Unmeasurable aspects of seismic data and implications for QI.

Patrick Connolly

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geophysics for integration

Deep Blue

Defeated World Chess Champion Garry Kasparov in 1997

Moravec's paradox

Computers and humans have complementary skills

‘Advanced Chess’; humans + machines

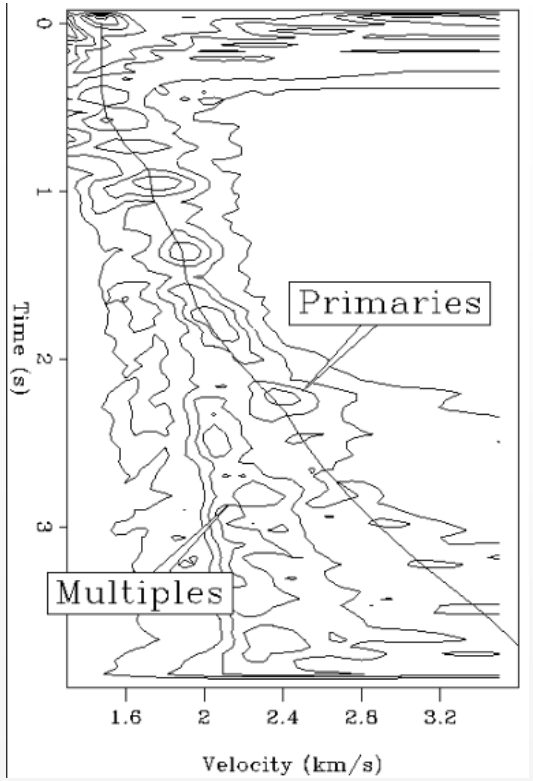
2005 Tournament:

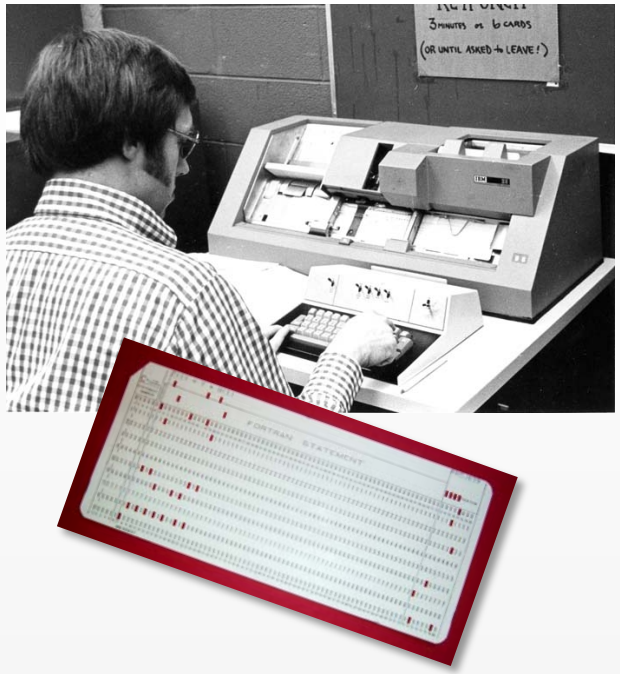
- ‘Dream-teams’: Grandmasters + Computer scientists
- Won by Steven Cramton and Zackary Stephen; amateur players using laptops
- *‘We had really good methodology for when to use the computer and when to use our human judgement’*
- *‘A clever process beat superior knowledge and superior technology’* - Garry Kasparov

Seismic

World leaders in optimising human + machine combination?

Perhaps we are!





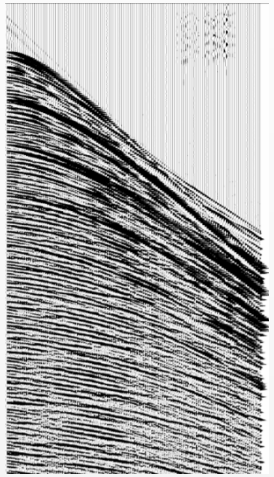
Seismic Data Processing & Interpretation

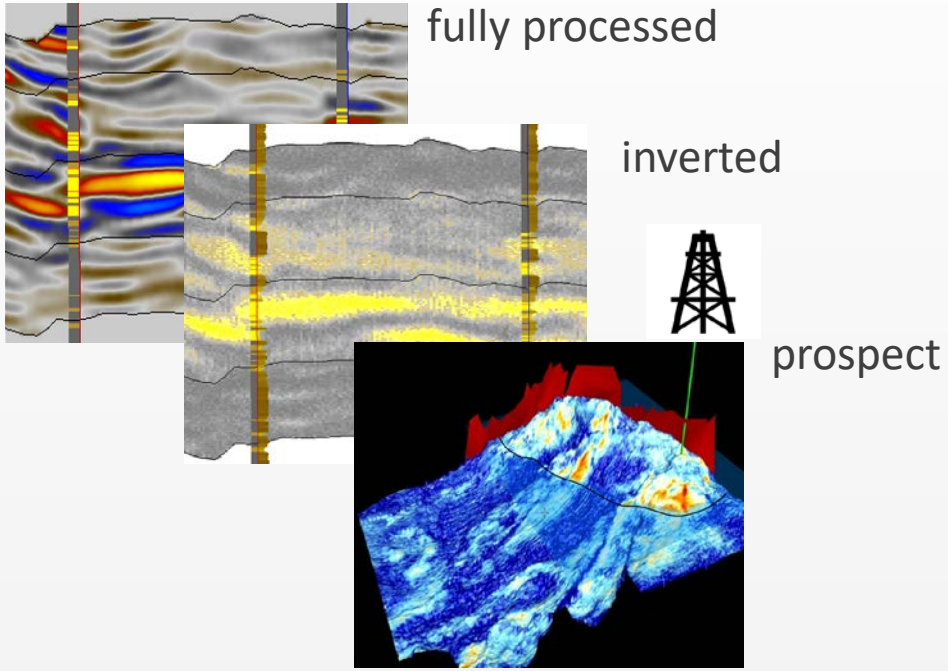
- Machines; applying decon, NMO and migration operators
- Humans; picking velocities, selecting optimal parameters, interpretation

QI?

Why can't computers do everything?

