Delivery: an open-source Bayesian seismic inversion tool

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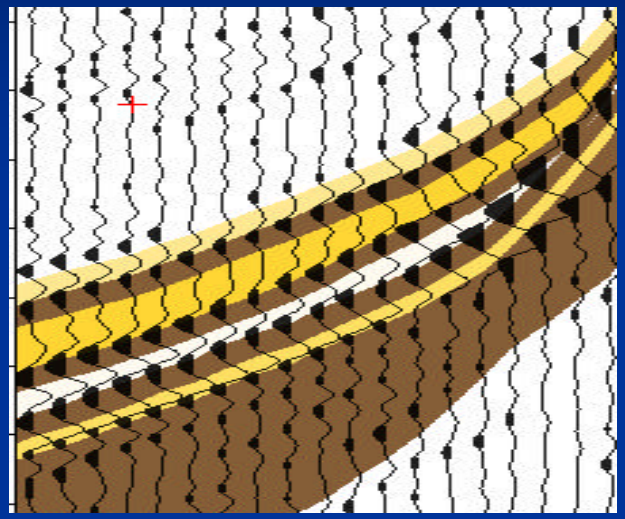
Application areas

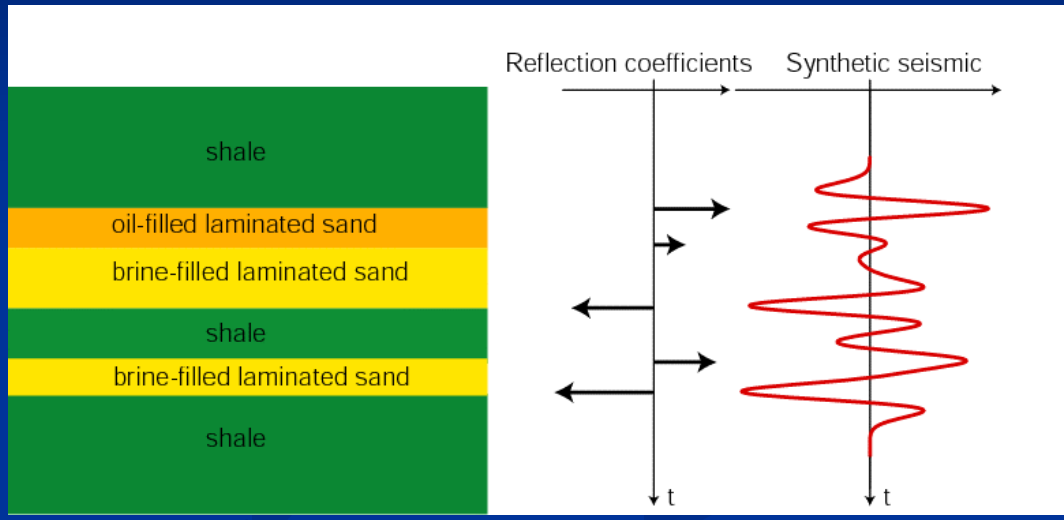
- Development, appraisal and exploration situations
- Requisite information
  - Seismic
  - At least one relevant well
  - Regional rock physics (sonic logs etc)
  - Wavelet from well tie

Desired rock physics

- Effect of rock
  - Location (geometry). Lithology changes
  - Velocity, density, porosity uncertainty
    - Compaction + uplift
  - Fluid content
    - Type, saturations, densities
  - Mixing
    - Net-to-gross (NG) effects…

Trace-local Model

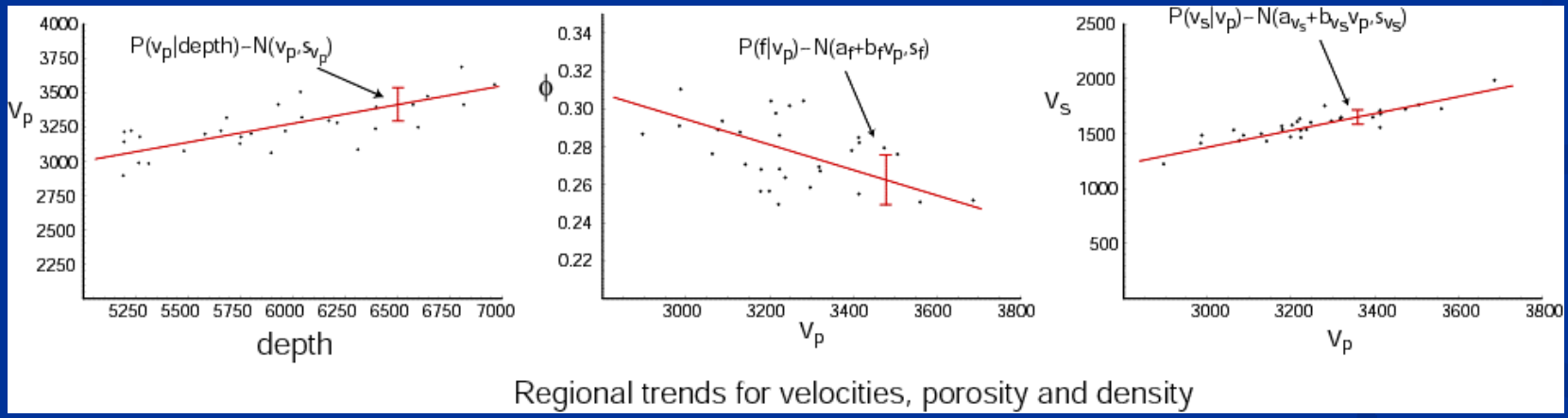




- Fundamental parameters
  - Layer times
  - Rock properties in each layer

Rock Physics (1)

- Each layer a blend of two rocks
- Model based on small number of rock types
- Compaction trends for each rock type



