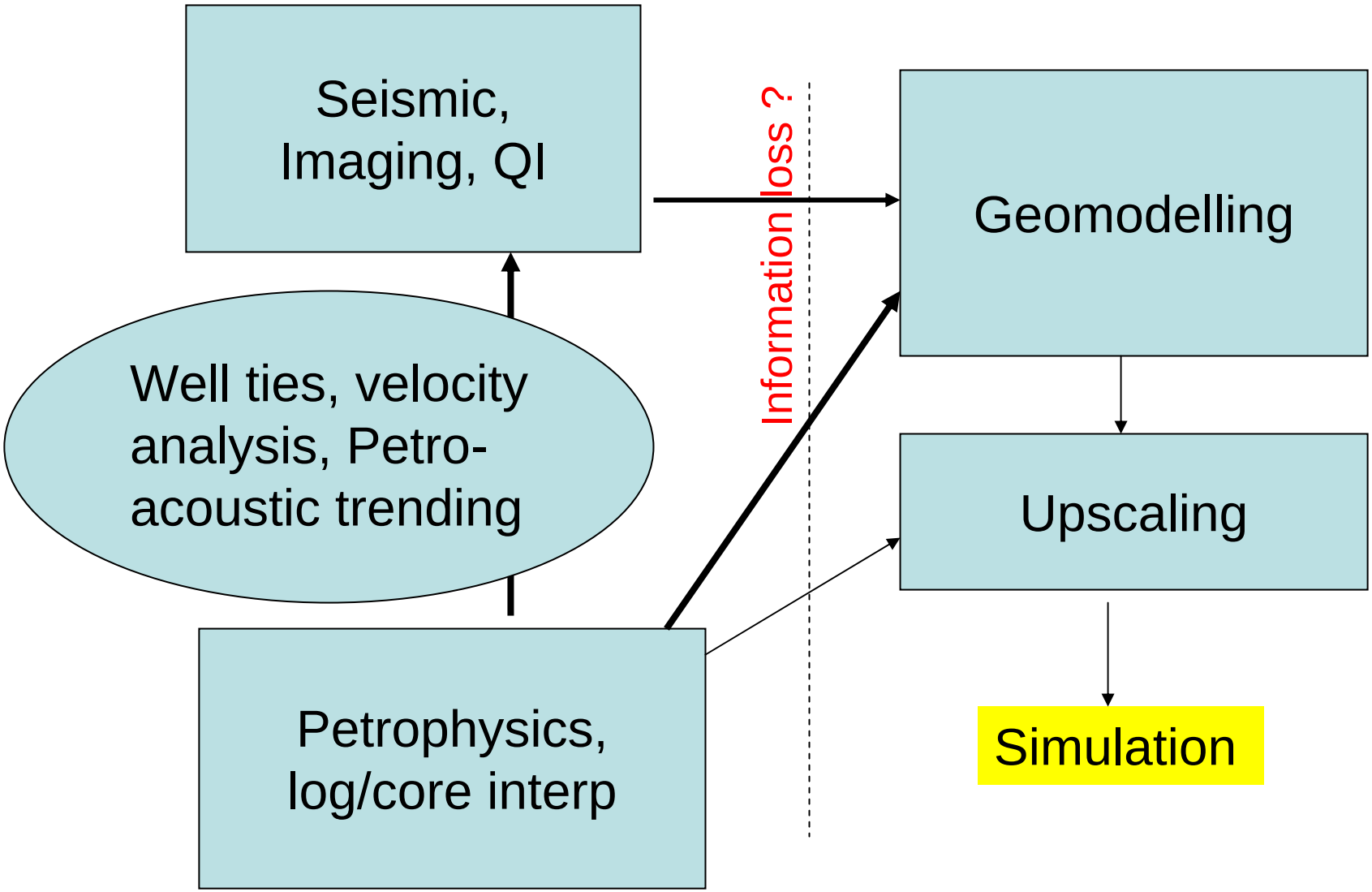
DeliveryMassager: propagating seismic inversion information into reservoir flow models