field data

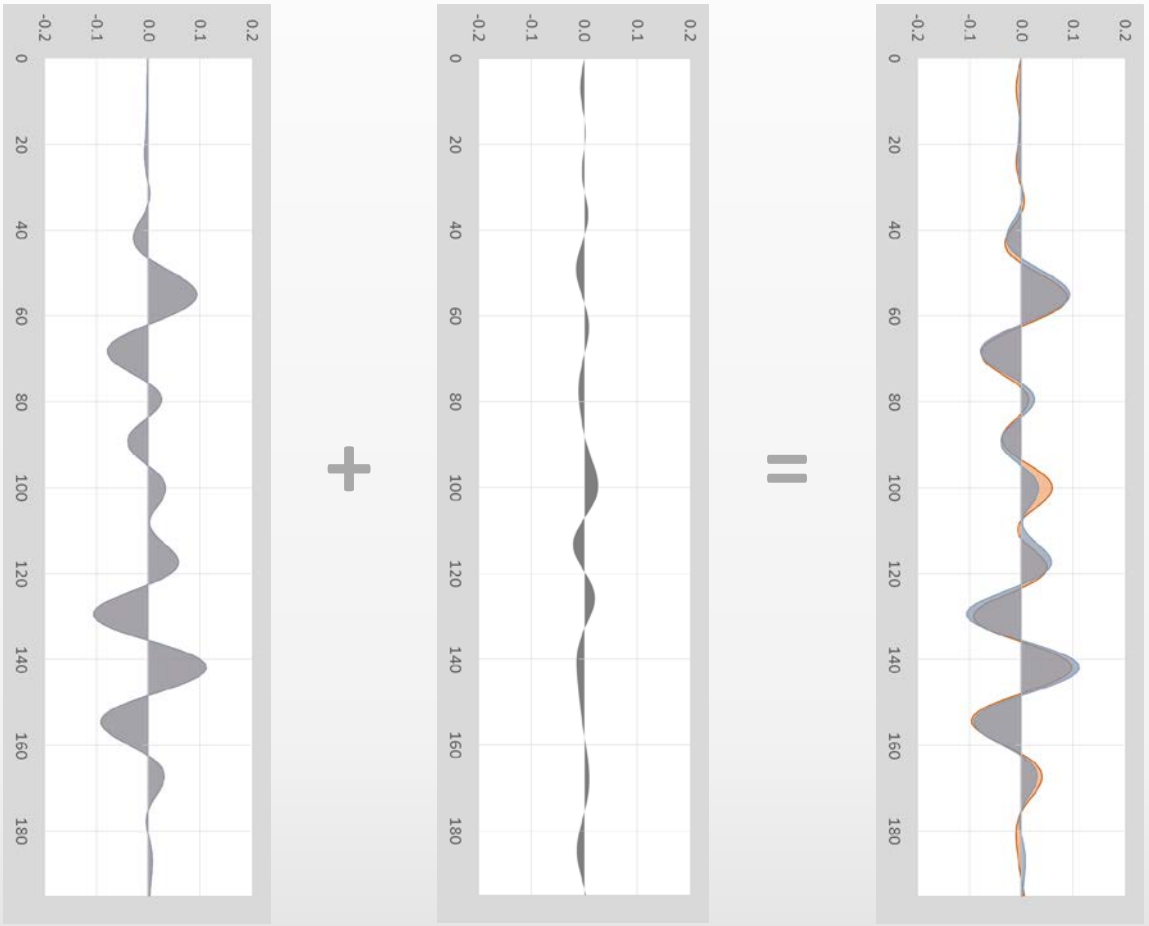




Because some aspects of seismic can't be measured

Signal-to-noise

Incoherent noise

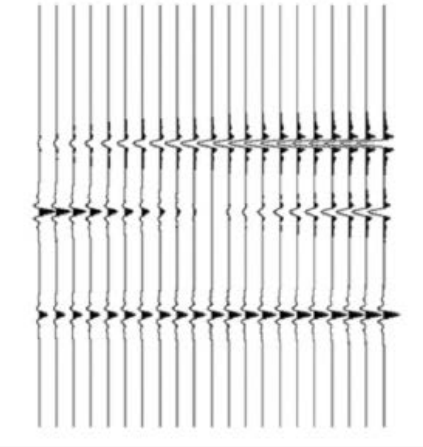


signal + noise

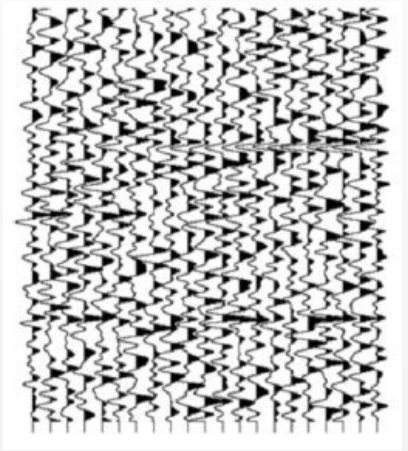
5:1

signal

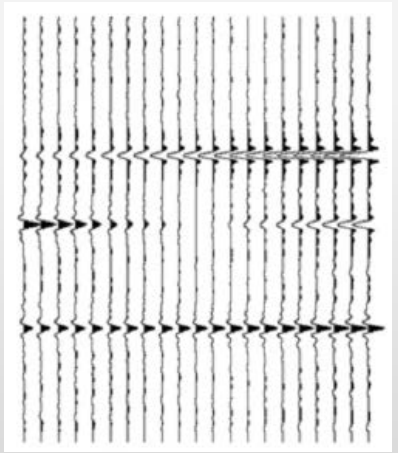
noise



signal



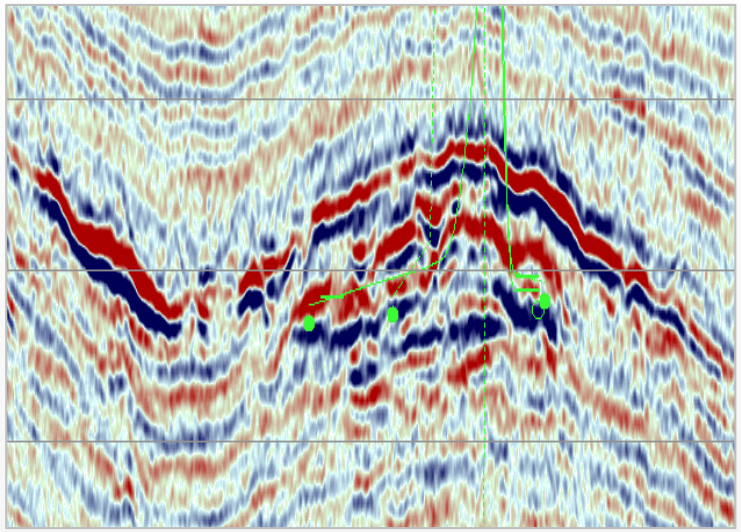
signal + noise



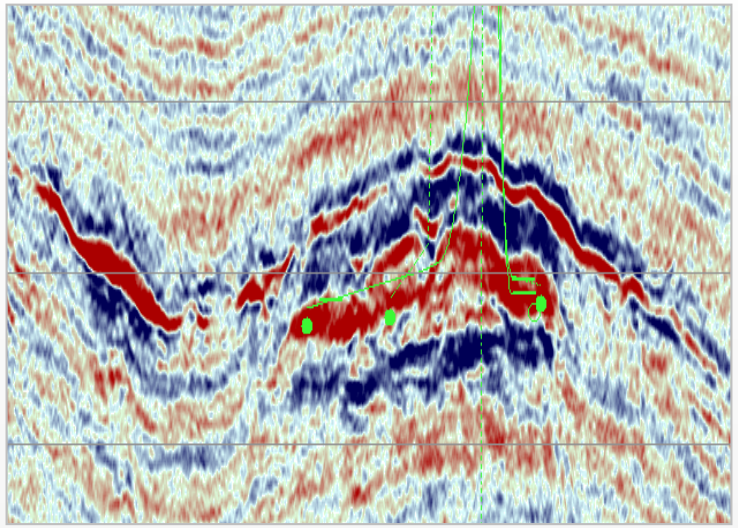
after noise reduction

Coloured Inversion

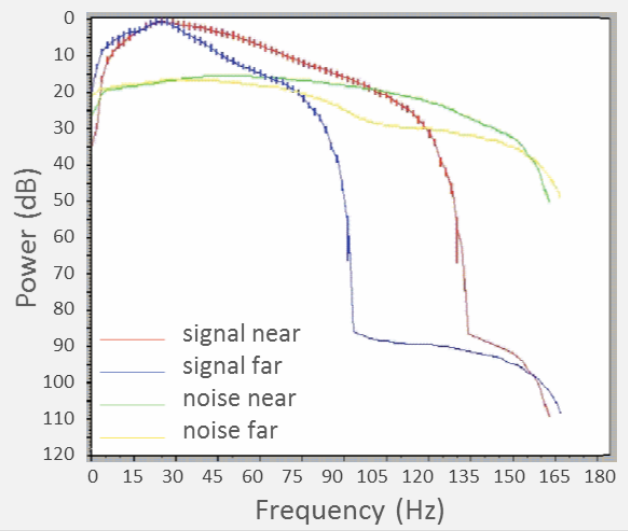
Fluid and lithology identification using high-resolution 3D seismic data
P. Connolly, S. Wilkins, T. Allen, G. Schurter & N. Rose-Innes,
Proceedings of the 6th Petroleum Geology Conference, 2005



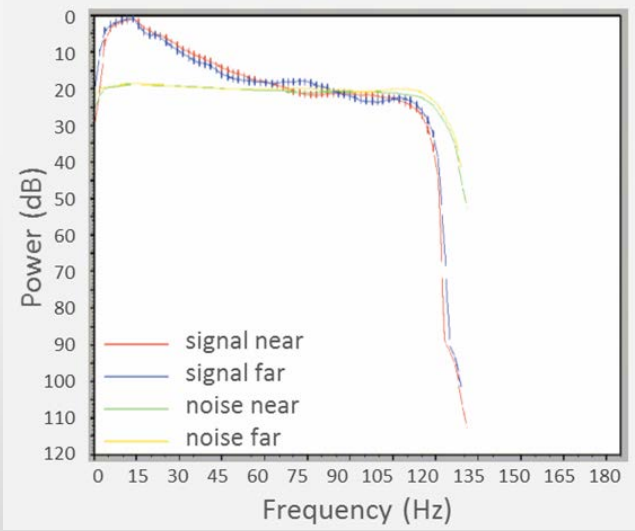
reflectivity



band-limited impedance
(colour inversion)

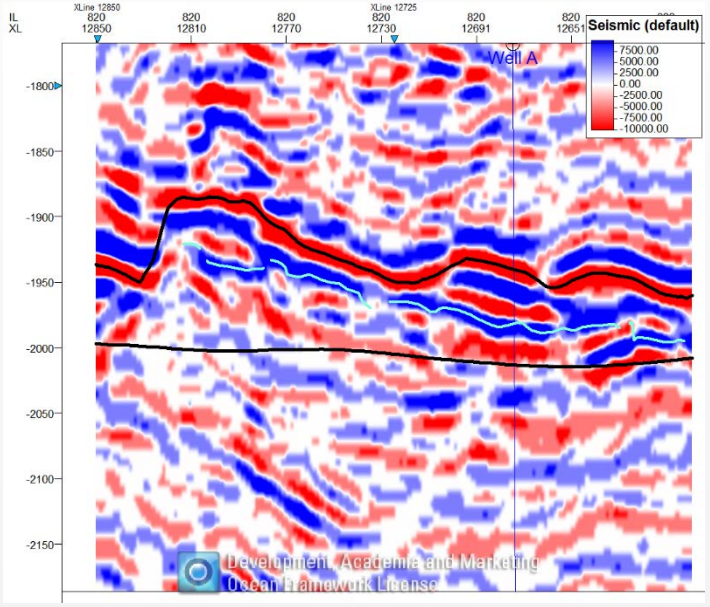


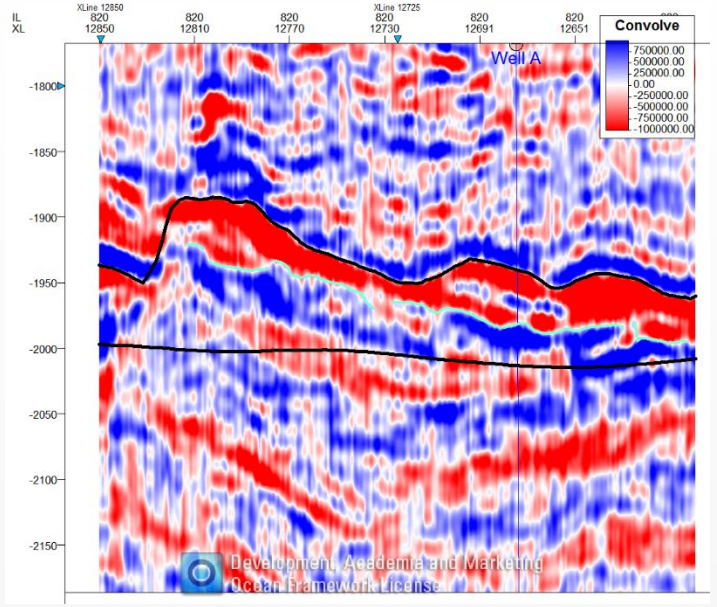
Signal changes but noise doesn't (?)



Trial & error

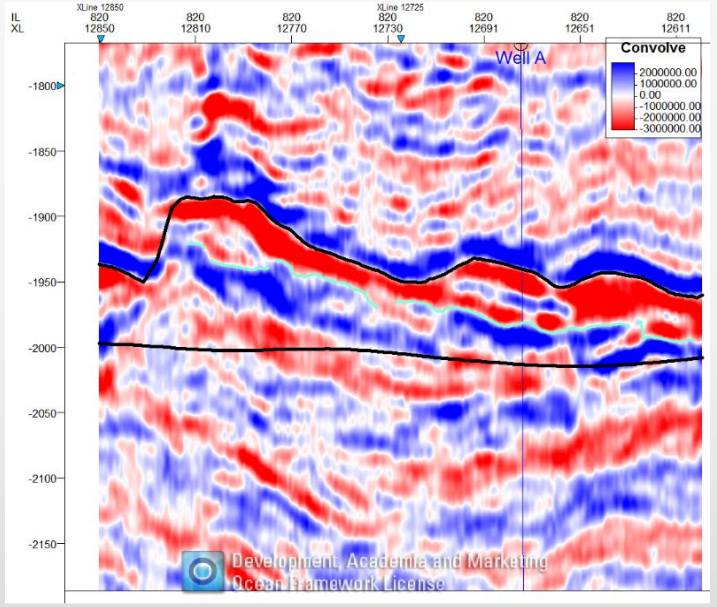
Input reflectivity data





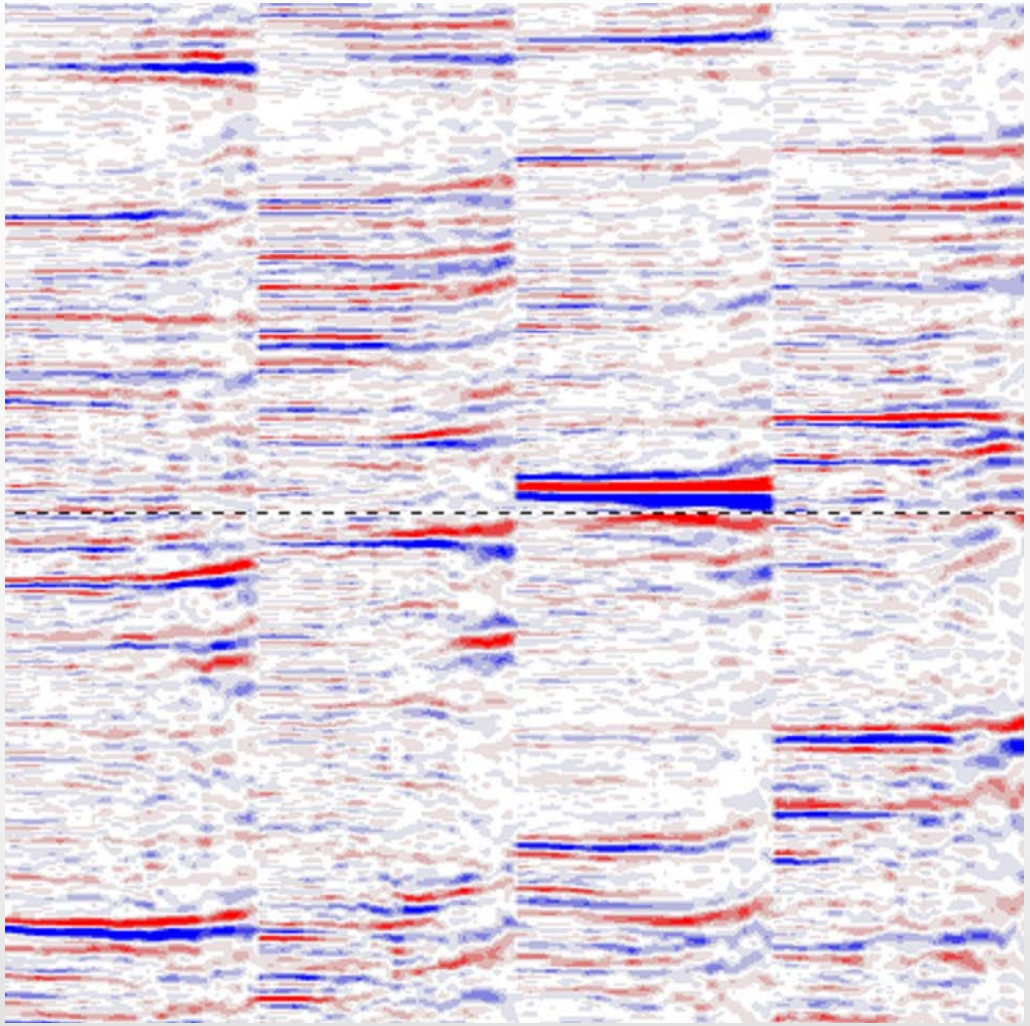
3-4-43-63Hz

Output CI



8-9-43-63Hz

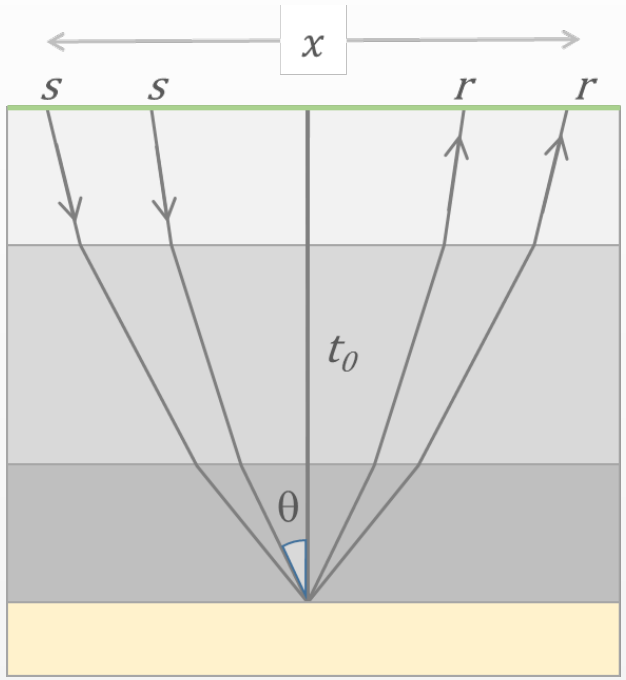
Gradient measurement errors



- Flat gathers
- Offset scaling
- Offset spectral balancing
- Offset to angle relationship
- Truncation bias
- Anisotropy
- Moveout correction artefacts:
  - NMO stretch
  - Offset tuning
- Random noise
- Coherent noise:
  - Multiples
  - Mode conversions
  - Residual noise