Regional trends for velocities, porosity and density

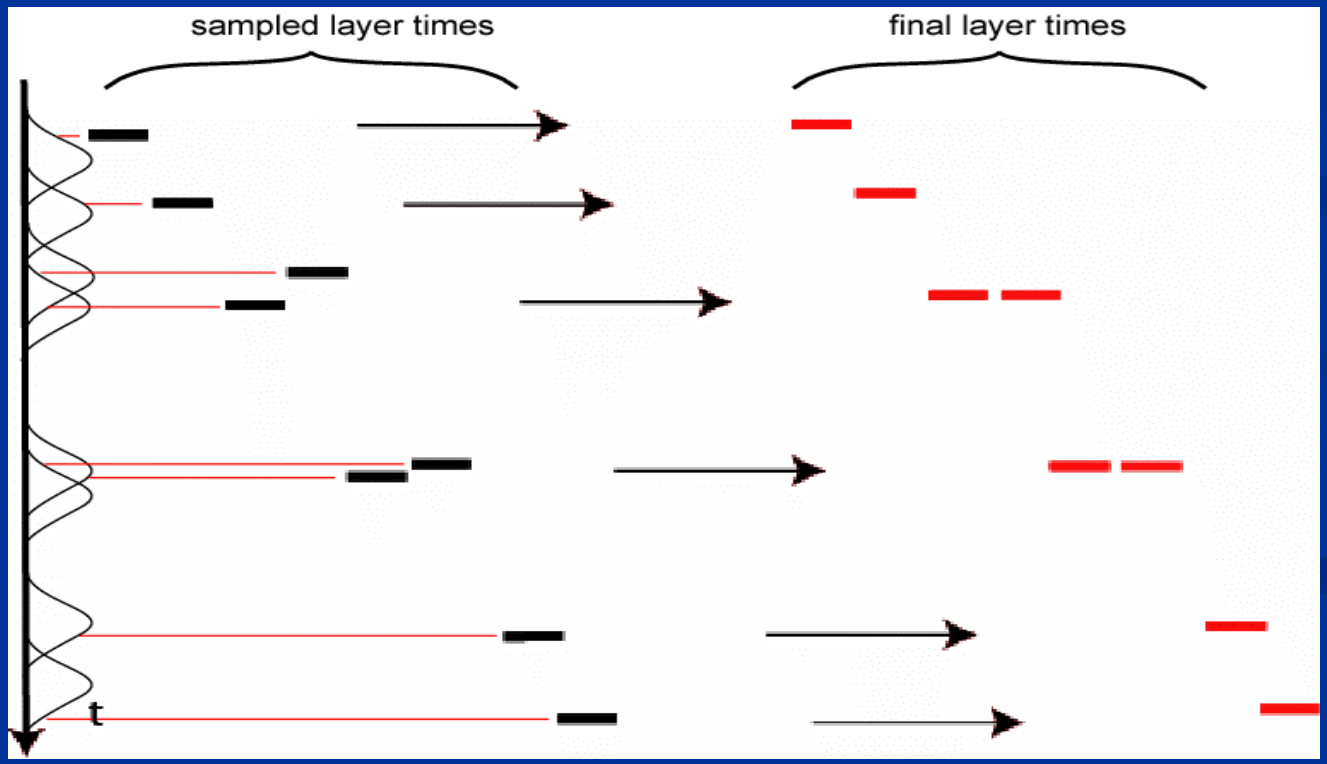
- Estimates of net-to-gross NG for each layer

Rock Physics (2)

- Effective media models
  - Effective fluids from fine-scale mixing (saturation based Reuss average)
  - Effective permeable medium from Gassman substitution of effective-fluid into permeable rock
  - Effective acoustic medium from Backus averaging of permeable and non-permeable rock

Construction of prior model

- Rock+fluid properties from regional trends
- Net-to-Gross from logs, regional knowledge
- Layer times from approximate picks+uncertainties
- Time truncations allowed for pinchouts



Fluid Combinations

- Permeable rocks can have oil/gas/fizz-gas/brine, with specified prior probability
- Density ordering of fluids in layers – various combinations
- Fluid combinations enumerated (e.g. 4…)

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1:   B B B B          P(1)=0.40
2:   B O G G          P(2)=0.25
3:   B O O G          P(3)=0.35
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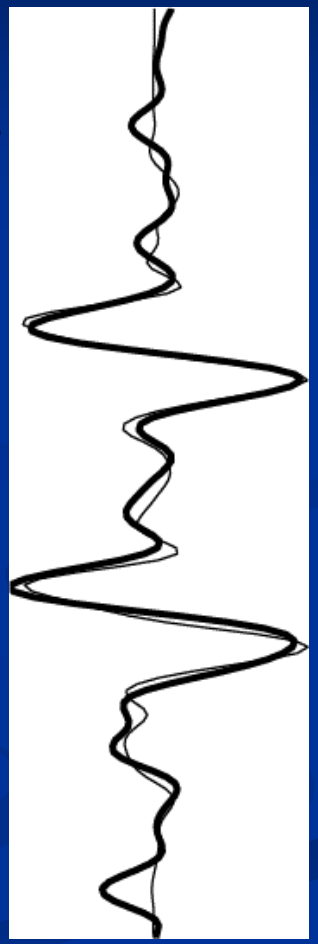
Likelihoods

- Seismic constraints (1D convolutional model). Multi-stack, AVO
- Isopach constraints (well ties)

Seismic Likelihood

- 1D convolutional model, subsampled l_2 norm $\chi^2 = \sum_{t,stacks} (w * R_{eff} - S)^2 / \sigma_s^2$
- Wavelet w provided, plus noise level σ_s
- Stack parameters provided for Zoeppritz equations (AVO effects)
- Effective refl. coefficients R_{eff} from effective properties v_p, v_s, ρ.
- Multistack: product of likelihoods