James Gunning CSIRO Petroleum

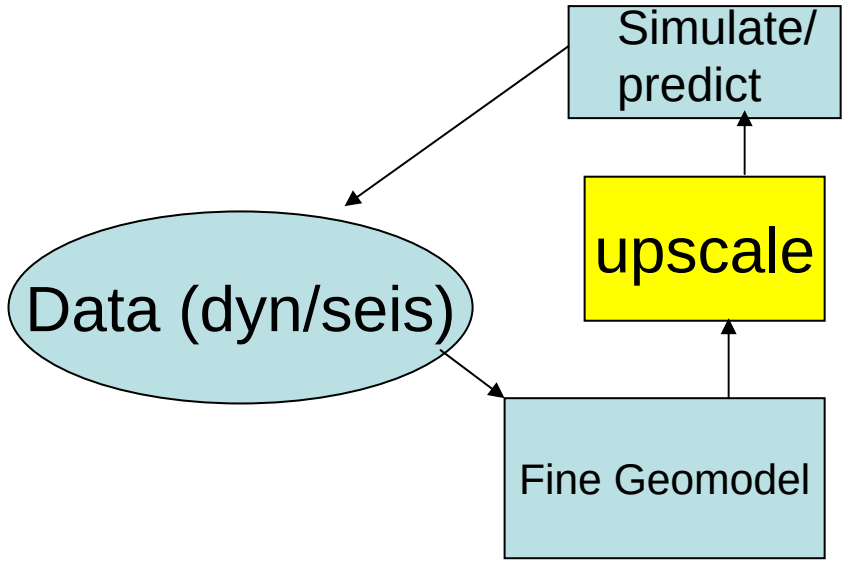
Michael Glinsky, BHP Billiton

Context

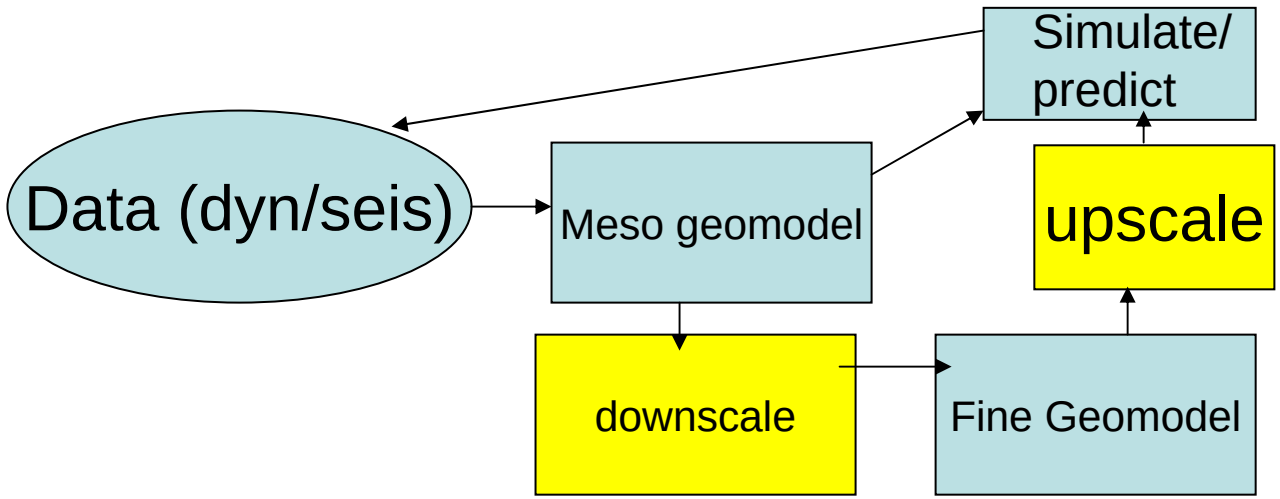

Seismic,
Imaging, QI
Well ties, velocity
analysis, Petro-
acoustic trending
Petrophysics,
log/core interp
Information loss ?
Geomodelling
Upscaling
Simulation

Modelling scale issues

Geomodelling de Facto convention: very high dimensional models ($d \sim 10^6$) with horrendous inverse problems



Alternative model: mesoscale inter-mediates ($d \sim 10^4$): reduce horror of inverse problems



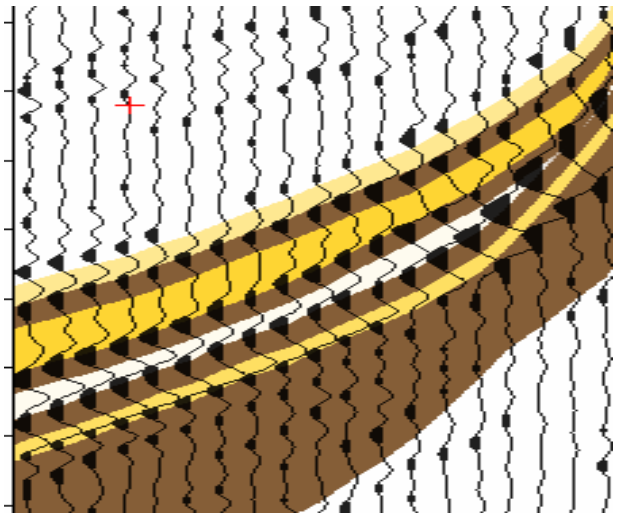
a-la-carte tools and workflows

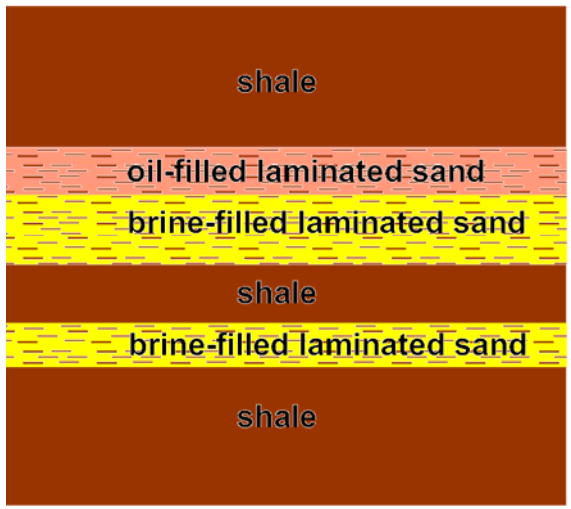
- Industry standard data formats for exchange
- Backbone models
- Open-source/in-house/commercial tool mixes
- E.g. SU/SEGY seismic, ECLIPSE cornerpoint grids

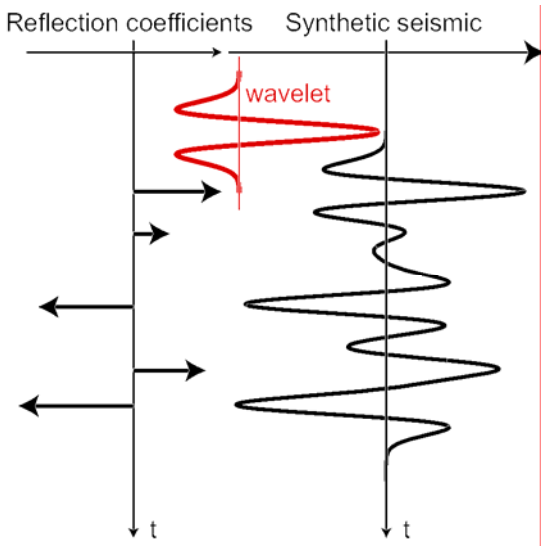
Delivery suite: open-source tools

- Bayesian well tie and wavelet extraction code (EAGE Madrid)
  - Wavelets
  - Time to depths maps
- Bayesian seismic inversion code (EAGE Stavanger)
  - Posterior stochastic ensembles for reservoir properties and geometry

Delivery seismic inversion - trace-local layer model





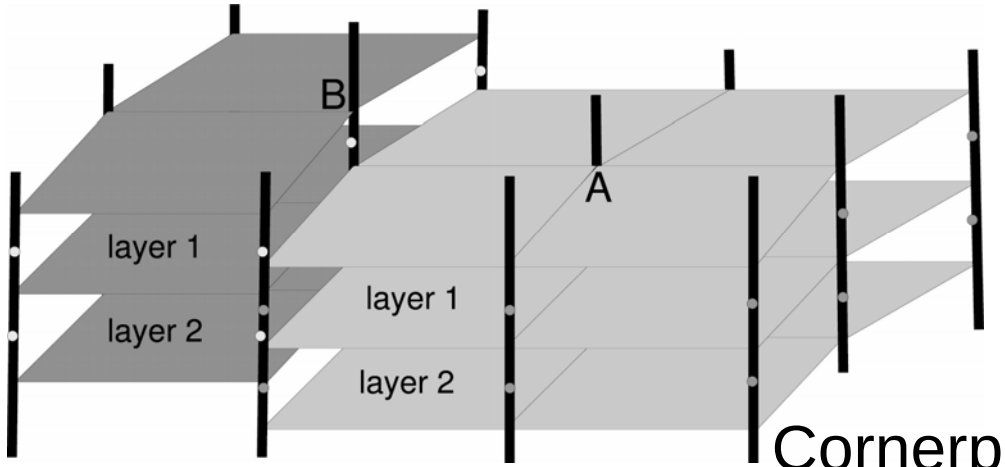


- Fundamental parameters
  - Layer times
  - Rock properties in each layer
  - Fluid type