Angle estimation errors

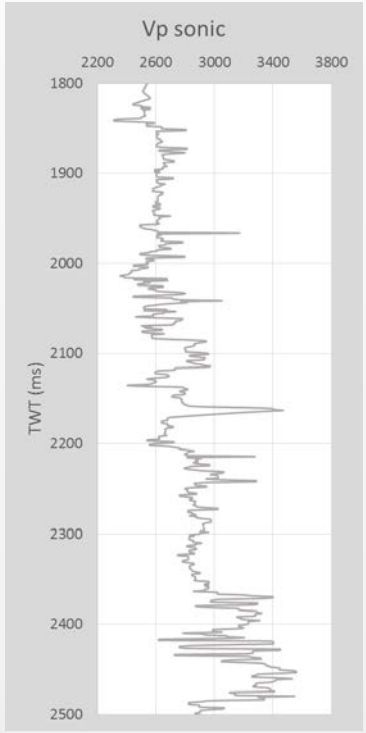
$$R(\theta) \approx A + B \sin^2 \theta$$



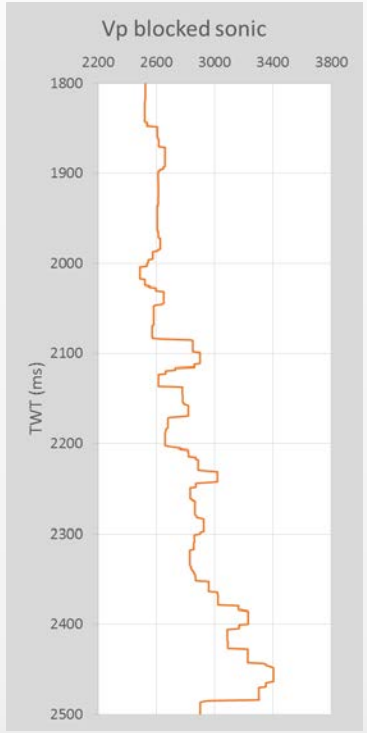
$$sin^2\theta = \frac{x^2 V_i^2}{V_r^2(V_r^2 t_0^2 + x^2)}$$

where x = offset
V_i = interval velocity
V_r = RMS velocity
t_0 = zero offset TWT

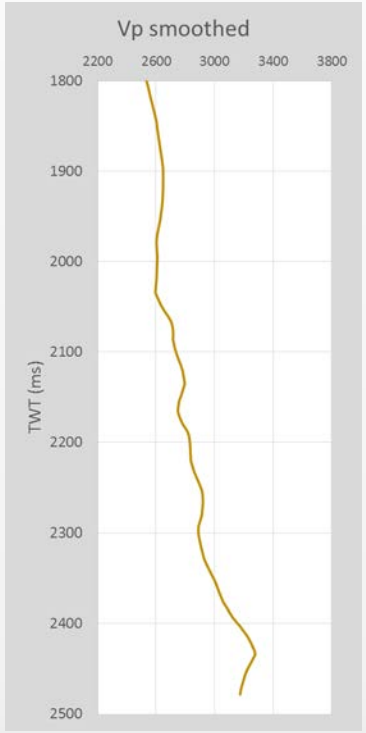
West-of-Shetland Tertiary sonic



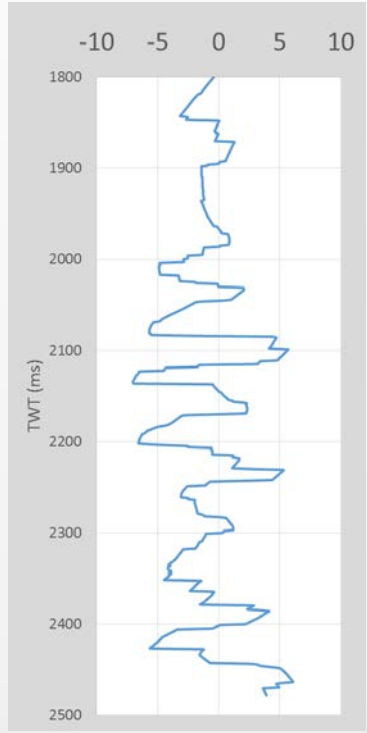
Blocked (22ms): ~seismic resolution



Smoothed (100ms): ~velocity resolution

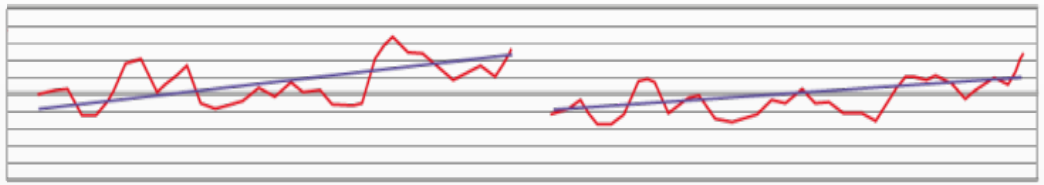


Difference: % velocity error

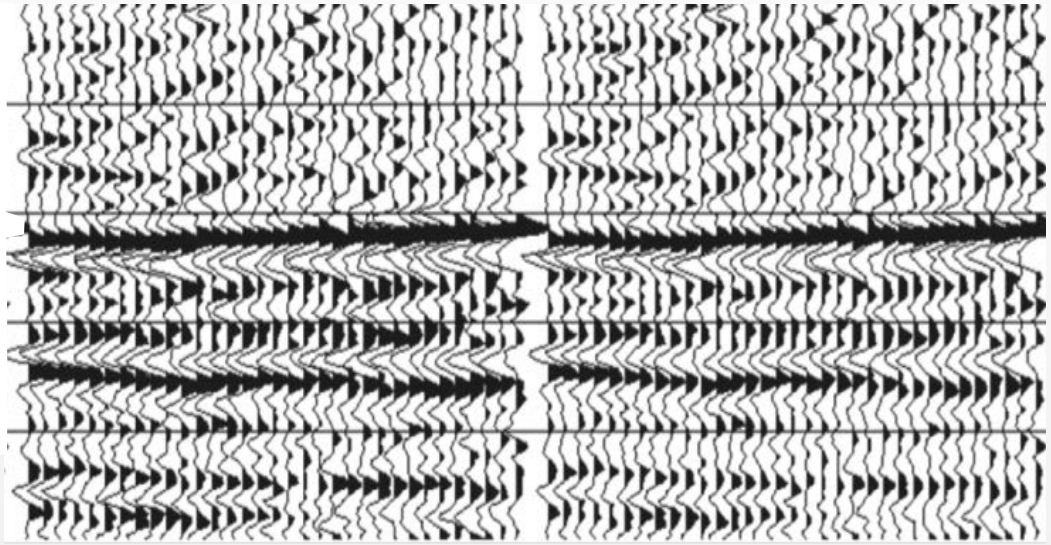


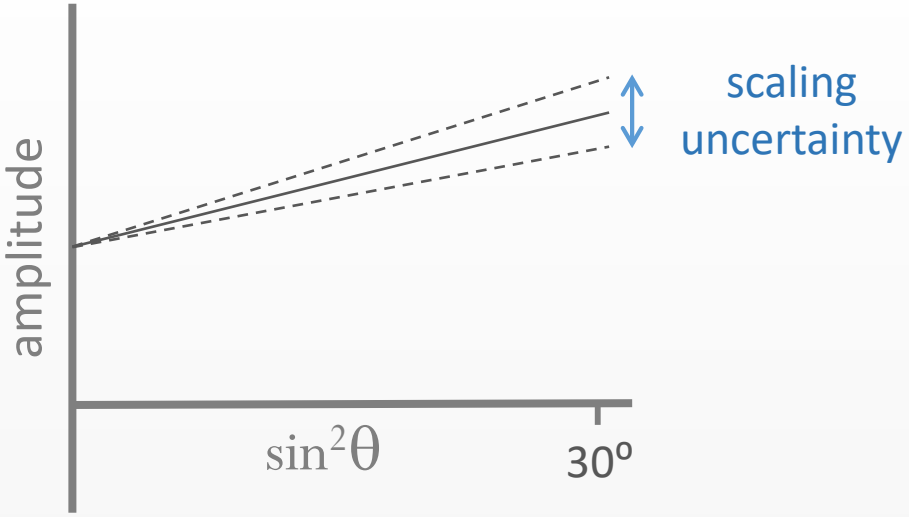
- 5% errors unavoidable, 10% errors likely
- Much larger errors quite possible

Offset scaling errors



~10% difference





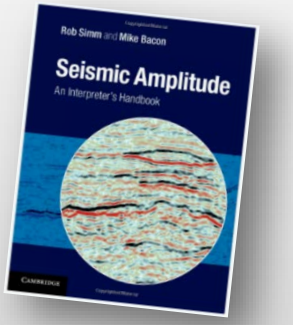
$$B_m = SB + 4(S-1)A$$

B = true gradient

S = scaling factor (1 = correct scaling)

B_m = measured gradient

- 10% errors unavoidable
- Much larger errors quite likely



Seismic Amplitude. An Interpreter's Handbook, 2014, R. Simm and M. Bacon,

Anisotropy — the Rüger equation

$$R(\theta) \approx A + B \sin^2\theta + C \sin^2\theta \tan^2\theta$$

$$A = \frac{1}{2}\left(\frac{\Delta V_P}{V_P} + \frac{\Delta\rho}{\rho}\right)$$

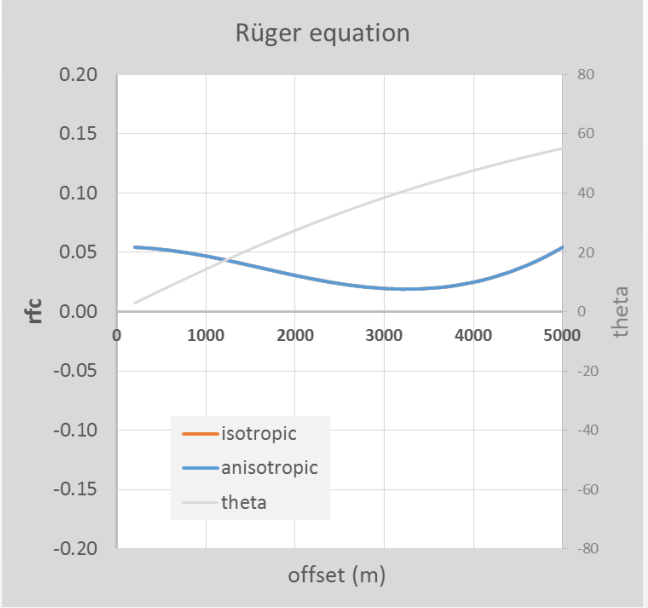
$$B = \frac{\Delta V_P}{2V_P} - 2k\left(\frac{\Delta\mu}{\mu}\right) + \frac{\Delta\delta}{2}$$

$$C = \frac{\Delta V_P}{2V_P} + \frac{\Delta\varepsilon}{2}$$

$$V_{NMO} = V_P(0°)[1+\delta]$$

$$V_P(90°) = V_P(0°)[1+\varepsilon]$$

Isotropic top brine sand

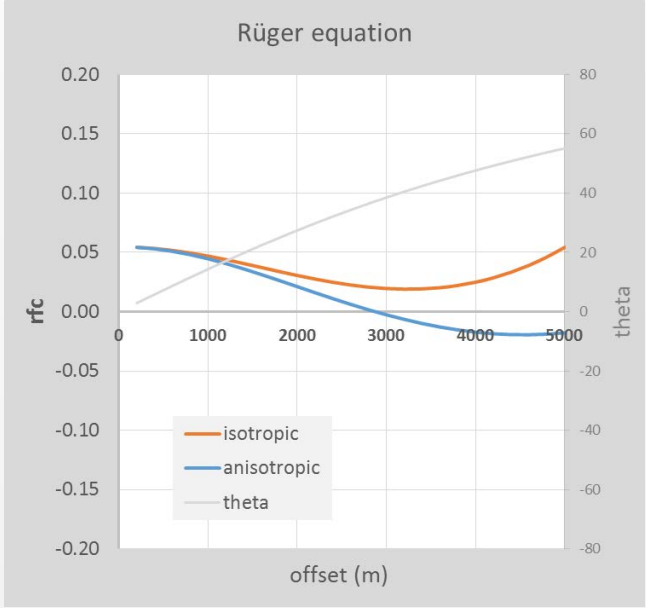


	Vp	Vs	rho
layer 1	2743	1273	2.38
layer 2	3113	1579	2.34

Offshore Angola well

- layer 1 average shale values
- layer 2 average brine-sand values.