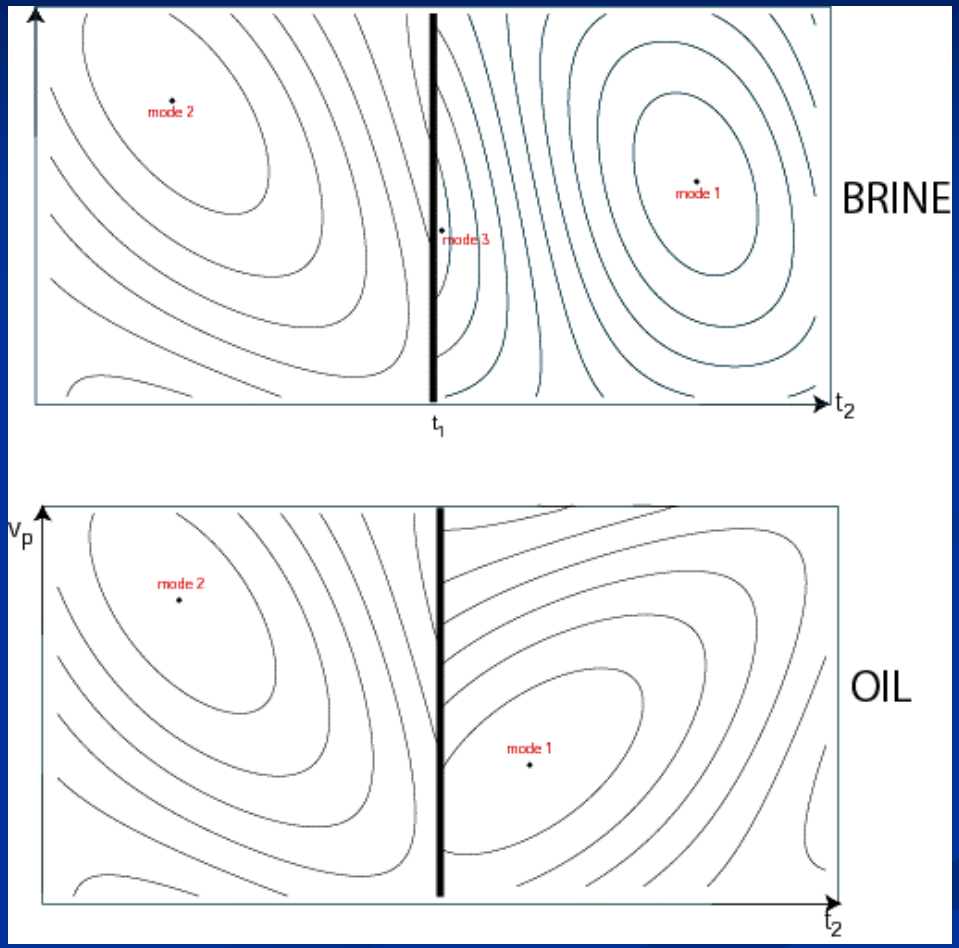
Isopach constraints

- Thickness from effective v_p, two-way time

$$\chi^2 = \Sigma (v_p \Delta t / 2 - d)^2 / \sigma_d^2$$

Bayesian Posterior

- $\Pi(m_k | S) \sim P(m_k)\, L(m_k | S)$
  - *k*th fluid combination
- $\Pi(m_k | S)$ is multimodal, high dimensional, non-Gaussian
- The "answer" is near the modes: most "inversion" programs give only the parameters at the (best?) mode
- Uncertainty of inversion determined by mode shape: must find all modes + quantify them
- Mode positions, covariances, heights found & collected using multidimensional optimisation methods
  - Quasi-Newton methods
  - Genetic algorithms



Sampling for the uncertainty

- Hybrid MCMC methods
  - Jumps *within* models
  - Jumping *between* models
- Acceptance probability (Metropolis Hastings)

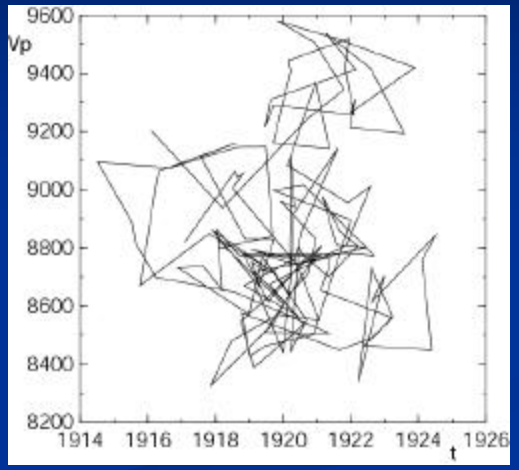
$$\alpha = \min\left(1, \frac{\Pi(m_{new})P(m_{old}|m_{new})}{\Pi(m_{old})P(m_{new}|m_{old})}\right)$$

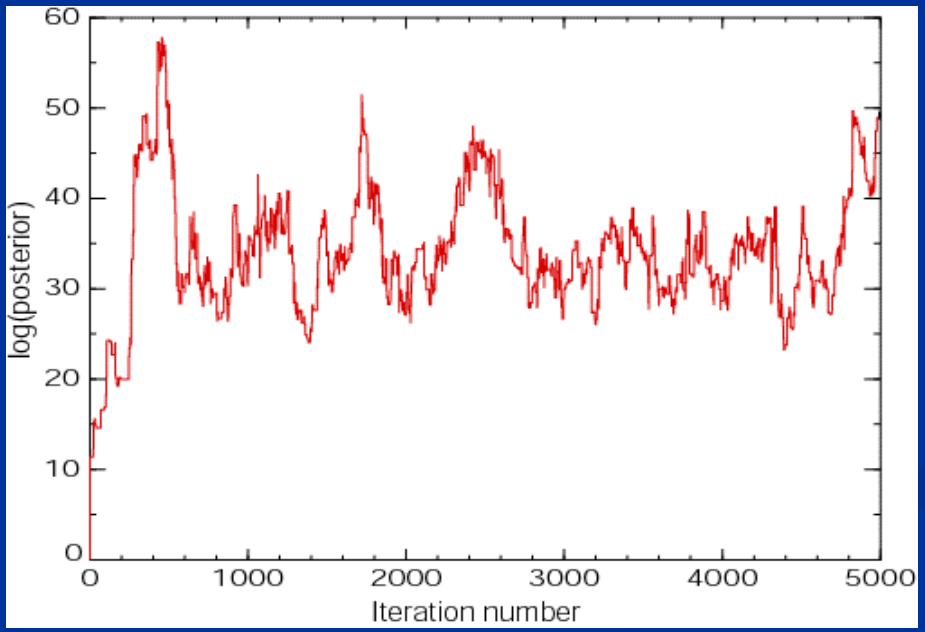
Random Walk Samplers

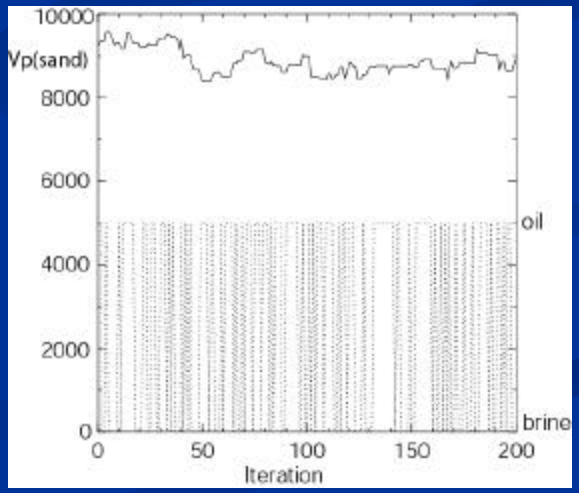
- Random walk *within* models

$$\alpha = \min(1, \frac{\Pi(m_{new})}{\Pi(m_{old})})$$

- Model jumping *between* models







Random Walk samplers (2)

- Advantages
  - High acceptance rates (~0.25)
  - Simple to code & get right
- Caveats
  - Long correlation lengths (~3d)
    - Decimation usually applied
  - Occasional slow tunneling effects