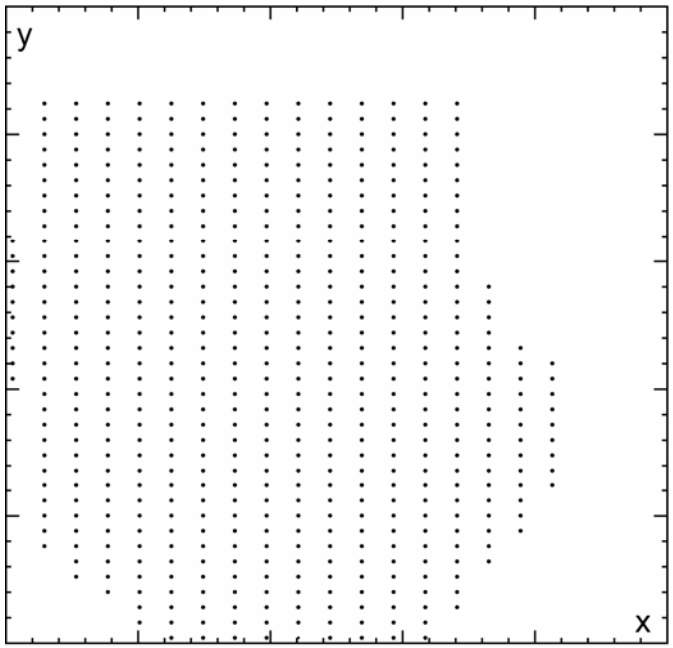
Outputs

- MCMC samples from posterior distribution
  - $\pi(t,v_p,v_s,\rho,\phi,NG,\text{fluid-type}\ldots.)$ for each layer
  - Samples buried in SU files: tied to regular seismic geometry

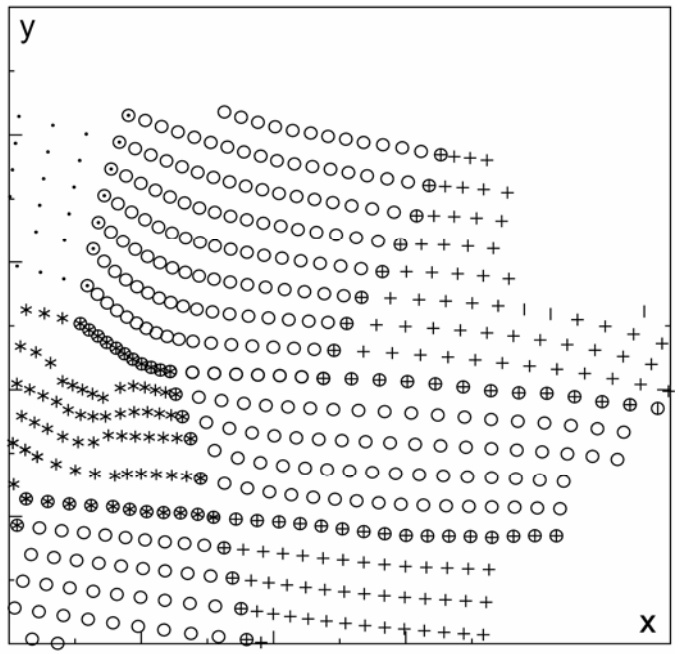
Geometry transformation



Cornerpoint grids



a) Seismic trace array



b) Cornerpoint grid corners, segment -coded

Fault blocks, segment labels

Correlations

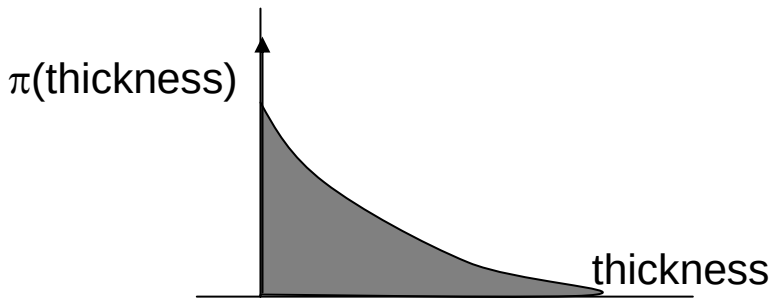
- Inter-property correlation from seismic inversion - couples vertical geometry and petrophysical properties
- Transverse correlations imputed from user-specifieds variograms and grid segmentations
- Notation
  - *l* = layer
  - *p* = property
  - *j* = spatial location

Smoothing of Most Likely models

- Segment-specific smoothing of p50 models for each property (thickness, ϕ etc)

$$\overline{m}_{l,p,j} = \frac{1}{N} \sum_{j' \sim j} W_{l,p,j'} \overline{m}_{l,p,j'}$$

  - Some posterior univariate distributions not Gaussian

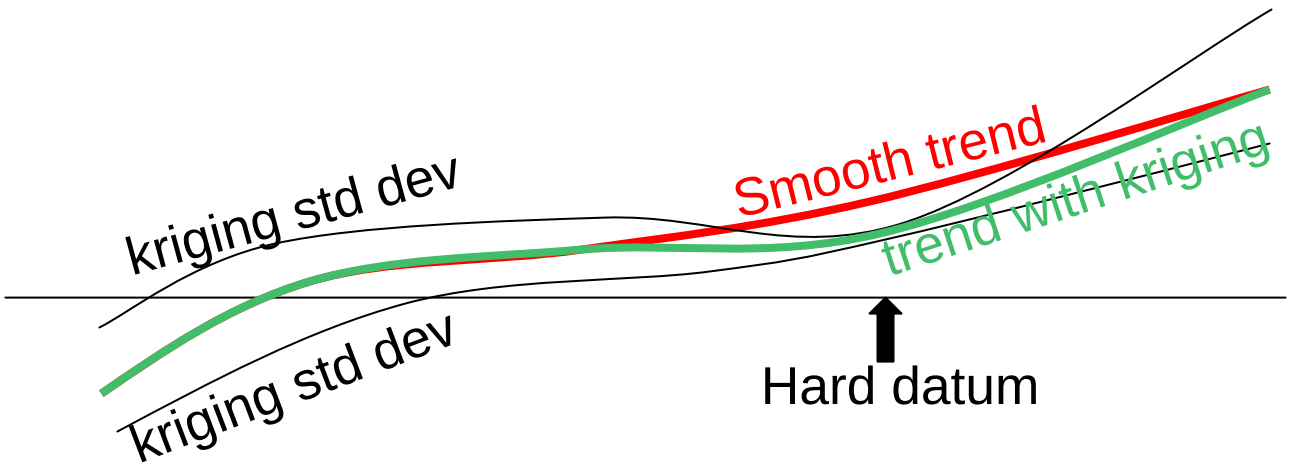


$$C_{l,p,l',p',j} = \frac{1}{N} \sum_{j' \sim j} W^{2}_{l,p,j'} C_{l,p,l',p',j'}$$

Hard data

$$\overline{m}'_{l,p,j} = \overline{m}_{l,p,j} + \Delta\overline{m}_{l,p,j} \quad \text{simple kriging}$$

$$\sigma^2_{l,p,j} = 1 - \sum_{q \in O_{l,p}} w_q C(r_q, r_j) \quad \text{SK variance, used later}$$