$\Delta\delta$ = -0.07 and $\Delta\varepsilon$ = -0.07

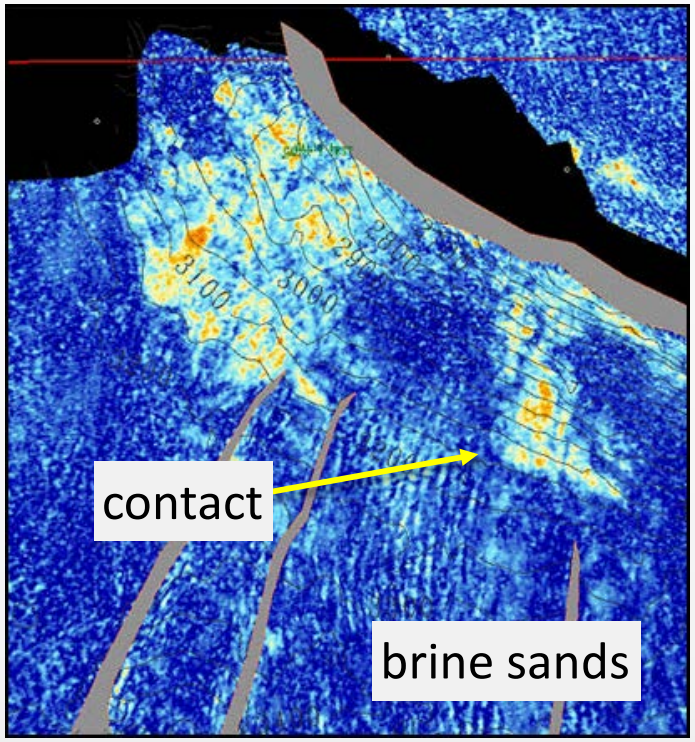


Typical sand/shale contrast for δ and ε = 0.07*

*Weak anisotropy, 1986, Leon Thomsen, Geophysics

Anisotropy — the Rüger equation

Amplitude map – far offsets



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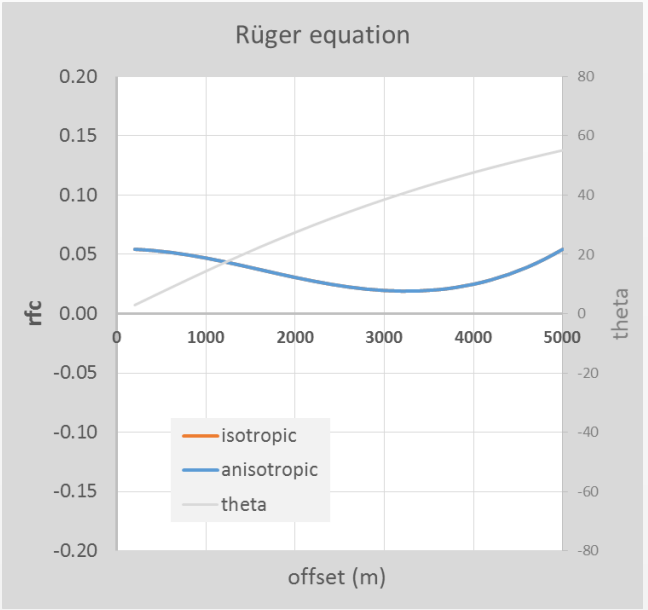

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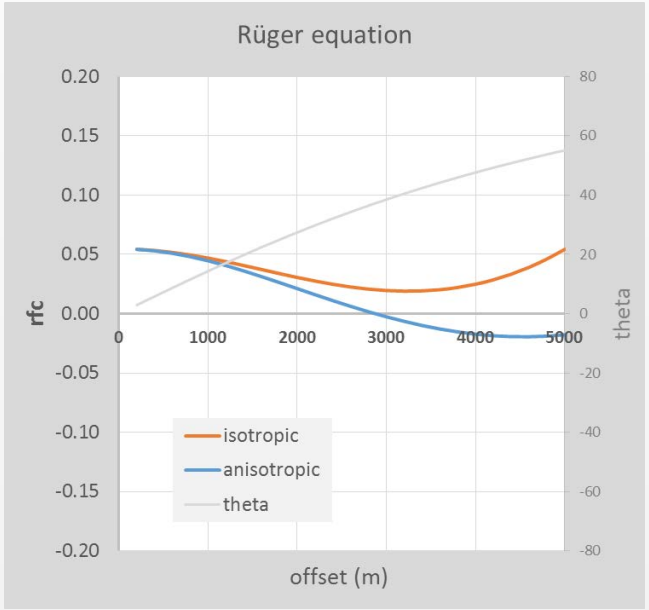

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Theory: elastic property reflectivity

P = elastic property (or product)

$R_P = \frac{\Delta P}{2P}$ = elastic property reflectivity

$$R_P = c_1 A + c_2 B + c_3 C$$

where

A = intercept

B = gradient

C = curvature

R_P	A	B	C
λρ	3	1	0
Kρ	2.5	0.5	0
μρ	0.5	-0.5	0
SI	0.5	-0.5	0
Eρ	1.17	-0.83	0
V_P/V_S	0.5	0.5	0
K	1.5	0.5	1
μ	0	-1	1

k = 0.25

Theory: elastic property reflectivity

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$$R_P = c_1 A + c_2 B + c_3 C$$

where

A = intercept

B = gradient

C = curvature

$$R_s(\chi) = A\cos(\chi) + B\sin(\chi)$$

R_P	A	B	C	χ
λρ	3	1	0	18.4°
Kρ	2.5	0.5	0	11.3°
μρ	0.5	-0.5	0	-45°
SI	0.5	-0.5	0	-45°
Eρ	1.17	-0.83	0	-35.5°
V_P/V_S	0.5	0.5	0	45°
K	1.5	0.5	1	~12.3°
μ	0	-1	1	~51.3°

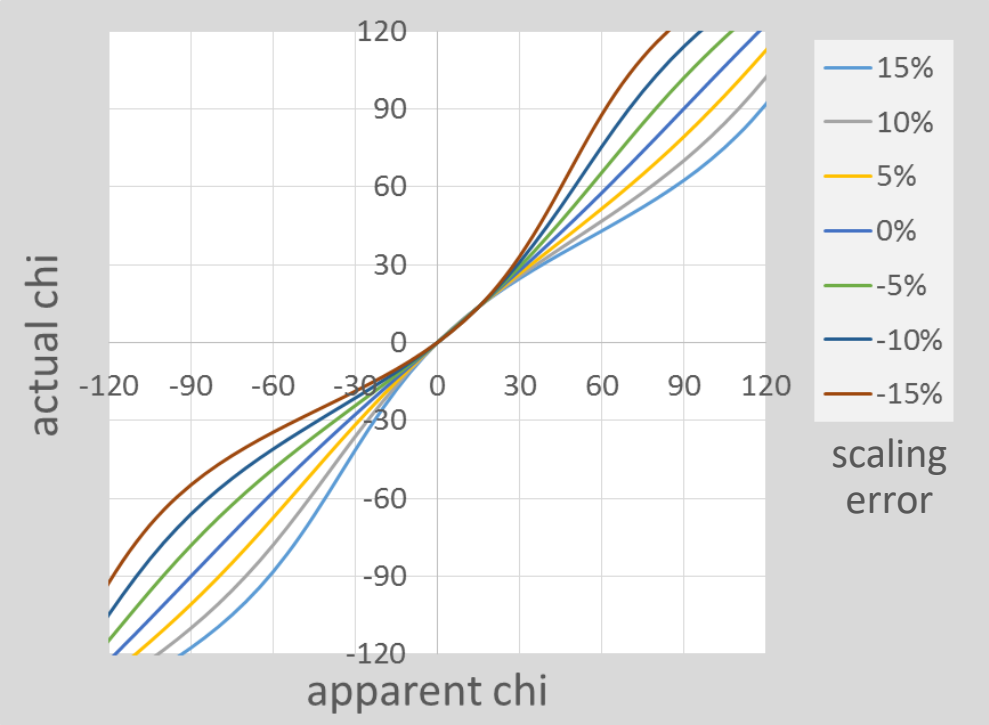
k = 0.25

k = 0.25 & Gardner ($C = 0.8A$)

Theory: elastic property reflectivity

Gradient measurements are in error;

actual χ not equal to apparent χ



Chi error curves

angle error = 10%, variable scaling error

R_P	A	B	C	χ
λρ	3	1	0	18.4°
Kρ	2.5	0.5	0	11.3°
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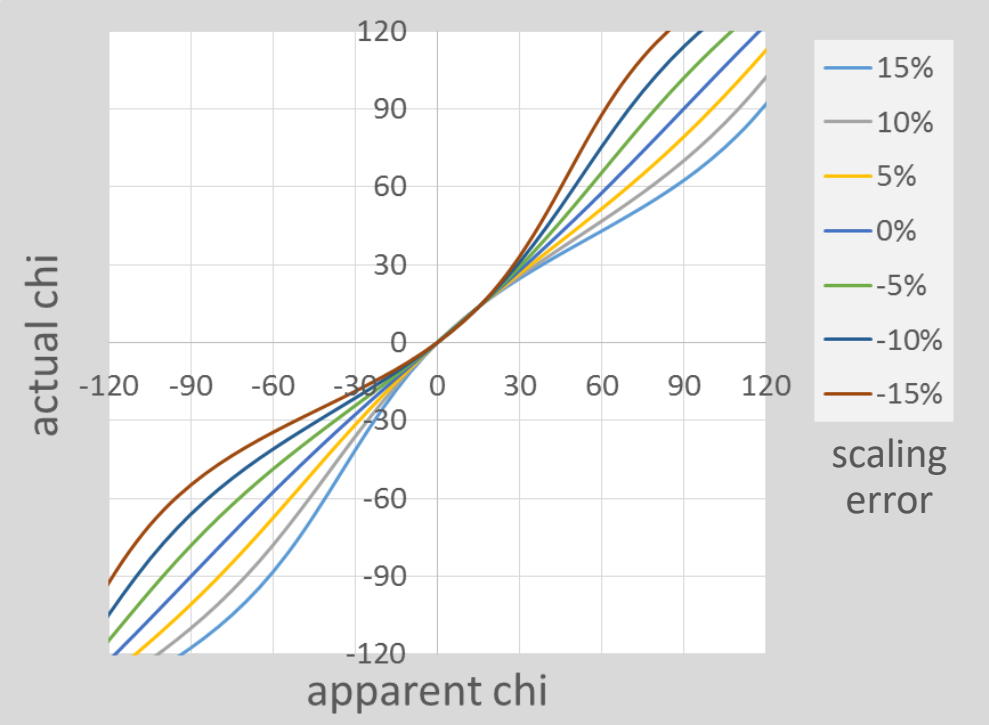


Chi error curves

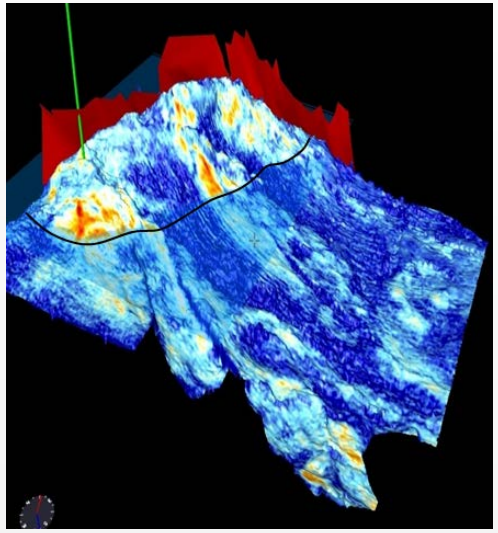
angle error = 10%, variable scaling error