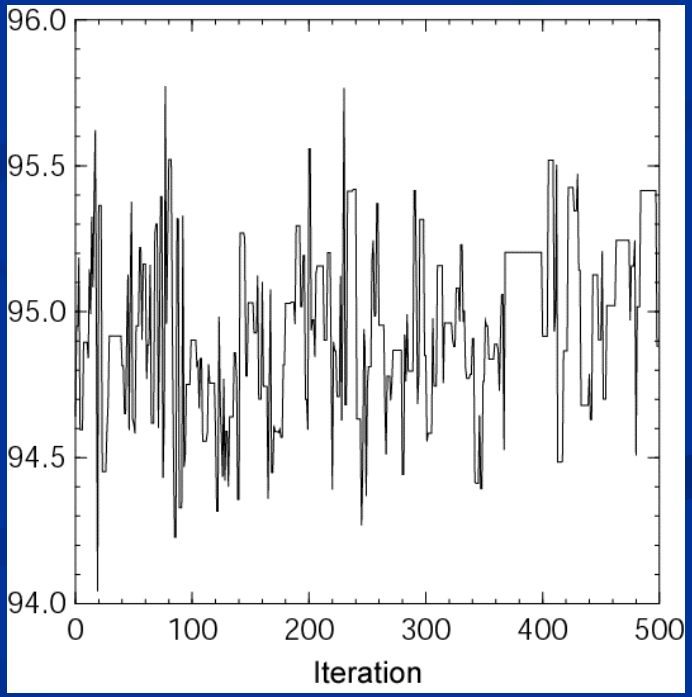
Independence Samplers

- Build mixed-Gaussian approximation to $\Pi(m|S)$:

  $P(m_{new}|m_{old})=P_{approx}(m_{new})$

- Advantages
  - Very efficient if $\Pi(m|S)$ close to Gaussian
- Disadvantages
  - Can lock up if posterior is wierdly shaped

$$\alpha = \min\left(1, \frac{\Pi(m_{new})P(m_{old}|m_{new})}{\Pi(m_{old})P(m_{new}|m_{old})}\right)$$



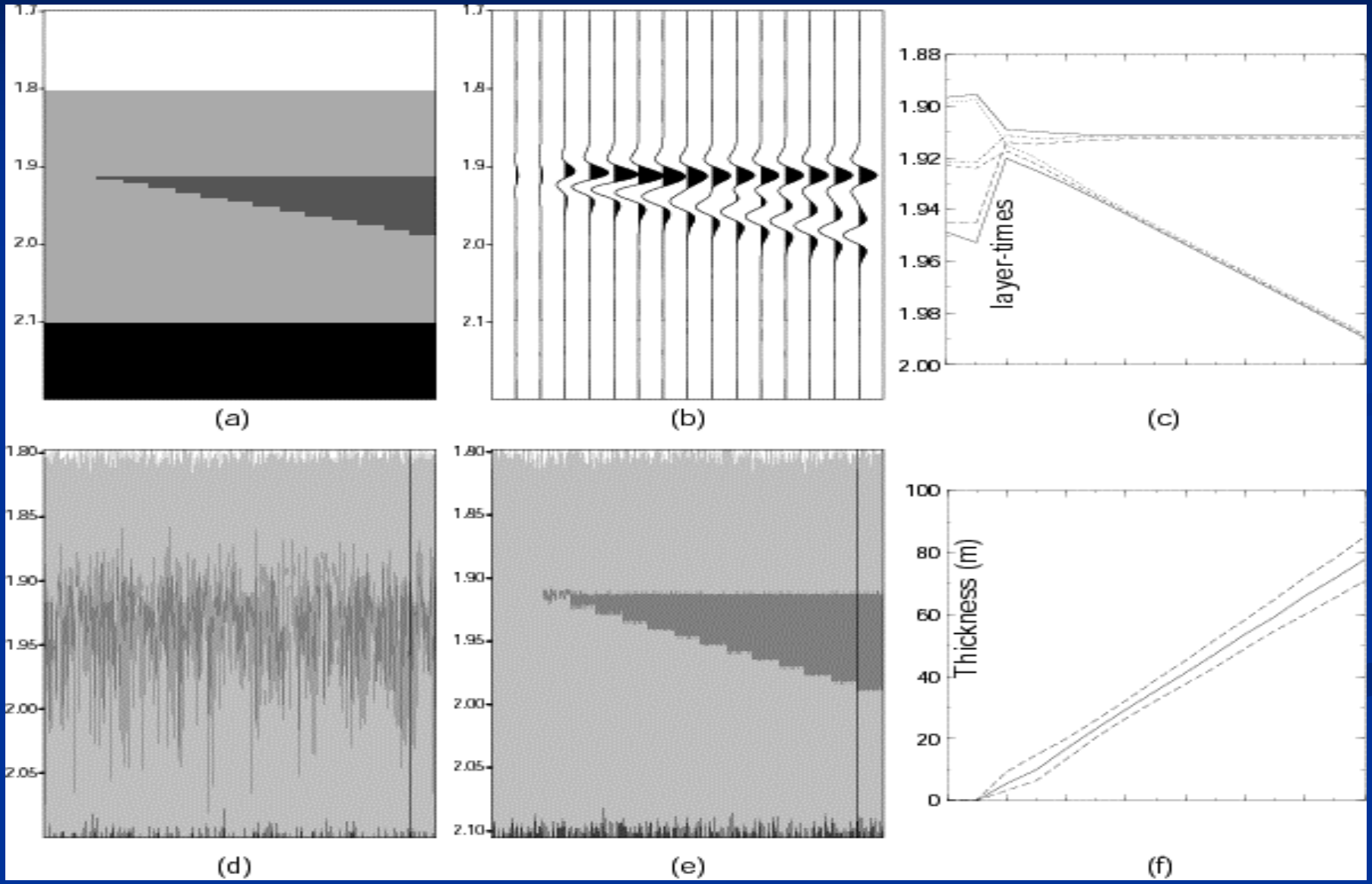
Outputs

- Stochastic samples in SU format
  - All layer properties
  - Useful commercial quantities
    - Net sand, net hydrocarbon, thickness…
    - Fluid content
  - Effective acoustic properties
  - Diagnostics