Generalised *p*-field algorithm for realisation

- Generate N_p normalised independent transversely correlated p-fields $\xi_{l,p,j}$ on corner point grid (sequential simulation)
- Project covariances onto cornerpoint grid

$$C_{l,p,l',p',j}^{crnrpt-grid} = \frac{1}{N}\sum_{j' \sim j} w_{l,j,j'} C_{l,p,l',p',j'}^{seismic-grid}$$

- Form Cholesky factor L of

$$L.L^T = C_{l,p,l',p',j}^{crnrpt-grid}$$

p-field mixing

$$m_{l,p,j,\alpha} = S^{(WO)}_{l,p,j} \sum_{l',p'} L_{l,p,l',p',j} \xi_{l',p',j,\alpha} + \overline{m}'_{l,p,j,\alpha}$$

Kriging std. deviations from well data

Inter-property correlations

Transverse correlations

Well data kriged mean

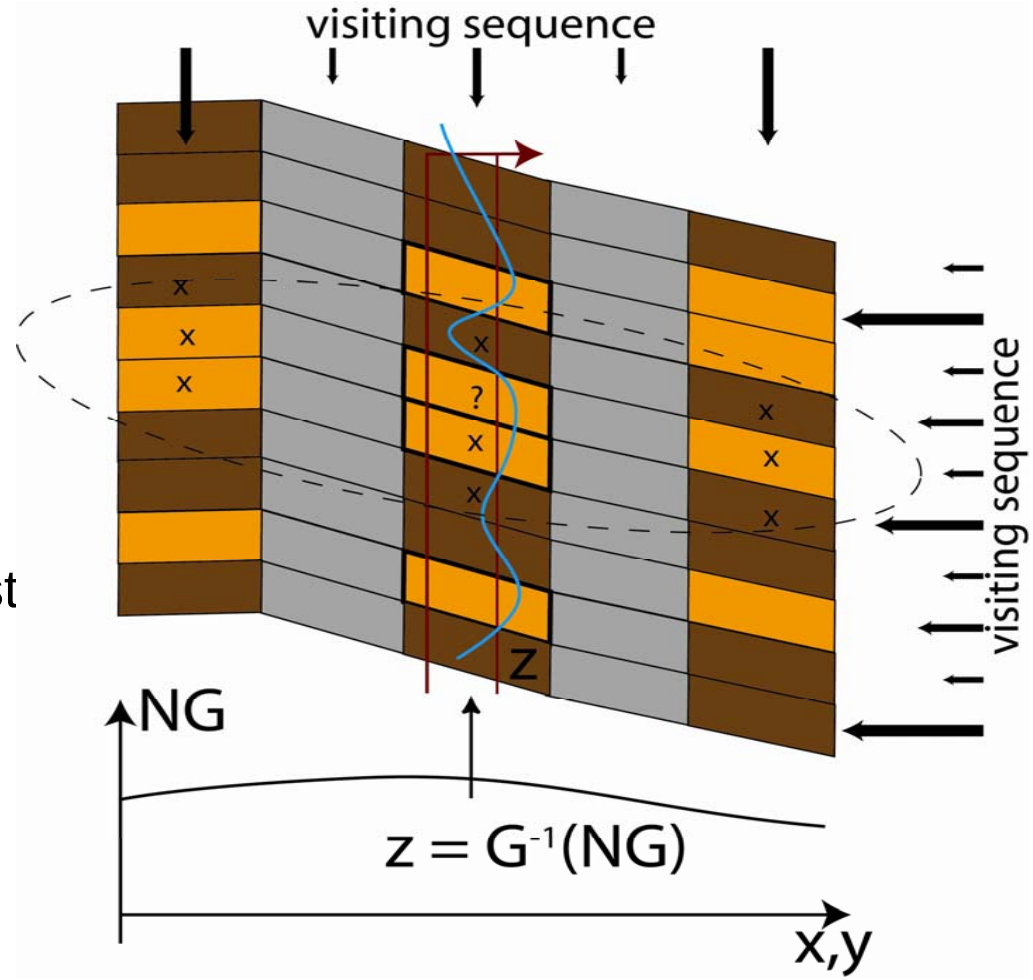
Downscaling

- Categorical
  - Truncated Gaussian implementation for sand/shale model
- Continuous
  - Linearised tweaks to compensate for errors in categorical model

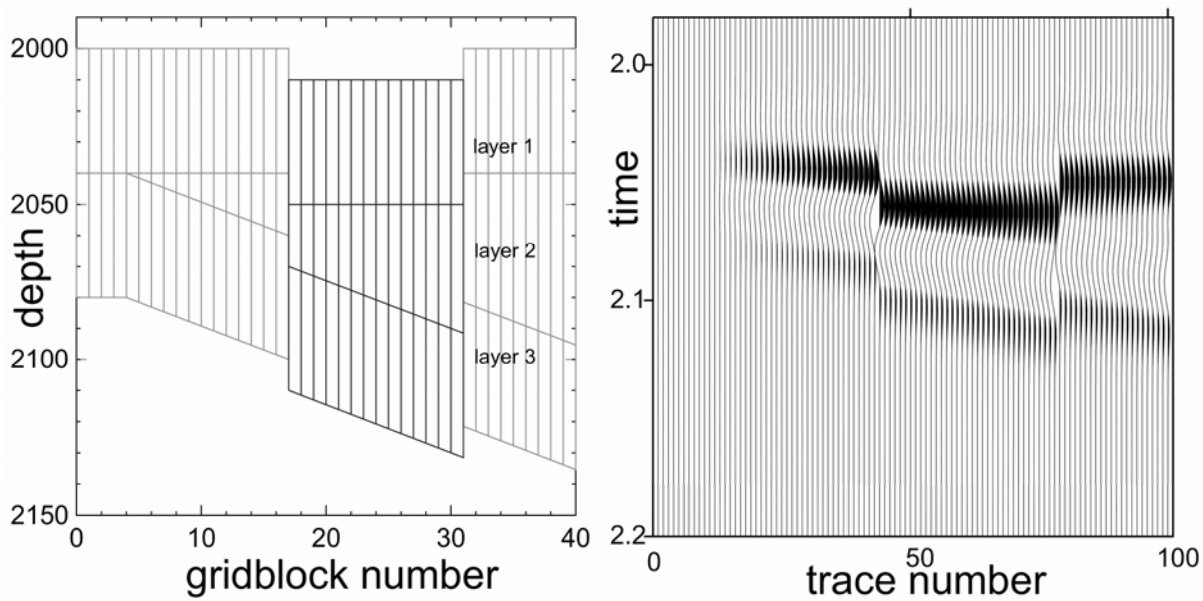
Columnwise greedy stochastic-optimised TG simulations