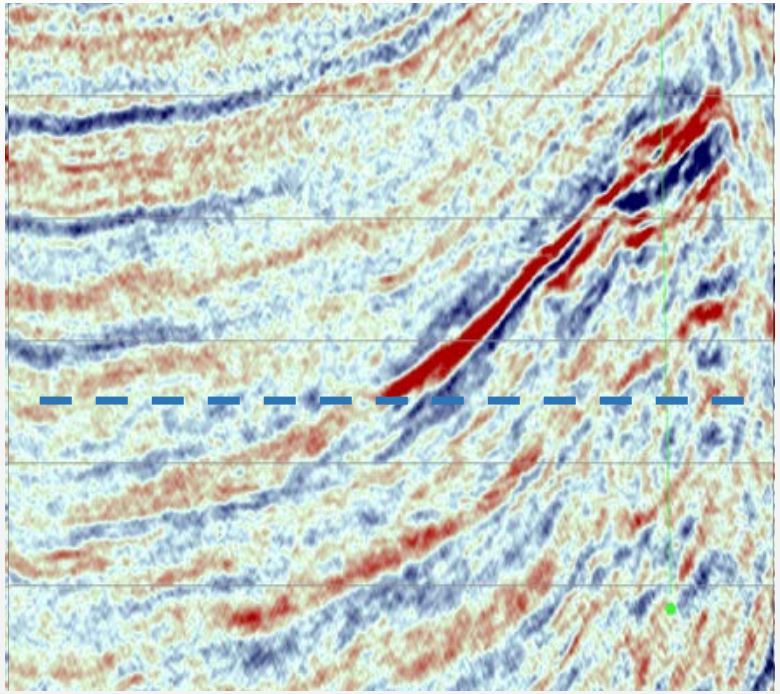
"No battle plan survives contact with the enemy"

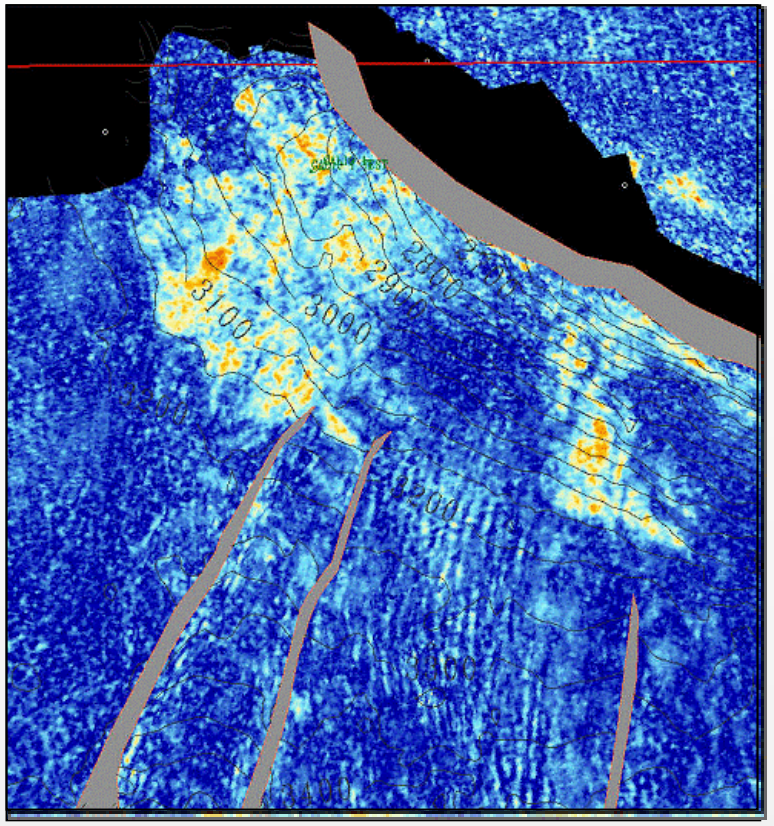
- Field Marshall Helmuth von Moltke

"No theory survives contact with the data"

Chi scan

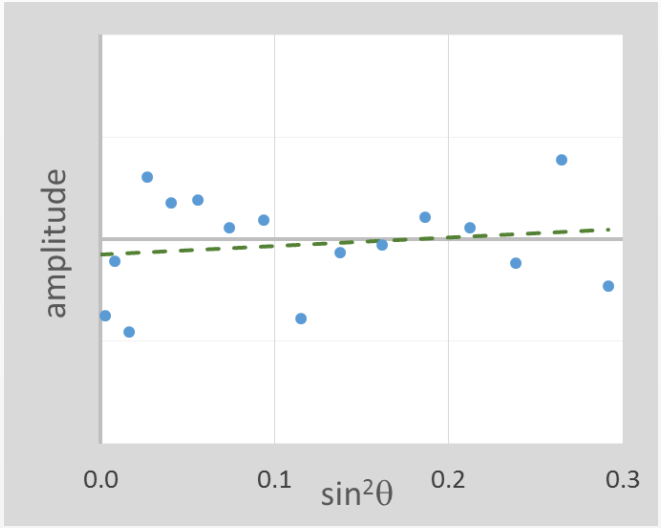




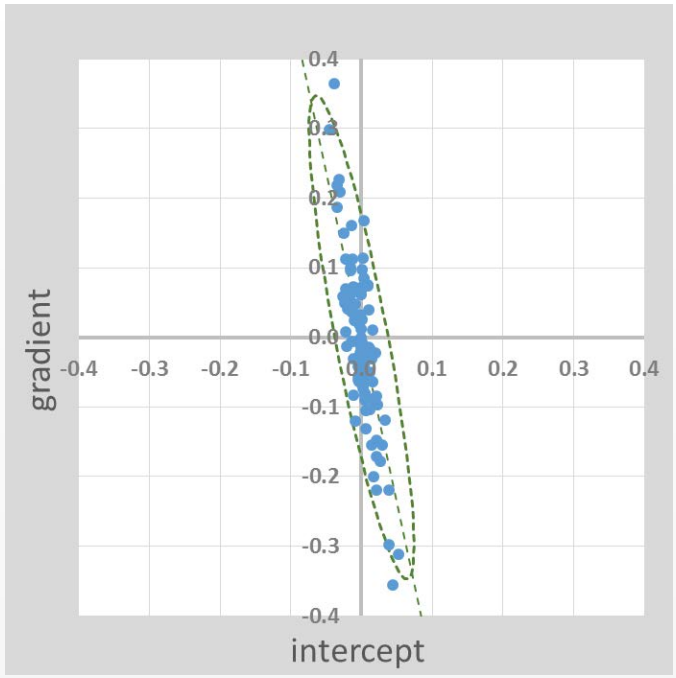


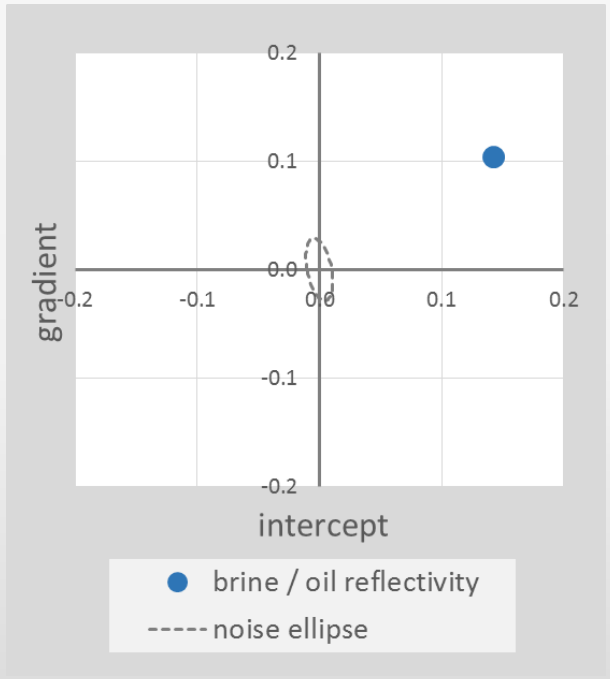
(simulated scan)

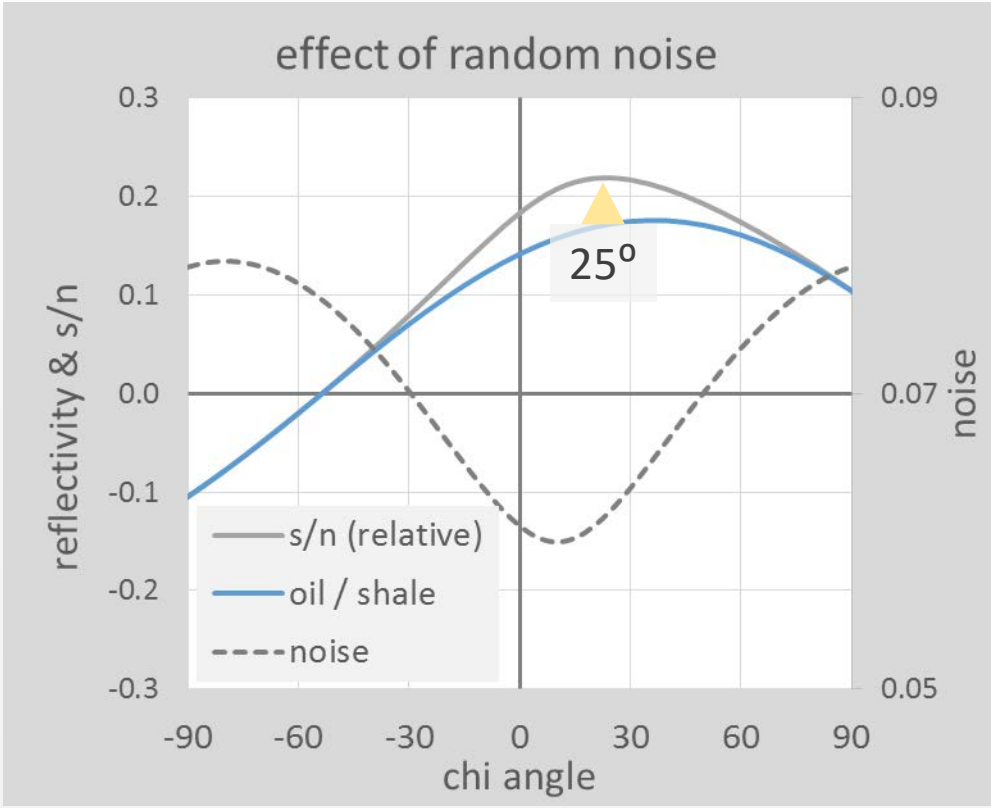
Noise



Random noise







The maximum signal-to-noise is shifted towards the stack chi value

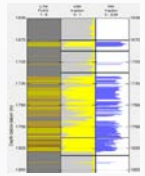
But we can't calculate the shift!

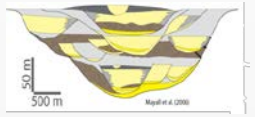
Inversion to reservoir properties

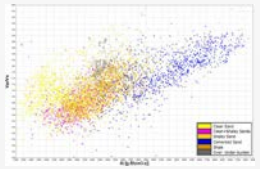
Reservoir

UNCERTAINTY

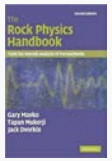
Geological Model



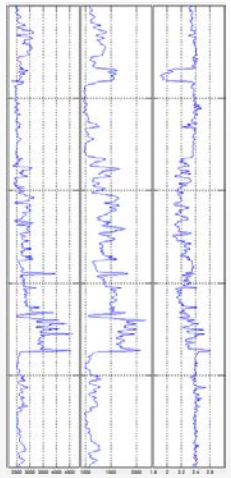




UNCERTAINTY



Elastic Properties



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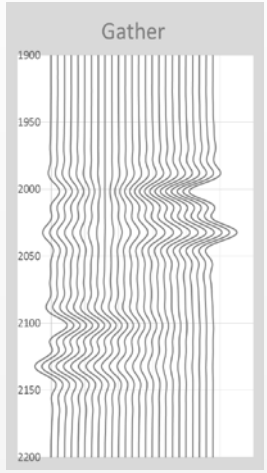
Ideal Seismic