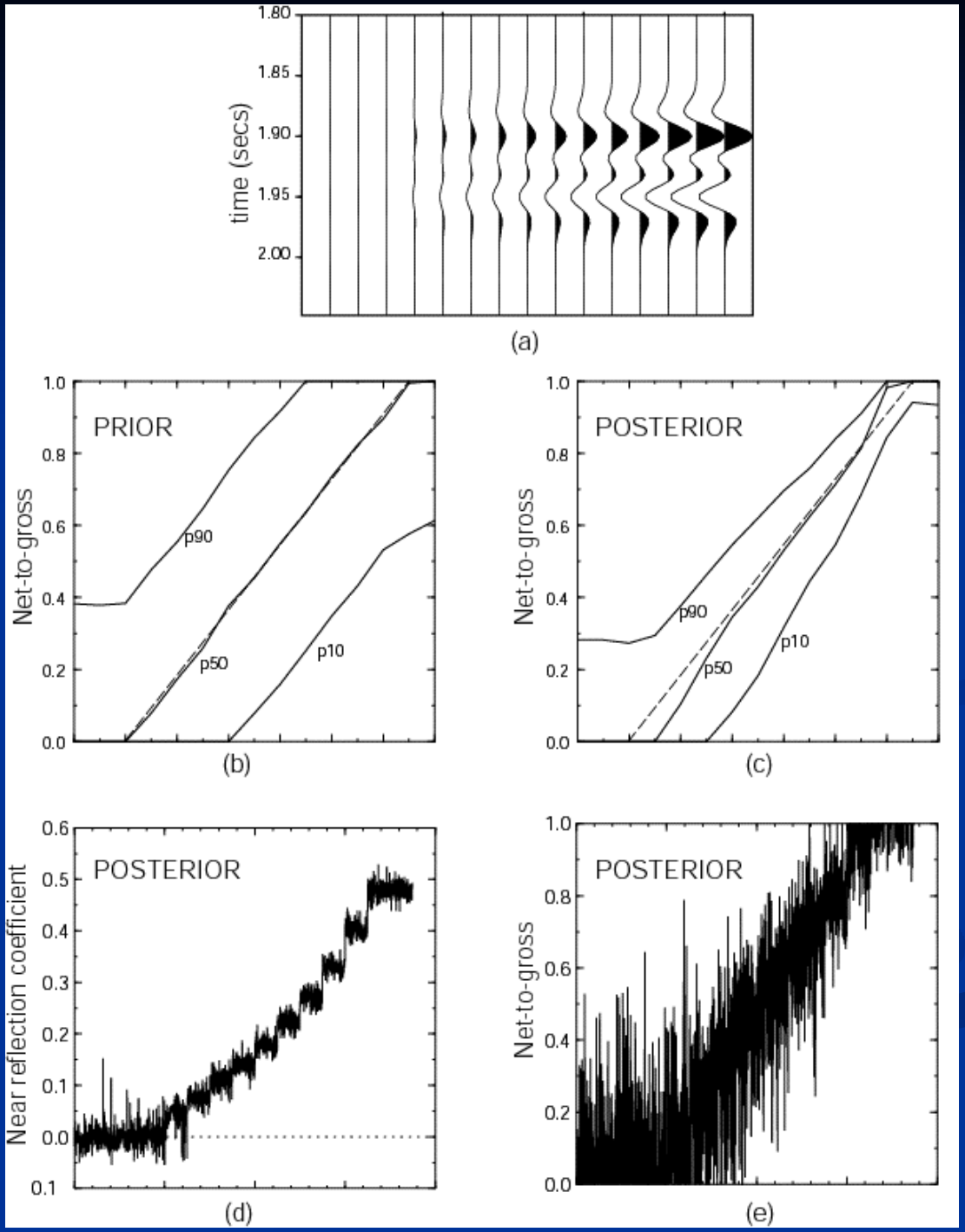
Ensemble analysis

- *deliveryAnalyser*: separate analysis module ("small is beautiful")
  - Quantity statistics
  - Histograms
  - Synthetic seismics
  - Diagnostics
- Interfaces nicely with
  - INT viewer
  - SU, BHP_SU