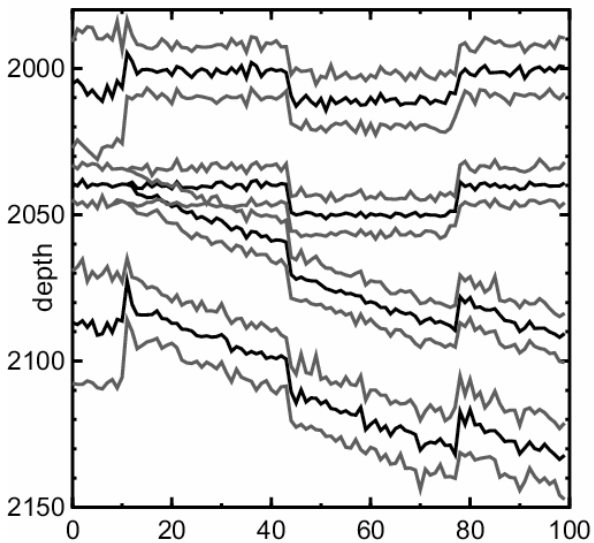
$S \sim N(\Sigma_i \lambda_i S_i, 1-\Sigma_i \lambda_i C(r_i, r_0))$

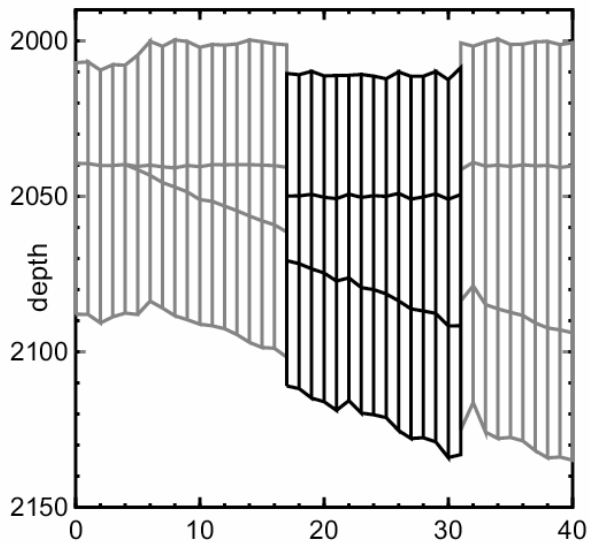
Precompute {λ} for column, resample and accept nearest match to target

