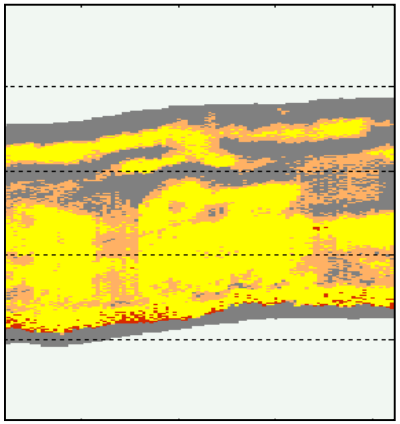


You'd never predict the bear!

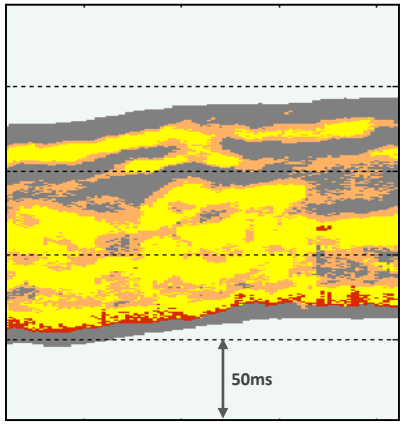
spatial correlation

most likely lithofacies

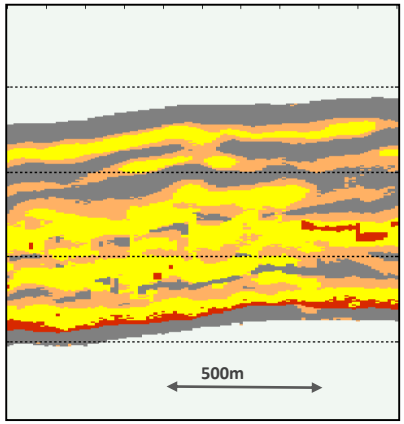




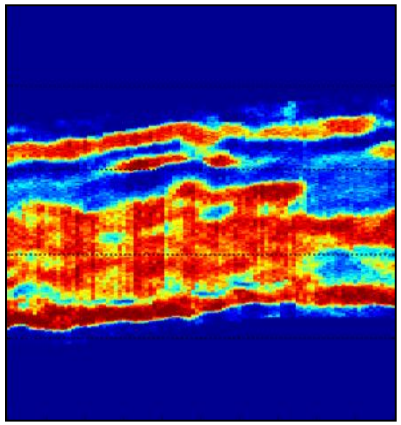
1D



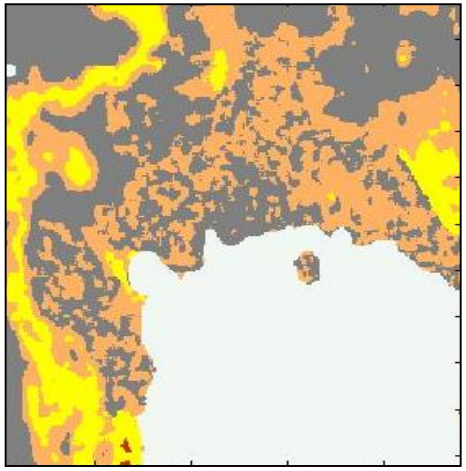
2.5D
(adjacent traces + dip-scan)

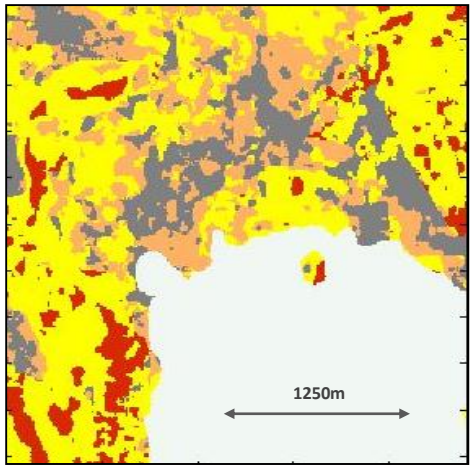


2.5D
(5 iterations)

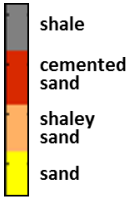


Search best-match pseudo-wells for continuity of lithofacies.



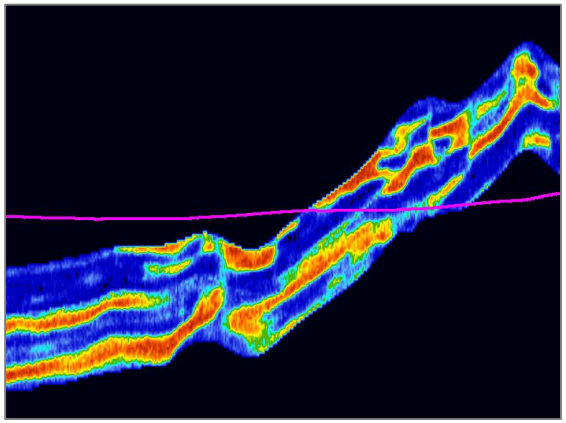


time slices



summary

- BP has developed a new stochastic inversion program
- It matches large numbers of pseudo-wells to seismic CI angle stacks
- It's been tested internally on many datasets
- Details will be published soon
- (and the software is available now)



Stochastic inversion by matching to large numbers of pseudo-wells, 2016, P. Connolly and M. Hughes, Geophysics, Vol. 81, No. 2 (March-April 2016);

Thanks to Gtr. Plutonio and Schiehallion partners and thanks to Cegal and many BP colleagues. Thanks also to Force.

[Exit, pursued by a bear]