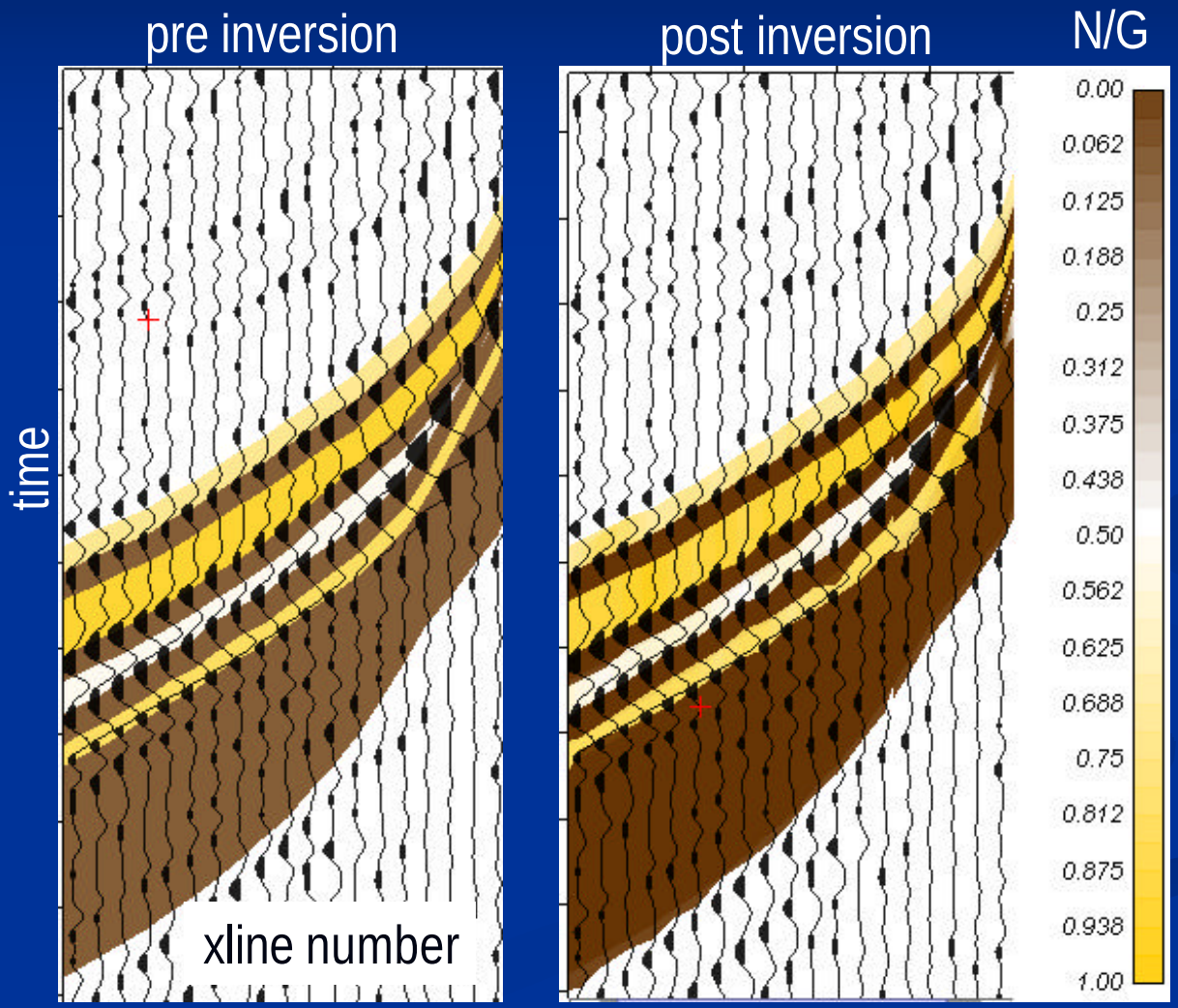
Example (1) Sand wedge



Example (2) Net-to-gross wedge

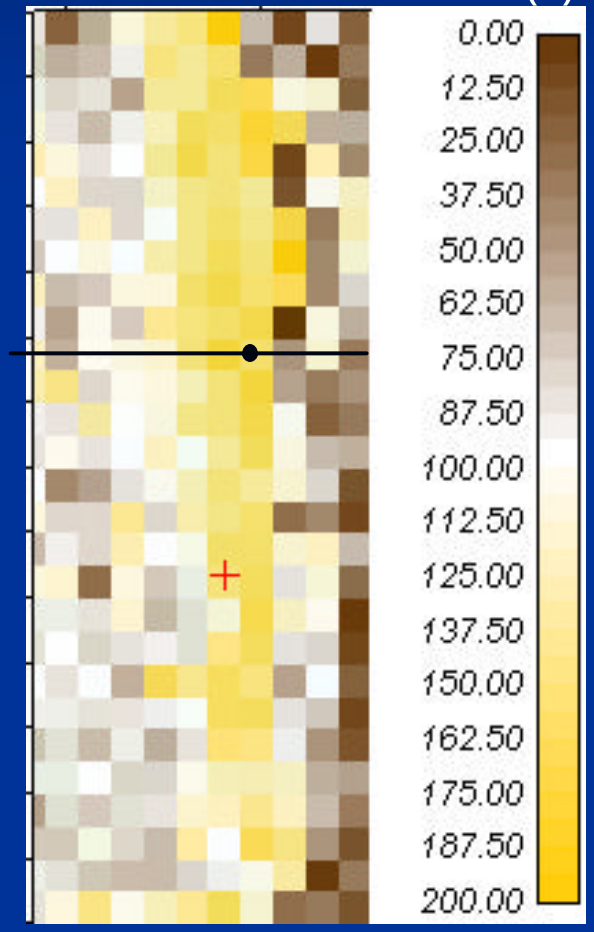


Example (3) Current BHP project

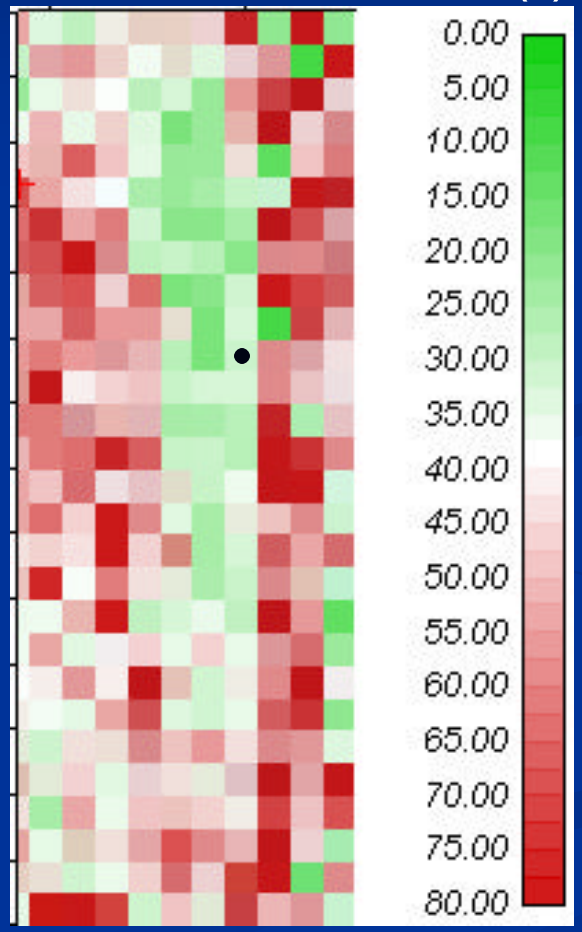


Net sand and P(oil) maps

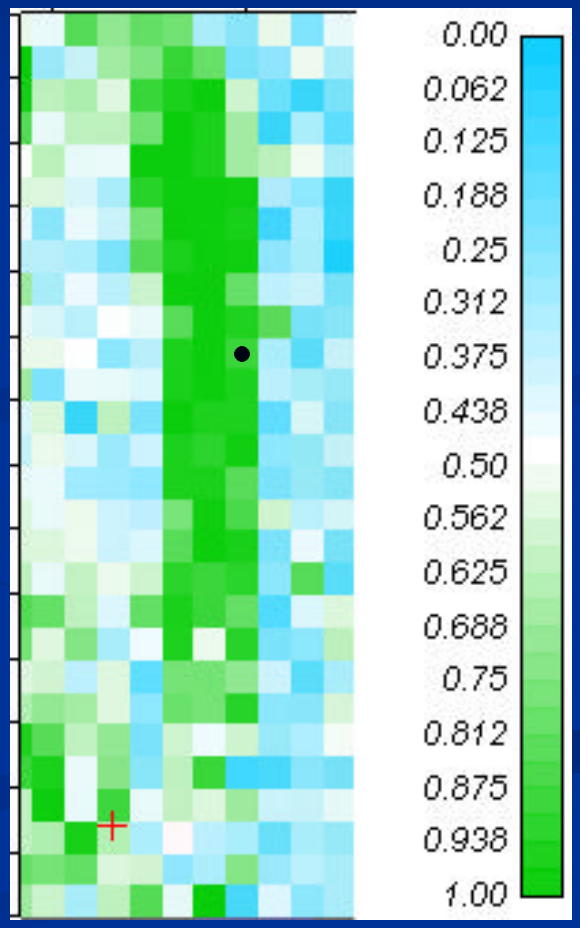
mean net sand (ft)