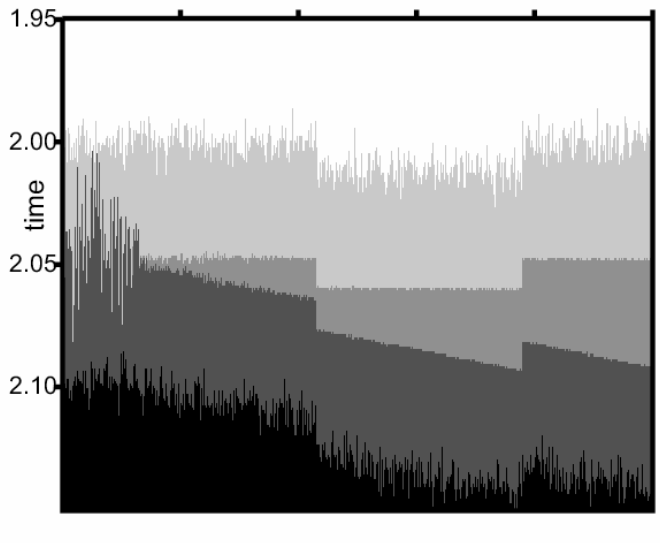


Example 1: test case

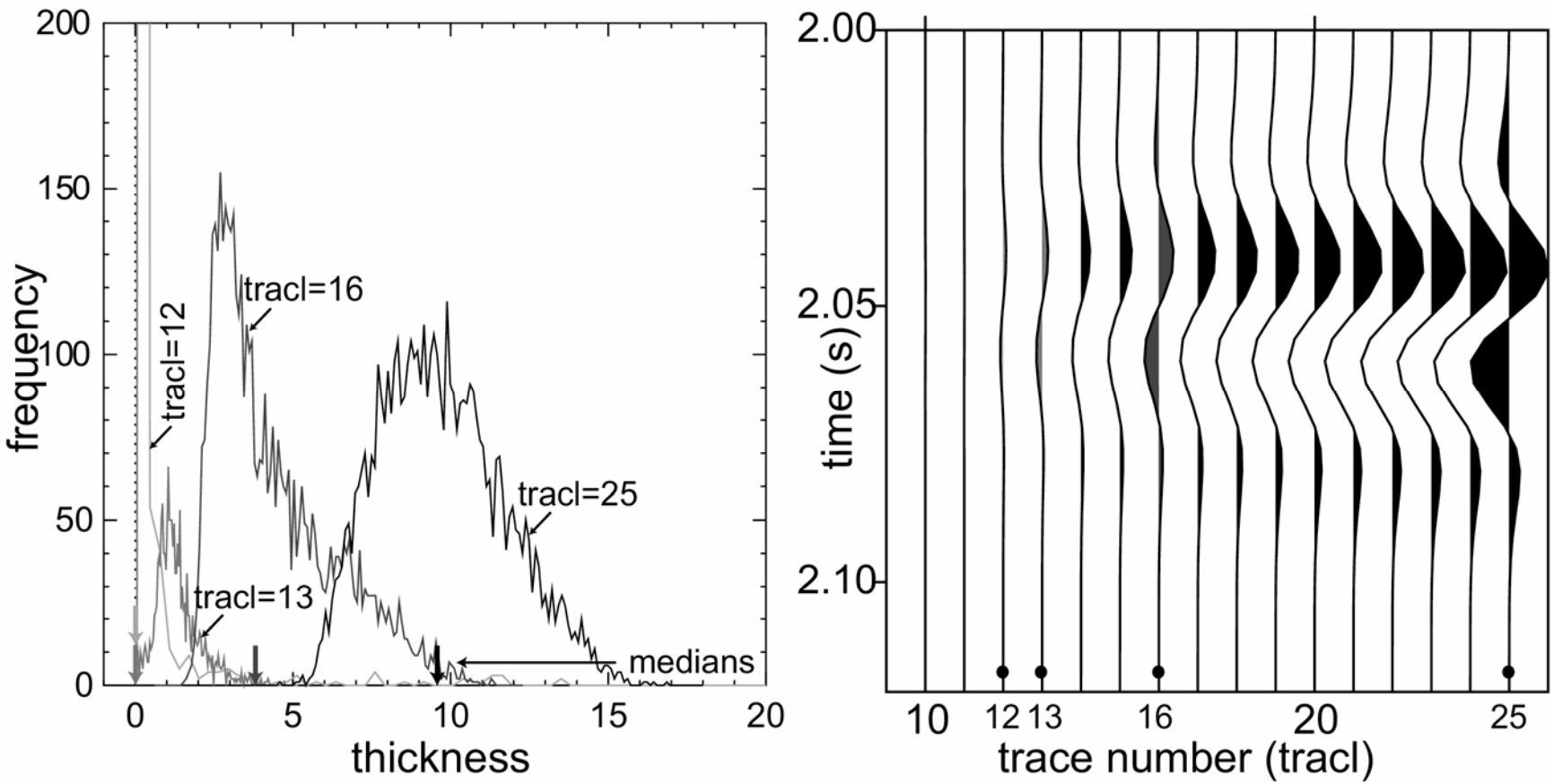




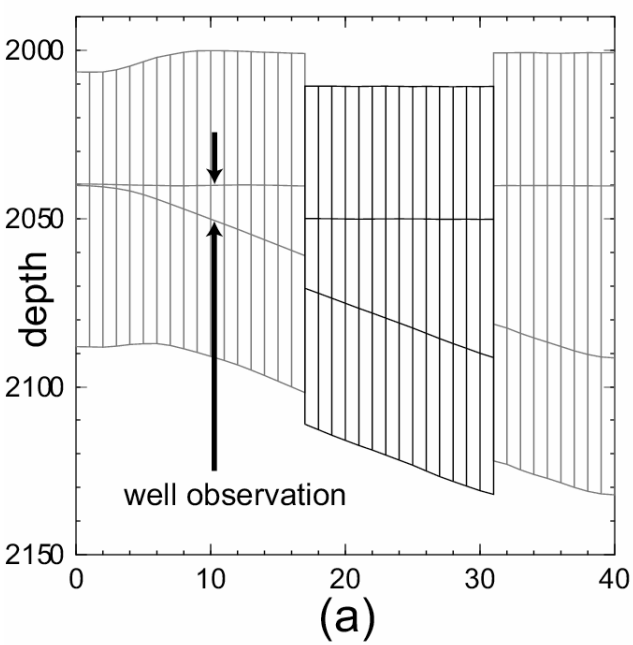


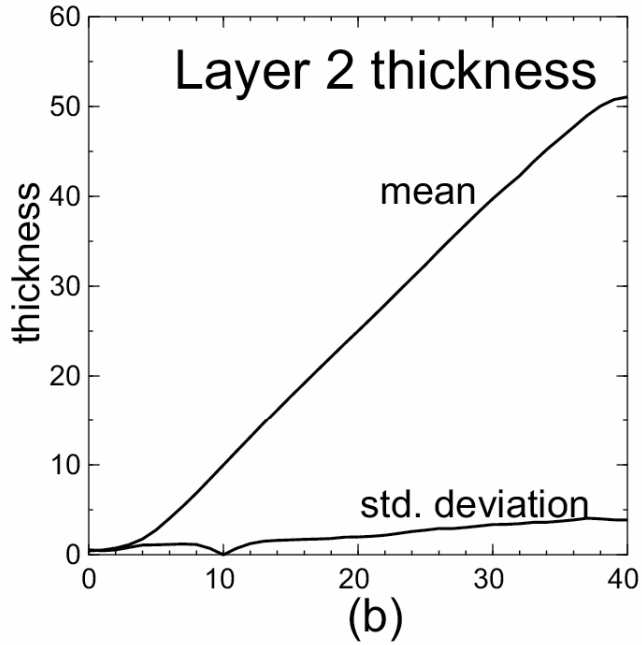


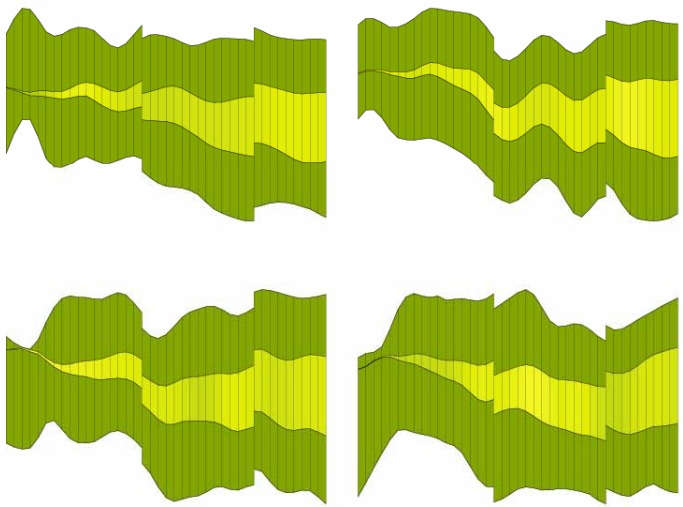