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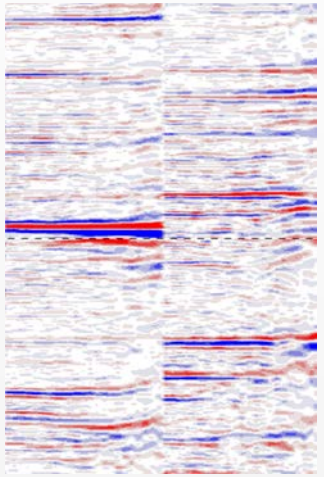
Real Seismic



inversion to reservoir properties

rock physics models

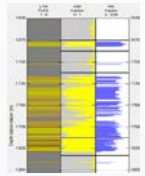
geological models

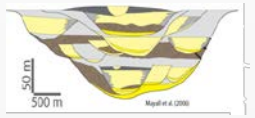
Probabilistic inversion

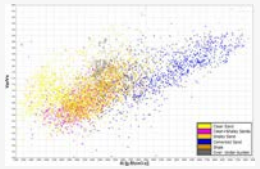
Reservoir

UNCERTAINTY

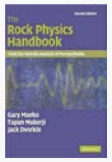
Geological Model



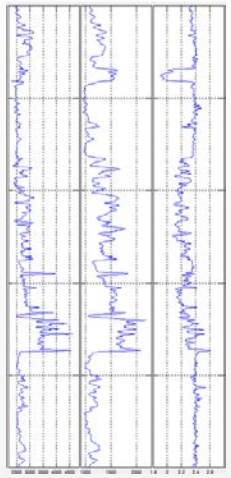




UNCERTAINTY

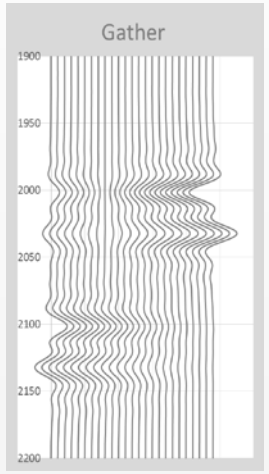


Elastic Properties



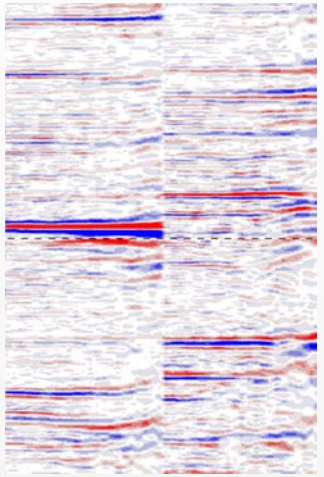
UNCERTAINTY

Ideal Seismic

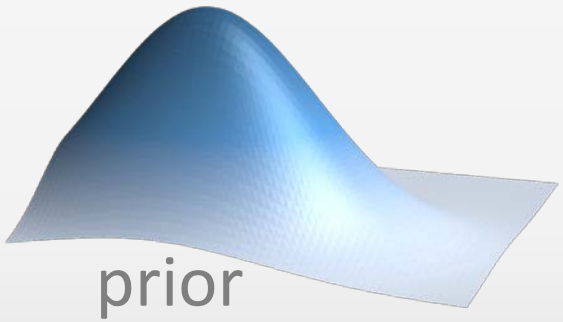


UNCERTAINTY

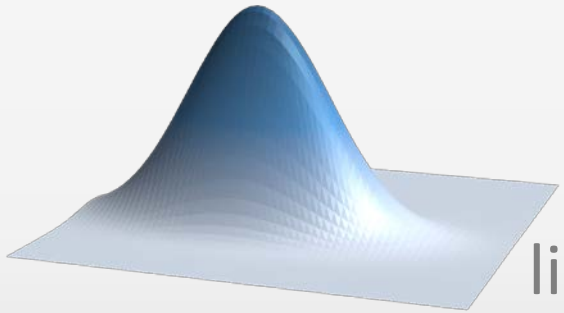
Real Seismic



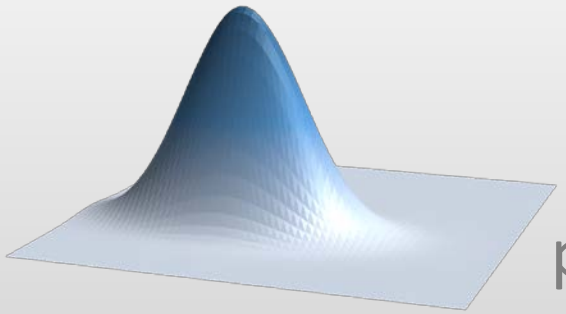
Bayes



prior



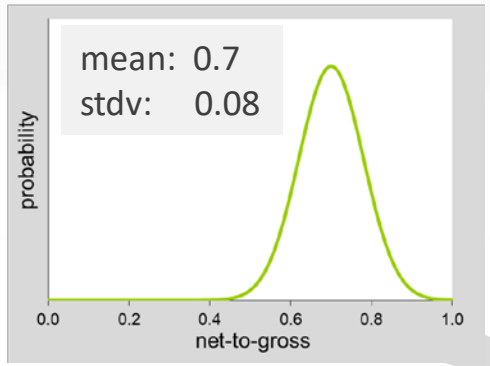
likelihood



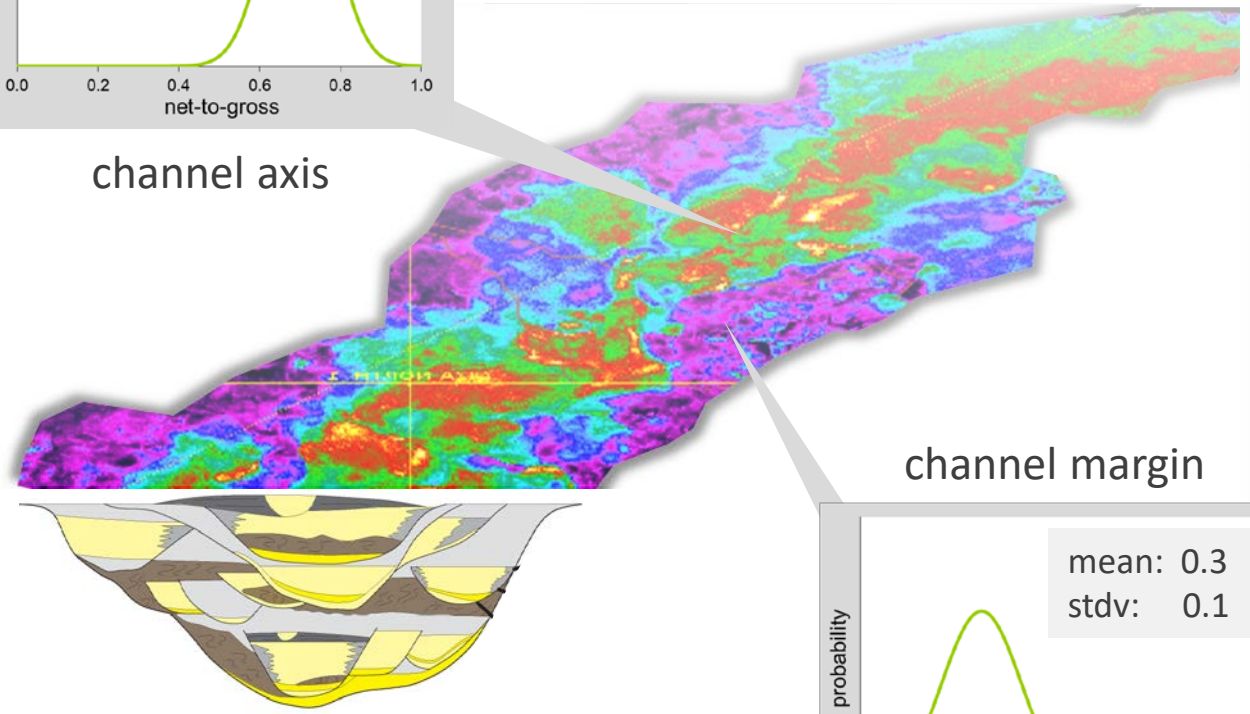
posterior

But, we can't measure uncertainties!

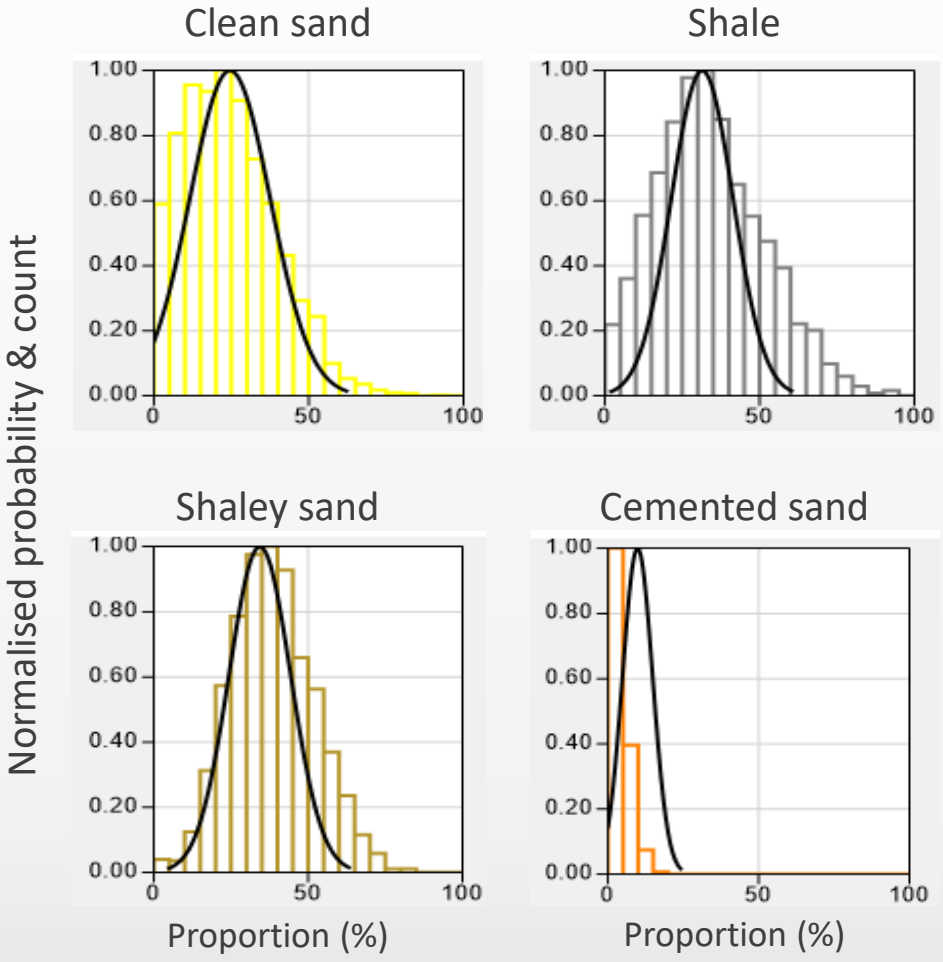
Geological model



channel axis



channel margin



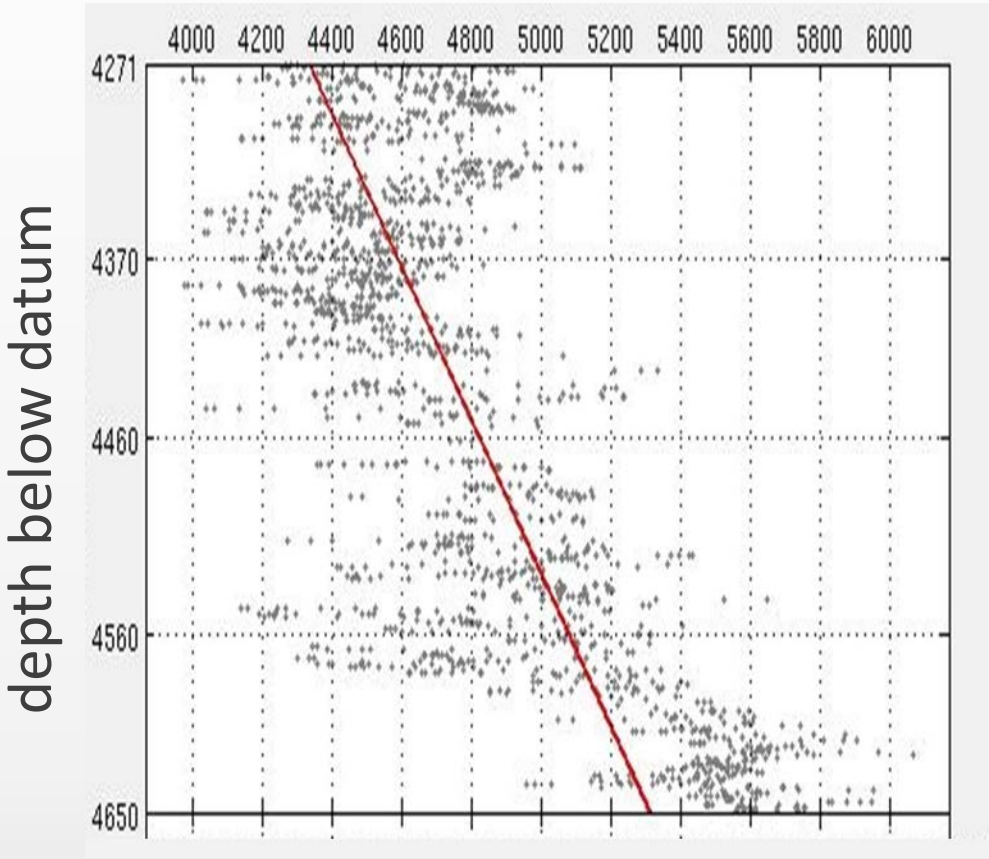
lithofacies proportions

Rock physics uncertainties

- Uncertainty measurements depend on the model.
- If the model is wrong the uncertainties will be too large, or too small.