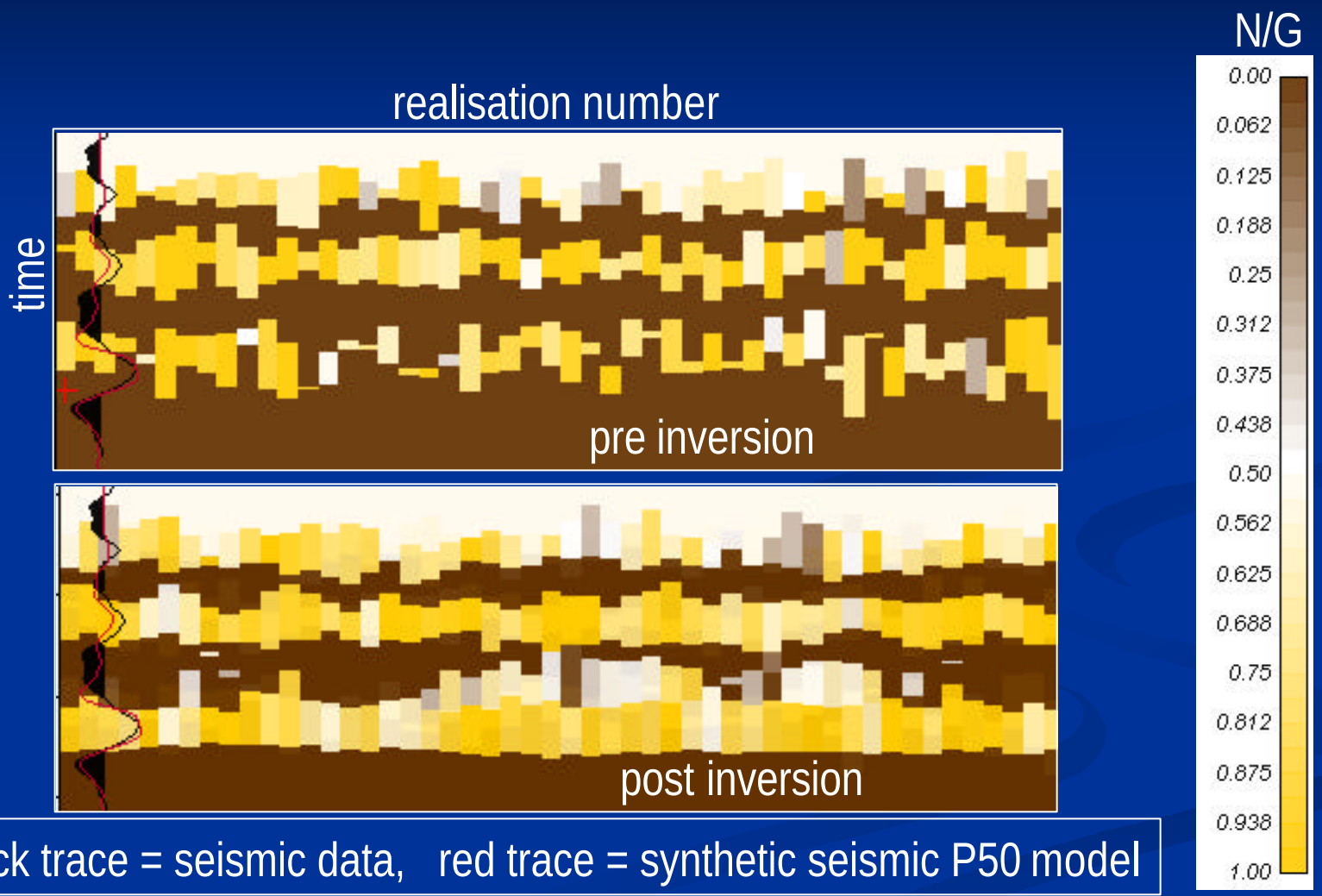
stddev net sand (ft)