Tuning histograms

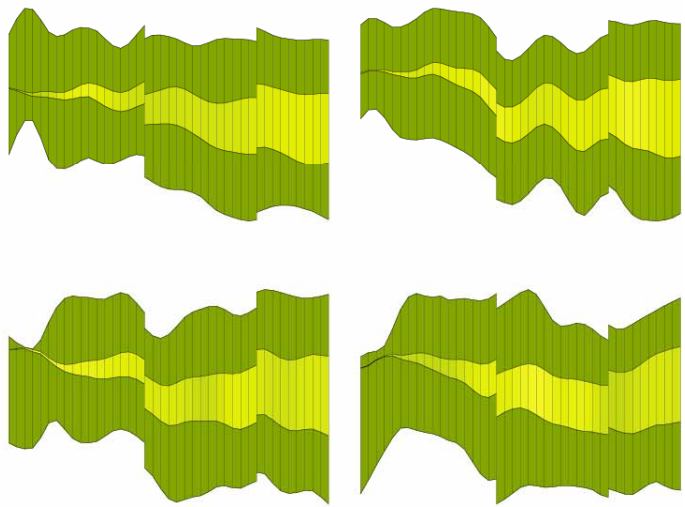


Massaged versions

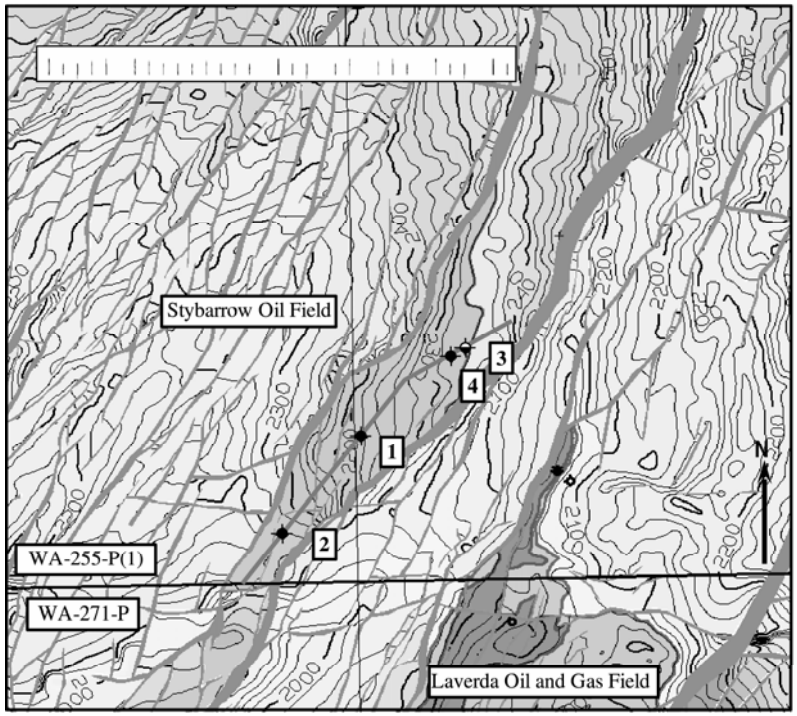




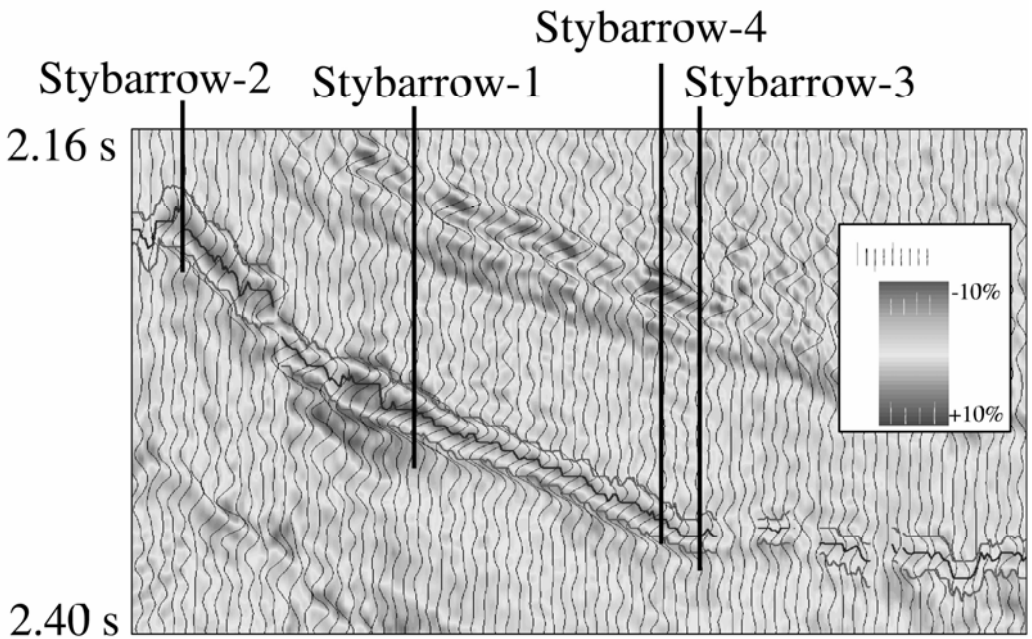




Field example: Stybarrow, W. Aust.

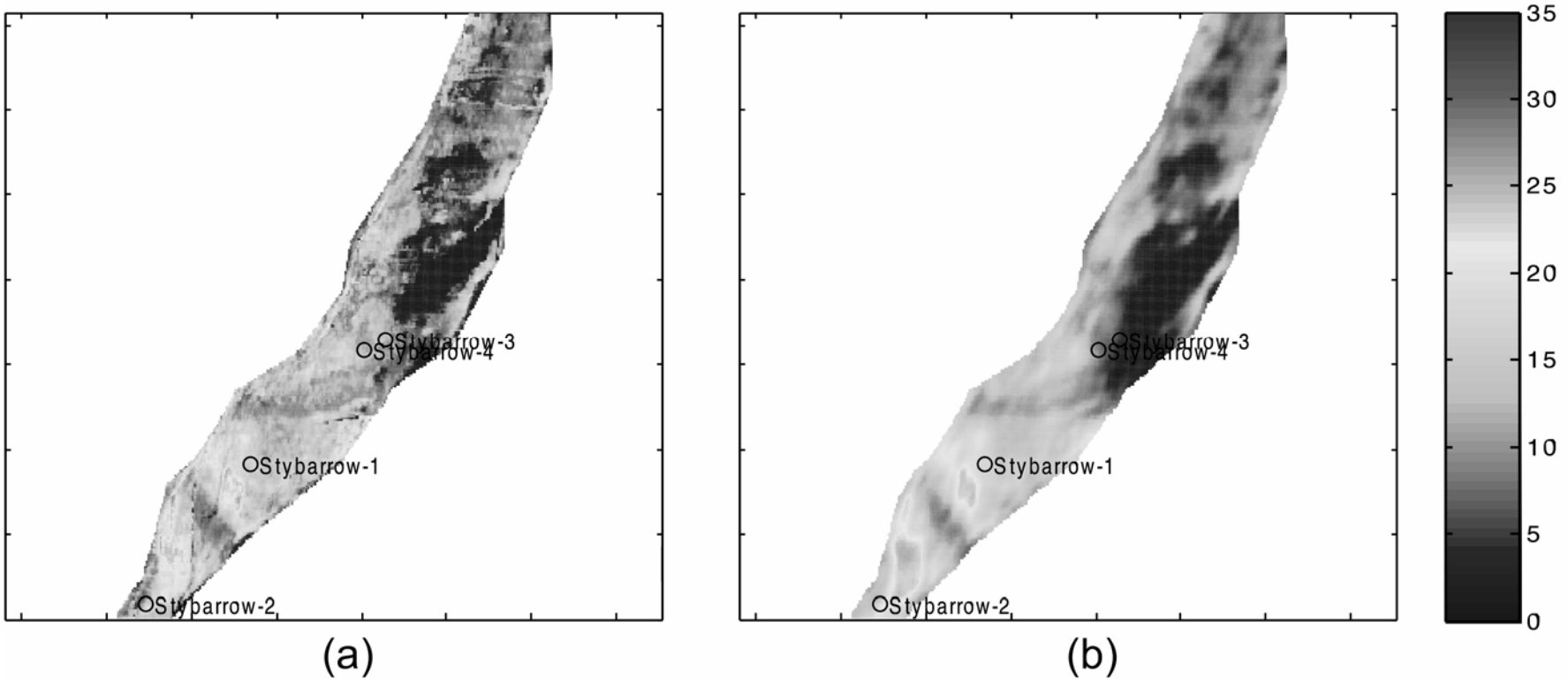


(a)