Uncertainty quantification is always subjective

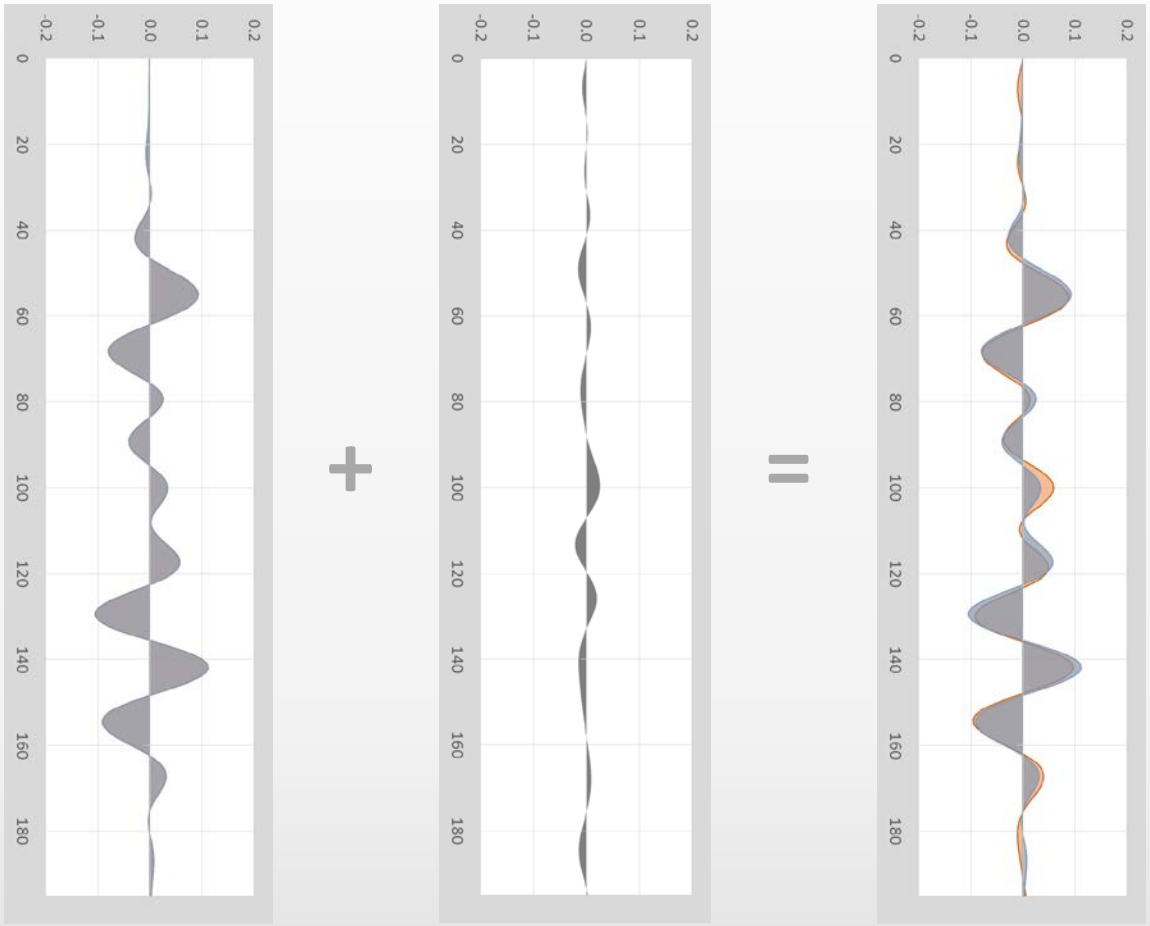
Shale V_P



What model would you fit to this?

Seismic uncertainty

Incoherent noise

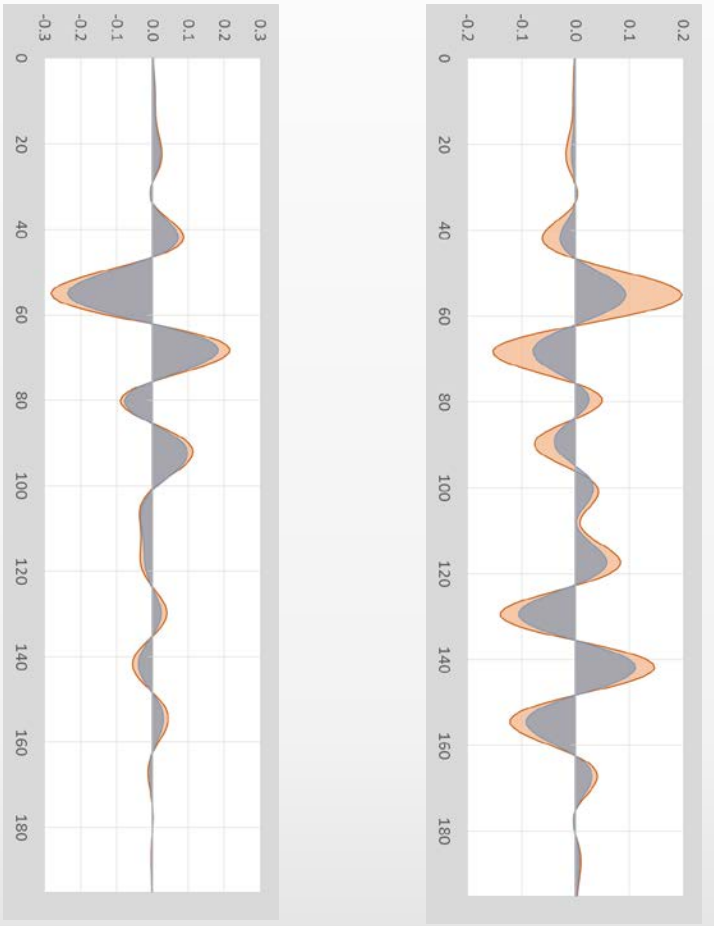


signal + noise
5:1

Coherent noise:

gradient measurement error

- 10% offset scaling error
- 10% angle estimation error
- 0.07 anisotropy (δ) contrast



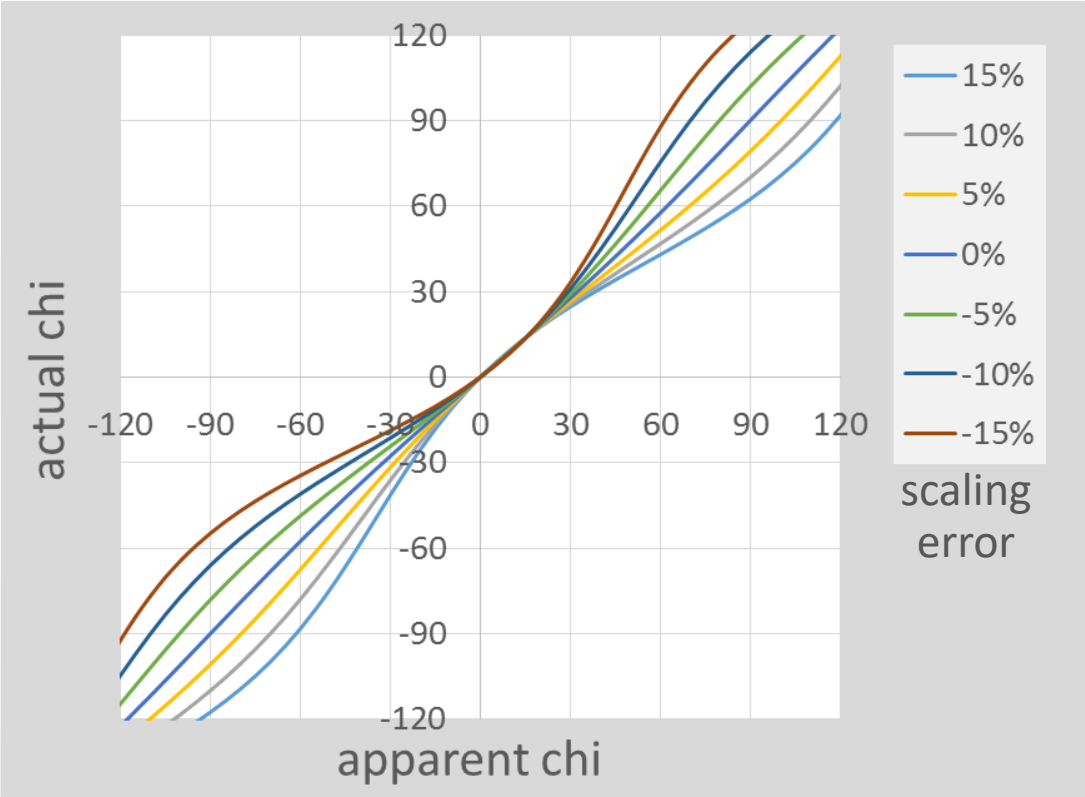
$\lambda\rho$ (χ = 18º)

$\mu\rho$ (χ = -45º)

Seismic uncertainty

Chi error curves

angle error = 10%, variable scaling error

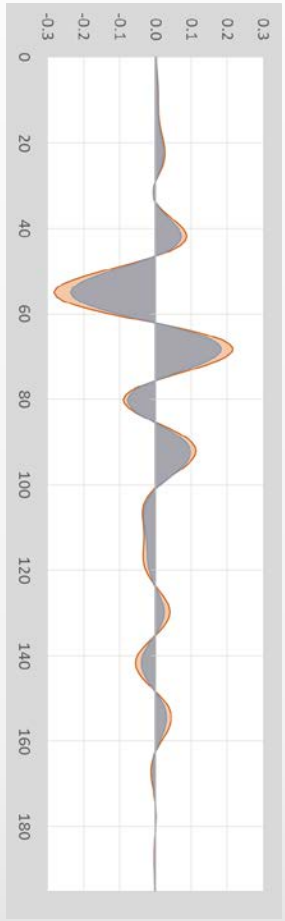


Actual χ not equal to apparent χ because of gradient measurement errors

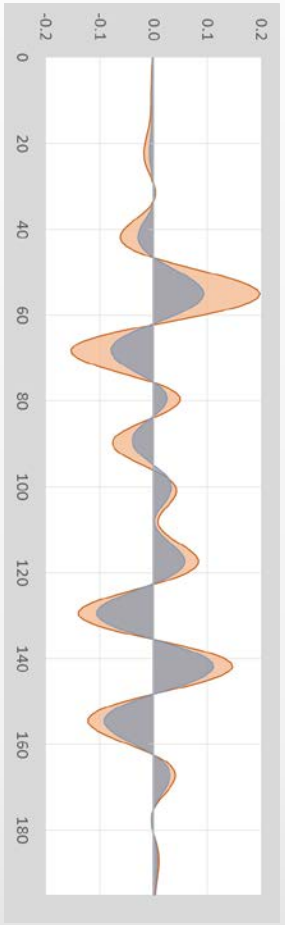
Coherent noise:

gradient measurement error

- 10% offset scaling error
- 10% angle estimation error
- 0.07 anisotropy (δ) contrast



$\lambda\rho$ (χ = 18º)