oil probability

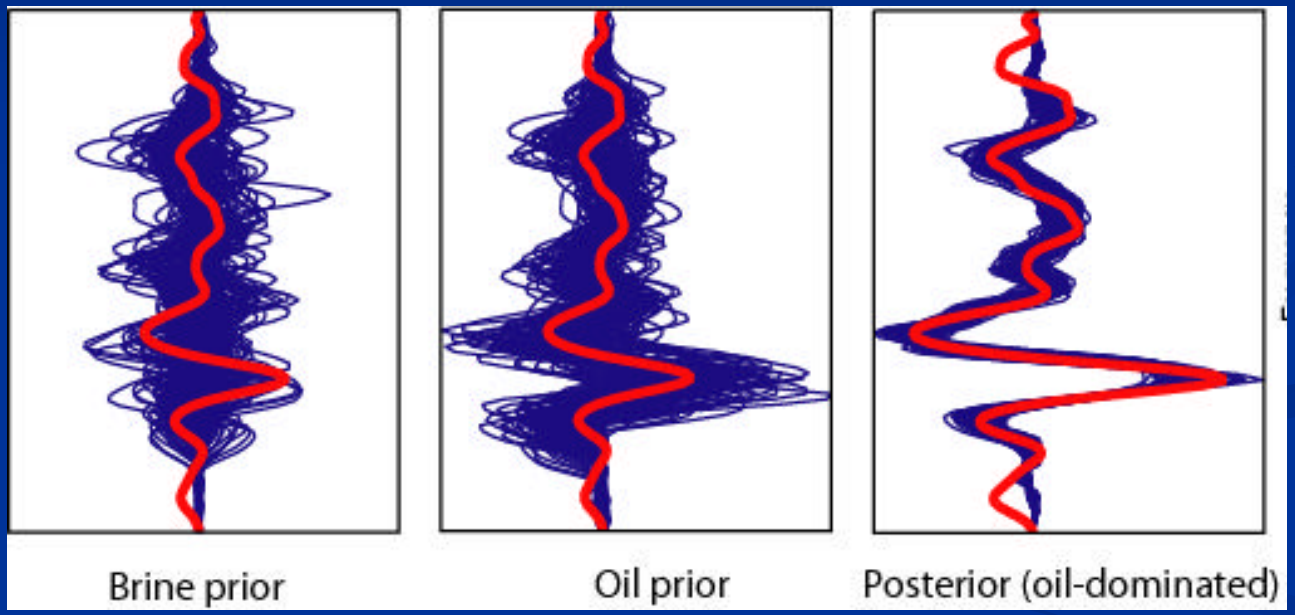


Realisations at a trace

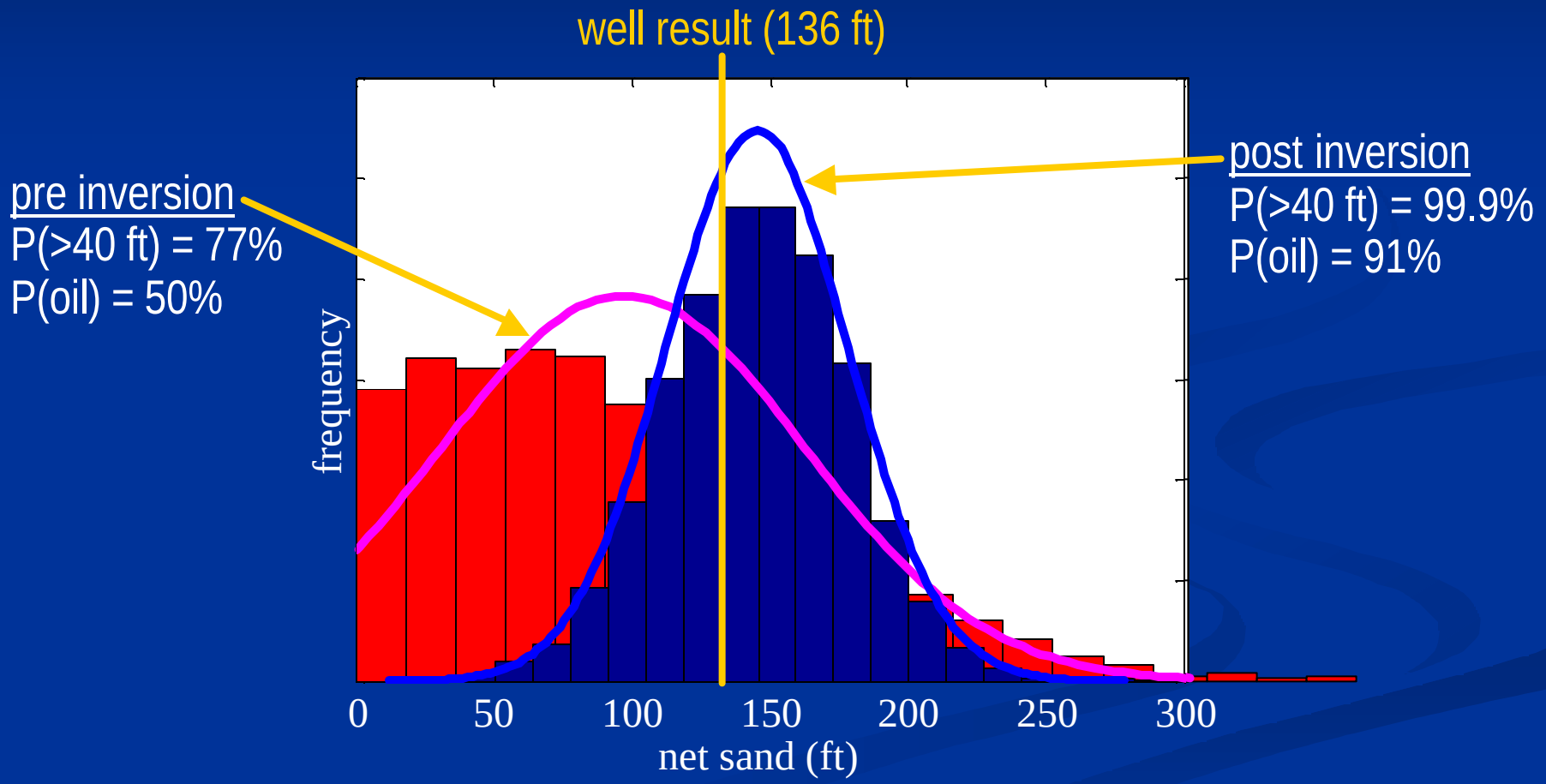


black trace = seismic data, red trace = synthetic seismic P50 model

Fluid probability and spaghetti plots



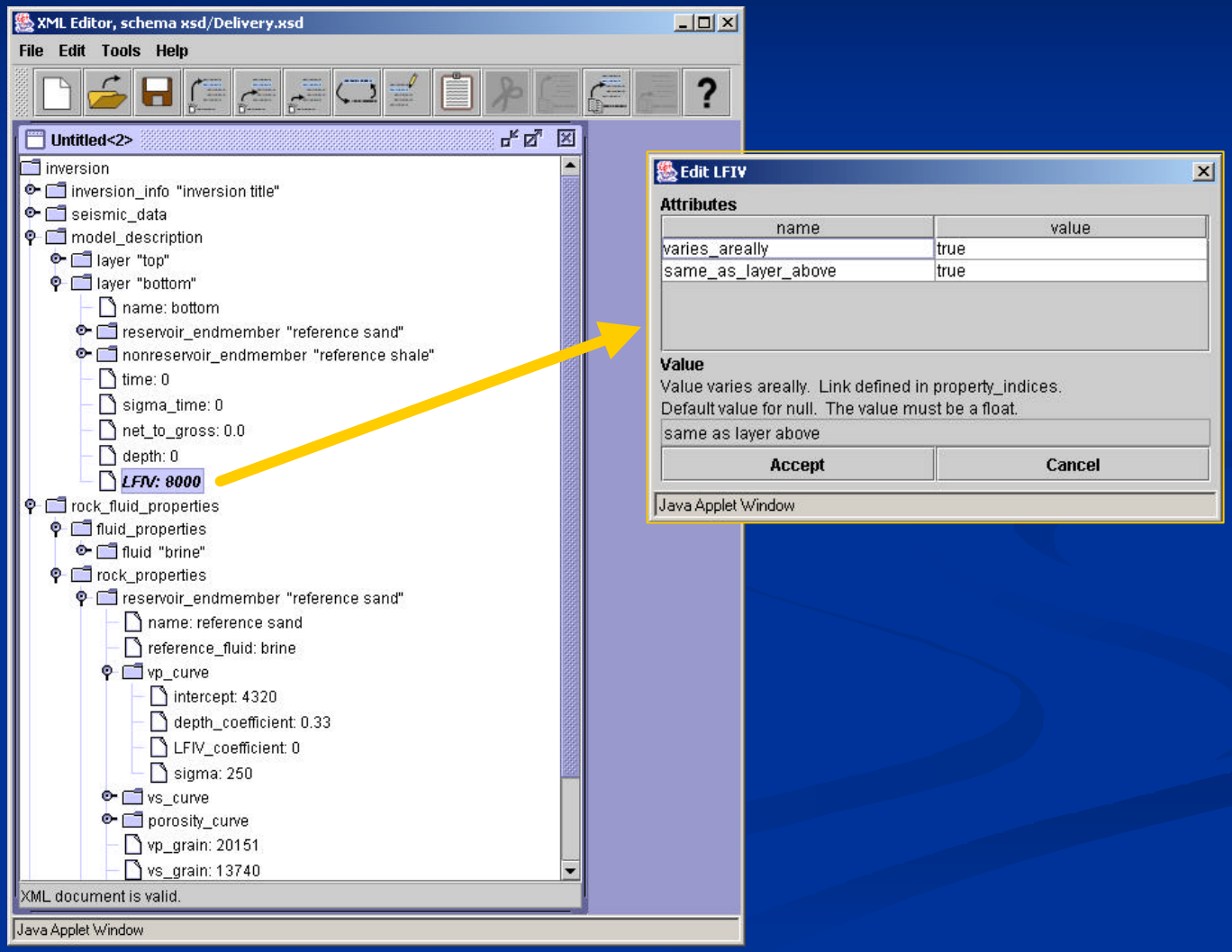
Prediction confirmed by well



The software

- 100% Java (platform independent)
- Uses high-quality public domain numerical libraries
- Public domain (open source), à la Linux, GNU...
  - improvements returned to maintainers
- Interfaces with INT viewer
  - servlet-applet, multi-tier structure
  - Java, XML saveset of view
  - Multidimentional 2D viewer, 3D in future
- General XML editor for parameters and distribution
  - Behavoir determined by xsd
  - Servlet-applet infrastructure

XML parameter & script editor



Under development

- Bayesian wavelet extraction modules
  - Multi-stack
  - Deviated wells
- 4D seismic inversion tools
  - Multiple survey, multiple stack seismic inversion
  - Coupled with reservoir dynamics using experimental design proxies (Chris White, LSU)

Where to get it

- www.petroleum.csiro.au
  - ? Open source projects

- Complete preprint (Computers & Geosciences)
- Source code (available early July)
  - Send email to james.gunning@csiro.au to be informed when it is available