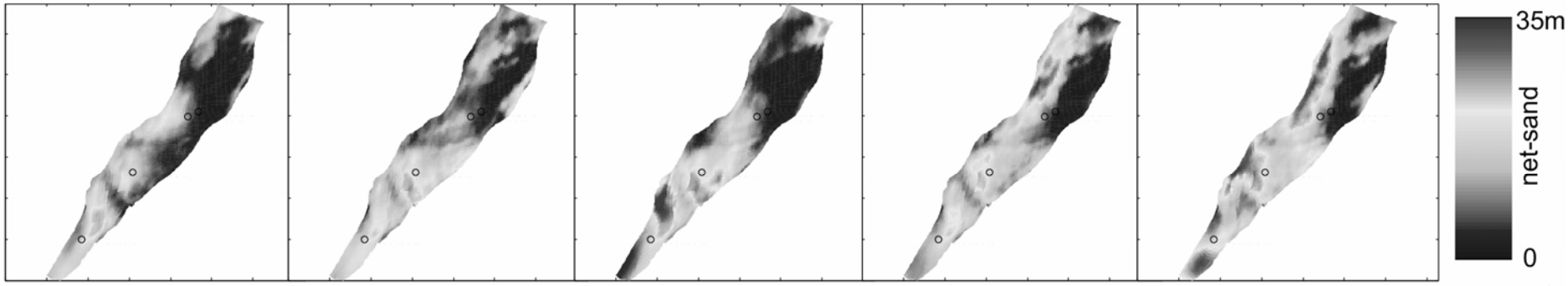


(b)

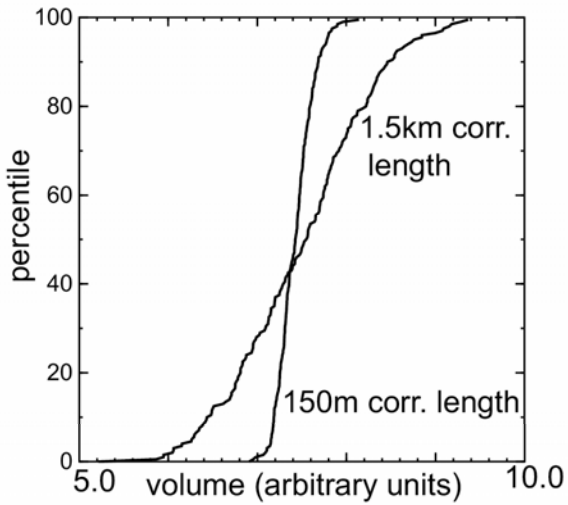
Stybarrow net sand



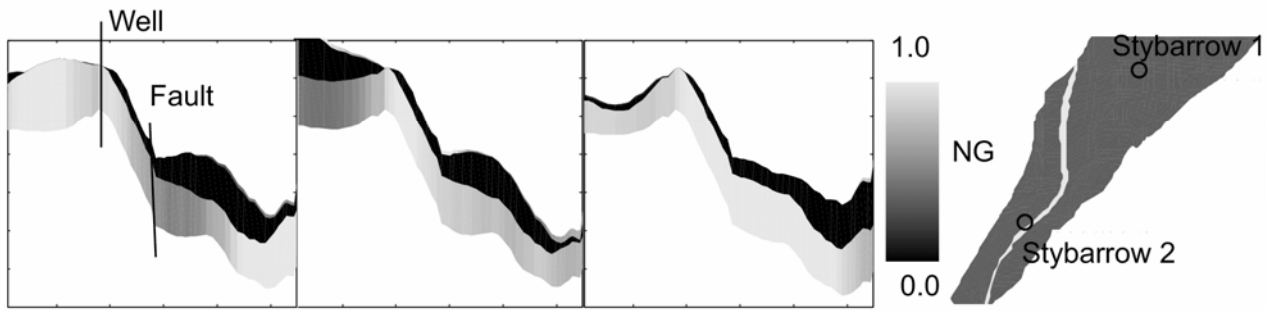
Stybarrow



(a) 5 realisations of net-sand in plan view

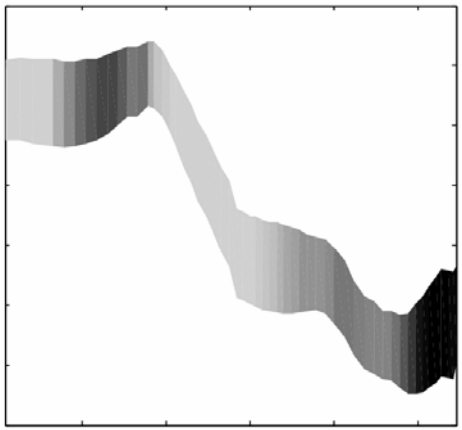


(b) overall net-sand volume CDF

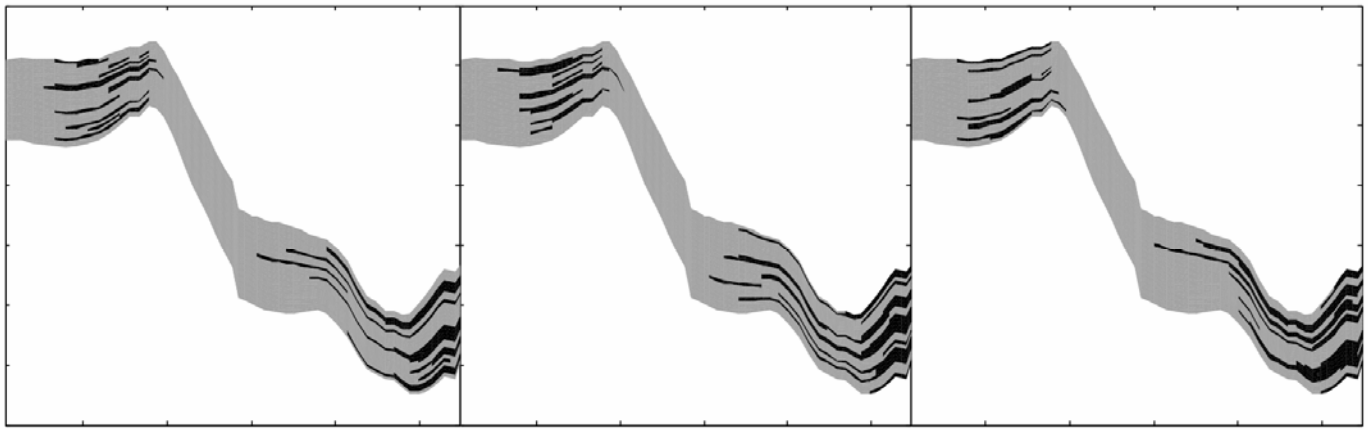


(c) elevation view of 3 realisations of 3 layers along line shown: main reservoir is third layer

Stybarrow downscaling



a) NG realisation



b) Decorated sand/shale realisations

Conclusions

- Eclipse grids
  - ML models, plus uncertainties as grid props
  - Eclipse realisations
- Statistics
  - Reserves in place, volumetrics of net-sand, net-oil etc etc.
- Downscaled grids
  - honouring mesoscale constraints, well data etc.

Where?

- www.petroleum.csiro.au

  Dig to /Projects/Delivery
- Delivery and WaveletExtraction - (Computers & Geosciences, 04,06)

  Massager: current preprint soon….
- Email James.Gunning@csiro.au