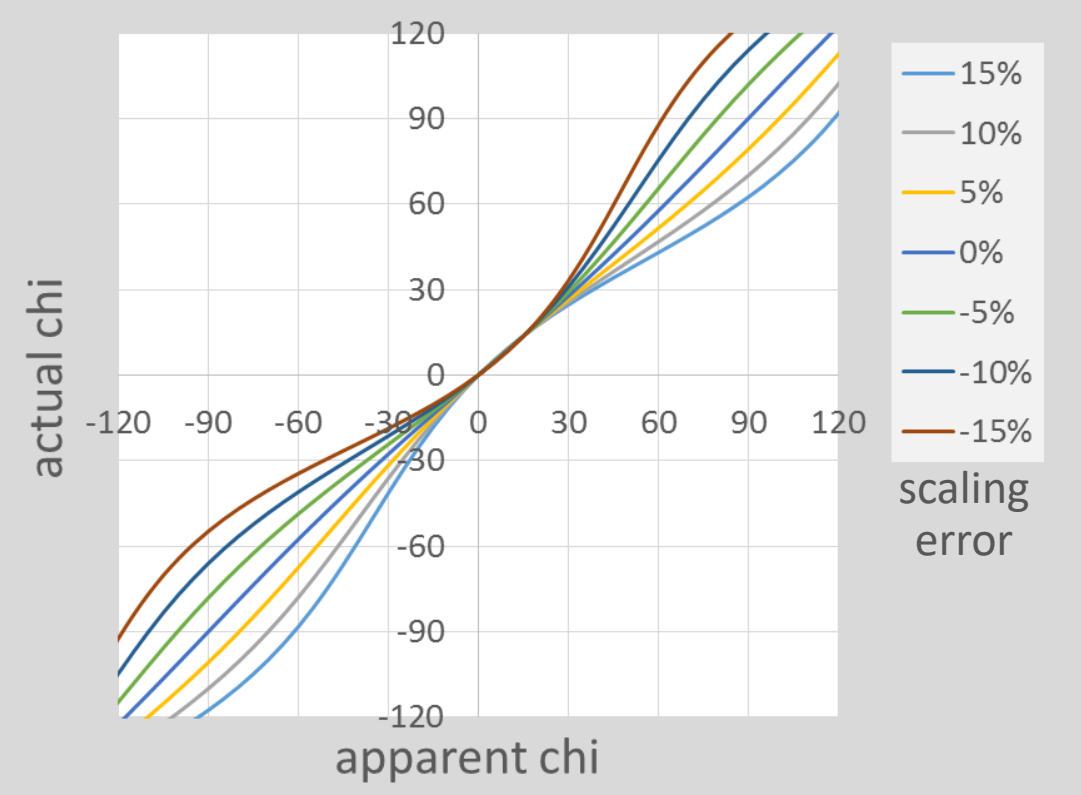


$\mu\rho$ (χ = -45º)

Seismic uncertainty

Chi error curves

angle error = 10%, variable scaling error



Actual χ not equal to apparent χ because of gradient measurement errors

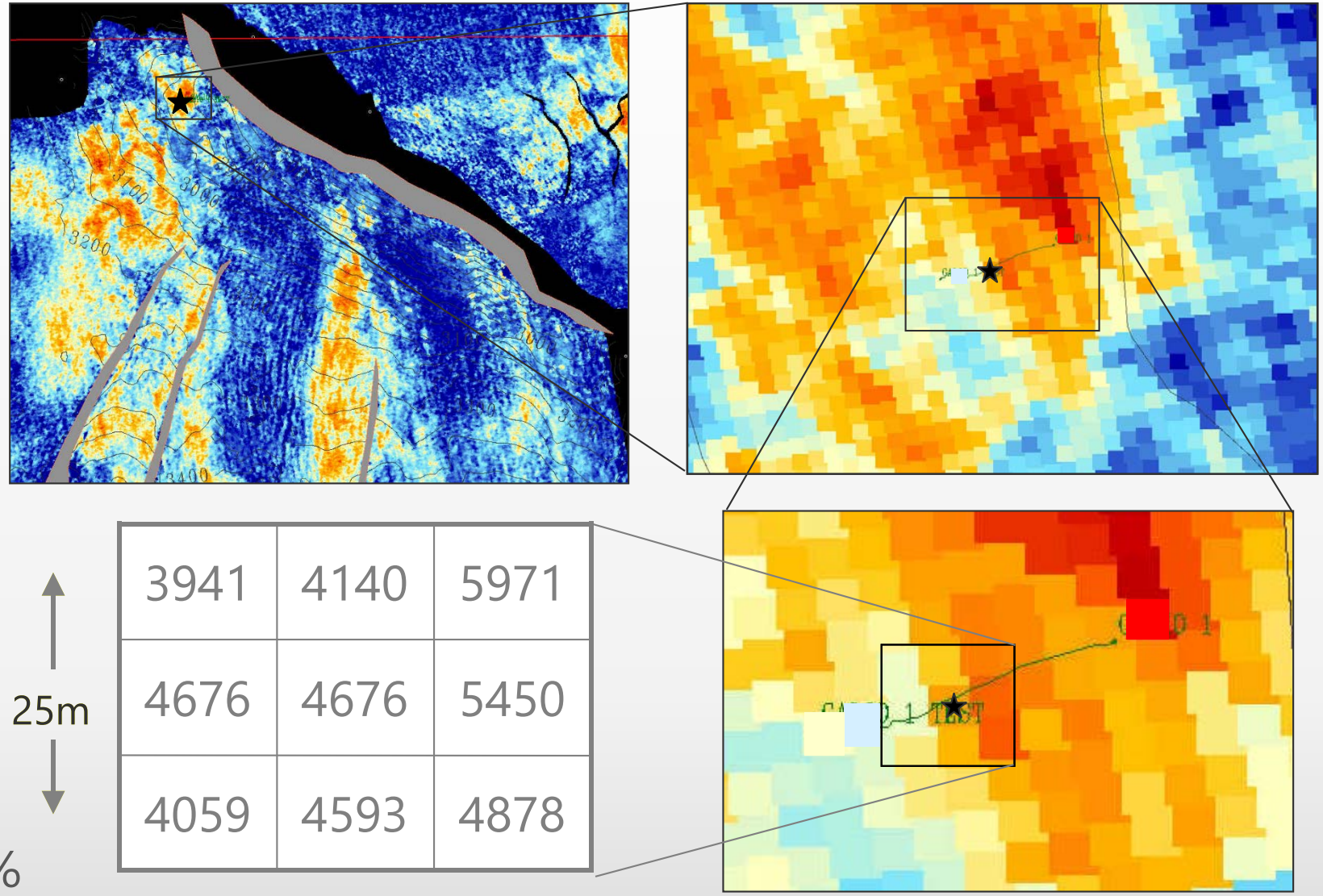
Characterise seismic uncertainty as uncertainty in chi angle?

Will depend on chi value and subjective assessment of;

- Scaling uncertainty
- Angle uncertainty (velocity uncertainty)
- Anisotropy uncertainty
- …

Well calibration?

Well-seismic positional uncertainty can result in significant calibration uncertainty

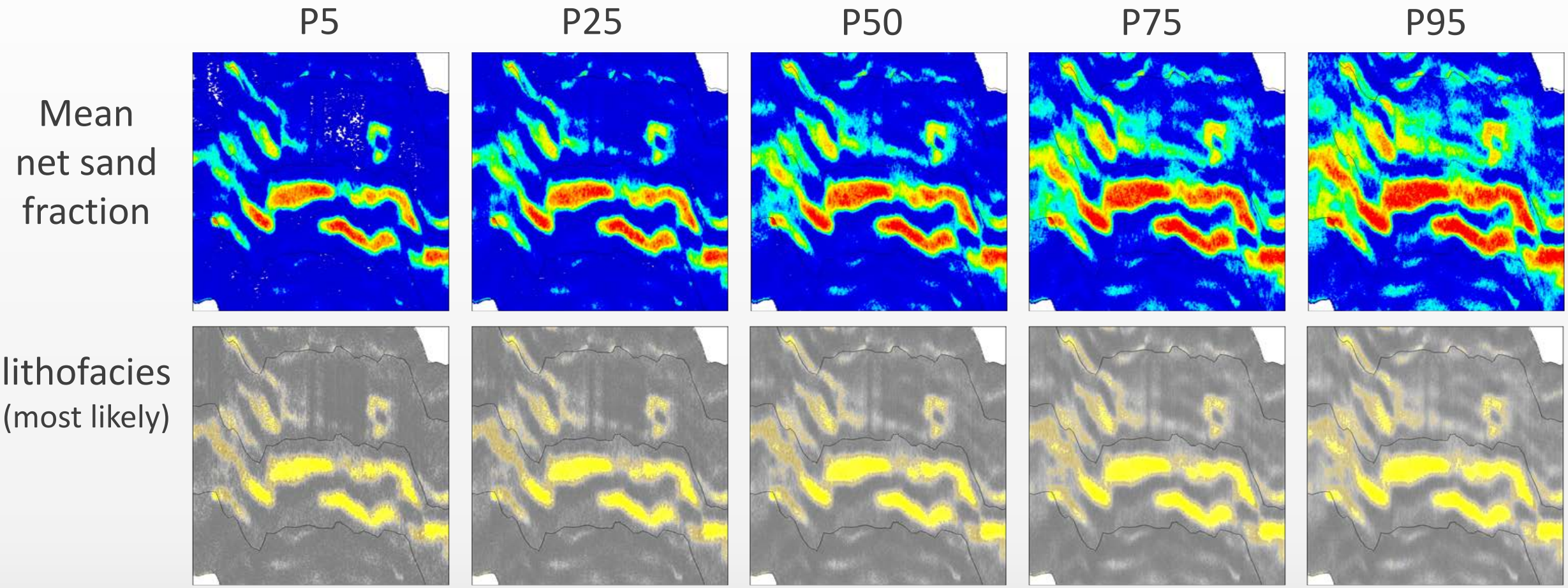


25m

3941	4140	5971
4676	4676	5450
4059	4593	4878

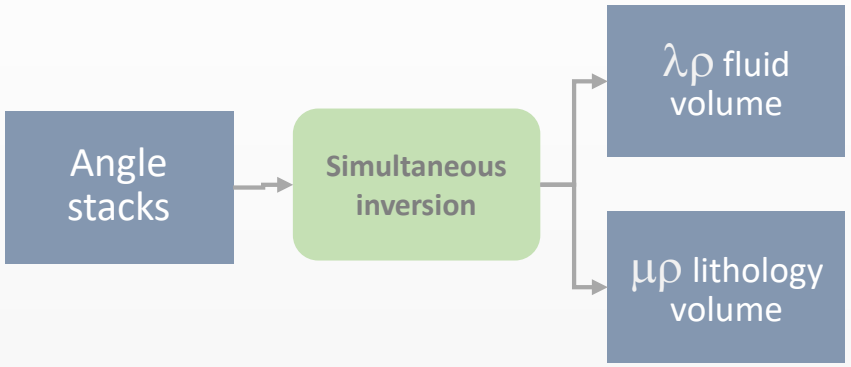
~±20%

Percentiles: Blueback ODiSI

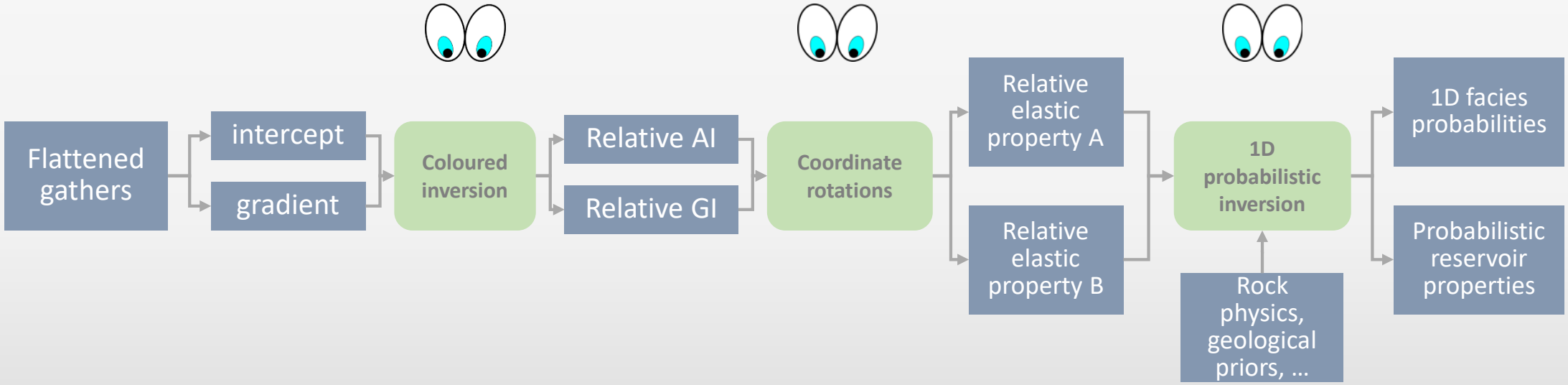


Ranges depend on subjective uncertainty values

QI Workflows



- No bandwidth optimisation
- No gradient error mitigation
- No uncertainty quantification



Summary

- QI workflows cannot be automated any more than processing workflows (yet).
- Focus on the largest unknowns and test options.
- Spread your workflows; use your judgement.
- Aim to develop *'… good methodology for when to use the computer and when to use … human judgement'*

"No theory survives contact with the data"

Acknowledgements

- Thanks to Cegal for Blueback ODiSI results.
- Thanks to Force for inviting me.
- Questions?

geophysics for integration